Butterfly and Moth Conservation

Global evidence for the effects of interventions for butterflies and moths

Andrew J. Bladon, Eleanor K. Bladon, Rebecca K. Smith & William J. Sutherland

CONSERVATION EVIDENCE SERIES SYNOPSES

Butterfly and Moth

Conservation

Global evidence for the effects of interventions for butterflies and moths

Andrew J. Bladon, Eleanor K. Bladon, Rebecca K. Smith & William J. Sutherland

Conservation Evidence Series Synopses

Bladon A.J., Bladon E.K., Smith R.K. & Sutherland W.J. (2023) *Butterfly and Moth Conservation: Global Evidence for the Effects of Interventions for butterflies and moths*. Conservation Evidence Series Synopsis. University of Cambridge, Cambridge, UK.

Cover image: Adonis Blue *Lysandra bellargus*. Photograph by Andrew Bladon, CC-BY.

Digital material and resources associated with this synopsis are available at https://www.conservationevidence.com/

Contents

Advisory Board

We thank the following people for advising on the scope and content of this synopsis:

Perpetra Akite, Makerere University, Uganda
Scott H. Black, The Xerces Society for Invertebrate Conservation, USA
Timothy C. Bonebrake, The University of Hong Kong, China
Pritha Dey, Indian Institute of Science, India
Jeremy Dobson, The Lepidopterists' Society of Africa, South Africa
David A. Edge, The Lepidopterists' Society of Africa, South Africa
David Heaver, Natural England, UK
Robert Hoare, Manaaki Whenua Landcare Research, New Zealand
Irena Kleckova, The Biology Centre of the Czech Academy of Sciences, Czech Republic
Nick A. Littlewood, Scotland’s Rural College, UK
Dirk Maes, Research Institute for Nature and Forest (INBO), Belgium & Radboud University, Netherlands
Riadh Moulai, Université de Béjaia, Algeria
Tim New, La Trobe University, Australia
Danilo Ribeiro, Universidade Federal do Mato Grosso do Sul, Brazil
Peter Smetacek, Butterfly Research Centre, India
Ann Swengel, Independent researcher, USA
Scott Swengel, Independent researcher, USA
Athayde Tonhasca, NatureScot, UK
Elli Tzirkalli, University of Ioannina & Cyprus Butterfly Study Group, Cyprus
Rudi Verovnik, University of Ljubljana, Slovenia

About the authors

Dr. Andrew J. Bladon is a Research Associate in the Department of Zoology, University of Cambridge, UK.

Dr. Eleanor K. Bladon is a Research Associate in the Department of Zoology, University of Cambridge, UK.

Dr. Rebecca K. Smith is a Senior Research Associate in the Department of Zoology, University of Cambridge, UK.

Professor William J. Sutherland is the Miriam Rothschild Professor of Conservation Biology at the University of Cambridge, UK.

Acknowledgements

This synopsis was funded by Arcadia and the MAVA Foundation. We would also like to thank all those who contributed to literature searches, and the rest of the team at Conservation Evidence for their expert advice and guidance.

1. About this book

1.1 The Conservation Evidence project

The Conservation Evidence project has four main parts:

1. The **synopses** of the evidence captured for the conservation of particular species groups or habitats, such as this synopsis. Synopses bring together the evidence for each possible intervention. They are freely available online and, in some cases, available to purchase in printed book form.

2. An ever-expanding **database of summaries** of previously published scientific papers, reports, reviews or systematic reviews that document the effects of interventions. This resource comprises over 8,500 pieces of evidence, all available in a searchable database on the website www.conservationevidence.com.

3. ***What Works in Conservation,*** which is an assessment of the effectiveness of interventions by expert panels, based on the collated evidence for each intervention for each species group or habitat covered by our synopses. This is available as part of the searchable database and is published as an updated book edition each year (www.conservationevidence.com/content/page/79).

4. An online, **open access journal** *Conservation Evidence* publishes new pieces of research on the effects of conservation management interventions. All our papers are written by, or in conjunction with, those who carried out the conservation work and include some monitoring of its effects (www.conservationevidence.com/collection/view).

1.2 The purpose of Conservation Evidence synopses

Conservation Evidence synopses **do**	Conservation Evidence synopses **do not**
• Bring together scientific evidence captured by the Conservation Evidence project (over 8,500 studies so far) on the effects of interventions to conserve biodiversity	• Include evidence on the basic ecology of species or habitats, or threats to them
• List all realistic interventions for the species group or habitat in question, regardless of how much evidence for their effects is available	• Make any attempt to weight or prioritize interventions according to their importance or the size of their effects

• Describe each piece of evidence, including methods, as clearly as possible, allowing readers to assess the quality of evidence	• Weight or numerically evaluate the evidence according to its quality
• Work in partnership with conservation practitioners, policymakers and scientists to develop the list of interventions and ensure we have covered the most important literature	• Provide recommendations for conservation problems, but instead provide scientific information to help with decision-making

1.3 Who this synopsis is for

If you are reading this, you may be someone who has to make decisions about how best to support or conserve biodiversity. You might be a land manager, a conservationist in the public or private sector, a farmer, a campaigner, an advisor or consultant, a policymaker, a researcher or someone taking action to protect your local wildlife. Our synopses summarize scientific evidence relevant to your conservation objectives and the actions you could take to achieve them.

We do not aim to make decisions for you, but to support your decision-making by telling you what evidence there is (or isn't) about the effects that your planned actions could have.

When decisions have to be made with particularly important consequences, we recommend carrying out a systematic review, as the latter is likely to be more comprehensive than the summary of evidence presented here. Guidance on how to carry out systematic reviews can be found from the Centre for Evidence-Based Conservation at the University of Bangor (www.cebc.bangor.ac.uk).

1.4 Background

Butterflies and moths (Lepidoptera) are the second most diverse Order of animals on Earth (after beetles), with around 180,000 species currently described, representing 10% of all described species (Jordan & Böhm 2021, Mallet 2014). They have a diverse life cycle with four distinct stages: egg, caterpillar, pupa and adult. The adults and caterpillars fill different ecological niches. The adults are mobile and feed mostly on sugars, such as flower nectar or fruit, while the caterpillars are normally herbivorous and feed mostly on leaves or dead wood, although a few species are carnivorous (Goldstein 2017). Some species specialize on feeding on just one or a few plant species as caterpillars, while others are more generalist and can eat a wider range of host plants (Thomas & Lewington 2016).

Butterflies and moths play a vital role in many terrestrial ecosystems, with adults acting as pollinators for a wide range of plant species (Hahn & Brühl 2016, Willmer 2011), while caterpillars consume large quantities of vegetation. Both are a critical food source for a variety of predators, including birds (Naef-Daenzer & Keller 2001), mammals (Black 1974, Whitaker & Black 1976), and other insects (Goldstein 2017). For example, in temperate regions, some insectivorous birds time their breeding cycle to coincide with the emergence of caterpillars in spring (Hinks *et al.* 2015), and many species of insect parasitoids specialize on caterpillars of a single species for their own reproductive cycle (Goldstein 2017).

Their diverse life-cycle means that butterflies and moths can function as ecological indicators, because they require a diverse range of resources in their habitat (Lomov *et al.* 2006). However, this same fact presents a particular challenge for conservation, with many species having exacting habitat requirements (Hayes *et al.* 2018, Thomas 1980) and limited dispersal ability (Thomas & Harrison 1992). On the other hand, species such as the Monarch *Danaus plexippus* and Painted Lady *Vanessa cardui* undertake long-distance migrations across multiple generations, requiring suitable habitat at a continental-scale in order to complete their life-cycle (Dilts *et al.* 2019, Stefanescu *et al.* 2017).

Butterflies are probably the most popular and well-known group of insects, and have perhaps the longest history of collecting (New 2004) and ecological recording (Bell *et al.* 2020, Thomas 2005). In an era of increasing concern about global declines in insect abundance (Hallmann *et al.* 2017, Leather 2017, van Klink *et al.* 2020), much of the evidence for these declines come from butterflies and moths (Bell *et al.* 2020, Fox *et al.* 2015, Fox *et al.* 2021, van Strien *et al.* 2019, van Swaay *et al.* 2010, Wagner *et al.* 2021, Warren *et al.* 2021, Wepprich *et al.* 2019). However, the majority of studies are from Europe and North America (although see Janzen & Hallwachs 2021 and Theng *et al.* 2020), and offer an incomplete picture of trends globally.

Nonetheless, butterflies and moths face a wide range of threats. As with many species, the greatest hazard comes from habitat loss and conversion, primarily to agriculture, and intensification of farming practices (Bubova *et al.* 2015, Maes & Van Dyck 2001, Numa *et al.* 2016, van Swaay *et al.* 2010). In some regions, particularly Europe, this has led to local extinction of specialist species from heavily modified landscapes (Theng *et al.* 2020, van Strien *et al.* 2019), possibly exacerbated by historical over-collecting (Duffey 1968). However, some species of butterfly and moth, whose caterpillars feed on crops, are important pest species (Goldstein 2017), and the use of chemicals to control them, and other insect pests, can have non-target impacts on a wide diversity of non-pest species (Gilburn *et al.* 2015, Numa *et al.* 2016). Elsewhere, the spread of non-native vegetation and changes to the traditional management of habitats such as grassland and woodland, including land abandonment, has resulted in a reduction in suitability for some species (Bubova *et al.* 2015, Henning *et al.* 2009, Numa *et al.* 2016, Slancarova *et al.* 2016). Additionally, increased human intrusion into natural habitats – through urban expansion, road and rail infrastructure, and the associated increase in light pollution – are all disrupting the suitability of habitats for butterflies and moths (Boyes *et al.* 2021). On top of this, climate change is altering the suitability of landscapes for species (Numa *et al.* 2016, Settele *et al.* 2008, van Swaay *et al.* 2010), and many butterflies and moths are already responding, with changes in phenology (Stefanescu *et al.* 2003, Van Dyck *et al.* 2015), range shifts (Devictor *et al.* 2012, Mason *et al.* 2015, Parmesan *et al.* 1999, Wilson *et al.* 2005, Wilson *et al.* 2007), and population expansions and declines (Forister *et al.* 2021, Hill *et al.* 2021). These changes threaten to mis-match butterflies and moths with their foodplants (Navarro-Cano *et al.* 2015), and are exacerbated by the already fragmented habitat in which populations persist.

While it is relatively easy to gather support for the conservation of conspicuous and recognisable butterflies, and to an extent macro-moths, the largely unknown micro-moths are harder to promote (New 2004). Yet this runs counter to their diversity (there are around 18,000 species of butterfly, compared to 160,000 moths), and ecological significance (Jordan & Böhm 2021). As of May 2021, only 1,377 species of butterfly and moth have received IUCN Red List assessments, and the majority of those (≈550 species) are the large and conspicuous swallowtails (Papilionidae) and the European butterflies (Jordan & Böhm 2021, van Swaay *et al.* 2010).

Of the communities which have been assessed, 9% (37 of 435 species) of European butterflies are considered threatened (Critically Endangered, Endangered or Vulnerable), with a further 10% (44 species) Near Threatened. However, 31% are declining in abundance while only 4% are increasing, although 10% do not have enough data to establish trends (van Swaay *et al.* 2010, van Swaay *et al.* 2011). A more recent assessment of 463 Mediterranean butterflies (which has some overlap in scope with van Swaay *et al.* 2010), found 5% (19 species) to be threatened and 2% Near Threatened, with more than 6% Data Deficient (Numa *et al.* 2016). In South Africa, 63 out of 801 species (7.9%) have been assessed as threatened, with a further 16 species Near Threatened or Data Deficient (Terblanche & Henning 2009). Overall, butterflies and moths with specialist habitat requirements, limited dispersal ability, and small ranges are likely to face greater extinction risks (Collen *et al.* 2012, Hill *et al.* 2021). However, for most tropical regions these assessments are absent.

Conservation management is required to reverse these declining population trends, and to recover species that have suffered local extinctions. Some conservation actions for target species have been remarkably successful. For example, the large blue *Phengaris arion*, which went extinct in the UK in 1979, was successfully reintroduced in the 1980s following efforts to understand its complex ecological requirements, and the implementation of suitable grassland management actions (Thomas 1980, Thomas *et al.* 2009).

Evidence-based knowledge is key for planning successful conservation strategies and for the cost-effective allocation of scarce resources (Sutherland *et al.* 2004). To date, butterfly and moth conservation efforts have largely focused on habitat management and restoration, often in human-modified landscapes such as agricultural areas or managed woodland, and with a particular focus on encouraging host plant populations (Henning *et al.* 2009). For rare or locally extinct species, captive-breeding and translocations have also been widely used (Duffey 1968, Wardlaw *et al.* 1998). Targeted reviews may be carried out to collate evidence on the effects of a particular conservation intervention, but this approach is labour-intensive, expensive and ill-suited for areas where the data are scarce and patchy. The evidence for the effectiveness of conservation interventions aimed at invertebrates is scarcer than for vertebrate taxa (Eisenhauer *et al.* 2019), and accordingly, only a small number of targeted reviews on butterflies and moths exist (e.g. Bernes *et al.* 2018, Bubova *et al.* 2015, Davies *et al.* 2008, Frampton & Dorne 2007, Humbert *et al.* 2012, Jakobsson *et al.* 2018, Wardlaw *et al.* 1998). These have not yet been synthesized in a formal review.

Here, we use a subject-wide evidence synthesis approach (Sutherland *et al*. 2019) to simultaneously summarize the evidence for all interventions dedicated to the conservation of butterflies and moths. By simultaneously targeting the entire range of potential interventions, we are able to review the evidence for each intervention cost-effectively. The resulting synopsis can be updated periodically and efficiently to incorporate new research. The synopsis is freely available at www.conservationevidence.com and, alongside the *Conservation Evidence* online database, is a valuable asset to the toolkit of practitioners and policy makers seeking sound information to support butterfly and moth conservation.

1.5 Scope of the Butterfly and Moth Conservation synopsis

Review subject

The original aim of this project was to synthesize the global evidence for the effectiveness of interventions for the conservation of all terrestrial and freshwater invertebrates (Bladon & Smith 2019). However, following the literature searches (see below) the extent of the literature was found to be too great for the time available, so the scope of the synopsis was narrowed.

This synthesis focuses on global evidence for the effectiveness of interventions for the conservation of butterflies and moths (Lepidoptera). This subject has not previously been covered by a subject-wide evidence synthesis. This is a systematic method of reviewing and synthesising evidence that covers broad subjects (in this case conservation of multiple taxa) at once, including all closed review topics within that subject at a fine scale, and analysing results through study summary and expert assessment, or through meta-analysis. The term can also refer to any product arising from this process (Sutherland *et al*. 2019).

For this synthesis, conservation interventions include management measures or interventions that aim to conserve wild butterfly and moth populations and reduce or remove the negative effects of threats. We have not included evidence from the literature on rearing captive butterflies and moths, except where these interventions are relevant to the conservation of wild declining or threatened species, e.g. captive breeding for the purpose of increasing population sizes (potentially for reintroductions) or gene banking (for future release). The output is a transparent, freely accessible evidence-base of summarized studies and expert assessment scores that will support butterfly and moth management decisions and help to achieve conservation outcomes.

Advisory board

For the original scope of the project (see above), an advisory board made up of international conservationists and academics with expertise in terrestrial and freshwater invertebrate conservation was formed. These experts contributed to the evidence synthesis at two stages: identifying key sources of evidence; and developing a comprehensive list of conservation interventions for review (Bladon & Smith 2019). After the scope of the synopsis was narrowed to butterflies and moths, the advisory board were offered the opportunity to continue if they felt able to review the revised synopsis, and one accepted this offer. A second advisory board of international conservationists and academics with expertise in butterfly and moth conservation was then formed. These experts added to the evidence synthesis at a third stage, namely reviewing the draft evidence synthesis. The original advisory board, for the broader subject, is listed in Bladon & Smith (2019), and the second advisory board focused on butterflies and moths is listed above.

Creating the list of interventions

At the start of the project, a comprehensive list of interventions was developed by searching the literature and in partnership with the original advisory board. The list was also checked by Conservation Evidence to ensure that it followed the standard structure. The aim was to include all interventions that have been carried out or advised to support populations or communities of terrestrial and freshwater invertebrates, whether evidence for intervention effectiveness is available or not.

During the synthesis process, further interventions were discovered and integrated into the synopsis structure, and the list was narrowed to only include interventions that could be implemented for butterflies and moths. The resulting list of interventions is organized into categories based on the IUCN classifications of direct threats (www.iucnredlist.org/resources/threat-classification-scheme) and conservation actions (www.iucnredlist.org/resources/conservation-actions-classification-scheme). For interventions with a large body of literature, the intervention may be split into different methods of implementation (e.g. different designs, seasons, methods for acclimatisation before release, etc.), different species/functional groups, or broad habitats, if relevant to do so.

We found 202 conservation or management interventions that could be carried out to conserve terrestrial and freshwater invertebrate populations, of which 151 could be carried out to conserve butterflies and moths. We found evidence for the effects on butterfly and moth populations for 105 of these interventions. The evidence was reported as 587 summaries from 316 relevant publications.

1.6 Methods

1.6.1 Literature searches

Literature was obtained from the Conservation Evidence discipline-wide literature database, and from searches of additional subject-specific sources (Appendices 1–3). The Conservation Evidence database is compiled by using systematic searches of journals (all titles and abstracts) and report series ('grey literature'). Relevant publications describing studies of conservation interventions for all species groups and habitats were added to the database. Additional searches were conducted before the scope of the synopsis was narrowed (see above), so covered literature relevant to all terrestrial and freshwater invertebrates. Unfortunately, resource constraints prevented later searches of butterfly- and moth-specific journals, the inclusion of which may have increased the resulting evidence base. Future work will seek to include these sources. The final list of evidence sources searched for this synopsis is provided in Appendices 1–3 and published online (www.conservationevidence.com/journalsearcher/synopsis).

a) Global evidence

Evidence from all around the world was included.

b) Languages included

Journals published in a total of 17 languages were searched and relevant papers extracted:

- Arabic (11 journals)
- Chinese, simplified (61 journals)
- Chinese, traditional (14 journals)
- English (301 journals)
- French (13 journals)
- German (39 journals)
- Hungarian (4 journals)
- Italian (7 journals)
- Japanese (18 journals)
- Korean (5 journals)
- Persian (9 journals)
- Polish (10 journals)
- Portuguese (29 journals)
- Russian (12 journals)
- Spanish (59 journals)
- Turkish (22 journals)
- Ukrainian (3 journals)

Journals listed as "English" are either published in English or at least carry English summaries (Appendix 1). Non-English-language journals are listed in Appendix 2.

c) Journals searched

i) From the Conservation Evidence discipline-wide literature database

All journals (and years) listed in Appendices 1b and 2 were searched for the Conservation Evidence project. An asterisk indicates the journals most relevant to this synopsis, but relevant papers found in any of the searched journals were summarized.

ii) Update searches

Additional searches up to the end of 2018 were undertaken by the synopsis authors for journals likely to yield studies for invertebrates (Appendix 1a, journals marked with asterisks).

iii) New searches

New focused searches of journals relevant to the conservation of terrestrial and freshwater invertebrate populations were undertaken by the synopsis authors (Appendix 1a, journals indicated in bold). These journals were identified through expert judgement by the project researchers and the advisory board and ranked in order of relevance.

d) Reports from specialist websites searched

i) From the Conservation Evidence discipline-wide literature database

All report series (and years) in Appendix 3b were searched for the Conservation Evidence project. An asterisk indicates the report series most relevant to this synopsis, but relevant reports found in any of the searched series were summarized.

ii) Update searches

Updated searches of report series already searched as part of the wider Conservation Evidence project were not undertaken for this synopsis.

iii) New searches

New searches targeting specialist reports relevant to terrestrial and freshwater invertebrate conservation are listed in Appendix 3a. These searches reviewed every report title and abstract or summary within each report series (published before the end of 2018).

e) Other literature searches

The online database www.conservationevidence.com was searched for relevant publications that have already been summarized.

Where a systematic review was found for an intervention, then only the systematic review was summarized (the separate relevant publications reference within it were not summarized individually). Non-systematic reviews (or editorial, synthesis, preface, introduction, etc.) that provided new/collective data were included/summarized (but the relevant publications referenced within it were not summarized individually). Relevant publications cited in other publications summarized for the synopsis were not included/summarized.

f) Supplementary literature identified by advisory board or relevant stakeholders

Additional relevant papers or reports suggested by members of the advisory board or relevant stakeholders were also included.

g) Search record database

A database was created of all relevant publications found during searches. Reasons for exclusion were recorded for all those included during screening that were not summarized for the synopsis.

1.6.2 Publication screening and inclusion criteria

A summary of the total number of evidence sources and papers/reports screened is presented in the diagram in Appendix 4.

a) Screening

To ensure consistency/accuracy when screening publications for inclusion in the literature database, an initial test using the Conservation Evidence inclusion criteria (provided below) and a consistent set of references was carried out by authors, compared with the decisions of the experienced core Conservation Evidence team. Results were analysed with the Cohen's Kappa test (Cohen 1960). Where initial results did not show 'substantial' (K = 0.61–0.8) or 'almost perfect' agreement (K = 0.81–1.0), authors were given further training. A second Kappa test was used to assess the consistency/accuracy of article screening for the first two years of the first journal searched by each author. Again, where results did not show 'substantial' or 'almost perfect' agreement, authors received further training before carrying out further searches. Authors of other synopses who have searched journals and added relevant publications to the Conservation Evidence literature database since 2018, and all other searchers since 2017, have undertaken the initial paper inclusion test described above; searchers prior to that have not. Kappa tests of the first two years searched have been carried out for all new searchers who have contributed to the Conservation Evidence literature database since July 2018.

We acknowledge that the literature search and screening method used by Conservation Evidence, as with any method, will result in gaps in the evidence. The Conservation Evidence literature database currently includes relevant papers from over 300 English language journals and 316 non-English language journals. Additional journals are frequently added to those searched, and years searched are often updated. It is also possible that searchers will have missed relevant papers from those journals searched. Publication bias, where studies reporting negative or non-significant findings are less likely to be written up and published in journals (e.g. Dwan *et al.* 2013), was not taken into account and it is likely that this, and other biases, exist in the available evidence.

b) Inclusion criteria

The following Conservation Evidence inclusion criteria were used.

Criterion A: Conservation Evidence includes studies that measure the effect of an intervention that might be done to conserve biodiversity

1. Does the study measure the effect of an intervention that is or was under the control of humans, on wild taxa (including captives), habitats, or invasive/problematic taxa? If yes, go to 3. If no, go to 2.

2. Does the study measure the effect of an intervention that is or was under the control of humans, on human behaviour that is relevant to conserving biodiversity? If yes, go to Criterion B. If no, the study was excluded.
3. Could the intervention be put in place by a conservationist/decision-maker to protect, manage or restore wild taxa or habitats, reduce impacts of threats to wild taxa or habitats, or control or mitigate the impact of an invasive/problematic taxon on wild taxa or habitats? If yes, the study was included. If no, the study was excluded.

Explanation:

1.a. Study must have a measured outcome on wild taxa, habitats or invasive species: studies on domestic/agricultural species, theoretical modelling or opinion pieces were excluded. See Criterion B for interventions that have a measured outcome on human behaviour only.

1.b. Intervention must be carried out by people: studies on impacts from natural processes (e.g. tree falls, natural fires), impacts from background variation (e.g. soil type, vegetation, climate change), correlations with habitat types, where there is no test of a specific intervention by humans, or pure ecology (e.g. movement, distribution of species) were excluded.

2. Study must test an intervention that could be put in place for conservation: studies assessing the impact of threats were excluded, but interventions that remove threats were included. The test may involve comparisons between sites/factors not originally put in place or modified for conservation, but which could be (e.g. mown vs not mown sites, fenced vs unfenced sites – where the mowing/fencing is as you would do for conservation, even if that was not the original intention in the study).

If the title or abstract were suggestive of fulfilling our criteria, but there was not sufficient information to judge whether the intervention was under human control, the intervention could be applied by a conservationist/decision-maker or whether there were data quantifying the outcome, then the study was included. If the article had no abstract, but the title was suggestive, then a study was included.

We sorted articles into folders by which taxon/habitat they have an outcome on. If the title/abstract did not specify which species/taxa/habitats were impacted, then the full article was searched and assigned to folders accordingly.

The outcome for wild taxa/habitats can be negative, neutral or positive, does not have to be statistically significant but must be quantified. It could be any outcome that has implications for the health of individuals, populations, species, communities or habitats, including, but not limited to the following:

- *Individual health, condition or behaviour, including in captivity*: e.g. growth, size, weight, stress, disease levels or immune function, movement, use of natural/artificial habitat/structure, range, or predatory or nuisance behaviour that could lead to retaliatory action by humans
- *Breeding*: egg/sperm/larvae production, sperm motility/viability after freezing, artificial fertilization success, mating/hatching success, clutch size, offspring condition, 'overall recruitment'
- *Genetics*: genetic diversity, genetic suitability (e.g. adaptation to local conditions, use of correct routes for migratory species, etc.)
- *Life history*: age/size at (sexual) maturity, survival, mortality
- *Population measures*: number, abundance, density, presence/absence, biomass, movement, cover, age-structure, species distributions (only in response to a human action), disease prevalence, sex ratio
- *Community/habitat measures*: species richness, diversity measures (including trait/functional diversity), community composition, community structure (e.g. trophic structure), area covered (e.g. by different habitat types), physical habitat structure (e.g. rugosity, height, basal area)

Interventions within the scope of Conservation Evidence include:

- Clear management interventions, e.g. prescribed burning, mowing, planting vegetation, controlling or eradicating invasive species, creating wildlife road crossings, creating or restoring habitats
- International or national policies, e.g. creation of protected areas, bylaws, local voluntary restrictions
- Reintroductions or management of wild species in captivity
- Interventions that reduce human-wildlife conflict
- Interventions that change human behaviour, resulting in an impact on wild taxa or habitats

See https://www.conservationevidence.com/data/index for more examples of interventions.

Literature reviews, systematic reviews, meta-analyses or short notes that review studies fulfilling these criteria were included. Theoretical modelling studies were excluded, as no intervention has been taken. However, studies that use models to analyse real-world data, or compare models to real-world situations were included.

Criterion B: Conservation Evidence includes studies that measure the effect of an intervention that might be done to change human behaviour for the benefit of biodiversity

1. Does the study measure the effect of an intervention that is or was under human control on human behaviour (actual or intentional) which is likely to protect, manage or restore wild taxa or habitats, or reduce threats to wild taxa or habitats? If yes, go to 2. If no, the study was excluded.
2. Could the intervention be put in place by a conservationist, manager or decision-maker to change human behaviour? If yes, the study was included. If no, the study was excluded.

Explanation:

1.a. Study must have a measured outcome on actual or intentional human behaviour including self-reported behaviours: outcomes on human psychology (tolerance, knowledge, awareness, attitude, perceptions or beliefs) were excluded.

1.b. Change in human behaviour must be linked to outcomes for wild taxa and habitats: changes in behaviour linked to outcomes for human benefit, even if they occurred under a conservation program, were excluded (e.g. a study demonstrating increased school attendance in villages under a community based conservation program).

1.c. Intervention must be under human control: impacts from climatic or other natural events were excluded.

2. Study must test an intervention that could be put in place for conservation: studies with no intervention were excluded, e.g. correlating human personality traits with likelihood of conservation-related behaviours.

The human behaviour outcome of the study can be negative, neutral or positive, does not have to be statistically significant but must be quantified. It could be any behaviour that is likely to have an outcome on wild taxa and habitats (including mitigating the impact of an invasive/problematic taxon on wild taxa or habitats).

Interventions include, but are not limited to, the following:

- Change in adverse behaviours (which directly threaten biodiversity), e.g. unsustainable or illegal hunting, burning, grazing, urban encroachment, creating noise, entering sensitive areas, polluting or dumping waste, clearing or habitat destruction, introducing invasive species
- Change in positive behaviours, e.g. uptake of alternative/sustainable livelihoods, number of households adopting sustainable practices, donations
- Change in policy or conservation methods, e.g. designation of protected areas, protection of key habitats/species

- Change in consumer or market behaviour e.g. purchasing, consuming, buying, willingness to pay, selling, illegal trading, advertising, consumer fraud
- Behavioural intentions to do any of the above

Interventions which are particularly likely to have a behaviour change outcome include, but are not limited to the following:

- *Enforcement*: no grazing areas, grazing limits, protected species, auditable/traceable reporting requirements, increase number of rangers, patrols or frequency of patrols in, around or within protected areas, improved fencing/physical barriers, improved signage, improved equipment/technology used by guards
- *Behaviour change*: promote alternative/sustainable livelihoods, payment for ecosystem services, ecotourism, poverty reduction, debunking misinformation, altering or re-enforcing local taboos, financial incentives
- *Governance*: protect or reward whistle-blowers, increase government transparency, ensure independence of judiciary, provide legal aid
- *Market regulation*: trade bans, taxation, supply chain transparency laws
- *Consumer demand reduction*: increase awareness or knowledge, fear appeals (negative association with undesirable product), benefit appeal (positive association with desirable behaviour), worldview framing, moral framing, employing decision defaults, providing decision support tools, simplifying advice to consumers, promoting desirable social norms, legislative prohibition
- *Sustainable alternatives*: certification schemes, captive bred or artificial alternatives, sustainable alternatives
- *New policies and regulations for conservation/protection*

We allocated studies to folders by their outcome. All studies under Criterion B were placed in a 'Behaviour change' folder, and duplicated into a taxon/habitat folder if there was a specific intended final outcome of the behaviour change (if none was mentioned, they were filed only in Behaviour change).

c) Relevant subject

Studies relevant to the synopsis subject include those focused on the conservation of wild, native, butterflies and moths.

d) Relevant types of intervention

An intervention has to be one that could be put in place by a manager, conservationist, policy-maker, advisor, consultant or scientific authority to protect, manage or restore wild, native butterflies and moths or reduce the impacts of threats to them. Alternatively, interventions may aim to change human behaviour (actual or intentional), which is likely to protect, manage or restore wild, native butterflies and moths or reduce threats to them. See inclusion criteria above for further details.

If the following two criteria were met, a combined intervention was created within the synopsis, rather than duplicating evidence under all the separate interventions: a) there were five or more publications that used the same well-defined combination of interventions, with a clear description of what they were, without separating the effects of each individual intervention, and b) the combined set of interventions is a commonly used conservation strategy.

e) Relevant types of comparator

To determine the effectiveness of interventions, studies must include a comparison, i.e. monitoring change over time (typically before and after the intervention was implemented), or for example at treatment and control sites. Alternatively, a study could compare one specific intervention (or implementation method) against another. For example, this could be comparing the abundance of a butterfly species before and after the creation of a protected area, or the reduction in moth activity around different types of artificial lights. Exceptions, which may not have a comparator but were still included are, for example, studies assessing the effectiveness of captive breeding or rehabilitation programmes.

f) Relevant types of outcome

Below we provide a list of anticipated metrics; others were included if reported within relevant studies.

- **Community response**
  - Community composition
  - Richness/diversity
- **Population response**
  - Abundance: number, density, presence/absence
  - Reproductive success: egg/sperm/larvae production, mating/hatching success, offspring quality/condition, overall recruitment, age/size at maturity
  - Survival: survival rates, mortality
  - Condition: growth, size, weight, condition factors, biochemical ratios, stress, energetics, disease levels or immune function, genetic diversity
- **Behaviour**
  - Use of natural/artificial habitat/structure
  - Behaviour change: movement, range, timing (e.g. of migration, foraging period)
- **Other**

- Change in human behaviour
- Human wildlife conflict
- Offspring sex ratio

g) Relevant types of study design

The table below lists the study designs included. The strongest evidence comes from replicated, randomized, controlled trials with paired sites and before-and-after monitoring.

Table 1. Study designs

Term	Meaning
Replicated	The intervention was repeated on more than one individual or site. In conservation and ecology, the number of replicates is much smaller than it would be for medical trials (when thousands of individuals are often tested). If the replicates are sites, pragmatism dictates that between five and ten replicates is a reasonable amount of replication, although more would be preferable. We provide the number of replicates wherever possible. Replicates should reflect the number of times an intervention has been independently carried out, from the perspective of the study subject. For example, 10 plots within a mown field might be independent replicates from the perspective of plants with limited dispersal, but not independent replicates for larger motile animals such as birds. In the case of translocations/release of captive bred animals, replicates should be sites, not individuals. In the case of captive-breeding programmes, studies were considered to be replicated when at least 5 breeding females were included.
Randomized	The intervention was allocated randomly to individuals or sites. This means that the initial condition of those given the intervention is less likely to bias the outcome.
Paired sites	Sites are considered in pairs, within which one was treated with the intervention and the other was not. Pairs, or blocks, of sites are selected with similar environmental conditions, such as water quality or adjacent land use. This approach aims to reduce environmental variation and make it easier to detect a true effect of the intervention.
Controlled*	Individuals or sites treated with the intervention are compared with control individuals or sites not treated with the intervention. (The treatment is usually allocated by the investigators (randomly or not), such that the treatment or control groups/sites could have received the treatment).
Before-and-after	Monitoring of effects was carried out before and after the intervention was imposed.

Site comparison*	A study that considers the effects of interventions by comparing sites that historically had different interventions (e.g. intervention vs no intervention) or levels of intervention. Unlike controlled studies, it is not clear how the interventions were allocated to sites (i.e. the investigators did not allocate the treatment to some of the sites).
Review	A conventional review of literature. Generally, these have not used an agreed search protocol or quantitative assessment of the evidence.
Systematic review	A systematic review follows structured, predefined methods to comprehensively collate and synthesise existing evidence. It must weight or evaluate studies, in some way, according to the strength of evidence they offer (e.g. sample size and rigour of design). Environmental systematic reviews are available at: www.environmentalevidence.org/index.htm
Study	If none of the above apply, for example a study measuring change over time in only one site or only after an intervention. Or a study measuring use of nest boxes at one site.

*Note that "controlled" is mutually exclusive from "site comparison". A comparison cannot be both controlled and a site comparison. However, one study might contain both controlled and site comparison aspects, e.g. study of bycatch by fishers using modified nets (e.g. with a smaller mesh size) and unmodified nets (controlled), and fishers using an alternative net modification, e.g. stiffened nets (site comparison).

1.6.3 Study quality assessment & critical appraisal

We did not quantitatively assess the evidence from each publication or weight it according to quality. However, to allow interpretation of the evidence, we reported the size and design of each study. We appraised each potentially relevant study and excluded those that did not provide data for a comparison to the treatment (where it was needed), those that did not statistically analyse the results (or if included this was stated in the summary paragraph), and those that had obvious errors in their design or analysis. A record of the reason for excluding any of the publications was included during screening and kept within the synopsis database.

1.6.4 Data extraction

Data on the effectiveness of the relevant intervention (e.g. mean species abundance inside or outside a protected area; change in breeding success after instigation of a new management action) were summarized for publications that included the relevant subject, types of intervention, comparator and outcomes outlined above. A summary of the number of sources and papers/reports searched and the number of publications included following data extraction is presented in Appendix 4.

In addition to ensuring consistency/accuracy when screening publications for inclusion in the discipline-wide literature database (see above), when authors first began summarizing, the first 10 publications were sent to Conservation Evidence for editing. Furthermore, to ensure agreement on the correct data and interpretation of the results for inclusion in the synopsis, relevant data were extracted by a member of the core Conservation Evidence team as well as the synopsis author for a subset of publications. Finally, summaries were occasionally swapped between authors for quality control.

1.6.5 Evidence synthesis

a) Summary protocol

Each publication usually has one paragraph for each intervention it tests, describing the study in no more than 150 words using plain English, although more complex studies required longer summaries. Each summary is in the following format:

A [TYPE OF STUDY] in [YEARS X-Y] in [HOW MANY SITES] in/of [HABITAT] in [REGION and COUNTRY] [REFERENCE] found that [INTERVENTION] [SUMMARY OF ALL KEY RESULTS] for [SPECIES/HABITAT TYPE]. [DETAILS OF KEY RESULTS, INCLUDING DATA]. In addition, [EXTRA RESULTS, IMPLEMENTATION OPTIONS, CONFLICTING RESULTS]. The [DETAILS OF EXPERIMENTAL DESIGN, INTERVENTION METHODS and KEY DETAILS OF SITE CONTEXT]. Data was collected in [DETAILS OF SAMPLING METHODS].

Type of study – use terms and order in Table 1.

Site context – for the sake of brevity, only details essential to the interpretation of the results are included. The reader is encouraged to read the original source to get a full understanding of the study site (e.g. history of management, physical conditions, landscape context etc.).

For example:

A replicated, randomized, paired, controlled study in 1936–2009 in eight sagebrush steppe sites in Oregon, USA (1) found that increasing the number of livestock decreased grass and herb cover, but did not significantly alter shrub cover. Grass and herb cover in grazed areas were lower (grass: 9%, herb: 17%) than in areas that were not grazed (grass: 18%, herb: 24%). However, shrub cover was not significantly different in grazed (16%) and ungrazed (16%) areas. Eight 2 ha fenced areas excluding livestock were established in 1936. Areas adjacent to the fenced areas were grazed by cattle from 1936–2008. In summer 2009, four 20 m transects were established in each study area and vegetation cover was assessed using a line intercept method.

(1) Davies K.W., Bates J.D., Svejcar T.J. & Boyd C.S. (2010) Effects of long-term livestock grazing on fuel characteristics in rangelands: an example from the sagebrush steppe. *Rangeland Ecology & Management*, 63, 662–669.

A replicated, randomized, controlled, before-and-after study in 1993–1999 of five harvested hardwood forests in Virginia, USA (2) found that harvesting trees in groups did not result in higher salamander abundances than clearcutting. Abundance was similar between treatments (group cut: 3; clearcut: 1/30 m²). Abundance was significantly lower compared to unharvested plots (6/30 m²). Species composition differed before and three years after harvest. There were five sites with 2 ha plots with each treatment: group harvesting (2–3 small area group harvests with selective harvesting between), clearcutting and an unharvested control. Salamanders were monitored on 9–15 transects (2 x 15 m)/plot at night in April–October. One or two years of pre-harvest and 1–4 years of post-harvest data were collected.

(2) Knapp S.M., Haas C.A., Harpole D.N. & Kirkpatrick R.L. (2003) Initial effects of clearcutting and alternative silvicultural practices on terrestrial salamander abundance. *Conservation Biology*, 17, 752–762.

b) Terminology used to describe the evidence

Unless stated otherwise, results reflect statistical tests performed on the data, i.e. we only state that there was a difference if it was supported by the statistical test used, and otherwise state that there was no difference or that outcomes were similar. If there was a good reason to report differences between treatments and controls that were not tested for statistical significance, it was made clear in the summary that statistical tests were not carried out. Table 1 above defines the terms used to describe the study designs.

Throughout the synthesis, the terms "butterflies" and "moths" are used for adults, and whenever studies covered other lifestages (eggs, caterpillars or pupae) this is stated explicitly.

c) Dealing with multiple interventions within a publication

When separate results were provided for the effects of each of the different interventions tested, separate summaries were written under each intervention heading. However, when several interventions were carried out at the same time and only the combined effect reported, the result was described with a similar paragraph under all relevant interventions. In these circumstances, we made it clear in the summary paragraph where multiple interventions were used in combination. For example, the first sentence would articulate that a combination of interventions was carried out, i.e. '... (REF) found that [x intervention], along with [y] and [z interventions], resulted in [describe effects]'.

d) Dealing with multiple publications reporting the same results and reviews

If two publications described results from the same intervention implemented in the same place and at the same time, we only included the higher profile publication (i.e.

journal of the highest impact factor). If one included initial results (e.g. after year one) of another (e.g. after 1–3 years), we only included the publication covering the longest time span. If two publications described at least partially different results, we included both but made clear they were from the same project in the paragraph, e.g. 'A controlled study... (Gallagher *et al*. 1999; same experimental set-up as Oasis *et al*. 2001)...'.

e) Taxonomy

Taxonomy was not updated but follows that used in the original publication. Where possible, common names and scientific names were both given the first time each species was mentioned within each summary, but not in the Key Messages.

f) Key messages

Each intervention has a set of concise, bulleted key messages at the top, written after all the literature had been summarized. These include information such as the number, design and location of studies included. The first bullet point describes the total number of studies that tested the intervention and the locations of the studies, followed by key information on the relevant metrics presented under the headings and sub-headings shown below (with number of relevant studies in parentheses for each).

- **X studies** examined the effects of [INTERVENTION] on [TARGET POPULATION]. Y studies were in [LOCATION 1][1,2] and Z studies were in [LOCATION 2][3,4].
  Locations will usually be countries, ordered based on chronological order of studies rather than alphabetically, i.e. 'the USA[1], Australia[2]' rather than 'Australia[2], the USA[1]'. However, when more than 4–5 separate countries, they may be grouped into regions to make it clearer e.g. Europe, North America. The distribution of studies amongst habitat types may also be added here if relevant.

COMMUNITY RESPONSE (x STUDIES)
- **Community composition (x studies):**
- **Richness/diversity (x studies):**

POPULATION RESPONSE (x STUDIES)
- **Abundance (x studies):**
- **Reproductive success (x studies):**
- **Survival (x studies):**
- **Condition (x studies):**

BEHAVIOUR (x STUDIES)
- **Use (x studies):**
- **Behaviour change (x studies):**

OTHER (x STUDIES) *(Included only for interventions/chapters where relevant)*

- **[Sub-heading(s) for the metric(s) reported will be created] (x studies):**

If no suitable studies are found for an intervention, the following text was added in place of the key messages above:

- We found no studies that evaluated the effects of [INTERVENTION] on [TARGET POPULATION].

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

g) Background information

Background information for an intervention is provided to describe it and where we feel recent knowledge is required to interpret the evidence. This is presented after the key messages, and relevant references are included in a reference list at the end of the Background section. In some cases, where a body of literature has strong implications for butterfly and moth conservation, but does not directly test interventions for their effects, we may also refer the reader to this literature in the background sections.

1.6.6 Dissemination/communication of evidence synthesis

The information from this evidence synthesis is available in three ways:

- A synopsis pdf, downloadable from www.conservationevidence.com, contains the study summaries, key messages and background information on each intervention.
- The searchable database at www.conservationevidence.com contains all the summarized information from the synopsis, along with expert assessment scores.
- A chapter in "*What Works in Conservation*", available as a pdf to download and a book from www.conservationevidence.com/content/page/79, contains the key messages from the synopsis as well as expert assessment scores on the effectiveness and certainty of the synopsis, with links to the online database.

1.7 How you can help to change conservation practice

If you know of evidence relating to butterfly and moth conservation that is not included in this synopsis, we invite you to contact us via our website www.conservationevidence.com. If you have new, unpublished evidence, you can submit a paper to the Conservation Evidence Journal (https://conservationevidencejournal.com/). We particularly welcome papers submitted by conservation practitioners.

1.8 References

Bell J.R., Blumgart D. & Shortall C.R. (2020) Are insects declining and at what rate? An analysis of standardised, systematic catches of aphid and moth abundances across Great Britain. *Insect Conservation and Diversity*, 13, 115–126.

Bernes C., Macura B., Jonsson B.G., Junninen K., Müller J., Sandström J., Lõhmus A. & Macdonald E. (2018) Manipulating ungulate herbivory in temperate and boreal forests: effects on vegetation and invertebrates. A systematic review. *Environmental Evidence*, 7, 13.

Black H.L. (1974) A north temperate bat community: structure and prey populations. *Journal of Mammology*, 55, 138–157.

Bladon A.J. & Smith R.K. (2019) Effects of conservation interventions on terrestrial and freshwater invertebrates: a protocol for subject-wide evidence synthesis.

Boyes D.H., Evans D.M., Fox R., Parsons M.S. & Pocock M.J.O. (2021) Is light pollution driving moth population declines? A review of causal mechanisms across the life cycle. *Insect Conservation and Diversity*, 14, 167–187.

Bubová T., Vrabec V., Kulma M. & Nowicki P. (2015) Land management impacts on European butterflies of conservation concern: a review. *Journal of Insect Conservation*, 19, 805–821.

Cohen J. (1960) A coefficient of agreement for nominal scales. *Educational and Psychological Measurement*, 20, 37–46.

Collen B., Böhm M., Kemp R. & Baillie J.E.M. (2012) *Spineless: Status and trends of the world's invertebrates*. Zoological Society of London, UK.

Davies Z.G., Tyler C., Stewart G.B. & Pullin A.S. (2008) Are current management recommendations for saproxylic invertebrates effective? A systematic review. *Biodiversity Conservation*, 17, 209–234.

Devictor V., van Swaay C., Brereton T., Brotons L., Chamberlain D., Heliölä J., Herrando S., Julliard R., Kuussaari M., Lindström Å., Reif J., Roy D.B., Schweiger O., Settele J., Stefanescu C., van Strien A., van Turnhout C., Vermouzek Z., WallisDeVries M., Wynhoff I. & Jiguet F. (2012) Differences in the climatic debts of birds and butterflies at a continental scale. *Nature Climate Change*, 2, 121–124.

Dilts T.E., Steele M.O., Engler J.D., Pelton E.M., Jepsen S.J., McKnight S.J., Taylor A.R., Fallon C.E., Black S.H., Cruz E.E., Craver D.R. & Forister M.L. (2019) Host Plants and Climate Structure Habitat Associations of the Western Monarch Butterfly. *Frontiers in Ecology and Evolution*, 7:188.

Duffey E. (1968) Ecological studies on the large copper butterfly *Lycaena dispar* (Haw.) *batavus* (Obth.) at Woodwalton Fen National Nature Reserve, Huntingdonshire. *Journal of Applied Ecology*, 5, 69–96.

Dwan K., Gamble C., Williamson P.R. & Kirkham J.J. (2013) Systematic review of the empirical evidence of study publication bias and outcome reporting bias—an updated review. *PloS ONE*, 8, e66844.

Eisenhauer N., Bonn A. & Guerra C.A. (2019) Recognizing the quiet extinction of invertebrates. *Nature Communications*, 10, 50.

Forister M.L., Halsch C.A., Nice C.C., Fordyce J.A., Dilts T.E., Oliver J.C., Prudic K.L., Shapiro A.M., Wilson J.K. & Glassberg J. (2021) Fewer butterflies seen by community scientists across the warming and drying landscapes of the American West. *Science*, 371, 1042–1045.

Fox R., Brereton T.M., Asher J., August T.A., Botham M.S., Bourn N.A.D., Cruickshanks K.L., Bulman C.R., Ellis S., Harrower C.A., Middlebrook I., Noble D.G., Powney G.D., Randle Z., Warren M.S. & Roy D.B. (2015) *The State of the UK's Butterflies*. Butterfly Conservation and the Centre for Ecology & Hydrology, Wareham, Dorset, UK.

Fox R., Dennis E.B., Harrower C.A., Blumgart D., Bell J.R., Cook P., Davis A.M., Evans-Hill L.J., Haynes F., Hill D., Isaac N.J.B., Parsons M.S., Pocock M.J.O., Prescott T., Randle Z., Shortall C.R., Tordoff G.M., Tuson D. & Bourn N.A.D. (2021) *The State of Britain's Larger Moths 2021*. Butterfly Conservation, Rothamsted Research and UK Centre for Ecology & Hydrology, Wareham, Dorset, UK.

Frampton G.K. & Dorne J.L.C.M. (2007) The effects on terrestrial invertebrates of reducing pesticide inputs in arable crop edges: a meta-analysis. *Journal of Applied Ecology*, 44, 362–373.

Gilburn A.S., Bunnefeld N., Wilson J.M., Botham M.S., Brereton T.M., Fox R. & Goulson D. (2015) Are neonicotinoid insecticides driving declines in widespread butterflies? *PeerJ*, 3:e1402.

Goldstein P.Z. (2017) Diversity and Significance of Lepidoptera: A Phylogenetic Perspective. In Foottit R.G. & Adler P.H. (*eds*) *Insect Biodiversity: Science and Society*. Second edition, Wiley Blackwell, UK.

Hahn M. & Brühl C.A. (2016) The secret pollinators: an overview of moth pollination with a focus on Europe and North America. *Arthropod-Plant Interactions*, 10, 21–28.

Hallmann C.A., Sorg M., Jongejans E., Siepel H., Hofland N., Schwan H., Stenmans W., Müller A., Sumser H., Hörren T., Goulson D. & de Kroon H. (2017) More than 75 Percent Decline over 27 Years in Total Flying Insect Biomass in Protected Areas. *PLoS ONE*, 12(10): e0185809.

Hayes M.P., Rhodes M.W., Turner E.C., Hitchcock G.E., Knock R.I., Lucas C.B.H. & Chaney P.K. (2018) Determining the long-term habitat preferences of the Duke of Burgundy butterfly, *Hamearis lucina*, on a chalk grassland reserve in the UK. *Journal of Insect Conservation*, 22, 329–343.

Henning G.A., Terblanche R.F. & Ball J.B. (*eds*) (2009) South African Red Data Book: butterflies. *SANBI Biodiversity Series 13*. South African National Biodiversity Institute, Pretoria.

Hill G.M., Kawahara A.Y., Daniels J.C., Bateman C.C. & Scheffers B.R. (2021) Climate change effects on animal ecology: butterflies and moths as a case study. *Biological Reviews*, 96, 2113–2126.

Hinks A.E., Cole E.F., Daniels K.J., Wilkin T.A., Nakagawa S. & Sheldon B.C. (2015) Scale-dependent phenological synchrony between songbirds and their caterpillar food source. *The American Naturalist*, 186, 84–97.

Humbert J.-Y., Pellet J., Buri P. & Arlettaz R. (2012) Does delaying the first mowing date benefit biodiversity in meadowland? *Environmental Evidence*, 1, 9.

Jakobsson S., Bernes C., Bullock J.M., Verheyen K. & Lindborg R. (2018) How does roadside vegetation management affect the diversity of vascular plants and invertebrates? A systematic review. *Environmental Evidence*, 7, 17.

Janzen D.H. & Hallwachs W. (2021) To us insectometers, it is clear that insect decline in our Costa Rican tropics is real, so let's be kind to the survivors. *Proceedings of the National Academy of Sciences*, 118, e2002546117.

Jordan M. & Böhm M. (2021) IUCN SSC Butterfly and Moth Specialist Group. Available at https://www.iucn.org/commissions/ssc-groups/invertebrates/butterfly-and-moth, accessed 28 October 2021.

Maes D. & Van Dyck H. (2001) Butterfly diversity loss in Flanders (north Belgium): Europe's worst case scenario? *Biological Conservation*, 99(3), 263-276.

Mason S.C., Palmer G., Fox R., Gillings S., Hill J.K., Thomas C.D. & Oliver T.H. (2015) Geographical range margins of many taxonomic groups continue to shift polewards. *Biological Journal of the Linnean Society*, 115, 586–597.

Leather S.R. (2017) "Ecological Armageddon" – more evidence for the drastic decline in insect numbers. *Annals of Applied Biology*, 172, 1–3.

Lomov B., Keith D.A., Britton D.R. & Hochuli D.F. (2006) Are butterflies and moths useful indicators for restoration monitoring? A pilot study in Sydney's Cumberland Plain Woodland. *Ecological Management & Restoration*, 7, 204–210.

Mallet J. (2014) The Lepidoptera Taxome Project. Available at https://www.ucl.ac.uk/taxome/, accessed 29 October 2021

Naef-Daenzer B. & Keller L.F. (2001) The foraging performance of great and blue tits (*Parus major* and *P. caeruleus*) in relation to caterpillar development, and its consequences for nestling growth and fledging weight. *Journal of Animal Ecology*, 68, 708–718.

Navarro-Cano J.A., Karlsson B., Posledovich D., Toftegaard T., Wiklund C., Ehrlén J. & Gotthard K. (2015) Climate change, phenology, and butterfly host plant utilization. *Ambio*, 44, 78–88.

New T.R. (2004) Moths (Insecta: Lepidoptera) and conservation: background and perspective. *Journal of Insect Conservation*, 8, 79–94.

Numa C., van Swaay C., Wynhoff I., Wiemers M., Barrios V., Allen D., Sayer C., López Munguira M., Balletto E., Benyamini D., Beshkov S., Bonelli S., Caruana R., Dapporto L., Franeta F., Garcia-Pereira Karaçetin E., Katbeh-Bader A., Maes D., Micevski N., Miller R., Monteiro E., Moulai R., Nieto A., Pamperis L., Pe'er G., Power A., Šašić M., Thompson K., Tzirkalli E., Verovnik R., Warren M. & Welch H. (2016) *The status and distribution of Mediterranean butterflies*. IUCN, Malaga, Spain.

Parmesan C., Ryrholm N., Stefanescu C., Hill J.K., Thomas C.D., Descimon H., Huntley B., Kaila L., Kullberg J., Tammaru T., Tennent W.J., Thomas J.A. & Warren M. (1999) Poleward shifts in geographical ranges of butterfly species associated with regional warming. *Nature*, 399, 579–583.

Settele J., Kudrna O., Harpke A., Kühn I., van Swaay C., Verovnik R., Warren M., Wiemers M., Hanspach J., Hickler T., Kühn E., van Halder I., Veling K., Vliegenthart A., Wynhoff I. & Schweiger O. (2008) *Climatic Risk Atlas of European Butterflies*. Biorisk 1 (Special Issue), Pensoft, Sofia–Moscow.

Slancarova J., Bartonova A., Zapletal M., Kotilinek M., Fric Z.F., Micevski N., Kati V. & Konvicka M. (2016) Life history traits reflect changes in Mediterranean butterfly communities due to forest encroachment. *PLoS ONE*, 11(3): e0152026.

Stefanescu C., Penuelas J. & Filella I. (2003) Effects of climatic change on the phenology of butterflies in the northwest Mediterranean Basin. *Global Change Biology*, 9, 1494–1506.

Stefanescu C., Puig-Montserrat X., Samraoui B., Izquierdo R., Ubach A. & Arrizabalaga A. (2017) Back to Africa: autumn migration of the painted lady butterfly *Vanessa cardui* is timed to coincide with an increase in resource availability. *Ecological Entomology*, 42, 737–747.

Sutherland W.J., Pullin A.S., Dolman P.M. & Knight T.M. (2004) The need for evidence-based conservation. *Trends in Ecology & Evolution*, 19, 305–308.

Sutherland W.J., Taylor N.G., MacFarlane D., Amano T., Christie A.P., Dicks L.V., Lemasson A.J., Littlewood N.A., Martin P.A., Ockendon N., Petrovan S.O., Robertson R.J., Rocha R., Shackelford G.E., Smith R.K., Tyler E.H.M. & Wordley C.R.F (2019) Building a tool to overcome barriers in research-implementation spaces: The Conservation Evidence database. *Biological Conservation*, 238, 108199.

Terblanche R.F. & Henning G.A. (2009) Threatened butterflies in South Africa: trends since 1989 and a future perspective. In Henning G.A., Terblanche R.F. & Ball J.B. (*eds*) South African Red Data Book: butterflies. *SANBI Biodiversity Series 13*. South African National Biodiversity Institute, Pretoria.

Theng M., Jusoh W.F.A, Jain A., Huertas B., Tan D.J.X., Tan H.Z., Kristensen N.P., Meier R. & Chisholm R.A. (2020) A comprehensive assessment of diversity loss in a well-documented tropical insect fauna: Almost half of Singapore's butterfly species extirpated in 160 years. *Biological Conservation*, 242, 108401.

Thomas C.D. & Harrison S. (1992) Spatial dynamics of a patchily distributed butterfly species. *Journal of Animal Ecology*, 61, 437–446.

Thomas J.A. (1980) Why Did the Large Blue Become Extinct in Britain? *Oryx*, 15, 243–247.

Thomas J.A. (2005) Monitoring change in the abundance and distribution of insects using butterflies and other indicator groups. *Philosophical Transactions of the Royal Society of Biological Sciences*, 360, 339–357.

Thomas J.A. & Lewington R. (2016) *The Butterflies of Britain & Ireland*. Third edition, Bloomsbury Publishing, UK.

Thomas J.A., Simcox D.J. & Clarke R.T. (2009) Successful Conservation of a Threatened *Maculinea* Butterfly. *Science*, 325, 80–83.

Van Dyck H., Puls R., Bonte D., Gotthard K. & Maes D. (2015) The lost generation hypothesis: could climate change drive ectotherms into a developmental trap? *Oikos*, 124(1): 54–61.

van Klink R., Bowler D.E., Gongalsky K.B., Swengel A.B., Gentile A. & Chase J.M. (2020) Meta-Analysis Reveals Declines in Terrestrial but Increases in Freshwater Insect Abundances. *Science*, 368 (6489): 417–420.

van Strien A.J., van Swaay C.A.M., van Strien-van Liempt W.T.F.H, Poot M.J.M. & WallisDeVries M.F. (2019) Over a century of data reveal more than 80% decline in butterflies in the Netherlands. *Biological Conservation*, 234, 116–122.

van Swaay C., Cuttelod A., Collins S., Maes D., López Munguira M., Šašić M., Settele J., Verovnik R., Verstrael T., Warren M., Wiemers M. & Wynhoff I. (2010) *European Red List of Butterflies*. Luxembourg: Publications Office of the European Union.

van Swaay C.A.M., Maes D., Collins S., Munguira M.L., Šašić M., Settele J., Verovnik R., Warren M.S., Wiemers M., Wynhoff I., Cuttelod A. (2011) Applying IUCN criteria to invertebrates: How red is the Red List of European butterflies? *Biological Conservation*, 144(1): 470–478.

Wagner D.L., Fox R., Salcido D.M. & Dyer L.A. (2021) A window to the world of global insect declines: Moth biodiversity trends are complex and heterogeneous. *Proceedings of the National Academy of Sciences*, 118(2): e2002549117.

Wardlaw J.C., Elmes G.W. & Thomas J.A. (1998) Techniques for studying *Maculinea* butterflies: I. Rearing *Maculinea* caterpillars with *Myrmica* ants in the laboratory. *Journal of Insect Conservation*, 2, 79–84.

Warren M.S., Maes D., van Swaay C.A.M., Goffart P., Van Dyck H., Bourn N.A.D., Wynhoff I., Hoare D. & Ellis S. (2021) The decline of butterflies in Europe: problems, significance, and possible solutions. *Proceedings of the National Academy of Sciences*, 118(2): e2002551117.

Wepprich T., Adrion J.R., Ries L., Wiedmann J. & Haddad N.M. (2019) Butterfly abundance declines over 20 years of systematic monitoring in Ohio, USA. *PLoS ONE*, 14(7): e0216270.

Whitaker J.O. & Black H. Food habits of cave bats from Zambia, Africa. *Journal of Mammology*, 57, 199–204.

Willmer P. (2011) Pollination by Butterflies and Moths. Chapter 14 in Willmer P. (*ed*) *Pollination & Floral Ecology*. Princeton University Press, USA.

Wilson R.J., Gutiérrez D., Gutiérrez J., Martínez D., Agudo R. & Monserrat V.J. (2005) Changes to the elevational limits and extent of species ranges associated with climate change. *Ecology Letters*, 8 (11): 1138–1146.

Wilson R.J., Gutiérrez D., Gutiérrez J. & Monserrat V.J. (2007) An elevational shift in butterfly species richness and composition accompanying recent climate change. *Global Change Biology*, 13(9): 1873–1887.

2. Threat: Residential and commercial development

Background

Residential and commercial developments pose a number of threats to butterflies and moths, through the loss of habitat during construction, the replacement of native vegetation with non-native turf and ornamental landscapes, and the unfavourable management of urban green spaces in the longer term. This chapter covers actions which aim to protect, restore and better manage urban habitats for the benefit of butterflies and moths. Further threats from development include the destruction of habitat, pollution and impacts from 'transportation and service corridors'. Actions in response to these threats are described in '*Habitat restoration and creation*', '*Threat: Pollution*' and '*Threat: Transportation and service corridors*'.

2.1. Plant parks, gardens and road verges with appropriate native species

- **Eight studies** evaluated the effects on butterflies and moths of planting parks and gardens with appropriate native species. Seven were in the USA[2-8] and one was in Germany[1].

COMMUNITY RESPONSE (5 STUDIES)

- **Richness/diversity (5 studies):** Three of five replicated studies (including three paired, three controlled and two site comparison studies) in Germany[1] and the USA[3,4,7,8] found that gardens[3,7] and road verges[1] planted with native species had a greater species richness of butterfly and moth adults[1] and caterpillars[3,7] than gardens or verges with mixed or exclusively non-native plant species. The other two studies found that the species richness of adult butterflies was similar in areas planted with native or non-native flowers[4,8].

POPULATION RESPONSE (6 STUDIES)

- **Abundance (4 studies):** Two of three replicated studies (including two paired and two controlled studies) in the USA[3,7,8] found that gardens planted with native species had a higher abundance of butterfly and moth caterpillars than gardens with mixed or exclusively non-native plant species[3,7]. The third study found that the abundance of adult butterflies was similar in areas planted with native or non-native flowers[8]. One replicated, randomized, controlled study in the USA[6] found that when taller native milkweed species were planted, they had a higher abundance of monarch butterfly eggs and caterpillars than shorter milkweed species.
- **Survival (2 studies):** One of two replicated, site comparison studies in the USA[2,5] found that the survival of pipevine swallowtail eggs and caterpillars was lower on California pipevine planted in gardens than in natural sites[2]. The other study found that the survival of monarch butterfly caterpillars was similar on common milkweed planted in gardens and meadows[5].
- **Condition (1 study):** One replicated, randomized, controlled study in the USA[6] found that the growth of monarch butterfly caterpillars was similar on eight different native milkweed species[6].

BEHAVIOUR (2 STUDIES)

- **Use (2 studies):** One of two replicated, site comparison studies in the USA[2,5] found that monarch butterfly adults used common milkweed planted in gardens more than milkweed planted in meadows[5]. The other study found that pipevine swallowtail adults used California pipevine planted in gardens less than in natural sites[2].

Background

Non-native ornamental plants dominate urban and suburban landscapes. A large number of butterflies and moths have specialist feeding requirements, and can only feed as caterpillars, or occasionally adults, on plants which they have evolved with (Burghardt *et al.* 2008). Therefore, butterfly and moth species richness often correlates with the number of potential larval host plant species present in urban parks (Koh & Sodhi 2004), and planting more native species may benefit a wide range of butterflies and moths. Moreover, caterpillar growth and survival can vary between different host plant species (Pocius *et al.* 2017), so the choice of host species for planting may be important.

Note that some non-native plants may still provide important nectar resources for butterflies and moths. For studies which include deliberate planting of non-native species, see "*Practise 'wildlife gardening'*".

Burghardt K.T., Tallamy D.W. & Shriver W.G. (2008) Impact of native plants on bird and butterfly biodiversity in suburban landscapes. *Conservation Biology*, 23, 219–224.

Koh L.P. & Sodhi N.S. (2004) Importance of reserves, fragments, and parks for butterfly conservation in a tropical urban landscape. *Ecological Applications*, 14, 1695–1708.

Pocius V.M., Debinski D.M., Pleasants J.M., Bidne K.G., Hellmich R.L. & Brower L.P. (2017) Milkweed Matters: Monarch Butterfly (Lepidoptera: Nymphalidae) Survival and Development on Nine Midwestern Milkweed Species. *Environmental Entomology*, 46, 1098–1105.

A replicated, site comparison study in 1992–1996 in urban road verges in Baden-Württemberg, Germany (1) reported that road verges sown with native wildflowers had a greater species richness of butterflies and day-flying moths than verges with non-native vegetation. Results were not tested for statistical significance. Over four years, eight butterfly and moth species were recorded on two verges sown with wildflowers, compared to none on verges with non-native plants. Only one species, small white *Pieris rapae*, occurred every year in the sown verges. Two road verges (1,100–1,500 m^2, up to 5–35 m wide) on busy roads in the centre of Stuttgart were sown with annual and biennial native wildflowers including white stonecrop *Sedum album*, common self-heal *Prunella vulgaris*, greater knapweed *Centaurea scabiosa* and wild carrot *Daucus carota*. For comparison an unspecified number of vegetated road verges that contained non-native bearberry cotoneaster *Cotoneaster dammeri*, scarlet firethorn *Pyracantha ccoccinea* and cultivated roses were also surveyed. From April–August 1992–1994 and 1996, butterflies and day-flying moths were surveyed 6–10 times/year on each verge, and plants were occasionally searched for caterpillars.

A replicated, site comparison study in 2001–2002 in 32 gardens and 20 mixed woodlands in California, USA (2) found that California pipevine *Aristolochia* *californica* planted in gardens was used less by pipevine swallowtails *Battus philenor* and had lower egg and caterpillar survival compared to that in natural sites. Adult swallowtails visited fewer gardens (9/32) than natural sites (19/20) where pipevine occurred, and eggs were laid in fewer gardens (7/32) than natural sites (19/20). Egg survival was lower in gardens (42–70%) than in natural sites (57–91%). Adult and egg presence were higher where pipevines were at least 7- (adults) and 17-years-old (eggs), and egg and caterpillar survival were higher at sites with older (>40 years) and larger pipevines (>185 m^2 of foliage) than in recently planted sites (data presented as model results). Egg densities were higher on pipevines grown in the sun (2–5.5 eggs/m^2/week) than in the shade (0–2 eggs/m^2/week). In 2001, nine gardens where pipevine had been planted and nine riparian oak woodland and redwood forests with naturally occurring pipevine were selected. In 2002, twenty-three gardens and 11 natural sites were studied. From March–July 2001–2002, pipevine foliage at each site was inspected for >15 minutes/week, and all swallowtail eggs, caterpillars and adults recorded. In 2002, the number of eggs/m^2 of foliage growing in the sun and shade at four garden and four natural sites was counted weekly for 12 weeks, and the survival of marked egg masses was recorded.

A replicated, paired, site comparison study in 2006 in 12 suburban gardens in Pennsylvania, USA (3) found that gardens planted exclusively with native plants had four times more butterfly and moth caterpillars and three times more caterpillar species than gardens with a conventional mixture of native and non-native plants. Both the abundance (12.7 individuals/site) and species richness (6.8 species/site) of caterpillars were higher in gardens with native plants than in conventional gardens (abundance: 3.0 individuals/site; richness: 1.8 species/site). Six pairs of gardens (0.13–5.26 ha) within 1.6 km of each other, and with similar area, vegetation structure and surrounding landscape, were selected. One garden in each pair was planted exclusively with native plants (canopy, understorey, shrubs and grasses), while the other contained a conventional mix of cool-season Eurasian grasses, Asian shrubs and understorey trees, and native canopy. From August–September 2006, each garden was surveyed once. All butterfly and moth caterpillars on all twigs and vegetation within reach and within a 0.5-m radius of 12 evenly-spaced points/garden were identified.

A replicated, paired, controlled study in 2004–2006 in 18 urban gardens in New York, USA (4) found that planting native plants did not increase the number of butterflies in gardens. In gardens where native wildflowers were planted, the number of species of butterflies was similar to gardens where no additional flowers were planted (data not presented). In addition, 88% of butterflies seen on flowers were using non-native species (statistical significance not assessed). In August 2004, in each of nine gardens (224–2,188 m^2, 0–33 years old), 70 plants of seven native wildflower species were planted in a sunny, composted 10 m^2 plot (or additional 24-inch diameter pots where limited soil was available). Any lost plants were replaced in May 2005. In a further nine gardens, similar in size and floral area, no wildflowers were planted. Prior to any planting, the majority of plants in the gardens (69%) were non-native. From June–September 2005–2006, butterflies were visually counted in each garden every two weeks, spending 5 minutes/600 m^2, and their use of native or non-native flowers was recorded.

A replicated, site comparison study in 2009–2010 in 20 residential gardens and five meadows in Pennsylvania, USA (5) found that common milkweed *Asclepias syriaca* planted in gardens was used by monarch butterflies *Danaus plexippus* more than milkweed planted in meadows, but caterpillar survival was similar across the sites. Milkweed patches in gardens contained more monarch eggs (47–109 eggs/plot) than milkweed patches in meadows (7–45 eggs/plot). Egg and caterpillar survival was similar in gardens (6.9–8.7%) and meadows (3.9–11.4%). In May–June 2009, twenty milkweed plants were planted in each of twenty 2-m^2 plots (130–1,500 m apart, >500 m from the nearest known milkweed) in heavily managed lawns and gardens and forty 2-m^2 plots across five minimally managed native meadows. Plants were grown from seed in greenhouses, surrounding vegetation was cut prior to planting, and sites were watered periodically. Plants were searched for eggs and caterpillars nine times from July–September 2009, and six times from 19–29 August 2010. Eggs and caterpillars were removed or marked to avoid double-counting. Monitoring ended if fewer than four healthy plants remained. On half of the plants at each site, survival of marked eggs and caterpillars was monitored over 11–14 days from the third week of August each year.

A replicated, randomized, controlled study in 2016–2017 in an arboretum in Kentucky, USA (6) found that following planting of eight milkweed species *Asclepias* spp. the number of monarch butterfly *Danaus plexippus* eggs and caterpillars was higher on taller species than on shorter species, but that caterpillar growth and survival were similar across all species. Taller milkweed species (*Asclepias syriaca*, *A. speciosa*, *A. incarnata*, *A. fascicularis*) had a higher number of monarch butterfly eggs and caterpillars (3.0–16.8 individuals/plot) than shorter species (0.0–5.4 individuals/plot). However, caterpillar growth (final weight: 169–437 mg) and survival (56–100%) were similar on all milkweed species in two of three trials. In the third trial, survival (40–65%) was similar but caterpillars were larger on *A. verticillata*, *A. tuberosa* and *A. speciosa* (868–1,032 mg) than on the other species (300–706 mg). Eight species of milkweed native to Kentucky or the central or western USA (common *A. syriaca*, swamp *A. incarnata*, butterfly *A. tuberosa*, green antelopehorn *A. viridis*, whorled *A. verticillata*, showy *A. speciosa*, Mexican whorled *A. fascicularis*, broadleaf milkweed *A. latifolia*) were grown from seed in a greenhouse. In May 2016, seedlings were transplanted into five (1.22 × 9.75 m) garden plots, each with eight subplots (1.22 × 1.22 m). Four individuals of a single species were sown into each subplot. From May–October 2016 and April–September 2017, monarch eggs and caterpillars were counted on all plants once every two weeks. The following three experiments measured monarch caterpillar growth and survival. In August 2016, two first or second instar monarch caterpillars were caged in white fine mesh bags (25 × 40 cm) on each of two plants/plot for nine days. In September 2016, three caterpillars were caged on each of nine plants for seven days. In August 2017, a single 1-day-old caterpillar was caged on each of 10 plants of each species in a greenhouse for five days.

A replicated, randomized, controlled study in 2014–2015 at a research farm in Alabama, USA (7) found that planted native trees supported a greater abundance and species richness of moth caterpillars than non-native trees. The abundance (260–281 individuals/year) and species richness (17 species) of moth caterpillars on planted native red maple *Acer rubrum* was higher than on non-native Norway maple *Acer platanoides* (abundance: 98–102 individuals/year; richness: 10 species) and crepe myrtle *Lagerstroemia indica* (abundance: 8 individuals/year; richness: 3 species/year). In March 2014, a native red maple was planted in the centre of each of 28 plots (5 × 5 m, 15 m apart) and surrounded by four further trees (3.5 m away) in one of four randomly assigned treatments: native red maples, non-native Norway maples, non-native crepe myrtles, or no trees. Herbicide was applied monthly, exposed ground covered with pine straw at the beginning of each season and nitrogen fertilizer applied to each tree in April and August each year. From June–September 2014, and May–September 2015, caterpillars were surveyed twice a month on the central maple and one neighbouring tree in each plot. All caterpillars on 30 leaves in each of four cardinal directions were counted.

A replicated, paired, controlled study in 2013–2014 in a managed park in Georgia, USA (8) found that areas planted with native flowers had a similar overall abundance and species richness of adult butterflies, but fewer adults and/or eggs, and more caterpillars, of specific species than areas planted with non-native flowers. The total abundance and species richness of butterflies was similar in plots planted with native and non-native plants (data presented as model results). However, in native flower plots the abundance of monarch *Danaus plexippus* (0.1–0.2 butterflies/plot) and gulf fritillary *Agraulis vanillae* adults (0.3–0.5 butterflies/plot), and of monarch and queen *Danaus gilippus* eggs (0.1 eggs/plant) was lower than in non-native flower plots (monarch: 1.6–3.1 butterflies/plot; gulf fritillary: 1.3–1.4 butterflies/plot; eggs: 0.7 eggs/plant). The abundance of black swallowtail *Papilio polyxenes* caterpillars was higher in native plots (0.7 caterpillars/plant) than in non-native plots (0.6 caterpillars/plant). Authors suggested that the difference in the number of butterflies of some species may have been caused by the fact that there were fewer flowering plants in native than non-native plots. In spring 2013, four fenced, irrigated experimental plots (7.6 × 15.2 m, 20–88 m apart) were established in each of three blocks, 250 m apart. Each plot was planted with 128 plants of 13 species, and was surrounded by mown grass. Plots were assigned to four treatments/block: planting with species native to Georgia or not native to the USA, and low (every other month) or high (every other week) weed maintenance. From May–September 2014, adult butterflies were surveyed for 7 minutes/plot, 1–4 times/month, and eggs and caterpillars of the four species were counted weekly or monthly on 2–14 host plants/butterfly species/plot.

(1) Schwenninger H.R. & Wolf-Schwenninger K. (1998) Modifying landscaped verges for conservation: new urban habitats for bees and butterflies? *Natur und Landschaft*, 73, 386–392.
(2) Levy J.M. & Connor E.F. (2004) Are gardens effective in butterfly conservation? A case study with the pipevine swallowtail, *Battus philenor*. *Journal of Insect Conservation*, 8, 323–330.
(3) Burghardt K.T., Tallamy D.W. & Shriver W.G. (2008) Impact of native plants on bird and butterfly biodiversity in suburban landscapes. *Conservation Biology*, 23, 219–224.
(4) Matteson K.C. & Langellotto G.A. (2011) Small scale additions of native plants fail to increase beneficial insect richness in urban gardens. *Insect Conservation and Diversity*, 4, 89–98.

(5) Cutting B.T. & Tallamy D.W. (2015) An Evaluation of Butterfly Gardens for Restoring Habitat for the Monarch Butterfly (Lepidoptera: Danaidae). *Environmental Entomology*, 44, 1328–1335.
(6) Baker A.M. & Potter D.A. (2018) Colonisation and usage of eight milkweed (*Asclepias*) species by monarch butterflies and bees in urban garden settings. *Journal of Insect Conservation*, 22, 405–418.
(7) Clem C.S. & Held D.W. (2018) Associational Interactions Between Urban Trees: Are Native Neighbors Better Than Non-Natives? *Environmental Entomology*, 47, 881–889.
(8) Majewska A.A., Sims S., Wenger S.J., Davis A.K. & Altizer S. (2018) Do characteristics of pollinator-friendly gardens predict the diversity, abundance, and reproduction of butterflies? *Insect Conservation and Diversity*, 11, 370–382.

2.2. Practise 'wildlife gardening'

- **Four studies** evaluated the effects of practising wildlife gardening on butterflies and moths. Two were in the UK[1,3] and one was in each of France[2] and the USA[4].

COMMUNITY RESPONSE (1 STUDY)

- **Richness/diversity (1 study):** One replicated, paired, controlled study in the USA[4] found that areas with reduced frequency weeding had a similar species richness of adult butterflies compared to areas with conventional weeding.

POPULATION RESPONSE (3 STUDIES)

- **Abundance (3 studies):** Two replicated studies (including one paired, controlled study) in the UK[1] and the USA[4] found that increasing the number and age of potted nettle plants in gardens[1] and weeding less frequently[4] did not increase abundance of butterflies[4], all caterpillars[1,4] and caterpillars and eggs of four target species[4]. One replicated, site comparison study in France[2] found that gardens where insecticides and herbicides were not used and where there were natural features had a higher abundance of butterflies, but gardens where fungicides and snail pellets were not used had a lower abundance of butterflies.

BEHAVIOUR (2 STUDIES)

- **Use (2 studies):** One replicated study in the UK[1] reported that caterpillars only occasionally used potted nettle plants in gardens. One site comparison study in the UK[3] found that planted buddleia and marjoram were visited by adult butterflies and moths more frequently than other plant species.

Background

Within urban areas, public parks and private gardens represent a significant area of potential habitat. Wildlife-friendly gardening could include a number of independent actions for butterflies and moths, such as planting nectar-rich flowers or native plant species, reducing the frequency of weeding or cutting, and reducing chemical impacts, as well as actions aimed at other wildlife. This action includes studies where two or more of these are carried out together, as well as less frequently tested actions.

This action includes studies where non-native plants are used to provide nectar resources. For studies exclusively testing the planting of native species, see "*Plant parks and gardens with appropriate native species*". See also "*Alter mowing regimes* *for greenspaces and road verges*", "*Pollution – Stop using herbicides on pavements and road verges*" and "*Pollution – Stop using pesticides as seed dressings and sprays in flower beds and greenspace*".

A replicated study in 2000–2002 in 20 urban gardens in Sheffield, UK (1) reported that caterpillars were only occasionally found on potted nettle *Urtica dioica* plants, and that increasing the number of plants or the age of the plants did not increase the number of caterpillars found. In the three years of the experiment, comma caterpillars *Polygonia c-album*, nettle tap moths *Anthophila fabriciana* and mother-of-pearl moths *Pleuroptya ruralis* (it is unclear whether these were adults or caterpillars) were found on potted nettle plants in one, eight and four of the gardens respectively. Authors reported that there was no difference in the number of butterfly and moth caterpillars found when the number of potted nettle plants was increased or on plants of different ages (data and statistics not presented). In June 2000 one tub of nettles was placed in each of 20 gardens. To encourage new growth half of the stems were cut at the first visit and all at the end of each autumn. To test whether patch size or age of plant affected caterpillar presence, in April 2002 five gardens had their plant replaced with a new plant, five had their original plant, five had their plant replaced with four new plants, and five had their original plant plus three new plants. During the summer and autumn of 2000, 2001 and 2002 nettles were checked for caterpillars and their presence (feeding damage and webs).

A replicated, site comparison study in 2009–2011 in 3,722 private gardens in France (2) found that there was a higher abundance of butterflies in gardens where insecticides and herbicides were not used and where there were more natural features, but a lower abundance of butterflies where fungicides and snail pellets were not used. There were significantly more butterflies in gardens that used no pesticides (average: 7) than those with insecticide (average: 6) and herbicide (average: 7) use, but fewer butterflies in gardens that did not use conventional (average: 7) or Bordeaux mixture (average: 7) fungicides or snail pellets (average: 7). There was no difference in abundance between gardens that did and did not use fertilizer. Additionally, there were more butterflies in gardens which had more "natural" features, such as fallow plots, nettles, ivy, brambles and dead trees (data presented as model results). Data was obtained from a citizen monitoring scheme across France. Monthly from March–October participants submitted information about their gardens, including the number of butterflies seen, the presence of fallow plots, nettles, ivy, brambles and dead trees, and whether they use chemicals in gardening.

A site comparison study in 2013 in a rural garden in East Sussex, UK (3) found that of 11 planted flower varieties, buddleia *Buddleia davidii* and marjoram *Origanum vulgare* were visited most by butterflies and day-flying moths, and they attracted different groups of species. Marjoram received the most visits by butterflies (50% of all visits), followed by buddleia (22% of all visits), compared to 0–12% visits for the other nine flower varieties. Meadow brown *Maniola jurtina* (213 out of 287 visits) and gatekeeper *Pyronia tithonus* (908/961 visits) were most attracted to marjoram, and peacock *Inachis io* (312/328 visits), painted lady *Vanessa cardui* (123/143 visits) and red admiral *Vanessa atalanta* (9/10 visits) were most attracted to buddleia. However, hemp agrimony *Eupatorium* *cannibinum* attracted the highest diversity of butterfly species (data presented as model results). See paper for more details. Eleven varieties of ornamental flowers were grown in 1–5 discrete patches (total: 1–15 m^2) around a garden. From 8–13th August 2013, butterflies and day-flying moths feeding on each patch were counted 105 times (three times/hour at 20-minute intervals) in good weather.

A replicated, paired, controlled study in 2013–2014 in a managed park in Georgia, USA (4) found that areas with reduced weeding had a similar overall abundance and species richness of adult butterflies, and adults, eggs and caterpillars of four target species, compared to areas with regular weeding. The total abundance and species richness of butterflies was similar in plots weeded every two months and plots weeded every two weeks (data presented as model results). In addition, the abundance of adults, eggs and caterpillars of four target species (monarch *Danaus plexippus*, queen *Danaus gilippus*, gulf fritillary *Agraulis vanillae*, and black swallowtail *Papilio polyxenes*) were similar in plots with reduced weeding and plots with regular weeding (see paper for details). In spring 2013, four fenced, irrigated experimental plots (7.6 × 15.2 m, 20–88 m apart) were established in each of three blocks, 250 m apart. Each plot was planted with 128 plants of 13 species, and was surrounded by mown grass. Plots were assigned to four treatments/block: planting with native or non-native species, and low (every other month) or high (every other week) weed maintenance by hand pulling, trimming, and spot herbicide application. From May–September 2014, adult butterflies were surveyed for 7 minutes/plot, 1–4 times/month, and eggs and caterpillars of four species (monarch, queen, black swallowtail, gulf fritillary) were counted weekly or monthly on 2–14 host plants/butterfly species/plot.

(1) Gaston K. J., Smith R. M., Thompson K. & Warren P. H. (2005) Urban domestic gardens (II): experimental tests of methods for increasing biodiversity. *Biodiversity and Conservation*, 14, 395-413.
(2) Muratet A. & Fontaine B. (2015) Contrasting impacts of pesticides on butterflies and bumblebees in private gardens in France. *Biological Conservation*, 182, 148-154.
(3) Shackleton K. & Ratnieks F.L.W. (2016) Garden varieties: How attractive are recommended garden plants to butterflies? *Journal of Insect Conservation*, 20, 141–148.
(4) Majewska A.A., Sims S., Wenger S.J., Davis A.K. & Altizer S. (2018) Do characteristics of pollinator-friendly gardens predict the diversity, abundance, and reproduction of butterflies? *Insect Conservation and Diversity*, 11, 370–382.

2.3. Alter mowing regimes on greenspaces and road verges

- **Seven studies** evaluated the effects of altering mowing regimes on greenspaces and road verges on butterflies and moths. One study was in each of Finland[1], the Netherlands[2], Poland[3], Germany[4], the UK[5], Canada[6] and Sweden[7].

COMMUNITY RESPONSE (3 STUDIES)

- **Richness/diversity (3 studies):** Two replicated, paired, controlled studies in Germany[4] and the UK[5] found that less frequently mown[4] or unmown[5] urban greenspaces had a higher species richness and diversity of butterflies and moths than more frequently mown areas. One replicated, site comparison study in Canada[6] found that the management of road verges (and land under power lines) did not affect the species richness of butterflies.

POPULATION RESPONSE (4 STUDIES)

- **Abundance (3 studies):** Two replicated studies (including one paired, controlled study) in the UK[5] and Canada[6] found that unmown public parks[5] and road verges (and land under power lines)[6] had a higher abundance of all adult butterflies[5] and pearl crescent and northern pearl crescent butterflies[6] than regularly mown areas, but the abundance of other butterflies on the road verges (and under power lines) was similar between mown and unmown areas in the second study[6]. One study in Finland[1] found that roadsides mown in late summer had more ringlet butterflies than those mown in mid-summer.
- **Survival (1 study):** One replicated, site comparison study in Poland[3] found that road verges mown less frequently, or later in summer, had fewer dead butterflies killed by traffic than more frequently or earlier mown verges.

BEHAVIOUR (2 STUDIES)

- **Use (2 studies):** One replicated, site comparison study in Sweden[7] reported that less frequently mown urban grasslands were more frequently occupied by scarce copper butterflies than more frequently mown grasslands. One replicated, randomized, controlled study in the Netherlands[2] found that butterflies were recorded on verges which were mowed once or twice a year and those which were not mowed, but on mowed verges butterflies were only recorded on those where hay was removed.

Background

Greenspaces and road verges offer potential habitat patches and corridors for butterflies and moths. However, management of these spaces must be carefully planned. Mowing may be required to keep vegetation down, but also reduces the availability of nectar resources, inhibits the growth of host plants used by caterpillars, reduces the structural diversity of the vegetation, and poses a risk from direct mortality, especially to eggs, caterpillars and pupae (Hopwood *et al.* 2015). Road verges with a higher species richness of plants attract more butterflies, and yet have fewer butterflies killed by traffic than less diverse road verges (Skórka *et al.* 2013). Therefore, altering mowing regimes to encourage plant growth and diversity may benefit butterfly and moth populations in urban areas.

See also: "*Transportation and service corridors – Restore or maintain species-rich grassland along road/railway verges*" and "*Pollution – Stop using herbicides on pavements and road verges*".

Hopwood J., Black S.H., Lee-Mäder E., Charlap A., Preston R., Mozumder K. & Fleury S. (2015) Literature review: Pollinator habitat enhancement and best management practices in highway rights-of-way. *Federal Highway Administration report by The Xerces Society for Invertebrate Conservation & ICF International*.

Skórka P., Lenda M., Moroń D., Kalarus K. & Tryjanowski P. (2013) Factors affecting road mortality and the suitability of road verges for butterflies. *Biological Conservation*, 159, 148–157.

A study in 2003 along a highway in South Karelia, Finland (1) found that roadsides mown in late summer had more ringlet butterflies *Aphantopus hyperantus* than those mown in mid-summer. There were more ringlets along road verges that were mown in late summer (estimated population size = 840–2720; population density = 1160–4360 individuals/ha) than those mown in mid-summer (estimated population size: 220–1500 individuals; population density: 500–1200 individuals/ha). A lower percentage of butterflies first caught along verges mown in late summer (11–31%) moved out of their original patch than those caught along verges mown in mid-summer (43–63%) (these data were not tested for statistical significance). On 30 days between June and August 2003, butterflies were sampled using mark-release-recapture surveys along a 2.2-km long transect along a highway intersection and adjacent roads. The site was divided into 80–280-m sections based on habitat: an intersection between two roads with either late summer mowing and hay removal or with mid-summer (June) mowing without hay removal, and a highway verge with either partial July and full late summer mowing without hay removal (counted as late summer mowing in the study) or with mid-summer (July) mowing without hay removal. The effect of hay removal was not tested.

A replicated, randomized, controlled study in 2004–2006 in 25 roadside verge sites in Limburg, the Netherlands (2) found that butterflies were recorded along verges with no management and mowed verges where hay was removed but no butterflies were recorded along mowed road verges where hay was not removed. No butterflies were recorded along verges mowed either once or twice a year where hay was not removed, but of insects recorded along verges, butterflies represented 14% where mowed once a year with hay removal, 8% where mowed twice a year with hay removal and 7% with no management. In 2004–2006 five treatments (each replicated five times) were conducted in 12 x 15 m plots along a highway: mowing once a year in mid-September with or without hay removal, mowing twice a year in late June and mid-September with or without hay removal, and no management. On four visits in May–August 2006, flower-visiting insects were counted in four 1-m^2 quadrats in each plot over a 15-minute period. Butterflies were not identified more precisely than order level and statistical tests did not look at the difference between the number of mowings or hay removal for butterflies alone.

A replicated, site comparison study in 2010 on 60 road verges in southern Poland (2) found that less frequently or later mown road verges, which provided more suitable habitat, had fewer individuals and a lower species diversity of dead butterflies killed by traffic than more frequently or earlier mown verges. Both the number of individual butterflies and number of species killed by traffic were lower on verges mown less frequently, or later in the summer, than on more frequently or earlier mown verges (data presented as model results). Sixty roads, >2 km apart, with verges of similar width and vegetation on each side, were selected. Between roads, verges differed in the frequency and timing at which they were mown. From April–September 2010, butterflies were surveyed 12 times on two 100-m transects along each side of each road. Dead butterflies were collected from the asphalt and the first metre of verge next to the road.

A replicated, paired, controlled study in 2011 in 10 urban greenspaces in Baden-Württemberg, Germany (3) found that less frequently mown areas had a greater diversity of butterflies and burnet moths than regularly mown areas. The species richness and diversity of butterflies and burnet moths in areas mown once in the summer (9 species/site) was higher than in areas mown every 3–4 weeks throughout the summer (4 species/site, diversity data presented as model results). In addition, four species only occurred on grasslands which had been mown once/year for >4 years, which had an average of 11 species/site (statistical significance not assessed). See paper for individual species results. One half of each of 10 public greenspaces (>200 m^2) was mown or mulched once in July or August 2011, while the other half was mown or mulched once every 3–4 weeks from April–August 2011. Five additional sites had only been mown once/year for >4 years. From April–early August 2011, butterflies were surveyed five times in each site, by walking with nets in large loops until no new species was found for 20 minutes.

A replicated, paired, controlled study in 2013 in a public park in Sussex, UK (4) found that unmown areas had higher abundance of butterflies and moths, and higher species richness of butterflies, than mown areas. The total abundance of butterflies (123 individuals) and moths (261 individuals) was higher in unmown strips than in strips mown every two weeks throughout the summer (butterflies: 32 individuals; moths: 23 individuals). In addition, the total abundance of butterflies (271 individuals) and moths (391 individuals), and the species richness of butterflies (8 species), were higher on the unmown half of the park than in the mown half (butterfly abundance: 6 individuals; moth abundance: 2 individuals; butterfly richness: 2 species) (moths not identified to species). From spring 2013, half of a 6-ha park was left unmown, while the other half continued to be mown every two weeks from spring to autumn. In addition, four blocks (20 × 30 m) of four strips (5 × 30 m) each were established in the unmown half of the park. Within each block, one strip was assigned to each of four mowing treatments: regular mowing every two weeks through the summer, regular mowing until 5 July, regular mowing until 2 June, and unmown. From June–September 2013, foraging and resting butterflies and moths were surveyed weekly by walking down the centre of each 30-m strip five times/visit. From July–September 2013, butterflies and moths were surveyed eight times on two 500-m transects, one around the regularly mown and one around the unmown half of the park.

A replicated, site comparison study in 2007–2008 along 52 road verges and power lines (collectively "transmission lines") in Manitoba, Canada (5) found that unmown transmission lines had more northern pearl crescent *Phyciodes morpheus* and pearl crescent *Phyciodes tharos* butterflies than lines mown twice/year, but mowing regime did not affect the abundance or species richness of other butterflies. There were more crescent butterflies on unmown transmission lines (2.7 individuals/visit) than on lines mown twice/year (0.1 individuals/visit). However, the abundance and species richness of other native butterflies was not significantly different between transmission lines which were not mown (abundance: 11 individuals/visit; richness: 32 species), mown once/year and not hayed (11 individuals/visit; 27 species), mown once/year and hayed (14 individuals/visit; 21 species), or mown twice/year and sprayed with herbicide (10 individuals/visit; 21 species). See paper for species results. Fifty-two road verges and power lines (>30 m wide, >400 m long) were managed in one of four ways: 21 were neither mown nor sprayed with herbicide, but some trees were removed; 14 were mown twice/year with cuttings left on site and sprayed frequently with herbicide; 10 were mown once/year with cuttings left on site and sprayed infrequently with herbicide; seven were mown once/year with cuttings baled and removed with no spraying. From 15 June–15 August 2007–2008, butterflies were surveyed on one 400- or 500-m transect at each site 2–4 times/year.

A replicated, site comparison study in 2015 in 30 grassland patches around an urban area in Scania, Sweden (6) reported that biodiversity areas mown once/year had a higher occupancy of scarce copper butterflies *Lycaena virgaureae* than regularly mown public parks, but lower occupancy than unmanaged grasslands. Results were not tested for statistical significance. Six biodiversity areas managed by the local authority were all occupied at least once, and often 2–3 times, by scarce coppers, but no butterflies were seen in nine regularly mown parks. However, 15 unmanaged grasslands were the most frequently occupied areas on all four surveys (data not presented). Thirty grassland habitat patches managed in three ways were studied: six biodiversity areas (cut once/year in mid-August), nine parks (cut several times/year) and 15 unmanaged grasslands (no cutting or grazing). From July–August 2015, butterflies were surveyed four times in each of 30 patches by systematic searching.

(1) Valtonen A. & Saarinen K. (2005) A highway intersection as an alternative habitat for a meadow butterfly: effect of mowing, habitat geometry and roads on the ringlet (*Aphantopus hyperantus*). *Annales Zoologici Fennici*, 42(5), 545-556.

(2) Noordijk J., Delille K., Schaffers A.P. & Sykora K.V. (2009) Optimizing grassland management for flower-visiting insects in roadside verges. *Biological Conservation*, 142(10), 2097–2103.

(3) Skórka P., Lenda M., Moroń D., Kalarus K. & Tryjanowski P. (2013) Factors affecting road mortality and the suitability of road verges for butterflies. *Biological Conservation*, 159, 148–157.

(4) Kricke C., Bamann T., Betz O. (2014) Influence of Urban Mowing Concepts on the Diversity of Butterflies – Investigations on public green space in the city of Tübingen. *Naturschutz und Landschaftsplanung*, 46, 052–058.

(5) Garbuzov M., Fensome K.A. & Ratnieks F.L.W. (2015) Public approval plus more wildlife: twin benefits of reduced mowing of amenity grass in a suburban public park in Saltdean, UK. *Insect Conservation and Diversity*, 8, 107–119.

(6) Leston L. & Koper N. (2016) Urban Rights-of-Way as Reservoirs for Tall-Grass Prairie Plants and Butterflies. *Environmental Management*, 57, 543–557.

(7) Haaland C. (2017) How to preserve a butterfly species within an urbanising settlement and its surroundings: a study of the scarce copper (*Lycaena virgaureae* L.) in southern Sweden. *Journal of Insect Conservation*, 21, 917–927.

2.4. Protect or restore brownfield or ex-industrial sites

- We found no studies that evaluated the effects of protecting or restoring brownfield or ex-industrial sites on butterflies and moths.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Ex-industrial, or brownfield, sites can provide important early-successional habitat for a range of species, including butterflies and moths. However, such sites are often targeted for urban development (Robins *et al.* 2013) or fertilized and planted to accelerate succession (Tropek *et al.* 2010). Legal protection which prevents development may be required to retain such sites, and restoration which maintains a state of early succession may be important for rare and sensitive species (Tropek *et al.* 2010).

Robins J., Henshall S. & Farr A. (2013) The state of brownfields in the Thames Gateway. *Buglife Report*, https://cdn.buglife.org.uk/2019/08/The-State-of-Brownfields-in-the-Thames-Gateway_0_0.pdf.

Tropek R., Kadlec T., Karesova P., Spitzer L., Kocarek P., Malenovsky I., Banar P., Tuf I.H., Hejda M., Konvicka M. (2010) Spontaneous succession in limestone quarries as an effective restoration tool for endangered arthropods and plants. *Journal of Applied Ecology*, 47, 139–147.

2.5. Protect greenfield sites or undeveloped land in urban areas

- **Two studies** evaluated the effects of protecting greenfield sites or undeveloped land in urban areas on butterflies and moths. One study was in Singapore[1] and the other was in Mexico[2].

COMMUNITY RESPONSE (2 STUDIES)

- **Richness/diversity (2 studies):** Two site comparison studies (including one replicated study) in Singapore[1] and Mexico[2] found that protected native forest[1,2] and grassland[2] in urban areas had a higher species richness of butterflies than urban parks[1] or non-native *Eucalyptus* plantations[2].

POPULATION RESPONSE (0 STUDIES)

BEHAVIOUR (0 STUDIES)

Background

Undeveloped land within urban areas, or greenfield sites, may provide important remnant habitat for butterfly and moth species which cannot otherwise survive in built-up areas. Protecting these sites from development may benefit populations of these sensitive species close to human populations.

A replicated, site comparison study in 2002–2003 in 39 tropical rainforest reserves, forest fragments and urban parks in Singapore (1) found that protected primary or secondary forest reserves had a higher species richness of butterflies than forest fragments or urban parks. In protected forest reserves, the species richness of butterflies (8–27 species) was higher than in forest fragments (1–12 species) or urban parks (3–16 species). Forest reserves also had more unique, forest dependent, or specialist species than urban parks (data presented as model results). Four forest reserves (54–1,147 ha) consisted of old secondary and primary lowland tropical rainforest and freshwater swamp forest. Fourteen forest fragments (2–73 ha) contained patches of abandoned plantation and degraded secondary forest. Twenty-one urban parks (1–53 ha) were land that had been cleared, revegetated and maintained with a mix of native and non-native plants. From June 2002–June 2003, butterflies (excluding blues (Lycaenidae) and skippers (Hesperiidae)) were surveyed three times along one to fourteen 100-m transects/site.

A site comparison study in 2012–2013 in an urban protected area in Puebla, Mexico (2) found that native woodland remnants and abandoned grassland had higher species richness of butterflies than non-native *Eucalyptus camaldulensis* plantations. The species richness of all butterflies and of forest specialist butterflies in dry oak forest remnants (all: 51–57; specialist: 27–28 species), moist oak forest remnants (all: 40–44; specialist: 21–22 species) and abandoned grassland (all: 43–61; specialist: 16–22 species) was higher than in *Eucalyptus* plantations in both the warm-rainy and cold-dry season (all: 22–25; specialist: 12 species). However, the four habitats had different species composition, especially in the warm rainy season. The 675-ha reserve consisted of four habitat types: moist (11% by area) and dry oak forest (58%), abandoned grassland previously used for grazing (23%), and *Eucalyptus* plantations (6%). From July–September 2012 (warm rainy season) and January–March 2013 (cold dry season), butterflies were surveyed nine times/season, at 9–12 day intervals, on three 300-m transects/habitat type. Butterfly species were divided into 48 habitat generalists adapted to human-disturbed landscapes, 41 forest specialists which require forests for at least part of their life cycle, and two unclassified species.

(1) Koh L.P. & Sodhi N.S. (2004) Importance of reserves, fragments, and parks for butterfly conservation in a tropical urban landscape. *Ecological Applications*, 14, 1695–1708.
(2) Barranco-León de las Nieves M., Luna-Castellanos F., Vergara C.H. & Badano E.I. (2016) Butterfly conservation within cities: a landscape scale approach integrating natural habitats and abandoned fields in central Mexico. *Tropical Conservation Science*, 9, 607–628.

2.6. Establish “green infrastructure” in urban areas

- **One study** evaluated the effects of establishing “green infrastructure in urban areas on butterflies and moths. This study was in Taiwan[1].

COMMUNITY RESPONSE (1 STUDY)

- **Richness/diversity (1 study):** One replicated, site comparison study in Taiwan[1] found that green roofs had a lower species richness of butterflies than urban parks.

POPULATION RESPONSE (1 STUDY)

- **Abundance (1 study):** One replicated, site comparison study in Taiwan[1] found that green roofs had a lower abundance of butterflies than urban parks, but the abundance was higher on older green roofs with more nectar plant species in a larger area.

BEHAVIOUR (0 STUDIES)

Background

Planting rooftops in urban areas, and growing plants up vertical structures such as walls and lamp-posts, often termed "green infrastructure", is becoming increasingly popular, and is usually done with the aim of reducing pollution and run-off, or to improve building insulation (Dunnett & Kingsbury 2008). However, they may also be put in place to increase biodiversity, by providing habitat for a range of species (Oberndorfer *et al.* 2007), including nectar resources or egg-laying sites for butterflies and moths.

Dunnett N. & Kingsbury N. (2008) Planting green roofs and living walls. *Timber*, Portland, Oregon, USA. Second edition, ISBN: 0881929115.

Oberndorfer E., Lundholm J., Bass B., Coffman R.R., Doshi H., Dunnett N., Gaffin S., Kohler M., Liu K.K.Y. & Rowe B. (2007) Green roofs as urban ecosystems: ecological structures, functions and services. *BioScience*, 57, 823–833.

A replicated, site comparison study in 2011–2012 on 11 green roofs in Taipei City, Taiwan (1) found that green roofs had a lower abundance and species richness of butterflies than urban parks, but the abundance of butterflies was higher on older green roofs with more nectar plant species in a larger area. On green roofs, both the abundance (514 individuals) and species richness (12 species) of butterflies was lower than in urban parks (abundance: 3,141–8,882 butterflies; richness: 50–109 species). However, the abundance of butterflies was higher on green roofs established longer ago, and on roofs with more nectar plant species covering a larger area (data presented as model results). Eleven green roofs (95–590 m^2, 7–34 m above ground), established 13–46 months before the study, contained a total of 34 butterfly nectar plant species (1–16 species/roof, covering 2–41 m^2). Two urban parks (13–26 ha), established 18–25 years before the study, contained 20–45 nectar plant species. From August 2011–May 2012, butterflies were surveyed for four hours twice/month on each roof. From July 2008–June 2009, butterflies were surveyed in one urban park, and from March 2011–February 2012 they were surveyed in a second park (no further details provided).

(1) Lee L.-H. & Lin J.-C. (2015) Green roof performance towards good habitat for butterflies in the compact city. International Journal of Biology, 7, 103–112.

2.7. Plant trees to reduce temperatures in cities

- We found no studies that evaluated the effects of planting trees to reduce temperatures in cities on butterflies and moths.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Cities generate large amounts of heat, and as a result are often warmer than surrounding areas of natural habitat, a phenomenon known as the 'urban heat island effect' (Kleerekoper *et al.* 2012). For species which are otherwise able to survive in cities, higher temperatures may cause problems for survival and reproduction. Planting trees within cities provides shade, and actively cools the environment by increasing evapotranspiration (Kleerekoper *et al.* 2012). This may provide benefits for temperature-sensitive butterflies and moths, but could be detrimental if the trees replace other important habitats.

Kleerekoper L., van Esch M. & Salcedo T.B. (2012) How to make a city climate-proof, addressing the urban heat island effect. *Resources, Conservation and Recycling*, 64, 30–38.

2.8. Apply ecological compensation for developments

- **Two studies** evaluated the effects of on butterflies and moths of applying ecological compensation for developments. One was in the USA[1] and the other was in Australia[2].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (1 STUDY)

- **Abundance (1 study):** One study in Australia[2] reported that a population of purple copper butterfly caterpillars translocated from a development site to an area of compensatory and retained habitat increased in number over three years.

BEHAVIOUR (1 STUDY)

Use (1 study): A site comparison study in the USA[1] reported that an area of lupines transplanted from a development site was used by a similar number of Karner blue butterflies to an area with no transplanted lupines.**Background**

Development projects destroy or disturb natural habitats, displacing animals living there. Ecological compensation for developments aims to create new habitat, or improve the condition of existing habitat, outside of the development area, to replace that which is lost (Kleintjes *et al.* 2003). This intervention tests whether these compensation areas are effective for butterflies and moths.

Kleintjes P.K., Sporrong J.M., Raebel C.A. & Thon S.F. (2003) Habitat type conservation and restoration for the Karner blue butterfly: a case study from Wisconsin. *Ecological Restoration*, 21, 107–115.

A site comparison study in 1997–2001 in a shrubland in Wisconsin, USA (1) reported that an area containing lupine *Lupinus perennis* transplanted from a development site was used by a similar number of Karner blue butterflies *Lycaeides melissa samuelis* as an area with no transplanted lupines. Results were not tested for statistical significance. One–four years after restoration, 4–8 Karner blue butterflies/year were recorded in an area with transplanted lupines, compared to 1–8 butterflies/year in an area without transplanted lupines. In June 1997, seventy-five plugs of lupine (0.76-m diameter, 1.2-m-deep) were removed from a construction area and planted in a 5 × 15 grid covering a 324-m^2 area cleared of young pine trees. In November 1997, the surrounding 641 m^2 was hand-seeded with a dry sand prairie seed mix (40% grasses, 50% non-woody broadleaved plants (forbs), 10% scarified lupine seed) at 22.6 lbs/ha. An adjacent 0.8-ha area, where the topsoil had been temporarily removed, was seeded with the same mix. In October 1999–2001, two 0.2-ha patches in each of the transplanted and seeded areas were cut to a height of 16 cm each year. From 1998–2001, Karner blue butterflies were surveyed 5–6 times/year (covering both flight periods) on a 103-m transect through the transplanted and seeded area, and a 570-m transect through the seeded non-transplanted area. The highest number of butterflies counted on a single date in each flight period at each site was used as the abundance for that year.

A study in 2004–2007 in one shrubland in New South Wales, Australia (2) reported that, three years after translocation, along with habitat management and host plant translocation, a population of purple copper butterfly *Paralucia spinifera* caterpillars that had been moved from land designated for development to an adjacent area of managed compensatory habitat and retained habitat had increased in number. The site designated for development and adjacent area initially had an estimated purple copper population of 2,000 caterpillars. After the development and translocation of butterflies into the retained and compensatory habitat, which had received habitat management, the estimated caterpillar population size reduced to 1,600 in the following year but increased to an estimated 1,995 two years and 2,780 three years after translocation. Of the caterpillars found in the third year, 39% were in the compensatory habitat and 61% were in the area of retained original habitat. In 2004–2005, two thirds of an area of purple copper butterfly habitat was cleared for road-building and an area adjacent to the retained third was designated as compensatory habitat. Invasive plants were cleared from the retained and compensatory habitat and caterpillars and their host plant blackthorn *Bursaria spinosa var. lasiophylla* were moved from the land about to the cleared to the retained and compensatory habitat. Over 12 nights in December 2004–January 2005, a total of 1,260 caterpillars were moved. In 2005–2007 blackthorn plants in the retained and compensatory habitats were surveyed for caterpillars, signs of their feeding, and their mutualistic ants *Anonychomyrma itinerans*. Estimated caterpillar population sizes were calculated by multiplying the number of caterpillars found by five.

(1) Kleintjes P.K., Sporrong J.M., Raebel C.A. & Thon S.F. (2003) Habitat type conservation and restoration for the Karner blue butterfly: a case study from Wisconsin. *Ecological Restoration*, 21, 107–115.
(2) Mjadwesch R. & Nally S. (2008) Emergency relocation of a Purple Copper Butterfly colony during roadworks: Successes and lessons learned. *Ecological Management & Restoration*, 9(2), 100–109.

2.9. Require developers to complete Environmental Impact Assessments when submitting planning applications

- We found no studies that evaluated the effects on butterflies and moths of requiring developers to complete Environmental Impact Assessment when submitting planning applications.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Any new residential or commercial development is likely to impact butterflies and moths through either habitat destruction or disturbance. However, by assessing the risk to species populations in advance, and making changes to the plans, it may be possible for careful planning of necessary developments to minimize these negative impacts. Legal requirements for developers to complete Environmental Impact Assessments (EIAs), if independently produced, reviewed and enforced, may be beneficial to butterfly and moth conservation. For example, see DFFE (2021).

Department of Forestry, Fisheries and the Environment (2021) National Web Based Environmental Screening Tool. Republic of South Africa Department of Forestry, Fisheries and the Environment, https://screening.environment.gov.za/screeningtool/index.html#/pages/welcome

3. Threat: Agriculture and aquaculture

Background

The widespread conversion of land from natural habitat to agriculture, and the continued intensification of production on farmed land, are among the greatest historical and current threats to butterflies and moths (Fox *et al.* 2015). However, many traditional farmed landscapes, such as extensive meadows, traditional orchards, and wood pasture, can also provide high-quality habitat for many species, if they are maintained. This chapter includes actions focused on changing, improving or maintaining farming practices for the conservation of butterflies and moths. Further threats from agriculture include the loss of habitat and pollution (e.g. from fertilizer and pesticide use). Actions in response to these threats are described in '*Habitat restoration and creation*', and '*Threat: Pollution*'.

Fox R., Brereton T.M., Asher J., August T.A., Botham M.S., Bourn N.A.D., Cruickshanks K.L., Bulman C.R., Ellis S., Harrower C.A., Middlebrook I., Noble D.G., Powney G.D., Randle Z., Warren M.S. & Roy D.B. (2015) The State of the UK's Butterflies. Butterfly Conservation and the Centre for Ecology & Hydrology, Wareham, Dorset, UK.

All farming systems

3.1. Increase or maintain the proportion of natural or semi‑natural habitat in the farmed landscape

- **Twelve studies** evaluated the effects of increasing or maintaining the proportion of natural or semi-natural habitat in the farmed landscape on butterflies and moths. Three studies were in Switzerland[5,10,12], two were in each of Germany[1,11], Sweden[3,7] and the UK[6,9], and one was in each of the USA[2], Malaysia[4], and New Zealand[8].

COMMUNITY RESPONSE (11 STUDIES)

- **Richness/diversity (11 studies):** Nine of eleven studies (including one replicated, randomized, controlled study, one before-and-after study and eight replicated, site comparison studies) in Germany[1,11], Sweden[3,7], Malaysia[4], Switzerland[5,10,12], the UK[6,9], and New Zealand[8] found that the species richness of butterflies[1,3,5,7,8,9,11,12], burnet moths[7] and all moths[1,3,6] was higher on farms with a greater proportion of semi-natural habitat[3,6,9,11,12] or with a greater proportion of woodland in the surrounding landscape[7], or after semi-natural habitat had been created[1], compared to conventional farmland[5,8] or farmland with a greater proportion of arable land in the surrounding landscape[7]. One study found that species richness of butterflies in oil palm plantations was higher where ground coverage of weeds had been maintained but similar whether or not epiphyte or fern coverage was maintained[4]. The eleventh study found that the species richness of butterflies was similar on farms with different proportions of semi-natural habitat[10].

POPULATION RESPONSE (8 STUDIES)

- **Abundance (8 studies):** Six replicated studies (including one randomized, controlled study and five site comparison studies) in Sweden[3], the UK[6,9], New Zealand[8], and Switzerland[10,12] found that the abundance of butterflies[3,8-10,12] and moths[3,6] was higher on farms with a greater proportion of semi-natural habitat[3,6,9,10,12], or in semi-natural habitat compared to conventional farmland[8]. One of two replicated, site comparison studies in the USA[2] and Sweden[7] found that the abundance of four out of eight species of butterflies was higher on farms surrounded by woodland, but the abundance of least skipper was lower on farms with more semi-natural habitat[2]. The other study found that overall butterfly abundance was similar on farms surrounded by different proportions of woodland and arable land[7].

BEHAVIOUR (0 STUDIES)

Background

The presence of natural or semi-natural habitat within farmland may protect butterflies and moths in intensively farmed landscapes, either because the habitat itself supports remnant populations of species which cannot survive on farmland, or because it allows individuals to move through the landscape more easily, reducing isolation. For example, the presence of woodland or scrub correlates with a higher abundance of butterflies on farmland (Pywell *et al.* 2004).

Pywell R.F., Warman E.A., Sparks T.H., Greatorex-Davies J.N., Walker K.J., Meek W.R., Carvell C., Petit S. & Firbank L.G. (2004) Assessing habitat quality for butterflies on intensively managed arable farmland. *Biological Conservation*, 118, 313–325.

A before-and-after study in 1987–1991 on an arable farm in Saarland, Germany (1) reported that increasing the area of meadows and field margins, and the length of field edges, increased the species richness of butterflies and burnet moths. Results were not tested for statistical significance. Four years after the semi-natural habitat was created, 24 species of butterflies and burnet moths were present on the farm, compared to 20 species before creation. Marbled white *Melanargia galathea* were present at eight survey sites in 1991, compared to one site in 1987. In 1987, on an intensively managed 30-ha farm with large fields, semi-natural meadows and field margins were created by sowing regional plant species including rosebay willowherb *Epilobium angustifolium,* danewort *Sambucus ebulus*, heather *Calluna vulgaris* and regional meadow seeds. The length of field edges was increased from 7,200 m to 17,420 m. From May–August 1987–1988 and 1991, butterflies and burnet moths were surveyed at sample sites (number not specified) across the whole farm.

A replicated, site comparison study in 2002–2003 in 38 field margins in an arable region of Minnesota, USA (2) found that the abundance of four of eight butterfly species was higher in margins surrounded by more woodland habitat. In areas with more woodland in the surrounding landscape, the abundance of four out of eight butterfly species (orange and clouded sulphur *Colias* spp., monarch *Danaus plexippus* and regal fritillary *Speyeria idalia*) was higher. However, the abundance of one species (least skipper *Ancyloxypha numitor*) was lower in more wooded landscapes (data presented as model results). A total of 38 field margins (8–148 m wide, and all >3 years old, >350 m long, >1 km apart and with <15% tree or shrub cover) between a crop field and a water course were surveyed. None of the strips were treated with insecticide or fertilizer, and most were infrequently spot-mown or spot-sprayed to control weeds. In July–August 2002 and June–August 2003, butterflies were surveyed twice/year along one 200-m transect/margin, halfway between the water course and crop field. The habitat in a 1-km radius surrounding the midpoint of each transect was classified as “herbaceous habitat”, “crops”, “wooded”, “wetland” or “developed” areas (see paper for details).

A replicated, site comparison study in 2003–2004 on 24 arable farms in Scania, Sweden (3) found that farms in more diverse landscapes had a higher abundance and species richness of butterflies and burnet moths than farms in intensively farmed landscapes. On farms in diverse landscapes, both the abundance (3.6–4.5 individuals/50 m) and species richness (1.4–1.6 species/50 m) of butterflies and burnet moths were higher than on farms in intensively farmed landscapes (abundance: 0.4–1.7 individuals/50 m; richness: 0.3–0.9 species/50 m). Twelve arable farms in diverse landscapes (15% arable land, 19% pasture, small fields (average: 31,600 m^2)), and 12 arable farms in intensively farmed landscapes (70% arable land, 3% pasture, large fields (average: 60,200 m^2)) were selected. From June–August 2003 and May–August 2004, butterflies and burnet moths were surveyed 5–6 times/year along 400–750 m routes along cereal field boundaries. Individuals occurring 5 m into the crop and in adjacent 2-m uncultivated margins were counted.

A replicated, site comparison study in 2006–2007 in 15 sites of oil palm plantation in East Sabah, Malaysia (4) found higher butterfly species in areas where the ground coverage of weeds had been maintained, but no effect of maintaining epiphytes or ferns. Sites with a higher percentage of ground cover of weeds had higher butterfly species richness. However, the number of nearby trees with high epiphyte growth, and the percentage ground coverage of ferns, had no effect on species richness. Additionally, there was higher butterfly species richness in sites where a higher proportion of old growth forest within the surrounding 1 km radius had been maintained. All results are presented as statistical tests. In September–October 2006 and March–April 2007, butterflies were counted along 100 m transects in 15 plantations. There were 3–10 transects at each site and each was surveyed 1–3 times over the entire sampling period. Only butterfly species known to occur in Malaysian primary forest were included in analyses, and *Hesperiidae* and *Lycaenidae* were excluded because of identification difficulties. Varying proportions of weeds, epiphytes and ferns had previously been removed at each site by plantation workers (the removal was not part of the study and removal details are not included). At the start and end of transects researchers counted the proportion of the nearest 10 palm trees with >50% epiphyte coverage, and the percentage of ground covered by ferns and weeds.

A replicated, site comparison study in 1998–2005 in mixed farmland in Aargau, Switzerland (5) found that areas of semi-natural habitat initially supported more butterfly species than farmed land, but over time the number of species decreased in both semi-natural habitat and farmed land. When initially surveyed, there were more species of butterfly in sites managed as Ecological Compensation Areas (ECA, 7.3 species/plot) than in non-ECA sites (5.6 species/plot). However, between the first survey and the second survey, the number of butterfly species decreased overall, but the decreases were similar on ECA and non-ECA sites (both -1.1 species/plot). Most ECA sites were established between 1992 and 1998. Sites were surveyed twice, five years apart, with the first survey taking place in 1998–2000 and the second in 2003–2005. At 52 ECA sites and 35 non-ECA sites, butterflies were surveyed along a 10 x 250 m transect 11 times/year. The authors noted that ECAs were typically established on farmland with potential for maximum biodiversity gain, which may have affected the relative numbers of species found in the first survey.

A replicated, site comparison study in 2008 on 36 farms in central Scotland, UK (6) found that farms with more semi-natural habitat had a higher abundance and species richness of moths than farms with less semi-natural habitat. The abundance of both micro-moths and macro-moths, and the species richness of macro-moths, were all higher on farms with more semi-natural habitat (data presented as model results). However, the species richness of micro-moths, and the diversity of both groups, was similar between farms with more and less semi-natural habitat (data presented as model results). In 2004, eighteen farms enrolled in agri-environment schemes, and were paired with 18 similar but conventionally-managed farms, <8 km away. From June–September 2008, moths were collected for four hours, on one night/farm, using a 6 W heath light trap located next to either a field margin, watercourse margin, beetle bank, hedgerow or grassland on each farm. Paired farms were surveyed on the same night.

A replicated, site comparison study in 2009 in 60 arable farms in Uppland and Scania, Sweden (7) found that butterfly and burnet moth species richness, but not abundance, was higher in farms surrounded by a greater proportion of forest-dominated land than those surrounded by a greater proportion of arable farmland. Farms within a 1 km radius with a higher proportion of forest-dominated land and a lower proportion of arable land had higher butterfly species richness compared to those with a higher proportion of arable land and a lower proportion of forest-dominated land (data presented as statistical results). However, the relative proportions of forest-dominated and arable land resulted in no difference in butterfly abundance. In June–August 2009, butterfly surveys were carried out in 40 organic and 20 conventionally-managed farms. On each farm, three 250 m transects were completed 5–6 times - one in an uncultivated margin of a cereal field, and two within the field at 50 m and 200 m from the margin transect. Butterflies Rhopalocera and burnet moths Zygaenidae were identified to species. The proportion of arable land within a radius of 1 km from each farm was calculated using remote sensing imagery. The proportion of arable land ranged from 20–80%.

A replicated, site comparison study in 2008–2009 in six vineyards in Canterbury Province, New Zealand (8) found that remnant native habitat patches had a higher abundance and species richness of butterflies than amongst the vines, on pasture or in planted native vegetation. In remnant habitat patches, the abundance (14 individuals/section) and species richness (0.7 species) of butterflies was higher than amongst the grape vines (abundance: 8 individuals/section; richness: 0.3 species), on pasture fields (abundance: 7 individuals/section; richness: 0.5 species), or in planted native vegetation (abundance: 3 individuals/section; richness: 0.5 species). See paper for individual species results. Six vineyards, each containing areas of remnant native vegetation (typically stands of matagouri *Discaria toumatou* and New Zealand bindweed *Calystegia tuguriorum*) and small (100–200 m^2) areas of planted native shrubs and grasses, alongside grape vines and grazed pasture, were selected. From October 2008–April 2009, butterflies were surveyed 13 times (once/fortnight) along a fixed transect through the different habitat patches on each vineyard. Transects were split into 9–14 sections based on habitat type for analysis.

A replicated, randomized, controlled study in 2007–2010 on 28 arable farms in Wessex and East Anglia, UK (9) found that farms with a higher proportion of uncropped habitat had a greater abundance and species richness of butterflies in early summer, but not in mid-summer. On farms where the proportion of uncropped habitat was >7.5%, the species richness of butterflies on field boundaries in early summer (2.9–3.0 species/100 m) was higher than on farms with <7.5% uncropped habitat (1.0–1.6 species/100 m). When the proportion of uncropped habitat was >10%, the abundance of butterflies in the wildlife habitat in early summer was higher than on farms with <10% uncropped habitat (data not presented). See paper for details of species groups. In spring 2007, twenty-four farms (12 in East Anglia and 12 in Wessex) were randomly assigned to two treatments: 16 farms with enhanced agri-environment scheme (AES) habitat (1.5–6.0 ha of floristically-enhanced grass mixes, wildflower strips, wild bird seed mixes and natural regeneration by annual cultivation); and eight farms with Entry-level Stewardship (ELS) habitat (1.5–6.0 ha of grass margins and game cover (usually maize)). Two additional ELS farms/region, already managed organically with 1.5 ha of ELS habitat, were also studied. From 2008–2010, butterflies were surveyed twice/year on 11 fixed 100-m transects, in mid-May–mid-June and mid-July–early August. Eight transects/site were located in AES habitat, and three transects/site were located on field boundaries away from the AES habitat.

A replicated, site comparison study in 2009–2011 in 133 mixed farms in the Central Plateau, Switzerland (10) found that farms managed with larger areas of semi-natural habitat had a higher abundance, but not species richness, of butterflies than farms with less semi-natural habitat. The abundance of butterflies on farms with more semi-natural habitat was higher than on farms with less semi-natural habitat, but there was no difference in butterfly species richness (data presented as model results). A total of 133 farms (17–34 ha, 13–91% arable crops) were managed with "Ecological Compensation Areas" under agri-environment schemes. Management included extensive and low-input meadows with reduced fertilizer and later cutting dates, and the presence of trees, hedgerows and wildflower patches. From May–September 2009–2011, butterflies were surveyed six times on 10–38 transects/farm, totalling 2,500 m/farm. Each transect ran diagonally through a single crop or habitat type, with all available crops and habitats represented. All visits to a farm were completed in a single year, and the species richness was summed across all visits. Total abundance of butterflies was calculated from the number recorded in each habitat, and the availability of each habitat across the farm. Semi-natural habitats on each farm were mapped between May and August.

A replicated, site comparison study in 2015 on seven arable farms in Germany (11) found that field margins on farms with more semi-natural habitat in the surrounding area had more butterfly species than margins on farms with less semi-natural habitat. The number of species of butterfly recorded on field margins was higher on farms with more semi-natural habitat within 1 km than on farms surrounded by less semi-natural habitat (data presented as model results). The amount of semi-natural habitat within 1 km of each of seven farms (58–700 ha) was estimated from aerial images. From June–August 2015, butterflies were surveyed six times along 10 permanent, unsprayed and uncropped arable field margins (≥1 m wide, 50–250 m long) on each farm.

A replicated, site comparison study in 2010–2014 in 50 agricultural areas in the Swiss Plateau, Switzerland (12) found that landscapes with a greater proportion of semi-natural habitat, provided through agri-environment schemes, had a higher abundance and species richness of butterflies than landscapes with less semi-natural habitat. Agricultural areas with more than 20% of the land managed as semi-natural habitat had a higher abundance and species richness of all butterflies than areas with less than 10% semi-natural habitat. The abundance of farmland butterflies, and the species richness of threatened butterflies, was higher in landscapes with more semi-natural habitat than in landscapes with less semi-natural habitat (all data presented as model results). Fifty mixed farming areas (1 km^2) were selected where 2.5–32.2% of agricultural land was managed under agri-environment schemes (primarily extensive meadows (cut or grazed once/year, no fertilizers or pesticides) and orchards). Butterflies were surveyed seven times along a 2.5-km transect through each 1-km^2 area in one of five years (2010–2014). Species were classified as "farmland species" if they occur in open habitat, and "threatened" species if they were listed as Near Threatened, Vulnerable or Critically Endangered on the Swiss RedList.

(1) Reck (1993) Creating new habitats on intensively used farmland, the "Pappelhof" in Saarland — a project supported by the German government. *Natur und Landschaft*, 68, 394–403.

(2) Davros N.M., Debinski D.M., Reeder K.F. & Hohman W.L. (2006) Butterflies and continuous conservation reserve program filter strips: Landscape considerations. *Wildlife Society Bulletin*, 34, 936–943.

(3) Rundlöf M. & Smith H.G. (2006) The effect of organic farming on butterfly diversity depends on landscape context. *Journal of Applied Ecology*, 43, 1121–1127.

(4) Koh L. P. (2008) Can oil palm plantations be made more hospitable for forest butterflies and birds? *Journal of Applied Ecology*, 45(4), 1002-1009

(5) Roth T., Amrhein V., Peter B. & Weber D. (2008) A Swiss agri-environment scheme effectively enhances species richness for some taxa over time. *Agriculture, Ecosystems & Environment*, 125, 167–172.

(6) Fuentes-Montemayor E., Goulson D. & Park K.J. (2011) The effectiveness of agri-environment schemes for the conservation of farmland moths: assessing the importance of a landscape-scale management approach. *Journal of Applied Ecology*, 48, 532–542.

(7) Jonason D., Andersson G.K.S., Öckinger E., Rundlöf M., Smith H.G. & Bengtsson J. (2011) Assessing the effect of the time since transition to organic farming on plants and butterflies. *Journal of Applied Ecology*, 48(3), 543-550.

(8) Gillespie M. & Wratten S.D. (2012) The importance of viticultural landscape features and ecosystem service enhancement for native butterflies in New Zealand vineyards. *Journal of Insect Conservation*, 16, 13–23.

(9) Holland J.M., Smith B.M., Storkey J., Lutman P.J.W. & Aebischer N.J. (2015) Managing habitats on English farmland for insect pollinator conservation. *Biological Conservation*, 182, 215–222.

(10) Stoeckli S., Birrer S., Zellweger-Fischer J., Balmer O., Jenny M. & Pfiffner L. (2017) Quantifying the extent to which farmers can influence biodiversity on their farms. *Agriculture, Ecosystems & Environment*, 237, 224–233.

(11) Sybertz J., Matthies S., Schaarschmidt F., Reich M. & von Haaren C. (2017) Assessing the value of field margins for butterflies and plants: how to document and enhance biodiversity at the farm scale. *Agriculture, Ecosystems & Environment*, 249, 165–176.
(12) Zingg S., Grenz J. & Humbert J.-Y. (2018) Landscape-scale effects of land use intensity on birds and butterflies. *Agriculture, Ecosystems & Environment*, 267, 119–128.

3.2. Pay farmers to cover the costs of conservation measures (as in agri-environment schemes or conservation incentives)

- **Thirty-two studies** evaluated the effects of paying farmers to cover the costs of conservation measures on butterflies and moths. Eighteen studies were in the UK[3,4,6,10–12,16–20,22–28], eight were in Switzerland[2,8,9,14,15,21,30,32], two were in Finland[1,5], and one was in each of Sweden[7], the Czech Republic[13], the USA[29] and Germany[31].

COMMUNITY RESPONSE (18 STUDIES)

- **Community composition (1 study):** One replicated, controlled study in Switzerland[2] found that the community composition of butterflies on grasslands that farmers were paid to manage for wildlife was similar to intensively managed grasslands.
- **Richness/diversity (19 studies):** Twelve of 15 studies (including eight controlled, one before-and-after and five site comparison studies) in Switzerland[2,8,9,14,15,21], the United Kingdom[4,6,17,18,19,22–24] and Sweden[7] found that the species richness or diversity of butterflies[2,6–9,14,19,21] and moths[7,17,18,22,24] on grassland[2,8,9], field margins[6,24], wildflower strips[21] or whole farms[7,14,17,18,22] managed under agri-environment schemes was higher than on conventional fields or farms. The other three studies found that the species richness of butterflies[4,15,23] and micro-moths[23] on grassland[15], field margins[4], wildflower strips[15] or whole farms[23] managed under agri-environment schemes was similar to conventional fields or farms. One of two replicated, site comparison studies in Switzerland[29,31] found that the species richness of butterflies was higher in landscapes with a greater proportion of land managed under agri-environment schemes than in landscapes with a smaller proportion of agri-environment schemes[31], but the other study found that species richness of butterflies was similar on individual farms with more land managed under agri-environment schemes than on farms with smaller areas of agri-environment schemes[29]. One replicated, site comparison study in the USA[28] found that the species richness of butterflies on grassland sown under a conservation incentive program was similar to that on native prairie. One replicated, site comparison study in Finland[1] found that the species richness of butterflies and day-flying moths on grassland managed under an agri-environment scheme was lower than on abandoned, unmanaged grassland.

POPULATION RESPONSE (27 STUDIES)

- **Abundance (27 studies):** Seventeen of 19 studies (including seven controlled studies, one replicated, site comparison study, two before-and-after studies, and eight site comparison studies) in the UK[3,4,10–12,16–20,22–25,27], Sweden[7], Switzerland[8,21] and Germany[31] found that the abundance of butterflies[4,7,8,10,11,18,21,23] and moths[16–18,22,23,28] overall, and of specific species of butterflies[3,10–12,24,31] or moths[7,20,31], in woodland[31], grassland[8,28], field margins[3,4,10,11,16,20], wildflower strips[21] or whole farms[7,12,17,18,22,23,24] managed under agri-environment schemes was higher than in unmanaged woodland or conventional fields or farms. The other two studies found that the abundance of butterflies[19] and macro-moths[25] on field margins managed under agri-environment schemes was similar to conventional margins. Three of four replicated studies (including one controlled and three site comparison studies) in the UK[26,27] and Switzerland[30,32] found that the abundance of butterflies was higher on farms[30] or in landscapes[26,32] with a higher proportion of land managed under agri-environment schemes[26,30,32] than in areas with less land in agri-environment schemes. The other study found that the abundance of some species was higher, but others were lower, on farms with enhanced agri-environment management compared to simple management[27]. Three studies (including one before-and-after and two replicated, site comparison studies) in Finland[1,5] and the Czech Republic[13] found that grassland grazed or restored under agri-environment scheme prescriptions had a lower abundance of all but three butterfly and day-flying moth species compared to unmanaged grassland[1,5], and that Danube clouded yellow abundance declined after agri-environment scheme mowing was initiated on abandoned grasslands[13]. One replicated, site comparison study in the USA[29] found that the abundance of butterflies on grassland sown under a conservation incentive program was lower than on native prairie.

BEHAVIOUR (0 STUDIES)

Background

Implementing conservation actions can be costly for landowners, either because of the direct management costs or due to the loss of income from other possible land uses, such as farming. Payments may be offered by Governments or inter-Governmental schemes to compensate landowners for these costs, and encourage more wildlife-friendly habitat management and creation on private land. In Europe, agri-environment schemes (AES) are an integral part of the European Common Agricultural Policy (CAP) and Member States devise their own AES prescriptions to suit their agricultural economies and environmental contexts. In the United States, these are often called conservation incentive payments and are mostly implemented through the Agriculture Improvement Act of 2018 (known as the Farm Bill, for example Kleintjes Neff & Mader 2013). Most schemes focus on reducing the intensity of farm management, or creating other habitats within the farmed landscape, but payments may also be made for managing other habitats such as woodland (in the USA often called agroforestry) or heathland on private land. As well as attempting to provide more favourable habitat, coordinated planning of the schemes may be important to ensure that a variety of habitats are created across the farmed landscape throughout the year.

This intervention includes any studies where landowners were paid to carry out an action in any habitat, but excludes studies testing AES options which were conducted outside of an AES (e.g. on research farms or nature reserves). Since AES represent many different specific interventions relevant to conservation, where a study's results can be clearly assigned to a specific intervention, the study is also summarized in the appropriate section. This section, meanwhile, includes evidence about the success of agri-environment or conservation incentive policies overall.

Kleintjes Neff P. & Mader E. (2013) CRP-SAFE for Karner Blue butterflies: Recommendations for Wisconsin landowners and conservationists. *The Xerces Society for Invertebrate Conservation* report.

A replicated, site comparison study in 1999–2000 in southwest Finland (1, same experimental set-up as 5) found that species-rich grasslands which farmers were paid to manage under agri-environment schemes (AES) had a lower abundance and species richness of butterflies and day-flying moths than abandoned, unmanaged grassland. The abundance of butterflies and moths was lower in both restored (126 individuals) and continuously grazed AES pastures (126 individuals) than in abandoned pastures not managed under AES (306 individuals). The number of species was also lower in restored pastures (22 species) than in abandoned pastures (33 species), but the number in continuously grazed pastures was intermediate (26 species). Butterflies and moths were monitored in 1999 or 2000 on 10 restored pastures where, after at least 10 years of abandonment, grazing had re-started 3–8 years before the study, 11 continuously grazed pastures, and 12 abandoned pastures which had not been grazed for at least 10 years. All restored and most continuously grazed pastures received support under the Finnish AES. All grazing was by cattle. Butterflies and day-flying moths were counted along transects four (1999) or seven (2000) times from May–August. Either searching time (1999) or transect length (2000) were standardized across sites.

A replicated, controlled study in 2000–2002 in three farmland regions of the Swiss Plateau, Switzerland (2) found more butterfly species on grasslands which farmers were paid to manage for wildlife than on intensively managed grasslands in one of two study years. In 2002, but not in 2000, grasslands managed under agri-environment schemes had more butterfly species than intensively managed grasslands (actual numbers not given). The identity of the butterfly species found was not significantly influenced by management intensity, but was different in different regions. The agri-environment scheme grasslands were managed as "Ecological Compensation Areas", with restricted fertilizer and pesticide use, and delayed mowing. Butterflies were recorded in 56 agri-environment grasslands and 48 intensively managed grasslands during the summers of 2000 and 2002.

A replicated, controlled study in 1996–2000 on three arable farms in Essex, UK (3, same experimental set-up as 4, 6, 10, 11) found that the number of gatekeepers *Pyronia tithonus* on sown grass margins which farmers were paid to create increased over four years, and was higher than on cropped field edges at one of three farms after 2–4 years. Gatekeeper abundance on 2-m-wide agri-environment scheme grass margins increased from 2.2 individuals/km to 12.9 individuals/km over four years after the margins were sown. However, abundance was significantly higher in grass margins than in cropped margins at only one of three farms after 2–4 years (grass margin: 9.1 individuals/km, cropped edges: 0.7 individuals/km; other farms grass margin: 6.8–11.9 individuals/km, cropped edges: 1.9–17.3 individuals/km). Thirteen grass margins (2 m wide, 141–762 m long) were established in October 1996–2000 by sowing one of three seed mixtures, containing 4–6 grass species, according to Countryside Stewardship Scheme requirements. Three field edges without margins (one on each farm, 133–343 m long) were used as controls. Gatekeeper abundance was monitored weekly along each grass margin and cropped edge in July and August 1997–2000.

A replicated, controlled study in 1996–2000 at two arable farms in Essex, UK (4, same experimental set-up as 3, 6, 10, 11) found that grass margins which farmers were paid to create had higher butterfly abundance, but not species richness, than in cropped field edges. More butterflies were recorded in sown or naturally regenerated agri-environment scheme grass margins (46 individuals/km) than in cropped field edges (21 individuals/km), but the species richness was similar (grass margin: 8; cropped edges: 9 species). Of the 'key' grassland butterfly species, only meadow brown *Maniola jurtina* was more abundant in grass margins (19 individuals/km) than in cropped field edges (9 individuals/km). More butterflies (125 individuals/km), including meadow brown (57 individuals/km), were found in a sown grass margin established next to a permanent set-aside field than on all other margin types (all butterflies: 32–41 individuals/km; meadow brown: 4–27 individuals/km). In 1996, eight 6-m-wide margins were established on two farms. Five were sown with grass seed mixtures (6 or 9 species) according to Countryside Stewardship Scheme requirements, and three were left to natural regeneration. One arable field edge without margins on each farm was used as a control. Butterfly abundance was monitored weekly from late June to early August 1997–2000. All butterflies were recorded, but special note was taken of 'key' grassland species: meadow brown, gatekeeper *Pyronia tithonus*, small skipper *Thymelicus sylvestris*, Essex skipper *Thymelicus lineola*, and large skipper *Ochlodes venata*.

A replicated, site comparison study in 1999–2000 in southwest Finland (5, same experimental set-up as 1) found that 11 of 32 butterfly and day-flying moth species were less abundant in species-rich grasslands which farmers were paid to manage under agri-environment schemes (AES) than in abandoned, unmanaged grassland. Eleven out of 32 species of butterfly and day-flying moth were less abundant in AES grassland than in abandoned grassland. However, three species were more abundant in continuously grazed AES grassland than in restored AES grassland or abandoned grassland. Five species had lower abundance in either restored or continuously grazed grassland than in the other two habitats. The remaining 13 species had similar abundance in all three grassland types (see paper for data on individual species). Butterflies and day-flying moths were monitored in 1999 or 2000 on 10 restored pastures where, after at least 10 years of abandonment, grazing had re-started 3–8 years before the study, 11 continuously grazed pastures and 12 abandoned pastures which had not been grazed for at least 10 years. All restored and most continuously grazed pastures received support under the Finnish AES. All grazing was by cattle. Butterflies and day-flying moths were counted along transects four (1999) or seven (2000) times from May–August. Either searching time (1999) or transect length (2000) were standardized across sites.

A replicated, controlled study in 1996–2000 on three arable farms in Essex, UK (6, same experimental set-up as 3, 4, 10, 11) found that 2-m-wide sown grass margins which farmers were paid to create, but not 6-m-wide grass margins, had higher butterfly species richness than field edges without grass margins. Butterfly species richness was higher in 2-m-wide agri-environment scheme grass margins (8–9 species) than in cropped field edges without margins (5–7 species), but was not significantly different in 6-m-wide margins compared to cropped field edges (data not presented). Species richness was also higher on 2-m grass margins sown with a more diverse seed mixture, and was higher on 2-m grass-sown margins next to hedgerows than on margins without hedgerows (data not presented). In October 1996–1998, twenty-six margins were established according to Countryside Stewardship Scheme requirements on three farms: 13 grass-sown that were 2 m wide, five grass-sown that were 6 m wide, three naturally regenerated (6 m wide) and five cropped field edges (2 and 6 m wide). Grass-sown margins were established using seed mixtures containing 4–9 common grass species. Butterflies were monitored weekly in summer from 1997–2000 in suitable weather.

A replicated, paired, site comparison study in 2003–2004 on 24 arable farms in Scania, Sweden (7) found that farms which landowners were paid to manage organically had a higher abundance and species richness of butterflies and burnet moths than conventional farms in intensively farmed but not more diverse landscapes. In intensively farmed landscapes, both the abundance (1.7 individuals/50 m) and species richness (0.9 species/50 m) of butterflies and burnet moths on subsidized organic farms were higher than on conventional farms (abundance: 0.4 individuals/50 m; richness: 0.3 species/50 m). However, in more diverse landscapes, the abundance (4.5 individuals/50 m) and species richness (1.6 species/50 m) of butterflies and burnet moths on subsidized organic farms were not significantly different from conventional farms (abundance: 3.6 individuals/50 m; richness: 1.4 species/50 m). Twelve arable farms with >50% of land under EU-subsidized organic management in 2002 and 12 conventional farms of similar size, crop type and landscape features, were selected. Farm pairs were 3–8 km apart. Six pairs of farms were in diverse landscapes (15% arable land, 19% pasture, small fields), and six pairs were in intensively farmed landscapes (70% arable land, 3% pasture, large fields). From June–August 2003 and May–August 2004, butterflies and burnet moths were surveyed 5–6 times/year along 400–750 m routes along cereal field boundaries. Individuals occurring 5 m into the crop and in adjacent 2-m uncultivated margins were counted.

A replicated, paired, controlled study in 2004 in 13 hay meadows in Aargau, Switzerland (8) found that paying farmers to manage meadows for wildlife resulted in higher species richness and abundance of butterflies compared to intensively managed meadows. Species richness and abundance of butterflies was higher in meadows managed under agri-environment schemes (AES) than in intensively managed meadows (data presented as model results). However, species richness and abundance of butterflies in intensively managed meadows was the same closer to and further from AES meadows (data presented as model results). The 13 low-input meadows (0.48–2.15 ha) had been managed as "Ecological Compensation Areas", with no fertilizer application and not mown until after 15 June, for at least 5 years, and were paired with adjacent intensively managed meadows. In May 2004 four pots, each containing one plant of radish *Raphanus sativus*, clustered bellflower *Campanula glomerata*, and common catsear *Hypochaeris radicata*, were placed in each AES meadow, and at 25, 50, 100 and 200 m into the adjacent intensive meadow. Flower visiting insects were collected between 10:00 and 16:00 in one 20-minute session/station in each of May, July and August 2004.

A replicated, controlled study in 1998–2004 in two farmland regions of the Swiss Plateau, Switzerland (9) found more species of butterfly on grassland which farmers were paid to manage for wildlife than on conventional grassland in one of the two areas. In Nuvilly, there was an average of 12 species on agri-environment scheme (AES) grasslands and 11 species on conventional grasslands. In Ruswil, there was an average of 3.4 species on AES grasslands and 2.6 species on conventional grasslands. When other factors such as number of plant species, coverage of woody plants or distance to forest were taken into account, this difference was only statistically significant in Ruswil, and not in Nuvilly. AES grasslands had more 'specialist' species – those with only one generation/year, poor dispersal ability or caterpillars that eat only one type of plant. AES grasslands, managed as "Ecological Compensation Areas", were fertilized with an average of 7 kg N/ha and cut on average twice a year. Conventional grasslands were fertilized with an average of 206 kg N/ha and cut on average three times each year. Every two years from 1998–2004, butterflies were surveyed in five 10-minute surveys every 2–3 weeks between May and August, in 20–22 AES grasslands and 6–16 conventional grasslands.

A replicated, controlled study in 1996–2000 on three arable farms in Essex, UK (10, same experimental set-up as 3, 4, 6, 11) found that planted grass margins which farmers were paid to create had higher butterfly abundance than cropped field edges without margins. Butterfly abundance was higher in sown agri-environment scheme grass margins (67 individuals/km) than in cropped field edges (26 individuals/km). In sown grass margins abundance was higher for meadow brown *Maniola jurtina* (16 individuals/km) and golden skipper *Thymelicus* spp. (14 individuals/km) compared to cropped margins (meadow brown: 4; *Thymelicus* spp.: 1 individuals/km), but the abundance of gatekeeper *Pyronia tithonus* was similar (grass margin: 8; cropped margin: 5 individuals/km). Over four years, the total abundance of butterflies in the sown margins decreased (from 101 to 47 individuals/km), as did the abundance of *Thymelicus* spp. (32 to 3 individuals/km) and large skipper *Ochlodes venata* (15 to 1 individuals/km). However, the abundance of gatekeeper increased (2 to 13 individuals/km). In October 1996, thirteen 2-m-wide grass margins were sown (20 kg seed/ha) and were not cut after the first year according to Countryside Stewardship Scheme requirements. Butterfly abundance was monitored weekly from late June to early August 1997–2000 in grass margins and cropped field edges on each farm. All butterflies were recorded, but special note was taken of 'key' grassland species: meadow brown, gatekeeper, small skipper *Thymelicus sylvestris*, Essex skipper *Thymelicus lineola* and large skipper.

A replicated, controlled study in 1996–2003 on three arable farms in Essex, UK (11, same experimental set-up as 3, 4, 6, 10) found that planted grass margins which farmers were paid to create had higher butterfly abundance than cropped field edges without grass margins. Butterfly abundance was higher in both 2-m-wide (64 individuals/km) and 6-m-wide (54 individuals/km) sown agri-environment scheme grass margins than in cropped field edges (19–24 individuals/km). Meadow brown *Maniola jurtina* abundance was higher in 2-m (15 individuals/km) and 6-m (22 individuals/km) margins than in cropped field edges (4–5 individuals/km), but abundance was similar for gatekeeper *Pyronia tithonus* (grass margin: 7–9; cropped: 5–6 individuals/km) and golden skipper *Thymelicus* spp. (grass margin: 5–14; cropped: 2–13 individuals/km). In October

1996–1997, three 2-m-wide margins were sown with grass seed (4–6 species) and left uncut after the first year, and three 6-m-wide margins were established through natural regeneration or by sowing (6–9 species), and cut annually after 15 July, according to Countryside Stewardship Scheme requirements. Butterfly abundance was monitored weekly in summer 1997–2000 and 2003 in the six grass margins and five cropped field edges.

A replicated, site comparison study in 1991–2000 in 128 grassland sites across southern England, UK (12) found that chalkhill blue *Polyommatus coridon* abundance increased more on sites with agri-environment scheme agreements than sites without agreements. Chalkhill blue numbers increased on average 3.2%/year at 66 sites with Countryside Stewardship Scheme or Environmentally Sensitive Area agreements, compared to a non-significant decline of -2.7%/year at 62 non-scheme sites. Chalkhill blues were counted annually from 1991 to 2000, at 128 sites across its entire UK range. This was part of the UK Butterfly Monitoring Scheme, which takes weekly transect counts along a set route at each site and follows standardized weather conditions.

A before-and-after study in 1980–2006 in a forest-steppe landscape in the White Carpathians, Czech Republic (13) reported that paying farmers to mow grasslands under agri-environment schemes (AES) decreased the abundance of Danube clouded yellow *Colias myrmidone*. Results were not tested for statistical significance. In the first year of AES management, only 11 observations of 26 individual Danube clouded yellows were recorded, compared to 2,345 records in the eight years immediately prior to AES management, and 3,838 records in the previous 15 years. In the second and third years of AES management, only five and two individuals were recorded, respectively, and these observations were from abandoned pasture outside of the reserves. From the 1970s to the mid-1990s, infrequent mowing and scrub removal were used to prevent succession on 2,457 ha of grassland reserves. From the mid-1990s to 2004, reserves were mown uniformly using national funding, and since 2004 this was increased to two cuts/year under AES on all but 355 ha of grassland. Historical butterfly records were compiled for 1980–1994 and 1995–2002, and butterflies were recorded 3–6 times/year on systematic surveys at prescribed sites.

A replicated, site comparison study in 1998–2005 in mixed farmland in Aargau, Switzerland (14) found that Ecological Compensation Areas (ECAs), which farmers were paid to create, initially supported more butterfly species than farmed land, but over time the number of species decreased in both ECAs and farmed land. When initially surveyed, there were more species of butterfly in ECAs (7.3 species/plot) than in non-ECA sites (5.6 species/plot). However, between the first survey and the second survey, the number of butterfly species decreased overall, but the decreases were similar on ECA and non-ECA sites (both -1.1 species/plot). Most ECA sites were established between 1992 and 1998, and were managed for wildlife for at least six years under the Swiss agri-environment scheme. Sites were surveyed twice, five years apart, with the first survey taking place in 1998–2000 and the second in 2003–2005. At 52 ECA sites and 35 non-ECA sites, butterflies were surveyed along a 10 x 250 m transect 11 times/ year. The authors noted that ECAs were typically established on farmland with potential for maximum biodiversity gain, which may have affected the relative numbers of species found in the first survey.

A replicated, controlled study in 1998–2004 in three grassland and arable farmland regions in central Switzerland (15) found that wildflower strips and low-input grasslands which farmers were paid to create or manage for wildlife contained similar numbers of butterfly species to conventional crop fields and conventionally managed grassland. The estimated number of butterfly species on wildflower strips (19 species) was the same as on conventional crop fields (19 species). The estimated number of species was also similar between low-input (36 species) and conventional (34 species) grassland. The study sampled 78 wildflower strips (sown with 20–40 plant species) and 72 crop fields, and 315 low-input grasslands managed as "Ecological Compensation Areas" and 216 conventionally managed grasslands. From 1998–2004, butterflies were surveyed every two years between May and September, using five 10-minute observation periods across 0.25 ha/field.

A replicated, paired, site comparison study in 2007 in four arable fields in Oxfordshire, UK (16, same experimental set-up as 17, 19, 20, 25) found a higher abundance of common farmland larger moth species in the margins and centres of fields with 6-m-wide perennial grass margins, which farmers were paid to maintain, than in fields with standard 1-m margins, but this varied between species. Fields with 6-m-wide agri-environment scheme grass margins had 40% more moths of nine common species combined than fields with standard margins (data presented as model results). However, only two individual species (treble lines *Charanyca trigrammica* and brown-line bright-eye *Mythimna conigera*) were more abundant in fields with wide margins (data presented as model results). On the 32 nights (dusk till dawn) with suitable weather between 5 June and 14 July 2007, ten Heath pattern actinic light traps (6 W) were positioned in two arable fields/night: one in the centre of each field, and one in each field margin (1 m from hedgerow). All traps were >100 m apart and >50 m from hedgerow intersections. Traps were alternated between two pairs of fields each night, one with 6-m-wide perennial grass margins maintained under agri-environment agreements, and the other with standard 1-m-wide margins. Moths were identified on the morning after capture.

A replicated, controlled study in 2004–2006 in four arable areas in Oxfordshire, UK (17, same experimental set-up as 16, 19, 20, 25) found that farms with mature hedgerow trees in areas where farmers were encouraged to sign-up to agri-environment schemes (AES) had a higher abundance and diversity of larger moths than farms with hedgerow trees where farmers signed-up voluntarily. Farms with mature trees in their hedgerows in areas where farmers were encouraged to sign-up to AES had a higher abundance (9.6 individuals) and species diversity of moths than farms with hedgerow trees in areas where farmers signed-up voluntarily (abundance: 8.5 individuals), and farms without hedgerow trees where farmers were encouraged to sign-up (abundance: 8.2 individuals; diversity presented as model results). After two years of encouraging AES sign-ups, the area of land with enhanced hedgerow management options in targeted areas (5,197 ha, 219 km hedgerow) was higher than in voluntary sign-up areas (1,972 ha, 83 km hedgerow). Enhanced management required maintaining hedges at a height of >2 m, and not cutting more than once every three years. From 2004–2006, farmers in two areas were systematically encouraged to sign-up to AES. In two other areas, no active encouragement was given, but some farmers entered the scheme voluntarily. Four farms in each area were divided into two experimental groups: with and without mature (>15 m high) hedgerow trees. All farms were sampled once during each of 11 discrete fortnightly periods from mid-May to mid-October 2006 using standardized moth traps.

A before-and-after study in 1994–2006 on a farm in Oxfordshire, UK (18) found that following adoption of the Environmentally Sensitive Areas (ESA) scheme, the abundance and species richness of large moths and some species of butterfly increased. After ESA management began, the total abundance (1,000–1,450 individuals) and species richness of large moth species was higher than before (800–1,250 individuals, richness data not presented). One of the five most abundant moth species (lunar underwing *Omphaloscelis lunosa*) and five of 23 butterfly species (meadow brown *Maniola jurtina*, brown argus *Aricia agestis*, common blue *Polyommatus icarus*, small copper *Lycaena phlaeas* and red admiral *Vanessa atalanta*) increased in abundance after the change in management. However, two butterfly species became less abundant (green-veined white *Pieris napi* and large white *Pieris brassicae*, data presented as model results). Overall butterfly abundance and species richness increased over the entire monitoring period, but the increase did not just happen after the management change. In 2002, the farm entered the ESA agri-environment scheme. The proportion of grassland increased, fertilizers, herbicides and pesticides were no longer used, and the total number of livestock dropped from 180 cows and 1,000 sheep to 120 cows and 850 sheep. Butterflies were monitored weekly from April–September on a fixed 3.6 km transect divided into 13 sections. Moths were monitored nightly from dusk to dawn using a light trap in a fixed position in the middle of the farm.

A replicated, site comparison study in 2008 in five arable fields in Oxfordshire, UK (19, same experimental set-up as 16, 17, 20, 25) found that 6-m-wide perennial grass margins, which farmers were paid to maintain, had a similar abundance of moths to standard <2-m margins. Agri-environment scheme 6-m-wide grass margins had similar numbers of moths to <2-m margins (data presented as model results). Two arable fields had 6-m-wide perennial grass margins maintained under agri-environment agreements and three had standard <2-m-wide margins. Four sampling points at 1 m from the hedgerow and >100 m apart were selected in each field (20 in total). Between dusk and dawn on 33 nights between 9 June and 19 July 2008 moths were caught (at 10 points/night) using standardized light traps, identified on the morning after capture, marked and released. Counts/treatment not stated. Only data from 23 species of moth, which were found at the study sites in the previous year and whose flight period coincided with the sampling, were analysed.

A replicated, site comparison study in 2006–2008 on four arable farms in Oxfordshire, UK (20, same experimental set-up as 16, 17, 19, 25) found that field margins next to hedgerow trees, which farmers were paid to maintain under agri-environment schemes, had more pale shining brown moths *Polia bombycina* than margins without hedgerow trees, but wider margins did not have more moths than standard margins. The number of individuals caught in margins next to hedgerow trees (1.0–1.3 individuals/trap) was higher than the number in margins without trees (0.3–0.4 individuals/trap). However, the number of individuals caught in wide field margins (0.4–1.3 individuals/trap) was not significantly different to the number caught in standard width margins (0.3–1.0 individuals/trap). Four farms were assigned to one of four treatments, based on their most common agri-environment schemes habitat: 6-m-wide perennial grass or 1–2-m-wide standard field margins, and with or without hedgerow trees (>15 m high, mostly pedunculated oak *Quercus robur*). From May–October 2006–2008, moths were sampled overnight, once/fortnight, using three 6 W Heath pattern actinic light traps/farm. In June–July 2007 and 2008, at one farm, an additional 8–10 traps were set for 32–33 nights/year, in margins with the same treatments across 4–5 fields (16–20 locations). All traps were 1 m from hedgerows (2–3 m high, 1.5–2.5 m wide), 5 m from trees (if applicable), >50 m from hedgerow intersections, and >100 m apart.

A replicated, site comparison study in 2000–2004 in an arable landscape in the Swiss Plateau, Switzerland (21) found that wildflower strips which farmers were paid to create contained a higher abundance and species richness of generalist but not specialist butterflies than other arable habitats. For generalist butterflies, both the average abundance (24.0 individuals) and species richness (7.0 species) were higher in wildflower strips than in conventional grassland (abundance: 12.0; richness: 5.0) or wheat, maize and root crop fields (abundance: 2.6–3.7, richness: 1.8–2.2). However, for specialist butterflies there was no significant difference in abundance or richness (wildflower: abundance = 2.4; richness = 1.0; grassland: abundance = 0.6, richness = 0.5; crops: abundance = 0.4; richness = 0.2). Species richness of generalists was also higher in fields with more wildflower strips in the surrounding area (data presented as model results). From 1994–2004, within an 822-ha arable landscape, wildflower strips were sown with buckwheat as ground cover, and 30–40 wild plant species. They received no fertilizer or pesticide, and were not cut between 15 March and 1 October. In 2000, 2002 and 2004, butterflies were surveyed in five habitats: wildflower strips, conventional grassland, wheat fields, root crops and maize fields. Each year, 37–39 fields (6–11 fields/habitat) were sampled with 5 × 10-minute surveys every 2–3 weeks between May and August. The surrounding land cover (200-m radius) was mapped from aerial photographs. Generalist and specialist species were determined based on the number of caterpillar food plants.

A replicated, paired, site comparison study in 2008 on 36 farms in central Scotland, UK (22) reported that farms managed under agri-environment schemes (AES) had a higher abundance and species richness of moths than conventionally-managed farms. Results were not tested for statistical significance. On AES farms, 390 individuals of 51 species of micro-moth were recorded, compared to 199 individuals of 43 species on conventionally-managed farms. On AES farms, 1,377 individuals of 71 species of all macro-moths, and 159 individuals of 13 species of declining macro-moths, were recorded, compared to conventional farms where 917 individuals of 61 species of all macro-moths and 111 individuals of 17 species of declining macro-moth were recorded. In 2004, eighteen farms enrolled in AES, and were paired with 18 similar but conventionally-managed farms, <8 km away. Each AES farm had at least three of four features (hedgerows, sown grass field margins or banks, sown species-rich grassland, >3-m-wide waterway margins) all with reduced chemical inputs and relaxed cutting and grazing regimes compared to similar habitat features on the conventional farms. From June–September 2008, moths were collected for four hours, on one night/farm, using 6 W heath light traps located next to each habitat type (3–4 traps/farm, ≥100 m apart). Paired farms were surveyed on the same night.

A replicated, randomized, paired, controlled study in 2005–2011 on an arable farm in Buckinghamshire, UK (23) found that land managed under an agri-environment scheme had a higher abundance, but not species richness, of butterflies and micro-moths than conventional farming, but there was no difference in abundance or species richness of other moths. Butterfly abundance was higher under enhanced Entry-Level Stewardship (ELS) (5,400 individuals/60 ha) and standard ELS (2,000 individuals/60 ha) than under conventional farming (1,400 individuals/60 ha). Micro-moth abundance was also higher under enhanced ELS (79 individuals) than standard ELS (32 individuals) or conventional farming (20 individuals). However, the abundance of macro-moths and threatened moths was similar under enhanced ELS (macro: 126; threatened: 6 individuals), standard ELS (macro: 79; threatened: 5 individuals) and conventional farming (macro: 79; threatened: 6 individuals). Species richness of all groups was similar under enhanced ELS (macro: 20; micro: 11; threatened: 3 species), standard ELS (macro: 20; micro: 8; threatened: 2 species) and conventional farming (macro: 18; micro: 5; threatened: 2 species) (butterfly data not presented). In 2005, a 1,000-ha farm was divided into five 180-ha blocks. Three 60-ha areas/block were assigned to three treatments: enhanced ELS (5% land removed from production); standard ELS (1% land removed from production); and conventional farming (see paper for details). From May–August 2006–2011, butterflies were recorded four times/year on one 50-m transect/60-ha area, passing through all available habitats. In late-May 2007–2011 and late-July 2006–2011 moths were surveyed using Robinson light traps. One block was surveyed/night, with one trap/treatment.

A replicated, site comparison study in 2001–2010 in 32 pastoral farms in Dorset, UK (24) reported that on farms in agri-environment schemes, marsh fritillary *Euphydryas aurinia* populations were more likely to have a positive response over nine years than on farms not in schemes. In 28 farms in agri-environment schemes, marsh fritillary populations showed a positive response in 20, a negative response in one and no change in seven. In four farms not in agri-environment schemes, populations showed a positive response in two and no change in two. The study does not clearly report whether responses of populations were measured as size, number/site or persistence. Data were provided for 32 farms which had populations of marsh fritillary. Twenty-eight were in either the Wildlife Enhancement Scheme, Countryside Stewardship Scheme or Higher Level Environmental Stewardship scheme. From 2001–2010 butterflies were surveyed annually via walking transects and caterpillars via web counts. It is not clear whether both transects and web counts were conducted at all farms.

A replicated, site comparison study in 2006–2009 on 16 arable farms in Oxfordshire, UK (25, same experimental set-up as 16, 17, 19, 20) found that extended-width field margins and margins next to hedgerow trees, which farmers were paid to maintain under agri-environment schemes, had a higher species richness, but not abundance, of macro-moths than standard-width margins and margins away from hedgerow trees, respectively. The species richness of macro-moths in extended-width margins (105 species) was higher than in standard-width margins (92 species), but the abundance was similar (data not presented). Species richness in margins next to hedgerow trees (105 species) was also higher than in margins next to hedgerows without trees (92 species), but abundance was similar (data not presented). Sixteen farms were categorized to one of four treatments, based on their most common agri-environment scheme habitat: extended 6-m-wide or standard 1-m-wide field margins, and with or without hedgerow trees (>15 m high, mostly pedunculated oak *Quercus robur*). All margins were well-established perennial grass strips, cut once every 2–3 years, ungrazed and unfertilized. From May–October 2006–2009, moths were sampled 40 times (once/fortnight), using three 6 W Heath pattern actinic light traps/farm. Traps were 1 m from hedgerows (2–3 m high, 1.5–2.5 m wide), 5 m from trees (if applicable), >50 m from hedgerow intersections, >100 m apart, and operated from dawn to dusk. Three farms (nine traps) were sampled/night.

A replicated, site comparison study in 1995–2011 in 850 sites across England, UK (26) found that sites surrounded by a larger area or greater number of individual agri-environment scheme (AES) options targeted at butterflies had more butterflies than sites surrounded by a smaller area or fewer individual AES options. There were more butterflies on sites with more AES options in the surrounding 3 km than on sites surrounded by fewer AES options (data presented as model results). However, the introduction of AES schemes near to individual sites did not alter local butterfly population trends (data presented as model results). Three agri-environment schemes, Environmentally Sensitive Areas (open from 1987–2005), Countryside Stewardship Scheme (1991–2005) and Environmental Stewardship (2005 onwards), were used to pay landowners for managing wildlife habitat on their land. The area of land managed to benefit butterflies under AES, and the number of individual AES options in place, around each survey site was calculated. Options for butterflies included conservation headlands, hedge planting or restoration, pollen and nectar mixes, and species-rich, semi-natural grassland. From 1995–2011, butterflies were surveyed once/week throughout the flight season (up to 26 weeks) along fixed transects at 451 sites as part of the UK Butterfly Monitoring Scheme. In July–August 2010–2011, butterflies were surveyed at least twice/year on two parallel transects within 399 1-km squares as part of the Wider Countryside Butterfly Monitoring Scheme.

A replicated, randomized, controlled study in 2007–2010 on 28 arable farms in Wessex and East Anglia, UK (27) found that farms with enhanced agri-environment scheme (AES) habitats had a higher abundance of some butterfly species than farms with simpler AES habitats. In early summer, farms with enhanced AES habitats had a higher abundance of blue (Lycaenidae: 0.05 individuals/100 m) and white (Pieridae: 0.46 individuals/100 m) butterflies along boundaries than farms with Entry Level Scheme (ELS) habitats (blues: 0.04; whites 0.21 individuals/100 m), but a lower abundance of skippers (Hesperiidae) in the AES habitat itself (enhanced: 0.00; ELS: 0.02 individuals/100 m). In mid-summer, enhanced AES farms had a higher abundance of white butterflies (0.69 individuals/100 m), but a lower abundance of brown butterflies (Satyridae: 0.16 individuals/100 m) in the AES habitat, and a lower abundance of blue butterflies (0.05 individuals/100 m) along boundaries than ELS farms (whites: 0.38; browns: 0.49; blues: 0.11 individuals/100 m). In spring 2007, twenty-four farms (12 in East Anglia and 12 in Wessex) were randomly assigned to two treatments: 16 farms with enhanced AES habitat (1.5–6.0 ha of floristically-enhanced grass mixes, wildflower strips, wild bird seed mixes and natural regeneration by annual cultivation); and eight farms with ELS habitat (1.5–6.0 ha of grass margins and game cover (usually maize)). Two additional ELS farms/region, already managed organically with 1.5 ha of ELS habitat, were also studied. From 2008–2010, butterflies were surveyed twice/year on 11 fixed 100-m transects, in mid-May–mid-June and mid-July–early August. Eight transects/site were located in AES habitat, and three transects/site were located on field boundaries away from the AES habitat.

A replicated, paired, site comparison study in 2015 on 22 farms in Berkshire, Hampshire and Wiltshire, UK (28) found that grassland restored through agri-environment schemes supported more moths than unrestored arable fields, and was similar to semi-natural grassland sites. Three to 20 years after restoration, the abundance of moths associated with calcareous grassland (6.3 individuals/trap) and other grassland (49.6 individuals/trap) on restored fields were higher than on arable fields (calcareous: 0.8; other: 14.6 individuals/trap), and similar to semi-natural grassland (calcareous: 7.2; other: 38.3 individuals/trap). The abundance of moths associated with other habitats was higher on restored (25.5 individuals/trap) than unrestored fields (15.3 individuals/trap), but lower than on semi-natural grassland sites (57.9 individuals/trap). Results for species occurrence were similar (data not presented). However, neither moth abundance nor occurrence increased with time since restoration (data not presented). Over 3–20 years, 32 former arable fields (2.6–37.5 ha) on 22 farms were restored to species-rich grassland by either natural regeneration or sowing of wildflowers, paid for by agri-environment schemes. All were cut or grazed at least once/year. Thirty-two paired, arable fields (2.2–49.3 ha) were unrestored, and eight semi-natural calcareous grasslands were used for comparison. On 21 nights between June–September 2015, moths were surveyed twice/site (2–4 restored-unrestored pairs/night, with a comparison site on >50% of nights) using one 15 W light trap in the centre of each field. Moths were classified as species associated with calcareous grassland, associated with grassland generally, or not associated with grassland.

A replicated, site comparison study in 2009–2014 in eight farm set-asides and two native prairies in Wisconsin, USA (29) found that set-aside fields which landowners were paid to sow with grasses and non-woody broadleaved plants (forbs) had a similar number of butterflies to native prairies in the first year, but lower numbers after 2–5 years. For the first year after establishment, set-aside areas had a similar number of butterflies (8–52 butterflies/200 m) to native prairie (5–42 butterflies/200 m). However, 2–5 years after establishment, the number of butterflies on set-aside (5–20 butterflies/200 m) was lower than in native prairie (22–68 butterflies/200 m). The total number of species recorded on set-aside (31 species, of which six were not seen on prairies) was similar to prairie sites (35 species, of which 10 were not seen on set-aside). In spring 2009, fields (average 6.8 ha) on eight farms enrolled in a set-aside program were pre-treated with glyphosate and seeded with a mix of six grasses and 11 forbs using a no-till seed drill. They were compared with two native dry sand prairies in a powerline right-of-way, managed to suppress woody vegetation. From May–August 2009–2012, butterflies were surveyed 2–4 times/year on one 200-m transect/farm. In 2013–2014, just four farms and the two native prairies were surveyed twice/year.

A replicated, site comparison study in 2009–2011 in 133 mixed farms in the Central Plateau, Switzerland (30) found that farms with more land managed under agri-environment schemes (AES) had a higher abundance, but not species richness, of butterflies than farms with less land under AES. The abundance of butterflies on farms with more land managed under AES was higher than on farms with less land managed under AES, but there was no difference in butterfly species richness (data presented as model results). A total of 133 farms (17–34 ha, 13–91% arable crops) were managed with "Ecological Compensation Areas" under AES. Management included extensive and low-input meadows with reduced fertilizer and later cutting dates, and the presence of trees, hedgerows and wildflower patches. From May–September 2009–2011, butterflies were surveyed six times on 10–38 transects/farm, totalling 2,500 m/farm. Each transect ran diagonally through a single crop or habitat type, with all available crops and habitats represented. All visits to a farm were completed in a single year, and the species richness was summed across all visits. Total abundance of butterflies was calculated from the number recorded in each habitat, and the availability of each habitat across the farm. Ecological Compensation Areas on each farm were mapped between May and August.

A replicated, before-and-after, site comparison study in 2000–2016 in 10 coppiced forests in Bavaria, Germany (31) found that the number of webs of Eastern eggar moth *Eriogaster catax* and scarce fritillary *Euphydryas maturna* caterpillars was higher in recently coppiced woodland, which landowners were paid to manage, than in older woodland. Eastern eggar moth caterpillars were most often found in patches 5–10 years after the last coppice, and their abundance peaked after 5–7 years (data presented as model results). Scarce fritillary caterpillars were most often found in patches 10–12 years after the last coppice, and their abundance peaked after 12–15 years (data presented as model results). Coppicing commenced in 2005 at nine sites (23–310 ha), and in 2012 at a tenth site (80 ha) under a Government-funded scheme. From 2000–2016, caterpillars of Eastern eggar moth and scarce fritillary were surveyed in early May and late July–early August, respectively, by counting their silk-woven webs, in both coppiced and non-coppiced areas at each site. Each site was surveyed 0–5 times before coppicing (2000–2004) and 1–12 times after coppicing (2005–2016).

A replicated, site comparison study in 2010–2014 in 50 agricultural areas in the Swiss Plateau, Switzerland (32) found that landscapes with a greater proportion of semi-natural habitat, provided through agri-environment schemes (AES), had a higher abundance and species richness of butterflies than landscapes with less semi-natural habitat. Agricultural areas with more than 20% of the land managed under AES had a higher abundance and species richness of all butterflies than areas with less than 10% AES. The abundance of farmland butterflies, and the species richness of threatened butterflies, was higher in landscapes with more AES than in landscapes with less AES (all data presented as model results). Fifty mixed farming areas (1 km^2) were selected where 2.5–32.2% of agricultural land was managed under AES (primarily extensive meadows (cut or grazed once/year, no fertilizers or pesticides) and orchards). Butterflies were surveyed seven times along a 2.5-km transect through each 1-km^2 area in one of five years (2010–2014). Species were classified as "farmland species" if they occur in open habitat, and "threatened" species if they were listed as Near Threatened, Vulnerable or Critically Endangered on the Swiss RedList.

(1) Pöyry J., Lindgren S., Salminen J. & Kuussaari M. (2004) Restoration of butterfly and moth communities in semi-natural grasslands by cattle grazing. *Ecological Applications*, 14, 1656–1670.
(2) Aviron S., Berner D., Bosshart S., Buholzer S., Herzog F., Jeanneret P., Klaus I., Pozzi S., Schneider K., Schüpbach B. & Walter T. (2005) Butterfly diversity in Swiss grasslands: respective impacts of low-input management, landscape features and region. Pages 340-343 in: R. Lillak, R. Viiralt, A. Linke & V. Geherman (eds.) *Grassland Science in Europe*. 10, Estonian Grassland Society, Tartu.
(3) Field R.G. & Mason C.F. (2005) The utilization of two-metre Countryside Stewardship Scheme grass margins by the gatekeeper *Pyronia tithonus* (L). *Journal of Natural History*, 39, 1533–1538.
(4) Field R.G., Gardiner T., Mason C.F. & Hill J. (2005) Agri-environment schemes and butterflies: the utilisation of 6 m grass margins. *Biodiversity and Conservation*, 14, 1969–1976.
(5) Pöyry J., Lindgren S., Salminen J. & Kuussaari M. (2005) Responses of butterfly and moth species to restored cattle grazing in semi-natural grasslands. *Biological Conservation*, 122, 465–478.
(6) Field R., Gardiner T., Mason C. & Hill J. (2006) Countryside Stewardship Scheme and butterflies: a study of plant and butterfly species richness. *Biodiversity and Conservation*, 15, 443–452.
(7) Rundlöf M. & Smith H.G. (2006) The effect of organic farming on butterfly diversity depends on landscape context. *Journal of Applied Ecology*, 43, 1121–1127.
(8) Albrecht M., Duelli P., Muller C., Kleijn D. & Schmid B. (2007) The Swiss agri-environment scheme enhances pollinator diversity and plant reproductive success in nearby intensively managed farmland. *Journal of Applied Ecology*, 44, 813–822.
(9) Aviron S., Jeanneret P., Schüpbach B. & Herzog F. (2007) Effects of agri-environmental measures, site and landscape conditions on butterfly diversity of Swiss grassland. *Agriculture, Ecosystems & Environment*, 122, 295-304.
(10) Field R.G., Gardiner T., Mason C.F. & Hill J. (2007a) Agri-environment schemes and butterflies: the utilisation of two metre arable field margins. *Biodiversity and Conservation*, 16, 465–474.
(11) Field R.G., Gardiner T. & Watkins G. (2007b) The use of farmland by butterflies: a study on mixed farmland and field margins. *Entomologist's Gazette*, 58, 3–15.
(12) Brereton T.M., Warren M.S., Roy D.B. & Stewart K. (2008) The changing status of the Chalkhill Blue butterfly *Polyommatus coridon* in the UK: the impacts of conservation policies and environmental factors. *Journal of Insect Conservation*, 12, 629-638.
(13) Konvicka M., Benes J., Cizek O., Kopecek F., Konvicka O. & Vitaz L. (2008) How too much care kills species: Grassland reserves, agri-environmental schemes and extinction of *Colias myrmidone* (Lepidoptera: Pieridae) from its former stronghold. *Journal of Insect Conservation*, 12, 519–525.
(14) Roth T., Amrhein V., Peter B. & Weber D. (2008) A Swiss agri-environment scheme effectively enhances species richness for some taxa over time. *Agriculture, Ecosystems & Environment*, 125, 167–172.
(15) Aviron S., Nitsch H., Jeanneret P., Buholzer S., Luka H., Pfiffner L., Pozzi S., Schüpbach B., Walter T. & Herzog F. (2009) Ecological cross compliance promotes farmland biodiversity in Switzerland. *Frontiers in Ecology and the Environment*, 7(5), 247-252.

(16) Merckx T., Feber R.E., Dulieu R.L., Townsend M.C., Parsons M.S., Bourn N.A.D., Riordan P. & Macdonald D.W. (2009a) Effect of field margins on moths depends on species mobility: field-based evidence for landscape-scale conservation. *Agriculture, Ecosystems & Environment*, 129, 302–309.
(17) Merckx T., Feber R.E., Riordan P., Townsend M.C., Bourn N.A.D., Parsons M.S. & Macdonald D.W. (2009b) Optimizing the biodiversity gain from agri-environment schemes. *Agriculture, Ecosystems & Environment*, 130, 177–182.
(18) Taylor M.E. & Morecroft M.D. (2009) Effects of agri-environment schemes in a long-term ecological time series. *Agriculture, Ecosystems & Environment*, 130, 9–15.
(19) Merckx T., Feber R.E., Mclaughlan C., Bourn N.A.D., Parsons M.S., Townsend M.C., Riordan P., Macdonald D.W. (2010) Shelter benefits less mobile moth species: The field-scale effect of hedgerow trees. *Agriculture, Ecosystems & Environment*, 138(3-4), 147-151.
(20) Merckx T., Feber R.E., Parsons M.S., Bourn N.A.D., Townsend M.C., Riordan P. & Macdonald D.W. (2010) Habitat preference and mobility of *Polia bombycina*: are non-tailored agri-environment schemes any good for a rare and localised species? *Journal of Insect Conservation*, 14, 499–510.
(21) Aviron S., Herzog F., Klaus I., Schüpbach B. & Jeanneret P. (2011) Effects of wildflower strip quality, quantity and connectivity on butterfly diversity in a Swiss arable landscape. *Restoration Ecology*, 19 (4), 500–508.
(22) Fuentes-Montemayor E., Goulson D. & Park K.J. (2011) The effectiveness of agri-environment schemes for the conservation of farmland moths: assessing the importance of a landscape-scale management approach. *Journal of Applied Ecology*, 48, 532–542.
(23) Heard M.S., Botham M., Broughton R., Carvell C., Hinsley S., Woodcock B., Pywell R.F., Amy S., Bellamy P.E., Hill R.A., Hulmes S., Hulmes L., Meek W.R., Nowakowski M., Peyton J., Redhead J.W., Shore R.F. & Turk A. (2011) Quantifying the effects of Entry Level Stewardship (ELS) on biodiversity at the farm scale: the Hillesden Experiment. *Natural England report*, RP00026.
(24) Bulman C., Bourn N., Belding R., Middlebrook I. Brook S., Shreeves B. & Warren M. (2012) Conserving the Marsh Fritillary in Dorset: lessons from over 15 years of landscape-scale conservation. In Ellis S., Bourn N. & Bulman C, *Landscape-scale conservation for butterflies and moths: Lessons from the UK*. 24-29.
(25) Merckx T., Marini L., Feber R.E. & Macdonald D.W. (2012) Hedgerow trees and extended-width field margins enhance macro-moth diversity: implications for management. *Journal of Applied Ecology*, 49, 1396–1404.
(26) Oliver T. (2014) Assessing the importance of spatial location of agri-environment options within the landscape to butterflies. *Natural England Commissioned Report*, NECR157.
(27) Holland J.M., Smith B.M., Storkey J., Lutman P.J.W. & Aebischer N.J. (2015) Managing habitats on English farmland for insect pollinator conservation. *Biological Conservation*, 182, 215–222.
(28) Alison J., Duffield S.J., Morecroft M.D., Marrs R.H. & Hodgson J.A. (2017) Successful restoration of moth abundance and species-richness in grassland created under agri-environment schemes. *Biological Conservation*, 213, 51–58.
(29) Kleintjes Neff P., Locke C. & Lee-Mäder E. (2017) Assessing a farmland set-aside conservation program for an endangered butterfly: USDA State Acres for Wildlife Enhancement (SAFE) for the Karner blue butterfly. *Journal of Insect Conservation*, 21, 929–941.
(30) Stoeckli S., Birrer S., Zellweger-Fischer J., Balmer O., Jenny M. & Pfiffner L. (2017) Quantifying the extent to which farmers can influence biodiversity on their farms. *Agriculture, Ecosystems & Environment*, 237, 224–233.
(31) Dolek M., Kőrösi Á & Freese-Hager A. (2018) Successful maintenance of Lepidoptera by government-funded management of coppiced forests. *Journal for Nature Conservation*, 43, 75–84.
(32) Zingg S., Grenz J. & Humbert J.-Y. (2018) Landscape-scale effects of land use intensity on birds and butterflies. *Agriculture, Ecosystems & Environment*, 267, 119–128.

3.3. Reduce field size (or maintain small fields)

- **Five studies** evaluated the effects of reducing field size on butterflies and moths. Two studies were in Switzerland[4,5], and one was in each of Germany[1], Sweden[2] and the Czech Republic and Poland[3].

COMMUNITY RESPONSE (5 STUDIES)

- **Richness/diversity (5 studies):** Two of four replicated, site comparison studies in Sweden[2], the Czech Republic and Poland[3] and Switzerland[4,5] found that arable farms (in more diverse landscapes)[2] and landscapes[3] with smaller fields had a higher species richness of butterflies[2,3] and burnet moths[2] than areas with larger fields. The other two studies found that mixed farms[4] and landscapes[5] with smaller fields had a similar species richness of butterflies to areas with larger fields[4,5]. One before-and-after study in Germany[1] found that after reducing field size by increasing the length of field edges on a farm, along with increasing the area of meadows and field margins, the species richness of butterflies and burnet moths increased.

POPULATION RESPONSE (4 STUDIES)

- **Abundance (4 studies):** Four replicated, site comparison studies in Sweden[2], the Czech Republic and Poland[3] and Switzerland[4,5] found that arable[2,3] and mixed[4,5] farms and landscapes with smaller fields had a higher abundance of butterflies[2–5] and burnet moths[2] than areas with larger fields.

BEHAVIOUR (0 STUDIES)

Background

Continuous large areas of arable crops or intensively-managed grassland can be inhospitable for butterflies and moths. However, field edges such as hedgerows, ditches and grass or flower margins may provide important resources which are lacking in the managed field centres. Reducing field sizes, and therefore increasing the density of field edge habitat, may improve the habitat quality for butterflies and moths within the farmed landscape.

See also "*Plant new hedges*", "*Create uncultivated margins around intensive arable or pasture fields*" and "*Plant grass buffer strips/margins around arable or pasture fields*".

A before-and-after study in 1987–1991 on an arable farm in Saarland, Germany (1) reported that reducing field size (by increasing the length of field edges), in combination with increasing the area of meadows and field margins, increased the species richness of butterflies and burnet moths. Results were not tested for statistical significance. Four years after field edges were increased and meadows and field margins created, 24 species of butterflies and burnet moths were present on the farm, compared to 20 species before creation. Marbled white *Melanargia galathea* were present at eight survey sites in 1991, compared to one site in 1987. In 1987, on an intensively managed 30-ha farm with large fields, the length of field edges was increased from 7,200 m to 17,420 m. Semi-natural meadows and field margins were created by sowing regional plant species including rosebay willowherb *Epilobium angustifolium,* danewort *Sambucus ebulus*, heather *Calluna vulgaris* and regional meadow seeds. From May–August

1987–1988 and 1991, butterflies and burnet moths were surveyed at sample sites (number not specified) across the whole farm.

A replicated, site comparison study in 2003–2004 on 24 arable farms in Scania, Sweden (2) found that farms with smaller fields in more diverse landscapes had a higher abundance and species richness of butterflies and burnet moths than farms with larger fields in intensively farmed landscapes. Both the abundance (3.6–4.5 individuals/50 m) and species richness (1.4–1.6 species/50 m) of butterflies and burnet moths on farms with small fields in more diverse landscapes were higher than on farms with larger fields (abundance: 0.4–1.7 individuals/50 m; richness: 0.3–0.9 species/50 m). Twelve arable farms with small fields (average: 31,600 m^2) in diverse landscapes (15% arable land, 19% pasture), and 12 arable farms with large fields (average: 60,200 m^2) in intensively farmed landscapes (70% arable land, 3% pasture) were selected. From June–August 2003 and May–August 2004, butterflies and burnet moths were surveyed 5–6 times/year along 400–750 m routes along cereal field boundaries. Individuals occurring 5 m into the crop and in adjacent 2-m uncultivated margins were counted.

A replicated, site comparison study in 2009 in two arable farmland areas in Opava-Raciborz, Czech Republic and Poland (3) found that land farmed with smaller field sizes had twice as many individual butterflies and butterfly species than land farmed with larger field sizes. Both the abundance (14 individuals/visit) and species richness (3 species/visit) of butterflies were higher where field sizes were small (in Poland) than where field sizes were large (in the Czech Republic; abundance: 6 individuals/visit, richness: 2 species/visit). See paper for individual species results. In Poland, the land had been managed as small, family farms for decades, whereas in the Czech Republic the field sizes were on average 10-times larger than in Poland (average field sizes not given). From May–September 2009, butterflies were recorded for five minutes, once/month, in a 10-m diameter circle at each of 20 points/country. Survey points were within 500 m of the state border, at least 200 m apart, and adjoined more than one crop.

A replicated, site comparison study in 2009–2011 in 133 mixed farms in the Central Plateau, Switzerland (4) found that farms with more, smaller fields had a higher abundance, but not species richness, of butterflies than farms with fewer, larger fields. The abundance of butterflies on farms with more, smaller fields was higher than on farms with fewer, larger fields, but there was no difference in butterfly species richness (data presented as model results). A total of 133 farms (17–34 ha, 13–91% arable crops) were surveyed. From May–September 2009–2011, butterflies were surveyed six times on 10–38 transects/farm, totalling 2,500 m/farm. Each transect ran diagonally through a single crop or habitat type, with all available crops and habitats represented. All visits to a farm were completed in a single year, and the species richness was summed across all visits. Total abundance of butterflies was calculated from the number recorded in each habitat, and the availability of each habitat across the farm.

A replicated, site comparison study in 2010–2014 in 50 agricultural areas in the Swiss Plateau, Switzerland (5) found that landscapes with smaller average field sizes had a higher abundance, but not species richness, of butterflies than landscapes with larger fields. Agricultural areas with average field sizes <1.5 ha had a higher abundance, but not species richness, of butterflies than areas with average field sizes >1.5 ha (data presented as model results). Fifty mixed farming areas (1 km^2) were selected which had average field sizes from 0.55 to 2.70 ha. Butterflies were surveyed seven times along a 2.5-km transect through each 1-km^2 area in one of five years (2010–2014).

(1) Reck (1993) Creating new habitats on intensively used farmland, the "Pappelhof" in Saarland — a project supported by the German government. *Natur und Landschaft*, 68, 394–403.
(2) Rundlöf M. & Smith H.G. (2006) The effect of organic farming on butterfly diversity depends on landscape context. *Journal of Applied Ecology*, 43, 1121–1127.
(3) Konvicka M., Benes J. & Polakova S. (2016) Smaller fields support more butterflies: comparing two neighbouring European countries with different socioeconomic heritage. *Journal of Insect Conservation*, 20, 1113–1118.
(4) Stoeckli S., Birrer S., Zellweger-Fischer J., Balmer O., Jenny M. & Pfiffner L. (2017) Quantifying the extent to which farmers can influence biodiversity on their farms. *Agriculture, Ecosystems & Environment*, 237, 224–233.
(5) Zingg S., Grenz J. & Humbert J.-Y. (2018) Landscape-scale effects of land use intensity on birds and butterflies. *Agriculture, Ecosystems & Environment*, 267, 119–128.

3.4. Manage hedgerows to benefit wildlife (e.g. no spray, gap-filling and laying)

- **Seventeen studies** evaluated the effects of managing hedgerows to benefit wildlife on butterflies and moths. Fourteen studies were in the UK[1–6,8,9,11–15,17], and one was in each of Belgium[7], Costa Rica[10] and Italy[16].

COMMUNITY RESPONSE (9 STUDIES)

- **Richness/diversity (9 studies):** Three replicated, site comparison studies in the UK[6,13] and Costa Rica[10] found that hedgerows with trees[6,13] or a more complex structure[10] had a higher species richness or diversity of butterflies[10] and macro-moths[6,13] than simpler hedgerows without trees. Three of six replicated studies (including three randomized, paired, controlled studies, one randomized, site comparison, and two site comparison studies) in the UK[2,11,12,14,15] and Italy[16] found that hedgerows cut to allow incremental growth had a higher diversity of caterpillars and pupae than hedgerows cut to the same size[15], that hedgerows kept between 1–2 m tall had a higher species richness of butterflies than hedgerows kept below 1 m tall[16] and that fields with hedgerows of a larger volume had higher species richness of butterflies than those with hedgerows of a smaller volume[2], but only in one of two study years[2]. The other three studies found that hedgerows managed according to agri-environment scheme prescriptions (including less frequent[11,12,14] or winter cutting[14], gap-filling[11] and restricted mowing[11], in one case in combination with other agri-environment scheme habitat[12]) had a similar species richness of butterflies[12] and moths[11,12,14] to conventionally managed hedgerows.

POPULATION RESPONSE (17 STUDIES)

- **Abundance (17 studies):** Four of six replicated studies (including four randomized, paired, controlled studies, one controlled study, and one paired, site comparison study) in the UK[4,11,12,14,15,17] found that hedgerows cut once every 2–3 years[12,15,17], cut in autumn[4,15,17], or cut to allow incremental growth[17], had a higher abundance of adult butterflies and moths[4,12], moth caterpillars and pupae[15] and brown hairstreak eggs[17] than hedgerows cut to the same size every winter. However, one of these studies also found that hedgerows cut to allow incremental growth had a similar abundance of moth caterpillars and pupae to hedgerows cut to the same size[15]. The other two studies found that hedgerows managed by gap-filling and cutting every three years had a similar abundance of moths to conventionally managed hedgerows[11], and that hedgerows cut in winter, or less frequently in autumn, had more concealed moth caterpillars, but a similar abundance of free-living caterpillars, to hedgerows cut annually in autumn[14]. Three of five replicated, site comparison studies (including one paired study) in the UK[5,6,9,13] and Costa Rica[10] found that hedgerows with trees had a similar total abundance of macro-moths to hedgerows without trees[5,6,13]. The other two studies found that hedgerows with trees[9], or with a more complex structure[10], had a higher abundance of butterflies[10] and pale shining brown moths[9] than simple hedgerows. Two replicated, site comparison studies in Belgium[7] and Italy[16] found that hedgerows managed with scalloped edges[7], or maintained at below 1 m tall[16], had more brown hairstreak eggs[7] and a higher abundance of adult butterflies[16], than hedgerows with straight edges[7] or allowed to grow over 2 m tall[16]. One of two studies (including one controlled and one replicated, site comparison study) in the UK[1,3] found that laid or coppiced hedgerows had a higher abundance of butterflies than unmanaged hedgerows[3]. The other study found that managed hedgerows had a lower abundance of caterpillars than remnant hedgerows[1]. One replicated, randomized, site comparison study in the UK[2] found that butterfly abundance was higher in fields with hedgerows of a larger volume, but only in one of two study years. One replicated, site comparison study in the UK[8] found that field margins next to hedgerow trees had a higher abundance of most shrub- and tree-feeding, but not grass- and herb-feeding, moth species than margins away from hedgerow trees.

BEHAVIOUR (0 STUDIES)

Background

Despite being originally man-made, hedgerows provide an important source of semi-natural habitat within the farmed landscape. In Europe, conventional hedgerow management consists of annual cutting to a standard shape and size, which is unlikely to encourage the diversity of growth and resources needed by butterflies and moths. The timing of hedgerow cutting may be important for some species, depending on whether they are in a life-stage which is actively using the hedgerow and how easily it can disperse (Waring 2004). On the other hand, unmanaged hedgerows can become too overgrown, and gaps can appear over time. Hedgerows with more gaps attract fewer meadow brown *Maniola jurtina* butterflies than continuous hedgerows (Pywell *et al.* 2004). Agri-environment schemes recommend a diversity of hedgerow management techniques, including gap-filling, reduced mowing at the base, less frequent cutting (once every two or three years), and advise cutting at specific times of years (often in winter, Facey *et al.* 2014).

For studies on planting new hedgerows, see "*Plant new hedges*". For studies on reducing chemical applications alone, see "*Pollution – Reduce fertilizer, pesticide or herbicide use generally*" and "*Pollution – Convert to organic farming*".

Facey S.L., Botham M.S., Heard M.S., Pywell R.F. & Staley J.T. (2014) Moth communities and agri-environment schemes: Examining the effects of hedgerow cutting regime on diversity, abundance, and parasitism. *Insect Conservation and Diversity*, 7, 543–552.

Pywell R.F., Warman E.A., Sparks T.H., Greatorex-Davies J.N., Walker K.J., Meek W.R., Carvell C., Petit S. & Firbank L.G. (2004) Assessing habitat quality for butterflies on intensively managed arable farmland. *Biological Conservation*, 118, 313–325.

Waring P. (2004) Successes in conserving the Barberry Carpet moth *Pareulype berberata* (D. & S.) (Geometridae) in England. *Journal of Insect Conservation*, 8, 167–171.

A replicated, site comparison study in 1979 on a farm in Hampshire, UK (1) found that regularly cut and uncut hedges had a lower abundance of caterpillars than patchy, remnant hedges. In regularly cut hedges, the abundance of caterpillars (7 individuals/hedge) was similar to uncut hedges (4 individuals/hedge), and both were lower than in remnant hedges (18 individuals/hedge). Three hedges (primarily containing hawthorn *Crataegus monogyna*, dog rose *Rosa canina* and blackthorn *Prunus spinosa*) in each of three management categories were selected. Cut hedges (2.0–2.1 m wide, 1.7–2.2 m high) were regularly managed, and last cut around eight months before sampling. Uncut hedges (2.6–2.9 m wide, 8.0–9.0 m high) had not been cut for >5 years, but remained stock-proof. Remnant hedges (2.5–3.0 m wide, 6.0–7.5 m high) consisted of individual trees and bushes along a field edge. In July 1979, caterpillars were sampled in three locations on each side of each hedge using a beating tray.

A replicated, randomized, site comparison study in 1986 and 1991 at a farmland and grassland site in Cambridgeshire, UK (2) found that butterfly abundance and species richness were higher in fields with larger hedgerows in one year but there was no difference in the other year. In 1991, but not in 1986, abundance and richness were higher in fields with hedges of greater volume (data presented as statistical results). See paper for details of the effects on individual butterfly species. From May–September in 1986 and 1991, butterflies were surveyed up to once/month in fine weather on ninety-nine 200 m transects along margins between fields of any combination of arable farmland and grassland. Each transect was surveyed 2–4 times in both years. Hedge volume was measured in both years and calculated by multiplying height, width and length measurements.

A controlled study in 1995–1996 along a hedgerow in Cambridgeshire, UK (3) found that laid or coppiced sections of hedge had a higher abundance of butterflies than uncut sections of hedge. There were more butterflies along laid (53–67 butterflies/plot) or coppiced (60–69 butterflies/plot) sections of hedge than along uncut sections (23–26 butterflies/plot). Meadow brown *Maniola jurtina* (laid: 29–48; coppiced: 28–31; uncut: 18–22 butterflies/plot), gatekeeper *Pyronia tithonus* (laid: 7–12; coppiced: 12–16; uncut: 1 butterflies/plot) and small heath *Coenonympha pamphilus* (laid: 4–5; coppiced: 7–14; uncut: 2 butterflies/plot) were all more abundant on laid or coppiced sections than on uncut sections, but small skipper *Thymelicus sylvestris* abundance was not significantly different between treatments (laid: 1–7; coppiced: 2–6; uncut: 0–1 butterflies/plot). A hedge was planted in the early 1960s. In winter 1990/91 the hedge was divided into twelve 20-m long experimental plots. One of three treatments was applied to each plot: laying, coppicing to ground level, or left uncut. In winter 1995/96, the laid and coppiced sections were trimmed. In summer 1995 and 1996, butterflies were surveyed on both sides of the hedge on 18–19 visits/year.

A replicated, controlled study on seven arable and pastoral farms in England and Wales, UK (4) found that hedgerows cut in February had a lower abundance of butterflies and moths than hedgerows cut in September. Cutting in February rather than September reduced numbers of butterflies and moths (February: 33/plot; September: 65/plot). In 1996–1997, hedgerows on seven farms were assigned to replicated treatments (15–21 plots/farm) of different cutting times (cut in September or February) and cutting frequency (annual, biennial and triennial cutting, and uncut; results not presented). Data were obtained on the abundance of butterflies and moths in May and July within each hedgerow plot (methods and years not given).

A replicated, paired, site comparison study in 2007 in four arable fields in Oxfordshire, UK (5, same experimental set-up as 6, 8, 9, 13) found no difference in the abundance of common farmland larger moth species in margins adjacent to hedgerows with or without mature trees. Field margins with trees in the adjacent hedgerow had similar numbers of nine common moth species to margins with no trees in the adjacent hedgerow (data presented as model results). On the 32 nights (dusk till dawn) with suitable weather between 5 June and 14 July 2007, eight Heath pattern actinic light traps (6 W) were positioned in two arable fields/night, one in each field margin (1 m from the hedgerow). Four traps were within 5 m of a mature (>15 m high) hedgerow tree, and four were next to hedgerows with no trees. All traps were >100 m apart and >50 m from hedgerow intersections. Traps were alternated between two pairs of fields each night, one with 6-m-wide perennial grass margins and the other with standard 1-m-wide margins. Moths were identified on the morning after capture.

A replicated, site comparison study in 2006 in four arable areas in Oxfordshire, UK (6, same experimental set-up as 5, 8, 9, 13) found that farms with mature trees in their hedgerows had a higher diversity of larger moths than farms without mature trees in their hedgerows, but that the abundance of moths was similar. Farms with mature trees in their hedgerows had a higher species diversity of moths than farms without hedgerow trees (data presented as model results). However, the abundance of moths was similar between hedgerows with (25–27 individuals) and without (22 individuals) trees. Three permanent sampling sites were established >100 m apart and >50 m from hedgerow intersections at each of 16 farms. Farms were divided between four experimental groups: sampling in a 6-m-wide perennial grass margin adjacent to a mature (>15 m high) hedgerow tree, sampling in a standard 1-m margin adjacent to a hedgerow tree, sampling in a 6-m margin not adjacent to a hedgerow tree, and sampling in a 1-m margin not adjacent to a hedgerow tree. All farms were sampled once during each of 11 discrete fortnightly periods from mid-May to mid-October 2006 using standardized moth traps.

A replicated, site comparison study in 2001–2005 in 63 hedgerows and woodland edges in an agricultural landscape in Flanders, Belgium (7) found that hedgerows with scalloped edges contained more brown hairstreak *Thecla betulae* eggs than hedgerows with straight borders. There were twice as many brown hairstreak eggs on blackthorn *Prunus spinosa* bushes in scalloped hedgerows than in straight hedgerows (data presented as model results). In addition, more eggs were present on hedgerows lower than 1.5 m than on taller hedgerows (data presented as model results). Hedgerows and woodland edges (1–250 m long, 2,260 m total) containing blackthorn were divided into 10-m sections (338 hedgerow sections), and categorized as "scalloped", "oval", "boxed" or "with gaps" (exact descriptions not provided). Each winter from 2001–2005, all blackthorn bushes were systematically searched for brown hairstreak eggs.

A replicated, site comparison study in 2008 in five arable fields in Oxfordshire, UK (8, same experimental set-up as 5, 6, 9, 13) found that field margins next to hedgerow trees had a higher overall abundance of most shrub- and tree-feeding moth species than margins away from hedgerow trees, but the same was not the case for grass- and herb-feeding moth species. Margins of either 2 m or 6 m next to an area of hedgerow containing at least one tree had a higher abundance of 11 of 13 shrub- and tree-feeding moths than margins without a hedgerow tree, but the presence of hedgerow trees did not affect the abundance of grass- and herb-feeding moths (data presented as model results). The other two species of shrub- and tree-feeding moths (scalloped oak *Crocallis elinguaria* and buff tip *Phalera bucephala*) had similar abundance in margins next to and away from hedgerow trees. The five arable fields selected were enclosed with hedgerows containing trees. Two fields had 6-m-wide perennial grass margins and three had <2-m-wide margins. Four sampling points >100 m apart were selected/field, with two/field being 5 m from the trunk of a hedgerow tree. Thus there were four experimental groups: a 6-m-wide margin adjacent to a tree, a <2-m margin adjacent to a tree, a 6-m margin not adjacent to a tree, and a <2-m margin not adjacent to a tree. Between dusk and dawn on 33 nights between 9 June and 19 July 2008 moths were caught (at 10 points/night) using standardized light traps, identified on the morning after capture, marked and released. Counts/treatment not stated.

A replicated, site comparison study in 2006–2008 on four arable farms in Oxfordshire, UK (9, same experimental set-up as 5, 6, 8, 13) found that field margins next to hedgerow trees had more pale shining brown moths *Polia bombycina* than margins without hedgerow trees. The number of individuals caught in margins next to hedgerow trees (1.0–1.3 individuals/trap) was higher than the number in margins without trees (0.3–0.4 individuals/trap). Four farms were assigned to one of four treatments, based on their most common boundary features: 6-m-wide perennial grass or 1–2-m-wide standard field margins, and with or without hedgerow trees (>15 m high, mostly pedunculated oak *Quercus robur*). From May–October 2006–2008, moths were sampled overnight, once/fortnight, using three 6 W Heath pattern actinic light traps/farm. In June–July 2007 and 2008, at one farm, an additional 8–10 traps were set for 32–33 nights/year, in margins with the same treatments across 4–5 fields (16–20 locations). All traps were 1 m from hedgerows (2–3 m high, 1.5–2.5 m wide), 5 m from trees (if applicable), >50 m from hedgerow intersections, and >100 m apart.

A replicated, site comparison study in 2005–2006 in 10 hedgerows in cattle pastures in Central Pacific Region, Costa Rica (10) found that structurally complex hedges had a higher abundance and species richness of butterflies than simple hedges. In structurally complex hedges, butterfly abundance (321 individuals/hedge) and species richness (37 species/hedge) was higher than in simple hedges (abundance: 235 individuals/hedge; richness: 28 species/hedge). In addition, 24 species were only recorded in complex hedges, including some forest-dependent species, while five species were only recorded in simple hedges, and 46 species were recorded in both hedge types (statistical significance not assessed). Ten hedges (>200 m long) in cattle pastures were studied. Five hedges were structurally complex, with up to 29 tree species (primarily copperwood *Bursera simaruba*, salmwood *Cordia alliodora*, and pink poui *Tabebuia rosea*) of different heights and widths (>6 m wide), and five hedges were simpler (<6 m high and <4 m wide) with smaller and pruned trees (primarily copperwood and pochote *Bombacopsis quinata*, up to 13 species). In 2005, and February–May 2006, butterflies were surveyed for 45 minutes on a 120-m transect along each hedge, four times in the dry season and four times in the rainy season.

A replicated, paired, site comparison study in 2008 on 26 farms in central Scotland, UK (11) found that hedgerows managed under agri-environment schemes (AES) had a similar abundance and species richness of moths to conventionally-managed hedgerows. In AES hedgerows, the abundance (64 individuals) and species richness (25 species) of micro-moths, the abundance (219 individuals) and species richness (33 species) of all macro-moths, and the abundance (26 individuals) and species richness (6 species) of declining macro-moths were all similar to conventionally-managed hedgerows (micro-moths: 81 individuals, 25 species; all macro-moths: 203 individuals, 32 species; declining macro-moths: 31 individuals, 7 species). In 2004, thirteen farms enrolled in AES, and were paired with 13 similar but conventionally-managed farms, <8 km away. Hedgerows on AES farms had gaps filled, and were managed with restrictions on pesticide use, no mowing of the hedge bottom, and were only cut once every three years with further restrictions on timing. Hedgerows on conventional farms had no management restrictions. From June–September 2008, moths were collected for four hours, on one night/farm, using a 6 W heath light trap located next to one hedgerow on each farm. Paired farms were surveyed on the same night.

A replicated, randomized, paired, controlled study in 2005–2011 on an arable farm in Buckinghamshire, UK (12) found that land managed under an agri-environment scheme, including hedgerow management, had a higher abundance, but not species richness, of butterflies and micro-moths than conventional farming, but there was no difference in abundance or species richness of other moths. Butterfly abundance was higher under enhanced Entry-Level Stewardship (ELS) (5,400 individuals/60 ha) and standard ELS (2,000 individuals/60 ha) than under conventional farming (1,400 individuals/60 ha). Micro-moth abundance was also higher under enhanced ELS (79 individuals) than standard ELS (32 individuals) or conventional farming (20 individuals). However, the abundance of macro-moths and threatened moths was similar under enhanced ELS (macro: 126; threatened: 6 individuals), standard ELS (macro: 79; threatened: 5 individuals) and conventional farming (macro: 79; threatened: 6 individuals). Species richness of all groups was similar under enhanced ELS (macro: 20; micro: 11; threatened: 3 species), standard ELS (macro: 20; micro: 8; threatened: 2 species) and conventional farming (macro: 18; micro: 5; threatened: 2 species) (butterfly data not presented). In 2005, a 1,000-ha farm was divided into five 180-ha blocks. Three 60-ha areas/block were assigned to three treatments: enhanced ELS (5% land removed from production, hedges cut every two years); standard ELS (1% land removed from production, hedges cut every two years);

conventional (hedges cut annually) (see paper for other details). From May–August 2006–2011, butterflies were recorded four times/year on one 50-m transect/60-ha area, passing through all available habitats. In late-May 2007–2011 and late-July 2006–2011 moths were surveyed using Robinson light traps. One block was surveyed/night, with one trap/treatment.

A replicated, site comparison study in 2006–2009 on 16 arable farms in Oxfordshire, UK (13, same experimental set-up as 5, 6, 8, 9) found that field margins next to hedgerow trees had a higher species richness, but not abundance, of macro-moths than margins away from hedgerow trees. The species richness of macro-moths in margins next to hedgerow trees (105 species) was higher than in margins next to hedgerows without trees (92 species), but abundance was similar (data not presented). Sixteen farms were categorized to one of four treatments, based on their most common agri-environment scheme habitat: extended 6-m-wide or standard 1-m-wide field margins, and with or without hedgerow trees (>15 m high, mostly pedunculated oak *Quercus robur*). All margins were well-established perennial grass strips, cut once every 2–3 years, ungrazed and unfertilized. From May–October 2006–2009, moths were sampled 40 times (once/fortnight), using three 6 W Heath pattern actinic light traps/farm. Traps were 1 m from hedgerows (2–3 m high, 1.5–2.5 m wide), 5 m from trees (if applicable), >50 m from hedgerow intersections, >100 m apart, and operated from dawn to dusk. Three farms (nine traps) were sampled/night.

A replicated, randomized, paired, controlled study in 2005–2011 in a field in Cambridgeshire, UK (14) found that hedges cut in winter, or less frequently in autumn, had more concealed moth caterpillars than hedges cut annually in autumn, but cutting did not affect the number of free-living caterpillars or total species richness. The abundance of concealed caterpillars on hedges cut in winter (8.5–9.9 individuals/plot), or every three years in autumn (10.5 individuals/plot) was higher than on hedges cut annually in autumn (7.5 individuals/plot). The abundance of free-living caterpillars did not vary with the timing or frequency of cutting (data not presented). The total number of moth species on hedges cut in winter (3.8 species/plot) was similar to hedges cut in autumn (3.0 species/plot), and was similar between different cutting frequencies (data not presented). In 2005, three hedgerows were divided into 32 contiguous, 15-m-long plots, and randomly assigned to two treatments: cut every one, two or three years, and cut in September or January/February. Annually cut treatments were replicated eight times, and other treatments were replicated four times. From May–July 2011, caterpillars were sampled monthly in two ways. All caterpillars and mined leaves within a 1 × 0.5 m square (placed 1.5 m high, 5- and 10-m along each plot) were collected for three minutes. A 2-m section of guttering was placed through the hedge (0.8 m high, two locations/plot), and the vegetation above struck three times with a pole. Caterpillars were reared in the lab for identification, and empty leaf mines and cases were identified. Species were classified as "free-living" caterpillars which feed on the outside of leaves, and "concealed" species which mine leaves or form protective cases from them.

A replicated, randomized, paired, controlled study in 2010–2013 on five farms in Oxfordshire, Buckinghamshire and Devon, UK (15, same experimental set-up as 17) found that hedges which were cut in autumn, or once every three years, had a higher abundance of moth caterpillars and pupae than hedges cut in winter or every year, and hedges cut to allow incremental growth had a greater species diversity but similar abundance of moth caterpillars and pupae to hedges cut to a standard size. Over three years, the total abundance of caterpillars and pupae on hedges cut in winter (8–12 individuals/plot) was higher than on hedges cut in autumn (6–10 individuals/plot), and the abundance on hedges cut once every three years was higher than on hedges cut annually (data used in analysis not presented). The diversity of species on hedges cut to allow incremental growth was greater than on hedges cut to a standard size (data presented as statistical result), but abundance was similar (incremental: 7–12 individuals/plot; standard: 6–10 individuals/plot). See paper for further details. In January–February 2010, three 260-m-long hedges on each of five farms were cut. From September 2010, each hedge was divided into twelve 20-m sections, to which each combination of three sets of management options were applied for three years: cut once every one, two or three years; cut in September or January/February; and cut to the same dimensions or with the cutting bar raised by 10 cm on each successive cut to allow incremental growth. In May 2011–2013, caterpillars and pupae were sampled by inserting guttering (2 m × 11.2 cm) through each hedge, 80 cm above ground, at 5, 10 and 15 m along each plot, and beating the vegetation. Caterpillars and pupae were reared until emerging adults could be identified.

A replicated, site comparison study in 2014–2015 in 44 sites in a mixed farming region in Lombardy, Italy (16) found that hedgerows which were kept between 1 and 2 m tall had a higher species richness of butterflies than shorter hedgerows, but that hedgerows less than 1 m tall had a higher abundance of butterflies than hedgerows over 2 m tall. The species richness of butterflies was higher on hedgerows which were 1–2 m tall than on hedgerows which were less than 1 m tall (data presented as model results). However, the abundance of butterflies was higher on hedgerows which were <1 m tall than on hedgerows which were >2 m tall (data presented as model results). See paper for details on individual species groups. Hedgerows were divided into four height categories (<1 m, 1–2 m, 2–3 m, >3 m). From April–September 2014–2015, butterflies were surveyed along 44 transects, divided into 8–26 × 50-m sections. In 2014, thirty transects were surveyed once/month, and in 2015 fourteen different transects were surveyed twice/month. Only transect sections along hedgerows were included (number not specified).

A replicated, randomized, paired, controlled study in 2010–2015 on a farm in Devon, UK (17, same experimental set-up as 15) found that hedges which were cut once every two or three years in autumn, and allowed to increase in size with each successive cut, had more brown hairstreak *Thecla betulae* eggs than hedges cut every year, in winter or to a standard size. Over four years, the total abundance of eggs on hedges cut to allow incremental growth (5–12 eggs) was higher than on hedges cut to a standard size (2–6 eggs). When cut in autumn, there were more eggs on hedges cut once every three years (6–12 eggs) than on hedges cut every year (2–6 eggs). Hedges cut once every two (3–11 eggs) or three (6–12 eggs) years in autumn had more eggs than hedges cut every two (3–5 eggs) or three (3–6 eggs) years in winter. Hedges which were not cut for five years had a total of 5 eggs on average. In January–February 2010, three 195-m-long hedges were cut. From

September 2010, the hedges were divided into thirteen 15-m sections, to which each combination of three sets of management options were applied for five years: cut once every one, two or three years; cut in September or January/February; and cut to the same dimensions or with the cutting bar raised by 10 cm on each successive cut. A section at the end of each hedge was left uncut throughout the experiment. In February–March 2012–2015, brown hairstreak eggs were surveyed by searching all blackthorn stems and shoots in the central 10 m of each hedge section for 20 minutes on each side of the hedge.

(1) Sotherton N.W., Wratten S.D., Price S.B. & White R.J. (1981) Aspects of hedge management and their effects on hedgerow fauna. *Zeitschrift Fur Angewandte Entomologie-Journal of Applied Entomology*, 92, 425–432.
(2) Sparks T. H. & Parish T. (1995) Factors affecting the abundance of butterflies in field boundaries in Swavesey fens, Cambridgeshire, UK, *Biological Conservation*, 73(3), 221-227.
(3) Dover J.W., Sparks T.H. & Greatorex-Davies J.N. (1997) The importance of shelter for butterflies in open landscapes. *Journal of Insect Conservation*, 1, 89–97.
(4) Maudsley M.J., Marshall E.J.P. & West T.M. (2000) Guidelines for hedge management to improve the conservation value of different types of hedge. Defra report.
(5) Merckx T., Feber R.E., Dulieu R.L., Townsend M.C., Parsons M.S., Bourn N.A.D., Riordan P. & Macdonald D.W. (2009a) Effect of field margins on moths depends on species mobility: field-based evidence for landscape-scale conservation. *Agriculture, Ecosystems & Environment*, 129, 302–309.
(6) Merckx T., Feber R.E., Riordan P., Townsend M.C., Bourn N.A.D., Parsons M.S. & Macdonald D.W. (2009b) Optimizing the biodiversity gain from agri-environment schemes. *Agriculture, Ecosystems & Environment*, 130, 177–182.
(7) Merckx T. & Berwaerts K. (2010) What type of hedgerows do Brown hairstreak (Thecla betulae L.) butterflies prefer? Implications for European agricultural landscape conservation. *Insect Conservation and Diversity*, 3, 194–204.
(8) Merckx T., Feber R.E., Mclaughlan C., Bourn N.A.D., Parsons M.S., Townsend M.C., Riordan P., Macdonald D.W. (2010) Shelter benefits less mobile moth species: The field-scale effect of hedgerow trees. *Agriculture, Ecosystems & Environment*, 138(3-4), 147-151.
(9) Merckx T., Feber R.E., Parsons M.S., Bourn N.A.D., Townsend M.C., Riordan P. & Macdonald D.W. (2010) Habitat preference and mobility of *Polia bombycina*: are non-tailored agri-environment schemes any good for a rare and localised species? *Journal of Insect Conservation*, 14, 499–510.
(10) Tobar D.E. & Ibrahim M. (2010) Do live fences help conserve butterfly diversity in agricultural landscapes? *Revista De Biologia Tropical*, 58, 447–463.
(11) Fuentes-Montemayor E., Goulson D. & Park K.J. (2011) The effectiveness of agri-environment schemes for the conservation of farmland moths: assessing the importance of a landscape-scale management approach. *Journal of Applied Ecology*, 48, 532–542.
(12) Heard M.S., Botham M., Broughton R., Carvell C., Hinsley S., Woodcock B., Pywell R.F., Amy S., Bellamy P.E., Hill R.A., Hulmes S., Hulmes L., Meek W.R., Nowakowski M., Peyton J., Redhead J.W., Shore R.F. & Turk A. (2011) Quantifying the effects of Entry Level Stewardship (ELS) on biodiversity at the farm scale: the Hillesden Experiment. *Natural England report*, RP00026.
(13) Merckx T., Marini L., Feber R.E. & Macdonald D.W. (2012) Hedgerow trees and extended-width field margins enhance macro-moth diversity: implications for management. *Journal of Applied Ecology*, 49, 1396–1404.
(14) Facey S.L., Botham M.S., Heard M.S., Pywell R.F. & Staley J.T. (2014) Moth communities and agri-environment schemes: Examining the effects of hedgerow cutting regime on diversity, abundance, and parasitism. *Insect Conservation and Diversity*, 7, 543–552.
(15) Staley J.T., Botham M.S., Chapman R.E., Amy S.R., Heard M.S., Hulmes L., Savage J. & Pywell R.F. (2016) Little and late: How reduced hedgerow cutting can benefit Lepidoptera. *Agriculture, Ecosystems & Environment*, 224, 22–28.

(16) Luppi M., Dondina O., Orioli V. & Bani L. (2018) Local and landscape drivers of butterfly richness and abundance in a human-dominated area. *Agriculture, Ecosystems & Environment*, 254, 138–148.
(17) Staley J.T., Botham M.S., Amy S.R., Hulmes S. & Pywell R.F. (2018) Experimental evidence for optimal hedgerow cutting regimes for Brown hairstreak butterflies. *Insect Conservation and Diversity*, 11, 213–218.

3.5. Plant new hedges

- **Seven studies** evaluated the effects of planting new hedges on butterflies and moths. Five studies were in the UK[1–3,5,7] and one was in each of Ireland[4] and Canada[6].

COMMUNITY RESPONSE (5 STUDIES)

- **Richness/diversity (5 studies):** Three of four site comparison studies (including three replicated and three paired studies) in the UK[1,2], Ireland[4] and Canada[6] found that established hedgerows had a higher species richness of butterflies[2,4] and macro-moths[6] than in-field beetle banks[2], crops[4,6] or pasture[4]. The other study found that hedgerows had a similar species richness of butterflies to grass banks between fields[1]. One replicated study in the UK[3] found that gorse, oak and blackthorn planted within hedgerows had more species of arthropods, including caterpillars, than more commonly planted hawthorn.

POPULATION RESPONSE (6 STUDIES)

- **Abundance (6 studies):** Five of six studies (including one replicated, controlled study, three paired, site comparison studies and two site comparison studies) in the UK[1,2,5,7], Ireland[4] and Canada[6] found that the abundance of butterflies[2,4], moths[7], macro-moths[6] and gatekeepers[5] was higher along hedgerows than on beetle banks[2], grass margins without hedgerows[5], in field interiors[4,6], or 5–10 metres away from hedgerows[7].The other study found that the abundance of butterflies along hedgerows was similar to grass banks between fields without hedgerows[1].

BEHAVIOUR (1 STUDY)

- **Behaviour change (1 study):** One site comparison study in the UK[7] found that moths recorded close to hedgerows were more likely to be flying parallel to it than moths recorded further away.

Background

Hedgerows provide important semi-natural habitat within farmland, offering food and shelter in their own right, as well as connectivity between other patches of semi-natural habitat, such as woodland. Hedgerows also reduce the temperature fluctuations experienced in open farmland, which may facilitate greater species survival or movement through the landscape. The presence of hedgerows in an agricultural landscape has been found to increase both the abundance and species richness of butterflies recorded (Luppi *et al.* 2018), therefore planting new hedgerows may help butterfly and moth populations on farmland to recover.

For studies on managing existing hedgerows, see "*Manage hedgerows to benefit wildlife (e.g. no spray, gap-filling and laying)*".

Luppi M., Dondina O., Orioli V. & Bani L. (2018) Local and landscape drivers of butterfly richness and abundance in a human-dominated area. *Agriculture, Ecosystems & Environment*, 254, 138–148.

A replicated, site comparison study in 1987–1988 and 1997 on two arable farms in England, UK (1) found that hedgerows did not have a higher abundance or species richness of butterflies than grass banks between fields. At one farm in 1987–1988, the abundance and species richness of butterflies was similar along hedgerows (abundance: 9–12 butterflies/100 m; richness: 11–13 species) and grass banks (abundance: 5–8 butterflies/100 m; richness: 7–9 species). In 1997, at a second farm, the abundance and species richness of butterflies was similar along hedgerows (abundance: 10 butterflies/100 m; richness: 1.5 species) and grass banks (abundance: 6 butterflies/100 m; richness: 1.1 species). At a farm in Hampshire, from May–September, butterflies were surveyed 13 times along four hedgerows and three grass banks in 1987, and 10 times along eight hedgerows and four grass banks in 1988. At a farm in Cheshire, from July–August 1997, butterflies were surveyed five times along 16 hedgerows and 12 grass banks.

A replicated, paired, site comparison study in 1999 on five farms in the UK (2) found that the abundance and species richness of butterflies was higher along hedgerows than on beetle banks established in the centre of fields. Along hedgerows both the abundance (2–6 individuals/transect) and species richness (1–3 species/transect) of adult butterflies were higher than on beetle banks (abundance: 1–2 individuals/transect; richness: 0.5–2 species/transect). A total of 19 species from four families were recorded along hedgerows, compared to 12 species from three families on beetle banks. Adult butterflies were recorded on 82 transects along hedgerows and beetle banks on five farms in June, July and August 1999.

A replicated study in 1996–1999 on semi-upland farmland in mid-Wales, UK (3) found that seven species planted in two hedgerows supported different numbers of arthropods, including moths and butterflies. The number of arthropods (e.g. insects) recorded differed between hedgerow species: common gorse *Ulex europaeus* (1,007 arthropods), sessile oak *Quercus petraea* (436), blackthorn *Prunus spinosa* (381), hawthorn *Crataegus monogyna* (258), silver birch *Betula pendula* (180), rowan *Sorbus aucuparia* (110) and ling heather *Calluna vulgaris* (53). Sessile oak supported the most diverse group in terms of arthropod orders, with 13 out of 15 orders recorded, two of which were not found on any other plant species. Hawthorn and common gorse were the next most diverse, each with one unique arthropod order. Common gorse, sessile oak, blackthorn and rowan between them had representatives of all 27 families of moths and butterflies (Lepidoptera), beetles (Coleoptera) and true bugs (Hemiptera) recorded in the study. Planting was undertaken in 1996 within the fenced (2 m wide) margins of two fields. Margins were divided into eight 6-m plots, which were planted with a double row of 30–40 plants of each species, replicated across three blocks. Arthropods were sampled by tree beating at five points/plot in June, August and September 1998–1999.

A paired, site comparison study in 2002 on one arable and one livestock farm in Ireland (4) reported that a higher abundance and species richness of butterflies was found along hedgerows than in field interiors. Results were not tested for statistical significance. On one farm, 13 butterflies of 7 species were recorded along a hedgerow transect next to arable fields, compared to 2 butterflies of 2 species in an arable field interior. On the other farm, 6 butterflies of 3 species were recorded along a hedgerow transect next to pasture fields, compared to 0 butterflies in a pasture field interior. From April–September 2002, one arable farm was surveyed seven times, and one livestock farm with improved grassland was surveyed 10 times. Butterflies were surveyed along four 250-m transects, one along a hedgerow and one through a field interior on each farm.

A replicated, controlled study in 1996–2000 on three arable farms in Essex, UK (5) found that gatekeepers *Pyronia tithonus* were more abundant on grass margins and cropped field edges next to hedgerows than on grass margins without hedgerows. Gatekeepers were more abundant on sown grass margins next to hedgerows (11.9 individuals/km) and on cropped field edges with hedgerows (0.7–17.3 individuals/km) than on sown grass margins without hedgerows (0.2 individuals/km). Eleven grass margins (2 m wide, 141–762 m long) were established in October 1996–2000 by sowing one of three seed mixtures containing 4–6 grass species next to 100–467 m of existing hedgerow. Two grass margins (2 m wide, 285 m long) were established on field edges without hedgerows. Three further field edges without margins (one on each farm, 133–343 m long) had 100–300 m of existing hedgerow. Gatekeeper abundance was monitored weekly along each grass margin and cropped edge in July and August 1997–2000.

A replicated, paired, site comparison study in 2001 on 16 arable farms in Ontario, Canada (6) found that woody hedgerows supported a higher abundance and species richness of macro-moths than crop fields. Along hedgerows, both the total abundance (80–418 individuals/trap) and species richness (13–26 species/trap) of moths were higher than in the centre of crop fields (abundance: 40–135 individuals/trap; richness: 8–17 species/trap). Of 126 species collected only once, 78 were found along hedgerows compared to 48 in crop fields (statistical significance not assessed). See paper for species results. Sixteen woody hedgerows (184–203 m long, 10–16 m wide, 18–21 m tall) and their adjacent arable fields were selected on eight organic farms (no chemical inputs for ≥3 years) and eight conventional farms (chemical fertilizers and herbicides applied). Hedgerows were trimmed when too wide, and dead trees were removed. From June–September 2001, macro-moths were sampled on six nights/site. Each night, one fluorescent UV black-light funnel trap was set halfway along a hedge, and one was set ~50 m away in the middle of the adjacent crop field. Two organic and two conventional farms were sampled each night, and all sites were sampled within five nights every two weeks.

A site comparison study in 2011–2013 on a mixed farm in Northamptonshire, UK (7) found that the abundance of moths was higher close to hedgerows than further away. The number of moths recorded 1 m from a hedgerow (225 individuals) was higher than the number recorded 5 m (73 individuals) or 10 m (34 individuals) away. Moths observed 1 m from a hedge were more likely to be moving along it (156 individuals) than at right angles (13 individuals) or diagonal (19 individuals) to it, whereas this was not the case for moths recorded 5 or 10 m from the hedge (5 m: along = 30, right angle = 18, diagonal = 11 individuals; 10 m:

along = 9, right angle = 11, diagonal = 10 individuals). Across a 600-ha predominantly arable farm, most hedgerows were cut and not laid, but the condition varied from thick and managed to gappy and derelict. On warm nights (>5°C) between May and July 2011–2013, moths were observed for 15 minutes at each of 1, 5 and 10 m away from 13 different hedgerows. The number of moths, and the direction of flight of each individual, was recorded.

(1) Dover J., Sparks T., Clarke S., Gobbett K. & Glossop S. (2000) Linear features and butterflies: the importance of green lanes. *Agriculture Ecosystems & Environment*, 80, 227–242.
(2) Thomas S.R., Goulson D. & Holland J.M. (2000) The contribution of beetle banks to farmland biodiversity. *Aspects of Applied Biology*, 62, 31–38.
(3) Hayes M.J., Jones A.T., Sackville Hamilton N.R., Wildig J. & Buse A. (2001) Hedgerows of the World: Their Ecological Functions in Different Landscapes. *10th Annual Conference of the International Association for Landscape Ecology*, Birmingham, UK, 339.
(4) Bracken F. (2004) The diversity of birds and butterflies in Irish lowland landscapes with special reference to the effects of set-aside management on birds in the breeding season. PhD thesis. University College Dublin. Chapter 4: The diversity of butterflies in different habitat types, pp 147–194.
(5) Field R.G. & Mason C.F. (2005) The utilization of two-metre Countryside Stewardship Scheme grass margins by the gatekeeper *Pyronia tithonus* (L). *Journal of Natural History*, 39, 1533–1538.
(6) Boutin C., Baril A., McCabe S.K., Martin P.A. & Guy M. (2011) The Value of Woody Hedgerows for Moth Diversity on Organic and Conventional Farms. *Environmental Entomology*, 40, 560–569.
(7) Coulthard E., McCollin D. & Littlemore J. (2016) The use of hedgerows as flight paths by moths in intensive farmland landscapes. *Journal of Insect Conservation*, 20, 345–350.

3.6. Manage ditches to benefit butterflies and moths

- We found no studies that evaluated the effects on butterflies and moths of managing ditches to benefit butterflies and moths.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Well-managed ditches running between agricultural fields could provide important resources to butterflies and moths, including food, shelter, and water or mud, as well as connectivity between other semi-natural habitat patches across the landscape.

3.7. Protect in-field trees

- One study evaluated the effects of protecting in-field trees on butterflies and moths. The study was in Sweden[1].

COMMUNITY RESPONSE (1 STUDY)

- **Richness/diversity (1 study):** One replicated, site comparison study in Sweden[1] found that where more trees and trees of more species had been retained in pastures, butterfly species richness was higher, but richness was lower when a high proportion of those trees were large.

POPULATION RESPONSE (0 STUDIES)

BEHAVIOUR (0 STUDIES)

Background

Within open farmland, protecting remnant habitat features which provide vertical structure, such as in-field trees or forest fragments, may provide pockets of resources to butterflies and moths. In some cases, this may be enough to support small, transient populations, but it may also provide important stepping stones which allow individuals to move through an otherwise hostile landscape.

For studies on planting new trees, see "*Plant in-field trees (e.g. copses)*".

A replicated, site comparison study in 1997 in 20 pastures in the Uppsala region, Sweden (1) found that where more trees and trees of more species had been retained in pastures, butterfly species richness was higher, but richness was lower when a high proportion of those trees were large. There was higher butterfly species richness in pastures with more trees and with more species of tree. However, there was lower species richness when a greater proportion of the trees were large (>30 cm diameter at breast height). All data presented as model results. Butterflies were surveyed along the borders of a 100 m^2 square walking transect in 20 grazed semi-natural pastures, repeated 18 times/pasture in July 1997. Tree cover was assessed using maps, aerial photos and field surveys, and tree species and diameter were assessed in the field.

(1) Söderström B., Svensson B., Vessby K. & Glimskär A. (2001) Plants, insects and birds in semi-natural pastures in relation to local habitat and landscape factors. Biodiversity and Conservation, 10, 1839-1863.

3.8. Plant in-field trees (e.g. copses)

- We found no studies that evaluated the effects of planting in-field trees on butterflies and moths.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Intensively farmed areas have often lost much of their natural habitat structure, such as woodland, which would provide shelter, resources and structural variation for butterflies and moths. One option for encouraging species back on to farmland is the creation of small areas of woodland – or copses – within or at the edge of farmed land.

For studies on protecting existing trees, see "*Protect in-field trees*".

3.9. Provide or retain set-aside areas in farmland

- **Nine studies** evaluated the effects of providing or retaining set-aside areas in farmland on butterflies and moths. Three studies were in the UK[1,3,5], and one was in each of Germany[2], Ireland[4], Switzerland[6], Hungary[7], Finland[8] and the USA[9].

COMMUNITY RESPONSE (5 STUDIES)

- **Community composition (1 study):** One replicated, site comparison study in Germany[2] found that butterfly communities in older set-aside fields included species which were less migratory, spent longer as caterpillars, and had fewer generations/year than species found in newer set-aside fields.
- **Richness/diversity (5 studies):** Three of four replicated studies (including one randomized, controlled study and three site comparison studies) in Germany[2], Ireland[4], Hungary[7] and Finland[8] found that sown[7,8] or naturally regenerating[2] set-aside had a greater species richness of butterflies[2,7,8] and day-flying moths[8] than cereal fields or pasture, especially when the set-aside was sown with less competitive grasses[8]. One of these studies found a higher species richness of butterflies and day-flying moths in second-year set-aside than in first-year set-aside[8], but another found no difference in butterfly species richness between 1–3-year-old set-aside[7]. The other study found that set-aside fields had a similar species richness of butterflies and moths to arable and pasture fields[4]. One replicated, site comparison study in the USA[9] found that set-aside fields had a similar species richness of butterflies to native prairies.

POPULATION RESPONSE (8 STUDIES)

- **Abundance (8 studies):** Two of five replicated studies (including one randomized, controlled study and four site comparison studies) in the UK[1,3], Ireland[4], Hungary[7] and Finland[8] found that the abundance of butterflies[7,8] and day-flying moths[8] in sown set-aside was higher than in cereal fields, especially when the set-aside was sown with less competitive grasses[8]. One of these studies found a higher abundance of butterflies and day-flying moths in second-year set-aside than in first-year set-aside[8], but another found no difference in butterfly abundance between 1–3-year-old set-aside[7]. The other three studies found that fallow[1,4] and stubble[3] set-aside had a similar abundance of adult butterflies[4] and butterfly and moth caterpillars[1,3] to arable fields[1,3,4] and pasture[4]. Two site comparison studies (including one replicated study) in the UK[5] and Switzerland[6] found that set-aside fields had a similar abundance of butterfly and moth adults[6] and caterpillars[5,6] to uncultivated field boundaries[5] and extensively farmed land[6]. One replicated, site comparison study in the USA[9] found that set-aside fields had a similar abundance of butterflies to native prairies in their first year, but a lower abundance of butterflies thereafter.

BEHAVIOUR (0 STUDIES)

Background

Within the farmed landscape, fields are sometimes temporarily left uncultivated (or "set-aside") for one or more years to allow the soil to recover, when the land is not required for production. Set-aside land may be left with the standing stubble of the previous crop, ploughed in and left fallow to allow natural regeneration, or sown with non-crop species such as lacy phacelia *Phacelia tanacetifolia* to encourage insect pollinators, including butterflies and moths (Steffan-Dewenter & Tscharntke 1997).

For studies of long-term or permanent set-aside, see "*Restore arable land to permanent grassland*".

Steffan-Dewenter I. & Tscharntke T. (1997) Early succession of butterfly and plant communities on set-aside fields. *Oecologia*, 109, 294–302.

A replicated, site comparison study in 1990–1991 on five arable farms in Hampshire and Wiltshire, UK (1) found that the abundance of caterpillars was similar on fallow set-aside and wheat fields. The number of caterpillars of butterflies, moths and sawflies (Lepidoptera and Symphyta combined) was not significantly different on set-aside (0.4 individuals/sample) and wheat fields (0.7 individuals/sample). A total of 44 fields on five farms in the first year of the UK's five-year set-aside scheme (left fallow or drilled with grass) were sampled in June 1990. In 1991, fifteen fields at two of the farms were re-sampled to evaluate second-year fallow set-aside. Caterpillars were collected using a D-Vac suction sampler in the headlands of fields, 3 m from the field edge. Five samples of 0.5 m^2 were taken at each site.

A replicated, site comparison study in 1992 in agricultural land in Baden-Württemberg, Germany (2) found that naturally regenerated set-aside had a higher species richness of butterflies than either set-aside sown with lacy phacelia *Phacelia tanacetifolia* or cereal crops, and that butterfly species composition changed with set-aside age. Butterfly species richness was higher in naturally regenerated set-aside (11–13 species) than in sown set-aside (7 species) or cereal crops (4 species), but lower than in old meadows (20 species). Species richness did not differ with set-aside age (11–13 species), but species composition did. Butterfly species found in older set-aside tended to be less migratory, spend longer as caterpillars (1-year-old: 61 days; 4-years-old: 105 days), and have fewer generations/year (1-year-old: 2.5 generations/year; 4-years-old: 1.9 generations/year). In 1992, four fields in each of seven management types were studied: former cereal fields left to naturally develop as set-aside for each of 1, 2, 3 and 4 years, 1-year-old set-aside sown with lacy phacelia, old meadows (>30 years old), and cereal fields (rye *Secale cereale* or wheat *Triticum aestivum*). Set-aside fields and old meadows were mown once/year in July. From May–October 1992, butterflies were counted along transects nine times/field.

A replicated, paired, site comparison study on 30 arable farms in southern and eastern England, UK (3) found that stubble set-aside fields had a similar abundance of caterpillars to wheat fields. The number of caterpillars of butterflies, moths and sawflies (Lepidoptera and Tenthredinidae combined; 0.2–0.5 individuals/sample) did not differ between set-aside and wheat fields. Additionally, cutting set-aside (to 10–15 cm) tended to decrease invertebrate numbers (including Lepidoptera) compared to topping it (to 25 cm) or leaving it uncut (data not presented). Set-aside fields were naturally regenerated after harvest. Wheat fields received pesticides. Invertebrates were sampled using a D-Vac suction sampler in 51 set-aside fields and 51 adjacent wheat fields on 30 farms in June–July (year not given).

A replicated, site comparison study in 2002 in 12 fields in County Laois and County Kildare, Ireland (4) found that set-aside did not support a higher abundance or species richness of butterflies than arable crop or pasture fields. The abundance of butterflies was similar in set-aside fields (16.3 individuals), arable crop (15.5 individuals) and pasture (14.5 individuals). The species richness of butterflies was also similar in set-aside (6 species), arable crop (4 species) and pasture (6 species) fields. See thesis for abundance of individual species. Four fields of each of three farmland habitats, set-aside, arable crop and cattle-grazed pasture, were studied. Set-aside fields were non-rotational, and had been out of production for at least three years. Set-aside and arable crop fields were paired close to each other on the same farms. From April–September 2002, butterflies were surveyed seven times along one 250-m transect in each field.

A replicated, site comparison study of 31 rotational set-aside fields in England, UK (5) found that caterpillar abundance was similar in set-aside fields and uncultivated field boundaries. The number of butterfly and moth caterpillars was similar in set-aside fields and uncultivated field boundaries (data not presented). Caterpillars were sampled in the uncultivated field boundary (0 m) and at 3 m and 50 m in to each of 31 rotational set-aside fields in mid-May (year not given).

A site comparison study in 1999–2000 in two agricultural regions in Geneva and Valais, Switzerland (6) found that sites within an intensively cultivated region with set-aside areas had a similar abundance and biomass of butterflies and moths to a traditional, extensively cultivated region. The abundance and biomass of adult butterflies and moths (abundance: 5.2 individuals/site; biomass: 6.9 mg/site) and caterpillars (abundance: 2.4–2.8 individuals/site; biomass: 23.1–28.3 mg/site) in set-aside strips in an intensively farmed landscape was not significantly different from sites in an extensively farmed landscape (adults: 1.5 individuals/site, 3.9 mg/site; caterpillars: 1.5–2.3 individuals/site, 3.9–57.6 mg/site). From 1991–1998, a total of 83 set-aside strips (10-m wide, totalling 19 ha) were established across one 500-ha agricultural region. A second, 360-ha region was extensively cultivated. Between March and September 1999 and 2000, grass-dwelling arthropods (including butterflies, moths and caterpillars) were surveyed by hand-netting along 30-m transects at each of five locations within set-aside strips in an intensive arable region, and six locations along irrigation canals and ditches in an extensively farmed region. Ground-dwelling arthropods (including caterpillars) were sampled for seven days using 15 pitfall traps next to each transect.

A replicated, site comparison study in 2008 in a mixed farming region in Hungary (7) found that sown set-aside fields had a higher abundance and species richness of butterflies than cereal fields, and this did not change with set-aside age. In set-aside fields both the abundance (28–33 individuals/field) and species richness (7–9 species/field) of butterflies were higher than in winter wheat fields (abundance: 4 individuals/field; richness: 2 species/field). There was no difference between 1-, 2- and 3-year-old set-aside fields (see paper for details). See paper for details of individual species. Seventeen set-aside fields were sown with one legume and two grass species in autumn 2005–2007, had no chemicals applied, and were mown once/year in June. Sixteen winter wheat fields were fertilized (70 kg/ha/year nitrogen), sprayed once/year in spring with herbicide and insecticide, and harvested in June. From May–August 2008, butterflies were surveyed on fixed transects four times in each field. Each field was surveyed for 10, 20 or 30 minutes, depending on field size.

A replicated, randomized, controlled study in 2003–2004 in an arable field in Jokioinen, Finland (8) found that second-year set-aside plots sown with less competitive grasses had a higher abundance and species richness of butterflies and day-flying moths than first-year set-aside or second-year set-aside sown with competitive grasses. On set-aside plots sown the previous year with less competitive grasses, both the abundance (30 individuals/1,000 m) and species richness (4.2 species/plot) of butterflies and day-flying moths were higher than in plots sown with competitive grasses (5 individuals/1,000 m; 0.7 species/plot) or plots sown that spring with competitive (2 individuals/1,000 m; 0.5 species/plot) or less competitive grasses (3 individuals/1,000 m; 0.7 species/plot). However, there was no significant difference from plots where competitive (9 individuals/1,000 m; 2.0 species/plot) or less competitive (21 individuals/1,000 m; 2.9 species/plot) grasses had been sown under the crop in the previous year, or from stubble fields (17 individuals/1,000 m; 4.2 species/plot). No butterflies or moths were recorded in cereal plots. In 2003, a 16.5-ha field was divided into four blocks, each containing eight 0.3-ha plots. Plots were assigned to eight treatments: grass mix sown in 2003 and left to develop in 2004, spring barley sown in 2003 followed by grass mix sown in 2004, spring barley sown in 2003 with undersown grass mix which developed in 2004, spring barley sown in 2003 and left as stubble in 2004, and spring barley sown in both years. Two grass mixes, containing more and less competitive species, were used. In June–July 2004, butterflies and day-flying moths were recorded four times, two weeks apart, on one 250-m zig-zag transect through each plot.

A replicated, site comparison study in 2009–2014 in eight farm set-asides and two native prairies in Wisconsin, USA (9) found that set-aside fields sown with grasses and non-woody broadleaved plants (forbs) had a similar number of butterflies to native prairies in the first year, but lower numbers after 2–5 years. For the first year after establishment, set-aside areas had a similar number of butterflies (8–52 butterflies/200 m) to native prairie (5–42 butterflies/200 m). However, 2–5 years after establishment, the number of butterflies on set-aside (5–20 butterflies/200 m) was lower than in native prairie (22–68 butterflies/200 m). The total number of species recorded on set-aside (31 species, of which six were not seen on prairies) was similar to prairie sites (35 species, of which 10 were not seen on set-aside). In spring 2009, fields (average 6.8 ha) on eight farms enrolled in a set-aside program were pre-treated with glyphosate and seeded with a mix of six grasses and 11 forbs using a no-till seed drill. They were compared with two native dry sand prairies in a powerline right-of-way, managed to suppress woody vegetation. From May–August 2009–2012, butterflies were surveyed 2–4 times/year on one 200-m transect/farm. In 2013–2014, just four farms and the two native prairies were surveyed twice/year.

(1) Moreby S.J. & Aebischer N.J. (1992) Invertebrate abundance on cereal fields and set-aside land – implications for wild gamebird chicks. *British Crop Protection Council Monographs*, 50, 181–186.
(2) Steffan-Dewenter I. & Tscharntke T. (1997) Early succession of butterfly and plant communities on set-aside fields. *Oecologia*, 109, 294–302.
(3) Moreby S.J. & Southway S. (2000) Management of stubble-set-aside for invertebrates important in the diet of breeding farmland birds. Aspects of Applied Biology, 62, 39–46.
(4) Bracken F. (2004) The diversity of birds and butterflies in Irish lowland landscapes with special reference to the effects of set-aside management on birds in the breeding season.

PhD thesis. University College Dublin. Chapter 4: The diversity of butterflies in different habitat types, pp 147–194.
(5) Moreby S.J. (2007) Invertebrate distributions between permanent field boundary habitats and temporary stubble set-aside. *Aspects of Applied Biology*, 81, 207–212.
(6) Revaz E., Schaub M. & Arlettaz R. (2008) Foraging ecology and reproductive biology of the Stonechat *Saxicola torquata*: comparison between a revitalized, intensively cultivated and a historical, traditionally cultivated agro-ecosystem. *Journal of Ornithology*, 149, 301–312.
(7) Kovács-Hostyánszki A., Kőrösi Á., Orci K.M., Batáry P. & Báldi A. (2011) Set-aside promotes insect and plant diversity in a Central European country. *Agriculture, Ecosystems & Environment*, 141, 296–301.
(8) Kuussaari M., Hyvönen T. & Härmä O. (2011) Pollinator insects benefit from rotational fallows. *Agriculture, Ecosystems & Environment*, 143, 28–36.
(9) Kleintjes Neff P., Locke C. & Lee-Mäder E. (2017) Assessing a farmland set-aside conservation program for an endangered butterfly: USDA State Acres for Wildlife Enhancement (SAFE) for the Karner blue butterfly. *Journal of Insect Conservation*, 21, 929–941.

3.10. Create uncultivated margins around intensive arable or pasture fields

- **Ten studies** evaluated the effects on butterflies and moths of creating uncultivated margins around intensive arable or pasture fields. Six studies were in the UK[2–7], two were in Sweden[1,8], and one was in each of Finland[9] and Germany[10].

COMMUNITY RESPONSE (9 STUDIES)

- **Richness/diversity (9 studies):** Two of five studies (including four replicated, one randomized, one paired, two controlled and two site comparison studies) in Sweden[1], the UK[4,5,6] and Finland[9], found that uncultivated margins had a lower species richness[4] or diversity[5] of butterflies than margins sown with grasses and non-woody broadleaved plants (forbs)[4] or wildflowers[5]. One other study found that the species richness of butterflies and day-flying moths was higher in permanent uncultivated margins than in sown fallow plots[9], and the other two found that the species richness of butterflies[1,6] and moths[1] was similar in uncultivated and sown margins. Three replicated studies (including one randomized, controlled study and two site comparison studies) in the UK[4,5] and Germany[10] found that uncultivated margins which were not grazed[5] or cut[4,5,10], or were only cut in spring or autumn[4], had a higher species richness of butterflies than margins which were cut in summer. Two site comparison studies (including one replicated study) in the UK[3] and Germany[10] found that the species richness of butterflies was higher in longer[10] or wider[3,10] uncultivated margins than in shorter[10], narrower[10] or conventional width[3] margins. One of two replicated studies (including one controlled study and one site comparison study) in the UK[7] and Finland[9] found that uncultivated margins had a higher species richness of butterflies and day-flying moths than cereal fields[9], but the other found that the species richness of butterflies was similar between regenerating margins and cropped field edges[7]. One replicated, paired, site comparison study in Sweden[8] found that uncultivated margins had a higher species richness of butterflies and burnet moths if they were located closer to existing grassland.

POPULATION RESPONSE (9 STUDIES)

- **Abundance (9 studies):** Six of seven studies (including six replicated, two randomized, four controlled and three site comparison studies) in Sweden[1], the UK[2,4–7] and Finland[9] found that the abundance of butterflies[1,4,5,7] and moths[1], and of adult but not caterpillar meadow brown[2], was lower in uncultivated margins[1,2,4-7] than in margins sown with grasses[7], or grasses and non-woody broadleaved plants (forbs)[1,2,4] or wildflowers[5], or a mixture of grasses and wildflowers[6]. However, one of these studies found that uncultivated margins had similar abundance of butterflies to margins sown with grasses or cereal crop[6]. The other study found that the abundance of butterflies and day-flying moths was higher in permanent uncultivated margins than in sown fallow plots[9]. Two of three replicated, site comparison studies (including two randomized studies) in the UK[2,4,5] found that uncultivated margins which were not cut, or were only cut in spring and autumn, had a higher abundance of butterflies[4], and adult but not caterpillar meadow brown[2], than margins cut in summer. The other study found that margins which were not cut and grazed had a similar abundance of butterflies to margins which were cut and grazed[5]. Two replicated studies (including one controlled study and one site comparison study) in the UK[7] and Finland[9] found that uncultivated margins had a higher abundance of butterflies[7,9] and day-flying moths[9] than cereal fields[9] or cropped field edges[7]. One site comparison study in the UK[3] found that the abundance of butterflies in wide uncultivated margins was higher than in conventional margins. One replicated, paired, site comparison study in Sweden[8] found that uncultivated margins had a higher abundance of butterflies and burnet moths if they were located closer to existing grassland.

BEHAVIOUR (0 STUDIES)

Background

Uncultivated margins around intensive arable or pasture fields may provide refuges for butterflies and moths, where a more diverse plant community can develop to provide shelter and food resources. They may also provide habitat which allows butterflies and moths to move through the farm landscape.

A site comparison study in 1989 on an arable farm in central Sweden (1) reported that uncultivated margins had a lower abundance but similar species richness of butterflies and moths to sown margins. Results were not tested for statistical significance. Over two months, fewer butterflies and moths were recorded in two uncultivated field margins (38–44 individuals) than in two sown margins (58–75 individuals), but the number of species was similar (uncultivated: 7 species; sown: 6 species). Fewer butterflies (24 individuals) of more species (8 species) were recorded in a species-rich pasture. Four existing field margins and a species-rich pasture were compared. Two margins were uncultivated (one with diverse weeds, the other with diverse herbs and grasses on a ditch bank) and two were sown (one with a mixture of legumes dominated by white melilot *Melilota alba*, the other with clover and ley grasses dominated by red clover *Trifolium pratense*). From 19 June–22 August 1989, butterflies and moths were recorded in the morning and evening at each site, three times/week.

A replicated, randomized, controlled study in 1987–1991 in Oxfordshire, UK (2, same experimental set-up as 3, 4) found that unsown field margins had fewer adult meadow brown *Maniola jurtina* than margins sown with wild grasses and non-woody broadleaved plants (forbs), and that margin management affected butterfly numbers. Fewer adult meadow browns were found on unsown, naturally regenerating margins (4–15 butterflies/50 m) than on sown margins (4–52 butterflies/50 m). However, unsown margins had more butterflies if they were left uncut (4–13 butterflies/50 m), or were cut in spring and autumn (7–15 butterflies/50 m), than if they were cut in summer (4–10 butterflies/50 m). There was no difference in the abundance of meadow brown caterpillars between unsown and sown, or uncut and cut, plots (3 caterpillars/plot). There were more meadow browns on all the experimental field margins than on narrow, unmanaged field boundaries of a neighbouring farm (numbers not given). In October 1987, two-metre-wide field margins around arable fields were rotovated, and either left to regenerate naturally or sown with a wildflower seed mix in March 1988. Within each unsown and sown margin, 50-m-long plots were managed in one of four ways, with eight replicates of each treatment: uncut; cut once in June; cut April and June; cut in April and September. Hay was collected after cutting. From June–September 1989, and April–September 1990–1991, meadow brown adults were monitored weekly. In spring 1991, meadow brown caterpillars were sampled by sweep netting and visual searching.

A site comparison study in 1988–1991 on two arable farms in Oxfordshire, UK (3, same experimental set-up as 2, 4) reported that a farm where wider field margins had been established and fertilizer application excluded had a higher abundance and species richness of butterflies than a farm with conventional field margins. Results not tested for statistical significance. The abundance of eight species (including small skipper *Thymelicus sylvestris*, small heath *Coenonympha pamphilus*, gatekeeper *Pyronia tithonus* and meadow brown *Maniola jurtina*) was higher on a farm with wider (2-m) field margins than on a farm with conventional (0.5-m) margins. No species was more abundant on the conventional farm. In addition, two species (marbled white *Melanargia galathea* and common blue *Polyommatus icarus*) were only recorded on the farm with wide margins, resulting in a higher species richness (16 species) than the conventional farm (14 species). In 1988, the margins of 10 fields on one farm were extended from 0.5-m to 2-m wide, and fertilizer application was excluded. Margins were either left to regenerate naturally, or sown with grasses and non-woody broadleaved plants (forbs). Margins were either left uncut, or cut in some combination of April, June and September 1989–1991. In summer 1991, butterflies were surveyed for two months on transects on this farm and on a second, intensively managed farm with conventional field margins (number not given).

A replicated, randomized, controlled study in 1987–1991 in Oxfordshire, UK (4, same experimental set-up as 2, 3) found that butterfly abundance and species richness were lower in unsown field margins than in margins sown with wild grasses and non-woody broadleaved plants (forbs), and that margin management affected butterfly numbers. From two years after establishment, both individual abundance (14–39 individuals/50 m) and species richness (6–9 species/50 m) of butterflies were lower in unsown, naturally regenerating margins than in sown margins (abundance: 21–91 individuals/50 m; richness: 7–10 species/50 m). However, in all three years, unsown margins had more butterflies if they were left uncut (abundance: 28–40 individuals/50 m; richness: 8–9 species/50 m), or were cut in spring and autumn (abundance: 29–44 individuals/50 m; richness: 8–9 species/50 m), than if they were cut in summer (abundance: 14–27 individuals/50 m; richness: 6–8 species/50 m). In autumn 1987, two-metre-wide field margins around arable fields were rotovated. In April 1988, they were either left to naturally regenerate or sown with a wildflower seed mix. Within each unsown and sown margin, 50-m-long plots were managed in one of four ways, with eight replicates of each treatment: uncut; cut once in June; cut April and June; cut in April and September. Hay was collected after cutting. Butterflies were monitored weekly from June–September 1989 and from April–September 1990 and 1991.

A replicated, site comparison study in 1994–1996 on an arable farm in Gloucestershire, UK (5) found that the abundance and diversity of butterflies was lower in unsown naturally regenerated field margins than in margins sown with wildflowers, and that margin management affected butterfly diversity. Unsown, naturally regenerated margins had a lower abundance (5–10 individuals) and diversity (3–6 species) of butterflies than sown wildflower margins (abundance: 15–16 individuals; diversity: 6–7 species). Cutting and subsequent grazing of naturally regenerated margins decreased butterfly diversity (3 species) but not abundance (5 individuals) compared to margins which were not cut or grazed (diversity: 6 species; abundance: 10 individuals). In 1994, two-metre margins were established around two organically managed arable fields by either natural regeneration or by sowing a seed mix containing five grasses and six wildflowers. In 1996, half of the margins were cut in June and grazed in July. The rest was left unmanaged. From May–September 1996, butterflies were monitored weekly along transects.

A replicated, controlled study in 1999–2000 in four arable sites in North Yorkshire, UK (6) found that butterfly abundance was lower along uncultivated margins than along margins sown with a grass and wildflower seed mix or a combination of tussocky grass seed and grass and wildflower mix, but abundance was similar between uncultivated margins and those sown with tussocky grass seed alone or cereal crop, and species richness did not differ between treatments. There were fewer butterflies along margins which were left to regenerate without sowing (average: 14 individuals), margins sown with tussocky grass seed (average: 21) and margins sown with cereal crop (average: 9) than those sown with a grass and wildflower seed mix (average: 44) or a combination of tussocky grass seed and grass and wildflower seed mix (average: 33). There was no difference in species richness between any of the treatments see paper for details). Four 6 m wide margins of winter cereal fields (all adjacent to hedges) on two farms were split into 72 m long plots and sown in September 1999 with either a tussocky grass mix, a grass and wildflower mix, half the width tussocky grass and half grass and wildflower mix, cereal crop or left to regenerate naturally with no sowing. Butterflies were surveyed weekly from May–September 2000 using walking transects (21 surveys/field in total).

A replicated, controlled study in 1996–2000 at two arable farms in Essex, UK (7) found that butterfly abundance, but not species richness, was higher in grass margins than in cropped field edges. More butterflies were recorded in sown or naturally regenerated grass margins (46 individuals/km) than in cropped field edges (21 individuals/km), but the species richness was similar (grass margin: 8; cropped edges: 9 species). Of the 'key' grassland butterfly species, only meadow brown *Maniola jurtina* was more abundant in grass margins (19 individuals/km) than in cropped field edges (9 individuals/km). However, fewer butterflies (32–38 individuals/km), including meadow brown (4–5 individuals/km), were found in naturally regenerated margins than in sown margins (all butterflies: 41–125 individuals/km; meadow brown: 27–57 individuals/km). In 1996, eight 6-m-wide margins were established on two farms. Five were sown with grass seed mixtures (6 or 9 species) and three were left to natural regeneration. One arable field edge without margins on each farm was used as a control. Butterfly abundance was monitored weekly from late June to early August 1997–2000. All butterflies were recorded, but special note was taken of 'key' grassland species: meadow brown, gatekeeper *Pyronia tithonus*, small skipper *Thymelicus sylvestris*, Essex skipper *Thymelicus lineola*, and large skipper *Ochlodes venata*.

A replicated, paired, site comparison study in 2004 in 12 agricultural areas in southern Sweden (8) found that uncultivated margins placed close to semi-natural grassland fragments had a higher abundance and species richness of grassland-dependent butterflies and burnet moths (Zygaenidae) than margins situated further from grassland. There was a higher abundance and species richness of butterflies and burnet moths in uncultivated margins which were next to semi-natural grasslands (abundance: 0.1–1.6 individuals/100 m^2; richness: 0.1–1.7 species/100 m) than in margins which were >1 km from the nearest grassland (abundance: 0.0–0.9 individuals/100 m^2; richness: 0.1–0.9 species/100 m). Butterfly abundance in margins close to grassland was similar to the grassland (0.5–1.2 individuals/100 m^2), but species richness in the margins was lower than the grassland (0.9–2.0 species/100 m). In each of 12 areas, two uncultivated strips of perennial grassland bordering cultivated fields were surveyed. One strip was situated within 100 m of an area of grazed, semi-natural grassland (5–12 ha), and the other was >1 km from the nearest grassland >0.5 ha. From late May–early August 2004, grassland-dependent butterflies and burnet moths were surveyed six times on one 300-m transect/margin, and on a transect through each semi-natural grassland (150 m/ha).

A replicated, site comparison study in 2003–2004 in an arable field in Jokioinen, Finland (9) reported that permanent, uncultivated field margins had a higher abundance and species richness of butterflies and day-flying moths than sown fallow plots or spring cereals. Results were not tested for statistical significance. In permanent, uncultivated margins the abundance (120 individuals/1,000 m) and species richness (9.4 species/plot) of butterflies and day-flying moths were higher than in temporary, in-field, sown fallow plots that were one-year-old (abundance: 2–3 individuals/1,000 m; richness: 0.5–0.7 species/plot) or two-years-old (abundance: 5–30 individuals/1,000 m; richness: 0.7–4.2 species/plot), or left as stubble (abundance: 17 individuals/1,000 m; richness: 4.2 species/plot). No butterflies or moths were recorded in spring cereal fields. Six species showed a significant preference for permanent margins over temporary fallow plots (Essex skipper *Thymelicus lineola*, ringlet *Aphantopus hyperantus*, Lewes wave *Scopula immorata*, shaded broad-bar *Scotopteryx chenopodiata*, silver-ground carpet *Xanthorhoe montanata*, black-veined moth *Siona lineata*). In 2003, ten permanently uncultivated, 250-m long, 2.5-m wide field margins next to a 16.5-ha field were selected. The field was divided into four blocks, each containing eight 0.3-ha plots. Six plots/block were sown with grasses in either 2003 or 2004 and left fallow (see paper for details), one plot/block was sown with spring barley in 2003 and left as stubble in 2004, and one plot/block was sown with spring barley in both years. In June–July 2004, butterflies and day-flying moths were recorded four times, two weeks apart, on one 250-m transect through each margin or plot.

A replicated, site comparison study in 2015 on seven arable farms in Germany (10) found that wider, longer, uncultivated permanent margins which were not mown in the summer had more butterfly species than narrower, shorter or summer-mown margins. All data were presented as model results. There were more butterfly species on longer or wider margins than on shorter or narrower margins. Margins which were completely mown in June or July had fewer butterfly species than margins which were only partially mown in June or July, or were mown at another time of year or not mown at all. On each of seven farms (58–700 ha), 10 permanent, unsprayed and uncropped arable field margins (≥50 m long and ≥1 m wide) were sampled. Margins were managed by either complete mowing in June or July, partial mowing in June or July, or mowing at other times of year (including unmown margins). From June–August 2015, butterflies were surveyed six times along a 50–250 m transect in each margin.

(1) Lagerlöf J., Stark J. & Svensson B. (1992) Margins of agricultural fields as habitats for pollinating insects. *Agriculture Ecosystems & Environment*, 40, 117–124.
(2) Feber R.E., Smith H. & Macdonald D.W. (1994) The effects of field margin restoration on the meadow brown butterfly (*Maniola jurtina*). *British Crop Protection Council Monographs*, 58, 295–300.
(3) Feber R.E. & Smith H. (1995) Butterfly conservation on arable farmland. pp 84–97 in: Pullin A.S. (ed) *Ecology and Conservation of Butterflies*. Springer, Dordrecht.
(4) Feber R.E., Smith H. & Macdonald D.W. (1996) The effects on butterfly abundance of the management of uncropped edges of arable fields. *Journal of Applied Ecology*, 33, 1191–1205.
(5) Feber R.E. & Hopkins A. (1997) Diversity of plant and butterfly species on organic farmland field margins in relation to management. *British Grassland Society Fifth Research Conference*, University of Plymouth, Devon, UK, 8-10 September 1997, 63–64.
(6) Meek B., Loxton D., Sparks T., Pywell R., Pickett H. & Nowakowski M. (2002) The effect of arable field margin composition on invertebrate biodiversity. *Biological Conservation*, 106(2), 259-271.
(7) Field R.G., Gardiner T., Mason C.F. & Hill J. (2005) Agri-environment schemes and butterflies: the utilisation of 6 m grass margins. *Biodiversity and Conservation*, 14, 1969–1976.
(8) Öckinger E. & Smith H.G. (2007) Semi-natural grasslands as population sources for pollinating insects in agricultural landscapes. *Journal of Applied Ecology*, 44, 50–59.
(9) Kuussaari M., Hyvönen T. & Härmä O. (2011) Pollinator insects benefit from rotational fallows. *Agriculture, Ecosystems & Environment*, 143, 28–36.
(10) Sybertz J., Matthies S., Schaarschmidt F., Reich M. & von Haaren C. (2017) Assessing the value of field margins for butterflies and plants: how to document and enhance biodiversity at the farm scale. *Agriculture, Ecosystems & Environment*, 249, 165–176.

3.11. Plant grass buffer strips/margins around arable or pasture fields

- **Twenty-six studies** evaluated the effects on butterflies and moths of planting grass margins around arable or pasture fields. Seventeen were in the UK[3–6,8,10–14,17–22,25], two were in each of Sweden[1,16], the Netherlands[2,15] and the USA[7,24], and one was in each of China[9], France[23] and Italy[26].

COMMUNITY RESPONSE (15 STUDIES)

- **Richness/diversity (15 studies):** One of two replicated, controlled studies in the UK[6,8] found that 2-m grass margins had a greater species richness of butterflies than cropped field edges, but 6-m grass margins did not[8]. The other study found that the species richness of butterflies was similar in grass margins and cropped field edges[6]. Five replicated, site comparison studies (including one paired study) in the USA[7], the UK[14,20,22] and Italy[26] found that wider grass margins (up to 6 m wide) had a greater species richness[7,20,22,26] or diversity[14] of butterflies[7,26], macro-moths[14,22] and micro-moths[20] than narrower or conventional width margins, although one of these studies found that the species richness of macro-moths was similar in wide and conventional grass margins[20]. Three of five replicated studies (including three randomized, controlled studies, one controlled study, and one site comparison study) in the UK[4,12,19,21] and Sweden[15] found that floristically enhanced grass buffers[12,19] or wildflower strips[16] had a greater species richness of butterflies than standard grass margins. The other two studies found that farms with floristically enhanced margins (along with other enhanced agri-environment scheme (AES) options) had a similar species richness of butterflies[4,21] and moths[21] to farms with standard grass margins (along with basic AES options) and farms with no grass margins or other AES options. One site comparison study in Sweden[1] found that grass margins sown with legumes or a clover and grass ley had a higher species richness of butterflies and moths than uncultivated margins, but less than a species-rich pasture. One replicated study in the Netherlands[15] found that the species richness of butterflies increased over time after the establishment of grass margins. One replicated, randomized, controlled, before-and-after study in the USA[24] found that disking or burning grass margins did not affect the species richness of butterflies.

POPULATION RESPONSE (22 STUDIES)

- **Abundance (21 studies):** Three of four replicated, controlled studies in the UK[5,6,10,11] found that grass margins had a higher abundance of butterflies than cropped field edges[6,10,11]. The other study found that the abundance of gatekeepers on grass margins increased over four years after they were sown, but was only higher than cropped field edges at one of three farms after 2–4 years[5]. Three of seven replicated, site comparison studies (including two paired studies) in the USA[7] and the UK[13,14,17,18,20,22] found that wider grass margins (up to 6 m wide) had a higher abundance of habitat-sensitive butterflies[7], macro-moths[13] and micro-moths[20] than narrower or conventional width margins. Two of these studies, and the other four studies, found that the abundance of disturbance-tolerant butterflies[7], macro-moths generally[14,17,20,22], and pale shining brown moths specifically[18], was similar in wide and conventional grass margins. Four replicated studies (including two randomized, controlled studies, one controlled study, and one site comparison study) in the UK[4,12,19] and Sweden[16] found that floristically enhanced grass buffers[4,12,19] or wildflower strips[4,16] had a higher abundance of butterflies than standard grass margins[12,16,19], uncultivated margins[4] or margins sown with cereal crop[4]. Two replicated, randomized, controlled studies in the UK[21,25] found that farms with floristically enhanced margins (along with other enhanced agri-environment scheme (AES) options) had a higher abundance of some butterflies[21,25] and micro-moths[21], a similar abundance of macro-moths[21], but a lower abundance of other butterflies[25], than farms with standard grass margins (along with basic AES options)[21,25] and farms with no grass margins or other AES options[21]. One site comparison study in Sweden[1] found that grass margins sown with legumes or a clover and grass ley had a higher abundance of butterflies and moths than uncultivated margins or a species-rich pasture. Two replicated, before-and-after studies (including one randomized, controlled study) in the Netherlands[2] and the

USA[24] found that mowing[2], disking[24] or burning[24] grass margins did not affect the abundance of butterflies[2,24] and moths[2] generally, or diamondback moths specifically[2], but that disking increased the abundance of disturbance-tolerant butterflies[24]. One replicated, paired, site comparison study in the UK[3] found that field margins had a similar abundance of butterfly and moth caterpillars to beetle banks established in the middle of fields.

- **Survival (1 study):** One site comparison study in China[9] found that the survival of marsh fritillary caterpillars in grass margins around lightly cultivated fields was lower, but survival of egg clusters similar, to in uncultivated, grazed meadows.

BEHAVIOUR (2 STUDIES)

- **Use (2 studies):** One replicated, site comparison study in China[9] found that grass margins around lightly cultivated fields were more likely to be occupied by marsh fritillary eggs and caterpillars than uncultivated, grazed meadows. One replicated, paired, site comparison study in France[23] found that meadow brown butterflies used grass margins in a similar way to meadows.

Background

Grass margins, or buffer strips, can be created around the edges of fields to reduce nutrient and chemical run-off into adjacent habitat, and provide corridors of habitat for farmland wildlife. In Europe, this is often implemented as an option within agri-environment schemes. While basic agri-environment schemes often allow simple grass margins, enhanced schemes often provide an option for sowing wildflowers alongside the grass to provide "floristic enhancement". This action includes tests of both simple and enhanced grass margins, as well as comparisons between them, and comparisons between other implementation options, such as changing the width of created margins.

A site comparison study in 1989 on an arable farm in central Sweden (1) reported that sown grass margins had a higher abundance but similar species richness of butterflies and moths to uncultivated margins. Results were not tested for statistical significance. Over two months, more butterflies and moths were recorded in two sown grass margins (58–75 individuals) than in two uncultivated margins (38–44 individuals), but the number of species was similar (sown: 6 species; uncultivated: 7 species). Fewer butterflies (24 individuals) of more species (8 species) were recorded in a species-rich pasture. Four existing field margins and a species-rich pasture were compared. Two margins were sown (one with a mixture of legumes dominated by white melilot *Melilota alba*, the other with clover and ley grasses dominated by red clover *Trifolium pratense*) and two were uncultivated (one with diverse weeds, the other with diverse herbs and grasses on a ditch bank). From 19 June–22 August 1989, butterflies and moths were recorded in the morning and evening at each site, three times/week.

A replicated, controlled, before-and-after study in 1996 in arable farmland in the Netherlands (2) found that mowing planted grass margins did not affect the abundance of moths and butterflies. After mowing, the abundance of moths and butterflies generally, and diamondback moth *Plutella xylostella* specifically, was similar to before mowing. Ten grass margins (3 × 900 m) on five farms were sown with grasses, including giant fescue *Festuca gigantea*, timothy *Phleum pratense* and cocksfoot *Dactylis glomerata*. Grassy margins were mown on approximately half of the farms at the beginning of July 1996. Moths and butterflies were sampled using two pyramid traps/margin, installed for a three-week period five times during the 1996 growing season.

A replicated, paired, site comparison study in 1999 on five farms in the UK (3) found that grass field margins had a similar abundance of butterfly and moth caterpillars to beetle banks established in the centre of fields. The abundance of butterfly and moth caterpillars did not differ significantly between field margins (0.5 individuals/sweep) and beetle banks (0.4 individuals/sweep). In summer 1999, butterfly and moth caterpillars were sampled by sweep-netting on 22 permanently established grass field margins and 22 beetle banks of different ages across five farms.

A replicated, controlled study in 1999–2000 in four arable sites in North Yorkshire, UK (4) found that along margins sown with a combination of tussocky grass seed and grass and wildflower mix or a grass and wildflower mix alone there was higher butterfly abundance than along those that naturally regenerated or were sown with cereal crop, but there was no difference in butterfly abundance between margins sown with tussocky grass seed and those that were left to regenerate naturally or those sown with cereal crop, and there was no difference in butterfly species richness between any of the treatments. There was no difference in butterfly abundance along margins sown with tussocky grass (average: 21 individuals) and those that regenerated naturally (average: 14). However, more butterflies were seen along margins where half their width was sown with tussocky grass and half sown with a wildflower and grass seed mix (average: 33), or their whole width was sown with wildflower and grass seed mix (average: 44), than on margins that regenerated naturally (average: 14) or were sown with cereal crop (average: 9). There was no difference in species richness between any of the treatments (see paper for details). Four 6 m wide margins of winter cereal fields (all adjacent to hedges) on two farms were split into 72 m long plots and sown in September 1999 with either a tussocky grass mix, a grass and wildflower mix, half the width tussocky grass and half grass and wildflower mix, cereal crop or left to regenerate naturally with no sowing. Butterflies were surveyed weekly from May–September 2000 using walking transects (21 surveys/field in total).

A replicated, controlled study in 1996–2000 on three arable farms in Essex, UK (5, same experimental set-up as 6, 8, 10, 11) found that the number of gatekeepers *Pyronia tithonus* on sown grass margins increased over four years, and was higher than on cropped field edges at one of three farms after 2–4 years. Gatekeeper abundance on 2-m-wide grass margins increased from 2.2 individuals/km to 12.9 individuals/km over four years after the margins were sown. However, abundance was significantly higher in grass margins than in cropped margins at only one of three farms after 2–4 years (grass margin: 9.1 individuals/km, cropped edges: 0.7 individuals/km; other farms grass margin: 6.8–11.9 individuals/km, cropped edges: 1.9–17.3 individuals/km). Thirteen grass margins (2 m wide, 141–762 m long) were established in October 1996–2000 by sowing one of three seed mixtures containing 4–6 grass species. Three field edges without margins (one on each farm, 133–343 m long) were used as controls. Gatekeeper abundance was monitored weekly along each grass margin and cropped edge in July and August 1997–2000.

A replicated, controlled study in 1996–2000 at two arable farms in Essex, UK (6, same experimental set-up as 5, 8, 10, 11) found that butterfly abundance, but not species richness, was higher in grass margins than in cropped field edges. More butterflies were recorded in sown or naturally regenerated grass margins (46 individuals/km) than in cropped field edges (21 individuals/km), but the species richness was similar (grass margin: 8; cropped edges: 9 species). Of the 'key' grassland butterfly species, only meadow brown *Maniola jurtina* was more abundant in grass margins (19 individuals/km) than in cropped field edges (9 individuals/km). More butterflies (125 individuals/km), including meadow brown (57 individuals/km), were found in a sown grass margin established next to a permanent set-aside field than on all other margin types (all butterflies: 32–41 individuals/km; meadow brown: 4–27 individuals/km). In 1996, eight 6-m-wide margins were established on two farms. Five were sown with grass seed mixtures (6 or 9 species) and three were left to natural regeneration. One arable field edge without margins on each farm was used as a control. Butterfly abundance was monitored weekly from late June to early August 1997–2000. All butterflies were recorded, but special note was taken of 'key' grassland species: meadow brown, gatekeeper *Pyronia tithonus*, small skipper *Thymelicus sylvestris*, Essex skipper *Thymelicus lineola*, and large skipper *Ochlodes venata*.

A replicated, site comparison study in 2002–2003 in 38 buffer strips in an arable region of Minnesota, USA (7) found that wide grass buffer strips had a higher abundance of habitat-sensitive butterflies, a similar abundance of disturbance-tolerant butterflies, and a higher species richness and diversity of all butterflies, than narrow buffer strips. The abundance of habitat-sensitive butterflies, and the species richness and diversity of all butterflies, was higher in wide buffer strips than in narrower strips, but the abundance of disturbance-tolerant butterflies was similar in strips of different widths (data presented as model results). See paper for individual species results. A total of 38 buffer strips (8–148 m wide, and all >3 years old, >350 m long, >1 km apart and with <15% tree or shrub cover) between a crop field and a water course were surveyed. None of the strips were treated with insecticide or fertilizer, and most were infrequently spot-mown or spot-sprayed to control weeds. In July–August 2002 and June–August 2003, butterflies were surveyed twice/year along one 200-m transect/buffer strip, halfway between the water course and crop field. Butterfly species were classified as "disturbance-tolerant" (species commonly found in human-modified landscapes) and "habitat-sensitive" (species with specific habitat requirements often found only in natural areas).

A replicated, controlled study in 1996–2000 on three arable farms in Essex, UK (8, same experimental set-up as 5, 6, 10, 11) found that 2-m-wide sown grass margins, but not 6-m-wide grass margins, had higher butterfly species richness than field edges without grass margins. Butterfly species richness was higher in 2-m-wide grass margins (8–9 species) than in cropped field edges without margins (5–7 species), but was not significantly different in 6-m-wide margins compared to cropped field edges (data not presented). Species richness was also higher on 2-m grass margins sown with a more diverse seed mixture, and was higher on 2-

m grass-sown margins next to hedgerows than on margins without hedgerows (data not presented). In October 1996–1998, twenty-six margins were established on three farms: 13 grass-sown that were 2-m-wide, five grass-sown that were 6-m-wide, three naturally regenerated (6 m wide) and five cropped field edges (2 and 6 m wide). Grass-sown margins were established using seed mixtures containing 4–9 common grass species. Butterflies were monitored weekly in summer from 1997–2000 in suitable weather.

A replicated, site comparison study in 2003 in 38 meadows in Hebei Province, China (9) found that lightly cultivated meadows with grass margins and intercrop were more likely to be occupied by marsh fritillary *Euphydryas aurinia* eggs and caterpillars than uncultivated, grazed meadows, but caterpillar survival was lower in the cultivated meadows. More meadows with some cultivation, including grass margins, contained egg clusters (9/11 meadows) and caterpillars (11/16 meadows) than entirely uncultivated, grazed meadows (eggs: 1/12; caterpillars: 5/22 meadows). In total, 179 egg clusters were found in cultivated meadows, compared to 70 egg clusters in grazed meadows (statistical significance not assessed). The mortality of egg clusters was similar in cultivated meadows (10% of 177 clusters) and grazed meadows (16% of 69 clusters), but the survival of pre-hibernation caterpillars was lower in cultivated meadows (23/164, 14%) than in grazed meadows (21/59, 33%). A total of 38 meadows (0.025 ha–3.200 ha) were studied. In 2003, sixteen meadows contained some cultivation (corn or potatoes), and were divided into cultivated habitat (grass strips within and around the crop, no grazing from April–October) and meadow habitat (meadows and fallow land, grazed by sheep and cattle). Another 22 meadows were entirely uncultivated and grazed. In June 2003, eleven cultivated and 12 uncultivated meadows were searched for egg clusters. These were marked and observed every other day until all hatched caterpillars had disappeared or begun overwintering. In September 2003, all 38 meadows were surveyed for caterpillar nests.

A replicated, controlled study in 1996–2000 on three arable farms in Essex, UK (10, same experimental set-up as 5, 6, 8, 11) found that planted grass margins had higher butterfly abundance than cropped field edges without margins. Butterfly abundance was higher in sown grass margins (67 individuals/km) than in cropped field edges (26 individuals/km). In sown grass margins abundance was higher for meadow brown *Maniola jurtina* (16 individuals/km) and golden skipper *Thymelicus* spp. (14 individuals/km) compared to cropped margins (meadow brown: 4; *Thymelicus* spp.: 1 individuals/km), but the abundance of gatekeeper *Pyronia tithonus* was similar (grass margin: 8; cropped margin: 5 individuals/km). Over four years, the total abundance of butterflies in the grass margins decreased (from 101 to 47 individuals/km), as did the abundance of *Thymelicus* spp. (32 to 3 individuals/km) and large skipper *Ochlodes venata* (15 to 1 individuals/km). However, the abundance of gatekeeper increased (2 to 13 individuals/km). In October 1996, thirteen 2-m-wide grass margins were sown (20 kg seed/ha), and were not cut after the first year. Butterfly abundance was monitored weekly from late June to early August 1997–2000 in grass margins and cropped field edges on each farm. All butterflies were recorded, but special note was taken of 'key' grassland species: meadow brown, gatekeeper, small skipper *Thymelicus sylvestris*, Essex skipper *Thymelicus lineola* and large skipper.

A replicated, controlled study in 1996–2003 on three arable farms in Essex, UK (11, same experimental set-up as 5, 6, 8, 10) found that planted grass margins had higher butterfly abundance than cropped field edges without grass margins. Butterfly abundance was higher in both 2-m-wide (64 individuals/km) and 6-m-wide (54 individuals/km) sown grass margins than in cropped field edges (19–24 individuals/km). Meadow brown *Maniola jurtina* abundance was higher in 2-m (15 individuals/km) and 6-m (22 individuals/km) margins than in cropped field edges (4–5 individuals/km), but abundance was similar for gatekeeper *Pyronia tithonus* (grass margin: 7–9; cropped: 5–6 individuals/km) and golden skipper *Thymelicus* spp. (grass margin: 5–14; cropped: 2–13 individuals/km). In October 1996–1997, three 2-m-wide margins were sown with grass seed (4–6 species) and left uncut after the first year, and three 6-m-wide margins were established through natural regeneration or by sowing (6–9 species), and cut annually after 15 July. Butterfly abundance was monitored weekly in summer 1997–2000 and 2003 in the six grass margins and five cropped field edges.

A replicated, randomized, controlled study in 2002–2006 on three farms in eastern England, UK (12) found that grass-only field margins supported fewer butterflies than floristically-enhanced grass margins and pollen and nectar mixes. In grass-only margins, the abundance (12 individuals/plot) and species richness (5 species/plot) of butterflies was lower than in margins sown with either a grass and wildflower mix or a pollinating insect mix (abundance: 18–20 individuals/plot; richness: 6 species/plot). Management of the margins did not affect either the abundance or species richness of butterflies (data not presented). Field margin plots (6 × 30 m) were established in 2000–2001 using one of three seed mixes: a grass-only "Countryside Stewardship mix" (seven grass species, sown at 20 kg/ha), a floristically-enhanced "tussock grass mix" (seven grass species, 11 wildflowers, sown at 35 kg/ha) and a mixture of grasses and wildflowers designed for pollinating insects (four grass species, 16–20 wildflowers, sown at 35 kg/ha). Margins were managed in spring from 2003–2005 with one of three treatments: cut to 15 cm, soil disturbed by scarification until 60% of the area was bare ground, treated with grass-specific herbicide in spring at half the recommended rate. There were five replicates of each treatment combination on three farms. No further details provided.

A replicated, paired, site comparison study in 2007 in four arable fields in Oxfordshire, UK (13, same experimental set-up as 14, 17, 18, 22) found a higher abundance of common farmland larger moth species in the margins and centres of fields with 6-m-wide perennial grass margins than in fields with standard 1-m margins, but this varied between species. Fields with 6-m-wide grass margins had 40% more moths of nine common species combined than fields with standard margins (data presented as model results). However, only two individual species (treble lines *Charanyca trigrammica* and brown-line bright-eye *Mythimna conigera*) were more abundant in fields with wide margins (data presented as model results). On the 32 nights (dusk till dawn) with suitable weather between 5 June and 14 July 2007, ten Heath pattern actinic light traps (6 W) were positioned in two arable fields/night: one in the centre of each field, and one in each field margin (1 m from hedgerow). All traps were >100 m apart and >50 m from hedgerow intersections. Traps were alternated between two pairs of fields each night, one with 6-m-wide perennial grass margins and the other with standard 1-m-wide margins. Moths were identified on the morning after capture.

A replicated, site comparison study in 2006 in four arable areas in Oxfordshire, UK (14, same experimental set-up as 13, 17, 18, 22) found that farms with wide perennial grass margins had a higher diversity, but not abundance, of larger moths than farms with standard narrow margins. Farms with 6-m-wide margins had a higher species diversity of moths than farms with 1-m-wide standard margins (data presented as model results). However, the abundance of moths was similar between wide (22–27 individuals) and standard (22–25 individuals) margins. Three permanent sampling sites were established >100 m apart and >50 m from hedgerow intersections at each of 16 farms. Farms were divided between four experimental groups: sampling in a 6-m-wide perennial grass margin adjacent to a mature (>15 m high) hedgerow tree, sampling in a standard 1-m margin adjacent to a hedgerow tree, sampling in a 6-m margin not adjacent to a hedgerow tree, and sampling in a 1-m margin not adjacent to a hedgerow tree. All farms were sampled once during each of 11 discrete fortnightly periods from mid-May to mid-October 2006 using standardized moth traps.

A replicated study on six arable farms in the Netherlands (15) found that the number of butterfly species in sown grass field margins increased in the eight years following establishment. More than half of the transects had increased butterfly species richness in the 1–8 years following the establishment of margins (data presented as model results). Field margins (2–3 m wide) were sown with grasses on six farms across the Netherlands. All margins were mown at least once a year and cuttings removed. No nutrients, pesticides or herbicides were applied to any of the margins. Butterflies were counted on twenty-one 50-m transects along field margins on six farms. Transect counts were either every week from April–September, or 2–5 times during summer, for 2–8 years after the margins were established (exact years not given).

A replicated, site comparison study in 2007 at four arable farms in south Sweden (16) found lower abundance and species richness of butterflies in grass margins (greenways or 'beträdor') than in sown wildflower strips. In grass margins, the abundance of butterflies (0.6–1.4 individuals/100 m) was lower than in wildflower strips (10.4 individuals/100 m). In total, 14% of the recorded butterflies were found in grass strips compared to 86% in the wildflower strips. Four species of butterfly were only found in the wildflower strips. Margins with adjacent bushes had higher abundance and species richness of butterflies than margins without bushes (data presented as model results). At three farms, 14 grass strips (total 6.8 km) were sown with a mixture of grass species in the 1990s, 2004 and 2005, and were cut several times a year. At one farm, six wildflower strips (total 2.9 km) were sown in the mid-1990s using either a commercial mix of wildflowers and grasses, or hay from a nearby meadow, and were cut once a year at the end of July. Butterflies were recorded on transects five times from June–September 2007.

A replicated, site comparison study in 2008 in five arable fields in Oxfordshire, UK (17, same experimental set-up as 13, 14, 18, 22) found that wide perennial grass margins had a similar abundance of moths to narrow margins. Margins that were 6-m-wide had a similar abundance of moths to 1-m-wide margins (data presented as model results). Two arable fields had 6-m-wide perennial grass margins and three had <2-m-wide margins. Four sampling points at 1 m from the hedgerow and >100 m apart were selected in each field (20 in total). Between dusk and dawn on 33 nights between 9 June and 19 July 2008 moths were caught (at 10 point/night) using standardized light traps, identified on the morning after capture, marked and released. Counts/treatment not stated. Only data from 23 species of moth, which were found at the study sites in the previous year and whose flight period coincided with the sampling, were analysed.

A replicated, site comparison study in 2006–2008 on four arable farms in Oxfordshire, UK (18, same experimental set-up as 13, 14, 17, 22) found that 6-m-wide grass margins did not have more pale shining brown moths *Polia bombycina* than 1–2-wide margins. The number of individuals caught in wide field margins (0.4–1.3 individuals/trap) was not significantly different to the number caught in standard width margins (0.3–1.0 individuals/trap). Four farms were assigned to one of four treatments, based on their most common boundary features: 6-m-wide perennial grass or 1–2-m-wide standard field margins, and with or without hedgerow trees (>15 m high, mostly pedunculated oak *Quercus robur*). From May–October 2006–2008, moths were sampled overnight, once/fortnight, using three 6 W Heath pattern actinic light traps/farm. In June–July 2007 and 2008, at one farm, an additional 8–10 traps were set for 32–33 nights/year, in margins with the same treatments across 4–5 fields (16–20 locations). All traps were 1 m from hedgerows (2–3 m high, 1.5–2.5 m wide), 5 m from trees (if applicable), >50 m from hedgerow intersections, and >100 m apart.

A replicated, randomized, controlled study in 2008–2009 on two arable farms in Berkshire, UK (19) found that sowing wildflowers in grass buffer strips which have been scarified and treated with grass-specific herbicide increased the abundance, diversity and species richness of butterflies. Butterfly species richness was higher in plots that had been scarified, sown with wildflower seeds and treated with grass-specific herbicide (5.8 species/plot) compared with single treatment plots (scarification and seeding: 2.6; herbicide: 2.5 species/plot) and plots with no scarification, seeding or herbicide (3.7 species/plot). Butterfly abundance (6.8 individuals/plot) and diversity were higher in plots that were scarified, seeded and treated with herbicide than single treatment plots (scarification and seeding: 2.5, herbicide: 2.2 individuals/plot), but similar to plots with no scarification, seeding or herbicide (3.7 individuals/plot; diversity presented as model results). Six-metre-wide grass buffer strips were created on two arable farms in 2004 and managed under an Entry Level Stewardship agreement from 2005. In spring 2008, three blocks of four 25 × 4 m plots were established at each farm. One of four treatments was applied randomly to each plot: scarification in March 2008; application of grass-specific herbicide ("fluazifop-P-butyl") in April 2008; scarification and herbicide application; and no scarification or herbicide. Scarification was always followed by sowing a seed mixture of nine wildflower species. All plots were cut to 15 cm in autumn, and cuttings left in place. From May–September 2008–2009, butterflies were surveyed twice on each of four days/year on a 25-m transect through the centre of each plot.

A replicated, paired, site comparison study in 2008 on 30 farms in central Scotland, UK (20) found that grass field margins and beetle banks managed under agri-environment schemes (AES) had a higher abundance and species richness of micro-moths, but not macro-moths, than conventionally-managed field margins. In AES field margins and beetle banks, both the abundance (57 individuals) and species richness (24 species) of micro-moths were higher than in conventional field margins (abundance: 17 individuals; richness: 8 species). However, the abundance (294 individuals) and species richness (34 species) of all macro-moths, and the abundance (24 individuals) and species richness (6 species) of declining macro-moths on AES margins and banks were not significantly different from conventional margins (all macro-moths: 207 individuals, 38 species; declining macro-moths: 32 individuals, 10 species). In 2004, fifteen farms enrolled in AES, and were paired with 15 similar but conventionally-managed farms, <8 km away. On AES farms, 1.5–6-m-wide field margins or beetle banks were sown with grass mixes, and managed with restrictions on grazing and fertilizer and pesticide use. Field margins on conventional farms had no management restrictions. From June–September 2008, moths were collected for four hours, on one night/farm, using a 6 W heath light trap located next to one margin or bank on each farm. Paired farms were surveyed on the same night.

A replicated, randomized, paired, controlled study in 2005–2011 on an arable farm in Buckinghamshire, UK (21) found that land managed under an agri-environment scheme, including planting grass margins, had a higher abundance, but not species richness, of butterflies and micro-moths than conventional farming, but there was no difference in abundance or species richness of other moths. Butterfly abundance was higher under enhanced Entry-Level Stewardship (ELS) (5,400 individuals/60 ha) and standard ELS (2,000 individuals/60 ha) than under conventional farming (1,400 individuals/60 ha). Micro-moth abundance was also higher under enhanced ELS (79 individuals) than standard ELS (32 individuals) or conventional farming (20 individuals). However, the abundance of macro-moths and threatened moths was similar under enhanced ELS (macro: 126; threatened: 6 individuals), standard ELS (macro: 79; threatened: 5 individuals) and conventional farming (macro: 79; threatened: 6 individuals). Species richness of all groups was similar under enhanced ELS (macro: 20; micro: 11; threatened: 3 species), standard ELS (macro: 20; micro: 8; threatened: 2 species) and conventional farming (macro: 18; micro: 5; threatened: 2 species) (butterfly data not presented). In 2005, a 1,000-ha farm was divided into five 180-ha blocks. Three 60-ha areas/block were assigned to three treatments: enhanced ELS (5% land removed from production, flower-rich margins sown with five grasses and six non-woody broadleaved plants “forbs”); standard ELS (1% land removed from production, 6-m margins sown with four grasses); conventional (margins only around hedges and watercourses) (see paper for other details). From May–August 2006–2011, butterflies were recorded four times/year on one 50-m transect/60-ha area, passing through all available habitats. In late-May 2007–2011 and late-July 2006–2011 moths were surveyed using Robinson light traps. One block was surveyed/night, with one trap/treatment.

A replicated, site comparison study in 2006–2009 on 16 arable farms in Oxfordshire, UK (22, same experimental set-up as 13, 14, 17, 18) found that extended-width grass field margins, which farmers were paid to maintain under agri-environment schemes, had a higher species richness, but not abundance, of macro-moths than standard-width margins. The species richness of macro-moths in extended-width margins (105 species) was higher than in standard-width margins (92 species), but the abundance was similar (data not presented). Sixteen farms were categorized to one of four treatments, based on their most common agri-environment scheme habitat: extended 6-m-wide or standard 1-m-wide field margins, and with or without hedgerow trees (>15 m high, mostly pedunculated oak *Quercus robur*). All margins were well-established perennial grass strips, cut once every 2–3 years, ungrazed and unfertilized. From May–October 2006–2009, moths were sampled 40 times (once/fortnight), using three 6 W Heath pattern actinic light traps/farm. Traps were 1 m from hedgerows (2–3 m high, 1.5–2.5 m wide), 5 m from trees (if applicable), >50 m from hedgerow intersections, >100 m apart, and operated from dawn to dusk. Three farms (nine traps) were sampled/night.

A replicated, paired, site comparison study in 2009 in a mixed farming region in Brittany, France (23) found that grass field margins were used by meadow brown *Maniola jurtina* butterflies in a similar way to meadows. Meadow brown flight patterns in grass field margins were similar to those in meadows (data presented as model results). In addition, meadow browns were more likely to fly along grass margins than across them. Meadow brown behaviour was studied in three pairs of grass field margins (5–20 m wide, 20–340 m long) and small meadows (0.05–5 ha), at sites 4–8.5 km apart. Grass field margins were mostly sown with a standard set of clover *Trifolium* spp. and grasses (Poacea). From June–August 2009, a total of 289 butterflies using field margins and 270 butterflies using meadows were followed individually from 15 m away, and the length and direction of their movements was recorded.

A replicated, randomized, controlled, before-and-after study in 2007–2009 on a mixed farm in Mississippi, USA (24) found that disking grass field margins increased the abundance, but not species richness, of disturbance-tolerant butterflies without affecting the abundance or species richness of grassland butterflies, while burning did not affect the abundance or species richness of any butterflies. The abundance of 18 disturbance-tolerant butterfly species was higher both one (10–14 individuals) and two (18 individuals) years after disking than on either burned (4–11 individuals) or undisturbed (4–14 individuals) margins. However, the species richness of disturbance-tolerant butterflies was similar between disked (7–9 species), burned (6–7 species) and undisturbed (6–8 species) margins. Both the abundance and species richness of 14 grassland butterfly species remained similar in disked (abundance: 0.6–1.4 individuals; richness: 2 species), burned (abundance: 0.3–1.3 individuals; richness: 1–3 species) and undisturbed (abundance: 0.5–1.3; richness: 1–3 species) margins. See paper for details of individual species. In spring 2004, grass margins totalling 79 ha were sown with a seed mix of common prairie species. Fifteen fields (containing 43 margins) were randomly assigned to one of three treatments: disking, burning and no disturbance. Within each disking field, one margin was disked in autumn 2007, and a different margin was disked in autumn 2008. Within each burning field, one margin was burned in spring 2008 and a different margin was burned in spring 2009. From June–August 2007–2009, butterflies were surveyed six times/year along three 50-m transects in the centre of each margin.

A replicated, randomized, controlled study in 2007–2010 on 28 arable farms in Wessex and East Anglia, UK (25) found that farms with enhanced agri-environment scheme (AES) habitats, including floristically-enhanced grass buffer strips, had a higher abundance of some butterfly species than farms with simpler AES habitats, including standard grass margins. In early summer, farms with enhanced AES habitats had a higher abundance of blue (Lycaenidae: 0.05 individuals/100 m) and white (Pieridae: 0.46 individuals/100 m) butterflies along boundaries than farms with Entry Level Scheme (ELS) habitats (blues: 0.04; whites 0.21 individuals/100 m), but a lower abundance of skippers (Hesperiidae) in the AES habitat itself (enhanced: 0.00; ELS: 0.02 individuals/100 m). In mid-summer, enhanced AES farms had a higher abundance of white butterflies (0.69 individuals/100 m), but a lower abundance of brown butterflies (Satyridae: 0.16 individuals/100 m) in the AES habitat, and a lower abundance of blue butterflies (0.05 individuals/100 m) along boundaries than ELS farms (whites: 0.38; browns: 0.49; blues: 0.11 individuals/100 m). In spring 2007, twenty-four farms (12 in East Anglia and 12 in Wessex) were randomly assigned to two treatments: 16 farms with enhanced AES habitat (1.5–6.0 ha of floristically-enhanced grass mixes, wildflower strips, wild bird seed mixes and natural regeneration by annual cultivation); and eight farms with ELS habitat (1.5–6.0 ha of grass margins and game cover (usually maize)). Two additional ELS farms/region, already managed organically with 1.5 ha of ELS habitat, were also studied. From 2008–2010, butterflies were surveyed twice/year on 11 fixed 100-m transects, in mid-May–mid-June and mid-July–early August. Eight transects/site were located in AES habitat, and three transects/site were located on field boundaries away from the AES habitat.

A replicated, site comparison study in 2014–2015 in 44 sites in a mixed farming region in Lombardy, Italy (26) found that grass margins wider than 3 m had a higher species richness of butterflies than narrower margins. The species richness of butterflies in grass margins which were more than 3 m wide was higher than in margins which were less than 1 m wide (data presented as model results). In addition, margins where the vegetation was higher than 15 cm had more species than margins with vegetation shorter than 15 cm (data presented as model results). See paper for details on individual species groups. Arable fields with grass margins were divided into three width categories (<1 m, 1–3 m, >3 m) and three height categories (<15 cm, 15–50 cm, >50 cm). From April–September 2014–2015, butterflies were surveyed along 44 transects, divided into 8–26 × 50-m sections. In 2014, thirty transects were surveyed once/month, and in 2015 fourteen different transects were surveyed twice/month. Only transect sections along field margins were included (number not specified).

(1) Lagerlöf J., Stark J. & Svensson B. (1992) Margins of agricultural fields as habitats for pollinating insects. *Agriculture Ecosystems & Environment*, 40, 117–124.

(2) Canters K.J. & Tamis W.L.M. (1999) Arthropods in grassy field margins in the Wieringermeer: Scope, population development and possible consequences for farm practice. *Landscape and Urban Planning*, 46, 63–69.

(3) Thomas S.R., Goulson D. & Holland J.M. (2000) The contribution of beetle banks to farmland biodiversity. *Aspects of Applied Biology*, 62, 31–38.

(4) Meek B., Loxton D., Sparks T., Pywell R., Pickett H. & Nowakowski M. (2002) The effect of arable field margin composition on invertebrate biodiversity. *Biological Conservation*, 106(2), 259-271.
(5) Field R.G. & Mason C.F. (2005) The utilization of two-metre Countryside Stewardship Scheme grass margins by the gatekeeper *Pyronia tithonus* (L). *Journal of Natural History*, 39, 1533–1538.
(6) Field R.G., Gardiner T., Mason C.F. & Hill J. (2005) Agri-environment schemes and butterflies: the utilisation of 6 m grass margins. *Biodiversity and Conservation*, 14, 1969–1976.
(7) Davros N.M., Debinski D.M., Reeder K.F. & Hohman W.L. (2006) Butterflies and continuous conservation reserve program filter strips: Landscape considerations. *Wildlife Society Bulletin*, 34, 936–943.
(8) Field R., Gardiner T., Mason C. & Hill J. (2006) Countryside Stewardship Scheme and butterflies: a study of plant and butterfly species richness. *Biodiversity and Conservation*, 15, 443–452.
(9) Liu W, Wang Y. & Xu R. (2006) Habitat utilization by ovipositing females and larvae of the Marsh fritillary (*Euphydryas aurinia*) in a mosaic of meadows and croplands. *Journal of Insect Conservation*, 10, 351–360.
(10) Field R.G., Gardiner T., Mason C.F. & Hill J. (2007a) Agri-environment schemes and butterflies: the utilisation of two metre arable field margins. *Biodiversity and Conservation*, 16, 465–474.
(11) Field R.G., Gardiner T. & Watkins G. (2007b) The use of farmland by butterflies: a study on mixed farmland and field margins. *Entomologist's Gazette*, 58, 3–15.
(12) Pywell R.F., Meek W.M., Carvell C. & Hulmes L. (2007) The SAFFIE project: enhancing the value of arable field margins for pollinating insects. *Aspects of Applied Biology*, 81, 239–245.
(13) Merckx T., Feber R.E., Dulieu R.L., Townsend M.C., Parsons M.S., Bourn N.A.D., Riordan P. & Macdonald D.W. (2009a) Effect of field margins on moths depends on species mobility: field-based evidence for landscape-scale conservation. *Agriculture, Ecosystems & Environment*, 129, 302–309.
(14) Merckx T., Feber R.E., Riordan P., Townsend M.C., Bourn N.A.D., Parsons M.S. & Macdonald D.W. (2009b) Optimizing the biodiversity gain from agri-environment schemes. *Agriculture, Ecosystems & Environment*, 130, 177–182.
(15) Musters C.J.M., Alebeek F.V., Geers R.H.E.M., Korevaar H., Visser A. & Snoo G.R.D. (2009) Development of biodiversity in field margins recently taken out of production and adjacent ditch banks in arable areas. *Agriculture, Ecosystems & Environment*, 129, 131–139.
(16) Haaland C. & Gyllin M. (2010) Butterflies and bumblebees in greenways and sown wildflower strips in southern Sweden. *Journal of Insect Conservation*, 14, 125–132.
(17) Merckx T., Feber R.E., Mclaughlan C., Bourn N.A.D., Parsons M.S., Townsend M.C., Riordan P., Macdonald D.W. (2010) Shelter benefits less mobile moth species: The field-scale effect of hedgerow trees. *Agriculture, Ecosystems & Environment*, 138(3-4), 147-151.
(18) Merckx T., Feber R.E., Parsons M.S., Bourn N.A.D., Townsend M.C., Riordan P. & Macdonald D.W. (2010) Habitat preference and mobility of *Polia bombycina*: are non-tailored agri-environment schemes any good for a rare and localised species? *Journal of Insect Conservation*, 14, 499–510.
(19) Blake R., Woodcock B., Westbury D., Sutton P. & Potts S. (2011) New tools to boost butterfly habitat quality in existing grass buffer strips. *Journal of Insect Conservation*, 15, 221–232.
(20) Fuentes-Montemayor E., Goulson D. & Park K.J. (2011) The effectiveness of agri-environment schemes for the conservation of farmland moths: assessing the importance of a landscape-scale management approach. *Journal of Applied Ecology*, 48, 532–542.
(21) Heard M.S., Botham M., Broughton R., Carvell C., Hinsley S., Woodcock B., Pywell R.F., Amy S., Bellamy P.E., Hill R.A., Hulmes S., Hulmes L., Meek W.R., Nowakowski M., Peyton J., Redhead J.W., Shore R.F. & Turk A. (2011) Quantifying the effects of Entry Level Stewardship (ELS) on biodiversity at the farm scale: the Hillesden Experiment. *Natural England report*, RP00026.

(22) Merckx T., Marini L., Feber R.E. & Macdonald D.W. (2012) Hedgerow trees and extended-width field margins enhance macro-moth diversity: implications for management. *Journal of Applied Ecology*, 49, 1396–1404.
(23) Delattre T., Vernon P. & Burel F. (2013) An agri-environmental scheme enhances butterfly dispersal in European agricultural landscapes. *Agriculture, Ecosystems & Environment*, 166, 102–109.
(24) Dollar J.G., Riffell S.K. & Burger L.W. (2013) Effects of managing semi-natural grassland buffers on butterflies. *Journal of Insect Conservation*, 17, 577–590.
(25) Holland J.M., Smith B.M., Storkey J., Lutman P.J.W. & Aebischer N.J. (2015) Managing habitats on English farmland for insect pollinator conservation. *Biological Conservation*, 182, 215–222.
(26) Luppi M., Dondina O., Orioli V. & Bani L. (2018) Local and landscape drivers of butterfly richness and abundance in a human-dominated area. *Agriculture, Ecosystems & Environment*, 254, 138–148.

Annual crops

3.12. Increase crop diversity across a farm or farmed landscape

- **Two studies** evaluated the effects on butterflies and moths of increasing crop diversity across a farm or farmed landscape. Both studies were in Switzerland[1,2].

COMMUNITY RESPONSE (2 STUDIES)

- **Richness/diversity (2 studies):** Two replicated, site comparison studies in Switzerland[1,2] found that farms[1] and landscapes[2] with a greater number of habitats[1] or crop types[2] had a similar species richness of butterflies to farms and landscapes with fewer different habitats or crop types.

POPULATION RESPONSE (1 STUDY)

- **Abundance (1 study):** One replicated, site comparison study in Switzerland[1] found that farms with a greater number of habitats had a similar abundance of butterflies to farms with fewer different habitats.

BEHAVIOUR (0 STUDIES)

Background

Agricultural landscapes are often homogenous, with the same crops being grown across a large area. Increasing the diversity of crops within a single farm, or across a farmed landscape, may improve the habitat suitability for butterflies and moths by increasing the availability of resources, or making that availability more consistent over time. For example, differences in flowering time or harvest time may increase the permability of the landscape for butterflies and moths, or mean that nectar resources are available for longer across the summer than if only a single crop type was present.

For studies on increasing diversity within a field, see "*Plant more than one crop per field (intercropping)*".

A replicated, site comparison study in 2009–2011 in 133 mixed farms in the Central Plateau, Switzerland (1) found that farms with a greater number of habitat types (including crop types) had a similar abundance and species richness of butterflies to farms with fewer habitat types. Both the abundance and species richness of butterflies on farms with more different habitats (>3/farm) were similar to farms with fewer habitats (<3/farm) (data presented as model results). A total of 133 farms (17–34 ha, 13–91% arable crops) were managed with "Ecological Compensation Areas" under agri-environment schemes. Management included extensive and low-input meadows with reduced fertilizer and later cutting dates, and the presence of trees, hedgerows and wildflower patches, as well as arable crops and pasture. From May–September 2009–2011, butterflies were surveyed six times on 10–38 transects/farm, totalling 2,500 m/farm. Each transect ran diagonally through a single crop or habitat type, with all available crops and habitats represented. All visits to a farm were completed in a single year, and the species richness was summed across all visits. Total abundance of butterflies was calculated from the number recorded in each habitat, and the availability of each habitat across the farm. Habitats on each farm were mapped between May and August.

A replicated, site comparison study in 2010–2014 in 91 agricultural areas in the Swiss Plateau, Switzerland (2) found that landscapes with a higher diversity of crops had a similar species richness of butterflies to landscapes with lower crop diversity. The species richness of butterflies was similar in agricultural areas with 7–12 different crops (11–33 species) and 1–6 crops (12–33 species). Ninety-one mixed farming areas (1 km^2) were selected where 1–12 crop types were grown. Butterflies were surveyed seven times along a 2.5-km transect through each 1-km^2 area in one of five years (2010–2014).

(1) Stoeckli S., Birrer S., Zellweger-Fischer J., Balmer O., Jenny M. & Pfiffner L. (2017) Quantifying the extent to which farmers can influence biodiversity on their farms. *Agriculture, Ecosystems & Environment*, 237, 224–233.

(2) Zingg S., Grenz J. & Humbert J.-Y. (2018) Landscape-scale effects of land use intensity on birds and butterflies. *Agriculture, Ecosystems & Environment*, 267, 119–128.

3.13. Plant more than one crop per field (intercropping)

- One study evaluated the effects on butterflies and moths of planting more than one crop per field. The study was in Malaysia[1].

COMMUNITY RESPONSE (1 STUDY)

- **Community composition (1 study):** One replicated, site comparison study in Malaysia[1] found that smallholdings planted with oil palm and other crops did not differ in butterfly community composition from those planted with oil palm alone.
- **Richness/diversity (1 study):** One replicated, site comparison study in Malaysia[1] found that smallholdings planted with oil palm and other crops did not have greater butterfly species richness than those planted with oil palm alone.

POPULATION RESPONSE (1 STUDY)

- **Abundance (1 study):** One replicated, site comparison study in Malaysia[1] found that smallholdings planted with oil palm and other crops did not have higher overall butterfly abundance than those planted with oil palm alone.

BEHAVIOUR (0 STUDIES)

Background

Modern agricultural fields normally only contain a single crop (monoculture), making sowing and harvest easier for the farmer. However, for butterflies and moths, this may reduce the availability of foraging resources (Asmah et al. 2017). Planting more than one crop per field (polyculture) may increase the diversity of resources available for butterflies and moths, enabling less mobile species in particular to make better use of the landscape.

For studies on increasing diversity across a farm or farmed landscape, see "*Increase crop diversity across a farm or farmed landscape*".

Asmah S., Ghazali A., Syafiq M., Yahya M.S., Peng T.L., Norhisham A.R., Puan C.L., Azhar B., Lindenmayer D.B. (2017) Effects of polyculture and monoculture farming in oil palm smallholdings on tropical fruit-feeding butterfly diversity. Agricultural and Forest Entomology, 19(1), 70-80

A replicated, site comparison study in 2014 in 120 sites of agricultural land in Selangor, Malaysia (1) found that smallholdings planted with oil palm and other crops (polyculture) did not differ in butterfly species richness, overall abundance or community composition from smallholdings planted with just oil palm (monoculture). There was no difference in the average number of butterfly species (polyculture: 4; monoculture: 3), overall number of individuals (polyculture: 29; monoculture: 36) or the composition of species between oil palm polycultures and monocultures (data presented as model results). Abundances of individual species in polycultures and monocultures were mixed and differences were not tested statistically (see paper for details). At 60 smallholdings oil palms were grown amongst other crops including bananas, coconuts, tapioca and sugar cane (polycultures), and at 60 oil palm was grown alone (monocultures). Smallholdings sampled were ≥300 m apart and mostly <5 ha in size. In January–August 2014, three fruit-baited traps were set ≥50 m apart from each other at each smallholding and operated for 12 h daily for three consecutive days, with regular checking. Butterflies caught were marked before release to avoid recounting. Each smallholding was sampled once.

(1) Asmah S., Ghazali A., Syafiq M., Yahya M.S., Peng T.L., Norhisham A.R., Puan C.L., Azhar B., Lindenmayer D.B. (2017) Effects of polyculture and monoculture farming in oil palm smallholdings on tropical fruit-feeding butterfly diversity. *Agricultural and Forest Entomology*, 19(1), 70-80.

3.14. Plant nectar flower mixture/wildflower strips

- **Twenty-three studies** evaluated the effects of planting nectar flower mixtures, or wildflower strips, on butterflies and moths. Eleven studies were in the UK[1–

[4,6,7,11,12,14,18,19,22], six were in Switzerland[5,8,10,13,16,17], two were in the USA[9,21], and one was in each of Sweden[15], Finland[20] and Germany[23].

COMMUNITY RESPONSE (20 STUDIES)

- **Richness/diversity (20 studies):** Eight of thirteen studies (including twelve replicated studies, two randomized studies, five controlled studies, one before-and-after study, and eight site comparison studies) in the UK[2,3,4,7,14], Switzerland[5,8,10,11,16,17], Finland[20] and Germany[23] found that sown wildflower strips had a higher species richness[2,3,8,10,14,16,20] and diversity[4] of all butterflies[2,3,4,8,10,14,20], generalist butterflies[16], and moths[20] than conventional field margins[2,10], unsown margins[3,4], cropped fields[8,16,20] or conventional grassland[14,16,20]. One of these studies also found that the species richness of specialist butterflies was similar in sown wildflower strips, cropped fields and conventional grassland[16]. Four studies found that the species richness[5,7,13,17] of butterflies was similar between sown wildflower strips and cropped fields[5,13], cropped margins[7], unsown strips[7] or extensively managed meadows[17]. The other study found that, five years after sowing wildflower strips, butterfly species richness, but not diversity had increased at one of two study sites[23]. One replicated, randomized, paired, controlled study in the UK[18] found that the species richness of butterflies and moths was similar on farms managed under agri-environment schemes, including with sown wildflower strips, and on conventionally managed farms. Two replicated studies (including one randomized, controlled study and one site comparison study) in the UK[11] and Sweden[15] found that field margins sown with wildflowers had a greater species richness of butterflies than grass-only field margins[11,15]. One of two replicated, paired, controlled studies (including one randomized study) in the USA[9] and the UK[19] found that plots sown with a mix of wildflowers had a greater species richness of caterpillars than plots sown with a single flower species[9]. The other study found that plots sown with either complex or simpler flower mixes had a similar species richness of butterflies[19]. Two replicated studies (including one randomized, controlled study) in the UK[6,12] found that wildflower plots sown with phacelia[6], borage[6] or lucerne[12] had a higher species richness[12] or diversity[6] of butterflies[6,12] and moths[6] than plots sown with other flower species.

POPULATION RESPONSE (16 STUDIES)

- **Abundance (17 studies):** Ten studies (including nine replicated studies, three randomized studies, three controlled studies and seven site comparison studies) in the UK[1,2,3,4,7,14], Switzerland[10,16,17] and Finland[20] found that sown wildflower strips had a higher abundance of all butterflies[2,3,4,7,10,14,17], generalist butterflies[16], specialist butterflies[20] and meadow brown butterflies[1] than conventional field margins[2,10], unsown margins[1,3,4], cropped fields[16,20], cropped margins[7], conventional grassland[14,16,20] or extensively managed meadows[17]. However, one of these studies only found this effect in one of two study years[7]. Two of these studies also found that the abundance of specialist butterflies[16] and meadow brown caterpillars[1] was similar in sown wildflower strips and unsown margins[1], cropped fields[16] and conventional grassland[16], and one found that the abundance of caterpillars was lower in sown wildflower strips than in conventional grassland[14]. One replicated, randomized, paired, controlled study in the UK[18] found that the abundance of butterflies and micro-moths was higher on farms managed under agri-environment schemes, including with sown wildflower strips, than on conventionally managed farms, but the abundance of other moths was similar. Two replicated studies (including one randomized, controlled study and one site comparison study) in the UK[11] and Sweden[15] found that field margins sown with wildflowers had a higher abundance of butterflies than grass-only field margins[11,15]. One replicated, randomized, controlled study in the UK[22] found that farms with wildflower strips (along with other enhanced agri-environment scheme options) had a higher abundance of some butterflies, but a lower abundance of other butterflies, than farms with simpler agri-environment scheme management such as grass-only margins. One of two replicated, paired, controlled studies (including one randomized study) in the USA[9] and the UK[19] found that plots sown with one of three wildflower mixes had a higher abundance of moths than plots sown with two other mixes or a single flower species[9]. The other study found that plots sown with either complex or simple flower mixes had a similar abundance of butterflies[19]. One replicated, randomized, controlled study in the UK[12] found that wildflower plots sown with lucerne[12] had a higher abundance of butterflies than plots sown with borage, chicory or sainfoin.

BEHAVIOUR (2 STUDIES)

- **Use (2 studies):** Two studies (including one replicated study) in the UK[6] and the USA[21] reported that sown nectar flower plots[6] and tropical milkweed plots[21] were used by six species of butterflies and moths[6] and monarch butterflies and caterpillars[21].

Background

Butterflies and moths often show a preference for areas with more floral resources (Vogel *et al.* 2007), but such resources are absent from intensive arable landscapes. Sown nectar flower mixtures, or wildflower strips, are common components of agri-environment schemes or conservation incentive programs which aim to increase the availability of flowers for insects. However, there can be many differences in the implementation methods used. For example, the exact seed mixture of species sown often differs between geographic regions and individual studies. Excluding grasses from nectar flower mixtures may reduce competition and aid re-establishment of the flowering species, while the rotation of the location of wildflower strips every 2–3 years may also be beneficial, as not all sown species will persist for longer than this (Heard *et al.* 2011).

Nectar flower mixes are normally composed of perennial plants, as opposed to annual species sown in wild bird seed mixes (Pywell et al. 2008). For studies on sowing these mixes, see "*Plant wild bird seed or cover mixture*".

Heard M.S., Botham M., Broughton R., Carvell C., Hinsley S., Woodcock B., Pywell R.F., Amy S., Bellamy P.E., Hill R.A., Hulmes S., Hulmes L., Meek W.R., Nowakowski M., Peyton J., Redhead J.W., Shore R.F. & Turk A. (2011) Quantifying the effects of Entry Level Stewardship (ELS) on biodiversity at the farm scale: the Hillesden Experiment. *Natural England report*, RP00026.

Pywell R., Hulmes L., Meek W. & Nowakowski M. (2008) Creation and Management of Pollen and Nectar Habitats on Farmland: Annual report 2007/8.

Vogel J.A., Debinski D.M., Koford R.R. & Miller J.R. (2007) Butterfly responses to prairie restoration through fire and grazing. *Biological Conservation*, 140, 78–90.

A replicated, randomized, controlled study in 1987–1991 in Oxfordshire, UK (1, same experimental set-up as 2, 3) found that field margins sown with wildflower seed mix had more adult meadow brown *Maniola jurtina* than unsown margins, and that margin management affected butterfly numbers. More adult meadow browns were found on margins sown with wildflowers (4–52 butterflies/50 m) than on unsown margins (4–15 butterflies/50 m). Sown margins also had more butterflies if they were left uncut (13–39 butterflies/50 m), or were cut in spring and autumn (16–52 butterflies/50 m), than if they were cut in summer (4–22 butterflies/50 m). There was no difference in the abundance of meadow brown caterpillars between sown and unsown, or cut and uncut, plots (3 caterpillars/plot). There were more meadow browns on all the experimental field margins than on narrow, unmanaged field boundaries of a neighbouring farm (numbers not given). In October 1987, two-metre-wide field margins around arable fields were rotovated, and either sown with a wildflower seed mix in March 1988 or left to regenerate naturally. Within each sown and unsown margin, 50-m-long plots were managed in one of four ways, with eight replicates of each treatment: uncut; cut once in June; cut April and June; cut in April and September. Hay was collected after cutting. From June–September 1989, and April–September 1990–1991, adult meadow brown were monitored weekly. In spring 1991, meadow brown caterpillars were sampled by sweep netting and visual searching.

A site comparison study in 1988–1991 on two arable farms in Oxfordshire, UK (2, same experimental set-up as 1, 3) reported that a farm where wider field margins (some of which were sown with grasses and non-woody broadleaved plants “forbs”) had been established, and fertilizer application excluded, had a higher abundance and species richness of butterflies than a farm with conventional field margins. Results were not tested for statistical significance. The abundance of eight species (including small skipper *Thymelicus sylvestris*, small heath *Coenonympha pamphilus*, gatekeeper *Pyronia tithonus* and meadow brown *Maniola jurtina*) was higher on a farm with wider (2-m) field margins, including those sown, than on a farm with conventional (0.5-m) margins. No species was more abundant on the conventional farm. In addition, two species (marbled white *Melanargia galathea* and common blue *Polyommatus icarus*) were only recorded on the farm with wide margins, resulting in a higher species richness (16 species) than the conventional farm (14 species). In 1988, the margins of 10 fields on one farm were extended from 0.5-m to 2-m wide, and fertilizer application was excluded. Margins were either sown with grasses and forbs or left to regenerate naturally. Margins were either left uncut, or cut in some combination of April, June and September 1989–1991. In summer 1991, butterflies were surveyed for two months on transects on this farm and on a second, intensively managed farm with conventional field margins (number not given).

A replicated, randomized, controlled study in 1987–1991 in Oxfordshire, UK (3, same experimental set-up as 1, 2) found that butterfly abundance and species richness were higher in sown wildflower margins than in unsown, naturally generated margins. From two years after establishment, both individual abundance (21–91 individuals/50 m) and species richness (7–10 species/50 m) of butterflies were higher in sown wildflower margins than in unsown margins (abundance: 14–39 individuals/50 m; richness: 6–9 species/50 m). Additionally, in all three years, sown margins had more butterflies if they were left uncut (abundance: 49–91 individuals/50 m; richness: 9–10 species/50 m), or were cut in spring and autumn (abundance: 27–88 individuals/50 m; richness: 7–9 species/50 m), than if they were cut in summer (abundance: 21–46 individuals/50 m; richness: 7–10 species/50 m). In autumn 1987, two-metre-wide field margins around arable fields were rotovated. In April 1988, half were sown with a seed mixture (3 kg/ha) containing six grasses and 17 non-woody broadleaved plants (forbs). The rest were left to regenerate naturally. Within each sown and unsown margin, 50-m-long plots were managed in one of four ways, with eight replicates of each treatment: uncut; cut once in June; cut April and June; cut in April and September. Hay was collected after cutting. Butterflies were monitored weekly from June–September 1989 and from April–September 1990 and 1991.

A replicated, site comparison study in 1994–1996 on an arable farm in Gloucestershire, UK (4) found that the abundance and diversity of butterflies was higher in margins sown with wildflowers than in naturally regenerated field margins, and that margin management affected butterfly diversity. Sown wildflower margins had a higher abundance (15–16 individuals) and diversity (6–7 species) of butterflies than naturally regenerated margins (abundance: 5–10 individuals; diversity: 3–6 species). Cutting and subsequent grazing of the sown margins decreased butterfly diversity (5.6 species) but not abundance (14.6 individuals) compared to margins which were not cut or grazed (diversity: 6.8 species; abundance: 16.3 individuals). In 1994, two-metre margins were established around two organically managed arable fields by either sowing a seed mix (containing five grasses and six wildflowers) or by natural regeneration. In 1996, half of the margins were cut in June and grazed in July. The rest were left unmanaged. From May–September 1996, butterflies were monitored weekly along transects.

A replicated, site comparison study in 1998 in two agricultural regions in the Swiss Plateau, Switzerland (5, same study as 8) found that the species richness of butterflies in wildflower strips sown on set-aside areas was similar to winter wheat fields. Butterfly species richness in the wildflower strips (more than 6 species) differed significantly only from forest edges (fewer than 4 species). However, wildflower strips attracted some species of butterfly that were never or only rarely found in other habitats. Across two arable regions, 109 sites were composed of eight habitat types: Ecological Compensation Areas including eleven wildflower strips on set-aside land, five hedgerows, 19 extensively managed meadows, 16 low intensity meadows and eight orchard meadows, along with 20 winter wheat fields, seven intensively managed meadows and 23 forest edges. From May–September 1998, butterflies were observed for 10 minutes on each of six visits to each site (0.25 ha/site).

A replicated study in 1996–1997 on an experimental farm in Hertfordshire, UK (6) reported that sown nectar flower mixtures were used by six species of butterfly and moth. Five species of butterfly (small skipper *Thymelicus sylvestris* (3 individuals), common blue *Polyommatus icarus* (4 individuals), small tortoiseshell *Aglais urticae* (17 individuals), painted lady *Cynthia cardui* (4 individuals) and small white *Pieris rapae* (18 individuals)) and one moth (silver Y *Autographa gamma* (327 individuals)) used nectar flower mixtures sown with six plant species. Phacelia *Phacelia tanacetifolia* and borage *Borago officinalis* attracted the highest diversity of butterflies and moths (5 species), but individual species preferred different plants (see paper for details). From mid-April to mid-July 1996 and 1997, one plot/month (22 × 14 m in 1996, 20 × 13 m in 1997) was sown with a seed mixture containing borage, phacelia, buckwheat *Fagopyrum esculentum*, cornflower *Centaurea cyanus*, mallow *Malva sylvestris* and marigold

Calendula officinalis at 91 kg/ha (1996) or 22 kg/ha (1997), and then harrowed. Flower-visiting butterflies and moths were recorded on 34 days from June–October 1996 and 21 days from June–November 1997 by walking around the edge of each plot.

A replicated, controlled study in 1999–2000 in four arable sites in North Yorkshire, UK (7) found that butterfly abundance was higher along margins sown with a grass and wildflower seed mix or a combination of grass and wildflower seed mix and tussocky grass seed than along margins left to regenerate naturally or those sown with cereal crop, but there was no difference in butterfly species richness between any of the treatments. More butterflies were seen along margins sown with a grass and wildflower seed mix (average: 44 individuals) or where half their width had been sown with grass and wildflower seed mix and half with tussocky grass seed (average: 33) than along margins which regenerated naturally (average: 14) or those sown with cereal crop seed (average: 9). However, there was no difference in butterfly abundance along margins sown with a grass and wildflower seed mix or a split margin of grass and wildflower seed mix and tussocky grass seed than along margins sown with tussocky grass seed alone (average: 21). There was no difference in species richness between any of the treatments (see paper for details). Four 6 m wide margins of winter cereal fields (all adjacent to hedges) on two farms were split into 72 m long plots and sown in September 1999 with either a tussocky grass mix, a grass and wildflower mix, half the width tussocky grass and half grass and wildflower mix, cereal crop or left to regenerate naturally. Butterflies were surveyed weekly from May–September 2000 using walking transects (21 surveys/field in total).

A replicated, site comparison study in 1998 in the arable region of Rafz, Swiss Plateau, Switzerland (8, same study as 5) found that butterfly species richness was higher in wildflower strips than in intensively managed wheat fields. Wildflower strips planted as Ecological Compensation Areas had more species of butterfly than intensively managed wheat fields (data not presented). Eleven wildflower strips and 20 wheat fields were sampled. Butterflies were observed for 10-minute periods on 0.25 ha of each site, on five occasions from May–August 1998, between 10:00–17:30 h on sunny days with temperatures of at least 18 °C.

A replicated, paired, controlled study in 2003 on an arable farm in North Carolina, USA (9) found that plots sown with one of three commercial seed mixes had a higher abundance of adult moths than the other two mixes or single species plots, and all three mixes had a higher species richness of caterpillars than single species plots. Plots sown with "Border Patrol" seed mix were visited by more adult hawk moths (Sphingidae: 1.8 individuals/minute) and noctuid moths (Noctuidae: 2.1 individuals/minute) than plots sown with "Beneficial Insect Mix" or "Good Bug Blend" (hawk moths: 0.1; noctuid moths: 0.8–1.1 individuals/minute) or single species of cut flowers or herbs (hawk moths: 0.0; noctuid moths: 1.0–1.6 individuals/minute). The species richness of non-pest herbivores (including geometrid moth (Geometridae), brush-footed butterfly (Nymphalidae) and skipper (Hesperiidae) caterpillars), was similar in all three seed mixes (8 species/plot) and higher than in the single species plots (5–6 species/plot). In March 2003, seeds from three commercial mixes were separated and sown in a greenhouse, along with seeds of three cut flowers/herbs (fennel *Foeniculum* *vulgare*, common zinnia *Zinnia elegans*, cockscomb *Celosia cristata*). In May 2003, plants were transplanted to field plots (6.0 × 1.2–2.1 m), arranged in three blocks, in their original mixes and relative abundance. Dead plants were replaced for two weeks, and hand-weeded. Plots were separated by 1.5-m millet strips. All areas had been pesticide-free for ≥3 years. On eight days in June–August 2003, insects were collected with a D-Vac vacuum sampler, and two aerial nets, for 1 min/plot. On four nights in July–August 2003, moths were observed visiting each plot for one minute, three times/night, in the hour after dusk.

A replicated, site comparison study in 2001–2005 in an arable region in Basel, Switzerland (10) found that wildflower strips sown with a 'locally adapted' mix of grass and flower species (species local to the area) had a higher abundance and species richness of butterflies than conventionally cropped margins. The 'locally adapted' field margins had more butterfly species and individuals than standard wildflower strips, and 40 times more species and individuals than conventional cropped margins (data not presented). In 2001, seven field margins (5 x 120 m) were sown with seeds of up to 38 native grass and wildflower species ('locally adapted' mix). Half of each margin was cut lengthwise, alternately, in late August each year. Butterflies were counted five times from May–August 2003 and 2005 on these 'locally adapted' margins, 10 standard wildflower strips, and 10 conventional cropped margins.

A replicated, randomized, controlled study in 2002–2006 on three farms in eastern England, UK (11) found that field margins sown with a flower mix designed for pollinating insects did not support more butterflies than floristically-enhanced grass margins, but both supported more butterflies than grass-only margins. In margins sown with either a pollinating insect mix or a grass and wildflower mix the abundance (18–20 individuals/plot) and species richness (6 species/plot) of butterflies was similar, but both were higher than in grass-only margins (abundance: 12 individuals/plot; richness: 5 species/plot). Management of the margins did not affect either the abundance or species richness of butterflies (data not presented). Field margin plots (6 × 30 m) were established in 2000–2001 using one of three seed mixes: a mixture of grasses and wildflowers designed for pollinating insects (four grass species, 16–20 wildflowers, sown at 35 kg/ha), a floristically-enhanced "tussock grass mix" (seven grass species, 11 wildflowers, sown at 35 kg/ha), and a grass-only "Countryside Stewardship mix" (seven grass species, sown at 20 kg/ha). Margins were managed in spring from 2003–2005 with one of three treatments: cut to 15 cm, soil disturbed by scarification until 60% of the area was bare ground, treated with grass-specific herbicide in spring at half the recommended rate. There were five replicates of each treatment combination on three farms. No further details provided.

A replicated, randomized, controlled study in 2006–2007 on a farm in Warwickshire, UK (12) found that butterfly abundance and species richness differed between three plant species commonly sown in nectar flower mixtures. In 2006, more butterflies were found in plots sown with lucerne *Medicago sativa* (6.3 individuals/plot) than plots sown with borage *Borago officinalis* (0.3 individuals/plot), chicory *Cichorium intybus* (0.8 individuals/plot) and sainfoin *Onobrychis viciifolia* (0.8 individuals/plot). More butterfly species were found in lucerne plots (3.5 species/plot) than in borage, chicory, sainfoin and fodder radish

Raphanus sativus (0.3–0.5 species/plot). There was no significant difference in abundance (1.0–3.3 individuals/plot) or species richness (1.0–2.8 species/plot) between the other plant species. In 2007, red clover *Trifolium pratense* had more butterflies (3.3 individuals/plot) than chicory (0.0 individuals/plot), but the abundance on all other plant species was similar (0.3–2.3 individuals/plot) and there were no significant differences in species richness (0.0–1.8 species/plot). In May 2006, three perennial species sown in pollen and nectar mixtures (chicory, red clover, sainfoin) and 10 small-seeded crop species commonly sown in wild bird seed mixtures (borage, buckwheat *Fagopyrum esculentum*, crimson clover *Trifolium incarnatum*, fodder radish, linseed *Linum usitatissimum*, lucerne, mustard *Brassica juncea*, phacelia *Phacelia tanacetifolia*, sunflower *Helianthus annuus* and sweet clover *Melilotus officinalis*) were sown individually in 6 × 4 m plots, replicated four times. Annual species were re-sown May 2007. Butterflies were surveyed six times/year, from July–September 2006 and May–September 2007.

A replicated, controlled study in 1998–2004 in an arable farmland region in central Switzerland (13) found that wildflower strips contained similar numbers of butterfly species to crop fields. The estimated number of butterfly species on wildflower strips (19 species) was the same as on conventional crop fields (19 species). The study sampled 78 wildflower strips (sown with 20–40 plant species) and 72 crop fields. From 1998–2004, butterflies were surveyed every two years between May and September, using five 10-minute observation periods across 0.25 ha/field.

A replicated, randomized, controlled study in 2002–2006 on four lowland farms in Devon and Somerset, UK (14) found that plots sown annually with mixes including legumes had a higher abundance and species richness of butterflies, but a lower abundance of caterpillars, than grassland plots. In the first two years, plots sown with legume mixes had a higher abundance (4–10 individuals/transect) and species richness (2–4 species/transect) of adult butterflies than extensively (abundance: 3–5 individuals/transect; richness: 2 species/transect) or conventionally managed (abundance: 1–2 individuals/transect; richness: 1 species/transect) grassland. However, there were fewer caterpillars in the sown plots (0–3 caterpillars/transect) than the extensively (1–8 caterpillars/transect) or conventionally managed (0–7 caterpillars/transect) grassland. In April 2002, experimental plots (50 × 10 m) were established on permanent pastures (>5-years-old) on four farms. There were nine treatments, with three replicates/farm. Two legume-sown treatments comprised barley *Hordeum vulgare* undersown with seven grasses and five legumes, and a mix of six crops and four legumes. Two extensive grassland treatments had minimal disturbance during summer and five conventional grassland treatments included modifications to conventional silage management (reducing fertilizer application, cutting and grazing). From June–September 2003–2006, butterflies were surveyed once/month on a 50-m transect through the centre of each plot. In April, June, July and September 2003–2006, caterpillars were counted (but not identified) on two 10-m transects/plot using a sweep net (20 sweeps/transect).

A replicated, site comparison study in 2007 at four arable farms in south Sweden (15) found higher abundance and species richness of butterflies in sown wildflower strips than in grass margins (greenways or 'beträdor'). In wildflower strips, the abundance of butterflies (10.4 individuals/100 m) was higher than in grass margins (0.6–1.4 individuals/100 m). In total, 86% of the recorded butterflies were found in the wildflower strips compared to 14% in the grass margins. Four species of butterfly were only found in the wildflower strips. Margins with more field scabious *Knautia arvensis* had higher species richness and abundance of butterflies (data presented as model results). At one farm, six wildflower strips (total 2.9 km) were sown in the mid-1990s using either a commercial mix of wildflowers and grasses, or hay from a nearby meadow, and were cut once a year at the end of July. At three farms, 14 grass strips (total 6.8 km) were sown with a mixture of grass species in the 1990s, 2004 and 2005, and were cut several times a year. Butterflies and the abundance of key flower species were recorded on transects five times from June–September 2007.

A replicated, site comparison study in 2000–2004 in an arable landscape in the Swiss Plateau, Switzerland (16) found that wildflower strips contained a higher abundance and species richness of generalist but not specialist butterflies than other arable habitats. For generalist butterflies, both the average abundance (24.0 individuals) and species richness (7.0 species) were higher in wildflower strips than in conventional grassland (abundance: 12.0, richness: 5.0) or wheat, maize and root crop fields (abundance: 2.6–3.7, richness: 1.8–2.2). However, for specialist butterflies there was no significant difference in abundance or richness (wildflower: abundance = 2.4, richness = 1.0; grassland: abundance = 0.6, richness = 0.5; crops: abundance = 0.4, richness = 0.2). Species richness of generalists was also higher in fields with more wildflower strips in the surrounding area (data presented as model results). From 1994–2004, within an 822-ha arable landscape, wildflower strips were sown with buckwheat as ground cover, and 30–40 wild plant species. They received no fertilizer or pesticide, and were not cut between 15 March and 1 October. In 2000, 2002 and 2004, butterflies were surveyed in five habitats: wildflower strips, conventional grassland, wheat fields, root crops and maize fields. Each year, 37–39 fields were sampled with 5 × 10-minute surveys every 2–3 weeks between May and August. The surrounding land cover (200-m radius) was mapped from aerial photographs. Generalist and specialist species were determined based on the number of caterpillar food plants.

A replicated, site comparison study in 2008 in a lowland agricultural landscape in Kanton Fribourg, Switzerland (17) found that sown wildflower strips had a higher abundance of butterflies, but a similar species richness and a different community composition, compared to extensively managed meadows. The abundance of butterflies in sown wildflower strips (0.29 individuals/m) was higher than in extensively managed meadows (0.12 individuals/m), but the species richness was similar in wildflower strips (0.07 species/m) and meadows (0.05 species/m). The species composition was different between the two habitats, with seven of 25 species occurring only in wildflower strips, and six species observed most frequently in the meadows. None of the five rarest species in the region were recorded in wildflower strips or meadows. See paper for details on individual species. Twenty-five wildflower strips (0.15–1.16 ha) were sown with a standard seed mixture of 24 plant species, and were 1–7 years old. Eleven meadows (0.21–1.64 ha) were cut at least twice/year after mid-June. From May–

September 2008, butterflies were surveyed once/month on a transect through the middle of each wildflower strip (70–450 m) or meadow (85–310 m).

A replicated, randomized, paired, controlled study in 2005–2011 on an arable farm in Buckinghamshire, UK (18) found that land managed under an agri-environment scheme, including sowing nectar flower mixtures, had a higher abundance, but not species richness, of butterflies and micro-moths than conventional farms, but there was no difference in abundance or species richness of other moths. Butterfly abundance was higher under enhanced Entry-Level Stewardship (ELS) (5,400 individuals/60 ha) and standard ELS (2,000 individuals/60 ha) than under conventional farming (1,400 individuals/60 ha). Micro-moth abundance was also higher under enhanced ELS (79 individuals) than standard ELS (32 individuals) or conventional farming (20 individuals). However, the abundance of macro-moths and threatened moths was similar under enhanced ELS (macro: 126; threatened: 6 individuals), standard ELS (macro: 79; threatened: 5 individuals) and conventional farming (macro: 79; threatened: 6 individuals). Species richness of all groups was similar under enhanced ELS (macro: 20; micro: 11; threatened: 3 species), standard ELS (macro: 20; micro: 8; threatened: 2 species) and conventional farming (macro: 18; micro: 5; threatened: 2 species) (butterfly data not presented). In 2005, a 1,000-ha farm was divided into five 180-ha blocks. Three 60-ha areas/block were assigned to three treatments: enhanced ELS (5% land removed from production, field corners sown with four grasses and 25 non-woody broadleaved plants (forbs), nectar flower mixtures sown with four legumes); standard ELS (1% land removed from production); conventional farming (see paper for other details). From May–August 2006–2011, butterflies were recorded four times/year on one 50-m transect/60-ha area, passing through all available habitats. In late-May 2007–2011 and late-July 2006–2011 moths were surveyed using Robinson light traps. One block was surveyed/night, with one trap/treatment.

A replicated, randomized, paired, controlled study in 2003–2005 in an arable farm in Yorkshire, UK (19) found that margins sown with complex seed mixes did not have a higher abundance or species richness of butterflies than simple mixes, but the timing of cutting and removal of cuttings did affect butterfly numbers. The abundance and species richness of butterflies was similar in plots sown with simple (abundance: 6–11 individuals/150 m^2; richness: 3–4 species/150 m^2) or complex (abundance: 6–8 individuals/150 m^2; richness: 3 species/150 m^2) seed mixes. In the first year of management, butterfly abundance (1–2 individuals/150 m^2) and species richness (1 species/150 m^2) were lower in plots cut in June than in plots cut at other times of year (abundance: 17 individuals/150 m^2; richness: 4–5 species/150 m^2). However, in the second year, there was a higher abundance, but not species richness, of butterflies in plots cut in April and June (9 individuals/150 m^2; 4 species/150 m^2) or October (8 individuals/150 m^2; 5 species/150 m^2) than plots cut in April and October (3 individuals/150 m^2; 2 species/150 m^2). Plots where cuttings were removed in April and June had a higher abundance and species richness of butterflies than plots where cuttings were left, but plots where cuttings were removed in October had a lower abundance and species richness than plots where cuttings were left (data not presented). In April 2003, two margins (200 × 6 m) were established in each of two cereal fields. One margin/field was sown with six legumes, common knapweed *Centaurea nigra*, and six grasses at 20 kg/ha (£140/ha), and the other was sown with four legumes and three grasses at 20 kg/ha (£55/ha). Margins were cut three times in 2003 with cuttings removed. In April 2004, each margin was sub-divided into eight 25 × 6 m plots, which were randomly assigned to one of eight treatments: cut in October, cut in October and April, cut in October and June, or cut in April and June, each with cuttings left in place or removed. From May–September 2004–2005, butterflies were counted 7–8 times/year on a 25-m transect through the middle of each plot.

A replicated, controlled study in 2007–2010 in six arable fields in Jokioinen, Finland (20) found that sown wildflower strips had a higher abundance of habitat specialist butterflies and total species richness of butterflies, moths and bumblebees (*Bombus* spp.) combined than either grass or cereal fields, or permanent field margins. Three years after sowing, the abundance of habitat specialist butterflies (1.5–3.1 individuals/strip) and total species richness of butterflies, moths and bumblebees (16–21 species/strip) were higher in wildflower strips than in reed canary grass *Phalaris arundinacea* (butterflies: 0.1–0.6 individuals/strip; richness: 2–7 species/strip), spring cereals (butterflies: 0 individuals/strip; richness: 1 species/strip) or permanent margins (butterflies: 0.9–1.2 individuals/strip; richness: 10–12 species/strip). Neither the diversity of the sown seed mixture, nor the shape, location or orientation of the wildflower strip, affected butterfly abundance or total species richness (see paper for details). In May 2007, six wildflower strips were sown in each of six fields. Five strips/field were sown with five wildflower species, and one was a monoculture of brown knapweed *Centaurea jacea*. Five strips/field were 5 × 50 m, and one was 10 × 25 m. Strips were located at the field edge, either adjacent to another field or to forest, or in the centre of the field. From May–August 2007–2010, butterflies, moths and bumblebees were surveyed seven times along one 5 × 50 m transect/wildflower strip, and in four strips/field within the surrounding crop (reed canary grass or spring cereals) and two strips/field in permanent, unsown field margins.

A study in 2009 on a peanut-cotton farm in Georgia, USA (21) reported that tropical milkweed *Asclepias curassavica* plants placed between peanut and cotton fields were used by monarch butterflies *Danaus plexippus*. Milkweed plants were visited by 0–0.03 monarch butterflies/plant/observation. Monarch caterpillars were also observed feeding on milkweed plants and developing in to pupae. In 2009, four plots (23 × 61 m) were established between a 10-ha peanut field and 9-ha cotton field (each planted in May). Two weeks before cotton bolls appeared, 25 potted, greenhouse grown, flowering tropical milkweed plants/plot were placed 1.2 m apart along a 1-m-wide strip of bare ground between the crops. On eight days in August 2009, each milkweed plant was observed for 15 seconds/day to record adult monarchs feeding on the flowers, and the presence of caterpillars was noted.

A replicated, randomized, controlled study in 2007–2010 on 28 arable farms in Wessex and East Anglia, UK (22) found that farms with enhanced agri-environment scheme (AES) habitats, including wildflower strips, had a higher abundance of some butterfly species than farms with simpler AES habitats. In early summer, farms with enhanced AES habitats had a higher abundance of blue

(Lycaenidae: 0.05 individuals/100 m) and white (Pieridae: 0.46 individuals/100 m) butterflies along boundaries than farms with Entry Level Scheme (ELS) habitats (blues: 0.04; whites 0.21 individuals/100 m), but a lower abundance of skippers (Hesperiidae) in the AES habitat itself (enhanced: 0.00; ELS: 0.02 individuals/100 m). In mid-summer, enhanced AES farms had a higher abundance of white butterflies (0.69 individuals/100 m), but a lower abundance of brown butterflies (Satyridae: 0.16 individuals/100 m) in the AES habitat, and a lower abundance of blue butterflies (0.05 individuals/100 m) along boundaries than ELS farms (whites: 0.38; browns: 0.49; blues: 0.11 individuals/100 m). In spring 2007, twenty-four farms (12 in East Anglia and 12 in Wessex) were randomly assigned to two treatments: 16 farms with enhanced AES habitat (1.5–6.0 ha of wildflower strips, floristically-enhanced grass mixes, wild bird seed mixes and natural regeneration by annual cultivation); and eight farms with ELS habitat (1.5–6.0 ha of grass margins and game cover (usually maize)). Two additional ELS farms/region, already managed organically with 1.5 ha of ELS habitat, were also studied. From 2008–2010, butterflies were surveyed twice/year on 11 fixed 100-m transects, in mid-May–mid-June and mid-July–early August. Eight transects/site were located in AES habitat, and three transects/site were located on field boundaries away from the AES habitat.

A replicated, controlled, before-and-after study in 2010–2015 at two arable sites in Baden-Württemberg, Germany (23) found that five years after starting to sow wildflower strips butterfly species richness increased at one site, but not at the other, compared to before sowing, and there was no difference in species diversity between before and after sowing at either site. At one site there were more butterfly species five years after sowing wildflower strips than before sowing (maximum species after: 21; before: 10), and on average there were seven more species in the areas sown with wildflowers than in areas not sown with wildflowers. At the other site there were no differences. There were no differences in species diversity between before and after sowing wildflowers in the areas that had been sown at either site. From 2011–2015, mixtures of annual seeds were sown in spring in strips distributed across 50 ha areas on two farms. From 2012–2015 perennial and winter-hardy seeds were also sown in autumn. On each farm, a 50 ha area with no wildflower sowing was also monitored as a control. From 2010–2015, butterflies were surveyed along 250 m transects in the most florally diverse areas of the treatment and control areas (5 transects in the treatment areas, 4 in the controls, in both farms). Each transect was surveyed twice daily on five days between April and August each year.

(1) Feber R.E., Smith H. & Macdonald D.W. (1994) The effects of field margin restoration on the meadow brown butterfly (*Maniola jurtina*). *British Crop Protection Council Monographs*, 58, 295–300.

(2) Feber R.E. & Smith H. (1995) Butterfly conservation on arable farmland. pp 84–97 in: Pullin A.S. (ed) *Ecology and Conservation of Butterflies*. Springer, Dordrecht.

(3) Feber R.E., Smith H. & Macdonald D.W. (1996) The effects on butterfly abundance of the management of uncropped edges of arable fields. *Journal of Applied Ecology*, 33, 1191–1205.

(4) Feber R.E. & Hopkins A. (1997) Diversity of plant and butterfly species on organic farmland field margins in relation to management. *British Grassland Society Fifth Research Conference*, University of Plymouth, Devon, UK, 8-10 September 1997, 63–64.

(5) Jeanneret P., Schüpbach B., Steiger J., Waldburger M. & Bigler F. (2000) Evaluation of ecological measures: Spiders and butterflies. *Agrarforschung*, 7, 112–116.

(6) Carreck N.L. & Williams I.H. (2002) Food for insect pollinators on farmland: insect visits to flowers of annual seed mixtures. *Journal of Insect Conservation*, 6, 13–23.
(7) Meek B., Loxton D., Sparks T., Pywell R., Pickett H. & Nowakowski M. (2002) The effect of arable field margin composition on invertebrate biodiversity. *Biological Conservation*, 106(2), 259-271.
(8) Jeanneret P., Schupbach B. & Pfiffner L. (2003) Arthropod reaction to landscape and habitat features in agricultural landscapes. *Landscape Ecology*, 18, 253–263.
(9) Forehand L.M., Orr D.B. & Linker H.M. (2006) Insect communities associated with beneficial insect habitat plants in North Carolina. *Environmental Entomology*, 35, 1541–1549.
(10) Jacot K., Eggenschwiler L., Junge X., Luka H. & Bosshard A. (2007) Improved field margins for a higher biodiversity in agricultural landscapes. *Aspects of Applied Biology*, 81, 277–283.
(11) Pywell R.F., Meek W.M., Carvell C. & Hulmes L. (2007) The SAFFIE project: enhancing the value of arable field margins for pollinating insects. *Aspects of Applied Biology*, 81, 239–245.
(12) Pywell R., Hulmes L., Meek W. & Nowakowski M. (2008) Creation and Management of Pollen and Nectar Habitats on Farmland: Annual report 2007/8.
(13) Aviron S., Nitsch H., Jeanneret P., Buholzer S., Luka H., Pfiffner L., Pozzi S., Schüpbach B., Walter T. & Herzog F. (2009) Ecological cross compliance promotes farmland biodiversity in Switzerland. *Frontiers in Ecology and the Environment*, 7(5), 247-252.
(14) Potts S.G., Woodcock B.A., Roberts S.P.M., Tscheulin T., Pilgrim E.S., Brown V.K. & Tallowin J.R. (2009) Enhancing pollinator biodiversity in intensive grasslands. *Journal of Applied Ecology*, 46, 369–379.
(15) Haaland C. & Gyllin M. (2010) Butterflies and bumblebees in greenways and sown wildflower strips in southern Sweden. *Journal of Insect Conservation*, 14, 125–132.
(16) Aviron S., Herzog F., Klaus I., Schüpbach B. & Jeanneret P. (2011) Effects of wildflower strip quality, quantity and connectivity on butterfly diversity in a Swiss arable landscape. *Restoration Ecology*, 19 (4), 500–508.
(17) Haaland C. & Bersier L. (2011) What can sown wildflower strips contribute to butterfly conservation?: an example from a Swiss lowland agricultural landscape. *Journal of Insect Conservation*, 15, 301–309.
(18) Heard M.S., Botham M., Broughton R., Carvell C., Hinsley S., Woodcock B., Pywell R.F., Amy S., Bellamy P.E., Hill R.A., Hulmes S., Hulmes L., Meek W.R., Nowakowski M., Peyton J., Redhead J.W., Shore R.F. & Turk A. (2011) Quantifying the effects of Entry Level Stewardship (ELS) on biodiversity at the farm scale: the Hillesden Experiment. *Natural England report*, RP00026.
(19) Pywell R.F., Meek W.R., Hulmes L., Hulmes S., James K.L., Nowakowski M. & Carvell C. (2011) Management to enhance pollen and nectar resources for bumblebees and butterflies within intensively farmed landscapes. *Journal of Insect Conservation*, 15, 853–864.
(20) Korpela E.-L., Hyvönen T., Lindgren S. & Kuussaari M. (2013) Can pollination services, species diversity and conservation be simultaneously promoted by sown wildflower strips on farmland? *Agriculture, Ecosystems & Environment*, 179, 18–24.
(21) Tillman P.G. & Carpenter J.E. (2014) Milkweed (Gentianales: Apocynaceae): A Farmscape Resource for Increasing Parasitism of Stink Bugs (Hemiptera: Pentatomidae) and Providing Nectar to Insect Pollinators and Monarch Butterflies. *Environmental Entomology*, 43, 370–376.
(22) Holland J.M., Smith B.M., Storkey J., Lutman P.J.W. & Aebischer N.J. (2015) Managing habitats on English farmland for insect pollinator conservation. *Biological Conservation*, 182, 215–222.
(23) Buhk C., Oppermann R., Schanowski A., Bleil R., Lüdemann J. & Maus C. (2018) Flower strip networks offer promising long term effects on pollinator species richness in intensively cultivated agricultural areas. *BMC Ecology*, 18(55).

3.15. Plant wild bird seed or cover mixture

- **Seven studies** evaluated the effects of planting wild bird seed or cover mixture on butterflies and moths. All seven were in the UK[1–7].

COMMUNITY RESPONSE (4 STUDIES)

- **Richness/diversity (4 studies):** Two of three replicated, controlled studies (including two randomized and one paired study) in the UK[3,5,6] found that plots sown with wild bird seed mixture had a greater species richness of butterflies than wheat crop[3] or extensively or conventionally managed grassland[5]. The other study found that land managed under an agri-environment scheme, including wild bird seed plots, had a similar species richness of butterflies to conventional farmland[6]. One replicated, randomized, controlled study in the UK[4] found that plots sown with lucerne had a greater species richness of butterflies than plots sown with borage, chicory, sainfoin and fodder radish.

POPULATION RESPONSE (7 STUDIES)

- **Abundance (7 studies):** Two replicated, controlled studies (including one randomized study) in the UK[3,5] found that plots sown with wild bird seed had a higher abundance of butterflies than wheat crop[3] or extensively or conventionally managed grassland[5], but that caterpillar abundance was lower in wild bird seed plots than either grassland[5]. Two replicated, site comparison studies in the UK[1,2] found that the abundance of butterfly and moth caterpillars in wild bird seed plots was similar to a range of other cropped and non-cropped farm habitats[1,2]. Two replicated, randomized, controlled studies (including one paired study) in the UK[6,7] found that farms with wild bird seed plots (along with other agri-environment scheme options) had a higher abundance of some butterflies[6,7] and micro-moths[6], a similar abundance of macro-moths[6], but a lower abundance of other butterflies[7], than farms without agri-environment scheme management. One replicated, randomized, controlled study in the UK[4] found that plots sown with lucerne and red clover had a higher abundance of butterflies than plots sown with borage, chicory and sainfoin.

BEHAVIOUR (0 STUDIES)

Background

Wild bird seed mixtures are commonly sown as part of agri-environment schemes aimed at restoring bird populations. Seed mixtures can contain a wide variety of plants, predominantly annual species, and are therefore re-sown every one or two years. Some commonly used plants may provide beneficial resources, in particular nectar, to butterflies and moths.

Wild bird seed mixes are normally composed of annual plants, as opposed to perennial species sown in nectar flower mixes (Pywell et al. 2008). For studies on sowing these mixes, see "*Plant nectar flower mixture/wildflower strips*".

Pywell R., Hulmes L., Meek W. & Nowakowski M. (2008) Creation and Management of Pollen and Nectar Habitats on Farmland: Annual report 2007/8.

A replicated, site comparison study in 2000 on a lowland arable farm in Leicestershire, UK (1, same experimental set-up as 2) found that wild bird cover contained similar densities of caterpillars to in other field edge habitats. There was no difference in caterpillar densities between habitat types (data not presented).

Ten edge habitats (first-year wild bird cover, second-year wild bird cover, non-rotational set-aside, beetle banks, brood cover, hedge bottoms, sheep-grazed pasture edges, ungrazed pasture edges, grass/wire fence lines and winter wheat headlands) were included in the study (sample size not given). Caterpillars were sampled with a vacuum suction sampler in June 2000 (no further details provided).

A replicated, site comparison study in 1995–1999 on an arable farm in Leicestershire, UK (2, same experimental set-up as 1) found that the abundance of moth and butterfly caterpillars was similar in non-crop strips (wild bird cover or grass beetle banks) and crop fields in most years. The abundance of moth and butterfly caterpillars was similar in non-crop strips (0–1 individuals/sample) and crop fields (0–1 individuals/sample) in four out of five years. In 1996, the abundance of caterpillars was lower in non-crop strips (0.4 individuals/sample) than in crop fields (0–2.2 individuals/sample). However, a composite group of key 'chick food insects' (including caterpillars) had higher densities in non-crop strips (65 individuals/sample) than in crop fields (2–10 individuals/sample) in all years. Wild bird cover was sown as 2–5-m-wide strips along field boundaries and re-sown every few years with a cereal or kale-based *Brassica* spp. mixture. Grass beetle banks (1 m wide) were sown onto a raised bank along edges or across the centre of fields. Invertebrates were sampled each year in the centre of 5–11 wild bird cover strips or grass beetle banks, and 3-m into 3–4 pasture, 8–12 wheat, 6–8 barley, 3–6 oilseed rape and 4 field bean fields. Two samples of 0.5 m^2 were taken in each habitat using a D-Vac suction sampler in June 1995–1999.

A replicated, controlled study in 2004–2005 on four arable farms in southern England, UK (3) found that sown wild bird seed mix plots had a higher abundance and species richness of butterflies than wheat crop. The abundance and species richness of butterflies were higher in the wild bird mix plots than in the crop (data not presented). In April 2004 and 2005, a seed mix containing white millet *Echinochloa esculenta*, linseed *Linum usitatissimum*, radish *Raphanus sativus* and quinoa *Chenopodium quinoa* was sown in a 150 × 30 m patch in the centre of an arable field (winter wheat) on each of four farms in Cambridgeshire, Bedfordshire, Oxfordshire and Buckinghamshire. Butterflies were counted in each patch in summer 2005.

A replicated, randomized, controlled study in 2006–2007 on a farm in Warwickshire, UK (4) found that butterfly abundance and species richness differed between 10 plant species commonly sown in wild bird seed mixtures. In 2006, more butterflies were found in plots sown with lucerne *Medicago sativa* (6.3 individuals/plot) than plots sown with borage *Borago officinalis* (0.3 individuals/plot), chicory *Cichorium intybus* (0.8 individuals/plot) and sainfoin *Onobrychis viciifolia* (0.8 individuals/plot). More butterfly species were found in lucerne plots (3.5 species/plot) than in borage, chicory, sainfoin and fodder radish *Raphanus sativus* (0.3–0.5 species/plot). There was no significant difference in abundance (1.0–3.3 individuals/plot) or species richness (1.0–2.8 species/plot) between the other plant species. In 2007, red clover *Trifolium pratense* had a higher abundance of butterflies (3.3 individuals/plot) than chicory (0.0 individuals/plot), but the abundance on all other plant species was similar (0.3–2.3 individuals/plot) and there were no significant differences in species richness (0.0–1.8 species/plot). In May 2006, ten small-seeded crop species commonly sown in wild bird seed mixtures (borage, buckwheat *Fagopyrum esculentum*, crimson clover *Trifolium incarnatum*, fodder radish, linseed *Linum usitatissimum*, lucerne, mustard *Brassica juncea*, phacelia *Phacelia tanacetifolia*, sunflower *Helianthus annuus* and sweet clover *Melilotus officinalis*) and three perennial species sown in pollen and nectar mixtures (chicory, red clover, sainfoin) were sown individually in 6 × 4 m plots, replicated four times. Annual species were re-sown May 2007. Butterflies were surveyed six times/year, from July–September 2006 and May–September 2007.

A replicated, randomized, controlled study in 2002–2006 on four lowland farms in Devon and Somerset, UK (5) found that plots sown annually with mixes including wild bird seed had a higher abundance and species richness of butterflies, but a lower abundance of caterpillars, than grassland plots. In the first two years, plots sown with wild bird seed mixes had a higher abundance (4–10 individuals/transect) and species richness (2–4 species/transect) of adult butterflies than extensively (abundance: 3–5 individuals/transect; richness: 2 species/transect) or conventionally managed (abundance: 1–2 individuals/transect; richness: 1 species/transect) grassland. However, there were fewer caterpillars in the sown plots (0–3 caterpillars/transect) than the extensively (1–8 caterpillars/transect) or conventionally managed (0–7 caterpillars/transect) grassland. In April 2002, experimental plots (50 × 10 m) were established on permanent pastures (>5-years-old) on four farms. There were nine treatments, with three replicates/farm. Two sown treatments comprised a mix of six crops and four legumes, or barley *Hordeum vulgare* undersown with seven grasses and five legumes. Two extensive grassland treatments had minimal disturbance during summer and five conventional grassland treatments included modifications to conventional silage management (reducing fertilizer application, cutting and grazing). From June–September 2003–2006, butterflies were surveyed once/month on a 50-m transect through the centre of each plot. In April, June, July and September 2003–2006, caterpillars were counted (but not identified) on two 10-m transects/plot using a sweep net (20 sweeps/transect).

A replicated, randomized, paired, controlled study in 2005–2011 on an arable farm in Buckinghamshire, UK (6) found that land managed under an agri-environment scheme, including sowing wild bird seed mixtures, had a higher abundance, but not species richness, of butterflies and micro-moths than conventional farming, but there was no difference in abundance or species richness of other moths. Butterfly abundance was higher under enhanced Entry-Level Stewardship (ELS) (5,400 individuals/60 ha) and standard ELS (2,000 individuals/60 ha) than under conventional farming (1,400 individuals/60 ha). Micro-moth abundance was also higher under enhanced ELS (79 individuals) than standard ELS (32 individuals) or conventional farming (20 individuals). However, the abundance of macro-moths and threatened moths was similar under enhanced ELS (macro: 126; threatened: 6 individuals), standard ELS (macro: 79; threatened: 5 individuals) and conventional farming (macro: 79; threatened: 6 individuals). Species richness of all groups was similar under enhanced ELS (macro: 20; micro: 11; threatened: 3 species), standard ELS (macro: 20; micro: 8; threatened: 2 species) and conventional farming (macro: 18; micro: 5; threatened:

2 species) (butterfly data not presented). In 2005, a 1,000-ha farm was divided into five 180-ha blocks. Three 60-ha areas/block were assigned to three treatments: enhanced ELS (5% land removed from production, three 0.5-ha winter bird food patches sown); standard ELS (1% land removed from production, one 0.25-ha winter bird food patch sown); conventional farming (no winter bird food patches) (see paper for other details). From May–August 2006–2011, butterflies were recorded four times/year on one 50-m transect/60-ha area, passing through all available habitats. In late-May 2007–2011 and late-July 2006–2011 moths were surveyed using Robinson light traps. One block was surveyed/night, with one trap/treatment.

A replicated, randomized, controlled study in 2007–2010 on 28 arable farms in Wessex and East Anglia, UK (7) found that farms with enhanced agri-environment scheme (AES) habitats, including areas of wild bird seed mixture, had a higher abundance of some butterfly species than farms with simpler AES habitats. In early summer, farms with enhanced AES habitats had a higher abundance of blue (Lycaenidae: 0.05 individuals/100 m) and white (Pieridae: 0.46 individuals/100 m) butterflies along boundaries than farms with Entry Level Scheme (ELS) habitats (blues: 0.04; whites 0.21 individuals/100 m), but a lower abundance of skippers (Hesperiidae) in the AES habitat itself (enhanced: 0.00; ELS: 0.02 individuals/100 m). In mid-summer, enhanced AES farms had a higher abundance of white butterflies (0.69 individuals/100 m), but a lower abundance of brown butterflies (Satyridae: 0.16 individuals/100 m) in the AES habitat, and a lower abundance of blue butterflies (0.05 individuals/100 m) along boundaries than ELS farms (whites: 0.38; browns: 0.49; blues: 0.11 individuals/100 m). In spring 2007, twenty-four farms (12 in East Anglia and 12 in Wessex) were randomly assigned to two treatments: 16 farms with enhanced AES habitat (1.5–6.0 ha of wild bird seed mixes, floristically-enhanced grass mixes, wildflower strips and natural regeneration by annual cultivation); and eight farms with ELS habitat (1.5–6.0 ha of grass margins and game cover (usually maize)). Two additional ELS farms/region, already managed organically with 1.5 ha of ELS habitat, were also studied. From 2008–2010, butterflies were surveyed twice/year on 11 fixed 100-m transects, in mid-May–mid-June and mid-July–early August. Eight transects/site were located in AES habitat, and three transects/site were located on field boundaries away from the AES habitat.

(1) Moreby S.J. (2002) Permanent and temporary linear habitats as food sources for the young of farmland birds. Pages 327-332 in: D.E. Chamberlain (ed.) *Avian Landscape Ecology: Pure and Applied Issues in the Large-Scale Ecology of Birds*. International Association for Landscape Ecology (IALE(UK)), Aberdeen.

(2) Moreby S.J. & Southway S. (2002) Cropping and year effects on the availability of invertebrate groups important in the diet of nestling farmland birds. *Aspects of Applied Biology*, 67, 107–112.

(3) Pywell R.F., Shaw L., Meek W., Turk A., Shore R.F. & Nowakowski M. (2007) Do wild bird seed mixtures benefit other taxa? *Aspects of Applied Biology*, 81, 69–76.

(4) Pywell R., Hulmes L., Meek W. & Nowakowski M. (2008) Creation and Management of Pollen and Nectar Habitats on Farmland: Annual report 2007/8.

(5) Potts S.G., Woodcock B.A., Roberts S.P.M., Tscheulin T., Pilgrim E.S., Brown V.K. & Tallowin J.R. (2009) Enhancing pollinator biodiversity in intensive grasslands. *Journal of Applied Ecology*, 46, 369–379.

(6) Heard M.S., Botham M., Broughton R., Carvell C., Hinsley S., Woodcock B., Pywell R.F., Amy S., Bellamy P.E., Hill R.A., Hulmes S., Hulmes L., Meek W.R., Nowakowski M., Peyton

J., Redhead J.W., Shore R.F. & Turk A. (2011) Quantifying the effects of Entry Level Stewardship (ELS) on biodiversity at the farm scale: the Hillesden Experiment. *Natural England report*, RP00026.

(7) Holland J.M., Smith B.M., Storkey J., Lutman P.J.W. & Aebischer N.J. (2015) Managing habitats on English farmland for insect pollinator conservation. *Biological Conservation*, 182, 215–222.

3.16. Leave uncropped, cultivated margins or plots

- **Four studies** evaluated the effects of leaving uncropped, cultivated margins or plots on butterflies and moths. Three were in the UK[1,2,3] and one was in Switzerland[4].

COMMUNITY RESPONSE (3 STUDIES)

- **Richness/diversity (3 studies):** Two of three replicated studies (including one randomized, paired, controlled study, one replicated, randomized, site comparison study, and one site comparison study) in the UK[1,2] and Switzerland[4] found that farms managed under agri-environment schemes[2], or with a greater area of in-field agri-environment scheme options[4], both including uncropped cultivated margins, had a similar species richness of butterflies[2,4] and moths[2] to conventional farms[2] or farms with a smaller area of in-field options[4]. The other study found that fields with wider margins between crops had higher butterfly species richness in one of two years[1].

POPULATION RESPONSE (4 STUDIES)

- **Abundance (4 studies):** One replicated, randomized, site comparison study in the UK[1] found that fields with wider margins between crops had a higher abundance of butterflies in one of two years[1]. One replicated, randomized, paired, controlled study in the UK[2] found that farms managed under agri-environment schemes (AES), including uncropped cultivated margins, had a higher abundance of butterflies and micro-moths, but a similar abundance of other moths, compared to conventionally managed farms. One replicated, randomized, controlled study in the UK[3] found that farms managed with enhanced AES options, including uncropped, cultivated margins, had a higher abundance of some butterflies, but a lower abundance of other butterflies, than farms with simpler AES management. One replicated, site comparison study in Switzerland[4] found that farms with a larger area of in-field AES options, including uncropped, cultivated plots, had a similar abundance of butterflies to farms with a smaller area of in-field AES options.

BEHAVIOUR (0 STUDIES)

Background

On intensively farmed land, crop monocultures typically flower in unison, and provide little variation in the vegetation structure. Uncropped, cultivated margins or plots are typically designed to benefit birds, however they may provide resources for butterflies and moths by increasing the structural diversity of the landscape, and allowing nectar-rich agricultural plants, which are typically considered as weeds, to grow around and among the crop.

A replicated, randomized, site comparison study in 1986 and 1991 at a farmland and grassland site in Cambridgeshire, UK (1) found that butterfly abundance and species richness were higher in fields with wider margins between crops in one year but there was no difference in the other year. In 1986, but not in

1991, there was higher butterfly abundance and richness in fields where margins between crops were wider (data presented as statistical results). See paper for details of the effects on individual butterfly species. From May–September in 1986 and 1991, butterflies were surveyed up to once/month in fine weather on ninety-nine 200 m transects along margins between fields of any combination of arable farmland and grassland. Each transect was surveyed 2–4 times in both years. Margin width was measured in both years.

A replicated, randomized, paired, controlled study in 2005–2011 on an arable farm in Buckinghamshire, UK (2) found that land managed under an agri-environment scheme, including uncropped cultivated margins, had a higher abundance, but not species richness, of butterflies and micro-moths than conventional farming, but there was no difference in abundance or species richness of other moths. Butterfly abundance was higher under enhanced Entry-Level Stewardship (ELS) (5,400 individuals/60 ha) and standard ELS (2,000 individuals/60 ha) than under conventional farming (1,400 individuals/60 ha). Micro-moth abundance was also higher under enhanced ELS (79 individuals) than standard ELS (32 individuals) or conventional farming (20 individuals). However, the abundance of macro-moths and threatened moths was similar under enhanced ELS (macro: 126; threatened: 6 individuals), standard ELS (macro: 79; threatened: 5 individuals) and conventional farming (macro: 79; threatened: 6 individuals). Species richness of all groups was similar under enhanced ELS (macro: 20; micro: 11; threatened: 3 species), standard ELS (macro: 20; micro: 8; threatened: 2 species) and conventional farming (macro: 18; micro: 5; threatened: 2 species) (butterfly data not presented). In 2005, a 1,000-ha farm was divided into five 180-ha blocks. Three 60-ha areas/block were assigned to three treatments: enhanced ELS (5% land removed from production, annually cultivated uncropped margins); standard ELS (1% land removed from production); conventional farming (see paper for other details). From May–August 2006–2011, butterflies were recorded four times/year on one 50-m transect/60-ha area, passing through all available habitats. In late-May 2007–2011 and late-July 2006–2011 moths were surveyed using Robinson light traps. One block was surveyed/night, with one trap/treatment.

A replicated, randomized, controlled study in 2007–2010 on 28 arable farms in Wessex and East Anglia, UK (3) found that farms with enhanced agri-environment scheme (AES) habitats, including naturally-regenerating margins, had a higher abundance of some butterfly species than farms with simpler AES habitats. In early summer, farms with enhanced AES habitats had a higher abundance of blue (Lycaenidae: 0.05 individuals/100 m) and white (Pieridae: 0.46 individuals/100 m) butterflies along boundaries than farms with Entry-Level Scheme (ELS) habitats (blues: 0.04; whites 0.21 individuals/100 m), but a lower abundance of skippers (Hesperiidae) in the AES habitat itself (enhanced: 0.00; ELS: 0.02 individuals/100 m). In mid-summer, enhanced AES farms had a higher abundance of white butterflies (0.69 individuals/100 m), but a lower abundance of brown butterflies (Satyridae: 0.16 individuals/100 m) in the AES habitat, and a lower abundance of blue butterflies (0.05 individuals/100 m) along boundaries than ELS farms (whites: 0.38; browns: 0.49; blues: 0.11 individuals/100 m). In spring 2007, twenty-four farms (12 in East Anglia and 12 in Wessex) were randomly assigned to two treatments: 16 farms with enhanced AES habitat (1.5–6.0 ha of natural regeneration by annual cultivation, floristically-enhanced grass mixes, wildflower strips and wild bird seed mixes); and eight farms with ELS habitat (1.5–6.0 ha of grass margins and game cover (usually maize)). Two additional ELS farms/region, already managed organically with 1.5 ha of ELS habitat, were also studied. From 2008–2010, butterflies were surveyed twice/year on 11 fixed 100-m transects, in mid-May–mid-June and mid-July–early August. Eight transects/site were located in AES habitat, and three transects/site were located on field boundaries away from the AES habitat.

A replicated, site comparison study in 2009–2011 in 133 mixed farms in the Central Plateau, Switzerland (4) found that farms with more in-field agri-environment scheme (AES) options, including uncropped, cultivated plots, had a similar abundance and species richness of butterflies to farms with fewer (AES) options. Both the abundance and species richness of butterflies on farms with a larger area of in-field AES options was similar to farms with smaller areas of in-field AES options (data presented as model results). A total of 133 farms (17–34 ha, 13–91% arable crops) were managed with in-field AES options, including undrilled patches in crops, wide-spaced rows, cover crops, undersown cereals, use of bar mowers, staggered mowing, no silage and no chemical inputs. Fields without chemical inputs contributed about half of the area of AES options, on average. From May–September 2009–2011, butterflies were surveyed six times on 10–38 transects/farm, totalling 2,500 m/farm. Each transect ran diagonally through a single crop or habitat type, with all available crops and habitats represented. All visits to a farm were completed in a single year, and the species richness was summed across all visits. Total abundance of butterflies was calculated from the number recorded in each habitat, and the availability of each habitat across the farm.

(1) Sparks T. H. & Parish T. (1995) Factors affecting the abundance of butterflies in field boundaries in Swavesey fens, Cambridgeshire, UK. *Biological Conservation*, 73(3), 221-227.
(2) Heard M.S., Botham M., Broughton R., Carvell C., Hinsley S., Woodcock B., Pywell R.F., Amy S., Bellamy P.E., Hill R.A., Hulmes S., Hulmes L., Meek W.R., Nowakowski M., Peyton J., Redhead J.W., Shore R.F. & Turk A. (2011) Quantifying the effects of Entry Level Stewardship (ELS) on biodiversity at the farm scale: the Hillesden Experiment. *Natural England report*, RP00026.
(3) Holland J.M., Smith B.M., Storkey J., Lutman P.J.W. & Aebischer N.J. (2015) Managing habitats on English farmland for insect pollinator conservation. *Biological Conservation*, 182, 215–222.
(4) Stoeckli S., Birrer S., Zellweger-Fischer J., Balmer O., Jenny M. & Pfiffner L. (2017) Quantifying the extent to which farmers can influence biodiversity on their farms. *Agriculture, Ecosystems & Environment*, 237, 224–233.

3.17. Leave unharvested crop headlands within arable fields

- **One study** evaluated the effects of leaving unharvested crop headlands within arable fields. This study was in France[1].

COMMUNITY RESPONSE (1 STUDY)

- **Richness/diversity (1 study):** One replicated, paired, site comparison study in France[1] found that unharvested alfalfa headlands had a greater species richness of butterflies than harvested alfalfa or wheat fields.

POPULATION RESPONSE (1 STUDY)

- **Abundance (1 study):** One replicated, paired, site comparison study in France[1] found that unharvested alfalfa headlands had a higher abundance of butterflies than harvested alfalfa or wheat fields.

BEHAVIOUR (0 STUDIES)

Background

Harvesting crops creates a dramatic change in the farmed landscape, by suddenly and simultaneously removing plants, which may be providing nectar resources to butterflies and moths, from a large area. Even if butterflies and moths are not using the crop itself, harvesting disturbs the structure of the field, and may cause mortality of caterpillars living on other plant species within or around the crop. Leaving unharvested strips, known as headlands, at the edge of fields may provide both shelter and a continued resource availability to butterflies and moths.

A replicated, paired, site comparison study in 2009–2010 on 24 farms in Champagne-Ardennes and Haute-Normandie, France (1) found that unharvested alfalfa *Medicago sativa* headlands had a higher abundance and species richness of butterflies than harvested alfalfa or wheat *Triticum* spp. fields. In unharvested strips of alfalfa, the abundance (53 individuals/transect) and species richness (4 species/transect) of butterflies was higher than in harvested alfalfa (abundance: 12–15 individuals/transect; richness: 2–3 species/transect) or in conventional wheat fields (abundance: 3–6 individuals/transect; richness: 1–2 species/transect). See paper for individual species results. On each of 24 farms, one alfalfa field was harvested conventionally 4–5 times/year, one alfalfa field had a rotational 7-m strip left unmown during each harvest, and one winter wheat field was managed conventionally. From May–September 2009–2010, butterflies were surveyed visually five times/year on two 200–400-m transects in each field (15–17 farms surveyed/year).

(1) Manil L. & Chagué J. (2014) Differentiated management of alfalfa fields: a positive impact on butterfly populations (Lepidoptera: Rhopalocera). *Revue d'écologie*, 69, 101–111.

3.18. Plant crops in spring rather than autumn

- We found no studies that evaluated the effects on butterflies and moths of planting crops in spring rather than autumn.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Sowing crops in autumn is commonly used to advance the harvest, as the crop begins to grow when sown and then overwinters as small plants in the ground. However, this head-start means that the crop flowers earlier, and may be too early to be beneficial for butterflies and moths. In addition, the disturbance to the previous year's stubble in autumn may kill butterflies and moths of any life-stage which are overwintering within the harvested crop. Planting crops in spring may, therefore, mitigate these impacts.

3.19. Undersow spring cereals, with clover for example

- **Two studies** evaluated the effects on butterflies and moths of undersowing spring cereals. One study was in the UK[1] and one was in Switzerland[2].

COMMUNITY RESPONSE (2 STUDIES)

- **Richness/diversity (2 studies):** One replicated, randomized, controlled study in the UK[1] found that spring barley undersown with a mix of grasses and legumes had a higher species richness of butterflies than extensively or conventionally managed grassland. One replicated, site comparison study in Switzerland[2] found that farms with a larger area of in-field agri-environment scheme options, including undersown cereals, had a similar species richness of butterflies to farms with a smaller area of in-field agri-environment scheme options.

POPULATION RESPONSE (2 STUDIES)

- **Abundance (2 studies):** One replicated, randomized, controlled study in the UK[1] found that spring barley undersown with a mix of grasses and legumes had a higher abundance of butterflies, but a lower abundance of caterpillars, than extensively or conventionally managed grassland. One replicated, site comparison study in Switzerland[2] found that farms with a larger area of in-field agri-environment scheme options, including undersown cereals, had a similar abundance of butterflies to farms with a smaller area of in-field agri-environment scheme options.

BEHAVIOUR (0 STUDIES)

Background

Undersowing cereals with plants such as clover, which are able to fix nitrogen in the soil, is commonly used in agri-environment schemes to reduce the need to apply artificial fertilizer. However, these plants may also provide an important source of nectar for butterflies and moths, which could improve the value of arable land for butterfly and moth populations.

A replicated, randomized, controlled study in 2002–2006 on four lowland farms in Devon and Somerset, UK (1) found that annually sown plots of spring barley *Hordeum vulgare* undersown with a mix of grasses and legumes had a higher abundance and species richness of butterflies, but a lower abundance of caterpillars, than grassland plots. In the first two years, undersown plots had a higher abundance (4–6 individuals/transect) and species richness (2–4 species/transect) of adult butterflies than extensively (abundance: 3–5 individuals/transect; richness: 2 species/transect) or conventionally managed (abundance: 1–2 individuals/transect; richness: 1 species/transect) grassland.

However, there were fewer caterpillars in the sown plots (0–3 caterpillars/transect) than the extensively (1–8 caterpillars/transect) or conventionally managed (0–7 caterpillars/transect) grassland. In April 2002, experimental plots (50 × 10 m) were established on permanent pastures (>5-years-old) on four farms. There were eight treatments, with three replicates/farm. The sown treatment comprised barley undersown with seven grasses and five legumes. Two extensive grassland treatments had minimal disturbance during summer and five conventional grassland treatments included modifications to conventional silage management (reducing fertilizer application, cutting and grazing). From June–September 2003–2006, butterflies were surveyed once/month on a 50-m transect through the centre of each plot. In April, June, July and September 2003–2006, caterpillars were counted (but not identified) on two 10-m transects/plot using a sweep net (20 sweeps/transect).

A replicated, site comparison study in 2009–2011 in 133 mixed farms in the Central Plateau, Switzerland (2) found that farms with more in-field agri-environment scheme (AES) options, including undersown cereals, had a similar abundance and species richness of butterflies to farms with fewer (AES) options. Both the abundance and species richness of butterflies on farms with a larger area of in-field AES options was similar to farms with smaller areas of in-field AES options (data presented as model results). A total of 133 farms (17–34 ha, 13–91% arable crops) were managed with in-field AES options, including undersown cereals, undrilled patches in crops, wide-spaced rows, cover crops, use of bar mowers, staggered mowing, no silage and no chemical inputs. Fields without chemical inputs contributed about half of the area of AES options, on average. From May–September 2009–2011, butterflies were surveyed six times on 10–38 transects/farm, totalling 2,500 m/farm. Each transect ran diagonally through a single crop or habitat type, with all available crops and habitats represented. All visits to a farm were completed in a single year, and the species richness was summed across all visits. Total abundance of butterflies was calculated from the number recorded in each habitat, and the availability of each habitat across the farm.

(1) Potts S.G., Woodcock B.A., Roberts S.P.M., Tscheulin T., Pilgrim E.S., Brown V.K. & Tallowin J.R. (2009) Enhancing pollinator biodiversity in intensive grasslands. *Journal of Applied Ecology*, 46, 369–379.
(2) Stoeckli S., Birrer S., Zellweger-Fischer J., Balmer O., Jenny M. & Pfiffner L. (2017) Quantifying the extent to which farmers can influence biodiversity on their farms. *Agriculture, Ecosystems & Environment*, 237, 224–233.

3.20. Restore arable land to permanent grassland

- **Ten studies** evaluated the effects on butterflies and moths of restoring arable land to permanent grassland. Six studies were in the UK[2–5,8,9], two were in Finland[6,7], and one was in each of Switzerland[1] and Taiwan[10].

COMMUNITY RESPONSE (9 STUDIES)

- **Community composition (2 studies):** One of two replicated, site comparison studies in the UK[4] and Finland[7] found that grasslands restored from bare soil by seeding developed butterfly communities that were increasingly similar to existing high-quality grasslands over the first 10 years after establishment[4]. The other study found that older grasslands established by sowing with competitive seed mixes had a greater proportion of specialist butterflies than newer grasslands sown with less competitive species which required re-seeding every 4–5 years[7].

- **Richness/diversity (8 studies):** Three replicated, site comparison studies (including two paired studies) in Switzerland[1], the UK[3] and Taiwan[10] found that 4–5-year-old created grasslands[1,3] and abandoned cropland[10] had a greater species richness of butterflies[1,10], burnet moths[1] and all moths[3] than conventionally managed grassland[1,3] or cultivated farms[10]. Two of three replicated studies (including one randomized, paired, controlled study and two site comparison studies) in the UK[5,8] and Finland[6] found that grasslands established by sowing grasses, legumes and other non-woody, broadleaved plants (forbs)[5], or perennial grass mixes[6], had a higher species richness of butterflies (in one case including other pollinators[5]) than grasslands established with grass-only mixes[5] or less competitive species[6]. The third study found that grasslands established by sowing complex or simple seed mixes, or by natural regeneration, all had a similar species richness of butterflies and day-flying moths, but species richness was higher on grasslands created <10 years ago than on grasslands created >20 years ago[8]. One before-and-after study in the UK[2] found that after the adoption of an Environmentally Sensitive Areas scheme, including reverting arable land to permanent grassland, the species richness of large moths on a farm increased. One replicated, site comparison study in the UK[4] found that over 10 years after restoration, the number of species of butterfly on seeded grassland remained similar each year.

POPULATION RESPONSE (7 STUDIES)

- **Abundance (7 studies):** Two of three replicated, paired, site comparison studies in the UK[3,9] and Taiwan[10] found that restored grassland had a higher abundance of moths than conventional grassland[3] or unrestored crop fields[3,9], and a similar abundance to semi-natural grasslands[9], but abundance did not increase with time since restoration[9]. The third study found that abandoned cropland had a similar abundance of butterflies to cultivated farms[10]. Two of three replicated studies (including one randomized, paired, controlled study and two site comparison studies) in the UK[5,8] and Finland[6] found that grasslands established by sowing grasses, legumes and other non-woody, broadleaved plants (forbs)[5], or perennial grass mixes[6], had a higher abundance of butterflies (in one case including other pollinators[5]) than grasslands established with grass-only mixes[5] or less competitive species[6]. The third study found that grasslands restored by sowing complex or simple seed mixes, or by natural regeneration, all had a similar abundance of caterpillars[8]. One before-and-after study in the UK[2] found that after the adoption of an Environmentally Sensitive Areas scheme on a farm, including reverting arable land to permanent grassland, the abundance of large moths and five species of butterfly increased, but the abundance of two species of butterfly decreased.

BEHAVIOUR (0 STUDIES)

Background

Large areas of grassland have been converted to arable land, leading to a loss of grassland-dependent species. Meadows can support a higher abundance and species richness of butterflies than arable land (Luppi *et al.* 2018). Restoring arable land to permanent grassland may recreate communities of invertebrates similar to those historically found in an area (Denning & Foster 2018).

For studies of short-term or rotational set-aside, see "*Provide or retain set-aside areas in farmland*". For studies on the restoration of species-rich grassland from intensively managed grassland, see "*Reduce management intensity on permanent grasslands (several interventions at once)*", "*Reduce grazing intensity on grassland by reducing stocking density*", "*Reduce grazing intensity on grassland by seasonal removal of livestock*" and "*Reduce cutting frequency on grassland*". For studies on the restoration of abandoned grassland, see "*Restore or create species-rich, semi-natural grassland*". For studies on grassland restoration outside of a farmland context, see "*Habitat restoration and creation – Restore or create grassland/savannas*".

Denning K.R. & Foster B.L. (2018) Flower visitor communities are similar on remnant and reconstructed tallgrass prairies despite forb community differences. *Restoration Ecology*, 26, 751–759.

Luppi M., Dondina O., Orioli V. & Bani L. (2018) Local and landscape drivers of butterfly richness and abundance in a human-dominated area. *Agriculture, Ecosystems & Environment*, 254, 138–148.

A replicated, site comparison study in 1999 on three mixed farms in central Switzerland (1) reported that 4–5-year-old flower-rich meadows created on set-aside land had a higher species richness of butterflies and burnet moths than intensively managed meadows, pasture or arable land, and similar species richness to traditionally managed meadows. Results were not tested for statistical significance. Recently created meadows had approximately 14 species of butterflies and burnet moths, compared to 5–7 species in intensively managed meadows or pasture, 10–12 species on traditional meadows, and 1 species in arable fields (data presented for only one farm). Authors reported that adult butterfly abundance was positively correlated with the number of flowers, and up to 98% of flower visits were recorded on only five plant species. In 1994–1995, species-rich grassland was created across 2–6% of the farmed area on three mixed farms (10–25 ha). From May–September 1999, butterflies were surveyed seven times along fixed 10-m-long transects through each habitat type on each farm.

A before-and-after study in 1994–2006 on a farm in Oxfordshire, UK (2) found that following adoption of the Environmentally Sensitive Areas scheme, including reverting arable land to permanent grassland, the abundance and species richness of large moths and some species of butterfly increased. After Environmentally Sensitive Area management began, the total abundance (1,000–1,450 individuals) and species richness of large moth species was higher than before (800–1,250 individuals, richness data not presented). One of the five most abundant moth species (lunar underwing *Omphaloscelis lunosa*) and five of 23 butterfly species (meadow brown *Maniola jurtina*, brown argus *Aricia agestis*, common blue *Polyommatus icarus*, small copper *Lycaena phlaeas* and red admiral *Vanessa atalanta*) increased in abundance after the change in management. However, two butterfly species became less abundant (green-veined white *Pieris napi* and large white *Pieris brassicae*, data presented as model results). Overall butterfly abundance and species richness increased over the entire monitoring period, but the increase did not just happen after the management change. In 2002, the farm entered the Environmentally Sensitive Areas agri-environment scheme, and 102 ha of arable land was reverted to extensive grassland. In addition, fertilizers, herbicides and pesticides were no longer used, and the total number of livestock dropped from 180 cows and 1,000 sheep to 120 cows and 850 sheep. Butterflies were monitored weekly from April–September on a fixed 3.6 km transect divided into 13 sections. Moths were monitored nightly from dusk to dawn using a light trap in a fixed position in the middle of the farm.

A replicated, paired, site comparison study in 2008 on 32 farms in central Scotland, UK (3) found that species-rich grassland created under agri-environment schemes (AES) had a higher abundance and species richness of micro- and macro-moths than conventionally-managed grassland or crop fields. In created AES species-rich grasslands, the abundance (156 individuals) and species richness (24 species) of micro-moths, the species richness of all macro-moths (46 species), and the abundance of declining macro-moths (44 individuals) were all higher than in improved grasslands or crop fields on conventional farms (micro-moths: 43 individuals, 19 species; all macro-moths: 33 species; declining macro-moths: 21 individuals). However, the abundance of all macro-moths (366 individuals) and species richness of declining macro-moths (10 species) on created AES species-rich grasslands was not significantly different from improved grasslands or crop fields (all macro-moths: 271 individuals; declining macro-moths: 9 species). In 2004, sixteen farms enrolled in AES, and were paired with 16 similar but conventionally-managed farms, <8 km away. On AES farms, species-rich grassland was created on former arable or improved grassland fields by sowing a low productivity grass and herb seed mix, and managed with fertilizer and pesticide restrictions, and no summer cutting or grazing. Improved pastures and crop fields on conventional farms had no management restrictions. From June–September 2008, moths were collected for four hours, on one night/farm, using a 6 W heath light trap located in one field on each farm. Paired farms were surveyed on the same night.

A replicated, site comparison study (years not given) in 10 grasslands in England, UK (4) found that grasslands restored from bare soil by seeding developed butterfly communities increasingly similar to existing high-quality grasslands over the first 10 years after establishment, but the number of species present remained similar. The butterfly communities on grasslands restored by arable reversion were more similar to those on existing grasslands 10–21 years after restoration (42–84% similarity) than one year after restoration (0–33% similarity). However, the number of butterfly species recorded each year on arable reversion sites (~12 species/year) remained similar over time. Four grasslands were restored from bare soil by sowing grassland seed mixes. Three of the sites (two former arable fields and one abandoned road covered with top soil) were then managed by sheep-grazing to produce calcareous grassland, while the fourth site (ex-landfill covered with topsoil) was cut annually and grazed by sheep or cattle to produce a lowland hay meadow. Six high-quality grasslands (three calcareous grasslands and three hay meadows) were used for comparison. From April–September each year, butterflies were surveyed weekly on a ~2 km transect at each site for 9–21 years after restoration.

A replicated, randomized, paired, controlled study in 2008–2012 on a farm in Berkshire, UK (5) found that grasslands established with seed mixes containing legumes and other non-woody, broadleaved plants (forbs) had a higher abundance and species richness of pollinators (including butterflies) than grasslands sown only with grasses. Plots sown with a mix of grasses, legumes and forbs had a higher abundance (9–70 individuals/plot) and species richness (3–7 species/plot) of pollinators over four years than plots sown with grasses only (abundance: 0–3 individuals/plot; richness: 0–2 species/plot). In the first year after establishment, plots sown with grasses and legumes but no forbs had the highest abundance (15–91 individuals/plot) and species richness (5–8 species/plot) of pollinators, but this decreased over time (fourth-year abundance: 3–8 individuals/plot; richness: 2–3 species/plot). Grass and legume plots managed by cutting had a higher abundance (6–91 individuals/plot) and species richness (3–8 species/plot) of pollinators than plots managed by grazing (abundance: 3–33 individuals/plot; richness: 2–5 species/plot). Management had less effect on other seed mixes. In spring 2008, ninety-six 875-m^2 plots were sown with one of three seed mixes: a "grass only" mix of five species (30 kg/ha, cost: €83/ha); a "grass and legume" mix of five grasses and seven agricultural legumes (34 kg/ha, €120/ha); or a "grass, legume and forb" mix of five grasses, seven legumes and six non-legume forbs (33.5 kg/ha, €190/ha). Half of the plots were grazed with cattle (3 animals/ha) and half were cut to 10 cm once or twice/year. In May, July and August 2009–2012, butterflies, bees (Apidae) and hoverflies (Syrphidae) were surveyed three times/year on two parallel 20 × 2 m transects/plot.

A replicated, site comparison study in 2013 in 40 grasslands in southern Finland (6, same experimental set-up as 7) found that long-term restored grassland fallows had a greater abundance and species richness of butterflies than recently established meadow fallows. In ≥8-year-old sown grasslands, the abundance (55–85 individuals/site) and species richness (7–12 species/site) of butterflies was higher than in 3–4-year-old sown meadows (abundance: 34–52 individuals/site; richness: 7 species/site). Forty fallow grasslands (0.3–5.8 ha) established under the Finnish Environmental Fallow agri-environment scheme were selected. Twenty long-term grassland fallows (≥8 years old) were either former set-aside areas or production grasslands, originally established by sowing conventional, competitive, perennial grassland mixtures. Twenty short-term meadow fallows (3–4 years old) were established by sowing low competitive meadow plants (see paper for details), which required re-establishment every 4–5 years. All sites were mown at least every three years, and no pesticides or fertilizers were applied. From June–July 2013, butterflies were surveyed four times (two weeks apart) along a 200-m transect in each fallow.

A replicated, site comparison study in 2013 in 40 grasslands in southern Finland (7, same experimental set-up as 6) found that long-term restored grassland fallows had more specialist butterflies than recently established meadow fallows. In ≥8-year-old grasslands, the relative abundance of habitat specialist butterflies was higher than in 3–4-year-old meadows (data presented as model results). Four species (large skipper *Ochlodes sylvanus*, Essex skipper *Thymelicus lineola*, lesser marbled fritillary *Brenthis ino*, mazarine blue *Polyommatus semiargus*) were strongly associated with ≥8-year-old grasslands, while no species was strongly associated with 3–4-year-old meadows. Forty fallow grasslands (0.3–5.8 ha) established under the Finnish Environmental Fallow agri-environment scheme were selected. Twenty long-term grassland fallows (≥8 years old) were either former set-aside areas or production grasslands, originally established by sowing conventional, competitive, perennial grassland mixtures. Twenty short-term meadow fallows (3–4 years old) were established by sowing low competitive meadow plants (see paper for details). All sites were mown at least every three years, and no pesticides or fertilizers were applied. From June–July 2013, butterflies were surveyed four times (two weeks apart) along a 200-m transect in each fallow.

A replicated, site comparison study in 2014 on 52 fields in arable reversion in southern England, UK (8) found that neither the method of restoring arable land to permanent grassland, nor current management of the field, affected adult butterfly and day-flying moth species richness or caterpillar abundance, but species richness of adult butterflies was lower in fields restored longer ago. One to 30 years after arable reversion began, butterfly species richness and caterpillar abundance were similar on fields established by sowing complex or simple seed mixes, or by allowing natural regeneration, and on fields managed by sheep or cattle grazing, and with or without mowing (data not presented). The species richness of adult butterflies was lower on arable reversion fields >20 years old (0–6 species/site) than fields <10 years old (1–8 species/site), but caterpillar abundance was similar (data not presented). Between 1984–2013, restoration of 52 former arable fields (1.0–22.8 ha) to calcareous grasslands began. Fields were restored by natural regeneration, re-seeding with simple grass or complex grass and non-woody broadleaved plant (forb) mixes, or by spreading green hay. Fields were cut every 1–4 years (normally after 15 July) and lightly grazed (typically 1 livestock unit/ha) by sheep or cattle, with some fields ungrazed. From July–August 2014, adult butterflies and day-flying moths were surveyed twice/day on three days, and caterpillars were sampled by 20 sweeps/day of a net, along a 100-m transect at each site.

A replicated, paired, site comparison study in 2015 on 22 farms in Berkshire, Hampshire and Wiltshire, UK (9) found that restored grassland supported a higher abundance of moths than unrestored arable fields, and was similar to semi-natural grassland sites. Three to 20 years after restoration, the abundance of moths associated with calcareous grassland (6.3 individuals/trap) and other grassland (49.6 individuals/trap) on restored fields were higher than on arable fields (calcareous: 0.8; other: 14.6 individuals/trap), and similar to semi-natural grassland (calcareous: 7.2; other: 38.3 individuals/trap). The abundance of moths associated with other habitats was higher on restored (25.5 individuals/trap) than unrestored fields (15.3 individuals/trap), but lower than on semi-natural grassland sites (57.9 individuals/trap). Results for species occurrence were similar (data not presented). However, neither moth abundance nor occurrence increased with time since restoration (data not presented). Over 3–20 years, 32 former arable fields (2.6–37.5 ha) on 22 farms were restored to species-rich grassland by either natural regeneration or sowing of wildflowers. All were cut or grazed at least once/year. Thirty-two paired, arable fields (2.2–49.3 ha) were unrestored, and eight semi-natural calcareous grasslands were used for comparison. On 21 nights between June–September 2015, moths were surveyed twice/site (2–4 restored-unrestored pairs/night, with a comparison site on >50% of nights) using one 15 W light trap in the centre of each field. Moths were classified as species associated with calcareous grassland, associated with grassland generally, or not associated with grassland.

A replicated, paired, site comparison study in 2017 on four farms in Hualien County, Taiwan (10) found that former cropland restored by natural regeneration had a higher species richness of butterflies, but a similar total abundance, than cultivated farms. On uncultivated, restored farms, the species richness of butterflies (16 species/farm) was higher than on active, conventional farms (9 species/farm), but the abundance of butterflies was similar between farms (restored: 185 individuals/ha; active: 191 individuals/ha). Within a National Park, 78 ha of restored former farmland had not been cultivated since the Park was established (number of years not given), and 39 ha of farmland remained in production. In each of two areas, one restored and one active farm were selected. Farms were 250–3,200 m apart. From May–September 2017, butterflies were surveyed once/month along 150-m transects at each farm (number not specified).

(1) Bosshard A. & Kuster D. (2001) The significance of restored flower-rich hay meadows on set-aside land for butterflies and grasshoppers. *Agrarforschung*, 8, 252–257.
(2) Taylor M.E. & Morecroft M.D. (2009) Effects of agri-environment schemes in a long-term ecological time series. *Agriculture, Ecosystems & Environment*, 130, 9–15.
(3) Fuentes-Montemayor E., Goulson D. & Park K.J. (2011) The effectiveness of agri-environment schemes for the conservation of farmland moths: assessing the importance of a landscape-scale management approach. *Journal of Applied Ecology*, 48, 532–542.
(4) Woodcock B.A., Bullock J.M., Mortimer S.R., Brereton T., Redhead J.W., Thomas J.A. & Pywell R.F. (2012) Identifying time lags in the restoration of grassland butterfly communities: A multi-site assessment. *Biological Conservation*, 155, 50–58.
(5) Woodcock B.A., Savage J., Bullock J.M., Nowakowski M., Orr R., Tallowin J.R.B. & Pywell R.F. (2014) Enhancing floral resources for pollinators in productive agricultural grasslands. *Biological Conservation*, 171, 44–51.
(6) Toivonen M., Herzon I. & Kuussaari M. (2015) Differing effects of fallow type and landscape structure on the occurrence of plants, pollinators and birds on environmental fallows in Finland. *Biological Conservation*, 181, 36–43.
(7) Toivonen M., Herzon I. & Kuussaari M. (2016) Community composition of butterflies and bumblebees in fallows: niche breadth and dispersal capacity modify responses to fallow type and landscape. *Journal of Insect Conservation*, 20, 23–34.
(8) Woodcock B., Ball S., Amy S., Edwards M., Redhead J., Mountford O., Gregory S., Duffield S., Macgregor N. & Pywell R. (2016) Evaluating the relative importance of site and landscape characteristics for invertebrate communities in grasslands restored through agri-environment schemes. *Natural England Report*, RP01878.
(9) Alison J., Duffield S.J., Morecroft M.D., Marrs R.H. & Hodgson J.A. (2017) Successful restoration of moth abundance and species-richness in grassland created under agri-environment schemes. *Biological Conservation*, 213, 51–58.
(10) Yen S.-C., Pan Y.-C., Wang L.-H. (2018) The Effects of Agricultural Lands Management Strategies for Biodiversity Recovery in Taroko National Park. *Journal of National Park*, 28, 29–43.

3.21. Create beetle banks

- **Four studies** evaluated the effects on butterflies and moths of creating raised beetle banks in arable fields. All four were in the UK[1–4].

COMMUNITY RESPONSE (2 STUDIES)

- **Richness/diversity (2 studies):** One replicated, paired, site comparison study in the UK[4] found that beetle banks and field margins managed under agri-environment schemes had a higher species richness of micro-moths, and a similar species richness of macro-moths, than conventionally managed field margins. One replicated, paired, site comparison study in the UK[1] found that the species richness of butterflies on beetle banks was lower than along hedgerows.

POPULATION RESPONSE (4 STUDIES)

- **Abundance (4 studies):** Three replicated, site comparison studies (including one paired study) in the UK[1,2,3] found that beetle banks had a similar abundance of caterpillars to field margins[1], crop fields[3] and a range of other field-edge farmland habitats[2]. One of these studies also found that the abundance of adult butterflies was lower on beetle banks than along hedgerows[1]. One replicated, paired, site comparison study in the UK[4] found that beetle banks and field margins managed under agri-environment schemes had a higher abundance of micro-moths, and a similar abundance of macro-moths, than conventionally managed field margins.

BEHAVIOUR (0 STUDIES)

Background

Beetle banks are raised grassy strips running through the centre of arable fields. They were originally designed to enable predatory invertebrates to access the centre of fields as a means of controlling pest species, but the habitat provided may support a range of other invertebrate groups, including butterflies and moths (Thomas *et al.* 2000).

Thomas S.R., Goulson D. & Holland J.M. (2000) The contribution of beetle banks to farmland biodiversity. *Aspects of Applied Biology*, 62, 31–38.

A replicated, paired, site comparison study in 1999 on five farms in the UK (1) found that beetle banks had a similar abundance of butterfly and moth caterpillars to field margins, but that the abundance and species richness of adult butterflies was lower on beetle banks than in hedgerows. The abundance of butterfly and moth caterpillars did not differ significantly between beetle banks (0.4 individuals/sweep) and field margins (0.5 individuals/sweep). However, both the abundance (1–2 individuals/transect) and species richness (0.5–2 species/transect) of adult butterflies were lower in beetle banks than along hedgerows (abundance: 2–6 individuals/transect; richness: 1–3 species/transect). A total of 12 species from three families were recorded on beetle banks, compared to 19 species from four families along hedgerows. In summer 1999, butterfly and moth caterpillars were sampled by sweep-netting on 22 beetle banks of different ages and 22 permanently established field margins across five farms. Adult butterflies were recorded on 82 transects along beetle banks and hedgerows in June, July and August 1999.

A replicated, site comparison study in 2000 on a lowland arable farm in Leicestershire, UK (2, same experimental set-up as 3) found that beetle banks contained similar densities of caterpillars to other field edge habitats. There was no difference in caterpillar densities between habitat types (data not presented). Ten edge habitats (beetle banks, first-year wild bird cover, second-year wild bird cover, non-rotational set-aside, brood cover, hedge bottoms, sheep-grazed pasture edges, ungrazed pasture edges, grass/wire fence lines and winter wheat headlands) were included in the study (sample size not given). Caterpillars were sampled with a vacuum suction sampler in June 2000 (no further details provided).

A replicated, site comparison study in 1995–1999 on an arable farm in Leicestershire, UK (3, same experimental set-up as 2) found that the abundance of moth and butterfly caterpillars was similar in non-crop strips (grass beetle banks or wild bird cover) and crop fields in most years. The abundance of moth and butterfly caterpillars was similar in non-crop strips (0–1 individuals/sample) and crop fields (0–1 individuals/sample) in four out of five years. In 1996, the abundance of caterpillars was lower in non-crop strips (0.4 individuals/sample) than in crop fields (0–2.2 individuals/sample). However, a composite group of key 'chick food insects' (including caterpillars) had higher densities in non-crop strips (65 individuals/sample) than in crop fields (2–10 individuals/sample) in all years. Grass beetle banks (1 m wide) were sown onto a raised bank along edges or across the centre of fields. Wild bird cover was sown as 2–5-m-wide strips along field boundaries and re-sown every few years with a cereal or kale-based *Brassica* spp. mixture. Caterpillars were sampled each year in the centre of 5–11 grass beetle banks or wild bird cover strips, and 3-m into 3–4 pasture, 8–12 wheat, 6–8 barley, 3–6 oilseed rape and 4 field bean fields. Two samples of 0.5 m^2 were taken in each habitat using a D-Vac suction sampler in June 1995–1999.

A replicated, paired, site comparison study in 2008 on 30 farms in central Scotland, UK (4) found that beetle banks and grass field margins managed under agri-environment schemes (AES) had a higher abundance and species richness of micro-moths, but not macro-moths than conventionally-managed field margins. In AES beetle banks and field margins, both the abundance (57 individuals) and species richness (24 species) of micro-moths were higher than in conventional field margins (abundance: 17 individuals; richness: 8 species). However, the abundance (294 individuals) and species richness (34 species) of all macro-moths, and the abundance (24 individuals) and species richness (6 species) of declining macro-moths on AES banks and margins were not significantly different from conventional margins (all macro-moths: 207 individuals, 38 species; declining macro-moths: 32 individuals, 10 species). In 2004, fifteen farms enrolled in AES, and were paired with 15 similar but conventionally-managed farms, <8 km away. On AES farms, 1.5–6-m-wide beetle banks or field margins were sown with grass mixes, and managed with restrictions on grazing and fertilizer and pesticide use. Field margins on conventional farms had no management restrictions. From June–September 2008, moths were collected for four hours, on one night/farm, using a 6 W heath light trap located next to one bank or margin on each farm. Paired farms were surveyed on the same night.

(1) Thomas S.R., Goulson D. & Holland J.M. (2000) The contribution of beetle banks to farmland biodiversity. *Aspects of Applied Biology*, 62, 31–38.
(2) Moreby S.J. (2002) Permanent and temporary linear habitats as food sources for the young of farmland birds. Pages 327-332 in: D.E. Chamberlain (ed.) *Avian Landscape Ecology: Pure and Applied Issues in the Large-Scale Ecology of Birds*. International Association for Landscape Ecology (IALE(UK)), Aberdeen.
(3) Moreby S.J. & Southway S. (2002) Cropping and year effects on the availability of invertebrate groups important in the diet of nestling farmland birds. *Aspects of Applied Biology*, 67, 107–112.

(4) Fuentes-Montemayor E., Goulson D. & Park K.J. (2011) The effectiveness of agri-environment schemes for the conservation of farmland moths: assessing the importance of a landscape-scale management approach. *Journal of Applied Ecology*, 48, 532–542.

3.22. Manage rice field banks to benefit butterflies and moths

- **One study** evaluated the effects on butterflies and moths of managing rice field banks to benefit butterflies and moths. This study was in Italy[1].

COMMUNITY RESPONSE (1 STUDY)

- **Richness/diversity (1 study):** One replicated, site comparison study in Italy[1] found that unmown, herbicide-free rice field banks had a greater species richness of butterflies than banks which were mown or sprayed with herbicide.

POPULATION RESPONSE (1 STUDY)

- **Abundance (1 study):** One replicated, site comparison study in Italy[1] found that unmown, herbicide-free rice field banks had a higher abundance of butterflies, including large copper, than banks which were mown or sprayed with herbicide.

BEHAVIOUR (0 STUDIES)

Background

Rice paddy fields are unusual among agricultural habitats as they normally have banks as field boundaries (rather than hedgerows, walls or ditches). The banks are often managed to reduce vegetation cover, either by spraying with herbicide or by mechanical cutting (Giuliano *et al.* 2018). However, reduced management may enable vegetation cover to develop and flower abundance to increase, which may benefit butterflies and moths.

Giuliano D., Cardarelli E. & Bogliani G. (2018) Grass management intensity affects butterfly and orthopteran diversity on rice field banks. *Agriculture, Ecosystems & Environment*, 267, 147–155.

A replicated, site comparison study in 2016 on three rice farms in Pavia province, Italy (1) found that unmown, herbicide-free rice field banks had a higher abundance and species richness of butterflies than banks which were mown or sprayed with herbicide. On unmanaged banks, the abundance (1.2–12.2 individuals/100 m) and species richness (0.7–2.6 species/100 m) of butterflies was higher than on mown (abundance: 0.5–6.1 individuals/100 m; richness: 0.4–2.0 species/100 m) or sprayed banks (abundance: 0.1–2.3 individuals/100 m; richness: 0.1–1.1 species/100 m). Endangered large copper *Lycaena dispar* butterflies were present on more unmanaged banks (48 individuals) than on sprayed banks (10 individuals). See paper for other species results. Banks (1–2 m wide) between paddy fields on three farms were managed in one of three ways: sprayed with herbicide (Glyphosate) in April, mown 1–3 times between late April and August, or left unmanaged with permanent herbaceous cover. From April–September 2016, butterflies were surveyed monthly on 160–440-m-long transects on 30 field banks (13 sprayed, 13 mown, four unmanaged).

(1) Giuliano D., Cardarelli E. & Bogliani G. (2018) Grass management intensity affects butterfly and orthopteran diversity on rice field banks. *Agriculture, Ecosystems & Environment*, 267, 147–155.

Livestock farming and ranching

3.23. Maintain species-rich, semi-natural grassland

- **Nineteen studies** evaluated the effects on butterflies and moths of maintaining species-rich, semi-natural grassland. Five studies were in Germany[1,2,4,17,19], four were in the USA[5–7,10], two were in each of Switzerland[3,13] and the Czech Republic[15,16], and one was in each of Finland and Russia[8], China[9], Italy[11], Spain[12], Hungary[14] and Austria[18].

COMMUNITY RESPONSE (12 STUDIES)

- **Community composition (6 studies):** Four replicated, site comparison studies in the USA[10], the Czech Republic[16], Austria[18] and Germany[19] found that the community composition of butterflies[10,18], day-flying moths[18] and nocturnal moths[16,19] was different between summer cattle-grazed, early-mown and late-mown grassland[18], between mown and grazed grassland[16,19], and between prairies managed by cattle grazing and/or rotational burning[10]. However, one of these studies found that the community composition of butterflies was similar in mown and grazed grassland[16]. Two replicated, site comparison studies in the Czech Republic[16] and Germany[17] found that species-rich grassland managed by grazing or mowing had a similar community composition of butterflies[16,17] and burnet moths[17] to abandoned grassland. One replicated, site comparison study in Switzerland[13] found that meadows managed by mowing at least twice/year after mid-June had a different community composition of butterflies to sown wildflower strips.
- **Richness/diversity (11 studies):** Three of six site comparison studies (including five replicated studies) in Germany[2], the USA[7,10], Russia and Finland[8], Italy[11] and the Czech Republic[16] found that the species richness of butterflies was similar on semi-natural grassland managed by light grazing or by annual mowing in July or August[2,8], and on prairies managed by cattle grazing and/or rotational burning[10]. One study found that the species richness of butterflies was higher in grassland managed by sheep and cattle grazing than in grassland mown annually for hay in June[11]. One study found that the species richness of moths was higher in grassland managed by annual mowing than grassland managed by grazing, and the species richness of butterflies was highest in grasslands where mowing was staggered throughout the year, with some areas left uncut[16]. The sixth study found that in some areas, the species richness of specialist and grassland butterflies was higher in prairies managed by two-year rotational haying, and in other areas it was higher in prairies managed by grazing, but in all cases richness was higher at sites longer after they were last managed[7]. Two replicated, site comparison studies in Germany[17,19] found that species-rich grasslands managed by summer-grazing[17], grazing[19] or mowing[17] had a similar species richness of butterflies and burnet moths[17] and nocturnal moths[19] to unmanaged grassland. However, one of these studies also found that grasslands managed by mowing had a lower species richness of nocturnal moths than unmown grassland[19]. Two replicated, site comparison studies in Germany[4] and Hungary[14] found that old meadows mown in July[4] and lightly grazed or annually mown meadows[14] had a higher species richness of adult butterflies[4,14] and

caterpillars[4] than recently established set-aside[4] or cereal crops[4,14]. One replicated, site comparison study in Switzerland[13] found that meadows mown at least twice/year after mid-June had a similar species richness of butterflies to sown wildflower strips.

POPULATION RESPONSE (16 STUDIES)

- **Abundance (16 studies):** Five of ten site comparison studies (including nine replicated studies) in Germany[1,2], the USA[5–7,10], Russia and Finland[8], Italy[11], Spain[12] and the Czech Republic[15] found that semi-natural grasslands had a similar abundance of butterflies generally[2,8], and individual species of butterflies[6,15] and moth caterpillars[1], when managed by extensive sheep[1], sheep and goat[15], cattle[8] or livestock[2,6] grazing compared to annual[1,2,8] or occasional[15] mowing, or rotational mowing or burning[6]. Four of these studies found that grasslands managed by cattle[11], sheep[1,11] or livestock[5,6] grazing had a higher abundance of butterflies generally[11], and individual species of butterflies[5,6] and moth caterpillars[1], than grasslands managed by annual mowing[1,11], rotational burning[5,6] or unmanaged grasslands[5,6]. Three of these studies found that grasslands managed by haying had a higher abundance of individual butterfly species[5,6,12] than grasslands managed by grazing[5,12] or burning[5,6], or unmanaged grasslands[5,6]. Four of these studies found that specific butterfly species[5,6,15] and all butterflies[10] were less abundant in mown[5,6,15], grazed[5,6,10,15] or rotationally burned[10] grassland than in unmanaged[5,6,15], rotationally burned[6] or grazed and burned[10] grassland. The ninth study found that in some areas, the abundance of specialist and grassland butterflies was higher in prairies managed by two-year rotational haying or by grazing, but in all cases abundance was higher at sites longer after they were last managed[7]. One of three replicated, site comparison studies in Germany[17,19] and Switzerland[3] found that traditional hay meadows mown once/year in June or July had a higher abundance of heath fritillary adults and caterpillars than old, abandoned meadows[3]. One study found that summer-grazed or mown grasslands had a higher abundance of farmland butterflies and burnet moths, but a lower abundance of woodland butterflies and burnet moths, than abandoned grasslands[17]. The third study found that mown grasslands had a lower abundance of moths than unmown grasslands, but grazed grasslands had a similar abundance of moths to ungrazed grasslands[19]. Two replicated, site comparison studies in China[9] and Switzerland[13] found that semi-natural grasslands managed by grazing[9] or cutting twice/year after mid-June[13] had a lower abundance of marsh fritillary eggs and caterpillars[9] and adult butterflies[13] than ungrazed margins and intercrops[9] or sown wildflower strips[13]. One replicated, site comparison study in Hungary[14] found that semi-natural grasslands managed by either light grazing or mowing once/year in May or June had a higher abundance of butterflies than conventional wheat fields.
- **Survival (1 study):** One replicated, site comparison study in China[9] found that marsh fritillary eggs had a similar survival rate in uncultivated, grazed meadows and cultivated, ungrazed field margins and intercrops, but the survival of caterpillars was higher in the grazed meadows.

BEHAVIOUR (5 STUDIES)

- **Use (5 studies):** Two replicated, site comparison studies in Austria[18] and Germany[19] found that 14 species of moth[18,19] preferred grazed pastures while 24 others avoided them[19], and three species of butterfly[18] and ten nocturnal moths[19] preferred mown meadows, while 19 nocturnal moth species avoided them. One replicated, site comparison study in Spain[12] found that meadows managed by summer-grazing or hay-mowing were more likely to be occupied by grizzled skipper and painted lady than unmanaged meadows, but small pearl-bordered fritillary occurred less frequently in grazed meadows than in hay meadows or abandoned meadows. One replicated, site comparison study in Finland and Russia[8] found that three of 37 butterfly species preferred meadows which were mown annually in July or August to cattle-grazed pasture, but the other 34 species showed no preference. One replicated, site comparison study in China[9] found that uncultivated, grazed meadows were less likely to be occupied by marsh fritillary eggs and caterpillars than cultivated field margins and intercrops.

Background

Species-rich, semi-natural grassland represents an important habitat for butterflies and moths, particularly in agricultural areas. Such grasslands can be maintained either by extensive livestock grazing, or by infrequent (often annual) cutting for hay (Dover *et al.* 2011). This intervention includes studies which compare the maintenance of grasslands under these two management techniques, as well as comparisons between semi-natural grassland and other agricultural grasslands.

For studies on the effects of abandoning management on semi-natural grasslands, see "*Cease grazing on grassland to allow early succession*" and "*Cease mowing on grassland to allow early succession*". For studies on restoring semi-natural grassland following a period of abandonment, see "*Restore or create species-rich, semi-natural grassland*". For studies on restoring grassland on former arable land, see "*Restore arable land to permanent grassland*". For studies on restoring species-rich grassland from productive grassland, see "*Reduce grazing intensity on grassland by reducing stocking density*", "*Reduce grazing intensity on grassland by seasonal removal of livestock*", "*Reduce cutting frequency on grassland*" and "*Reduce management intensity on permanent grasslands (several interventions at once)*".

For other grassland management options, see "*Natural system modifications – Use prescribed fire to maintain or restore disturbance on grasslands or other open habitats*" and "*Habitat restoration and creation – Change mowing regime on grassland*".

Dover J.W., Spencer S., Collins S., Hadjigeorgiou I. & Rescia A. (2011) Grassland butterflies and low intensity farming in Europe. *Journal of Insect Conservation*, 15, 129–137.

A replicated, paired, site comparison study in 1990–1991 in 35 calcareous grasslands in Northern Bavaria, Germany (1) reported that semi-natural grasslands maintained by sheep grazing had a higher density of meadow neb moth *Metzneria metzneriella* caterpillars, and a similar occurrence of hoary bell moth *Eucosma cana* caterpillars, compared to mown grasslands. Results were not tested for statistical significance. In grazed grasslands, 2.9–3.3% of greater knapweed *Centaurea scabiosa* flowerheads contained meadow neb caterpillars, compared to 0–0.3% of flowerheads in mown grasslands, and 2.2–2.5% of flowerheads in abandoned grasslands. The occurrence of hoary bell was similar in mown, grazed and abandoned grasslands (data not presented). Thirty-five grasslands (0.5–2 ha) were managed by either light sheep grazing in early autumn (7 sites, vegetation <10 cm) or annual mowing (usually in midsummer, 7 sites, vegetation ~25 cm before cutting), or had been abandoned for at least five years (21 sites, vegetation

>25 cm with shrubs). In September–October 1990 and 1991, samples of 100–350 greater knapweed flowerheads/site were collected from seven pairs of grazed-abandoned and mown-abandoned grasslands, and seven (1990) and four (1991) unpaired, abandoned grasslands. Flowerheads were dissected in the laboratory to identify caterpillars.

A replicated, site comparison study in 1994 in 19 traditional hay meadows in Bavaria, Germany (2) found that the abundance and species richness of all butterflies, and of threatened species only, was similar in mown and grazed grassland. In lightly grazed meadows, the abundance of all species of butterfly (39.5 individuals) and of 16 threatened species (6.9 individuals) was similar to the abundance in meadows mown once/year (all species: 25.8 individuals; threatened species: 7.5 individuals). The species richness of butterflies was also similar in grazed and mown meadows (data not presented). However, managed meadows had a higher abundance and species richness of butterflies than abandoned meadows (data not presented). Nineteen meadows, which had been managed in the same way for at least 5–20 years, were compared. Six traditionally managed hay meadows were mown once/year in July or early August, nine meadows were extensively grazed with sheep, cattle or horses for a few weeks each summer, one meadow was grazed by sheep throughout the summer, and three meadows were not managed (abandoned). From June–August 1994, butterflies were surveyed along a fixed transect five times in each meadow.

A replicated, site comparison study in 1993–1994 in 16 alpine meadows in southern Switzerland (3) found that traditional hay meadows and recently abandoned meadows had a higher abundance of heath fritillary *Mellicta athalia* adult males and caterpillars, but not females, than old, abandoned or restored meadows. There were more adult males and caterpillars in traditional hay meadows (males peak: 30 individuals/hour; caterpillars: 0.5–3.5 individuals/hour) and recently abandoned meadows (males: 40 individuals/hour; caterpillars: 4–8 individuals/hour) than in old, abandoned (males: 21 individuals/hour; no caterpillars) or restored meadows (males: 20–22 individuals/hour; caterpillars: 0–0.2 individuals/hour). The number of females was not significantly different between meadows (traditional: 5; recently abandoned: 14; old abandoned: 5; restored: 7–14 individuals/hour). Marked butterflies were recorded moving between all habitat types. Five traditional hay meadows were mown once/year in June or July, five old, abandoned meadows had been unmanaged for >25 years, two recently abandoned meadows had been unmanaged for around six years. From 1992, two abandoned meadows were restored by annual mowing, and two were restored by mowing every 4–5 years. From June–July 1993–1994, adult butterflies were caught and marked for 45 minutes/meadow every other day. In 1994, each meadow was searched for three hours, spread over several days, to record solitary caterpillars.

A replicated, site comparison study in 1992 in agricultural land in Baden-Württemberg, Germany (4) found that old meadows had a higher species richness of adult butterflies and caterpillars than either recently established set-aside. Adult butterfly species richness was higher in old meadows (20 species) than in naturally regenerated set-aside (11–13 species), sown set-aside (7 species) or cereal crops (4 species). Caterpillar species richness was also higher in old meadows (16 species) than in naturally regenerated set-aside (3–7 species). Butterfly species found in meadows tended to be less migratory, spend longer as caterpillars (meadow: 121 days; set-aside: 44–105 days), and have fewer generations/year (meadow: 1.8 generations/year; set-aside: 1.9–2.7 generations/year) than species in recently established set-aside. In 1992, four fields in each of seven management types were studied: old meadows (>30 years old), former cereal fields left to naturally develop as set-aside for each of 1, 2, 3 and 4 years, 1-year-old set-aside sown with lacy phacelia *Phacelia tanacetifolia*, and cereal fields (rye *Secale cereale* or wheat *Triticum aestivum*). Meadows and set-aside fields were mown once/year in July. From May–October 1992, adult butterflies were counted along transects nine times/field. In September 1992, moth and butterfly caterpillars were sampled twice by sweep-netting.

A replicated, site comparison study in 1988–1996 in 17 upland prairies in Missouri, Minnesota, North Dakota and Wisconsin, USA (5, same experimental set-up as 6, 7) found that prairies managed by haying or grazing had a higher abundance of four specialist butterfly species, but a lower abundance of three species than prairies managed by burning or unmanaged sites. Of seven prairie specialist butterfly species, three (regal fritillary *Speyeria idalia*, Pawnee skipper *Hesperia leonardus pawnee*, Dakota skipper *Hesperia dacotae*) were more abundant in prairies managed by haying than in rotationally burned, grazed or unmanaged prairies in at least one of three regions. Gorgone checkerspot *Chlosyne gorgone* was more abundant in grazed prairies than burned or unmanaged areas. However, three species (gray copper *Lycaena dione*, arogos skipper *Atrytone arogos*, Poweshiek skipperling *Oarisma poweshiek*) were less abundant in hayed or grazed prairies than in unmanaged prairies in at least one of three regions. See paper for individual species data. Across 17 prairies (16 to >120 ha), two areas were managed by grazing, six by haying (often in rotation), eight by burning on rotation, three by burning and haying, and two were unmanaged. From 1988–1996, butterflies were surveyed on transects through different management areas at each site. Sites were not surveyed in every year.

A replicated, site comparison study in 1986–1995 in 104 tallgrass prairies and 141 pine barrens in Illinois, Iowa, Minnesota, Missouri, North Dakota and Wisconsin, USA (6, same experimental set-up as 5, 7) found that hayed, mown, cut or grazed grasslands had a higher abundance of six of 16 specialist butterfly species, but a lower abundance of three specialist species, than burned or unmanaged grasslands. Of 16 prairie or pine barren specialist butterfly species, five were more abundant in sites managed by haying (Dakota skipper *Hesperia dacotae*, pawnee skipper *Hesperia leonardus pawnee*), mowing (Persius duskywing *Erynnis persius*), cutting (cobweb skipper *Hesperia metea*) or grazing and haying (regal fritillary *Speyeria idalia*), than burned or unmanaged sites. Arogos skipper *Atrytone arogos* was most abundant in grazed and hayed, or unmanaged, sites. Poweshiek skipper *Oarisma poweshiek* was less abundant in sites managed by haying than in unmanaged sites, and Ottoe skipper *Hesperia ottoe* and dusted skipper *Atrytonopsis hianna* were less abundant in sites managed by grazing or mowing than in rotationally burned sites. See paper for individual species data. Seven species had similar abundance between management types (see paper for details). Of 104 prairies (1–2,024 ha), 27 were hayed in summer on a 1–2-year rotation, of which two were also grazed occasionally with cattle; 10 were grazed; 61 were managed by cool-season burning on a 2–5-year rotation, of which 21 were additionally mown or hayed; and six had not been managed for many years. Of 141 pine barrens, some were burned by wildfires, some were used for off-road vehicle trails, and some were power line rights-of-way (no further detail provided). From April–September 1986–1995, butterflies were surveyed on transects at each site. Most sites were surveyed more than once/year, and in >1 year.

A replicated, site comparison study in 1990–1997 in 106 tallgrass prairies in Illinois, Iowa, Minnesota, Missouri, North Dakota and Wisconsin, USA (7, same experimental set-up as 5, 6) found that in some states, prairies managed by haying had the highest abundance and species richness of specialist and grassland butterflies, but in other states grazing supported a higher abundance and species richness of butterflies compared to other management types. In Missouri, the abundance and species richness of specialist and grassland butterflies was higher in prairies managed by two-year rotational haying than in rotationally burned areas. In Minnesota, North Dakota and western Iowa, the abundance of specialist and grassland species was higher in hayed areas than in burned areas, and the abundance and richness of specialist species was lower in rotationally grazed areas. However, in eastern Iowa, Illinois, and Wisconsin, the abundance of specialist and grassland species, and the richness of specialists, was higher at a continuously grazed site than in other management types. All data were presented as models results. Across all prairies, specialist and grassland butterfly abundance and richness tended to be higher at rotationally managed sites (haying, grazing or burning) longer after they were last managed. Of 106 prairies (1.2–2,024 ha), 27 contained areas managed by haying, mostly on a two-year rotation, seven were managed by rotational grazing (0.3–0.6 animals/ha/year) and one by continuous grazing (3–6 animals/ha/year), 77 areas were managed by rotational burning (every 2–5 years) in the cool-season (of which 24 were also hayed or mown), and nine had been unmanaged for many years. From May–September 1990–1997, butterflies were surveyed on parallel transects (5–10 m apart) at each site. Most sites were surveyed more than once/year, and in >1 year. Species were classified as “specialists” (of native plants), “grassland” (occurring widely in open habitat) and “generalist” (occurring in a range of habitats).

A replicated, site comparison study in 1997–1999 in 16 pastures and meadows in northwest Russia and southeast Finland (8) found that butterfly abundance, species richness and diversity were similar in mown meadows and grazed pastures. In mown meadows, the total abundance (3,660 individuals) and species richness (46 species) of butterflies was not significantly different from the total abundance (2,082 individuals) and species richness (42 species) in grazed pastures (see paper for diversity data). Only three out of 37 species showed a significant preference for mown meadows (Amanda’s blue *Polyommatus amandus*, large skipper *Ochlodes sylvanus* and ringlet *Aphantopus hyperantus*, see paper for data). The remaining 34 species did not show a significant preference for either field type. Butterfly communities were affected more by the origin and age of the grassland than the present management method (see paper for details). Eight meadows were mown annually in late July or August and eight pastures were grazed by cattle, although some had sheep or horses temporarily. Tilling and fertilisation (manure) tended to occur at intervals of 3–10 years. In June–July 1997–1999, butterflies were surveyed 12–13 times/site along transects (640–720 m).

A replicated, site comparison study in 2003 in 38 meadows in Hebei Province, China (9) found that uncultivated, grazed meadows were less likely to be occupied by marsh fritillary *Euphydryas aurinia* eggs and caterpillars than lightly cultivated meadows with grass margins and intercrop, but caterpillar survival was higher in the uncultivated meadows. Fewer entirely uncultivated, grazed meadows contained eggs (1/12 meadows) and caterpillars (5/22 meadows) than meadows with some cultivation (eggs: 9/11; caterpillars: 11/16 meadows). In total, 70 egg clusters were found in grazed meadows, compared to 179 egg clusters in cultivated meadows (statistical significance not assessed). The mortality of egg clusters was similar in grazed meadows (16% of 69 clusters) and cultivated meadows (10% of 177 clusters), but the survival of pre-hibernation caterpillars was higher in grazed meadows (21/59, 33%) than in cultivated meadows (23/164, 14%). A total of 38 meadows (0.025 ha–3.200 ha) were studied. In 2003, twenty-two meadows were entirely uncultivated and grazed. Another 16 meadows contained some cultivation (corn or potatoes), and were divided into cultivated habitat (grass strips within and around the crop, no grazing from April–October) and meadow habitat (meadows and fallow land, grazed by sheep and cattle). In June 2003, twelve uncultivated and 11 cultivated meadows were searched for egg clusters. These were marked and observed every other day until all hatched caterpillars had disappeared or begun overwintering. In September 2003, all 38 meadows were surveyed for caterpillar nests.

A replicated, site comparison study in 2004–2005 in two remnant prairies and adjacent land in Iowa, USA (10) found that prairies which were grazed and burned had a higher abundance, but not species richness, of butterflies than prairies which only received grazing or burning, but the three management practices supported different species. The abundance of butterflies in grazed and burned prairies (31.5 individuals/unit) was higher than in prairies which were only grazed (27.8 individuals/unit) or only burned (20.2 individuals/unit). Species richness of butterflies was similar in prairies managed by grazing and burning (8.5 species/unit), only grazing (7.4 species/unit) and only burning (8.6 species/unit). Butterfly diversity was lower in prairies managed by grazing only, or grazing and burning, than in prairies managed by burning only (data presented as model results). However, each management practice supported different species (see paper for details). Across two remnant prairie reserves (320 and 1,800 ha) and surrounding land, 28 management units (10–167 ha) were managed consistently for ≥4 years. Six units were lightly grazed on rotation (1 cow-calf pair/4 ha). Ten units were burned during autumn or spring every 1–6 years. Twelve units were burned and grazed. From June–August 2004–2005, butterflies were surveyed for 30 minutes twice/year at 69 sites (50 × 50 m, >150 m apart) across the 28 units.

A site comparison study in 2008–2009 on two semi-natural grasslands in southern Italy (11) found that a grassland grazed with sheep and cattle had a higher abundance and species richness of butterflies than a grassland cut for hay. The grazed grassland had a higher abundance (6,005 individuals) and species richness (45 species) of butterflies than the mown grassland (abundance: 2,416 individuals; richness: 28 species). All species found in the mown grassland were also found in the grazed grassland, and most species were more abundant at the grazed site (23/28). See paper for data on individual species. Two 6-ha grasslands surrounded by woodland, both at 850 m altitude and 3 km apart, were studied. One site was mown for hay once/year, in June, and the other site was grazed with sheep and cattle. Both meadows had received the same management for at least 20 years. From April–September 2008–2009, butterflies were surveyed on a weekly 1-km transect around the edge of each site.

A replicated, site comparison study in 2003–2005 in 47 alpine meadows in Picos de Europa, Spain (12) found that mown hay meadows had a higher abundance of two out of 44 butterfly species than summer grazed or abandoned meadows, and summer grazed meadows had a lower abundance or occurrence of four out of 44 butterfly species than mown or abandoned meadows. The abundance of two species (black-veined white *Aporia crataegi* and meadow brown *Maniola jurtina*) was higher in hay meadows than in grazed or abandoned meadows (data presented as model results). The abundance of three species (small skipper *Thymelicus sylvestris*, small white *Pieris rapae*, ringlet *Aphantopus hyperantus*) was lower, and one species (small pearl-bordered fritillary *Boloria selene*) occurred less frequently, in summer grazed meadows than in hay meadows or abandoned meadows (data presented as model results). Two species (grizzled skipper *Pyrgus malvae* and painted lady *Vanessa cardui*) occurred more frequently in managed meadows than in abandoned meadows (data presented as model results). The remaining 36 species did not differ in abundance or occurrence between management types. From summer 2003–2005, management was recorded on 47 meadows. Seven meadows were grazed by livestock in summer, 24 meadows were cut for hay, and 16 meadows were either abandoned or only grazed in the winter. The abandoned meadows had different amounts of scrub growing within them. From June–July 2004, butterflies were surveyed nine times on a transect around the edge of each meadow.

A replicated, site comparison study in 2008 in a lowland agricultural landscape in Kanton Fribourg, Switzerland (13) found that extensively managed meadows had a lower abundance of butterflies, but a similar species richness and a different community composition, compared to sown wildflower strips. The abundance of butterflies in extensively managed meadows (0.12 individuals/m) was lower than in sown wildflower strips (0.29 individuals/m), but the species richness was similar in meadows (0.05 species/m) and wildflower strips (0.07 species/m). The species composition was different between the two habitats, with six of 25 species observed most frequently in the meadows and seven species occurring only in wildflower strips. None of the five rarest species in the region were recorded in either the meadows or wildflower strips. See paper for details on individual species. Eleven meadows (0.21–1.64 ha) were cut at least twice/year after mid-June. Twenty-five wildflower strips (0.15–1.16 ha) were sown with a standard seed mixture of 24 plant species, and were 1–7 years old. From May–September 2008, butterflies were surveyed once/month on a transect through the middle of each meadow (85–310 m) or wildflower strip (70–450 m).

A replicated, site comparison study in 2008 in a mixed farming region in Hungary (14) found that established semi-natural grassland supported a higher abundance and species richness of butterflies than cereal fields. In semi-natural grassland fields both the abundance (74 individuals/field) and species richness (8 species/field) of butterflies were higher than in winter wheat fields (abundance: 4 individuals/field; richness: 2 species/field). See paper for details of individual species. From at least 2005, six established semi-natural grassland fields had no fertilizer or chemicals applied, and were either lightly grazed or mown once/year in May–June. Sixteen winter wheat fields were fertilized (70 kg/ha/year nitrogen), sprayed once/year in spring with herbicide and insecticide, and harvested in June. From May–August 2008, butterflies were surveyed on fixed transects four times in each field. Each field was surveyed for 10, 20 or 30 minutes, depending on field size.

A replicated, site comparison study in 2007 in a grassland and woodland reserve in the Czech Republic (15) found that grasslands managed by occasional mowing had a similar abundance of Scotch argus *Erebia aethiops* to grasslands managed by sheep and goat grazing. On occasionally mown grasslands, the abundance of Scotch argus males (9 individuals/ha) and females (5 individuals/ha) was similar to grazed grasslands (males: 7; females: 4 individuals/ha). However, the abundance of Scotch argus males (19 individuals/ha) and females (13 individuals/ha) was highest on temporarily abandoned grasslands, and lowest on intensively mown grasslands (males: 3; females: 2 individuals/ha). Within a 55-ha reserve, 27 grasslands (128–6,072 m^2) were managed by either occasional mowing, sheep and goat grazing or intensive mowing, or were temporarily abandoned. On 33 days from July–August 2007, butterflies were caught, individually marked, and recaptured at each site.

A replicated, site comparison study in 2007–2010 in 28 grassland sites in Bílé Karpaty Protected Landscape Area, Czech Republic (16) found that the management of semi-natural grassland affected the species richness and composition of butterfly and moth communities differently. The species richness of moths was highest in mown grasslands and lowest in grazed grasslands, and these sites had different species composition. However, the species richness of butterflies was highest under mixed management, though species composition was not affected (all data presented as model results). One of four different management practices (mown once/year; grazed by sheep, cattle or deer; abandoned (no grazing or mowing); or 'mixed' management) was applied to each of 28 sites (1.5–70.7 ha) for at least five consecutive years. 'Mixed' management included mowing different parts of the site at different times, often with patches left uncut for a year, or mowing followed by grazing. From 2007–2010, butterflies and moths were surveyed on >6 visits between April and October in each of two consecutive years to each site.

A replicated, site comparison study in 2015 in 20 grasslands in Saxony, Germany (17) found that managed grasslands had a higher abundance of farmland butterflies and burnet moths, but a lower abundance of woodland butterflies and burnet moths, than abandoned grasslands, but there was no difference in species richness or community composition. In managed grasslands, the abundance of 35 species of farmland butterflies and burnet moths (195–206 individuals) was higher than in abandoned grasslands (127 individuals). However, the abundance of 20 species of woodland butterflies and burnet moths was lower in managed grasslands (17–36 individuals) than abandoned grasslands (34–44 individuals). The species richness of both farmland and woodland species was similar in managed (farmland: 14; woodland: 5–6 species) and abandoned (farmland: 13–14; woodland: 5–6 species) grassland. The community composition was also similar in managed and abandoned grasslands (data presented as model results). Twenty calcareous grasslands (0.90–5.38 ha) were surveyed. Eight were managed by summer grazing (May–September, <1 animal/ha, with cattle, sheep, goats, horses or donkeys), one was managed by mowing, one was mown and grazed, and 10 were abandoned (not grazed or mown). From May–August 2015, butterflies and burnet moths were surveyed three times along a 20-minute transect on a 0.8 ha patch at each site. Butterflies and burnet moths were classified as 35 farmland and 20 woodland species.

A replicated, site comparison study in 2013–2015 in 45 semi-natural grasslands in eastern Austria (18) found that grasslands managed by grazing, early mowing and late mowing had distinct butterfly and day-flying moth communities. Butterfly and day-flying moth communities in semi-natural grasslands managed by extensive grazing were different to communities in early-mown and late-mown meadows (data presented as model results). In addition, some species showed a preference for sites that were grazed (crepuscular burnet *Zygaena carniolica*, transparent burnet *Zygaena purpuralis*/*minos*), early-mown (marbled white *Melanargia galathea*, meadow brown *Maniola jurtina*) or late-mown (short-tailed blue *Cupido argiades*). The use of all three grassland management regimes (grazing, early mowing and late mowing) in different parts of the landscape increased butterfly diversity across the landscape (data presented as model results). Semi-natural grasslands managed in three ways were studied: extensive pastures grazed by cattle from April–October, meadows mown once/year in early summer with cuttings removed, and former vineyards mown once/year in late summer with cuttings not removed. In June 2013–2015, all butterflies, burnet moths (Zygaenidae) and hummingbird hawk-moths *Macroglossum stellatarum* were counted once on 9–11 sites/year (50 × 50 m) under each management type.

A replicated, site comparison study in 2014 in 26 grasslands in Germany (19) found that grasslands managed by mowing (sometimes alongside grazing) had a lower abundance, species richness and diversity of moths than unmown, grazed grasslands, but grasslands managed by grazing (sometimes alongside mowing) had a similar abundance, species richness and diversity of moths to ungrazed, mown grasslands. Mown grasslands had a lower abundance, species richness and diversity of moths, and more generalist and widespread species, than unmown, grazed grasslands (data presented as model results). Grazed grasslands had a similar abundance, species richness and diversity of moths to ungrazed, mown grasslands (data presented as model results). In addition, grazed and mown grasslands were inhabited by different moth communities (see paper for details). Of 87 individual species monitored, 10 species preferred mown grasslands and 19 species avoided mown grasslands, while 12 species preferred grazed grasslands and 24 species avoided grazed grasslands (see paper for individual species data).

From 2006, across three regions, nine grasslands were managed by grazing (by cattle, sheep or horses at 26–520 livestock units/ha/year), nine by mowing (1–2 cuts/year, often with nitrogen fertilization), and eight were grazed and mown (76–163 livestock units/ha/year; 1–2 cuts/year). Moths were collected once/month from nine grasslands in each of two regions (May–August 2014), and from eight grasslands in one region (June–July 2014). Each night, a 12 V actinic and black-light trap were placed in the centre of each of three grasslands for 138–317 minutes/night.

(1) Völkl W., Zwölfer H., Romstöck-Völkl M. & Schmelzer C. (1993) Habitat management in calcareous grasslands: effects on the insect community developing in flower heads of Cynarea. *Journal of Applied Ecology*, 30, 307–315.

(2) Dolek M. & Geyer A. (1997) Influence of management on butterflies of rare grassland ecosystems in Germany. *Journal of Insect Conservation*, 1, 125–130.

(3) Schwarzwälder B., Lörtscher M., Erhardt A. & Zettel J. (1997) Habitat utilizations by the heath fritillary butterfly, *Mellicta athalia* ssp. *celadussa* (Rott.) (Lepidoptera: Nymphalidae) in montane grasslands of different management. *Biological Conservation*, 82, 157–165.

(4) Steffan-Dewenter I. & Tscharntke T. (1997) Early succession of butterfly and plant communities on set-aside fields. *Oecologia*, 109, 294–302.

(5) Swengel A.B. & Swengel S.R. (1997) Co-occurrence of prairie and barrens butterflies: applications to ecosystem conservation. *Journal of Insect Conservation*, 1, 131–144.

(6) Swengel A.B. (1998) Effects of management on butterfly abundance in tallgrass prairie and pine barrens. *Biological Conservation*, 83, 77–89.

(7) Swengel A.B. & Swengel S.R. (2001) Effects of prairie and barrens management on butterfly faunal composition. *Biodiversity and Conservation*, 10, 1757–1785.

(8) Saarinen K. & Jantunen J. (2005) Grassland butterfly fauna under traditional animal husbandry: contrasts in diversity in mown meadows and grazed pastures. *Biodiversity and Conservation*, 14, 3201–3213.

(9) Liu W, Wang Y. & Xu R. (2006) Habitat utilization by ovipositing females and larvae of the Marsh fritillary (*Euphydryas aurinia*) in a mosaic of meadows and croplands. *Journal of Insect Conservation*, 10, 351–360.

(10) Vogel J.A., Debinski D.M., Koford R.R. & Miller J.R. (2007) Butterfly responses to prairie restoration through fire and grazing. *Biological Conservation*, 140, 78–90.

(11) D'Aniello B., Stanislao I., Bonelli S. & Balletto E. (2011) Haying and grazing effects on the butterfly communities of two Mediterranean-area grasslands. *Biodiversity and Conservation*, 20, 1731–1744.

(12) Dover J.W., Rescia A., Fungarino S., Fairburn J., Carey P., Lunt P., Arnot C., Dennis R.L.H. & Dover C.J. (2011) Land-use, environment, and their impact on butterfly populations in a mountainous pastoral landscape: individual species distribution and abundance. *Journal of Insect Conservation*, 15, 207–220.

(13) Haaland C. & Bersier L. (2011) What can sown wildflower strips contribute to butterfly conservation?: an example from a Swiss lowland agricultural landscape. *Journal of Insect Conservation*, 15, 301–309.

(14) Kovács-Hostyánszki A., Kőrösi Á., Orci K.M., Batáry P. & Báldi A. (2011) Set-aside promotes insect and plant diversity in a Central European country. *Agriculture, Ecosystems & Environment*, 141, 296–301.

(15) Slamova I., Klecka J. & Konvicka M. (2013) Woodland and grassland mosaic from a butterfly perspective: habitat use by *Erebia aethiops* (Lepidoptera: Satyridae). *Insect Conservation and Diversity*, 6(3), 243–254.

(16) Bonari G., Fajmon K., Malenovský I., Zelený D., Holuša J., Jongepierová I., Kočárek P., Konvička O., Uřičář J. & Chytrý M. (2017) Management of semi-natural grasslands benefiting both plant and insect diversity: The importance of heterogeneity and tradition. *Agriculture, Ecosystems & Environment*, 246, 243–252.

(17) Ernst L.M., Tscharntke T. & Batary P. (2017) Grassland management in agricultural vs. forested landscapes drives butterfly and bird diversity. *Biological Conservation*, 216, 51–59.

(18) Fiedler K., Wrbka T. & Dullinger S. (2017) Pluralism in grassland management promotes butterfly diversity in a large Central European conservation area. *Journal of Insect Conservation*, 21, 277–285.
(19) Mangels J., Fiedler K., Schneider F.D. & Bluthgen N. (2017) Diversity and trait composition of moths respond to land-use intensification in grasslands: generalists replace specialists. *Biodiversity and Conservation*, 26, 3385–3405.

3.24. Restore or create species-rich, semi-natural grassland

- **Six studies** evaluated the effects on butterflies and moths of restoring or creating species-rich, semi-natural grassland. Two studies were in Finland[2,3], and one was in each of Switzerland[1], Sweden[4], the UK[5] and Germany[6].

COMMUNITY RESPONSE (3 STUDIES)

- **Community composition (1 study):** One replicated, site comparison study in the UK[5] found that semi-natural grasslands restored by scrub clearance and the reintroduction of grazing or mowing had different butterfly communities to existing species-rich grasslands, and they did not become more similar over time.
- **Richness/diversity (3 studies):** One of two replicated, site comparison studies in Finland[2] and Sweden[4] found that semi-natural grasslands restored by scrub clearance and grazing had a similar species richness of butterflies and burnet moths to both unrestored and continuously managed grassland[4]. The other study found that semi-natural grasslands restored by cattle grazing had a lower species richness of butterflies and day-flying moths than unrestored and continuously managed grasslands[2]. One replicated, site comparison study in the UK[5] found that the species richness of butterflies on semi-natural grasslands restored by scrub clearance and the reintroduction of grazing or mowing remained similar over time since restoration.

POPULATION RESPONSE (5 STUDIES)

- **Abundance (5 studies):** Two of five replicated, site comparison studies (including one paired study) in Switzerland[1], Finland[2,3], Sweden[4] and Germany[6] found that semi-natural grasslands restored by cattle grazing had a lower total abundance of butterflies and day-flying moths[2], and of 13 out of 32 individual species[3], than unmanaged, abandoned grasslands, but that three species had higher abundance, and three had lower abundance, on restored grasslands than on continuously grazed grasslands[3]. Two studies found that grasslands restored by scrub clearing and grazing[4] or mowing[1] had a similar abundance of butterflies and burnet moths[4] and heath fritillaries[1] to unmanaged grasslands[1,4] and continuously managed grasslands[4], although the abundance of heath fritillary adults and caterpillars was lower on restored grasslands than on continuously managed grasslands[1]. The fifth study found that the density of blue-spot hairstreak eggs, and egg batches, was higher in grasslands restored by scrub cutting than in unrestored or continuously managed grasslands[6].

BEHAVIOUR (1 STUDY)

- **Use (1 study):** One replicated, site comparison study in Germany[6] found that in grasslands restored by scrub cutting, a greater proportion of small buckthorn bushes contained blue-spot hairstreak eggs than in unrestored or continuously managed grasslands.

Background

In marginal lands where agriculture ceases to be viable, traditionally managed pastures and hay meadows are frequently abandoned. This leads to an increase in scrub cover, changing the habitat from open grassland to early successional woodland. While this may encourage butterflies and moths which prefer more closed habitats (see "*Abandon/fallow grassland to allow early succession*"), it is detrimental to species which prefer open habitats. This intervention covers the restoration of species-rich, semi-natural grassland from abandoned pasture or hay meadows, by clearing scrub and/or reintroducing low intensity grazing or mowing management.

For studies on the restoration of grassland from former arable land, "*Restore arable land to permanent grassland*". For studies on the restoration of species-rich grassland from intensively managed grassland, see "*Reduce grazing intensity on grassland by reducing stocking density*", "*Reduce grazing intensity on grassland by seasonal removal of livestock*", "*Reduce cutting frequency on grassland*" and "*Reduce management intensity on permanent grasslands (several interventions at once)*". For studies on the maintenance of species-rich grassland, see "*Maintain species-rich, semi-natural grassland*". For studies on grassland restoration outside of a farmland context, see "*Habitat restoration and creation – Restore or create grassland/savannas*".

A replicated, site comparison study in 1993–1994 in 16 alpine meadows in southern Switzerland (1) found that restored meadows had a similar number of adult heath fritillary *Mellicta athalia* to old, abandoned meadows, and fewer adult males and caterpillars, but not females, than traditional hay meadows. The abundance of adult male heath fritillaries and caterpillars on restored meadows (males peak: 20–22 individuals/hour; caterpillars: 0–0.2 individuals/hour) was similar to old, abandoned meadows (males: 21 individuals/hour; no caterpillars), but less than traditionally managed hay meadows (males: 30 individuals/hour; caterpillars: 0.5–3.5 individuals/hour) and recently abandoned meadows (males: 40 individuals/hour; caterpillars: 4–8 individuals/hour). The number of females was not significantly different between meadows (restored: 7–14; old abandoned: 5; traditional: 5; recently abandoned: 14 individuals/hour). Marked butterflies were recorded moving between all habitat types. From 1992, two abandoned meadows were restored by annual mowing, and two were restored by mowing every 4–5 years. Five old, abandoned meadows had been unmanaged for >25 years, five traditional hay meadows were mown once/year in June or July, two recently abandoned meadows had been unmanaged for around six years. From June–July 1993–1994, adult butterflies were caught and marked for 45 minutes/meadow every other day. In 1994, each meadow was searched for three hours, spread over several days, to record solitary caterpillars.

A replicated, site comparison study in 1999–2000 in southwest Finland (2, same experimental set-up as 3) found that species-rich grasslands restored with cattle grazing had a lower abundance and species richness of butterflies and day-flying moths than abandoned (unrestored) grassland. The abundance of butterflies and moths was lower in both restored (126 individuals) and continuously grazed pastures (126 individuals) than in abandoned, unrestored pastures (306 individuals). The number of species was also lower in restored pastures (22 species) than in abandoned pastures (33 species), but the number in continuously grazed pastures was intermediate (26 species). Butterflies and moths were monitored in 1999 or 2000 on 10 restored pastures where, after at least 10 years of abandonment, grazing had re-started 3–8 years before the study, 12 abandoned pastures which had not been grazed for at least 10 years, and 11 continuously grazed pastures. All restored and most continuously grazed pastures received support under the Finnish agri-environment scheme. All grazing was by cattle. Butterflies and day-flying moths were counted along transects four (1999) or seven (2000) times from May–August. Either searching time (1999) or transect length (2000) were standardized across sites.

A replicated, site comparison study in 1999–2000 in southwest Finland (3, same experimental set-up as 2) found that 13 of 32 butterfly and day-flying moth species were less abundant in restored semi-natural grassland than in abandoned (unrestored) grassland. Thirteen out of 32 species of butterfly and day-flying moth were less abundant in restored grassland than in abandoned, unrestored grassland, and a further three species were less abundant in restored grassland than in continuously grazed grassland. Three species were more abundant in restored or abandoned grassland than in continuously grazed grassland. The remaining 13 species had similar abundance in all three grassland types (see paper for data on individual species). Butterflies and day-flying moths were monitored in 1999 or 2000 on 10 restored pastures where, after at least 10 years of abandonment, grazing had re-started 3–8 years before the study, 12 abandoned pastures which had not been grazed for at least 10 years and 11 continuously grazed pastures. All restored and most continuously grazed pastures received support under the Finnish agri-environment scheme. All grazing was by cattle. Butterflies and day-flying moths were counted along transects four (1999) or seven (2000) times from May–August. Either searching time (1999) or transect length (2000) were standardized across sites.

A replicated, paired, site comparison study in 2003–2004 in 36 semi-natural grasslands near Lund, Sweden (4) found that the species richness and abundance of butterflies and burnet moths was similar in recently restored, abandoned and continuously grazed semi-natural grasslands. On restored grassland, the species richness (9 species) and abundance (101 individuals) of butterflies and burnet moths was similar to that on both abandoned (richness: 11 species; abundance: 216 individuals) and continuously grazed grassland (richness: 13 species; abundance: 225 individuals). However, sites currently grazed by sheep (7 species) had a lower species richness of butterflies than sites grazed by horses (13 species) or cattle (12 species), or with no grazing (12 species). From 1999–2003, twelve abandoned, semi-natural grasslands were restored by clearing trees and shrubs, erecting fences, and re-introducing grazing animals. Butterflies and burnet moths were surveyed using transects (150 m/ha) six or seven times in May–August 2003 or June–August 2004 on 12 restored grasslands, 12 abandoned grasslands which had not been managed for 5–15 years, and 12 continuously grazed semi-natural grasslands. Under current management, 12 sites were cattle grazed, six were horse grazed, eight were sheep grazed and 10 had no grazing.

A replicated, site comparison study (years not given) in 10 grasslands in England, UK (5) found that grasslands restored by clearing scrub and restarting management did not develop butterfly communities more similar to existing high-quality grasslands, or increase the number of species present, over time since restoration. The similarity between the butterfly communities on restored and target grasslands did not increase with time since restoration, but was very variable between years (0–73% similarity). The number of butterfly species recorded each year on restored grasslands (~13–14 species/year) remained similar over time. Four species-poor grasslands dominated by competitive plants and scrub were restored by scrub removal. Two of the sites were then managed by low intensity sheep grazing to produce calcareous grassland, while the other two were cut annually with aftermath cattle or sheep grazing to produce lowland hay meadows. Six high-quality grasslands (three calcareous grasslands and three hay meadows) were used for comparison. From April–September each year, butterflies were surveyed weekly on a ~2 km transect at each site for 12–21 years after restoration.

A replicated, site comparison study in 2013 on 17 calcareous grasslands in the Diemel Valley, Germany (6) found that grasslands restored by shrub cutting had a higher occupancy and density of blue-spot hairstreak *Satyrium spini* eggs than unrestored grassland. In restored grasslands, more small buckthorn *Rhamnus cathartica* bushes had blue-spot hairstreak eggs (20%) than in unrestored (9%) or continuously managed (3%) grasslands. The density and size of egg batches on small bushes were higher in restored grasslands (density: 1.8 batches/plant; size: 2.6 eggs/batch) than in unrestored grasslands (density: 1.0 batches/plant; size: 1.4 eggs/batch). Continuously managed grasslands were intermediate (density: 1.4 batches/plant; size: 2.2 eggs/batch). There were no differences in occupancy, density or size of batches on large buckthorn bushes (see paper for details). Five restored grasslands had been abandoned for >15 years before shrubs were cut back four years before monitoring, and had a high density of small buckthorn (height <130 cm). Five unrestored grasslands had been abandoned for >20 years, and had a dense shrub layer. Seven continuously managed grasslands had been grazed, with irregular mulching, for >20 years, and contained both large (height >130 cm) and small buckthorn. Grasslands were similar in size (ca. 0.9 ha) and separated by >50 m of unsuitable habitat. In March 2013, every buckthorn in each grassland was searched for >10mins to record hairstreak eggs. The number of egg batches/plant, and the number of eggs/batch, were recorded.

(1) Schwarzwälder B., Lörtscher M., Erhardt A. & Zettel J. (1997) Habitat utilizations by the heath fritillary butterfly, *Mellicta athalia* ssp. *celadussa* (Rott.) (Lepidoptera: Nymphalidae) in montane grasslands of different management. *Biological Conservation*, 82, 157–165.

(2) Pöyry J., Lindgren S., Salminen J. & Kuussaari M. (2004) Restoration of butterfly and moth communities in semi-natural grasslands by cattle grazing. *Ecological Applications*, 14, 1656–1670.

(3) Pöyry J., Lindgren S., Salminen J. & Kuussaari M. (2005) Responses of butterfly and moth species to restored cattle grazing in semi-natural grasslands. *Biological Conservation*, 122, 465–478.

(4) Öckinger E., Eriksson A.K. & Smith H.G. (2006) Effects of grassland abandonment, restoration and management on butterflies and vascular plants. *Biological Conservation*, 133, 291–300.

(5) Woodcock B.A., Bullock J.M., Mortimer S.R., Brereton T., Redhead J.W., Thomas J.A. & Pywell R.F. (2012) Identifying time lags in the restoration of grassland butterfly communities: A multi-site assessment. *Biological Conservation*, 155, 50–58.
(6) Helbing F., Cornils N., Stuhldreher G. & Fartmann T. (2015) Populations of a shrub-feeding butterfly thrive after introduction of restorative shrub cutting on formerly abandoned calcareous grassland. *Journal of Insect Conservation*, 19, 457–464.

3.25. Cease grazing on grassland to allow early succession

- **Twenty-six studies** evaluated the effects on butterflies and moths of ceasing grazing on grassland to allow early succession. Five studies were in the UK[1,4,6,14,15], four were in each of Germany[2,3,10,24] and the USA[5,7,9,20], three were in each of Sweden[13,16,25] and Finland[11,12,17], two were in each of Spain[18,19] and the Czech Republic[21,23], and one was in each of Switzerland[8], Europe[22] and Israel[26].

COMMUNITY RESPONSE (14 STUDIES)

- **Community composition (3 studies):** Two replicated, site comparison studies in the Czech Republic[23] and Germany[24] found that the community composition of butterflies and moths in grasslands which had been abandoned for >5 years[23] or an unspecified length of time[24] was similar to grasslands managed by grazing or mowing (results not distinguished). One replicated, controlled, before-and-after study in Spain[18] found that after grazing and mowing management was abandoned, over 6 years the butterfly community became dominated by generalist species, and species with fewer generations/year.
- **Richness/diversity (12 studies):** Six of nine replicated studies (including one randomized, controlled study, one paired, site comparison, and seven site comparisons) in Germany[3,24], the USA[9,20], Finland[11,17], Sweden[13,16] and the Czech Republic[23] found that grasslands which had been not been grazed for >5 years[11,13,16,23], or an unspecified length of time[20,24], in one case with burning[20], had a similar species richness of butterflies[11,13,16,20,23,24] and day-flying[11], burnet[13,16,24] or all moths[23] to grasslands grazed by cattle[11], horses and cattle[16] or a mix of livestock[13,23,24] (in two studies grazing and mowing were not distinguished[23,24]) or grazed with cattle and burned[20]. One of these studies also found that grasslands abandoned for 5–15 years had a greater species richness than grasslands grazed by sheep[13]. A further two studies found that grasslands which had been abandoned for >5–20 years[3] or many years[9] had a lower species richness of butterflies than grazed grasslands (in one study grazing and mowing were not distinguished[3]). The other study found that butterfly species richness was higher in grasslands where grazing ceased 2–9 years ago than those abandoned >10 years ago or those currently grazed[17]. Three replicated studies (including one randomized, controlled study and two site comparison studies) in Switzerland[8], Germany[10] and the UK[15] found that grasslands which had been abandoned for 4[15], 5–10[10] or >10 years[8] had a higher species richness of butterflies and day-flying moths[8,10] and nocturnal moths[15] than extensively grazed[8,10], recently abandoned[8] or commercially grazed grasslands[15]. Two of these studies also found that grassland abandoned for 4[15] or 5–10[10] years had a similar species richness of butterflies and day-flying moths[10] and all moths[15] to grassland lightly grazed by cattle[10] or sheep/sheep and cattle[15].

POPULATION RESPONSE (24 STUDIES)

- **Abundance (24 studies):** Six of 20 replicated studies (including one paired, controlled, before-and-after study, three randomized controlled studies, and 15 site comparison studies) in Germany[2,3,10], the USA[5,7,9,20], the UK[1,6,14,15], Switzerland[8], Finland[11,12,17], Sweden[13,16], Spain[19], the Czech Republic[21] and Israel[26] found that grasslands which had been abandoned for 1-25 years had a higher abundance of Scotch argus[21], butterflies and day-flying moths[10,11], nocturnal moths[15], caterpillars[10,14], and of small insects including caterpillars[6], than grasslands grazed by goats[21], sheep[14,15,21] and/or cattle[6,10,11,14]. Two of these studies only found a difference compared to grazing at commercial/intensive, not low, densities[10,15]. Four of the studies found that grasslands which had been abandoned for two weeks[26], 5–20 years[3,9,26] or an undetermined time[19] had a lower abundance of butterflies[3,9,19] and spring webworm caterpillars[26] than grasslands grazed by cattle[26] or a mix of livestock[3,9,19] (in two studies grazing and mowing were not distinguished[3,19]). A further four of the studies found that grasslands which had been abandoned for 5-15 years had a similar abundance of butterflies[8,13,16], burnet moths[13,16], day-flying moths[8] and meadow neb moth caterpillars[2] to grasslands grazed by sheep[2], horses and cattle[16] or a mix of livestock[8,13]. A further four of the studies found that in grasslands which had been abandoned for >10 years[12], many years[5,7] or an unspecified number of years[20], and in one case with burning[20], abundance or density was mixed depending on butterfly[5,7,12,20] and moth[12] species compared to grasslands grazed by cattle[12] or unspecified grazers[5,7] or grazed with cattle and burned[20]. The other study found that butterfly density was higher in grasslands where grazing ceased 2–9 years ago than those abandoned >10 years ago or those currently grazed[17]. Two replicated studies (including one controlled, before-and-after study and one site comparison study) in Spain[18] and Germany[24] found that grasslands which had been abandoned for 1–6 years[18] or an unspecified time period[24] had a higher abundance of woodland and hedgerow butterflies[18,24] and burnet moths[24], but a lower abundance of grassland[18] or farmland[24] species, than grasslands managed by grazing and/or mowing (results not distinguished). Two studies also found that the large blue[1] and silver-studded blue[18] went extinct in some abandoned meadows. One replicated, site comparison study in Sweden[25] found that grasslands which were ungrazed for the year had a lower abundance of clouded Apollo butterflies than lightly grazed grasslands, but a higher abundance than heavily grazed grasslands. One review in Europe[22] reported that ceasing grazing on grassland benefitted six out of 67 butterfly species of conservation concern.

BEHAVIOUR (3 STUDIES)

- **Use (3 studies):** One replicated, paired, site comparison study in Germany[2] found that grassland which had been abandoned for >5 years had a similar occurrence of hoary bell moth caterpillars to grassland grazed by sheep. One replicated, site comparison study in the UK[4] found that a similar proportion of grasslands which had been abandoned for one year, and grazed grasslands, contained >20 marsh fritillary caterpillar webs. One replicated, site comparison study in Spain[19] found that grizzled skipper and painted lady occurred less frequently, but small pearl-bordered fritillary occurred more frequently, in meadows which had been abandoned for at least 1–2 years than in meadows managed by grazing or mowing (results not distinguished).

Background

Some grassland butterfly and moth species, which require generally open habitats, are also dependent on host plant species which are sensitive to disturbance

(Eichel & Fartmann 2008), or may themselves suffer decreased juvenile survival from grazing (Dover *et al.* 2011). The cessation of grazing on grassland, also known as abandoning or fallowing, may enable host plant species to establish (Eichel & Fartmann 2008) or lead to an increase in the survival of eggs, caterpillars or pupae of butterflies and moths (Dover *et al.* 2011). It may also allow larger, woody plants to establish through succession, which increases habitat complexity, and may enable a more diverse, or different, community of butterflies and moths to establish, at least in the short-term (Bubová *et al.* 2015).

This action contains studies which compare abandoned grassland to grazed pasture. Note that the effect of grazing cessation may vary depending on the intensity of grazing before abandonment. See also "*Cease mowing on grassland to allow early succession*".

For other studies on reducing grassland management, see "*Reduce grazing intensity on grassland by reducing stocking density*", "*Reduce grazing intensity on grassland by seasonal removal of livestock*" and "*Reduce management intensity on permanent grasslands (several interventions at once)*". For studies on reversing the process of abandonment, see "*Restore or create species-rich, semi-natural grassland*".

Eichel S. & Fartmann T. (2008) Management of calcareous grasslands for Nickerl's fritillary (*Melitaea aurelia*) has to consider habitat requirements of the immature stages, isolation, and patch area. *Journal of Insect Conservation*, 12, 677–688.

Dover J.W., Spencer S., Collins S., Hadjigeorgiou I. & Rescia A. (2011) Grassland butterflies and low intensity farming in Europe. *Journal of Insect Conservation*, 15, 129–137.

Bubová T., Vrabec V., Kulma M. & Nowicki P. (2015) Land management impacts on European butterflies of conservation concern: a review. *Journal of Insect Conservation*, 19, 805–821.

A before-and-after study in the 1920s in a grassland in England, UK (1) reported that one year after sheep grazing was ceased, a large blue butterfly *Maculina arion* population was no longer recorded. Results were not tested for statistical significance. Before fencing was erected to stop sheep from grazing, there was a population of large blue butterflies, but later in the year after fencing was erected numbers of adults had declined and one year later no butterflies were recorded (no data provided). Fencing was erected around an area of grassland which contained a population of large blue butterflies to exclude sheep and other intruders. Surveys were conducted in the two flight seasons after fencing. Further survey details are not provided.

A replicated, paired, site comparison study in 1990–1991 in 21 calcareous grasslands in Northern Bavaria, Germany (2) reported that abandoned grasslands had a similar density of meadow neb moth *Metzneria metzneriella* caterpillars, and a similar occurrence of hoary bell moth *Eucosma cana* caterpillars, to grazed grasslands. Results were not tested for statistical significance. In abandoned grasslands, 2.2–2.5% of greater knapweed *Centaurea scabiosa* flowerheads contained meadow neb caterpillars, compared to 2.9–3.3% of flowerheads in grazed grasslands. The occurrence of hoary bell was similar in abandoned and grazed grasslands (data not presented). Twenty-one grasslands (0.5–2 ha) were either abandoned for at least five years (14 sites, vegetation >25 cm with shrubs) or managed by light sheep grazing in early autumn (7 sites, vegetation <10 cm). In September–October 1990 and 1991, samples of 100–350 greater knapweed flowerheads/site were collected from seven pairs of grazed-abandoned grasslands, and seven (1990) and four (1991) unpaired, abandoned grasslands. Flowerheads were dissected in the laboratory to identify caterpillars.

A replicated, site comparison study in 1994 in 19 traditional hay meadows in Bavaria, Germany (3) reported that the abundance and species richness of all butterflies, and of threatened species only, was lower in abandoned meadows than in meadows managed by grazing or mowing. Abandoned meadows had fewer butterflies of all species, and of threatened species alone, than grazed or mown meadows (data not presented). Two out of three abandoned meadows also had lower species richness than grazed or mown meadows (data not presented). Nineteen meadows, which had been managed in the same way for at least 5–20 years, were compared. Three meadows were not managed (abandoned), nine meadows were extensively grazed with sheep, cattle or horses for a few weeks each summer, one meadow was grazed by sheep throughout the summer, and six traditionally managed hay meadows were mown once/year in July or early August. From June–August 1994, butterflies were surveyed along a fixed transect five times in each meadow.

A replicated, site comparison study in 1993 in 34 fen meadows in Glamorgan, UK (4) found that abandoning grassland did not affect marsh fritillary *Eurodryas aurinia* population size compared to grazing grassland. There was no significant difference in the proportion of unmanaged (4/8), cattle-grazed (3/9), horse-grazed (2/6), sheep-grazed (0/2), burned (5/8 sites) and mown (0/1) sites that had >20 caterpillar webs recorded. However, the three largest populations (>200 caterpillar webs) were on sites burned in early spring. Caterpillar webs were present on 28/34 sites where adults had been recorded in May/June. In 1993, eight grasslands were unmanaged, nine were cattle-grazed, six were horse-grazed, two were sheep-grazed, eight were burned and one was mown. Sites were separated by >1 km of unoccupied grassland, or >0.5 km of unsuitable habitat. From late August–mid-October 1993, caterpillar webs were surveyed on 34 fen grasslands. On sites <2 ha, all devil's bit scabious *Succisa pratensis* were searched in 2-m-wide parallel strips until the whole area had been searched. On larger sites, 2-m-wide strips at 10-m intervals were searched, and areas around caterpillar webs were then searched comprehensively.

A replicated, site comparison study in 1988–1996 in 17 upland prairies in Missouri, Minnesota, North Dakota and Wisconsin, USA (5, same experimental set-up as 6, 8) found that abandoned prairies had a higher abundance of four specialist butterfly species, but a lower abundance of three species than prairies managed by grazing, haying or burning. Of seven prairie specialist butterfly species, four (gray copper *Lycaena dione*, regal fritillary *Speyeria idalia*, arogos skipper *Atrytone arogos*, Poweshiek skipperling *Oarisma poweshiek*) were more abundant in abandoned, unmanaged areas than in prairies managed by grazing, hayed or burning in at least one of three regions. However, three species were less abundant in abandoned prairies than in grazed (Gorgone checkerspot *Chlosyne gorgone*) or hayed (Pawnee skipper *Hesperia leonardus pawnee*, Dakota skipper

Hesperia dacotae) prairies. See paper for individual species data. Across 17 prairies (16 to >120 ha), two areas were unmanaged for a long time (abandoned), while two areas were managed by grazing, six by haying (often in rotation), eight by burning on rotation, and three by burning and haying. From 1988–1996, butterflies were surveyed on transects through different management areas at each site. Sites were not surveyed in every year.

A replicated, paired, site comparison study in 1989–1993 in three upland grasslands in Scotland, UK (6) found that in two of three sites ungrazed grassland had a higher abundance of small invertebrates (including caterpillars) than sites with low or high grazing intensity. In two out of three grasslands, the abundance of invertebrates was higher in plots which had been ungrazed for 1 and 25 years (70–250 individuals) than in plots with low (6–125 individuals) or high (4–70 individuals) grazing intensity. At the third site, there was no significant difference between a plot which had been ungrazed for four years (35–78 individuals) and sites grazed at low (17–78 individuals) or high intensity (17–55 individuals). From 1989–1991, at three sites, experimental grazing plots were established where the number of sheep was adjusted weekly in order to maintain different sward heights from May–October each year. At two sites, two 0.3-ha plots had sward kept at each of 3.0, 4.5 (high intensity) or 6.0 cm (low intensity). At the third site, four 1–3 ha plots had sward kept at each of 4.5 and 6.5 cm, but from June–August six cattle were grazed on half of the plots. Separate plots which had been ungrazed for one, four or 25 years were also monitored at each site. In August 1993, invertebrates (insects and arachnids) were sampled from both tussocks and low sward at each of six randomly selected points/plot using a d-vac suction sampler.

A replicated, site comparison study in 1987–1995 in 16 tallgrass prairies in the upper Midwest, USA (7, same experimental set-up as 4, 8) found that abandoned prairies had a higher abundance of five of 16 specialist butterfly species, but a lower abundance of four specialist species, than prairies managed by grazing. Of 16 prairie specialist butterfly species, five were more abundant in abandoned, unmanaged prairies than in grazed prairies, but four were less abundant in abandoned prairies than in grazed prairies. Two species were more abundant in abandoned prairies in one region, but less abundant in abandoned prairies in a second region. Five species had similar abundance in abandoned and grazed prairies. See paper for individual species data. Six prairies (including one previously grazed site in Wisconsin, locations and sizes not given) had not been managed for many years (abandoned). Nine prairies (259–2,024 ha) in Sheyenne National Grassland, North Dakota, and one prairie in Wisconsin, were managed by grazing. From April–September 1987–1995, butterflies were surveyed on transects at each site. Most sites were surveyed more than once/year, and in >1 year.

A replicated, site comparison study in 1997 in 14 alpine calcareous grassland sites in the Jura Mountains, Switzerland (8) found that old fallow pastures which had not been grazed for 10 years had a higher species richness, but not abundance, of butterflies and day-flying moths than extensively grazed pastures, young fallow pastures or young forest. Old fallow pastures had a higher species richness (37–50 species), species diversity and more Swiss Red List species (9 species) than extensively grazed pastures (27–44 species, 4–9 Red List species), young fallow pastures (27–38 species, 4–7 Red List species) or young forest (2–5 species, 0–1 Red List species). However, total abundance was not significantly different between pasture types (old fallow: 282–560; extensive pasture: 387–823; young fallow: 420–1,103 individuals). Fourteen 1,000-m^2 sites with a southerly aspect were selected, including three old fallow pastures had not been grazed for around 10 years, five extensively grazed pastures were still cultivated, three young fallow pastures had not been grazed for 2–3 years, and three dense young forests (up to 4 m) had not been grazed for 20–30 years. The old pastures contained scattered blackthorn *Prunus spinosa*, 50–60 cm in height. From June–September 1997, butterflies and day-flying moths were surveyed once/week on each site.

A replicated, site comparison study in 1990–1997 in 106 tallgrass prairies in Illinois, Iowa, Minnesota, Missouri, North Dakota and Wisconsin, USA (9, same experimental set-up as 4, 6) found that in some states, abandoned, unmanaged prairies had a lower abundance and species richness of specialist and grassland butterflies than prairies managed by grazing, but a higher abundance and species richness than prairies managed by burning. In Illinois, Wisconsin and eastern Iowa, the abundance and species richness of specialist and grassland butterflies was lower in unmanaged prairies than in grazed prairies, but higher than in rotationally burned prairies. However, there were no differences in western Iowa, Minnesota, North Dakota or Missouri. All data were presented as models results. Across all prairies, specialist and grassland butterfly abundance and richness tended to be higher at rotationally managed sites (grazed, hayed or burned) longer after they were last managed. Of 106 prairies (1.2–2,024 ha), nine contained areas which had been unmanaged for many years (abandoned), eight were managed by grazing, 27 were managed by haying (mostly on a two-year rotation), and 77 areas were managed by rotational burning (every 2–5 years) in the cool-season (of which 24 were also hayed or mown). From May–September 1990–1997, butterflies were surveyed on parallel transects (5–10 m apart) at each site. Most sites were surveyed more than once/year, and in >1 year. Species were classified as "specialists" (of native plants), "grassland" (occurring widely in open habitat) and "generalist" (occurring in a range of habitats).

A replicated, site comparison study in 1996 in 18 grasslands in Schleswig-Holstein, Germany (10) found that adult butterfly and burnet moth species richness and abundance and caterpillar abundance at ungrazed sites was higher than at intensively grazed sites but similar to low intensity grazed sites, and caterpillar species richness was higher at ungrazed sites than low and intensively grazed sites. Butterfly species richness and abundance and caterpillar abundance were higher at ungrazed (butterflies: average richness = 7, average abundance = 21; caterpillars: average abundance = 12) than intensively grazed (butterflies: average richness = 2, average abundance = 1; caterpillars: average abundance = 1) sites, but statistically similar between ungrazed and low intensity grazing (butterflies: average richness = 4, average abundance = 8; caterpillars: average abundance = 9) sites. Caterpillar species richness was higher at ungrazed sites (average = 7) than low (average = 4) and high intensity grazing (average = 2) sites. Intensively grazed sites (6) had an average stocking density of 1.4 cattle/ha annually from May–November, low intensity grazed sites (6) had an average density of 5.5 cattle/ha annually from April–October, and ungrazed sites (6) had not been stocked for 5–10 years. From May–September 1996, at each site separate transect walks were conducted once monthly for adult butterflies and burnet moths (45-minute transects) and caterpillars (45-minute transects in grazed sites and 60-minutes in ungrazed sites).

A replicated, site comparison study in 1999–2000 in southwest Finland (11, same experimental set-up as 10) found that abandoned grasslands had a higher abundance of butterflies and day-flying moths than grazed pastures, but a similar species richness. The abundance of butterflies and moths was higher in abandoned pastures (306 individuals) than in both continuously grazed (126 individuals) and restored (126 individuals) pastures. The number of species was not significantly higher in abandoned pastures (33 species) than in continuously grazed pastures (26 species), but was higher than in restored pastures (22 species). Butterflies and moths were monitored in 1999 or 2000 on 12 abandoned pastures which had not been grazed for at least 10 years, 11 continuously grazed pastures, and 10 restored pastures where, after at least 10 years of abandonment, grazing had re-started 3–8 years before the study. All restored and most continuously grazed pastures received support under the Finnish agri-environment scheme. All grazing was by cattle. Butterflies and day-flying moths were counted along transects four (1999) or seven (2000) times from May–August. Either searching time (1999) or transect length (2000) were standardized across sites.

A replicated, site comparison study in 1999–2000 in southwest Finland (12, same experimental set-up as 9) found that 14 of 32 butterfly and day-flying moth species were more abundant in abandoned grassland than in grazed, semi-natural pasture. Fourteen out of 32 species of butterfly and day-flying moth were more abundant in abandoned grassland than in either continuously grazed or restored pasture, but three species were less abundant in abandoned grassland than in continuously grazed pasture. A further two species were more abundant in both abandoned grassland and continuously grazed pasture than in restored grassland. The remaining 13 species had similar abundance in all three grassland types (see paper for data on individual species). Butterflies and day-flying moths were monitored in 1999 or 2000 on 12 abandoned pastures which had not been grazed for at least 10 years, 11 continuously grazed pastures, and 10 restored pastures where, after at least 10 years of abandonment, grazing had re-started 3–8 years before the study. All restored and most continuously grazed pastures received support under the Finnish agri-environment scheme. All grazing was by cattle. Butterflies and day-flying moths were counted along transects four (1999) or seven (2000) times from May–August. Either searching time (1999) or transect length (2000) were standardized across sites.

A replicated, paired, site comparison study in 2003–2004 in 36 semi-natural grasslands near Lund, Sweden (13) found that the species richness and abundance of butterflies and burnet moths was similar in abandoned and grazed semi-natural grasslands. On abandoned grassland, the species richness (11 species) and abundance (216 individuals) of butterflies and burnet moths was similar to the richness and abundance on both continuously grazed (richness: 13 species; abundance: 225 individuals) and recently restored grassland (richness: 9 species;

abundance: 101 individuals). However, sites with no grazing had more species (12) than sites currently grazed by sheep (7 species). Butterflies and burnet moths were surveyed using transects (150 m/ha) six or seven times in May–August 2003 or June–August 2004 on 12 grasslands which had been abandoned for 5–15 years, 12 continuously grazed semi-natural grasslands, and 12 previously abandoned grasslands which had been restored from 1999–2003 by clearing trees and shrubs, erecting fences, and re-introducing grazing animals. Under current management, 12 sites were cattle grazed, six were horse grazed, eight were sheep grazed and 10 had no grazing.

A replicated, randomized, controlled study in 2003–2005 on an upland grassland in Perthshire, UK (14, same experimental set-up as 13) found that in ungrazed plots the abundance of moth caterpillars was higher than in grazed plots, but only after >2 years. After 18 months of grazing, there was no significant difference in the number of caterpillars on ungrazed (2.8 individuals/plot), lightly grazed (1.9–2.4 individuals/plot) or commercially grazed plots (2.3 individuals/plot). However, after 30 months, there were more caterpillars in the ungrazed plots (4.9 individuals/plot) than in the lightly grazed (1.9–2.4 individuals/plot) or commercially grazed plots (0.5 individuals/plot). From January 2003, four management regimes (no grazing; light grazing: sheep at 0.9 ewes/ha or sheep and cattle equivalent to 0.9 ewes/ha; commercial grazing: sheep at 2.7 ewes/ha) were replicated six times each in twenty-four 3.3-ha plots (in three pairs of adjacent blocks). Caterpillars were sampled by sweep net in 2003–2005.

A replicated, randomized, controlled study in 2003–2007 on an upland estate in Scotland, UK (15, same experimental set-up as 12) found that ungrazed plots had a higher abundance and species richness of moths than plots grazed by sheep at a commercial stocking rate, or sheep and cattle at low density, but were similar to low density sheep-grazed plots. After four years, ungrazed plots had a higher abundance (48 individuals/night) and species richness (13.2 species/night) of moths than plots grazed by sheep at commercial densities (abundance: 34 individuals/night; richness: 10.6 species/night), or plots grazed by sheep and cattle at low density (abundance: 42 individuals/night; richness: 11.3 species/night), but were similar to low density sheep-grazed plots (abundance: 52 individuals/night; richness: 12.3 species/night). In January 2003, one of four management regimes was established on each of 24 plots (3.3 ha each) on a grazed acid grassland upland estate. The treatments were: no grazing; commercial high density sheep grazing (9 sheep/plot); low density mixed grazing (2 sheep/plot plus two cows and calves for 4 weeks in autumn); and low density sheep grazing (3 sheep/plot). Moths were sampled between June and October 2007 using four 15 W light traps placed randomly within plots of each treatment, for six or seven sample nights/plot.

A replicated, site comparsion study in 2004 in an agricultural region in central Sweden (16) found that abandoned grasslands did not have a greater abundance or species richness of butterflies and burnet moths than low intensity or intensively grazed pasture. On abandoned grassland, the abundance (29.5 individuals/visit) and species richness (10.4 species/visit) of butterflies and burnet moths was not significantly different from either low intensity pasture (abundance: 22.9 individuals/visit; richness: 9.1 species/visit) or intensively grazed pasture (abundance: 22.8 individuals/visit; richness: 9.4 species/visit). Three pastures, >2 km apart, were selected in each of eight sites (>10 km apart). Within a site, one abandoned pasture had been ungrazed for >10 years, one low intensity pasture was managed by horse or cattle grazing, and one high intensity pasture was managed by cattle grazing. From June–August 2004, flower-visiting insects were surveyed four times on four 5 × 5 m plots/pasture. Plots were observed for 10 minutes/visit.

A replicated, site comparison study in 2000 in 48 grassland sites in Uusimaa and Pirkanmaa, Finland (17) found that at sites where grazing had recently ceased, butterfly density and species richness was higher, compared to sites where it had ceased a decade before or sites currently grazed. Butterfly species richness and density were higher on grasslands where grazing was stopped two to nine years before (richness: 22–34 species, density: 201–688 butterflies/0.25 ha), than on sites where grazing stopped ≥10 years before (richness: 19–30 species, density: 130–876 butterflies/0.25 ha) or on currently grazed pastures (richness: 7–28 species, density: 36–489 butterflies/0.25 ha). Seven surveys were carried out in May–August 2000, at 48 unforested 0.25–6 ha grassland sites (10 grazed two to nine years before, 15 grazed ≥10 years before, 23 currently grazed). Butterflies and day-flying moths were surveyed along a 350 m transect within a 0.25 ha study plot at each site to calculate density, and then along a transect outside the plot which was proportionate to the size of the site to record all species. Butterfly density was measured as the number of individuals seen within the study plot transect.

A replicated, controlled, before-and-after study in 1997–2004 in six meadows in Catalonia, Spain (18) found that in meadows where grazing and mowing were abandoned, grassland butterflies decreased while woodland and hedge butterflies increased, and the community became dominated by generalist species and species with fewer generations/year. Over seven years after abandonment, species which prefer grasslands declined in abundance, and species which prefer woodland and bramble hedges increased. The abundance of "generalist" butterfly species (which are able to persist in a wide range of habitats) and species with only one generation/year increased in abandoned meadows, while the abundance of "specialist" species (with specific habitat requirements) and species with multiple generations/year decreased. One grassland specialist, the silver-studded blue *Plebejus argus*, went extinct in some abandoned meadows. There was little change in the butterfly community in the continuously managed meadow. All data presented as model results. In 1997, six traditional hay meadows (0.55–3.71 ha) were managed normally: two were mown in June, and four were mown in June and August and grazed by cows in winter. From 1998–2004, five of the meadows were abandoned, but the sixth meadow continued to be mown in June and grazed by cattle and horses in winter. From March–September 1997–2004, butterflies were surveyed once/week along a fixed 1,122-m transect through the meadows (117–286 m/meadow), and the total number of each species recorded in each meadow each year was compared.

A replicated, site comparison study in 2003–2005 in 47 alpine meadows in Picos de Europa, Spain (19) found that abandoned or winter grazed meadows had a lower abundance or occurrence of seven out of 44 butterfly species than managed meadows, but one species occurred more frequently in abandoned meadows. In abandoned meadows, the abundance of five species (black-veined white *Aporia crataegi*, meadow brown *Maniola jurtina*, small skipper *Thymelicus sylvestris*, small white *Pieris rapae*, ringlet *Aphantopus hyperantus*) was lower than in meadows managed by grazing or mowing (data presented as model results). In addition, two species (grizzled skipper *Pyrgus malvae* and painted lady *Vanessa cardui*) occurred less frequently in abandoned meadows than in managed meadows, but one species (small pearl-bordered fritillary *Boloria selene*) occurred more frequently in abandoned meadows than in managed meadows (data presented as model results). The remaining 36 species did not differ in abundance or occurrence between abandoned and managed meadows. From summer 2003–2005, management was recorded on 47 meadows. Sixteen meadows were either abandoned or only grazed in the winter, seven meadows were grazed by livestock in summer and 24 meadows were cut for hay. The abandoned meadows had different amounts of scrub growing within them. From June–July 2004, butterflies were surveyed nine times on a transect around the edge of each meadow.

A replicated, randomized, controlled study in 2007–2009 in 13 tallgrass prairies in Iowa and Missouri, USA (20) found that butterfly species richness did not differ between pastures with no grazing where the whole area was burned every three years and those with grazing and either complete burning or rotational burning, but the density of some species differed depending on management and year. There was no difference in species richness between pastures entirely burned once every three years without grazing (7) and those either burned entirely every three years (6–7) or rotationally (6–7) with grazing. Regal fritillary *Speyeria idalia* densities were higher in the pastures with no grazing (average: 5–7 individuals/ha) than those with grazing and complete burning (0 individuals/ha) or rotational burning (0 individuals/ha). The same trend was seen in the common wood-nymph *Cercyonis pegala* (complete burning/no grazing = 21 individuals/ha; complete burning/grazing = 2; rotational burning/grazing = 2) and the monarch *Danaus plexippus* (complete burning/no grazing = 2; complete burning/grazing = 1; rotational burning/grazing = 1) but only in 2009 (the survey after the burn in the non-rotational pastures, no difference in 2008). In 2008 only, eastern tailed-blue *Cupido comyntas* population densities were lower in pastures without grazing (55 individuals/ha) than those with grazing and complete burning (101 individuals/ha) or rotational burning (124 individuals/ha) (no difference in 2009). Other species analysed were not affected by management in either year. Pastures (15–31 ha) were managed in one of three ways: 1) rotational burning, with a third of each pasture burned annually in spring 2007–2009 and cattle grazing May–October annually (five pastures), 2) complete pasture burning in spring 2008 or 2009 and cattle grazing May–October annually (four pastures), or 3) complete pasture burning in spring 2008 or 2009 without grazing (four pastures). Butterflies were surveyed in June–July 2008–2009 along six 100-m transects/pasture.

A replicated, site comparison study in 2007 in a grassland and woodland reserve in the Czech Republic (21) found that temporarily abandoned grasslands had a higher abundance of Scotch argus *Erebia aethiops* than grasslands managed by sheep and goat grazing. On temporarily abandoned grasslands, the abundance of Scotch argus males (19 individuals/ha) and females (13 individuals/ha) was higher than on grazed grasslands (males: 7; females: 4 individuals/ha). The abundance of Scotch argus was also lower on occasionally mown (males: 9; females: 5 individuals/ha) and intensively mown (males: 3; females: 2 individuals/ha) grasslands. Within a 55-ha reserve, 27 grasslands (128–6,072 m^2) were either temporarily abandoned, or managed by sheep and goat grazing, occasional mowing or intensive mowing. On 33 days from July–August 2007, butterflies were caught, individually marked, and recaptured at each site.

A review in 2015 of 126 studies in Europe (22) reported that abandoning grassland to allow early succession benefitted six out of 67 butterfly species of conservation concern. Results were not tested for statistical significance. The review reported that six studies found that abandoning grassland benefitted six butterfly species (blue argus *Aricia anteros*, large heath *Coenonympha tullia*, El Hierro grayling *Hipparchia bacchus*, Zullich's blue *Plebejus zullichi*, Lulworth skipper *Thymelicus action* and *Turanana taygetica*). Grazing was abandoned on meadows to allow taller vegetation and shrubs to develop, but the optimal length of time for abandonment is not given. The review focussed on 67 butterfly species of conservation concern. The available information was biased towards studies in Northern and Western Europe.

A replicated, site comparison study in 2006–2010 in 28 grassland sites in Bílé Karpaty Protected Landscape Area, Czech Republic (23) found that abandoning semi-natural grassland did not affect the species richness or species composition of butterfly and moth communities. Both the species richness and species composition of butterflies and moths were similar in abandoned, unmanaged grasslands and in grasslands which were managed by grazing, mowing or a mix of management types (all data presented as model results). One of four different management practices (abandoned (no grazing or mowing); grazed by sheep, cattle or deer; mown once/year; or 'mixed' management) was applied to each of 34 sites (1.5–70.7 ha) for at least five consecutive years. 'Mixed' management included mowing different parts of the site at different times, often with patches left uncut for a year, or mowing followed by grazing. From 2007–2010, butterflies and moths were surveyed on >6 visits between April and October in each of two consecutive years to each of 28 sites.

A replicated, site comparison study in 2015 in 20 grasslands in Saxony, Germany (24) found that abandoned grasslands had a higher abundance of woodland butterflies and burnet moths, but a lower abundance of farmland butterflies and burnet moths, than managed grasslands, but there was no difference in species richness or community composition. In abandoned grasslands, the abundance of 20 species of woodland butterflies and burnet moths (34–44 individuals) was higher than in managed grasslands (17–36 individuals). However, the abundance of 35 species of farmland butterflies and burnet moths was lower in abandoned grasslands (127 individuals) than managed grasslands (195–206 individuals). The species richness of both farmland and woodland species was similar in abandoned (farmland: 13–14; woodland: 5–6 species) and managed (farmland: 14; woodland: 5–6 species) grassland. The community composition was also similar in managed and abandoned grasslands (data presented as model results). Twenty calcareous grasslands (0.90–5.38 ha) were surveyed. Ten were abandoned (not grazed or mown), eight were managed by summer grazing (May–September, <1 animal/ha, with cattle, sheep, goats, horses or donkeys), one was managed by mowing, and one was mown and grazed. From May–August 2015, butterflies and burnet moths were surveyed three times along a 20-minute transect on a 0.8 ha patch at each site. Butterflies and burnet moths were classified as 35 farmland and 20 woodland species.

A replicated, site comparison study in 1984–2015 in 24 grasslands in Blekinge province, Sweden (25) found that ungrazed grasslands had a lower abundance of clouded Apollo *Parnassius mnemosyne* than lightly grazed grasslands, but a higher abundance than heavily grazed grasslands. In ungrazed grasslands, the abundance of clouded Apollo (0–109 individuals/grassland/year) was lower than in lightly grazed grasslands (1–169 individuals/grassland/year), but higher than in heavily grazed grasslands (2–22 individuals/grassland/year). In addition, abundance was higher on larger grasslands, and grasslands which were close together were more likely to be colonized (data presented as model results). From 1984–2015, twenty-four open grasslands (>150 m apart) with >0.5 m^2 cover of the host plant *Corydalis* spp. and the presence of a major nectar plant *Lychnis viscaria* were assigned annually to one of three management categories: no grazing; light grazing (grazing commenced after 15 June with 1–9 animals/hectare); heavy grazing (grazing commenced before 15 June or with ≥10 animals/hectare for ≥8 weeks). Grazing animals were cattle and sheep. In 1984–1987, 1991 and 2003–2015, butterflies were surveyed ≥6 times/year on each site, by marking and recapturing individuals along irregular routes through each grassland. In 1988–1989 and 1992–2002, grasslands were visited more irregularly and their presence recorded. Surveys were used to estimate the local population size on each grassland each year.

A replicated, paired, site comparison study and a replicated, paired, controlled, before-and-after study in 2014–2015 on a farm in Galilee, Israel (26) found that ungrazed paddocks had fewer spring webworm *Ocnogyna loewii* caterpillar nests and solitary caterpillars than grazed paddocks. After 10–20 years of abandonment, the number of caterpillar nests and older, solitary caterpillars in ungrazed paddocks (nests: 1; individuals: 6–14) and plots (nests: 1–6; individuals: 1–2) was lower than in grazed paddocks (nests: 3–10; individuals: 24–77) and plots (nests: 2–14; individuals: 3). In addition, after two weeks of grazing exclusion, there were fewer caterpillar nests in recently fenced areas (5–21 individuals) than in unfenced, grazed areas (13–31 individuals), despite having similar numbers before fencing was installed (fenced: 16–19; unfenced: 18–20 individuals). From 1994, a 1,450-ha farm was divided into paddocks managed permanently by moderate (0.55 cows/ha) or heavy (1.1 cows/ha) grazing, or left ungrazed. In January 2015 and March 2014–2015, caterpillar nests (January) and individuals (March) were counted once/year on three 20-m-long transects in each of four ungrazed paddocks (0.5–4 ha) and four grazed paddocks (~27 ha). Within each of the four grazed paddocks, cattle were excluded from five fenced, 10 × 10 m plots for >10 years. In January 2014–2015, all caterpillar nests were counted in each fenced, ungrazed plot and a paired, grazed plot 3 m away in the surrounding paddock. In March 2015, individual caterpillars were counted in three 30 × 30 cm sub-plots in each grazed and ungrazed plot. In January 2014 and 2015, seven and six fenced plots (6 × 6 m, 12 m apart) were constructed within a 50-ha, heavily grazed paddock to exclude cattle. From January 2014 and 2015, caterpillar nests were counted weekly in each ungrazed, fenced plot and a paired, grazed plot 3 m away.

(1) Henning S.F. (1987) Outline of Lepidoptera conservation with special reference to ant associated Lycaenidae. *Proceedings of the first Lepidoptera Conservation Symposium, Roodepoort, South Africa*. 5–7.
(2) Völkl W., Zwölfer H., Romstöck-Völkl M. & Schmelzer C. (1993) Habitat management in calcareous grasslands: effects on the insect community developing in flower heads of Cynarea. *Journal of Applied Ecology*, 30, 307–315.
(3) Dolek M. & Geyer A. (1997) Influence of management on butterflies of rare grassland ecosystems in Germany. *Journal of Insect Conservation*, 1, 125–130.
(4) Lewis O.T. & Hurford C. (1997) Assessing the status of the marsh fritillary butterfly (*Eurodryas aurinia*): an example from Glamorgan, UK. *Journal of Insect Conservation*, 1, 159–166.
(5) Swengel A.B. & Swengel S.R. (1997) Co-occurrence of prairie and barrens butterflies: applications to ecosystem conservation. *Journal of Insect Conservation*, 1, 131–144.
(6) Dennis P., Young M.R. & Gordon I.J. (1998) Distribution and abundance of small insects and arachnids in relation to structural heterogeneity of grazed, indigenous grasslands. *Ecological Entomology*, 23, 253–264.
(7) Swengel A.B. (1998) Effects of management on butterfly abundance in tallgrass prairie and pine barrens. *Biological Conservation*, 83, 77–89.
(8) Balmer O. & Erhardt A. (2000) Consequences of succession on extensively grazed grasslands for central European butterfly communities: rethinking conservation practices. *Conservation Biology*, 14, 746–757.
(9) Swengel A.B. & Swengel S.R. (2001) Effects of prairie and barrens management on butterfly faunal composition. *Biodiversity and Conservation*, 10, 1757–1785.
(10) Kruess A. and Tscharntke T. (2002) Grazing intensity and the diversity of grasshoppers, butterflies, and trap-nesting bees and wasps. *Conservation Biology*, 16(6), 1570–1580.
(11) Pöyry J., Lindgren S., Salminen J. & Kuussaari M. (2004) Restoration of butterfly and moth communities in semi-natural grasslands by cattle grazing. *Ecological Applications*, 14, 1656–1670.
(12) Pöyry J., Lindgren S., Salminen J. & Kuussaari M. (2005) Responses of butterfly and moth species to restored cattle grazing in semi-natural grasslands. *Biological Conservation*, 122, 465–478.
(13) Öckinger E., Eriksson A.K. & Smith H.G. (2006) Effects of grassland abandonment, restoration and management on butterflies and vascular plants. *Biological Conservation*, 133, 291–300.
(14) Dennis P., Skartveit J., McCracken D.I., Pakeman R.J., Beaton K., Kunaver A. & Evans D.M. (2008) The effects of livestock grazing on foliar arthropods associated with bird diet in upland grasslands of Scotland. *Journal of Applied Ecology*, 45, 279–287.
(15) Littlewood N.A. (2008) Grazing impacts on moth diversity and abundance on a Scottish upland estate. *Insect Conservation and Diversity*, 1, 151–160.
(16) Sjodin N.E., Bengtsson J. & Ekbom B. (2008) The influence of grazing intensity and landscape composition on the diversity and abundance of flower-visiting insects. *Journal of Applied Ecology*, 45, 763–772.
(17) Pöyry J., Paukkunen J., Heliölä J. and Kuussaari M. (2009) Relative contributions of local and regional factors to species richness and total density of butterflies and moths in semi-natural grasslands. *Community Ecology*, 160, 577–587.
(18) Stefanescu C., Peñuelas J. & Filella I. (2009) Rapid changes in butterfly communities following the abandonment of grasslands: a case study. *Insect Conservation and Diversity*, 2, 261–269.
(19) Dover J.W., Rescia A., Fungarino S., Fairburn J., Carey P., Lunt P., Arnot C., Dennis R.L.H. & Dover C.J. (2011) Land-use, environment, and their impact on butterfly populations in a mountainous pastoral landscape: individual species distribution and abundance. *Journal of Insect Conservation*, 15, 207–220.

(20) Moranz R.A., Debinski D.M., McGranahan D.A., Engle D.M. & Miller J.R. (2012) Untangling the effects of fire, grazing, and land-use legacies on grassland butterfly communities. *Biodiversity and Conservation*, 21, 2719-2746.
(21) Slamova I., Klecka J. & Konvicka M. (2013) Woodland and grassland mosaic from a butterfly perspective: habitat use by *Erebia aethiops* (Lepidoptera: Satyridae). *Insect Conservation and Diversity*, 6(3), 243–254.
(22) Bubová T., Vrabec V., Kulma M. & Nowicki P. (2015) Land management impacts on European butterflies of conservation concern: a review. *Journal of Insect Conservation*, 19, 805–821.
(23) Bonari G., Fajmon K., Malenovský I., Zelený D., Holuša J., Jongepierová I., Kočárek P., Konvička O., Uřičář J. & Chytrý M. (2017) Management of semi-natural grasslands benefiting both plant and insect diversity: The importance of heterogeneity and tradition. *Agriculture, Ecosystems & Environment*, 246, 243–252.
(24) Ernst L.M., Tscharntke T. & Batary P. (2017) Grassland management in agricultural vs. forested landscapes drives butterfly and bird diversity. *Biological Conservation*, 216, 51–59.
(25) Johansson V., Knape J. & Franzen M. (2017) Population dynamics and future persistence of the clouded Apollo butterfly in southern Scandinavia: The importance of low intensity grazing and creation of habitat patches. *Biological Conservation*, 206, 120–131.
(26) Berman T.S., Ben-Ari M., Henkin Z. & Inbar M. (2018) Immediate and long-term facilitative effects of cattle grazing on a polyphagous caterpillar. *Agriculture, Ecosystems & Environment*, 261, 45–53.

3.26. Cease mowing on grassland to allow early succession

- **Sixteen studies** evaluated the effects on butterflies and moths of ceasing mowing on grassland to allow early succession. Three studies were in Germany[1,2,14], two were in each of the USA[4,5], Spain[7,8] and the Czech Republic[10,13], and one was in each of Switzerland[3], Poland[6], Slovakia[9], Hungary[11], Japan[12], Russia[15] and Italy[16].

COMMUNITY RESPONSE (8 STUDIES)

- **Community composition (3 studies):** Two replicated, site comparison studies in the Czech Republic[13] and Germany[14] found that the community composition of butterflies and moths in grasslands which had been abandoned for >5 years[13] or an unspecified length of time[14] was similar to grasslands managed by mowing or grazing (results not distinguished). One replicated, controlled, before-and-after study in Spain[7] found that after mowing and grazing was abandoned, over 6 years the butterfly community became dominated by generalist species, and species with fewer generations/year.
- **Richness/diversity (7 studies):** Five of seven replicated, site comparison studies in Germany[2,14], Poland[6], Japan[12], the Czech Republic[13], Russia[15] and Italy[16] found that grasslands which had been abandoned for 3–13 years[12,13,15], 10–20 years[6] or an unspecified length of time[14], had a similar species richness of butterflies[6,12–15] and burnet moths[14] or all moths[13] to grasslands managed by annual[6,12,13] or unspecified frequency[14] mowing, or mown within the last three years[15] (in two studies mowing and grazing were not distinguished[13,14]). One of these studies also found that grasslands abandoned for more than 50 years had lower species richness than grasslands mowed annually to up to 20 years ago[6], and another found that grasslands abandoned for 6–13 years had a lower species richness of butterflies than grasslands managed by traditional rotational mowing and burning[12]. One of the studies found that meadows not cut all summer had a higher species richness of butterflies than meadows cut 1–3 times/summer[16]. The

other study found that grasslands abandoned for at least 5–20 years had a lower species richness of butterflies than grasslands managed by mowing or grazing (results not distinguished)[2].

POPULATION RESPONSE (14 STUDIES)

- **Abundance (14 studies):** Four replicated studies (including one randomized, paired, controlled study and three site comparison studies) in Germany[2], Spain[8], Slovakia[9] and Hungary[11] found that grasslands which had been abandoned for >1–20 years had a lower abundance of all butterflies[2] or some species of butterfly[8,9,11] and caterpillars[9], than grasslands managed by mowing once[2,8,9,11] or twice[11] per year (in two studies mowing and grazing were not distinguished[2,8]). Four replicated, site comparison studies (including one paired study) in Germany[1], the Czech Republic[10], Russia[15] and Italy[16] found that grasslands which had been abandoned for >3 years[1,15], were temporarily abandoned[10], or were uncut all summer[16], had a higher abundance of all butterflies[16], 11 species of butterfly[15], Scotch argus adults[10] and meadow neb moth caterpillars[1], than grasslands managed by mowing[10] annually[1], 1–3 times/summer[16], or within the last three years[15]. Two replicated studies (including one controlled, before-and-after study and one site comparison study) in Spain[7] and Germany[14] found that grasslands which had been abandoned for 1–6 years[7] or an unspecified time period[14] had a higher abundance of woodland and hedgerow butterflies[7,14] and burnet moths[14], but a lower abundance of grassland[7] or farmland[14] species, than grasslands managed by mowing and/or grazing (results not distinguished). One of these studies also found that silver-studded blue went extinct in some abandoned meadows[7]. Three replicated, site comparison studies in the USA[4,5] and Poland[6] found that in grasslands which had been abandoned for many years[4,5] or 10 to over 50 years before[6] abundance was mixed depending on butterfly species compared to grasslands managed by grazing[4,5] or mowing[6]. One replicated, site comparison study in Switzerland[3] found that grasslands which had been abandoned for around six years had a similar abundance of heath fritillary adults and caterpillars to grasslands managed by annual mowing, but that grasslands abandoned for >25 years had a lower abundance of adults and no caterpillars.

BEHAVIOUR (2 STUDIES)

- **Use (2 studies):** One replicated, paired, site comparison study in Germany[1] found that grassland which had been abandoned for >5 years had a similar occurrence of hoary bell moth caterpillars to grassland managed by mowing. One replicated, site comparison study in Spain[8] found that grizzled skipper and painted lady occurred less frequently, but small pearl-bordered fritillary occurred more frequently, in meadows which had been abandoned for at least 1–2 years than in meadows managed by mowing or grazing (results not distinguished).

Background

Some grassland butterfly and moth species, which require generally open habitats, are also dependent on host plant species which are sensitive to disturbance (Eichel & Fartmann 2008), or may themselves suffer decreased juvenile survival from mowing or haying (Dover *et al.* 2011). The cessation of mowing on grassland, also known as abandoning or fallowing, may enable host plant species to establish (Eichel & Fartmann 2008) or lead to an increase in the survival of juvenile life stages of butterflies and moths (Dover *et al.* 2011). It may also allow larger, woody plants to establish through succession, which increases habitat complexity, and may enable a more diverse, or different, community of butterflies and moths to establish, at least in the short-term (Bubová *et al.* 2015).

This action contains studies which compare abandoned grassland to traditionally mown meadows. Note that the effect of mowing cessation may vary depending on the frequency of mowing before abandonment. See also "*Cease grazing on grassland to allow early succession*".

For other studies on reducing grassland management, see "*Reduce cutting frequency on grassland*" and "*Reduce management intensity on permanent grasslands (several interventions at once)*". For studies on reversing the process of abandonment, see "*Restore or create species-rich, semi-natural grassland*".

Eichel S. & Fartmann T. (2008) Management of calcareous grasslands for Nickerl's fritillary (*Melitaea aurelia*) has to consider habitat requirements of the immature stages, isolation, and patch area. *Journal of Insect Conservation*, 12, 677–688.

Dover J.W., Spencer S., Collins S., Hadjigeorgiou I. & Rescia A. (2011) Grassland butterflies and low intensity farming in Europe. *Journal of Insect Conservation*, 15, 129–137.

Bubová T., Vrabec V., Kulma M. & Nowicki P. (2015) Land management impacts on European butterflies of conservation concern: a review. *Journal of Insect Conservation*, 19, 805–821.

A replicated, paired, site comparison study in 1990–1991 in 21 calcareous grasslands in Northern Bavaria, Germany (1) reported that abandoned grasslands had a higher density of meadow neb moth *Metzneria metzneriella* caterpillars, and a similar occurrence of hoary bell moth *Eucosma cana* caterpillars, compared to mown grasslands. Results were not tested for statistical significance. In abandoned grasslands, 2.2–2.5% of greater knapweed *Centaurea scabiosa* flowerheads contained meadow neb caterpillars, compared to 0–0.3% of flowerheads in mown grasslands. The occurrence of hoary bell was similar in abandoned and mown grasslands (data not presented). Twenty-one grasslands (0.5–2 ha) were either abandoned for at least five years (14 sites, vegetation >25 cm with shrubs) or managed by annual mowing (usually in midsummer, 7 sites, vegetation ~25 cm before cutting). In September–October 1990 and 1991, samples of 100–350 greater knapweed flowerheads/site were collected from seven pairs of mown-abandoned grasslands, and seven (1990) and four (1991) unpaired, abandoned grasslands. Flowerheads were dissected in the laboratory to identify caterpillars.

A replicated, site comparison study in 1994 in 19 traditional hay meadows in Bavaria, Germany (2) reported that the abundance and species richness of all butterflies, and of threatened species only, was lower in abandoned meadows than in meadows managed by mowing or grazing. Abandoned meadows had fewer butterflies of all species, and of threatened species alone, than mown or grazed meadows (data not presented). Two out of three abandoned meadows also had lower species richness than mown or grazed meadows (data not presented). Nineteen meadows, which had been managed in the same way for at least 5–20 years, were compared. Three meadows were not managed (abandoned), six traditionally managed hay meadows were mown once/year in July or early August, nine meadows were extensively grazed with sheep, cattle or horses for a few weeks each summer, and one meadow was grazed by sheep throughout the summer. From June–August 1994, butterflies were surveyed along a fixed transect five times in each meadow.

A replicated, site comparison study in 1993–1994 in 16 alpine meadows in southern Switzerland (3) found that recently abandoned meadows had a similar abundance of heath fritillary *Mellicta athalia* adults and caterpillars to traditional hay meadows, but old, abandoned, unmanaged meadows had fewer adult males and caterpillars, and a similar number of adult females. The abundance of adult male heath fritillaries and caterpillars on recently abandoned meadows (males peak: 40 individuals/hour; caterpillars: 4–8 individuals/hour) was similar to traditional hay meadows (males: 30 individuals/hour; caterpillars: 0.5–3.5 individuals/hour), but higher than on old, abandoned meadows (males: 21 individuals/hour; no caterpillars). The number of females was not significantly different between meadows (recently abandoned: 14; traditional: 5; old abandoned: 5 individuals/hour). Marked butterflies were recorded moving between all habitat types. Two recently abandoned meadows had been unmanaged for around six years, five traditional hay meadows were mown once/year in June or July, and five old, abandoned meadows had been unmanaged for >25 years. From June–July 1993–1994, adult butterflies were caught and marked for 45 minutes/meadow every other day. In 1994, each meadow was searched for three hours, spread over several days, to record solitary caterpillars.

A replicated, site comparison study in 1988–1996 in 17 upland prairies in Missouri, Minnesota, North Dakota and Wisconsin, USA (4, same experimental set-up as 5) found that abandoned prairies had a higher abundance of four specialist butterfly species, but a lower abundance of three species, than prairies managed by haying, grazing or burning. Of seven prairie specialist butterfly species, four (gray copper *Lycaena dione*, regal fritillary *Speyeria idalia*, arogos skipper *Atrytone arogos*, Poweshiek skipperling *Oarisma poweshiek*) were more abundant in abandoned, unmanaged areas than in prairies managed by grazing, hayed or burning in at least one of three regions. However, three species were less abundant in abandoned prairies than in hayed (Pawnee skipper *Hesperia leonardus pawnee*, Dakota skipper *Hesperia dacotae*) or grazed (Gorgone checkerspot *Chlosyne gorgone*) prairies. See paper for individual species data. Across 17 prairies (16 to >120 ha), two areas were unmanaged for a long time (abandoned), while six areas were managed by haying (often in rotation), eight by burning on rotation, three by burning and haying, and two by grazing. From 1988–1996, butterflies were surveyed on transects through different management areas at each site. Sites were not surveyed in every year.

A replicated, site comparison study in 1986–1995 in 104 tallgrass prairies and 141 pine barrens in Illinois, Iowa, Minnesota, Missouri, North Dakota and Wisconsin, USA (5, same experimental set-up as 4) found that abandoned grasslands had a higher abundance of two of 16 specialist butterfly species, but a lower abundance of seven specialist species, than grasslands managed by mowing, grazing or burning. Of 16 prairie or pine barren specialist butterfly species, two (arogos skipper *Atrytone arogos*, Poweshiek skipper *Oarisma poweshiek*) were more abundant in abandoned, unmanaged sites than in sites managed by haying or rotational burning. However, seven species were less abundant in abandoned sites than in sites managed by haying (Dakota skipper *Hesperia dacotae*, pawnee skipper *Hesperia leonardus pawnee*), mowing (Persius duskywing *Erynnis persius*), cutting (cobweb skipper *Hesperia metea*), grazing and haying (regal fritillary *Speyeria idalia*) or rotational burning (ottoe skipper *Hesperia ottoe* and dusted skipper *Atrytonopsis hianna*). Seven species had similar abundance between management types. See paper for individual species data. Of 104 prairies (1–2,024 ha), six had not been managed for many years (abandoned), 61 were managed by cool-season burning on a 2–5-year rotation, of which 21 were additionally mown or hayed; 27 were hayed in summer on a 1–2-year rotation, of which two were also grazed occasionally with cattle and 10 were grazed. Of 141 pine barrens, some were burned by wildfires, some were used for off-road vehicle trails, and some were power line rights-of-way (no further detail provided). From April–September 1986–1995, butterflies were surveyed on transects at each site. Most sites were surveyed more than once/year, and in >1 year.

A replicated, site comparison study (years not stated) in 15 grassland and woodland sites in Kraków, Poland (6) found that ceasing mowing on meadows initially did not affect butterfly species richness, but species richness decreased as mature forest developed, and effects of ceasing mowing on individual species abundances were mixed. Similar numbers of butterfly species were present on mown meadows (mowed annually: 19–21), fallow land (not mowed for about 10 years: 22–29), old fallow land (not mowed for 10–20 years: 25–37) and young forest (not mowed for between 10–20 years: 25–29), but mature forest had fewer species than all other types of land (not mowed for about 50 years: 12–13) (text in paper reports that species richness was higher in old fallow land than mown meadows but this contrasts with graph captions). Numbers of scarce large blue *Maculinea teleius*, dusky large blue *Maculinea nausithous* and Alcon blue *Maculinea alcon* were highest on old fallow, but gypsy moths *Lymantria dispar* and violet coppers *Lycaena helle* were highest on mown meadows (results presented as statistical tests). See paper for results for other species. Three replicates of five types of land at different stages of succession were compared (15 sites in total) – meadows mowed annually in summer (mown meadows) and land which hadn't been mowed for about 10 years (fallow), 10–20 years (old fallow), about 20 years (young forest) and about 50 years (mature forest). On 11 occasions from May–September, butterflies were counted along a 200 m transect in each of the 15 sites, positioned >50 m from the habitat type boundary.

A replicated, controlled, before-and-after study in 1997–2004 in six meadows in Catalonia, Spain (7) found that in meadows where mowing and grazing were abandoned, grassland butterflies decreased while woodland and hedge butterflies increased, and the community became dominated by generalist species and species with fewer generations/year. Over seven years after abandonment, species which prefer grasslands declined in abundance, and species which prefer woodland and bramble hedges increased. The abundance of "generalist" butterfly species (which are able to persist in a wide range of habitats) and species with only one generation/year increased in abandoned meadows, while the abundance of "specialist" species (with specific habitat requirements) and species with multiple generations/year decreased. One grassland specialist, the silver-studded blue *Plebejus argus*, went extinct in some abandoned meadows. There was little change in the butterfly community in the continuously managed meadow. All data presented as model results. In 1997, six traditional hay meadows (0.55–3.71 ha) were managed normally: two were mown in June, and four were mown in June and August and grazed by cows in winter. From 1998–2004, five of the meadows were abandoned, but the sixth meadow continued to be mown in June and grazed by cattle and horses in winter. From March–September 1997–2004, butterflies were surveyed once/week along a fixed 1,122-m transect through the meadows (117–286 m/meadow), and the total number of each species recorded in each meadow each year was compared.

A replicated, site comparison study in 2003–2005 in 47 alpine meadows in Picos de Europa, Spain (8) found that abandoned or winter grazed meadows had a lower abundance or occurrence of seven out of 44 butterfly species than managed meadows, but one species occurred more frequently in abandoned meadows. In abandoned meadows, the abundance of five species (black-veined white *Aporia crataegi*, meadow brown *Maniola jurtina*, small skipper *Thymelicus sylvestris*, small white *Pieris rapae*, ringlet *Aphantopus hyperantus*) was lower than in meadows managed by mowing or grazing (data presented as model results). In addition, two species (grizzled skipper *Pyrgus malvae* and painted lady *Vanessa cardui*) occurred less frequently in abandoned meadows than in managed meadows, but one species (small pearl-bordered fritillary *Boloria selene*) occurred more frequently in abandoned meadows than in managed meadows (data presented as model results). The remaining 36 species did not differ in abundance or occurrence between abandoned and managed meadows. From summer 2003–2005, management was recorded on 47 meadows. Sixteen meadows were either abandoned or only grazed in the winter, 24 meadows were cut for hay and seven were grazed by livestock in summer. The abandoned meadows had different amounts of scrub growing within them. From June–July 2004, butterflies were surveyed nine times on a transect around the edge of each meadow.

A replicated, site comparison study in 2003–2006 in 16 hay meadows in central Slovakia (9) found that abandoned meadows had a lower abundance of meadow brown *Maniola jurtina* butterflies and caterpillars than meadows mown once/year. In unmown, abandoned meadows, the abundance of both meadow brown adults (6–33 individuals/transect) and caterpillars (1–2 individuals/transect) was lower than in meadows mown once/year (adults: 12–81; caterpillars: 10–26 individuals/transect). Meadows mown twice/year had intermediate abundance of both adults (14–45 individuals/transect) and caterpillars (1–8 individuals/transect). Four abandoned meadows had not been mown for 15 years. Four meadows at the edge of oak-hornbeam forests and four open meadows were mown once/year in late June or July. A further four meadows were mown twice/year in late May–early June and from late July–September. From June–August 2003–2005, adult butterflies were counted 4–7 times/year on seven 50-m transects in each habitat type. In May 2005 and 2006, caterpillars were surveyed at night, 1–4 times/year, by sweeping vegetation with a net along ten 50-m transects in each habitat type (60 sweeps/transect).

A replicated, site comparison study in 2007 in a grassland and woodland reserve in the Czech Republic (10) found that temporarily abandoned grasslands had a higher abundance of Scotch argus *Erebia aethiops* than grasslands managed by mowing. On temporarily abandoned grasslands, the abundance of Scotch argus males (19 individuals/ha) and females (13 individuals/ha) was higher than on occasionally mown (males: 9; females: 5 individuals/ha) or intensively mown (males: 3; females: 2 individuals/ha) grasslands. The abundance of Scotch argus was also lower on grazed (males: 7; females: 4 individuals/ha) grasslands. Within a 55-ha reserve, 27 grasslands (128–6,072 m^2) were either temporarily abandoned, or managed by occasional mowing, intensive mowing, or sheep and goat grazing. On 33 days from July–August 2007, butterflies were caught, individually marked, and recaptured at each site.

A replicated, randomized, paired, controlled study in 2007–2010 in four meadows in Őrség National Park, Hungary (11) found that abandoned grassland had fewer scarce large blue butterflies *Phengaris teleius* than mown grassland. Three years after abandonment, the number of scarce large blue butterflies in abandoned plots (0.28 individuals/plot/day) was lower than in plots mown once/year (0.86–0.94 individuals/plot/day) or twice/year (0.70 individuals/plot/day). In May 2007, four meadows were each divided into four equal-size plots, and one of four management regimes was randomly applied to each plot. Three plots/meadow were mown for four years, either once/year in May, once/year in September, or twice/year in May and September, all with cuttings removed. The fourth plot in each meadow was abandoned (not mown). In July 2007 and 2010, butterflies were surveyed for five minutes, 15–20 times/year, in each of three or four 20 × 20 m squares/plot.

A replicated, site comparison study in 2012–2013 in 12 semi-natural grasslands in Nagano Prefecture, Japan (12) found that abandoned meadows had a lower species richness and diversity of butterflies than meadows managed by traditional rotational burning and mowing. In abandoned meadows, the diversity and species richness of threatened (1–2 species/meadow) and common (1–2 species/meadow) butterflies was lower than in rotationally managed meadows (threatened: 6–7; common: 10–12 species/meadow), but similar to annually mown (threatened: 3; common: 4 species/meadow) and annually burned meadows (threatened: 2–3; common: 6 species/meadow) (diversity data presented as model results). Three meadows had been abandoned (unmanaged) for 6–13 years. Three meadows were managed traditionally: each year half of the meadow was burned in April and mown in September, while the other half was unmanaged, and management rotated each year. An additional three meadows had been mown annually in April or August for 8–9 years and three meadows had been burned annually for 7–13 years. From May–September 2012–2013, butterflies were surveyed monthly on three 5 × 30 m plots/meadow.

A replicated, site comparison study in 2006–2010 in 28 grassland sites in Bílé Karpaty Protected Landscape Area, Czech Republic (13) found that abandoning semi-natural grassland did not affect the species richness or species composition of butterfly and moth communities. Both the species richness and species composition of butterflies and moths were similar in abandoned, unmanaged grasslands and in grasslands which were managed by mowing, grazing or a mix of management types (all data presented as model results). One of four different management practices (abandoned (no mowing or grazing); mown once/year; grazed by sheep, cattle or deer; or 'mixed' management) was applied to each of 34 sites (1.5–70.7 ha) for at least five consecutive years. 'Mixed' management included mowing different parts of the site at different times, often with patches left uncut for a year, or mowing followed by grazing. From 2007–2010, butterflies and moths were surveyed on >6 visits between April and October in each of two consecutive years to each of 28 sites.

A replicated, site comparison study in 2015 in 20 grasslands in Saxony, Germany (14) found that abandoned grasslands had a higher abundance of woodland butterflies and burnet moths, but a lower abundance of farmland butterflies and burnet moths, than managed grasslands, but there was no difference in species richness or community composition. In abandoned grasslands, the abundance of 20 species of woodland butterflies and burnet moths (34–44 individuals) was higher than in managed grasslands (17–36 individuals). However, the abundance of 35 species of farmland butterflies and burnet moths was lower in abandoned grasslands (127 individuals) than managed grasslands (195–206 individuals). The species richness of both farmland and woodland species was similar in abandoned (farmland: 13–14; woodland: 5–6 species) and managed (farmland: 14; woodland: 5–6 species) grassland. The community composition was also similar in managed and abandoned grasslands (data presented as model results). Twenty calcareous grasslands (0.90–5.38 ha) were surveyed. Ten were abandoned (not mown or grazed), one was managed by mowing, eight were managed by summer grazing (May–September, <1 animal/ha, with cattle, sheep, goats, horses or donkeys), and one was mown and grazed. From May–August 2015, butterflies and burnet moths were surveyed three times along a 20-minute transect on a 0.8 ha patch at each site. Butterflies and burnet moths were classified as 35 farmland and 20 woodland species.

A replicated, site comparison study in 2015 in 40 hay meadows in Tyumen Province, Russia (15) found that abandoned meadows had a similar species richness and diversity of butterflies to mown meadows, but a higher abundance of more individual species. On abandoned meadows, the species richness (8.6 species/site) and diversity of butterflies was similar to mown meadows (9.2 species/site, diversity data presented as model results). However, seven species (dark green fritillary *Argynnis aglaja*, dusky meadow brown *Hyponephele lycaon*, dryad *Minois dryas*, swallowtail *Papilio machaon*, brimstone *Gonepteryx rhamni*, Esper's marbled white *Melanargia russiae*, Weaver's fritillary *Boloria dia*) occurred at higher density in abandoned meadows on a floodplain than at other sites, compared to four species (ringlet *Aphantopus hyperantus*, small white *Pieris rapae*, chestnut heath *Coenonympha glycerion*, mazarine blue *Cyaniris semiargus*) which occurred at higher density in abandoned meadows not on the floodplain than at other sites, and no species which occurred at higher density in the mown meadows than in abandoned meadows (see paper for details). Forty hay meadows, >1 km apart, were selected within a 20 × 20 km area. Twenty meadows had been abandoned for at least three years (although often much longer), and 20 had been mown within the last three years. Half of the abandoned sites were located on a floodplain. From June–early August 2015, butterflies were surveyed twice along one 200-m transect/meadow.

A replicated, site comparison study in 2014–2015 in a mixed farming region in Lombardy, Italy (16) found that meadows which were not cut had a higher abundance and species richness of butterflies than meadows which were cut. The abundance and species richness of butterflies in uncut meadows was higher than in meadows cut once, twice or three times/summer (data presented as model results). See paper for details on individual species groups. In 2014 and 2015, meadows within an arable landscape were cut 0–3 times between April and September each year. From April–September 2014–2015, butterflies were surveyed along 44 transects, divided into 8–26 × 50-m sections. In 2014, thirty transects were surveyed once/month, and in 2015 fourteen different transects were surveyed twice/month. Only transect sections which passed through meadows were included (number not specified).

(1) Völkl W., Zwölfer H., Romstöck-Völkl M. & Schmelzer C. (1993) Habitat management in calcareous grasslands: effects on the insect community developing in flower heads of Cynarea. *Journal of Applied Ecology*, 30, 307–315.

(2) Dolek M. & Geyer A. (1997) Influence of management on butterflies of rare grassland ecosystems in Germany. *Journal of Insect Conservation*, 1, 125–130.

(3) Schwarzwälder B., Lörtscher M., Erhardt A. & Zettel J. (1997) Habitat utilizations by the heath fritillary butterfly, *Mellicta athalia* ssp. *celadussa* (Rott.) (Lepidoptera: Nymphalidae) in montane grasslands of different management. *Biological Conservation*, 82, 157–165.

(4) Swengel A.B. & Swengel S.R. (1997) Co-occurrence of prairie and barrens butterflies: applications to ecosystem conservation. *Journal of Insect Conservation*, 1, 131–144.

(5) Swengel A.B. (1998) Effects of management on butterfly abundance in tallgrass prairie and pine barrens. *Biological Conservation*, 83, 77–89.

(6) Skórka P, Settele J, Woyciechowski M (2007) Effects of management cessation on grassland butterflies in southern Poland. *Agriculture, Ecosystems & Environment*, 121(4), 319-324.

(7) Stefanescu C., Peñuelas J. & Filella I. (2009) Rapid changes in butterfly communities following the abandonment of grasslands: a case study. *Insect Conservation and Diversity*, 2, 261–269.

(8) Dover J.W., Rescia A., Fungarino S., Fairburn J., Carey P., Lunt P., Arnot C., Dennis R.L.H. & Dover C.J. (2011) Land-use, environment, and their impact on butterfly populations in a mountainous pastoral landscape: individual species distribution and abundance. *Journal of Insect Conservation*, 15, 207–220.

(9) Kulfan J., Strbova E. & Zach P. (2012) Effect of vegetation and management on occurrence of larvae and adults of generalist *Maniola jurtina* L. (Lepidoptera) in meadow habitats. *Polish Journal of Ecology*, 60, 601–609.

(10) Slamova I., Klecka J. & Konvicka M. (2013) Woodland and grassland mosaic from a butterfly perspective: habitat use by *Erebia aethiops* (Lepidoptera: Satyridae). *Insect Conservation and Diversity*, 6(3), 243–254.

(11) Kőrösi Á., Szentirmai I., Batáry P., Kövér S., Örvössy N. & Peregovits L. (2014) Effects of timing and frequency of mowing on the threatened scarce large blue butterfly – A fine-scale experiment. *Agriculture, Ecosystems & Environment*, 196, 24–33.

(12) Uchida K., Takahashi S., Shinohara T. & Ushimaru A. (2016) Threatened herbivorous insects maintained by long-term traditional management practices in semi-natural grasslands. *Agriculture, Ecosystems & Environment*, 221, 156–162.

(13) Bonari G., Fajmon K., Malenovský I., Zelený D., Holuša J., Jongepierová I., Kočárek P., Konvička O., Uřičář J. & Chytrý M. (2017) Management of semi-natural grasslands benefiting both plant and insect diversity: The importance of heterogeneity and tradition. *Agriculture, Ecosystems & Environment*, 246, 243–252.

(14) Ernst L.M., Tscharntke T. & Batary P. (2017) Grassland management in agricultural vs. forested landscapes drives butterfly and bird diversity. *Biological Conservation*, 216, 51–59.

(15) Trappe J., Kunz F., Weking S. & Kamp J. (2017) Grassland butterfly communities of the Western Siberian forest steppe in the light of post-Soviet land abandonment. *Journal of Insect Conservation*, 21, 813–826.

(16) Luppi M., Dondina O., Orioli V. & Bani L. (2018) Local and landscape drivers of butterfly richness and abundance in a human-dominated area. *Agriculture, Ecosystems & Environment,* 254, 138–148.

3.27. Reduce management intensity on permanent grasslands (several interventions at once)

- **Twelve studies** evaluated the effects on butterflies and moths of reducing management intensity on permanent grasslands. Seven studies were in Switzerland[1–7], three were in the UK[8–10], and one was in each of Greece[11] and Germany[12].

COMMUNITY RESPONSE (12 STUDIES)

- **Community composition (2 studies):** Two replicated studies (including one controlled study and one site comparison study) in Switzerland[4,6] found that the composition of butterfly communities differed between low-input and intensively managed grasslands. One of these studies found that low-input grasslands tended to have more butterfly species whose caterpillars feed on a single host plant, have one generation/year and poor dispersal ability[6].
- **Richness/diversity (11 studies):** Six of 10 studies (including five controlled studies and five site comparison studies) in Switzerland[1–3,5–7], the UK[8,10], Greece[11] and Germany[12] found that less intensively managed grasslands had a higher species richness of butterflies[2,3,5,6,11] and moths[10] than conventionally managed grasslands, although two of these studies only found a difference in one of two years[3] or regions[6]. The other four studies found that less intensively managed grasslands had a similar species richness of butterflies[1,7,8] and moths[12] to conventionally managed grasslands. However, one of these studies also found that less intensively managed grassland had more specialist species of moths, and species of conservation concern, than conventionally managed grassland[12]. One before-and-after study in the UK[9] found that after grazing was reduced and chemical application stopped, the species richness of large moths increased.

POPULATION RESPONSE (5 STUDIES)

- **Abundance (5 studies):** Three of four replicated studies (including two controlled studies and two site comparison studies) in Switzerland[5], the UK[8,10] and Germany[12] found that low-input[5,10] or unfertilized, ungrazed grassland managed with a single cut[8] had a higher abundance of butterflies[5,8], micro-moths[10] and declining macro-moths[10] than intensively managed grassland. Two of these studies also found that the abundance of caterpillars[8] and of all macro-moths[10] was similar between less intensively and more intensively managed grasslands. The other study found that less intensively managed grassland had a similar abundance of moths to more intensively managed grassland[12]. One before-and-after study in the UK[9] found that after grazing was reduced and chemical application stopped, the total abundance of large moths and the abundance of five out of 23 butterfly species increased, but the abundance of two butterfly species decreased.

BEHAVIOUR (1 STUDY)

- **Use (1 study):** One replicated, site comparison study in Germany[12] reported that 24 out of 58 moth species preferred less intensively managed grasslands, but 12 species preferred more intensively managed grasslands.

Background

Intensive, conventional grassland management, with high fertilizer input and regular cutting or grazing, creates species-poor plant communities which in turn result in a lower diversity of butterflies and moths (Marini *et al.* 2009). Reducing management intensity may, therefore, enable species-rich plant and butterfly and moth communities to recover.

This intervention is for studies which look at the effect of a combination of measures to reduce management intensity, including reducing or delaying grazing or mowing, sometimes in combination, and often alongside a reduction or removal of the application of fertilizers, herbicides or pesticides. For individual effects of these actions, see "*Reduce grazing intensity on grassland by reducing stocking density*", "*Reduce grazing intensity on grassland by seasonal removal of livestock*", "*Reduce cutting frequency on grassland*", "*Delay cutting or first grazing date on grasslands to create variation in sward height*", "*Pollution – Reduce fertilizer, pesticide or herbicide use generally*" and "*Pollution – Convert to organic farming*".

Marini L., Fontana P., Battisti A. & Gaston K.J. (2009) Agricultural management, vegetation traits and landscape drive orthopteran and butterfly diversity in a grassland-forest mosaic: a multi-scale approach. *Insect Conservation and Diversity*, 2, 213–220.

A replicated, site comparison study in 1998 in two agricultural regions in the Swiss Plateau, Switzerland (1, same experimental set-up as 2 and partially the same as 4) found that grasslands managed with reduced intensity had a similar species richness of butterflies to conventional grasslands. Butterfly species richness was similar on low intensity meadows, extensively managed meadows and intensively managed meadows. However, butterfly species richness was higher in extensively managed meadows (but not in low intensity meadows) than in cereal fields. See paper for details. Across two arable regions, 109 sites were composed of eight habitat types: Ecological Compensation Areas including 19 extensively managed meadows, 16 low intensity meadows, eight orchard meadows, five hedgerows and eleven wildflower strips on set-aside land, along with seven intensively managed meadows, 20 winter wheat fields, and 23 forest edges. From May–September 1998, butterflies were observed for 10 minutes on each of six visits to each site (0.25 ha/site).

A replicated, site comparison study in 1998 in an agricultural region in the Swiss Plateau, Switzerland (2, same experimental set-up as 1, 4) found that butterfly species richness was higher in grassland with reduced management intensity than in intensively managed grassland. The species richness of butterflies was higher in grassland with reduced management intensity than in intensively managed grassland (data not presented). Two types of reduced management intensity grassland, managed as Ecological Compensation Areas, were surveyed: 16 'extensively used meadows' with late mowing and no fertilizer, and seven 'low-input meadows' with late mowing and restricted fertilization (up to 60 kg N/ha/year). Each was around 400 m^2. Fifteen intensively managed meadows were surveyed: seven conventional grasslands and eight Ecological Compensation Area meadows in traditional orchards with no restrictions on cutting or fertilizer use. Butterflies were observed for 10-minute periods on 0.25

ha of each site, on five occasions from May–August 1998, between 10:00–17:30 h on sunny days with temperatures of at least 18 °C. More detailed results (in German) are presented in (1).

A replicated, controlled study in 2000–2002 in three farmland regions of the Swiss Plateau, Switzerland (3) found more butterfly species on low-input grasslands than on intensively managed grasslands in one of two study years. In 2002, but not in 2000, low-input grasslands had more butterfly species than intensively managed grasslands (actual numbers not given). The identity of the butterfly species found was not significantly influenced by management intensity, but was different in different regions. The low-input grasslands were managed as “Ecological Compensation Areas”, with restricted fertilizer and pesticide use, and delayed mowing. Butterflies were recorded in 56 low-input grasslands and 48 intensively managed grasslands during the summers of 2000 and 2002.

A replicated, site comparison study in 2000–2004 in two agricultural regions in the Swiss Plateau, Switzerland (4, same experimental set-up as 1, 2) found that butterfly communities on low-input grasslands were distinct and different from those on intensively managed grasslands. Butterfly communities in low-input grasslands were different from those in intensively managed grasslands (data presented as model results). Thirty-three low-input grasslands were managed as Ecological Compensation Areas, comprising 23 extensively used meadows (late mowing and no fertilizer application) and 10 low-input meadows (late mowing and restricted fertilizer application (up to 60 kg N/ha/year)). Twenty-four intensively managed grasslands, where fertilizer application and mowing were unrestricted, comprised eight permanent intensively managed meadows, 14 meadows in traditional orchards, and two seeded meadows. Butterflies were monitored in three years between 2000 and 2004.

A replicated, paired, controlled study in 2004 in 13 hay meadows in Aargau, Switzerland (5) found that meadows managed with low inputs had a higher species richness and abundance of butterflies compared to intensively managed meadows. Species richness and abundance of butterflies was higher in low-input meadows than in intensively managed meadows (data presented as model results). However, species richness and abundance of butterflies in intensively managed meadows did not change with distance from the low-input meadows (data presented as model results). The 13 low-input meadows (0.48–2.15 ha) had been managed as “Ecological Compensation Areas”, with no fertilizer application and not mown until after 15 June, for at least 5 years, and were paired with adjacent intensively managed meadows. In May 2004 four pots, each containing one plant of radish *Raphanus sativus*, clustered bellflower *Campanula glomerata*, and common catsear *Hypochaeris radicata*, were placed in each low-input meadow, and at 25, 50, 100 and 200 m into the adjacent intensive meadow. Flower visiting insects were collected between 10:00 and 16:00 in one 20-minute session/station in each of May, July and August 2004.

A replicated, controlled study in 1998–2004 in two farmland regions of the Swiss Plateau, Switzerland (6) found more species of butterfly on low-input grassland than conventional grassland in one of the two areas. In Nuvilly, there was an average of 12 species on low-input grasslands and 11 species on conventional grasslands. In Ruswil, there was an average of 3.4 species on low-input grasslands and 2.6 species on conventional grasslands. When other factors such as number of plant species, coverage of woody plants or distance to forest were taken into account, this difference was only statistically significant in Ruswil, and not in Nuvilly. Low-input grasslands had more 'specialist' species – those with only one generation/year, poor dispersal ability or caterpillars that eat only one type of plant. Low-input grasslands, managed as "Ecological Compensation Areas", were fertilized with an average of 7 kg N/ha and cut on average twice a year. Conventional grasslands were fertilized with an average of 206 kg N/ha and cut on average three times each year. Every two years from 1998–2004, butterflies were surveyed in five 10 minute surveys every 2–3 weeks between May and August, in 20–22 low-input grasslands and 6–16 conventional grasslands.

A replicated, controlled study in 1998–2004 in two grassland and mixed farmland regions in central Switzerland (7) found that low-input grasslands contained similar numbers of butterfly species to conventionally managed grasslands. The estimated number of butterfly species on low-input grasslands (36 species) was similar to on conventional grasslands (34 species). The study sampled 315 low-input grasslands managed as "Ecological Compensation Areas" and 216 conventionally managed grasslands. From 1998–2004, butterflies were surveyed every two years between May and September, using five 10-minute observation periods across 0.25 ha/field.

A replicated, randomized, controlled study in 2002–2006 on four lowland farms in Devon and Somerset, UK (8) found that plots of unfertilized, ungrazed grassland cut once in July or not cut during the summer had a higher abundance, but not species richness, of butterflies than fertilized silage plots cut twice/year. In extensive, unfertilized plots cut in July, or not cut all summer, the abundance of butterflies (1–6 individuals/transect) was higher than in intensively managed plots (0–4 individuals/transect), but the number of species was similar (extensive: 1–2; intensive: 0–2 species/transect). The number of caterpillars in extensive plots (1–8 caterpillars/transect) was higher than in one intensive treatment (0–4 caterpillars/transect), but did not differ significantly from other intensive treatments (0–7 caterpillars/transect). In April 2002, experimental plots (50 × 10 m) were established on permanent pastures (>5-years-old) on four farms. There were seven treatments, with three replicates/farm. Three extensive treatments were not fertilized or grazed, and were either cut to 10 cm once/year in May or July, or topped in early spring and undisturbed in summer. Four intensive treatments included modifications to conventional silage management (reducing fertilizer application or grazing, or raising cutting height), but were all cut twice/year. From June–September 2003–2006, butterflies were surveyed once/month on a 50-m transect through the centre of each plot. In April, June, July and September 2003–2006, caterpillars were counted (but not identified) on two 10-m transects/plot using a sweep net (20 sweeps/transect).

A before-and-after study in 1994–2006 on a farm in Oxfordshire, UK (9) found that following adoption of the Environmentally Sensitive Areas scheme, including reducing grazing intensity and stopping the application of fertilizers, herbicides and pesticides, the abundance and species richness of large moths and some species of butterfly increased. After Environmentally Sensitive Area management began, the total abundance (1,000–1,450 individuals) and species richness of large moth species was higher than before (800–1,250 individuals, richness data not presented). One of the five most abundant moth species (lunar underwing *Omphaloscelis lunosa*) and five of 23 butterfly species (meadow brown *Maniola jurtina*, brown argus *Aricia agestis*, common blue *Polyommatus icarus*, small copper *Lycaena phlaeas* and red admiral *Vanessa atalanta*) increased in abundance after the change in management. However, two butterfly species became less abundant (green-veined white *Pieris napi* and large white *Pieris brassicae*, data presented as model results). Overall butterfly abundance and species richness increased over the entire monitoring period, but the increase did not just happen after the management change. In 2002, the farm entered the Environmentally Sensitive Areas agri-environment scheme. Fertilizers, herbicides and pesticides were no longer used, the total number of livestock dropped from 180 cows and 1,000 sheep to 120 cows and 850 sheep, and the proportion of grassland increased. Butterflies were monitored weekly from April–September on a fixed 3.6 km transect divided into 13 sections. Moths were monitored nightly from dusk to dawn using a light trap in a fixed position in the middle of the farm.

A replicated, paired, site comparison study in 2008 on 32 farms in central Scotland, UK (10) found that created species-rich grassland managed at low intensity had a higher abundance and species richness of micro- and macro-moths than conventionally-managed grassland or crop fields. In low intensity grasslands, the abundance (156 individuals) and species richness (24 species) of micro-moths, the species richness of all macro-moths (46 species), and the abundance of declining macro-moths (44 individuals) were all higher than in improved grasslands or crop fields on conventional farms (micro-moths: 43 individuals, 19 species; all macro-moths: 33 species; declining macro-moths: 21 individuals). However, the abundance of all macro-moths (366 individuals) and species richness of declining macro-moths (10 species) on low intensity grasslands was not significantly different from improved grasslands or crop fields (all macro-moths: 271 individuals; declining macro-moths: 9 species). In 2004, sixteen farms enrolled in agri-environment schemes, and were paired with 16 similar but conventionally-managed farms, <8 km away. On agri-environment scheme farms, species-rich grassland was created on former arable or improved grassland fields by sowing a low productivity grass and herb seed mix, and managed with fertilizer and pesticide restrictions, and no summer cutting or grazing. Improved pastures and crop fields on conventional farms had no management restrictions. From June–September 2008, moths were collected for four hours, on one night/farm, using a 6 W heath light trap located in one field on each farm. Paired farms were surveyed on the same night.

A site comparison study in 2008 in 10 wet grasslands in the Epirus district, Greece (11) found that sites with lower grazing intensity or cutting frequency had a higher species richness of butterflies than sites with higher intensity management. The species richness of butterflies was higher at less disturbed sites (10–23 species) than at more disturbed sites (3–11 species). Ten 1-ha wet grasslands, managed by either grazing (by cattle from May–August), mowing (1–2 times/year from June–August), grazing and mowing, or neither, were surveyed (exact grazing and cutting details not provided). From May–July 2008, butterflies were surveyed three times on one 200-m transect/site.

A replicated, site comparison study in 2014 in 26 grasslands in Germany (12) found that grasslands managed less intensively had a similar abundance, species richness and diversity of moths to more intensively managed grasslands. The abundance, species richness and diversity of moths on grasslands managed with lower grazing intensity, less frequent cutting and/or less fertilizer input was similar to more intensively managed grasslands (data presented as model results). However, less intensively managed grasslands did support more specialist moth species, and species of greater conservation concern, than more intensively managed grasslands (data presented as model results). Of 87 individual species monitored, 24 species preferred less intensively managed grasslands, and 12 preferred more intensively managed grasslands (see paper for individual species data). From 2006, across three regions, nine grasslands were managed by grazing (by cattle, sheep or horses at 26–520 livestock units/ha/year), nine by mowing (1–2 cuts/year, often with nitrogen fertilization), and eight were grazed and mown (76–163 livestock units/ha/year; 1–2 cuts/year). Eleven of the mown or mown and grazed grasslands were fertilized with 1–138 kg nitrogen/ha. Moths were collected once/month from nine grasslands in each of two regions (May–August 2014), and from eight grasslands in one region (June–July 2014). Each night, a 12 V actinic and black-light trap were placed in the centre of each of three grasslands for 138–317 minutes/night. Moths were classified as specialists based on the number of food plants eaten by their caterpillars.

(1) Jeanneret P., Schüpbach B., Steiger J., Waldburger M. & Bigler F. (2000) Evaluation of ecological measures: Spiders and butterflies. *Agrarforschung*, 7, 112–116.

(2) Jeanneret P., Schupbach B. & Pfiffner L. (2003) Arthropod reaction to landscape and habitat features in agricultural landscapes. *Landscape Ecology*, 18, 253–263.

(3) Aviron S., Berner D., Bosshart S., Buholzer S., Herzog F., Jeanneret P., Klaus I., Pozzi S., Schneider K., Schüpbach B. & Walter T. (2005) Butterfly diversity in Swiss grasslands: respective impacts of low-input management, landscape features and region. Pages 340-343 in: R. Lillak, R. Viiralt, A. Linke & V. Geherman (eds.) *Grassland Science in Europe*. 10, Estonian Grassland Society, Tartu.

(4) Jeanneret P., Aviron S., Herzog F., Luka H., Pozzi S. & Walter T. (2005) Temporal trends of arthropod diversity in conventional and low-input meadows. Pages 344–347 in: *Grassland Science in Europe*. 10, Estonian Grassland Society, Tartu.

(5) Albrecht M., Duelli P., Muller C., Kleijn D. & Schmid B. (2007) The Swiss agri-environment scheme enhances pollinator diversity and plant reproductive success in nearby intensively managed farmland. *Journal of Applied Ecology*, 44, 813–822.

(6) Aviron S., Jeanneret P., Schüpbach B. & Herzog F. (2007) Effects of agri-environmental measures, site and landscape conditions on butterfly diversity of Swiss grassland. *Agriculture, Ecosystems & Environment*, 122, 295-304.

(7) Aviron S., Nitsch H., Jeanneret P., Buholzer S., Luka H., Pfiffner L., Pozzi S., Schüpbach B., Walter T. & Herzog F. (2009) Ecological cross compliance promotes farmland biodiversity in Switzerland. *Frontiers in Ecology and the Environment*, 7(5), 247-252.

(8) Potts S.G., Woodcock B.A., Roberts S.P.M., Tscheulin T., Pilgrim E.S., Brown V.K. & Tallowin J.R. (2009) Enhancing pollinator biodiversity in intensive grasslands. *Journal of Applied Ecology*, 46, 369–379.

(9) Taylor M.E. & Morecroft M.D. (2009) Effects of agri-environment schemes in a long-term ecological time series. *Agriculture, Ecosystems & Environment*, 130, 9–15.

(10) Fuentes-Montemayor E., Goulson D. & Park K.J. (2011) The effectiveness of agri-environment schemes for the conservation of farmland moths: assessing the importance of a landscape-scale management approach. *Journal of Applied Ecology*, 48, 532–542.

(11) Kati V., Zografou K., Tzirkalli E., Chitos T. & Willemse L. (2012) Butterfly and grasshopper diversity patterns in humid Mediterranean grasslands: the roles of disturbance and environmental factors. *Journal of Insect Conservation*, 16, 807–818.
(12) Mangels J., Fiedler K., Schneider F.D. & Bluthgen N. (2017) Diversity and trait composition of moths respond to land-use intensification in grasslands: generalists replace specialists. *Biodiversity and Conservation*, 26, 3385–3405.

3.28. Reduce grazing intensity on grassland by reducing stocking density

- **Fourteen studies** evaluated the effects on butterflies and moths of reducing grazing intensity on grassland by reducing stocking density. Four studies were in the UK[1,4,5,11], two were in each of Sweden[2,6,12] and Germany[3,9,13], one was in each of the USA[7], Belgium and the Netherlands[8], Europe[10] and Switzerland[14].

COMMUNITY RESPONSE (8 STUDIES)

- **Richness/diversity (8 studies):** Five of eight replicated studies (including two randomized, controlled studies and six site comparison studies) in the UK[5], Sweden[2,6], Germany[3,9,13], the USA[7] and Switzerland[14] found that grasslands grazed with lower stocking densities of sheep[5], cattle[2,3,9] or a mix of sheep, cattle and horses[13] had a greater species richness of adult butterflies[2,3,9], all moths[5,13] and burnet moths[3] than grassland grazed at higher stocking densities. However, one of these studies also found that butterfly and burnet moth caterpillar species richness was similar at sites with low and high stocking densities[3]. Two of the other studies found that grasslands grazed with lower stocking densities of cattle and horses[6] or unspecified grazing animals[14] had a similar species richness of butterflies[6,14] and burnet moths[6] to grassland grazed at higher stocking densities. The other study found that, in one of two study years, grasslands grazed with cattle at a low density had lower species richness than grasslands grazed at moderate density[7].

POPULATION RESPONSE (12 STUDIES)

- **Abundance (11 studies):** Eight replicated studies (including four controlled studies and four site comparison studies) in the UK[1,4,5,11], Germany[3,9], the USA[7] and Sweden[12] found that grasslands grazed with lower stocking densities of sheep[1,4,5], cattle[3,9,11] or both[12] (in one case combined with a later start to grazing[12]) had a greater abundance of all butterflies[3,9], butterflies with grass host plants[7], all moths[5], burnet moths[3], their caterpillars[1,4,11] or specific species[9,12] (in two cases as part of combined invertebrate counts[1,11]) than grasslands grazed at higher stocking densities. The three studies on caterpillars only found a higher abundance at two out of three sites[1] or in earlier[11] or later[4] sampling periods, and one of the studies found that sites with low and high intensity grazing had a similar abundance of butterfly and burnet moth caterpillars[3]. Two replicated, site comparison studies in Sweden[6] and Switzerland[14] found that grasslands grazed with lower stocking densities of cattle and horses[6] or unspecified grazing animals[14] had a similar abundance of butterflies[6,14] and burnet moths[6] to grassland grazed at higher stocking densities. One review of studies in Europe[10] reported that reducing grazing intensity benefitted 41 out of 67 butterfly species of conservation concern, but did not distinguish between reducing stocking density and seasonal removal of livestock.

- **Survival (1 study):** One site comparison study in Belgium and the Netherlands[8] reported that the survival of Glanville fritillary caterpillar nests was similar between grasslands with low and high stocking density of sheep.
- **Condition (1 study):** One site comparison study in Belgium and the Netherlands[8] found that after 6–10 days of sheep grazing, fewer Glanville fritillary caterpillar nests were damaged in a grassland with lower stocking density than in a grassland with higher stocking density, but there was no difference after two months.

BEHAVIOUR (0 STUDIES)

Background

Productive grasslands used for livestock production are intensively managed, with high stocking densities resulting in a closely cropped sward (Bubová *et al.* 2015). While grazing is important for maintaining open grassland, reducing grazing intensity by decreasing stocking density allows some vegetation to grow taller, increasing structural complexity and floral diversity (Morris 2000), and this may provide more suitable habitat for some grassland butterflies and moths (e.g. Elligsen *et al.* 1997).

For studies on reducing grazing intensity by removing livestock for part of the year, see "*Reduce grazing intensity on grassland by seasonal removal of livestock*". For studies on reducing grazing intensity alongside other reductions in management intensity, such as reduced chemical input, see "*Reduce management intensity on permanent grasslands (several interventions at once)*". For studies on removing grazing entirely, see "*Cease grazing on grassland to allow early succession*". For studies on increasing grassland management, see "*Increase grazing intensity or cutting frequency on grassland*".

Elligsen H., Beinlich B. & Plachter H. (1997) Effects of large-scale cattle grazing on populations of *Coenonympha glycerion* and *Lasiommata megera* (Lepidoptera: Satyridae). *Journal of Insect Conservation*, 1, 13–23.

Morris M.G. (2000) The effects of structure and its dynamics on the ecology and conservation of arthropods in British grasslands. *Biological Conservation*, 95, 129–142.

Bubová T., Vrabec V., Kulma M. & Nowicki P. (2015) Land management impacts on European butterflies of conservation concern: a review. *Journal of Insect Conservation*, 19, 805–821.

A replicated, paired, site comparison study in 1989–1993 in three upland grasslands in Scotland, UK (1) found that two of three sites with reduced stocking density had a higher abundance of small invertebrates (including caterpillars) than sites with higher stocking density. In two out of three grasslands, the abundance of invertebrates was higher in plots with reduced stocking density (6–125 individuals) and ungrazed plots (70–250 individuals) than in plots with higher stocking density (4–70 individuals). At the third site, there was no significant difference between reduced stocking (17–78 individuals), ungrazed (35–78 individuals) and higher stocking density plots (17–55 individuals). From 1989–1991, at three sites, experimental grazing plots were established where the number of sheep was adjusted weekly in order to maintain different sward heights from May–October each year. At two sites, two 0.3-ha plots had sward kept at each of 3.0, 4.5 (high stocking density) or 6.0 cm (reduced stocking density). At the third site, four 1–3 ha plots had sward kept at each of 4.5 and 6.5 cm, but from June–August six cattle were grazed on half of the plots. Separate plots which had been ungrazed for one, four or 25 years were also monitored at each site. In August 1993, invertebrates (insects and arachnids) were sampled from both tussocks and low sward at each of six randomly selected points/plot using a d-vac suction sampler.

A replicated, site comparison study in 1997 in 20 pastures in the Uppsala region, Sweden (2) found that on pastures with lower grazing intensity, butterfly species richness was higher. In pastures with lower grazing intensity butterfly richness was higher (data presented as model results). Pastures were mostly cattle-grazed annually from May–October. Grazing intensity was measured as the proportion of grass shorter than 5 cm throughout the period. Grass height was estimated three times in May–June 1997 in 1-ha quadrats covering the whole of each of 20 grazed semi-natural pastures. In July 1997, butterflies were surveyed along the borders of a 100 m^2 square walking transect in pastures, repeated 18 times/pasture.

A replicated, site comparison study in 1996 in 18 grasslands in Schleswig-Holstein, Germany (3) found that the species richness and abundance of adult butterflies and burnet moths at sites grazed at low intensity was higher than at intensively grazed sites and similar to ungrazed sites, but the responses of caterpillar richness and abundance to grazing intensity were mixed. Butterfly and burnet moth species richness and abundance were higher at low intensity grazing (average richness: 4; average abundance: 8) and ungrazed (average richness: 7; average abundance: 21) sites than at sites which were intensively grazed (average richness: 2; average abundance: 1). Caterpillar species richness was statistically similar at low intensity grazing (average: 4) and intensively grazed sites (average: 2), but lower in both than in ungrazed sites (average: 7). Caterpillar abundance was statistically similar in low intensity grazed sites (average: 9) and both intensively (average: 1) and ungrazed (average: 12) sites, but ungrazed sites had higher abundance than intensively grazed sites. Intensively grazed sites (6) had an average stocking density of 1.4 cattle/ha annually from May–November, low intensity grazed sites (6) had an average density of 5.5 cattle/ha annually from April–October, and ungrazed sites (6) had not been stocked for 5–10 years. From May–September 1996, at each site separate transect walks were conducted once monthly for adult butterflies and burnet moths (45-minute transects) and caterpillars (45-minute transects in grazed sites and 60-minutes in ungrazed sites).

A replicated, randomized, controlled study in 2003–2005 on an upland grassland in Perthshire, UK (4, same experimental set-up as 3) found that plots grazed with a lower stocking density had a higher abundance of moth caterpillars than commercially grazed plots, but only after >2 years. After 18 months of grazing, there was no significant difference in the number of caterpillars on lightly grazed (1.9–2.4 individuals/plot), commercially grazed (2.3 individuals/plot) or ungrazed plots (2.8 individuals/plot). However, after 30 months, there were more caterpillars in the lightly grazed plots (1.9–2.4 individuals/plot) than in the commercially grazed plots (0.5 individuals/plot), but fewer than in the ungrazed plots (4.9 individuals/plot). From January 2003, three grazing regimes (light grazing: sheep at 0.9 ewes/ha or sheep and cattle equivalent to 0.9 ewes/ha; commercial grazing: sheep at 2.7 ewes/ha) and an ungrazed treatment were replicated six times each in twenty-four 3.3-ha plots (in three pairs of adjacent blocks). Caterpillars were sampled by sweep net in 2003–2005.

A replicated, randomized, controlled study in 2003–2007 on an upland estate in Scotland, UK (5, same experimental set-up as 2) found that lightly grazed plots had a higher abundance and species richness of moths than plots grazed at a commercial stocking density. Plots grazed by sheep at low density had a higher abundance (52 individuals/night) and species richness (12.3 species/night) of moths than plots grazed by sheep at commercial densities (abundance: 34 individuals/night; richness: 10.6 species/night), or plots grazed by sheep and cattle at low density (abundance: 42 individuals/night; richness: 11.3 species/night), and were similar to ungrazed plots (abundance: 48 individuals/night; richness: 13.2 species/night). In January 2003, one of four grazing treatments was established on each of 24 plots (3.3 ha each) on a grazed acid grassland upland estate. The treatments were: low density sheep grazing (3 sheep/plot); commercial high density sheep grazing (9 sheep/plot); low density mixed grazing (2 sheep/plot plus two cows and calves for 4 weeks in autumn); ungrazed control. Moths were sampled between June and October 2007 using four 15 W light traps placed randomly within plots of each treatment, for six or seven sample nights/plot.

A replicated, site comparison study in 2004 in an agricultural region in central Sweden (6) found that grasslands grazed at low intensity did not have a greater abundance or species richness of butterflies and burnet moths than intensively grazed or abandoned grasslands. On low intensity pasture, the abundance (22.9 individuals/visit) and species richness (9.1 species/visit) of butterflies and burnet moths was not significantly different from either intensively grazed pasture (abundance: 22.8 individuals/visit; richness: 9.4 species/visit) or abandoned grassland (abundance: 29.5 individuals/visit; richness: 10.4 species/visit). Three pastures, >2 km apart, were selected in each of eight sites (>10 km apart). Within a site, one low intensity pasture was managed by cattle or horse grazing, one high intensity pasture was managed by cattle grazing, and one abandoned pasture had been ungrazed for >10 years. From June–August 2004, flower-visiting insects were surveyed four times on four 5 × 5 m plots/pasture. Plots were observed for 10 minutes/visit.

A replicated, site comparison study in 2003–2004 in 27 oak and conifer woodland and shrubland sites in Oregon, USA (7) found that at sites with no or low grazing intensity there was lower overall butterfly species richness in one of two years and higher abundance of butterflies with grass host plants in both years compared to sites with moderate grazing, but butterfly density and community evenness were not affected by grazing intensity. In 2003, but not 2004, butterfly species richness was lower along transects with low grazing intensity (0–15%) than those with moderate intensity (30–45%) (data presented as log species richness). There was no difference in species richness between any other grazing intensities (15–30%, 45–60% or 60–75%). Grazing intensity did not affect butterfly density or community evenness (data not provided). Butterflies with grass host plants were more abundant along transects with 0–30% grazing intensity than 30–45% intensity, but there were no differences between abundances at any of the other grazing intensity categories (data presented as log abundance). See paper for individual species results. Twenty-seven butterfly transects of varying lengths were conducted in April–September 2003 and 2004 either in oak woodland and shrubland or in meadows in areas dominated by mixed-conifer forest. Sites were cattle-grazed from May–November. Each transect was surveyed for butterflies 0–7 times in 2003 and eight times in 2004. In 2004, at each transect, cattle grazing intensity (0–75%) was estimated by measuring the height of that transect's dominant cattle-palatable plant at every metre for 50 m, calculating the average height across the transect's sampling points, and comparing this to the height of a reference ungrazed plant of that species from the same transect to calculate a grazing intensity percentage.

A site comparison study in 2009–2010 in two calcareous grasslands in Belgium and the Netherlands (8) found that fewer Glanville fritillary *Melitaea cinxia* caterpillar nests were damaged at less intensively grazed and ungrazed sites than at a more intensively grazed site. After 6–10 days of autumn grazing, fewer caterpillar nests had signs of damage in a lightly grazed (2/25 nests damaged) and ungrazed (2/24 nests damaged) site than nests in a heavily grazed site (15/25 nests damaged). Two months later, the number of nests with signs of damage was similar in lightly grazed (3/25 nests damaged), ungrazed (6/24 nests damaged) and heavily grazed (6/25 nests damaged) areas. All 24 nests in the ungrazed area, and 24/25 nests in the lightly grazed area, survived until spring, compared to 22/25 surviving in the heavily grazed area (statistical significance not assessed). In July–August 2009, a lightly grazed 0.52-ha grassland and a heavily grazed 4-ha grassland were searched three times for caterpillar nests. At the larger site, half of the area with the most nests was fenced to create a 0.15-ha ungrazed site. The 24–25 largest nests (>1 m apart) in each site were selected, and their location marked on GPS. In September 2009, the 0.52-ha grassland was grazed by 26 sheep for six days, and a 1.23-ha area of the larger site was grazed by 114 sheep for 10 days, after which an expanded 1.76-ha area was grazed by 15 sheep for 50 days. In October and December 2009, nests were checked for damage, and in March 2010 the survival of each nest was recorded.

A replicated, randomized, paired, controlled study in 2002–2011 in a grassland in Lower Saxony, Germany (9) found that grassland grazed at reduced cattle density had a higher species richness and abundance of butterflies than grassland grazed at moderate density, but there was no additional benefit of more recent very low density grazing. After 8–9 years, plots grazed at reduced density had a higher abundance (18.7–30.6 individuals/transect) and species richness (6.0–8.4 species/transect) of butterflies than plots grazed at moderate density (abundance: 8.1–20.0 individuals/transect, richness: 3.3–5.3 species/transect). However, on plots grazed at very low density butterfly abundance (16.3–34.1 individuals/transect) and species richness (5.4–7.8 species/transect) were similar to the reduced density plots. Over nine years, the abundance of marbled white *Melanargia galathea* increased more on reduced density plots (2002: 0–1 individuals; 2011: 4–12 individuals) than on moderate density plots (2002: 0–1 individuals; 2011: 1–5 individuals). From 2002–2011, three 3-ha paddocks were each divided into three treatments, each grazed annually from April–October: moderate density (3–6 cattle/ha, target sward height 6 cm), reduced density (1–3 cattle/ha, 12 cm sward) and very low density (2 cattle/ha, 18 cm sward, from 2005 only). Target sward heights were maintained by varying numbers of Simmental cattle in each paddock following biweekly sward height measurements. From July–September 2002–2004 and 2010–2011, butterflies were recorded biweekly on three 50-m transects/treatment.

A review in 2015 of 126 studies in Europe (10) reported that reducing grazing intensity on grassland benefitted 41 out of 67 butterfly species of conservation concern. Results were not tested for statistical significance. The review reported that 44 studies found that reducing grazing intensity benefitted 41 butterfly species, but did not distinguish between reducing stocking density and using seasonal grazing. The optimal grazing intensity was 0.2–0.5 livestock/ha (data not presented). See paper for information on individual species. Meadows were extensively grazed by different livestock and at different times, sometimes with rotational mowing. The review focussed on 67 butterfly species of conservation concern. The available information was biased towards studies in Northern and Western Europe.

A replicated, paired, controlled study in 2010–2012 in six permanent pasture fields in Devon, UK (11) found that grassland managed with reduced stocking density initially had a higher abundance of invertebrates (including caterpillars) than conventional grassland, but the effect disappeared over three years. In the first year, the abundance of "bird food invertebrates" was higher on grassland grazed at a reduced density (202 individuals/plot) than on grassland grazed conventionally (112 individuals/plot). However, after two and three years, there was no significant difference between reduced (two years: 97; three years: 48 individuals/plot) and conventionally grazed plots (two years: 78; three years: 42 individuals/plot). From April 2010–September 2012, six permanent pasture fields were divided into two 1-ha plots. One plot/pair was grazed by cattle at reduced stocking density, managed to keep sward height between 9–12 cm, and the other was grazed at conventional stocking density, keeping the sward at 6–8 cm. None of the fields were fertilized during the trial. In July 2010–2012, invertebrates were sampled in 10 locations/plot using a Vortis suction sampler (ten 15-second samples over 0.19 m^2) and sweep-netting (20 double sweeps with a 46-cm diameter net). Invertebrates <2 mm long were excluded from analysis.

A replicated, site comparison study in 1984–2015 in 24 grasslands in Blekinge province, Sweden (12) found that grasslands grazed lightly, with fewer animals or later in the year, had a higher abundance of clouded Apollo *Parnassius mnemosyne* than grasslands grazed heavily, with more animals or earlier in the summer. In grasslands managed by light grazing, the abundance of clouded Apollo (1–169 individuals/grassland/year) was higher than in heavily grazed grasslands (2–22 individuals/grassland/year) or ungrazed grasslands (0–109 individuals/grassland/year). In addition, abundance was higher on larger grasslands, and grasslands which were close together were more likely to be colonized (data presented as model results). From 1984–2015, twenty-four open grasslands (>150 m apart) with >0.5 m^2 cover of the host plant *Corydalis* spp. and the presence of a major nectar plant *Lychnis viscaria* were assigned annually to one of three management categories: light grazing (grazing with 1–9 animals/hectare commenced after 15 June); heavy grazing (grazing with ≥10 animals/hectare for ≥8 weeks or commenced before 15 June); no grazing. Grazing animals were cattle and sheep. In 1984–1987, 1991 and 2003–2015, butterflies were surveyed ≥6 times/year on each site, by marking and recapturing individuals along irregular routes through each grassland. In 1988–1989 and 1992–2002, grasslands were visited more irregularly and their presence recorded. Surveys were used to estimate the local population size on each grassland each year.

A replicated, site comparison study in 2014 in 26 grasslands in Germany (13) reported that grasslands managed with lower stocking density (sometimes also mown) supported more moth species than grasslands grazed at higher stocking density. Results were not tested for statistical significance. Grasslands managed with a lower stocking density had more moth species (143 species) than grasslands managed with a higher stocking density (35 species). From 2006, across three regions, nine grasslands were managed by grazing (by cattle, sheep or horses) at low (0–113 livestock units/ha/year) or high density (113–520 livestock units/ha/year), nine were managed by mowing (1–2 cuts/year, often with nitrogen fertilization), and eight were grazed and mown (76–163 livestock units/ha/year; 1–2 cuts/year). Moths were collected once/month from nine grasslands in each of two regions (May–August 2014), and from eight grasslands in one region (June–July 2014). Each night, a 12 V actinic and black-light trap were placed in the centre of each of three grasslands for 138–317 minutes/night.

A replicated, site comparison study in 2009–2011 in 133 mixed farms in the Central Plateau, Switzerland (14) found that farms with a lower livestock density had a similar abundance and species richness of butterflies to farms with higher livestock density. Both the abundance and species richness of butterflies on farms with a lower density of livestock was similar to farms with higher livestock densities (data presented as model results). A total of 133 farms (17–34 ha, 13–91% arable crops) were managed with "Ecological Compensation Areas" under agri-environment schemes, and pastures were stocked at a range of livestock densities. From May–September 2009–2011, butterflies were surveyed six times on 10–38 transects/farm, totalling 2,500 m/farm. Each transect ran diagonally through a single crop or habitat type, with all available crops and habitats represented. All visits to a farm were completed in a single year, and the species richness was summed across all visits. Total abundance of butterflies was calculated from the number recorded in each habitat, and the availability of each habitat across the farm.

(1) Dennis P., Young M.R. & Gordon I.J. (1998) Distribution and abundance of small insects and arachnids in relation to structural heterogeneity of grazed, indigenous grasslands. *Ecological Entomology*, 23, 253–264.

(2) Söderström B., Svensson B., Vessby K. & Glimskär A. (2001) Plants, insects and birds in semi-natural pastures in relation to local habitat and landscape factors. *Biodiversity and Conservation*, 10, 1839-1863.

(3) Kruess A. and Tscharntke T. (2002) Grazing intensity and the diversity of grasshoppers, butterflies, and trap-nesting bees and wasps. Conservation Biology, 16(6), 1570–1580.

(4) Dennis P., Skartveit J., McCracken D.I., Pakeman R.J., Beaton K., Kunaver A. & Evans D.M. (2008) The effects of livestock grazing on foliar arthropods associated with bird diet in upland grasslands of Scotland. *Journal of Applied Ecology*, 45, 279–287.
(5) Littlewood N.A. (2008) Grazing impacts on moth diversity and abundance on a Scottish upland estate. *Insect Conservation and Diversity*, 1, 151–160.
(6) Sjodin N.E., Bengtsson J. & Ekbom B. (2008) The influence of grazing intensity and landscape composition on the diversity and abundance of flower-visiting insects. *Journal of Applied Ecology*, 45, 763–772.
(7) Runquist E.B. (2011) Butterflies, cattle grazing, and environmental heterogeneity in a complex landscape. *The Journal of Research on the Lepidoptera*, 44, 61-76.
(8) van Noordwijk C.G.E., Flierman D.E., Remke E., WallisDeVries M.F. & Berg M.P. (2012) Impact of grazing management on hibernating caterpillars of the butterfly *Melitaea cinxia* in calcareous grasslands. *Journal of Insect Conservation*, 16, 909–920.
(9) Jerrentrup J.S., Wrage-Mönnig N., Röver K.-U. & Isselstein J. (2014) Grazing intensity affects insect diversity via sward structure and heterogeneity in a long-term experiment. *Journal of Applied Ecology*, 51, 968–977.
(10) Bubová T., Vrabec V., Kulma M. & Nowicki P. (2015) Land management impacts on European butterflies of conservation concern: a review. *Journal of Insect Conservation*, 19, 805–821.
(11) Royal Society for the Protection of Birds (2016) Utility of lenient grazing of agricultural grassland to promote in-field structural heterogeneity, invertebrates and bird foraging [BD5207: Extensive cattle grazing: what is the best approach to improve species-poor pastures for birds and invertebrates? (Phase 2)] - Project BD5206/BD5207 Final Report to DEFRA/Natural England (RP00196). Natural England report.
(12) Johansson V., Knape J. & Franzen M. (2017) Population dynamics and future persistence of the clouded Apollo butterfly in southern Scandinavia: The importance of low intensity grazing and creation of habitat patches. *Biological Conservation*, 206, 120–131.
(13) Mangels J., Fiedler K., Schneider F.D. & Bluthgen N. (2017) Diversity and trait composition of moths respond to land-use intensification in grasslands: generalists replace specialists. *Biodiversity and Conservation*, 26, 3385–3405.
(14) Stoeckli S., Birrer S., Zellweger-Fischer J., Balmer O., Jenny M. & Pfiffner L. (2017) Quantifying the extent to which farmers can influence biodiversity on their farms. *Agriculture, Ecosystems & Environment*, 237, 224–233.

3.29. Reduce grazing intensity on grassland by seasonal removal of livestock

- **Seven studies** evaluated the effects on butterflies and moths of reducing grazing intensity on grassland by seasonal removal of livestock. Five studies were in the UK[1–4,6], one was in France[5] and one was a review across Europe[7].

COMMUNITY RESPONSE (3 STUDIES)

- **Richness/diversity (3 studies):** Two of three replicated, controlled studies (including one randomized, paired study and one randomized study) in the UK[2,3,6] found that upland pasture where cattle were removed in the summer[2], and silage fields where cattle were not grazed in September[3], had a similar species richness of butterflies[2,3] to pasture grazed throughout the growing season[2] and silage fields grazed in September[3]. The other study found that grasslands where cattle were removed in the summer had a greater species richness of butterflies (and other pollinators) than grasslands grazed throughout the summer[6].

POPULATION RESPONSE (7 STUDIES)

- **Abundance (7 studies):** Three controlled studies (including two replicated, randomized studies) in the UK[1,4,6] found that grasslands where cattle[6] or cattle and sheep[1] were removed in the summer[1,6], or sheep were removed in the winter[4], had a higher abundance of butterflies (and other pollinators)[6] and caterpillars[1,4] than grasslands grazed throughout the summer[1,6] or all year[4]. Three replicated, controlled studies (including one randomized study and one paired study) in the UK[2,3] and France[5] found that upland pasture where cattle were removed in the summer[2], silage fields where cattle were not grazed in September[3], and semi-natural grasslands where sheep were removed during the peak flowering period[5], had a similar abundance of butterflies[2,3,5], burnet moths[5] and caterpillars[3] to pasture grazed throughout the growing season[2], silage fields grazed in September[3], and rotationally grazed grassland[5]. One review of studies in Europe[7] reported that reducing grazing intensity benefitted 41 out of 67 butterfly species of conservation concern, but did not distinguish between the seasonal removal of livestock and reducing stocking density.

BEHAVIOUR (0 STUDIES)

Background

Productive grasslands used for livestock production are intensively managed, with permanent grazing resulting in a closely cropped sward (Bubová *et al.* 2015). While grazing is important for maintaining open grassland, reducing grazing intensity by removing livestock for part of the year allows some vegetation to grow taller, increasing structural complexity and floral diversity (Morris 2000), and this may provide more suitable habitat for some grassland butterflies and moths (e.g. Elligsen *et al.* 1997).

For studies on reducing grazing intensity by decreasing the number of livestock, see "*Reduce grazing intensity on grassland by reducing stocking density*". For studies on reducing grazing intensity alongside other reductions in management intensity, such as reduced chemical input, see "*Reduce management intensity on permanent grasslands (several interventions at once)*". For studies on removing grazing entirely, see "*Cease grazing on grassland to allow early succession*". For studies on increasing grassland management, see "*Increase grazing intensity or cutting frequency on grassland*".

Elligsen H., Beinlich B. & Plachter H. (1997) Effects of large-scale cattle grazing on populations of *Coenonympha glycerion* and *Lasiommata megera* (Lepidoptera: Satyridae). *Journal of Insect Conservation*, 1, 13–23.

Morris M.G. (2000) The effects of structure and its dynamics on the ecology and conservation of arthropods in British grasslands. *Biological Conservation*, 95, 129–142.

Bubová T., Vrabec V., Kulma M. & Nowicki P. (2015) Land management impacts on European butterflies of conservation concern: a review. *Journal of Insect Conservation*, 19, 805–821.

A replicated, randomized, controlled trial in 1997–1998 on permanent pasture at three sites in Dumfries and Galloway, UK (1) found that fencing field headlands to prevent grazing during the summer increased the abundance of caterpillars. After one year, headlands protected from summer grazing had more caterpillars (18 individuals/10 samples) than grazed headlands (1 individual/10 samples). From spring 1997, four treatments were carried out in adjacent plots

(10 × 50 m long) on the boundaries of seven pasture fields: fenced (May–September) unsprayed, fenced (May–September) sprayed, unfenced unsprayed, and unfenced sprayed. Unfenced plots were grazed by cattle and sheep during summer, and all plots were intermittently grazed by sheep during winter. In sprayed plots, herbicide (6 l glyphosate/ha) was applied in April 1997 to clear strips to trial a method for increasing foraging access for birds. Insects were sweep net sampled in June and July 1997 and 1998.

A replicated, controlled study in 2005–2007 at an upland site in the UK (exact location not given) (2) found that improved grassland from which cattle were excluded in summer had a similar abundance and species richness of butterflies to permanently grazed grassland. In exclusion plots, the abundance (15–67 individuals) and species richness (5–10 species) of butterflies was similar to permanently grazed plots (abundance: 42–156 individuals; richness: 7–11 species). Ten plots of improved perennial rye grass *Lolium perenne*/white clover *Trifolium repens* were grazed in spring and autumn, but had livestock excluded from May–September and one silage cut taken. Ten similar plots were grazed throughout the growing season by livestock. Butterfly transect counts were conducted weekly from mid-April to mid-September 2005–2007.

A replicated, randomized, controlled study in 2002–2006 on four lowland farms in Devon and Somerset, UK (3) found that plots of intensively-managed grassland without autumn cattle grazing did not have a greater abundance or species richness of butterflies, or abundance of caterpillars, than plots which were grazed. On intensively managed silage plots which were not grazed in September, the abundance (1–3 individuals/transect) and species richness (1 species/transect) of butterflies, and the abundance of caterpillars (0–7 caterpillars/transect), was similar to that on silage plots with September grazing (butterfly abundance: 0–2 individuals/transect; richness: 0–1 species/transect; caterpillar abundance: 0–4 caterpillars/transect). In April 2002, six experimental plots (50 × 10 m) were established on permanent pastures (>5-years-old) on four farms. All plots were fertilized (225 kg nitrogen/ha, 22 kg phosphorus/ha, 55 kg potassium/ha) and cut twice/year to 5 cm in May and July. Three plots/farm were then grazed by cattle in September until the sward was 5–7 cm. The remaining plots were not grazed. From June–September 2003–2006, butterflies were surveyed once/month on a 50-m transect through the centre of each plot. In April, June, July and September 2003–2006, caterpillars were counted (but not identified) on two 10-m transects/plot using a sweep net (20 sweeps/transect).

A controlled study in 2002–2004 at an upland semi-natural grassland in the Scottish Borders, UK (4) found that a summer-grazed area had a higher abundance of caterpillars than an area with year-round grazing. A site which was only grazed in the summer had a higher abundance of caterpillars than a site which was grazed all year (data presented as statistical results). From autumn 2002, two large (>40 ha) plots were grazed by 3–4 sheep/ha: one during June–September only (49.7 ha), and the other year round (74.9 ha). Invertebrates were sampled using pitfall transects (9 traps, 2 m apart) at 15 locations/plot for four weeks during May–June 2004.

A replicated, paired, controlled study in 2009–2010 in two semi-natural grasslands in central France (5) found that plots which were not grazed during the peak flowering period had a similar number of butterflies and burnet moths to rotationally grazed plots. In plots where sheep were excluded in summer, the abundance of butterflies and burnet moths (17 individuals/plot) was not significantly different from in rotationally grazed plots (10 individuals/plot). Two grasslands were studied: one which had been extensively managed for 40 years, and one which had been fertilized and grazed at a higher stocking density. From 15 May–30 September 2009–2010, two 5,500-m^2 patches/grassland were grazed by five (extensive management history) or seven (intensive management history) 3-year-old ewes/patch. The patches were divided into four plots and sheep were grazed on rotation, spending seven days/plot before moving on. One plot was excluded from the rotation from 26 May–14 July during peak flowering. From June–July 2009–2010, butterflies and burnet moths were surveyed four times on one 30-m transect/plot.

A replicated, randomized, paired, controlled study in 2008–2012 on a farm in Berkshire, UK (6) found that grasslands established with flowering plants where cattle were removed for part of the summer had a greater abundance and species richness of pollinators (including butterflies) than grasslands grazed throughout summer. When sown with a seed mix including legumes or legumes and other non-woody, broadleaved plants (forbs), plots where cows were removed in the summer had a higher abundance (8–56 individuals/plot) and species richness (3–6 species/plot) than plots where cattle grazed throughout the summer (abundance: 3–49 individuals/plot; richness: 2–7 species/plot). In plots sown with grasses alone, pollinator abundance (0–3 individuals/plot) and species richness (0–2 species/plot) were lower regardless of grazing intensity. In spring 2008, forty-eight 875-m^2 plots were sown with one of three seed mixes: a "grass only" mix of five species (30 kg/ha, cost: €83/ha); a "grass and legume" mix of five grasses and seven agricultural legumes (34 kg/ha, €120/ha); or a "grass, legume and forb" mix of five grasses, seven legumes and six non-legume forbs (33.5 kg/ha, €190/ha). Half of the plots were lightly grazed (3 cows/ha, May and September–October) and half were more heavily grazed (3 cows/ha, May–October). In May, July and August 2009–2012, butterflies, bees (Apidae) and hoverflies (Syrphidae) were surveyed three times/year on two parallel 20 × 2 m transects/plot.

A review in 2015 of 126 studies in Europe (7) reported that reducing grazing intensity on grassland benefitted 41 out of 67 butterfly species of conservation concern. Results were not tested for statistical significance. The review reported that 44 studies found that reducing grazing intensity benefitted 41 butterfly species, but did not distinguish between using seasonal grazing and reducing stocking density. Grazing was most beneficial in autumn (September–November) and spring (April), but was potentially harmful in late spring to mid-summer (data not presented). See paper for information on individual species. Meadows were extensively grazed by different livestock and at different times, sometimes with rotational mowing. The review focussed on 67 butterfly species of conservation concern. The available information was biased towards studies in Northern and Western Europe.

(1) Haysom K.A., McCracken D.I., Roberts D.J. & Sotherton N.W. (2000) Grassland conservation headlands: a new approach to enhancing biodiversity on grazing land. Grazing Management: the Principles and Practice of Grazing, for Profit and Environmental Gain, within Temperate Grassland Systems: *Proceedings of the British Grassland Society Conference*, 29 February-2 March, 2000, Harrogate, UK, 159–160.
(2) Fraser M.D., Evans J.G., Davies D.W.R. & Vale J.E. (2008) Effect of sward type and management on butterfly numbers in the uplands. *Aspects of Applied Biology*, 85, 15–18.
(3) Potts S.G., Woodcock B.A., Roberts S.P.M., Tscheulin T., Pilgrim E.S., Brown V.K. & Tallowin J.R. (2009) Enhancing pollinator biodiversity in intensive grasslands. *Journal of Applied Ecology*, 46, 369–379.
(4) Cole L.J., Pollock M.L., Robertson D., Holland J.P., McCracken D.I. & Harrison W. (2010) The influence of fine-scale habitat heterogeneity on invertebrate assemblage structure in upland semi-natural grassland. *Agriculture, Ecosystems & Environment*, 136, 69-80.
(5) Scohier A., Ouin A., Farruggia A. & Dumont B. (2013) Is there a benefit of excluding sheep from pastures at flowering peak on flower-visiting insect diversity? *Journal of Insect Conservation*, 17, 287–294.
(6) Woodcock B.A., Savage J., Bullock J.M., Nowakowski M., Orr R., Tallowin J.R.B. & Pywell R.F. (2014) Enhancing floral resources for pollinators in productive agricultural grasslands. *Biological Conservation*, 171, 44–51.
(7) Bubová T., Vrabec V., Kulma M. & Nowicki P. (2015) Land management impacts on European butterflies of conservation concern: a review. *Journal of Insect Conservation*, 19, 805–821.

3.30. Reduce cutting frequency on grassland

- **Six studies** evaluated the effects on butterflies and moths of reducing cutting frequency on grassland. One study was in each of Slovakia[1], the Czech Republic[2], Hungary[3], the UK[4], Germany[5] and Italy[6].

COMMUNITY RESPONSE (3 STUDIES)

- **Richness/diversity (3 studies):** Two of three replicated studies (including one randomized, paired, controlled study and two site comparison studies) in the UK[4], Germany[5] and Italy[6] found that meadows cut once/year had a higher species richness of butterflies (along with other pollinators)[4] and moths[5] than meadows cut two or more times/year. The other study found that meadows cut one, two or three times/year all had a similar species richness of butterflies[6].

POPULATION RESPONSE (5 STUDIES)

- **Abundance (5 studies):** Three of five replicated studies (including two randomized, paired, controlled studies and three site comparison studies) in Slovakia[1], the Czech Republic[2], Hungary[3], the UK[4] and Italy[6] and found that meadows cut once/year had a similar abundance of all butterflies[6], and of meadow brown adults and caterpillars[1] and scarce large blue adults[3], to meadows cut two[1,3,6] or three[6] times/year. The other two studies found that meadows cut occasionally[2] or once/year[4] had a higher abundance of Scotch argus[2] and pollinators (including butterflies)[4] than intensively mown grasslands[2] and meadows cut twice/year[4].

BEHAVIOUR (0 STUDIES)

Background

Productive grasslands used for silage are intensively managed, with frequent cutting resulting in a short and uniform sward (Bubová *et al.* 2015). While mowing is important for maintaining open grassland, reducing cutting frequency allows some vegetation to grow taller, increasing structural complexity and floral diversity (Morris 2000), and this may provide more suitable habitat for some grassland butterflies and moths (e.g. Elligsen *et al.* 1997).

For studies on reducing cutting frequency alongside other reductions in management intensity, such as reduced chemical input, see "*Reduce management intensity on permanent grasslands (several interventions at once)*". For studies on removing grassland management entirely, see "*Cease mowing on grassland to allow early succession*". For studies on increasing grassland management, see "*Increase grazing intensity or cutting frequency on grassland*".

Elligsen H., Beinlich B. & Plachter H. (1997) Effects of large-scale cattle grazing on populations of *Coenonympha glycerion* and *Lasiommata megera* (Lepidoptera: Satyridae). *Journal of Insect Conservation*, 1, 13–23.

Morris M.G. (2000) The effects of structure and its dynamics on the ecology and conservation of arthropods in British grasslands. *Biological Conservation*, 95, 129–142.

Bubová T., Vrabec V., Kulma M. & Nowicki P. (2015) Land management impacts on European butterflies of conservation concern: a review. *Journal of Insect Conservation*, 19, 805–821.

A replicated, site comparison study in 2003–2006 in 16 hay meadows in central Slovakia (1) found that meadows which were mown once/year had a similar abundance of meadow brown *Maniola jurtina* butterflies and caterpillars to meadows mown twice/year, but a higher abundance than abandoned, unmown meadows. In meadows mown once/year, the abundance of both meadow brown adults (12–81 individuals/transect) and caterpillars (10–26 individuals/transect) was not significantly different from meadows mown twice/year (adults: 14–45; caterpillars: 1–8 individuals/transect). However, meadows mown once/year had a higher abundance of both adults and caterpillars than abandoned, unmown meadows (adults: 6–33; caterpillars: 1–2 individuals/transect). Four meadows at the edge of oak-hornbeam forests and four open meadows were mown once/year in late June or July. Four further meadows were mown twice/year in late May–early June and from late July–September, and four abandoned meadows had not been mown for 15 years. From June–August 2003–2005, adult butterflies were counted 4–7 times/year on seven 50-m transects in each habitat type. In May 2005 and 2006, caterpillars were surveyed at night, 1–4 times/year, by sweeping vegetation with a net along ten 50-m transects in each habitat type (60 sweeps/transect).

A replicated, site comparison study in 2007 in a grassland and woodland reserve in the Czech Republic (2) found that occasionally mown grasslands had a higher abundance of Scotch argus *Erebia aethiops* than intensively mown grasslands. On occasionally mown grasslands, the abundance of Scotch argus males (9 individuals/ha) and females (5 individuals/ha) was higher than on intensively mown grasslands (males: 3; females: 2 individuals/ha). However, the abundance of Scotch argus males (19 individuals/ha) and females (13 individuals/ha) was highest on temporarily abandoned grasslands, and similar on grazed grasslands (males: 7; females: 4 individuals/ha) to occasionally mown grasslands. Within a 55-ha reserve, 27 grasslands (128–6,072 m^2) were managed by either occasional mowing, intensive mowing, or sheep and goat grazing, or were temporarily abandoned. On 33 days from July–August 2007, butterflies were caught, individually marked, and recaptured at each site.

A replicated, randomized, paired, controlled study in 2007–2010 in four meadows in Őrség National Park, Hungary (3) found that grassland mown once/year had a similar abundance of scarce large blue butterflies *Phengaris teleius* to grassland mown twice/year, but a higher abundance than abandoned, unmown plots. Three years after management began, the number of scarce large blue butterflies in plots mown once/year in May (0.86 individuals/plot/day) or September (0.94 individuals/plot/day) was similar to the number in plots mown twice/year (0.70 individuals/plot/day). All mown plots had more butterflies than abandoned plots (0.28 individuals/plot/day). In May 2007, four meadows were each divided into four equal-size plots, and one of four management regimes was randomly applied to each plot. Three plots/meadow were mown for four years, either once/year in May, once/year in September, or twice/year in May and September, all with cuttings removed. The fourth plot in each meadow was abandoned (not mown). In July 2007 and 2010, butterflies were surveyed for five minutes, 15–20 times/year, in each of three or four 20 × 20 m squares/plot.

A replicated, randomized, paired, controlled study in 2008–2012 on a farm in Berkshire, UK (4) found that grasslands established with flowering plants which were cut once/year had a greater abundance and species richness of pollinators (including butterflies) than grasslands cut twice/year. When sown with a seed mix including legumes or legumes and other non-woody, broadleaved plants (forbs), plots cut once/year had a higher abundance (8–91 individuals/plot) and species richness (3–8 species/plot) of pollinators than plots cut twice/year (abundance: 6–52 individuals/plot; richness: 3–6 species/plot). In plots sown with grasses alone, pollinator abundance (0–3 individuals/plot) and species richness (0–2 species/plot) were lower regardless of cutting frequency. In spring 2008, forty-eight 875-m^2 plots were sown with one of three seed mixes: a “grass only” mix of five species (30 kg/ha, cost: €83/ha); a “grass and legume” mix of five grasses and seven agricultural legumes (34 kg/ha, €120/ha); or a “grass, legume and forb” mix of five grasses, seven legumes and six non-legume forbs (33.5 kg/ha, €190/ha). Half of the plots were cut to 10 cm once/year in May, and half were cut to 10 cm twice/year in May and August. In May, July and August 2009–2012, butterflies, bees (Apidae) and hoverflies (Syrphidae) were surveyed three times/year on two parallel 20 × 2 m transects/plot.

A replicated, site comparison study in 2014 in 26 grasslands in Germany (5) reported that grasslands managed with reduced cutting frequency (sometimes also grazed) supported more moth species than more frequently mown grasslands. Results were not tested for statistical significance. Grasslands managed with less frequent cutting had more moth species (99 species) than grasslands managed with more frequent cutting (79 species). From 2006, across three regions, nine grasslands were managed by mowing (often with nitrogen fertilization) at low (0–1 cuts/year) or high frequency (2 cuts/year), nine were managed by grazing (by cattle, sheep or horses at 26–520 livestock units/ha/year), and eight were mown and grazed (1–2 cuts/year; 76–163 livestock units/ha/year). Moths were collected once/month from nine grasslands in each of two regions (May–August 2014), and from eight grasslands in one region (June–July 2014). Each night, a 12 V actinic and black-light trap were placed in the centre of each of three grasslands for 138–317 minutes/night.

A replicated, site comparison study in 2014–2015 in a mixed farming region in Lombardy, Italy (6) found that meadows cut less frequently had a similar abundance and species richness of butterflies to more frequently cut meadows, but a lower abundance and species richness compared to uncut meadows. The abundance and species richness of butterflies were similar in meadows cut once, twice or three times/summer (data presented as model results). However, both the abundance and species richness of butterflies were lower on meadows which were cut at least once than on meadows left uncut (data presented as model results). See paper for details on individual species groups. In 2014 and 2015, meadows within an arable landscape were cut 0–3 times between April and September each year. From April–September 2014–2015, butterflies were surveyed along 44 transects, divided into 8–26 × 50-m sections. In 2014, thirty transects were surveyed once/month, and in 2015 fourteen different transects were surveyed twice/month. Only transect sections which passed through meadows were included (number not specified).

(1) Kulfan J., Strbova E. & Zach P. (2012) Effect of vegetation and management on occurrence of larvae and adults of generalist *Maniola jurtina* L. (Lepidoptera) in meadow habitats. *Polish Journal of Ecology*, 60, 601–609.
(2) Slamova I., Klecka J. & Konvicka M. (2013) Woodland and grassland mosaic from a butterfly perspective: habitat use by *Erebia aethiops* (Lepidoptera: Satyridae). *Insect Conservation and Diversity*, 6(3), 243–254.
(3) Kőrösi Á., Szentirmai I., Batáry P., Kövér S., Örvössy N. & Peregovits L. (2014) Effects of timing and frequency of mowing on the threatened scarce large blue butterfly – A fine-scale experiment. *Agriculture, Ecosystems & Environment*, 196, 24–33.
(4) Woodcock B.A., Savage J., Bullock J.M., Nowakowski M., Orr R., Tallowin J.R.B. & Pywell R.F. (2014) Enhancing floral resources for pollinators in productive agricultural grasslands. *Biological Conservation*, 171, 44–51.
(5) Mangels J., Fiedler K., Schneider F.D. & Bluthgen N. (2017) Diversity and trait composition of moths respond to land-use intensification in grasslands: generalists replace specialists. *Biodiversity and Conservation*, 26, 3385–3405.
(6) Luppi M., Dondina O., Orioli V. & Bani L. (2018) Local and landscape drivers of butterfly richness and abundance in a human-dominated area. *Agriculture, Ecosystems & Environment*, 254, 138–148.

3.31. Increase grazing intensity or cutting frequency on grassland

- **Five studies** evaluated the effects on butterflies and moths of increasing grazing intensity or cutting frequency on grassland. Two studies were in Germany[1,2], and one study was in each of the Czech Republic[3], the USA[4] and Israel[5].

COMMUNITY RESPONSE (1 STUDY)

- **Richness/diversity (1 study):** One replicated, site comparison study in Germany[2] found that at intensively grazed sites species richness of adult butterflies and burnet moths was lower than at sites with low or no grazing, but caterpillar richness was lower in intensively grazed and low grazing sites than in sites with no grazing.

POPULATION RESPONSE (5 STUDIES)

- **Abundance (5 studies):** Four studies (including one replicated, randomized, paired, controlled study, one replicated, site comparison study, and two site comparison studies) in Germany[1,2], the USA[4] and Israel[5] found that grasslands managed with more intensive grazing[1,2,5] or with grazing in addition to rotational burning[4] had a lower abundance of all adult butterflies[1,2], adult burnet moths[2], adult regal fritillaries[4] and spring webworm caterpillar nests[5] than ungrazed grasslands[2], lightly[2] or moderately grazed grasslands[1,5] or rotationally burned grasslands with occasional light grazing[4]. However, one of these studies[2] found that, while intensively grazed sites had lower butterfly and burnet moth caterpillar abundance than ungrazed sites, there was no difference in caterpillar abundance between ungrazed and lightly grazed sites. One before-and-after study in the Czech Republic[3] reported that after increasing the cutting frequency on traditional meadows (under agri-environment scheme prescriptions) the abundance of Danube clouded yellow decreased.

BEHAVIOUR (0 STUDIES)

Background

Although intensive grazing or regular mowing of grasslands is often seen as a threat to butterflies and moths, increasing management intensity can be an important option for controlling dominant plant species and encouraging beneficial plants, such as caterpillar host plants. For example, Goodenough & Sharp (2016) found that increasing autumn and winter grazing intensity led to an increase in the abundance of *Primula* species, the sole food plant of the Duke of Burgundy *Hamearis lucina*. Therefore, increasing grazing intensity could, in some cases, be beneficial for butterflies and moths. Alternatively, increased cutting or grazing frequency may be applied to a landscape by the introduction of agri-environment scheme (AES) prescriptions to land previously managed at very low intensity (e.g. Konvicka *et al.* 2008).

For studies on the effects of reducing management intensity, see "*Reduce grazing intensity on grassland by reducing stocking density*", "*Reduce grazing intensity on grassland by seasonal removal of livestock*", "*Reduce cutting frequency on grassland*" and "*Reduce management intensity on permanent grasslands (several interventions at once)*".

Goodenough A.E. & Sharp M.H. (2016) Managing calcareous grassland for the declining Duke of Burgundy *Hamearis lucina* butterfly: effects of grazing management on Primula host plants. *Journal of Insect Conservation*, 20, 1087–1098.

Konvicka M., Benes J., Cizek O., Kopecek F., Konvicka O. & Vitaz L. (2008) How too much care kills species: Grassland reserves, agri-environmental schemes and extinction of *Colias myrmidone* (Lepidoptera: Pieridae) from its former stronghold. *Journal of Insect Conservation*, 12, 519–525.

A site comparison study in 1994 in 19 traditional hay meadows in Bavaria, Germany (1) found that the abundance of all butterflies, and of threatened species only, was lower in a more intensively grazed meadow than in extensively mown or grazed meadows. A meadow which was grazed throughout the summer had fewer butterflies of all species, and of threatened species alone, than meadows grazed for a few weeks/year or mown once/year (data not presented). However, the extensively managed meadows had a higher abundance and species richness of butterflies than three abandoned meadows. Nineteen meadows, which had been managed in the same way for at least 5–20 years, were compared. One former hay meadow was grazed by sheep throughout the summer (intensive management), nine meadows were extensively grazed with sheep, cattle or horses for a few weeks each summer, six traditionally managed hay meadows were mown once/year in July or early August, and three meadows were not managed (abandoned). From June–August 1994, butterflies were surveyed along a fixed transect five times in each meadow.

A replicated, site comparison study in 1996 in 18 grasslands in Schleswig-Holstein, Germany (2) found that species richness and abundance of adult butterflies and burnet moths at intensively grazed sites was lower than at sites with low or no grazing, but the responses of caterpillar richness and abundance to grazing intensity were mixed. Butterfly species richness and abundance were lower at intensively grazed sites (average richness = 2; average abundance = 1) than low intensity grazing (average richness = 4; average abundance = 8) and ungrazed (average richness = 7; average abundance = 21) sites. Caterpillar species richness was statistically similar in intensively grazed (average = 2) and low intensity grazing (average = 4) sites, but lower in both than in ungrazed sites (average = 7). Caterpillar abundance was statistically similar between intensively grazed (average = 1) and low intensity grazed (average = 9) sites, but intensively grazed sites had lower abundance than ungrazed sites (average = 12). Intensively grazed sites (6) had an average stocking density of 1.4 cattle/ha annually from May–November, low intensity grazed sites (6) had an average density of 5.5 cattle/ha annually from April–October, and ungrazed sites (6) had not been stocked for 5–10 years. From May–September 1996, at each site separate transect walks were conducted once monthly for adult butterflies and burnet moths (45-minute transects) and caterpillars (45-minute transects in grazed sites and 60-minutes in ungrazed sites).

A before-and-after study in 1980–2006 in a forest-steppe landscape in the White Carpathians, Czech Republic (3) reported that increasing cutting frequency on grasslands decreased the abundance of Danube clouded yellow *Colias myrmidone*. Results were not tested for statistical significance. In the first year of increased cutting, only 11 observations of 26 individual Danube clouded yellows were recorded, compared to 2,345 records in the eight years immediately prior to increased cutting, and 3,838 records in the previous 15 years. In the second and third years of increased cutting, only five and two individuals were recorded, respectively, and these observations were from abandoned pasture outside of the reserves. From the 1970s to the mid-1990s, infrequent mowing and scrub removal were used to prevent succession on 2,457 ha of grassland reserves. From the mid-1990s to 2004, reserves were mown uniformly using national funding, and since 2004 this was increased to two cuts/year on all but 355 ha of grassland. Historical butterfly records were compiled for 1980–1994 and 1995–2002, and butterflies were recorded 3–6 times/year on systematic surveys at prescribed sites.

A replicated, randomized, paired, controlled study in 2005–2007 in four tallgrass prairies in Missouri, USA (4) found that increasing cattle grazing reduced the abundance of regal fritillary *Speyeria idalia*, particularly after recent burning.

The number of regal fritillaries in grazed prairie (0–14 individuals/ha) was lower than in ungrazed prairie (1–25 individuals/ha) throughout the summer. However, the difference was greatest in prairies which had been burned earlier the same year (grazed: 0–2 individuals/ha; ungrazed: 3–22 individuals/ha). From 2000–2004, four remnant prairies were burned on rotation and occasionally hayed or lightly grazed. In 2005, half of each prairie was randomly assigned to one of two treatments: grazing and rotational burning, or rotational burning only. Each half was sub-divided into three plots (20–34 ha), which were randomly assigned to be burned in either March 2005, 2006 or 2007. The grazed sites were stocked with cattle (2.2 ha/animal unit) annually from April–August. From June–July 2006–2007, butterflies were surveyed three times/year on a transect through each plot.

A replicated, paired, site comparison study in 2014–2015 on a farm in Galilee, Israel (5) found that heavily grazed paddocks had fewer spring webworm *Ocnogyna loewii* caterpillar nests than moderately grazed paddocks, but grazed paddocks had more nests and solitary individuals than ungrazed paddocks. After 20 years of grazing, the number of caterpillar nests in heavily grazed paddocks (transects: 2.8; plots: 2.1–8.5 nests) was lower than in moderately grazed paddocks (transects: 10.0; plots: 7.1–14.1 nests), but higher than in ungrazed paddocks (transects: 1.1; plots: 0.5–6.1 nests). The number of older, solitary caterpillars was higher in heavily (transects: 23.5–77.0; plots: 2.7 individuals) or moderately (transects: 32.3–36.5; plots: 3.0 individuals) grazed paddocks than in ungrazed paddocks (transects: 6.4–14.2; plots: 1.5 individuals). From 1994, a 1,450-ha farm was divided into paddocks managed permanently by heavy (1.1 cows/ha) or moderate (0.55 cows/ha) grazing, or left ungrazed. In January 2015 and March 2014–2015, caterpillar nests (January) and individuals (March) were counted once/year on three 20-m-long transects in each of two heavily grazed and two moderately grazed paddocks (~27 ha) and in four ungrazed paddocks (0.5–4 ha). Within each of the four grazed paddocks, cattle were excluded from five fenced, 10 × 10 m plots for >10 years. In January 2014–2015, all caterpillar nests were counted in each fenced, ungrazed plot and a paired, grazed plot 3 m away in the surrounding paddock. In March 2015, individual caterpillars were counted in three 30 × 30 cm sub-plots in each grazed and ungrazed plot.

(1) Dolek M. & Geyer A. (1997) Influence of management on butterflies of rare grassland ecosystems in Germany. *Journal of Insect Conservation*, 1, 125–130.

(2) Kruess A. and Tscharntke T. (2002) Grazing intensity and the diversity of grasshoppers, butterflies, and trap-nesting bees and wasps. *Conservation Biology*, 16(6), 1570–1580.

(3) Konvicka M., Benes J., Cizek O., Kopecek F., Konvicka O. & Vitaz L. (2008) How too much care kills species: Grassland reserves, agri-environmental schemes and extinction of *Colias myrmidone* (Lepidoptera: Pieridae) from its former stronghold. *Journal of Insect Conservation*, 12, 519–525.

(4) Moranz R.A., Fuhlendorf S.D. & Engle D.M. (2014) Making sense of a prairie butterfly paradox: The effects of grazing, time since fire, and sampling period on regal fritillary abundance. *Biological Conservation*, 173, 32–41.

(5) Berman T.S., Ben-Ari M., Henkin Z. & Inbar M. (2018) Immediate and long-term facilitative effects of cattle grazing on a polyphagous caterpillar. *Agriculture, Ecosystems & Environment*, 261, 45–53.

3.32. Change type of livestock grazing

- **Four studies** evaluated the effects on butterflies and moths of changing the type of livestock grazing. One study was in each of the UK[1], Sweden[2], China[3] and France[4].

COMMUNITY RESPONSE (2 STUDIES)

- **Richness/diversity (2 studies):** Two replicated studies (including one paired, site comparison study and one randomized, controlled study) in Sweden[2] and France[4] found that semi-natural grasslands grazed by cattle[2,4] or horses[2] had a greater species richness of butterflies and burnet moths than grasslands grazed by sheep.

POPULATION RESPONSE (2 STUDIES)

- **Abundance (2 studies):** One of two replicated, randomized, controlled studies (including one paired study) in China[3] and France[4] found that semi-natural grasslands grazed by cattle had a higher abundance of butterflies and burnet moths than grasslands grazed by sheep[4]. The other study found that meadow steppe grazed by cattle, goats or sheep for 1–5 years had a similar abundance of butterflies and moths[3].

BEHAVIOUR (1 STUDY)

- **Use (1 study):** One replicated, site comparison study in the UK[1] found that a similar proportion of fen meadows were occupied by marsh fritillary caterpillars whether they were managed by cattle, horse or sheep grazing.

Background

Livestock prefer to eat different plants, and graze at different heights or in different patterns. For example, sheep graze to a uniform height, while cattle leave heavily trampled areas and eat grass in clumps, leaving patches of taller vegetation (Schultz *et al.* 2008). These grazing patterns encourage different vegetation communities to develop, with different plants dominating. Therefore, changing the type of livestock used to graze grassland may create differences in the butterfly and moth community, with individual species preferring the landscape created by particular grazers.

This action includes studies comparing the use of different types of livestock alone. For studies comparing the use of single and multiple livestock types, see "*Use mixed stocking*".

Schultz C.B., Russell C. & Wynn L. (2008) Restoration, reintroduction, and captive propagation for at-risk butterflies: A review of British and American conservation efforts. *Israel Journal of Ecology & Evolution*, 54, 41–61.

A replicated, site comparison study in 1993 in 34 fen meadows in Glamorgan, UK (1) found that changing the type of livestock grazing did not affect marsh fritillary *Eurodryas aurinia* population size. There was no significant difference in the proportion of cattle-grazed (3/9), horse-grazed (2/6), sheep-grazed (0/2), unmanaged (4/8), burned (5/8 sites), and mown (0/1) sites that had >20 caterpillar webs recorded. However, the three largest populations (>200 caterpillar webs) were on sites burned in early spring. Caterpillar webs were present on 28/34 sites where adults had been recorded in May/June. In 1993, nine grasslands were cattle-grazed, six were horse-grazed, two were sheep-grazed, eight were unmanaged, eight were burned, and one was mown. Sites were separated by >1 km of unoccupied grassland, or >0.5 km of unsuitable habitat. From late August–mid-October 1993, caterpillar webs were surveyed on 34 fen grasslands. On sites <2 ha, all devil's bit scabious *Succisa pratensis* were searched in 2-m-wide parallel strips until the whole area had been searched. On larger sites, 2-m-wide strips at 10-m intervals were searched, and areas around caterpillar webs were then searched comprehensively.

A replicated, paired, site comparison study in 2003–2004 in 36 semi-natural grasslands near Lund, Sweden (2) found that grasslands grazed by cattle or horses had a greater species richness of butterflies and burnet moths than grasslands grazed by sheep. Sites had a greater species richness of butterflies and burnet moths if they were currently grazed by horses (13 species) or cattle (12 species) compared to sites grazed by sheep (7 species), and were similar to sites with no grazing (12 species). From 1999–2003, twelve abandoned, semi-natural grasslands were restored by clearing trees and shrubs, erecting fences, and re-introducing grazing animals. Butterflies and burnet moths were surveyed using transects (150 m/ha) six or seven times in May–August 2003 or June–August 2004 on 12 restored grasslands, 12 continuously grazed semi-natural grasslands and 12 abandoned grasslands. Under current management, 12 sites were cattle grazed, six were horse grazed, eight were sheep grazed and 10 had no grazing.

A replicated, randomized, paired, controlled study in 2007–2008 in a meadow steppe grassland in Jilin Province, China (3) found that plots grazed by cattle, goats or sheep all had a similar abundance of butterflies and moths, but the abundance was lower than on ungrazed plots. After a year and a half of grazing, the abundance of butterflies and moths was similar on plots grazed by cattle (2–7 individuals/plot), goats (3–7 individuals/plot) or sheep (3–6 individuals/plot), but was lower on all grazed plots than on ungrazed plots (6–22 individuals/plot). Nine 0.3-ha blocks were each divided into four fenced, 0.05-ha plots, 18–20 m apart, to which four grazing treatments were randomly assigned. From July 2007 and 2008, plots were either grazed by two cattle, eight goats, or eight sheep, or left ungrazed. Grazing was conducted for two hours each morning and evening, until 60% of forage was removed (10–15 days/month, number of months not given). From July–October 2008, insects were surveyed four times by walking two 25-m-long transects/plot, twice/day, and taking 15 sweeps/transect through the vegetation with a 40-cm diameter net. All adult insects were identified to species.

A replicated, randomized, controlled study in 2011–2013 in semi-natural mountain pastures in Massif Central, France (4) found that plots grazed by cattle had a higher abundance and species richness of butterflies and burnet moths than plots grazed by sheep. In plots grazed by cattle, the abundance (37 individuals/plot) and species richness (9.1 species/plot) of butterflies and moths was higher than in plots grazed by sheep (abundance: 22 individuals/plot; richness: 6.4 species/plot). From 1992–2011, pastures were grazed extensively by cattle without fertilization. From May–October 2011–2013, six 3.6-ha plots were each grazed by seven Charolais cattle (heifers), and six 0.6-ha plots were each grazed by seven female Limousine sheep (both 1.75 livestock units/ha). Three plots in each group were grazed continuously, and three were sub-divided into four subplots each grazed for 35 days/year. One subplot in each plot was not grazed for 63 days from early June–early August each year. From early July–early August 2011–2013, butterflies and burnet moths were surveyed twice/year on four 50-m fixed transects/plot (one in each rotational subplot).

(1) Lewis O.T. & Hurford C. (1997) Assessing the status of the marsh fritillary butterfly (*Eurodryas aurinia*): an example from Glamorgan, UK. *Journal of Insect Conservation*, 1, 159–166.
(2) Öckinger E., Eriksson A.K. & Smith H.G. (2006) Effects of grassland abandonment, restoration and management on butterflies and vascular plants. *Biological Conservation*, 133, 291–300.
(3) Zhu H., Wang D., Guo Q., Liu J. & Wang L. (2015) Interactive effects of large herbivores and plant diversity on insect abundance in a meadow steppe in China. *Agriculture, Ecosystems & Environment*, 212, 245–252.
(4) Ravetto Enri S., Probo, M., Farruggia A., Lanore L., Blanchetete A. & Dumont B. (2017) A biodiversity-friendly rotational grazing system enhancing flower-visiting insect assemblages while maintaining animal and grassland productivity. *Agriculture, Ecosystems & Environment*, 241, 1–10.

3.33. Use mixed stocking

- **Three studies** evaluated the effects on butterflies and moths of grazing with mixed livestock. All three studies were in the UK[1–3] and compared grazing with sheep and cattle to sheep only.

COMMUNITY RESPONSE (1 STUDY)

- **Richness/diversity (1 study):** One replicated, randomized, controlled study in the UK[3] found that grassland plots grazed at low intensity with sheep and cattle had fewer moth species than plots grazed at low intensity with sheep only.

POPULATION RESPONSE (3 STUDIES)

- **Abundance (3 studies):** Two of three replicated studies (including two randomized, controlled studies and one paired, site comparison study) in the UK[1–3] found that grassland plots grazed at low intensity with sheep and cattle had a similar abundance of moth caterpillars[2] and small invertebrates including caterpillars[1] to plots grazed at low intensity with sheep only. One of these studies found that in plots grazed at high intensity, the abundance of small invertebrates including caterpillars was lower in plots with sheep and cattle than in sheep only plots[1]. The other study found that grassland plots grazed at low intensity with sheep and cattle had a lower abundance of adult moths than plots grazed at low intensity with sheep only[3].

BEHAVIOUR (0 STUDIES)

Background

Livestock prefer to eat different plants, and graze at different heights or in different patterns. For example, sheep graze to a uniform height, while cattle leave heavily trampled areas and eat grass in clumps, leaving patches of taller vegetation (Schultz *et al.* 2008). These grazing patterns encourage different vegetation communities to develop, with different plants dominating. Therefore, grazing with a mix of livestock, rather than just one type, may encourage a more diverse community of butterflies and moths, with individual species preferring the patches created by particular grazers.

This action includes studies comparing the use of multiple livestock types with single types of livestock. For studies comparing the use of different single types of livestock, see "*Change type of livestock grazing*".

Schultz C.B., Russell C. & Wynn L. (2008) Restoration, reintroduction, and captive propagation for at-risk butterflies: A review of British and American conservation efforts. *Israel Journal of Ecology & Evolution*, 54, 41–61.

A replicated, paired, site comparison study in 1989–1993 at an upland grassland in Scotland, UK (1) found that plots grazed with sheep and cattle had a lower abundance of small invertebrates (including caterpillars) than plots grazed by sheep alone when grazing intensity was high, but there was no difference when grazing intensity was reduced. Heavily grazed plots with both sheep and cattle had fewer invertebrates (4–15 individuals) than plots grazed at high intensity by sheep alone (4–31 individuals). However, when grazing intensity was reduced there was no significant difference in the number of invertebrates between plots grazed by sheep and cattle (9–35 individuals) and sheep-only plots (6–39 individuals). Invertebrate abundance was highest at a fifth plot that was ungrazed (70–223 individuals). From 1989–1991, four experimental grazing plots (1–3 ha) were established. From May–October each year, the number of sheep/plot was adjusted weekly in order to maintain different sward heights (4.5 and 6.5 cm). From June–August, six yearling cattle were also grazed on two of the plots. From 1992, a fifth plot was left ungrazed. In August 1993, invertebrates were sampled from both tussocks and low sward at each of six randomly selected points/plot using a d-vac suction sampler.

A replicated, randomized, controlled study in 2003–2005 on an upland grassland in Perthshire, UK (2, same experimental set-up as 3) found that mixed stocking did not affect the abundance of moth caterpillars under low intensity grazing. After 18 months of grazing, there was no significant difference in the number of caterpillars on lightly grazed mixed stocking (2.4 individuals/plot), sheep-only (1.9 individuals/plot), ungrazed (2.8 individuals/plot) and commercially grazed plots (2.3 individuals/plot). After 30 months, the number of caterpillars remained similar in the mixed stocking (2.4 individuals/plot) and sheep-only (1.9 individuals/plot) plots, but this was lower than in the ungrazed plots (4.9 individuals/plot) and higher than in the commercially grazed plots (0.5 individuals/plot). From January 2003, three grazing regimes (mixed: sheep and cattle equivalent to 0.9 ewes/ha; sheep-only: sheep at 0.9 ewes/ha; commercial: sheep at 2.7 ewes/ha) and an ungrazed treatment were replicated six times each in twenty-four 3.3-ha plots (in three pairs of adjacent blocks). Caterpillars were sampled by sweep net in 2003–2005.

A replicated, randomized, controlled study in 2003–2007 on an upland estate in Scotland, UK (3, same experimental set-up as 2) found that plots grazed with sheep and cattle at low density had a lower abundance of moths and fewer moth species than plots grazed with sheep only at low density, but more moths than plots grazed by sheep at commercial stocking densities. On mixed grazing plots, both moth abundance (42 individuals/night) and species richness (11.3 species/night) were lower than on sheep-only plots grazed at the same low density (abundance: 52 individuals/night; richness: 12.3 species/night) and ungrazed plots (abundance: 48 individuals/night; richness: 13.2 species/night), but higher than on sheep-only plots grazed at commercial densities (abundance: 34 individuals/night; richness: 10.6 species/night). In January 2003, one of four grazing treatments was established on each of 24 plots (3.3 ha each) on a grazed acid grassland upland estate. The treatments were: low density mixed grazing (2 sheep/plot plus two cows and calves for 4 weeks in autumn); low density sheep grazing (3 sheep/plot); commercial high density sheep grazing (9 sheep/plot); ungrazed control. Moths were sampled between June and October 2007 using four 15 W light traps placed randomly within plots of each treatment, for six or seven sample nights/plot.

(1) Dennis P., Young M.R. & Gordon I.J. (1998) Distribution and abundance of small insects and arachnids in relation to structural heterogeneity of grazed, indigenous grasslands. *Ecological Entomology*, 23, 253–264.
(2) Dennis P., Skartveit J., McCracken D.I., Pakeman R.J., Beaton K., Kunaver A. & Evans D.M. (2008) The effects of livestock grazing on foliar arthropods associated with bird diet in upland grasslands of Scotland. *Journal of Applied Ecology*, 45, 279–287.
(3) Littlewood N.A. (2008) Grazing impacts on moth diversity and abundance on a Scottish upland estate. *Insect Conservation and Diversity*, 1, 151–160.

3.34. Use rotational grazing

- **Six studies** evaluated the effects on butterflies and moths of using rotational grazing. Three studies were in France[2,3,5], two were in the USA[1,6] and one was in the UK[4].

COMMUNITY RESPONSE (5 STUDIES)

- **Community composition (1 study):** One replicated, site comparison study in the USA[6] found that rotational, cattle-grazed grasslands had a similar butterfly community to continuously grazed or patch-burned grasslands.
- **Richness/diversity (5 studies):** Two of four replicated studies (including one randomized, controlled study, two controlled studies and one site comparison study) in France[2,3,5] and the USA[6] found that rotational cattle-[5,6] and sheep-grazed[5] grasslands had a greater species richness of butterflies[5,6] and burnet moths[5] than continuously grazed[5,6] or patch-burned[6] grassland. Another of these studies found that rotationally sheep-grazed grassland had a similar species richness of butterflies and burnet moths to continuously grazed grassland[3]. The other study found that rotational cattle-grazed pastures had a greater species richness of butterflies than constantly grazed pastures but only at a high, not low, stocking density[2]. One replicated, site comparison study in the USA[1] found that rotationally managed grasslands, including some rotationally grazed grasslands, which were last managed longer ago had a higher species richness of butterflies than more recently managed grasslands.

POPULATION RESPONSE (6 STUDIES)

- **Abundance (6 studies):** Two of four replicated, controlled studies (including two randomized studies and one paired study) in France[2,3,5] and the UK[4] found that rotational cattle-[4,5] and sheep-grazed[5] grassland had a higher abundance of butterflies and burnet moths[5] and caterpillars (along with other invertebrates)[4] than continuously grazed grasslands. However, one of these studies only found this in the first of three years of management[4]. Another of these studies found that rotationally sheep-grazed grassland had a similar abundance of butterflies and burnet moths to continuously grazed grassland[3]. The other study found that rotational cattle-grazed pastures had a higher abundance of butterflies than constantly grazed pastures but only at a high, not low stocking density[2]. One replicated, site comparison study in the USA[6] found that the abundance of two species was higher, two species were lower and the other five species did not differ in rotationally cattle-grazed grasslands compared to continuously grazed or patch-burned grasslands. One replicated, site comparison study in the USA[1] found that rotationally managed grasslands, including some rotationally grazed grasslands, which were last managed longer ago had a higher abundance of butterflies than more recently managed grasslands.

BEHAVIOUR (0 STUDIES)

Background

Many butterfly species rely on transitional grassland habitats, where continuous management (often by grazing) results in a grass sward which is too short, or prevents the growth of their host plant, but complete abandonment leads to the sward becoming too long or the host plant being outcompeted (e.g. Eichel & Fartmann 2008). Rotational grazing, where livestock are moved between different areas of a site throughout the year, is one option for creating this kind of intermediate habitat, as well as generating a mosaic of more or less recently grazed areas on a larger scale. For other rotational management options, see "*Use rotational mowing*", "*Reduce grazing intensity on grassland by seasonal removal of livestock*" and "*Natural system modifications – Use rotational burning*".

Eichel S. & Fartmann T. (2008) Management of calcareous grasslands for Nickerl's fritillary (*Melitaea aurelia*) has to consider habitat requirements of the immature stages, isolation, and patch area. *Journal of Insect Conservation*, 12, 677–688.

A replicated, site comparison study in 1990–1997 in 105 tallgrass prairies in Illinois, Iowa, Minnesota, Missouri, North Dakota and Wisconsin, USA (1) found that rotationally managed prairies (grazed, hayed or burned) which were last managed longer ago had a higher abundance and species richness of specialist and grassland butterflies than more recently managed prairies. All data were presented as models results. Of 105 prairies (1.2–2,024 ha), seven areas within the Sheyenne National Grassland, North Dakota, were managed by rotational grazing (0.3–0.6 animal use months/ha/year), 77 prairies were managed by rotational burning (every 2–5 years) in the cool-season (of which 24 were also hayed or mown), and 27 were managed by haying, mostly on a two-year rotation. From May–September 1990–1997, butterflies were surveyed on parallel transects (5–10 m apart) at each site. Most sites were surveyed more than once/year, and in >1 year. Species were classified as "specialists" (of native plants), "grassland" (occurring widely in open habitat) and "generalist" (occurring in a range of habitats).

A replicated, randomized, controlled study in 2005–2008 in six pastures in Auvergne-Rhône-Alpes, France (2) found that, at high, but not low, stocking density, pastures cattle-grazed in rotation with one area left ungrazed for two months had higher butterfly species richness and abundance than constantly stocked areas. At high cattle stocking density, rotational pastures had higher butterfly species richness (7) and abundance (22) than constantly stocked pastures (richness: 4; abundance: 8), but at low stocking density there was no difference between rotational (richness: 6; abundance: 17) or constant pastures (richness: 5; abundance: 13). Within rotationally grazed pastures, at both high and low stocking the ungrazed sub-plot had higher butterfly species richness (4–5) and abundance (10–13) than three grazed sub-plots (richness: 2–4; abundance: 3–5). Within an 80-ha mountain pasture, two grazing treatments (each replicated three times) were compared: cows grazing on rotation around four sub-plots, with one plot being left ungrazed early June–early August, and constant grazing across the whole plot. Plots were grazed at a high stocking rate (1.6 livestock units/ha) from late May–late September 2005–2006 and at a low rate (1.2 livestock units/ha) from late May–mid- or late October 2007–2008. Butterflies and burnet moths were counted twice annually along 50-m walking transects in July and/or August. There was one transect/rotational sub-plot and three transects overall/constant grazing plot.

A replicated, controlled study in 2009–2010 in two semi-natural grasslands in central France (3) found that rotationally grazed plots had a similar abundance and species richness of butterflies and burnet moths to continuously grazed plots. In rotationally grazed plots, the abundance (15 individuals/plot) and species richness (7 species/plot) of butterflies and burnet moths was not significantly different from in continuously grazed plots (abundance: 15 individuals/plot; richness: 8 species/plot). Two grasslands were studied: one which had been extensively managed for 40 years, and one which had been fertilized and grazed at a higher stocking density. From 15 May–30 September 2009–2010, four 5,500-m^2 plots/grassland were grazed by five (extensive management history) or seven (intensive management history) 3-year-old ewes/plot. Two plots/grassland were divided into four and sheep were grazed on rotation, spending seven days/sub-plot before moving on. One sub-plot was excluded from the rotation from 26 May–14 July during peak flowering. The other two plots/grassland were grazed continuously. From June–July 2009–2010, butterflies and burnet moths were surveyed four times on one 30-m transect/sub-plot in the rotationally grazed plots, and three 30-m transects in each continuously grazed plot.

A replicated, paired, controlled study in 2010–2012 in six permanent pasture fields in Devon, UK (4) found that rotationally grazed grassland initially had a higher abundance of invertebrates (including caterpillars) than continuously grazed grassland, but the effect disappeared over three years. In the first year, the number of “bird food invertebrates” was higher on rotational grassland (154 individuals/plot) than on continuously grazed grassland (112 individuals/plot). However, after two and three years, there was no significant difference between rotational (two years: 76; three years: 51 individuals/plot) and continuously grazed plots (two years: 78; three years: 42 individuals/plot). From April 2010–September 2012, six permanent pasture fields were divided into two 1-ha plots. One plot/pair was rotationally grazed by cattle, managed to keep sward height between 9–12 cm, and the other was continuously grazed, keeping the sward at 6–8 cm. None of the fields were fertilized during the trial. In July 2010–2012, invertebrates were sampled in 10 locations/plot using a Vortis suction sampler (ten 15-second samples over 0.19 m^2) and sweep-netting (20 double sweeps with a 46-cm diameter net). Invertebrates <2 mm long were excluded from analysis.

A replicated, randomized, controlled study in 2011–2013 in semi-natural mountain pastures in Massif Central, France (5) found that rotationally grazed grassland plots had a higher abundance and species richness of butterflies and burnet moths than continuously grazed plots, and subplots which were not grazed in summer had the most butterflies and burnet moths. In rotationally grazed plots, both the abundance (36 individuals/plot) and species richness (8.4 species/plot) of butterflies and burnet moths was higher than in continuously grazed plots (abundance: 23 individuals/plot; richness: 7.1 species/plot). Within rotationally grazed plots, subplots which were not grazed in summer had a higher abundance (14 individuals/subplot) and species richness (5.3 species/subplot) of butterflies and moths than subplots grazed in summer (abundance: 5–9 individuals/subplot; richness: 2.7–3.8 species/subplot). From 1992–2011, pastures were grazed extensively by cattle without fertilization. From May–October 2011–2013, six 3.6-ha plots were each grazed by seven Charolais cattle (heifers), and six 0.6-ha plots were each grazed by seven female Limousine sheep (both 1.75 livestock units/ha). Three plots in each group were grazed continuously, and three were sub-divided into four subplots each grazed for 35 days/year. One subplot in each plot was not grazed for 63 days from early June–early August each year. From early July–early August 2011–2013, butterflies and burnet moths were surveyed twice/year on four 50-m fixed transects/plot (one in each rotational subplot).

A replicated, site comparison study in 2015–2016 in two grassland reserves in North Dakota, USA (6) found that rotational grazing did not affect butterfly community composition, but did affect the species richness and abundance of individual species, compared to pastures managed by rotational grazing with mowing, season-long grazing, or patch-burn grazing. Rotational grazing did not affect butterfly community composition compared to other management (data presented as model results). Two out of nine species (meadow fritillary *Boloria bellona* and regal fritillary *Speyeria idalia*) were more abundant in rotationally grazed pastures, while two species (small pearl-bordered fritillary *Boloria selene* and purplish copper *Lycaena helloides*) were less abundant in rotationally grazed pastures than other management, and five species had a similar abundance between management types (see paper for details). Thirty butterfly species were recorded in rotationally grazed pastures, compared to 25 species in rotationally grazed pastures with mowing, 22 species in season-long grazed pastures and 26 species in patch-burned grazed pastures (statistical significance not assessed). Eight pastures (54–484 ha) managed under one of four management practices (rotational grazing, rotational grazing with lowland mowing, season-long grazing, patch-burn grazing) were selected. Rotational pastures were sub-divided into four paddocks, each grazed twice/season. In mown pastures, sedge-dominated patches were cut once/summer. On season-long pastures cattle were free to select grazing areas. One-third of each patch-burn grazed pasture was burned in the dormant season, but prior to April 2015 these sites were rotationally grazed. All other sites had the same management for at least a decade. Pastures were stocked with cattle (0.5–0.75 cow-calf pairs/ha) from May–October. From June–August 2015 and 2016, butterflies were surveyed three times/year along twelve 100-m transects/pasture.

(1) Swengel A.B. & Swengel S.R. (2001) Effects of prairie and barrens management on butterfly faunal composition. *Biodiversity and Conservation*, 10, 1757–1785.

(2) Farruggia A., Dumont B., Scohier A., Leroy T., Pradel P., Garel J.-P. (2011) An alternative rotational stocking management designed to favour butterflies in permanent grasslands. *Grass and Forage Science*, 67(1), 136–149.
(3) Scohier A., Ouin A., Farruggia A. & Dumont B. (2013) Is there a benefit of excluding sheep from pastures at flowering peak on flower-visiting insect diversity? *Journal of Insect Conservation*, 17, 287–294.
(4) Royal Society for the Protection of Birds (2016) Utility of lenient grazing of agricultural grassland to promote in-field structural heterogeneity, invertebrates and bird foraging [BD5207: Extensive cattle grazing: what is the best approach to improve species-poor pastures for birds and invertebrates? (Phase 2)] - Project BD5206/BD5207 Final Report to DEFRA/Natural England (RP00196). Natural England report.
(5) Ravetto Enri S., Probo, M., Farruggia A., Lanore L., Blanchetete A. & Dumont B. (2017) A biodiversity-friendly rotational grazing system enhancing flower-visiting insect assemblages while maintaining animal and grassland productivity. *Agriculture, Ecosystems & Environment*, 241, 1–10.
(6) Bendel C.R., Hovick T.J., Limb R.F. & Harmon J.P. (2018) Variation in grazing management practices supports diverse butterfly communities across grassland working landscapes. *Journal of Insect Conservation*, 22, 99–111.

3.35. Use rotational mowing

- **Ten studies** evaluated the effects on butterflies and moths of using rotational mowing. Two studies were in each of the USA[2,3], the Czech Republic[5,9] and Switzerland[7,10], and one was in each of the UK[1], Germany[4], Europe[6] and Japan[8].

COMMUNITY RESPONSE (6 STUDIES)

- **Community composition (1 study):** One replicated, site comparison study in the Czech Republic[9] found that grasslands managed with "mixed management", which included mowing parts of a site at different times and leaving some areas uncut, had a similar community composition of butterflies, but a different community composition of moths, to grasslands managed by complete annual mowing.

- **Richness/diversity (6 studies):** Three of four replicated studies (including two paired, controlled studies and two site comparison studies) in Germany[4], Switzerland[7], Japan[8] and the Czech Republic[9] found that grasslands managed by mowing strips in alternate years[4], by mowing and burning one half of the meadow each year[8], or by mowing parts of a site at different times and leaving some areas uncut[9], had a greater species richness[4,8,9] and diversity[8] of butterflies than grasslands cut in full once/year. However, one of these studies also found that grasslands managed by mowing parts of a site at different times and leaving some areas uncut had a lower species richness of moths than grasslands cut in full once/year[9]. The fourth study found that grasslands managed by leaving a rotational area uncut on each mow had a similar species richness of butterflies and burnet moths to grasslands cut in full twice/year[7]. One replicated, site comparison study in the USA[3] found that rotationally managed grasslands, including some rotationally mown grasslands, which were last managed longer ago had a higher species richness of butterflies than more recently managed grasslands. One replicated, site comparison study in Switzerland[10] found that farms managed with more in-field agri-environment scheme (AES) options, including staggered mowing dates, had a similar species richness of butterflies to farms with fewer AES options.

POPULATION RESPONSE (7 STUDIES)

- **Abundance (7 studies):** Two replicated, paired, controlled studies (including one randomized study) in Germany[4] and Switzerland[7] found that grasslands managed by mowing strips in alternate years[4], or by leaving a rotational area uncut on each mow[7], had a higher abundance of butterflies[4,7] and burnet moths[7] than grasslands cut in full once[4] or twice[7] per year. One of two replicated, site comparison studies in the USA[2,3] found that rotationally managed grasslands, including some rotationally mown grasslands, which were last managed longer ago had a higher abundance of butterflies than more recently managed grasslands[3]. The other study found that rotationally mown grasslands had a lower abundance of butterflies in the second year after they were last cut than in the first year after mowing[2]. One replicated, site comparison study in the UK[1] reported that two heath fritillary populations survived on rotationally mown grasslands while six populations went extinct on unmanaged grasslands. One review in Europe[6] reported that rotationally mowing grassland benefitted 27 out of 67 butterfly species of conservation concern. One replicated, site comparison study in Switzerland[10] found that farms managed with more in-field agri-environment scheme (AES) options, including staggered mowing dates, had a similar abundance of butterflies to farms with fewer AES options.

BEHAVIOUR (1 STUDY)

- **Use (1 study):** One replicated, controlled study in the Czech Republic[5] found that 29 out of 32 butterfly species preferred meadows which were half mown in June and August to meadows cut in full twice/year. The other three species were woodland species which only visited meadows temporarily[5].

Background

Mowing large areas of grassland at once creates a uniform habitat structure, and removes all floral resources simultaneously (Morris 2000). It can also kill or injure butterfly and moth eggs or caterpillars living among the grass. Rotational mowing resembles many traditional meadow management practices, and involves cutting different areas at different times, such that some patches remain uncut (Bubova *et al.* 2015). This creates a more heterogeneous sward height, and may provide a refuge habitat for butterflies and moths (Morris 2000). Studies are included here if they look at rotational mowing both within and between growing seasons.

For other changes to mowing techniques or timing in productive grasslands, see "*Reduce cutting frequency on grassland*", "*Delay cutting or first grazing date on grasslands to create variation in sward height*", "*Raise cutting height on grasslands*" and "*Use motor bar mowers rather than rotary mowers*". For studies on using mowing to manage wild or semi-natural grasslands, see "*Habitat restoration and creation – Change mowing regime on grassland*".

Bubová T., Vrabec V., Kulma M. & Nowicki P. (2015) Land management impacts on European butterflies of conservation concern: a review. *Journal of Insect Conservation*, 19, 805–821.

Morris M.G. (2000) The effects of structure and its dynamics on the ecology and conservation of arthropods in British grasslands. *Biological Conservation*, 95, 129–142.

A replicated, site comparison study in 1980–1989 on eight grasslands in Cornwall, UK (1) reported that grasslands managed by rotational mowing supported populations of heath fritillary *Mellicta athalia* while populations on unmanaged grasslands went extinct. Results were not tested for statistical significance. Two grasslands managed by rotational mowing maintained heath fritillary populations of 1,300–2,700 adults/year (5-ha site) and 200–600 adults/year (0.25-ha site), compared to six unmanaged grasslands where the heath fritillary populations went extinct (data not presented). From 1981–1989, the flatter areas of a 5-ha grassland were mown annually in autumn using a tractor-drawn 'bush-hog' cutter, while the steeper areas were cut every two or four years using hand-held brush cutters. A second 0.25-ha grassland was managed by cutting half of the site each year. Six other grasslands were unmanaged throughout this period. From 1980–1989, butterflies were surveyed annually on timed counts along a zig-zag route covering the known flight areas at each site. The total yearly population at a site was estimated by multiplying the peak population count by three.

A replicated, site comparison study in 1992–1993 in 42 tall-grass prairies in Missouri, USA (2) found that butterflies were more abundant in the first year after haying than in the second year after haying. In the first year following haying, the abundance of prairie specialist butterflies (81 individuals/hour) was higher than two years after haying (68 individuals/hour). The abundance of grassland species (11 individuals/hour), generalists (17 individuals/hour) and migrants (19 individuals/hour) in the year following haying was also higher than two years after haying (grassland: 9; generalist: 10; migrant: 5 individuals/hour). See paper for individual species results. Of 42 sites (6–571 ha), some were primarily managed by summer haying on a 1–2 year rotation with occasional cattle grazing (number not given). In June 1992–1993, butterflies were surveyed at least once/year at most sites, either along a transect (35 sites) or from a single point (7 sites, recording only regal fritillary *Speyeria idalia*). Transects were sub-divided by the most recent management. Sixteen species observed >49 times and at >5 sites were included, and divided into "prairie specialists" (only found on prairies), "grassland species" (found in prairies and other grasslands), "generalists" (found in grasslands and other habitats) and "migrants" (only present in the study area during the growing season).

A replicated, site comparison study in 1990–1997 in 105 tallgrass prairies in Illinois, Iowa, Minnesota, Missouri, North Dakota and Wisconsin, USA (3) found that rotationally managed prairies (hayed, grazed or burned) which were last managed longer ago had a higher abundance and species richness of specialist and grassland butterflies than more recently managed prairies. All data were presented as models results. Of 105 prairies (1.2–2,024 ha), 27 were managed by haying, mostly on a two-year rotation, 77 areas were managed by rotational burning (every 2–5 years) in the cool-season (of which 24 were also hayed or mown), and seven areas within the Sheyenne National Grassland, North Dakota, were managed by rotational grazing (0.3–0.6 animal use months/ha/year). From May–September 1990–1997, butterflies were surveyed on parallel transects (5–10 m apart) at each site. Most sites were surveyed more than once/year, and in >1 year. Species were classified as "specialists" (of native plants), "grassland" (occurring widely in open habitat) and "generalist" (occurring in a range of habitats).

A replicated, paired, controlled study in 2006–2008 in 10 meadows in Hessen, Germany (4) found that after three years, rotationally mown grassland had a greater abundance and species richness of butterflies than annually mown grassland. Three years after rotational mowing began, the abundance and species richness of butterflies was higher on the rotational strips (abundance: 120 individuals/strip; richness: 7 species/strip) than on strips cut annually (abundance: 10 individuals/strip; richness: 5 species/strip) after mowing, but there was no significant difference between strips before mowing in any year (rotational: 10–70 individuals/strip, 4–7 species/strip; annual: 10–120 individuals/strip, 4–8 species/strip). However, in the first year, species richness on the rotational strips (7 species/strip) was lower than on the annual strips (12 species/strip) after the latter had been mown, but the abundance was similar (rotational: 60 individuals/strip; annual: 50 individuals/strip). From 2006–2008, in each of 10 meadows, two 500-m^2 strips (usually 5 × 100 m) were managed in one of two ways: mown every two years (i.e. not mown in 2006 and 2008) or mown annually after 10 June. In 2007, most mowing took place in August due to wet weather. From May–August 2006–2008, butterflies were surveyed 4–6 times/year with 100 sweeps/strip of a 32-cm diameter net, and recording of other individuals at the same time (two meadows not surveyed in 2008).

A replicated, controlled study in 2005–2006 in 11 hay meadows in Eastern Bohemia, Czech Republic (5) found that rotationally mown meadows were preferred by most species of butterfly. Most butterfly species (29/32 species) preferred rotationally mown meadows to complete cut meadows. The three species which preferred complete cut meadows were all woodland species which would only be visiting the meadows temporarily. In 2005 and 2006, one of three mowing regimes was applied to 11 meadows: alternating cut and uncut 5–10-m strips in June and cutting the remaining strips in August; alternating cut and uncut 50-m blocks in June and cutting the remaining blocks in August; mowing the whole meadow in June and August. The latter represented standard agri-environment scheme meadow management in the Czech Republic, and all meadows were managed like this prior to the study. Management of some meadows changed between years. From May–September 2005–2006, butterflies were surveyed fortnightly along transects through 11 meadows.

A review in 2015 of 126 studies in Europe (6) reported that rotational mowing of grassland benefitted 27 out of 67 butterfly species of conservation concern. Results were not tested for statistical significance. The review reported that 30 studies found that rotational mowing benefitted 27 butterfly species. See paper for information on individual species. Meadows were mown in rotation at low intensity, with different fragments cut at different times, and with a single fragment mown no more than once/year. Rotational mowing was often combined with extensive grazing. The review focussed on 67 butterfly species of conservation concern. The available information was biased towards studies in Northern and Western Europe.

A replicated, randomized, paired, controlled study in 2010–2013 in 24 meadows in the Swiss Plateau, Switzerland (7) found that leaving some areas uncut when mowing extensively managed meadows increased the abundance, but not species richness, of butterflies and burnet moths. Before first mowing, the abundance of butterflies and burnet moths in meadows with uncut refuges from previous years (1.0–2.9 individuals/100 m) was higher than in standard agri-environment scheme (AES) meadows without refuges (1.1–1.3 individuals/100 m). After 15 June, there was no difference in butterfly abundance between meadows with refuges (1.8–19.9 individuals/100 m) and standard meadows (2.3–17.9 individuals/100 m). The overall species richness of meadows with refuges (10 species) was similar to standard meadows (8 species). However, species richness of specialist butterflies was higher in meadows with refuges (1.7 species) than in standard meadows (1.1 species). In 2010, at 12 sites (>5 km apart), two meadows (0.3–1.7 ha) which had been in AES since at least 2004 were randomly allocated to two treatments: standard Swiss AES management (no cutting before 15 June) or refuge cutting (no cutting before 15 June and leaving 10–20% of the meadow uncut). The location of the uncut area had to vary between cuts. Meadows were cut on average twice/year. From late April–August 2013, butterflies were surveyed along a transect (65–215 m) through the middle of each meadow. Three surveys were conducted before 15 June, one between 15 June and 15 July, and two after 15 July.

A replicated, site comparison study in 2012–2013 in 12 semi-natural grasslands in Nagano Prefecture, Japan (8) found that meadows managed by traditional rotational mowing and burning had a higher species richness and diversity of butterflies than annually mown, annually burned or abandoned meadows. In rotationally managed meadows, the diversity and species richness of threatened (6–7 species/meadow) and common (10–12 species/meadow) butterflies was higher than in annually mown (threatened: 3; common: 4 species/meadow), annually burned (threatened: 2–3; common: 6 species/meadow) or abandoned meadows (threatened: 1–2; common: 1–2 species/meadow) (diversity data presented as model results). Three meadows were managed traditionally: each year half of the meadow was burned in April and mown in September, while the other half was unmanaged, and management rotated each year. An additional three meadows had been mown annually in April or August for 8–9 years, three meadows had been burned annually for 7–13 years and three meadows had been abandoned (unmanaged) for 6–13 years. From May–September 2012–2013, butterflies were surveyed monthly on three 5 × 30 m plots/meadow.

A replicated, site comparison study in 2007–2010 in 28 grassland sites in Bílé Karpaty Protected Landscape Area, Czech Republic (9) found that mixed grassland management, which included leaving some areas uncut each year, supported the highest species richness of butterflies, but an intermediate species richness of moths. The species richness of butterflies was higher in grasslands under mixed management than in mown, grazed or abandoned grasslands, but species composition was not affected by management. However, the species richness of moths was highest in mown grasslands, lowest in grazed grasslands, and intermediate in mixed management, and these sites had different species composition (all data presented as model results). One of four different management practices (mown once/year; grazed by sheep, cattle or deer; abandoned (no grazing or mowing); or 'mixed' management) was applied to each of 28 sites (1.5–70.7 ha) for at least five consecutive years. 'Mixed' management included mowing different parts of the site at different times, often with patches left uncut for a year, or mowing followed by grazing. From 2007–2010, butterflies and moths were surveyed on >6 visits between April and October in each of two consecutive years to each site.

A replicated, site comparison study in 2009–2011 in 133 mixed farms in the Central Plateau, Switzerland (10) found that farms with more in-field agri-environment scheme (AES) options, including staggered mowing, had a similar abundance and species richness of butterflies to farms with fewer (AES) options. Both the abundance and species richness of butterflies on farms with a larger area of in-field AES options were similar to farms with smaller areas of in-field AES options (data presented as model results). A total of 133 farms (17–34 ha, 13–91% arable crops) were managed with in-field AES options, including staggered mowing, use of bar mowers, no silage, undersown cereals, undrilled patches in crops, wide-spaced rows, cover crops and no chemical inputs. Fields without chemical inputs contributed about half of the area of AES options, on average. From May–September 2009–2011, butterflies were surveyed six times on 10–38 transects/farm, totalling 2,500 m/farm. Each transect ran diagonally through a single crop or habitat type, with all available crops and habitats represented. All visits to a farm were completed in a single year, and the species richness was summed across all visits. Total abundance of butterflies was calculated from the number recorded in each habitat, and the availability of each habitat across the farm.

(1) Warren M.S. (1991) The successful conservation of an endangered species, the heath fritillary butterfly *Mellicta athalia*, in Britain. *Biological Conservation*, 55, 37–56.

(2) Swengel A.B. (1996) Effects of fire and hay management on abundance of prairie butterflies. *Biological Conservation*, 76, 73–85.

(3) Swengel A.B. & Swengel S.R. (2001) Effects of prairie and barrens management on butterfly faunal composition. *Biodiversity and Conservation*, 10, 1757–1785.

(4) Handke K., Otte A. & Donath T.W. (2011) Late mowed stripes of grassland promote invertebrates in floodplain meadows: Results from the nature reserve "Kühkopf-Knoblochsaue". *Naturschutz und Landschaftsplanung*, 43, 280–288.

(5) Cizek O., Zamecnik J., Tropek R., Kocarek P. & Konvicka M. (2012) Diversification of mowing regime increases arthropods diversity in species-poor cultural hay meadows. *Journal of Insect Conservation*, 16, 215–226.

(6) Bubová T., Vrabec V., Kulma M. & Nowicki P. (2015) Land management impacts on European butterflies of conservation concern: a review. *Journal of Insect Conservation*, 19, 805–821.

(7) Bruppacher L., Pellet J., Arlettaz R. & Humbert J.Y. (2016) Simple modifications of mowing regime promote butterflies in extensively managed meadows: Evidence from field-scale experiments. *Biological Conservation*, 196, 196–202.

(8) Uchida K., Takahashi S., Shinohara T. & Ushimaru A. (2016) Threatened herbivorous insects maintained by long-term traditional management practices in semi-natural grasslands. *Agriculture, Ecosystems & Environment*, 221, 156–162.

(9) Bonari G., Fajmon K., Malenovský I., Zelený D., Holuša J., Jongepierová I., Kočárek P., Konvička O., Uřičář J. & Chytrý M. (2017) Management of semi-natural grasslands benefiting both plant and insect diversity: The importance of heterogeneity and tradition. *Agriculture, Ecosystems & Environment*, 246, 243–252.

(10) Stoeckli S., Birrer S., Zellweger-Fischer J., Balmer O., Jenny M. & Pfiffner L. (2017) Quantifying the extent to which farmers can influence biodiversity on their farms. *Agriculture, Ecosystems & Environment*, 237, 224–233.

3.36. Delay cutting or first grazing date on grasslands to create variation in sward height

- **Seven studies** evaluated the effects on butterflies and moths of delaying cutting or first grazing dates on grasslands. Two studies were in Germany[1,3] and one was in each of the UK[2], Hungary[4], Switzerland[5], Austria[6] and Sweden[7].

COMMUNITY RESPONSE (4 STUDIES)

- **Community composition (1 study):** One replicated, site comparison study in Austria[6] found that the community composition of butterflies and day-flying moths was different between early-mown and late-mown grasslands.
- **Richness/diversity (3 studies):** One of three replicated, controlled studies (including two randomized studies and two paired studies) in the UK[2], Germany[3] and Switzerland[5] found that, in one of four years, grassland plots cut once/year in July had a higher species richness of butterflies than plots cut once/year in May[2]. One study found that, in one of three years, grassland strips mulched once/year in September had a lower species richness of butterflies than strips mown once/year after 10 June[3]. The third study found that meadows mown 1–2 times/year after 15 July had a similar species richness of butterflies and burnet moths to meadows mown twice/year after 15 June[5].

POPULATION RESPONSE (6 STUDIES)

- **Abundance (6 studies):** Three of four replicated, controlled studies (including three randomized studies and three paired studies) in the UK[2], Germany[3], Hungary[4] and Switzerland[5] found that grassland cut once/year in July[2,5] or September[3] had a greater abundance of butterflies[2,3,5], burnet moths[5] and caterpillars[2] than grassland cut once[2,3] or twice[5] per year in May[2] or June[3,5], but in two of the cases only in one of four[2] or two of three[3] years. The fourth study found that meadows mown once/year in September had a similar abundance of scarce large blue butterflies to meadows mown once/year in May, and abundance remained stable in September-mown meadows but decreased over time in May-mown meadows[4]. One site comparison study in Germany[1] found that a meadow mown once/year after the flight season of tufted marbled skipper had a lower density of eggs than a meadow mown before the flight season. One replicated, site comparison study in Sweden[7] found that meadows where grazing commenced after 15 June (together with a lower stocking density) had a higher abundance of clouded Apollo butterflies than meadows where grazing commenced before 15 June (together with a higher stocking density).

BEHAVIOUR (1 STUDY)

- **Use (1 study):** One replicated, site comparison study in Austria[6] found that short-tailed blue showed a preference for late-mown meadows, but marbled white and meadow brown preferred early-mown meadows.

Background

Cutting or grazing are important management techniques for maintaining grassland habitats, but both represent a threat to butterflies and moths through either direct mortality or damage to food plants. However, alterations to the timing of management to when species are less vulnerable or need fewer resources (e.g. during the pupal phase) may be important for creating the optimal habitat conditions, in terms of structural variation, host plant abundance or quality (Goodenough & Sharp 2016), or the abundance of host species such as ants (Grill *et al.* 2008).

For other changes to grazing regimes on productive grasslands, see "*Reduce grazing intensity on grassland by reducing stocking density*", "*Reduce grazing intensity on grassland by seasonal removal of livestock*" and "*Use rotational grazing*". For other changes to mowing techniques or timing in productive grasslands, see "*Reduce cutting frequency on grassland*", "*Use rotational mowing*", "*Raise cutting height on grasslands*", "*Use motor bar mowers rather than rotary mowers*". For studies on using mowing to manage wild or semi-natural grasslands, see "*Habitat restoration and creation – Change mowing regime on grassland*".

Goodenough A.E. & Sharp M.H. (2016) Managing calcareous grassland for the declining Duke of Burgundy *Hamearis lucina* butterfly: effects of grazing management on Primula host plants. *Journal of Insect Conservation*, 20, 1087–1098.

Grill A., Cleary D.F.R., Stettmer C., Bräu M. & Settele J. (2008) A mowing experiment to evaluate the influence of management on the activity of host ants of *Maculinea* butterflies. *Journal of Insect Conservation*, 12, 617–627.

A site comparison study in 1994 in three traditional hay meadows in Bavaria, Germany (1) found that the egg density of tufted marbled skipper *Carcharodus flocciferus* was higher in a meadow mown before the flight season than in either a meadow mown after the flight season or a grazed meadow. The egg density of tufted marbled skipper were higher in a meadow mown before the species' flight season (4.3 eggs/20 leaves) than in a meadow mown after the flight season (0.3 eggs/20 leaves) or a grazed meadow (0.2 eggs/20 leaves). Three meadows, which had been managed in the same way for at least 5–20 years, were compared. Two traditionally managed hay meadows were mown once/year in either July or early August, and one meadow was extensively grazed with sheep, cattle or horses for a few weeks each summer. No information is provided on how eggs were recorded.

A replicated, randomized, controlled study in 2002–2006 on four lowland farms in Devon and Somerset, UK (2) found that grassland plots cut in July had a higher abundance and species richness of butterflies, and abundance of caterpillars, than plots cut in May in only one out of four years. In the second year of management, the abundance of caterpillars on plots cut in July (6 caterpillars/transect) was higher than on plots cut in May (2 caterpillars/transect), but in other years there was no significant difference (July: 1–8; May: 0–5 caterpillars/transect). In the third year, the abundance (4 individuals/transect) and species richness (2 species/transect) of butterflies on plots cut in July was higher than on plots cut in May (abundance: 2 individuals/transect; richness: 1 species/transect), but both abundance and richness were similar in all other years (July: 1–5 individuals/transect, 1–2 species/transect; May: 1–3 individuals/transect, 1–2 species/transect). In April 2002, six experimental plots (50 × 10 m) were established on permanent pastures (>5-years-old) on four farms. Three plots/farm were cut to 10 cm height in May, and three were cut to 10 cm height in July. From June–September 2003–2006, butterflies were surveyed once/month on a 50-m transect through the centre of each plot. In April, June, July and September 2003–2006, caterpillars were counted (but not identified) on two 10-m transects/plot using a sweep net (20 sweeps/transect).

A replicated, paired, controlled study in 2006–2008 in 10 meadows in Hessen, Germany (3) found that grassland cut in autumn had a higher abundance, but not species richness, of butterflies than grassland cut in summer. In the first and third year, the abundance of butterflies on strips where mowing was delayed (80–90 individuals/strip) was higher than on conventionally mown strips (10–50 individuals/strip), but in the first year the species richness on the delayed strips (9 species/strip) was lower than on the conventional strips (12 species/strips). There was no significant difference between strips before mowing in any year (delayed: 10–110 individuals/strip, 4–7 species/strip; conventional: 10–120 individuals/strip, 4–8 species/strip), or after the conventional strips were cut in the second year (delayed: 40 individuals/strip, 4 species/strip; conventional: 10 individuals/strip, 2 species/strip). From 2006–2008, in each of 10 meadows, two 500-m^2 strips (usually 5 × 100 m) were managed in one of two ways: mulched annually in September or mown annually after 10 June. In 2007, most mowing took place in August due to wet weather. From May–August 2006–2008, butterflies were surveyed 4–6 times/year with 100 sweeps/strip of a 32-cm diameter net, and recording of other individuals at the same time (two meadows not surveyed in 2008).

A replicated, randomized, paired, controlled study in 2007–2010 in four meadows in Őrség National Park, Hungary (4) found that grassland mown in September had a similar abundance of scarce large blue butterflies *Phengaris teleius* to grassland mown in May, and that numbers decreased in May-mown grassland but remained stable in September-mown grassland. Three years after management began, the number of scarce large blue butterflies in plots mown in September (0.94 individuals/plot/day) was similar to the number in plots mown in May (0.86 individuals/plot/day). However, the number of butterflies in September-mown plots was similar to the first year of management (1.21 individuals/plot/day), whereas the number in May-mown plots was higher in the first year of management (1.64 individuals/plot/day). In May 2007, four meadows were each divided into two equal-size plots, and one of two management regimes was randomly applied to each plot. For four years, one plot/meadow was mown annually in May and the other was mown annually in September, all with cuttings removed. In July 2007 and 2010, butterflies were surveyed for five minutes, 15–20 times/year, in each of three or four 20 × 20 m squares/plot.

A replicated, randomized, paired, controlled study in 2010–2013 in 23 meadows in the Swiss Plateau, Switzerland (5) found that delaying the first cutting date on extensively managed meadows increased the abundance, but not species richness, of butterflies and burnet moths. Before 15 June, the abundance of butterflies and burnet moths in delayed cut meadows (1.7–2.3 individuals/100 m) was higher than in standard agri-environment scheme (AES) meadows (1.1–1.3 individuals/100 m). After 15 June, delayed cut meadows retained higher butterfly abundance (12.6 individuals/100 m) than standard meadows (2.3 individuals/100 m). After 15 July, delayed cut meadows had lower abundance (9.3 individuals/100 m) than standard meadows (17.9 individuals/100 m), but there was no difference by the end of the summer (delayed: 12.0; standard: 14.6

individuals/100 m). There was no significant difference in the species richness of delayed (10 species) and standard (8 species) meadows. In 2010, at 11 sites (>5 km apart), two meadows (0.3–1.7 ha) which had been in AES since at least 2004 were randomly allocated to two treatments: standard Swiss AES management (no cutting before 15 June) or delayed cutting (no cutting before 15 July). An additional standard meadow was included at a 12th site. On average, standard meadows were cut twice/year, while delayed cutting meadows were cut 1.5 times/year. From late April–August 2013, butterflies were surveyed along a transect (65–215 m) through the middle of each meadow. Three surveys were conducted before 15 June, one from 15 June–15 July, and two after 15 July.

A replicated, site comparison study in 2013–2015 in 45 semi-natural grasslands in eastern Austria (6) found that grasslands managed by early mowing and former vineyards managed by late mowing had distinct butterfly and day-flying moth communities. Butterfly and day-flying moth communities in semi-natural grasslands managed by early mowing were different to those in grasslands (former vineyards) managed by late mowing, and both were different to communities in grasslands managed by extensive grazing (data presented as model results). In addition, some species showed a preference for sites that were early-mown (marbled white *Melanargia galathea*, meadow brown *Maniola jurtina*), late-mown (short-tailed blue *Cupido argiades*) or grazed (crepuscular burnet *Zygaena carniolica*, transparent burnet *Zygaena purpuralis*/*minos*). The use of all three grassland management regimes (early mowing, late mowing and grazing) in different parts of the landscape increased butterfly diversity across the landscape (data presented as model results). Semi-natural grasslands managed in three ways were studied: meadows mown once/year in early summer with cuttings removed, former vineyards mown once/year in late summer with cuttings not removed, and extensive pastures grazed by cattle from April–October. In June 2013–2015, all butterflies, burnet moths (Zygaenidae) and hummingbird hawk-moths *Macroglossum stellatarum* were counted once on 9–11 sites/year (50 × 50 m) under each management type.

A replicated, site comparison study in 1984–2015 in 24 grasslands in Blekinge province, Sweden (7) found that grasslands grazed lightly, later in the year or with fewer animals, had a higher abundance of clouded Apollo *Parnassius mnemosyne* than grasslands grazed heavily, earlier in the summer or with more animals. In grasslands managed by light grazing, the abundance of clouded Apollo (1–169 individuals/grassland/year) was higher than in heavily grazed grasslands (2–22 individuals/grassland/year) or ungrazed grasslands (0–109 individuals/grassland/year). In addition, abundance was higher on larger grasslands, and grasslands which were close together were more likely to be colonized (data presented as model results). From 1984–2015, twenty-four open grasslands (>150 m apart) with >0.5 m^2 cover of the host plant *Corydalis* spp. and the presence of a major nectar plant *Lychnis viscaria* were assigned annually to one of three management categories: light grazing (grazing commenced after 15 June with 1–9 animals/hectare); heavy grazing (grazing commenced before 15 June or with ≥10 animals/hectare for ≥8 weeks); no grazing. Grazing animals were cattle and sheep. In 1984–1987, 1991 and 2003–2015, butterflies were surveyed ≥6 times/year on each site, by marking and recapturing individuals along irregular routes through each grassland. In 1988–1989 and 1992–2002, grasslands were visited more irregularly and their presence recorded. Surveys were used to estimate the local population size on each grassland each year.

(1) Dolek M. & Geyer A. (1997) Influence of management on butterflies of rare grassland ecosystems in Germany. *Journal of Insect Conservation*, 1, 125–130.
(2) Potts S.G., Woodcock B.A., Roberts S.P.M., Tscheulin T., Pilgrim E.S., Brown V.K. & Tallowin J.R. (2009) Enhancing pollinator biodiversity in intensive grasslands. *Journal of Applied Ecology*, 46, 369–379.
(3) Handke K., Otte A. & Donath T.W. (2011) Late mowed stripes of grassland promote invertebrates in floodplain meadows: Results from the nature reserve "Kühkopf-Knoblochsaue". *Naturschutz und Landschaftsplanung*, 43, 280–288.
(4) Kőrösi Á., Szentirmai I., Batáry P., Kövér S., Örvössy N. & Peregovits L. (2014) Effects of timing and frequency of mowing on the threatened scarce large blue butterfly – A fine-scale experiment. *Agriculture, Ecosystems & Environment*, 196, 24–33.
(5) Bruppacher L., Pellet J., Arlettaz R. & Humbert J.Y. (2016) Simple modifications of mowing regime promote butterflies in extensively managed meadows: Evidence from field-scale experiments. *Biological Conservation*, 196, 196–202.
(6) Fiedler K., Wrbka T. & Dullinger S. (2017) Pluralism in grassland management promotes butterfly diversity in a large Central European conservation area. *Journal of Insect Conservation*, 21, 277–285.
(7) Johansson V., Knape J. & Franzen M. (2017) Population dynamics and future persistence of the clouded Apollo butterfly in southern Scandinavia: The importance of low intensity grazing and creation of habitat patches. *Biological Conservation*, 206, 120–131.

3.37. Raise cutting height on grasslands

- **Two studies** evaluated the effects on butterflies and moths of raising cutting height on grasslands. One study was in each of the UK[1] and Switzerland[2].

COMMUNITY RESPONSE (1 STUDY)

- **Richness/diversity (1 study):** One replicated, randomized, controlled study in the UK[1] found that intensively managed grassland plots cut to 10 cm in May and July had a similar species richness of butterflies to plots cut to 5 cm.

POPULATION RESPONSE (1 STUDY)

- **Abundance (1 study):** One replicated, randomized, controlled study in the UK[1] found that intensively managed grassland plots cut to 10 cm in May and July had a similar abundance of butterflies and caterpillars to plots cut to 5 cm.
- **Survival (1 study):** One replicated, randomized, paired, controlled study in Switzerland[2] found that the survival of large white caterpillars in grassland plots cut to 9 cm was similar to in plots cut to 6 cm[2].
- **Condition (1 study):** One replicated, randomized, paired, controlled study in Switzerland[2] found that a similar proportion of wax model caterpillars were damaged when meadows were cut to 9 cm or 6 cm.

BEHAVIOUR (0 STUDIES)

Background

In productive grasslands, cutting or mowing is used to harvest vegetation, such as for hay or silage, but the harvest causes a sudden loss of habitat structure and resources used by butterflies and moths. It may also kill or injure eggs or caterpillars living within the sward (Humbert et al. 2010). Raising the cutting height by a few centimetres may allow more individuals to survive underneath the mower, or leave more resources available.

Humbert J.Y., Ghazoul J., Sauter G.J. & Walter T. (2010) Impact of different meadow mowing techniques on field invertebrates. *Journal of Applied Entomology*, 134, 592–599.

A replicated, randomized, controlled study in 2002–2006 on four lowland farms in Devon and Somerset, UK (1) found that plots of intensively managed grassland cut to 10 cm in May and July did not have a higher abundance or species richness of butterflies, or abundance of caterpillars, than plots cut to 5 cm. On plots cut to 10 cm, the abundance (1–2 individuals/transect) and species richness (1 species/transect) of butterflies, and the abundance of caterpillars (0–5 caterpillars/transect), were not significantly different from plots cut to 5 cm (butterfly abundance: 0–2 individuals/transect; richness: 0–1 species/transect; caterpillar abundance: 0–4 caterpillars/transect). In April 2002, six experimental plots (50 × 10 m) were established on permanent pastures (>5-years-old) on four farms. All plots were fertilized (225 kg nitrogen/ha, 22 kg phosphorus/ha, 55 kg potassium/ha), cut twice/year in May and July, and grazed in September. Three plots/farm were cut to 10 cm, and three were cut to 5 cm. From June–September 2003–2006, butterflies were surveyed once/month on a 50-m transect through the centre of each plot. In April, June, July and September 2003–2006, caterpillars were counted (but not identified) on two 10-m transects/plot using a sweep net (20 sweeps/transect).

A replicated, randomized, paired, controlled study in 2007–2008 in Switzerland (2) found that raising the cutting height when mowing meadows did not increase the survival of large white *Pieris brassicae* caterpillars. The proportion of large white caterpillars killed by mowing at 9 cm (30–43%) was not significantly different from the proportion killed by mowing at 6 cm (35–37%). Similarly, the proportion of wax models damaged by mowing at 9 cm (16.9%) was not significantly different from the proportion damaged by mowing at 6 cm (17.4%). In 2007–2008, in each of nine meadows, two 2.5-m-long plots were randomly assigned to either 9 cm or 6 cm cutting height, and mown with a 2.5-m-wide tractor-pulled rotary mower. Before mowing, half of 200 wax caterpillar models (100 large and 100 small) were placed on the ground and half were tied to vegetation 20–30 cm high in each plot. In 2008, on five meadows, large white caterpillars were placed on the ground (50 caterpillars) and in the vegetation (50 caterpillars) in each plot. After mowing, wax models and caterpillars that survived were checked for damage or injuries.

(1) Potts S.G., Woodcock B.A., Roberts S.P.M., Tscheulin T., Pilgrim E.S., Brown V.K. & Tallowin J.R. (2009) Enhancing pollinator biodiversity in intensive grasslands. *Journal of Applied Ecology*, 46, 369–379.
(2) Humbert J.Y., Ghazoul J., Sauter G.J. & Walter T. (2010) Impact of different meadow mowing techniques on field invertebrates. *Journal of Applied Entomology*, 134, 592–599.

3.38. Use motor bar mowers rather than rotary mowers

- **Two studies** evaluated the effects on butterflies and moths of using motor bar mowers rather than rotary mowers. Both studies were in Switzerland[1,2].

COMMUNITY RESPONSE (1 STUDY)

- **Richness/diversity (1 study):** One replicated, site comparison study in Switzerland[2] found that farms managed with more in-field agri-environment scheme options, including using bar mowers instead of rotary mowers, had a similar species richness of butterflies to farms with fewer agri-environment scheme options.

POPULATION RESPONSE (2 STUDIES)

- **Abundance (1 study):** One replicated, site comparison study in Switzerland[2] found that farms managed with more in-field agri-environment scheme options, including using bar mowers instead of rotary mowers, had a similar abundance of butterflies to farms with fewer agri-environment scheme options.
- **Survival (1 study):** One replicated, randomized, paired, controlled study in Switzerland[1] found that fewer large white caterpillars were killed when meadows were harvested using a hand-pushed bar mower than with a tractor-pulled rotary mower.
- **Condition (1 study):** One replicated, randomized, paired, controlled study in Switzerland[1] found that fewer wax model caterpillars were damaged when meadows were harvested using a hand-pushed bar mower than with a tractor-pulled rotary mower.

BEHAVIOUR (0 STUDIES)

Background

In productive grasslands, cutting or mowing is used to harvest vegetation, such as for hay or silage, but the process kills or injures the eggs and caterpillars of butterflies and moths living within the grassland (Humbert et al. 2010). However, the mortality of individuals may depend on the equipment used for mowing. For example, mechanized tractor-pulled rotary mowers may have a larger impact than hand-pushed bar mowers (Humbert et al. 2010). Using a different type of mower may increase butterfly and moth survival.

Humbert J.Y., Ghazoul J., Sauter G.J. & Walter T. (2010) Impact of different meadow mowing techniques on field invertebrates. *Journal of Applied Entomology*, 134, 592–599.

A replicated, randomized, paired, controlled study in 2007–2008 in Switzerland (1) found that harvesting meadows using a hand-pushed bar mower killed or injured fewer large white *Pieris brassicae* caterpillars than using a tractor-pulled rotary mower. Fewer caterpillars were killed by a bar mower (20%) than by a rotary mower used without (35–37% killed) or with (41–69% killed) a rear flail conditioner attached. Similarly, fewer wax models were damaged by the bar mower (11%) than the rotary mower used without (17% damaged) or with (28% damaged) a conditioner. In 2007–2008, in each of nine meadows, three 2.5-m-long plots were randomly assigned to three mowing treatments: 1.7-m-wide hand-pushed bar mower, or 2.5-m-wide tractor-pulled rotary drum mower without or with a rear flail conditioner, all cut to 6 cm. Before mowing, half of 200 wax caterpillar models (100 large and 100 small) were placed on the ground and half were tied to vegetation 20–30 cm high in each plot. In 2008, on five meadows, large white caterpillars were placed on the ground (50 caterpillars) and in the vegetation (50 caterpillars) in each plot. After mowing, wax models and caterpillars that survived were checked for damage or injuries.

A replicated, site comparison study in 2009–2011 in 133 mixed farms in the Central Plateau, Switzerland (2) found that farms with more in-field agri-environment scheme (AES) options, including using bar mowers instead of rotary mowers, had a similar abundance and species richness of butterflies to farms with fewer AES options. Both the abundance and species richness of butterflies on farms with a larger area of in-field AES options was similar to farms with smaller areas of in-field AES options (data presented as model results). A total of 133 farms (17–34 ha, 13–91% arable crops) were managed with in-field AES options, including use of bar mowers, staggered mowing, no silage, undersown cereals, undrilled patches in crops, wide-spaced rows, cover crops and no chemical inputs. Fields without chemical inputs contributed about half of the area of AES options, on average. From May–September 2009–2011, butterflies were surveyed six times on 10–38 transects/farm, totalling 2,500 m/farm. Each transect ran diagonally through a single crop or habitat type, with all available crops and habitats represented. All visits to a farm were completed in a single year, and the species richness was summed across all visits. Total abundance of butterflies was calculated from the number recorded in each habitat, and the availability of each habitat across the farm.

(1) Humbert J.Y., Ghazoul J., Sauter G.J. & Walter T. (2010) Impact of different meadow mowing techniques on field invertebrates. *Journal of Applied Entomology*, 134, 592–599.
(2) Stoeckli S., Birrer S., Zellweger-Fischer J., Balmer O., Jenny M. & Pfiffner L. (2017) Quantifying the extent to which farmers can influence biodiversity on their farms. *Agriculture, Ecosystems & Environment*, 237, 224–233.

3.39. Mark the location of webs or caterpillars before mowing

- **One study** evaluated the effects on butterflies and moths of marking the location of webs or caterpillars before mowing. This study was in Poland[1].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (1 STUDY)

- **Abundance (1 study):** One replicated, before-and-after study in Poland[1] reported that after marsh fritillary caterpillar webs were marked before mowing, the number of webs increased the following year.

BEHAVIOUR (0 STUDIES)

Background

In productive grasslands, cutting or mowing is used to harvest vegetation, such as for hay or silage, but the process kills or injures the eggs and caterpillars of butterflies and moths living within the grassland (Humbert et al. 2010). However, for conspicuous species, individual caterpillars or their webs can be located and marked prior to mowing so that they can be avoided during the harvest (Błoński 2016), which may increase survival.

Błoński W. (2016) Preliminary assessment of active protection measures of the Marsh Fritillary *Euphydryas aurinia* (Rottemburg, 1775) habitats in the Świętokrzyski National Park. *Naturalia*, 5, 132–138.

Humbert J.Y., Ghazoul J., Sauter G.J. & Walter T. (2010) Impact of different meadow mowing techniques on field invertebrates. *Journal of Applied Entomology*, 134, 592–599.

A replicated, before-and-after study in 2015–2016 in four wet meadows in Świętokrzyskie Voivodeship, Poland (1) reported that after marsh fritillary *Euphydryas aurinia* caterpillar webs were marked prior to mowing, the number of webs increased the following year. Results were not tested for statistical significance. One year after marsh fritillary caterpillar webs were marked prior to mowing there were 17–46 webs/site, compared to 10–20 webs/site the previous year. In 2015, marsh fritillary caterpillar webs in four meadows were marked with flags so that they could be avoided during mowing (at one site trees and shrubs were also removed to restore habitat). In August 2015–2016, marsh fritillary caterpillar webs were surveyed at each site.

(1) Błoński W. (2016) Preliminary assessment of active protection measures of the Marsh Fritillary *Euphydryas aurinia* (Rottemburg, 1775) habitats in the Świętokrzyski National Park. *Naturalia*, 5, 132–138.

3.40. Maintain or restore traditional water meadows and bogs

- **Five studies** evaluated the effect on butterflies and moths of maintaining or restoring traditional water meadows and bogs. Two studies were in the UK[2,4] and one was in each of Germany[1], Belgium[3] and Poland[5].

COMMUNITY RESPONSE (1 STUDY)

- **Richness/diversity (1 study):** One replicated, site comparison study in Germany[1] found that the species richness of butterflies was similar in wet meadows managed by mowing once/year in autumn, or by light grazing with cattle or horses.

POPULATION RESPONSE (4 STUDIES)

- **Abundance (4 studies):** One of two replicated, before-and-after studies in Belgium[3] and Poland[5] found that after cattle grazing on wet grassland began, the number of bog fritillaries which emerged on grazed areas was lower than before grazing started[3]. The other study reported that after trees and shrubs were removed from wet meadows, the number of marsh fritillary caterpillar webs increased the following year[5]. One replicated, site comparison study in Germany[1] found that the abundance of butterflies was similar in wet meadows managed by mowing once/year in autumn, or by light grazing with cattle or horses. One site comparison study in the UK[4] found that wet grassland grazed at an intermediate intensity by cattle had a higher abundance of marsh fritillary caterpillar webs, but a similar abundance of adults, to grassland grazed at high or low intensity.

BEHAVIOUR (2 STUDIES)

- **Use (2 studies):** One replicated, before-and-after study in Belgium[3] found that after cattle grazing on wet grassland began, the use of the grazed areas by bog fritillaries was lower than before grazing started. One replicated, site comparison study in the UK[2] found that a similar proportion of fen meadows were occupied by marsh fritillary caterpillars whether they were managed by grazing (with cattle, sheep or horses), burning or were unmanaged.

Background

Traditionally managed, extensive wet grasslands and water meadows provide an important habitat for many specialist butterfly and moth species. These habitats have suffered from historical drainage, to reduce flooding and allow cultivation, and from scrub encroachment caused by the removal of grazing or other management. Therefore, the restoration or maintenance of wet meadows could include raising water levels, scrub cutting, or the reintroduction of grazing. Studies are also included here if they compare different management techniques on wet grassland, such as grazing and mowing.

For studies on dry agricultural grasslands, see "*Maintain species-rich, semi-natural grassland*" and "*Restore or create species-rich, semi-natural grassland*". For studies on non-agricultural grasslands, see "*Habitat restoration and creation – Restore or create grassland/savannas*". For studies on using rough grazing in other semi-natural habitats, see "*Habitat restoration and creation – Employ areas of semi-natural habitat for rough grazing (includes salt marsh, lowland heath, bog, fen)*".

A replicated, site comparison study in 1994 in 22 wet meadows in Bavaria, Germany (1) found that the abundance and species richness of all butterflies, and of fenland specialist butterflies only, was similar in mown and grazed fens. The abundance of all species of butterfly (17.3 individuals) and of seven threatened fenland specialist species only (8.8 individuals) in lightly grazed meadows was not significantly different to the abundance in meadows mown once/year (all species: 16.8 individuals; specialist species: 8.6 individuals). The species richness of butterflies was also similar in grazed and mown meadows (data not presented). Twenty-two traditionally managed fens were compared. Eleven fens were mown once/year from September onwards, and 11 were grazed with cattle or horses. The mown sites received financial support to maintain management. From June–August 1994, butterflies were surveyed along a fixed transect five times in each meadow.

A replicated, site comparison study in 1993 in 34 fen meadows in Glamorgan, UK (2) found that managing meadows by grazing or burning did not affect marsh fritillary *Eurodryas aurinia* population size compared to unmanaged meadows. There was no significant difference in the proportion of cattle-grazed (3/9), horse-grazed (2/6), sheep-grazed (0/2), burned (5/8 sites), mown (0/1) and unmanaged (4/8) sites that had >20 caterpillar webs recorded. However, the three largest populations (>200 caterpillar webs) were on sites burned in early spring. Caterpillar webs were present on 28/34 sites where adults had been recorded in May/June. In 1993, nine grasslands were cattle-grazed, six were horse-grazed, two were sheep-grazed, eight were burned, one was mown and eight were unmanaged. Sites were separated by >1 km of unoccupied grassland, or >0.5 km of unsuitable habitat. From late August–mid-October 1993, caterpillar webs were surveyed on 34 fen grasslands. On sites <2 ha, all devil's bit scabious *Succisa pratensis* were searched in 2-m-wide parallel strips until the whole area had been searched. On larger sites, 2-m-wide strips at 10-m intervals were searched, and areas around caterpillar webs were then searched comprehensively.

A replicated, before-and-after study in 1992–2006 in a wet grassland in Wallonia, Belgium (3) found that cattle grazing reduced the use of wet grassland patches by bog fritillaries *Proclossiana eunomia*, and reduced the number of adults emerging. From 1–4 years after grazing of the wet grassland began, the number of bog fritillaries using grazed areas (6–10% of recaptures) was lower than before grazing started (17–44% of recaptures). The number of butterflies which emerged on grazed patches was also lower after grazing commenced than before grazing (data not presented). From July 2002–June 2004, Galloway cattle were grazed in a wet grassland reserve (June–September: 0.43–0.75 cows/ha; October–May: 0.11–0.38 cows/ha), but were excluded from four patches of high-quality bog fritillary habitat that were monitored (1.05 ha). In the grazed areas, three patches of low-quality habitat (1.26 ha) were monitored. From 1992–2006, bog fritillaries were monitored by catching, marking, releasing and re-catching individuals in all seven patches (details not provided). Each year, the "use rate" of each patch (number of recaptures within the patch divided by the total number of recaptures across all patches) and "emergence" (number of butterflies caught soon after emergence in each patch) were calculated.

A site comparison study in 2004–2008 on five wet grasslands in Cornwall, UK (4) found that sites grazed by cattle at an intermediate intensity supported the highest abundance of marsh fritillary *Euphydryas aurinina* caterpillars, but there was no difference in adult abundance between sites with different grazing intensities. The abundance of marsh fritillary caterpillar webs was higher at sites with intermediate grazing intensity (6.5 webs) than sites with high (1.6 webs) or low (3.7 webs) grazing intensity, but the abundance of adults did not differ between sites (data not presented). Five wet grasslands with populations of marsh fritillary were managed by cattle grazing at different intensities, and occasional burning (no further details provided). In May–June 2004–2008, adult butterflies were surveyed twice/year on 33 transects across the five sites. In August–September 2004–2008, caterpillar webs were surveyed on the same transects, and in fixed plots (number not specified). At 30 points along each transect, evidence of stock grazing was recorded to estimate grazing intensity.

A replicated, before-and-after study in 2014–2016 in six wet meadows in Świętokrzyskie Voivodeship, Poland (5) reported that after trees and shrubs were removed from the wet meadows the number of marsh fritillary *Euphydryas aurinia* caterpillar webs increased the following year. Results were not tested for statistical significance. One year after trees and shrubs were removed there were 14–57 webs/site, compared to 8–35 webs/site the previous year. From 2014–2015, six meadows were managed by manual cutting and mowing of trees and bushes (at one site marsh fritillary caterpillar webs were also marked with flags so that they could be avoided during mowing). In August–September 2014–2016, marsh fritillary caterpillar webs were surveyed at each site (four sites in 2014 and 2015, two sites in 2015 and 2016).

(1) Dolek M. & Geyer A. (1997) Influence of management on butterflies of rare grassland ecosystems in Germany. *Journal of Insect Conservation*, 1, 125–130.
(2) Lewis O.T. & Hurford C. (1997) Assessing the status of the marsh fritillary butterfly (*Eurodryas aurinia*): an example from Glamorgan, UK. *Journal of Insect Conservation*, 1, 159–166.
(3) Schtickzelle N., Turlure C. & Baguette M. (2007) Grazing management impacts on the viability of the threatened bog fritillary butterfly *Proclossiana eunomia*. *Biological Conservation*, 136, 651–660.
(4) Smee M., Smyth W., Tunmore M., ffrench-Constant R. & Hodgson D. (2011) Butterflies on the brink: habitat requirements for declining populations of the marsh fritillary (*Euphydryas aurinia*) in SW England. *Journal of Insect Conservation*, 15, 153–163.
(5) Błoński W. (2016) Preliminary assessment of active protection measures of the Marsh Fritillary *Euphydryas aurinia* (Rottemburg, 1775) habitats in the Świętokrzyski National Park. *Naturalia*, 5, 132–138.

3.41. Maintain or restore native wood pasture and parkland

- We found no studies that evaluated the effects of maintaining or restoring native wood pasture and parkland on butterflies and moths.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Wood pasture, where livestock are grazed at a low intensity under widely spaced mature trees, can support a diverse community of invertebrates, including butterflies and moths (Runquist 2011). For example, 12% of all British butterfly and moth species were recorded in a single summer in three small, traditionally managed orchards grazed by cattle (Smart & Winnall 2006). However, traditional wood pastures have been lost due to conversion into more intensive forms of agriculture or pasture, or abandonment. Restoring management may therefore benefit a wide range of butterflies and moths.

Runquist E. (2011) Butterflies, cattle grazing, and environmental heterogeneity in a complex landscape. *Journal of Research on the Lepidoptera*, 44, 61–76.

Smart M.J. & Winnall R.A. (2006) The biodiversity of three traditional orchards within the Wyre Forest SSSI in Worcestershire: a survey by the Wyre Forest Study Group (ENRR707). *English Nature Research Reports*, No 707.

3.42. Maintain upland heath/moorland

- **Three studies** evaluated the effects of maintaining upland heath/moorland on butterflies and moths. All three studies were in the UK[1–3].

COMMUNITY RESPONSE (1 STUDY)

- **Richness/diversity (1 study):** One replicated, randomized, controlled study in the UK[2] found that lightly grazed or ungrazed upland acid grassland had a higher species richness of moths than commercially grazed grassland.

POPULATION RESPONSE (3 STUDIES)

- **Abundance (3 studies):** Three controlled studies (including two replicated, randomized studies) in the UK[1–3] found that ungrazed[1,2], lightly grazed[2] or summer grazed[3] upland grassland had a higher abundance of adult moths[2], moth caterpillars[1] and all caterpillars[3] than grassland grazed at commercial stocking densities[1,2] or all year round[3].

BEHAVIOUR (0 STUDIES)

Background

Increased management of upland heath, or moorland, in particular by overgrazing, has led to a reduction in characteristic vegetation cover in favour of more dominant grass species, which are less favoured by sheep (Martin *et al.* 2013). A reduction in grazing pressure, or a switch to low intensity cutting or burning regimes, may allow moorland vegetation to recover, and in turn potentially support larger populations of heathland butterflies and moths.

See also "*Habitat restoration and creation – Restore or create heathland/shrubland*".

Martin D., Fraser M.D., Pakeman R.J. & Moffat A.M. (2013) Impact of moorland grazing and stocking rates. *Natural England Evidence Review*, Number 006, Report.

A replicated, randomized, controlled study in 2003–2005 on an upland grassland in Perthshire, UK (1, same experimental set-up as 2) found that the abundance of moth caterpillars was higher in ungrazed plots compared to lightly or commercially grazed plots after 30 months. After 18 months of grazing, there was no significant difference in the number of caterpillars on ungrazed (2.8 individuals/plot), lightly grazed (1.9–2.4 individuals/plot) and commercially grazed plots (2.3 individuals/plot). However, after 30 months, there were more caterpillars in the ungrazed plots (4.9 individuals/plot) than in the lightly grazed (1.9–2.4 individuals/plot) or commercially grazed plots (0.5 individuals/plot). From January 2003, three grazing regimes (light grazing: sheep at 0.9 ewes/ha; mixed grazing: sheep and cattle equivalent to 0.9 ewes/ha; commercial grazing: sheep at 2.7 ewes/ha) and an ungrazed treatment were replicated six times each in twenty-four 3.3-ha plots (in three pairs of adjacent blocks). Caterpillars were sampled by sweep net in 2003–2005.

A replicated, randomized, controlled study in 2003–2007 on an upland estate in Scotland, UK (2, same experimental set-up as 1) found that ungrazed and lightly grazed plots had a higher abundance and species richness of moths than plots grazed at a commercial stocking densities. Plots grazed by sheep at low density had a higher abundance (52 individuals/night) and species richness (12.3 species/night) of moths than plots grazed by sheep at commercial densities (abundance: 34 individuals/night; richness: 10.6 species/night), or plots grazed by sheep and cattle at low density (abundance: 42 individuals/night; richness: 11.3 species/night), and were similar to ungrazed plots (abundance: 48 individuals/night; richness: 13.2 species/night). In January 2003, one of four grazing treatments was established on each of 24 plots (3.3 ha each) on a grazed acid grassland upland estate. The treatments were: low density sheep grazing (3 sheep/plot); commercial high density sheep grazing (9 sheep/plot); low density mixed grazing (2 sheep/plot plus two cows and calves for 4 weeks in autumn); ungrazed control. Moths were sampled between June and October 2007 using four 15 W light traps placed randomly within plots of each treatment, for six or seven sample nights/plot.

A controlled study in 2002–2004 at an upland semi-natural grassland site in the Scottish Borders, UK (3) found that a site managed with low intensity grazing had a higher abundance of caterpillars than an intensively grazed site. A site which was only grazed in the summer had a higher abundance of caterpillars than a site which was grazed all year (data presented as statistical results). Two large (>40 ha) plots were grazed by 3–4 sheep/ha from autumn 2002: one during June–September only (low intensity grazing, 49.7 ha), the other year round (high intensity grazing, 74.9 ha). Invertebrates were sampled using pitfall transects (9 traps, 2 m apart) at 15 locations/plot for four weeks during May–June 2004.

(1) Dennis P., Skartveit J., McCracken D.I., Pakeman R.J., Beaton K., Kunaver A. & Evans D.M. (2008) The effects of livestock grazing on foliar arthropods associated with bird diet in upland grasslands of Scotland. *Journal of Applied Ecology*, 45, 279–287.
(2) Littlewood N.A. (2008) Grazing impacts on moth diversity and abundance on a Scottish upland estate. *Insect Conservation and Diversity*, 1, 151–160.
(3) Cole L.J., Pollock M.L., Robertson D., Holland J.P., McCracken D.I. & Harrison W. (2010) The influence of fine-scale habitat heterogeneity on invertebrate assemblage structure in upland semi-natural grassland. *Agriculture, Ecosystems & Environment*, 136, 69-80.

Perennial, non-timber crops

3.43. Maintain traditional orchards to benefit butterflies and moths

- **Two studies** evaluated the effects of maintaining traditional orchards on butterflies and moths. One study was in each of the USA[1] and Germany[2].

COMMUNITY RESPONSE (2 STUDIES)

- **Community composition (1 study):** One replicated, site comparison study in Germany[2] found that managed orchards had a similar community composition of butterflies and burnet moths to abandoned orchards.
- **Richness/diversity (2 studies):** One replicated, site comparison study in Germany[2] found that managed orchards had a similar species richness of butterflies and burnet moths to abandoned orchards. One controlled study in the USA[1] found that an unmanaged and a partially managed orchard had a greater species richness and diversity of leaf-eating arthropods (including caterpillars) than a commercially managed orchard.

POPULATION RESPONSE (1 STUDY)

- **Abundance (1 study):** One replicated, site comparison study in Germany[2] found that managed orchards had a lower abundance of butterflies and burnet moths than abandoned orchards.

BEHAVIOUR (0 STUDIES)

Background

Traditional orchards, with large numbers of veteran trees and managed with no chemical inputs, can support a diverse community of invertebrates, including butterflies and moths. For example, 12% of all British butterfly and moth species were recorded in a single summer in three small, traditionally managed orchards (Smart & Winnall 2006). However, the dual threats of intensification and abandonment have led to the loss of many traditionally managed orchards. Restoring and maintaining extensive, low-input management of orchards – including pruning trees, occasional mowing or light grazing between the trees, and limiting the application of pesticides and herbicides – may benefit a large number of butterfly and moth species.

Smart M.J. & Winnall R.A. (2006) The biodiversity of three traditional orchards within the Wyre Forest SSSI in Worcestershire: a survey by the Wyre Forest Study Group (ENRR707). *English Nature Research Reports*, No 707.

A controlled study in 1984–1988 in three orchards in West Virginia, USA (1) found that orchards with reduced management had more leaf-eating arthropod species, including caterpillars, and greater diversity, than a conventionally managed orchard. Three to five years after establishment, the number of species and diversity of leaf-eating arthropods (e.g. insects and mites) in an unmanaged (23–27 species) and a partially managed (21–33 species) orchard were higher than in a conventionally managed orchard (7–11 species, see paper for diversity data). Over five years, the diversity increased in the reduced management orchards, but in the conventionally managed orchard diversity decreased in the third year and remained low (see paper for details). In spring 1984, three orchards (0.30–0.35 ha) were planted with young trees (1–2 cm diameter). Two reduced management orchards had five apple cultivars at 5 × 4-m spacing. One conventional orchard had one apple cultivar at 5 × 7.5-m spacing. The unmanaged orchard was mown three times/year in 1984–1985, but unmanaged thereafter. The partially managed orchard was pruned commercially, with four annual herbicide applications and monthly mowing. The conventionally managed orchard was pruned and fertilized, mown every 3–4 weeks, and received regular herbicide and pesticide applications, which increased in the third year. From April–September 1984–1988, all leaf-eating arthropods were recorded on 5–10 randomly selected trees/orchard, 4–5 times/year.

A replicated, site comparison study in 2015 in 20 orchard meadows in Saxony, Germany (2) found that managed orchards had a lower abundance of butterflies and burnet moths than abandoned orchards, but species richness and community composition was similar between sites. In managed orchard meadows, the abundance of 35 species of farmland butterflies and burnet moths (16–36 individuals) and 20 species of woodland butterflies and burnet moths (17–20 individuals) was lower than in abandoned orchards meadows (farmland: 25–59; woodland: 36–39 individuals). However, the species richness of both farmland and woodland species was similar in managed (farmland: 4–7; woodland: 4 species) and abandoned (farmland: 4–9; woodland: 4–6 species) orchards. The community composition was also similar in managed and abandoned orchards (data presented as model results). Twenty orchard meadows (0.85–3.34 ha) were surveyed. Eight were managed by summer grazing (May–September, <1 animal/ha, with cattle, sheep, goat, horse or donkey), two were managed by mowing, and 10 were abandoned (not grazed or mown). From May–August 2015, butterflies and burnet moths were surveyed three times along a 20-minute transect on a 0.8 ha patch at each site. Butterflies and burnet moths were classified as 35 farmland and 20 woodland species.

(1) Brown M.W. & Welker W.V. (1992) Development of the phytophagous arthropod community on apple as affected by orchard management. *Environmental Entomology*, 21, 485–492.
(2) Ernst L.M., Tscharntke T. & Batary P. (2017) Grassland management in agricultural vs. forested landscapes drives butterfly and bird diversity. *Biological Conservation*, 216, 51–59.

3.44. Manage perennial bioenergy crops to benefit butterflies and moths

- **One study** evaluated the effects on butterflies and moths of managing perennial bioenergy crops to benefit butterflies and moths. This study was in the USA[1].

COMMUNITY RESPONSE (1 STUDY)

- **Richness/diversity (1 study):** One replicated, controlled study in the USA[1] found that plots planted with a diverse mix of bioenergy crops had a greater species richness of butterflies than plots planted with fewer species.

POPULATION RESPONSE (1 STUDY)

- **Abundance (1 study):** One replicated, controlled study in the USA[1] found that plots planted with a diverse mix of bioenergy crops had a higher abundance of butterflies than plots planted with fewer species.

BEHAVIOUR (0 STUDIES)

Background

Bioenergy crops are grown to produce oil, which is used as fuel in place of traditional fossil fuel derivatives. Perennial bioenergy crops, such as grasses, can be sown once and harvested for multiple years, which creates opportunities to establish grassland ecosystems, unlike annual cropping systems. Management of perennial bioenergy crops to benefit butterflies and moths may include changing the mix of seeds planted, altering the timing or frequency of harvest, or limiting the application of chemicals to the crop.

Studies on annual bioenergy crops are included within actions for annual crops, for example "*Increase crop diversity across a farm or farmed landscape*", "*Plant more than one crop per field (intercropping)*", "*Leave uncropped, cultivated margins or plots*" and "*Leave unharvested crop headlands within arable fields*". For studies which test reductions in chemical application alone, see "*Threat: Pollution*".

A replicated, controlled study in 2009–2010 on an arable farm in Iowa, USA (1) found that plots planted with a diverse mix of bioenergy crops had a higher abundance and species richness of butterflies than plots with a restricted range of grass species. On plots sown with 16 or 32 plant species, both the abundance (4–8 individuals/50 m) and species richness (3–5 species/month) of butterflies were higher than on plots sown with one or five plant species (abundance: 1–3 individuals/50 m; richness: 1–3 species/month). The difference was consistent across sandy loam, loam and clay loam soils. See paper for individual species results. In May 2009, forty-eight 0.30–0.56 ha plots were established across seven fields (3.7–6.1 ha) previously sown with soybean on a 40-ha farm. In each plot, one of four native seed mixes was sown: switchgrass *Panicum virgatum* monoculture, "warm-season mix" (five grasses), "biomass mix" (16 grasses, legumes and non-woody, broadleaved plants "forbs"), or "prairie mix" (32 grasses, legumes, forbs and sedges). There were four replicates of each mix on each of three soil types: sandy loam, loam and clay loam. All plots were mown to 10 cm height in July 2009. From June–September 2010, butterflies were surveyed along one 50-m transect/plot twice during each of five survey periods.

(1) Myers M.C., Hoksch, B.J. & Mason J.T. (2012) Butterfly response to floral resources during early establishment at a heterogeneous prairie biomass production site in Iowa, USA. *Journal of Insect Conservation*, 16, 457–472.

3.45. Manage vineyards to benefit butterflies and moths

- **Two studies** evaluated the effects on butterflies and moths of managing vineyards to benefit butterflies and moths. One study was in each of the USA[1] and Spain[2].

COMMUNITY RESPONSE (2 STUDIES)

- **Richness/diversity (2 studies):** One of two replicated, site comparison studies (including one paired study) in the USA[1] and Spain[2] found that grass strips between vine rows had a greater species richness of butterflies than the vine rows themselves, and vineyards managed with fewer chemicals had a greater species richness of butterflies than conventionally managed vineyards[2]. The other study found that vineyards managed to encourage native plants, and where insecticide was rarely used, had a similar species richness of butterflies to conventionally managed vineyards[1].

POPULATION RESPONSE (1 STUDY)

- **Abundance (1 study):** One replicated, paired, site comparison study in the USA[1] found that vineyards managed to encourage native plants, and where insecticide was rarely used, had a greater abundance of butterflies than conventionally managed vineyards.

BEHAVIOUR (0 STUDIES)

Background

As perennial crops, vineyards form large areas of consistent agricultural habitat across Mediterranean-type landscapes. Like other perennial crops, this creates opportunities to manage vineyards as complete ecosystems, by providing the resources which butterflies and moths need within the crop. This could include encouraging native plant species to grow around the vines, altering the timing or frequency of management such as pruning and tillage, or reducing the application of chemicals to the vines or surrounding habitat.

For studies which test reductions in chemical application alone, see "*Threat: Pollution*".

A replicated, paired, site comparison study in 2012–2013 in eight vineyards in Washington State, USA (1) found that vineyards which were managed to encourage native plants had a higher abundance, but not species richness, of butterflies than conventionally managed vineyards. Butterfly abundance was higher in habitat-enhanced vineyards (20 individuals/visit) than in conventionally managed vineyards (6 individuals/visit). Butterfly species richness was not significantly higher in enhanced vineyards (5.6 species/visit) than conventional vineyards (2.8 species/visit), although a total of 29 species were recorded in enhanced vineyards compared to nine in conventional vineyards over the two years. Four pairs of vineyards (0.5–32 km apart) were selected. In each pair, one "habitat-enhanced" vineyard had native plants restored at the site for five years (2 sites) or 15–20 years (2 sites), and insecticides were never, or rarely, used. The four "conventional" vineyards did not encourage native plants, frequently applied herbicides and occasionally sprayed pesticides. From May–September 2012–2013, butterflies were surveyed for 30–40 minutes every two weeks in each vineyard.

A replicated, site comparison study in 2013–2014 in 20 vineyards in Catalonia, Spain (2) found that grass strips between the crop lines had more butterfly species than the crop lines themselves. There were more species of butterfly along grass strips in vineyards (32–33 species) than along the crop lines (22–30 species). In addition, vineyards managed with fewer chemicals had more butterfly species (30–33 species) than conventionally managed vineyards (22–32 species). Twenty vineyards managed with uncultivated grass strips between the crop lines were surveyed. Ten vineyards were managed with fewer insecticide and herbicide (Glyphosate) applications/year than 10 conventionally managed vineyards. From April–August 2013–2014, butterflies were surveyed four times/year on two 100-m transects/vineyard in nine vineyards/year. One transect was along crop lines, and the other was along grass strips between crop lines.

(1) James D.G., Seymour L., Lauby G. & Buckley K. (2015) Beauty with benefits: butterfly conservation in Washington State, USA, wine grape vineyards. *Journal of Insect Conservation*, 19, 341–348.
(2) Puig-Montserrat X., Stefanescu C., Torre I., Palet J., Fàbregas E., Dantart J., Arrizabalaga A. & Flaquer C. (2017) Effects of organic and conventional crop management on vineyard biodiversity. *Agriculture, Ecosystems & Environment*, 243, 19–26.

3.46. Produce coffee in shaded plantations

- **Three studies** evaluated the effects on butterflies and moths of producing coffee in shaded plantations. Two studies were in Mexico[1,3] and one was in Puerto Rico[2].

COMMUNITY RESPONSE (2 STUDIES)

- **Richness/diversity (2 studies):** One paired sites, site comparison study in Mexico[1] found that a plantation with its original canopy but understory replaced with coffee had higher species richness of fruit-eating butterflies than one with its original canopy and understory replaced with coffee and other vegetation or those with canopies replaced with other shading trees and understories replaced with coffee with or without other vegetation. One site comparison study in Mexico[3] found that shaded coffee plantations had a higher species richness of caterpillars than a sun-grown monoculture.

POPULATION RESPONSE (2 STUDIES)

- **Abundance (2 studies):** Two site comparison studies (including one replicated study) in Puerto Rico[2] and Mexico[3] found that shade-grown coffee plantations had a greater abundance of caterpillars than sun-grown coffee plantations. One of these studies also found that the abundance of coffee leaf miner was similar in shade-grown and sun-grown plantations[2].

BEHAVIOUR (0 STUDIES)

Background

Coffee is often grown commercially in large monocultures, with no taller trees providing shade, often referred to as "sun-grown" coffee. However, as a perennial species which grows naturally in the forest understorey, coffee can also be grown among other, taller trees, which may or may not also provide a commercial product ("shade-grown coffee"). By retaining a more diverse forest structure, shade-grown coffee may allow a more diverse forest ecosystem to develop or persist, including communities of butterflies and moths. However, some species of moth, such as the coffee leaf miner, are a coffee pest, and growers may want to reduce their abundance (Borkhataria *et al.* 2012).

Borkhataria R.R., Collazo J.A. & Groom M.J. (2012) Species abundance and potential biological control services in shade vs. sun coffee in Puerto Rico. *Agriculture, Ecosystems & Environment*, 151, 1–5.

A paired sites, site comparison in 1998 in seven areas of shaded coffee plantation and forest in Chiapas, Mexico (1) found that a plantation with the original canopy retained and understory replaced with coffee ("rustic" management) had higher species richness of fruit-eating butterflies than a plantation with its original canopy retained and understory replaced with coffee and other vegetation ("traditional polyculture") or plantations with their original canopies replaced with other shading trees and understories replaced with coffee with ("commercial polyculture") or without other vegetation ("shaded monoculture"). The rustic plantation had higher species richness of fruit-eating butterflies (25) than traditional polyculture (10), commercial polyculture (10–11) and shaded monoculture (10) plantations. The rustic plantation had similar species richness to a nearby intact area of forest (27) but lower species richness than a further away forest (36). In two areas of Mexico, one rustic, one traditional polyculture, one shaded monoculture and two traditional polyculture plantations were surveyed. In summer 1998 at four points in each location (28 points in total) two fruit-baited traps were set, one in the understory and one in the canopy, for eight days. Estimated species richness was calculated statistically from numbers of butterflies caught in traps.

A replicated, site comparison study in 1999–2000 in six coffee plantations in Puerto Rico (2) found that shade-grown coffee plantations had a higher abundance of caterpillars than sun-grown coffee plantations. In shade-grown coffee plantations, the abundance of caterpillars (1.3 individuals/tree) was higher than in sun-grown plantations (0.6 individuals/tree). However, the abundance of a coffee pest species (coffee leaf miner *Leucoptera coffeela*) was not significantly different in shade-grown (2.0 individuals/tree) and sun-grown coffee (1.7 individuals/tree). In April 1999 and March–April 2000, caterpillars were surveyed in two or three randomly-located plots (>120 m apart) in each of three shade- and three sun-grown coffee plantations (1.35–5.95 ha). Caterpillars were surveyed by turning 100 leaves (>10 cm long, 0.5–2 m high) in each of 12–14 coffee trees/plot.

A site comparison study in 2016 in five coffee plantations in Veracruz, Mexico (3) found that shaded coffee plantations had a higher abundance and species richness of caterpillars than a sun-grown monoculture plantation. On four polyculture and shaded monoculture coffee plantations, the abundance (124–212 individuals) and species richness (83–129 species) of caterpillars was higher than in a sun-grown coffee monoculture (abundance: 47 individuals; richness: 46 species). In addition, the amount of damage found on coffee leaves was not related to either caterpillar abundance or species richness (data not presented). The management intensity of five coffee plantations was measured based on 10 vegetation characteristics (including canopy cover, epiphyte cover, area of shade trees and presence of herbs) and the frequency of six external inputs (fertilizers, insecticides, herbicides, fungicides, irrigation and ploughing). In July, September and December 2016, all caterpillars were collected by hand from all plants along three 30 × 2-m transects in the centre of each plantation, and reared to adults for species identification.

(1) Mas A.H. & Dietsch T.V. (2004) Linking Shade Coffee Certification to Biodiversity Conservation: Butterflies and Birds in Chiapas, Mexico. *Ecological Applications*, 14(3), 642-654.
(2) Borkhataria R.R., Collazo J.A. & Groom M.J. (2012) Species abundance and potential biological control services in shade vs. sun coffee in Puerto Rico. *Agriculture, Ecosystems & Environment*, 151, 1–5.
(3) Sosa-Aranda I., del-Val E., Hernández-Martínez G., Arroyo-Lambaer D., Uscanga A. & Boege K. (2018) Response of lepidopteran herbivore communities to crop management in coffee plantations. *Agriculture, Ecosystems & Environment*, 265, 37–44.

3.47. Grow native trees within perennial crop plantations

- **One study** evaluated the effects on butterflies and moths of growing native trees within perennial crop plantations. This study was in Costa Rica[1].

COMMUNITY RESPONSE (1 STUDY)

- **Richness/diversity (1 study):** One replicated, site comparison study in Costa Rica[1] found that coffee farms with a native and a non-native tree species growing within them had a higher diversity of butterflies than coffee farms with a single non-native tree species, but a similar diversity to coffee farms with two non-native tree species. The same study found a similar species richness of butterflies on all farms[1].

POPULATION RESPONSE (1 STUDY)

- **Abundance (1 study):** One replicated, site comparison study in Costa Rica[1] found that coffee farms with a native and a non-native tree species growing within them had a similar abundance of butterflies to coffee farms with one or two non-native tree species.

BEHAVIOUR (0 STUDIES)

Background

Perennial crops, such as coffee, chocolate, oil palm and vines, are planted and left in place for many years, with harvest taking place from mature plants. Many of these species are grown both within and outside their native ranges, but in all cases are often farmed in monocultures. However, it is possible to allow or encourage other plant species to grow among perennial crops, which may provide benefits in terms of natural pest control or disease resistance, as well as allowing native animals, including butterflies and moths, to persist among the crop.

See also "*Produce coffee in shaded plantations*".

A replicated, site comparison study in 2007 in 18 coffee farms and six forest fragments in Costa Rica (1) found that farms with a native tree species had a greater diversity of butterflies than farms with one non-native species, but a similar diversity to farms with two non-native species, while abundance and species richness were similar on all farms. On farms with coffee crops mixed with a native tree there was a higher diversity of forest butterflies than farms with crops mixed with one non-native tree, but a similar diversity to farms with crops mixed with two non-native trees and lower than forest fragments (see paper for details). However, the abundance (12.5 individuals/site) and species richness (6.5 species/site) of forest butterflies on farms with native trees was similar to farms with one (abundance: 15.8 individuals/site; richness: 4.3 species/site) or two non-native trees (abundance: 18.5 individuals/site; richness: 7.0 species/site), and lower on all farms than in forest fragments (abundance: 49.0 individuals/site; richness: 19.3 species/site). Eighteen coffee farms were managed with mountain immortelle *Erythrina poeppigiana* shade trees. Six farms also mixed crops with native salmwood *Cordia alliodora*, six mixed with non-native banana or plantain *Musa* spp., and six had no additional trees. From May–July 2007, butterflies were surveyed once/month along three parallel 80-m transects (25 m apart) in each farm, and in six forest fragments.

(1) Pérez-Garcia O., Benjamin T.J. & Tobar D.E. (2018) Modern coffee agroecosystems and their relationship with butterflies conservation in fragmented landscapes. *Revista De Biologia Tropical*, 66, 394–402.

4. Threat: Energy production and mining

Background

The impacts of energy production (renewable and non-renewable) on butterflies and moths are perhaps less severe than for other groups of animals, such as birds and bats (Williams *et al.* 2012, Berthinussen *et al.* 2014). Nonetheless, the design of infrastructure for energy production can still be improved, and the impact of prospecting for new fuel supplies can still be reduced, to minimize the effects on butterfly and moth populations. This chapter includes actions which aim to reduce the impacts of new and ongoing energy production, as well as the restoration of land after production has ceased. For more general actions that relate to habitat restoration or addressing impacts of pollution, see '*Habitat restoration and creation*' and '*Threat: Pollution*'.

Williams D.R., Pople R.G., Showler D.A., Dicks L.V., Child M.F., zu Ermgassen E.K.H.J. & Sutherland W.J. (2012) Bird Conservation: Global evidence for the effects of interventions. Exeter, Pelagic Publishing.

Berthinussen A., Richardson O.C. & Altringham J.D. (2014) Bat Conservation: Global evidence for the effects of interventions. Exeter, Pelagic Publishing.

4.1. Remove or change turbine lighting to reduce insect attraction

- We found no studies that evaluated the effects on butterflies and moths of removing or changing turbine lighting to reduce insect attraction.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Wind turbines, like other large structures, are illuminated at night to alert aircraft to their presence. However, lighting attracts nocturnal moths, reducing their ability to forage as well as causing direct mortality (van Langevelde *et al.* 2017). The colour or type of lighting used also affects how attractive lights are to moths, with shorter wavelength light (ultraviolet, blue and green) being more attractive than longer wavelengths (red and yellow; van Langevelde *et al.* 2011). Removing or changing the lighting used on turbines may therefore reduce their impact on moth populations.

For studies on reducing light pollution generally, see "*Threat: Pollution*".

van Langevelde F., Ettema J., Donners M., WallisDeVries M.F., Groenendijk D. (2011) Effect of spectral composition of artificial light on the attraction of moths. *Biological Conservation*, 144, 2274–2281.

van Langevelde F., van Grunsven R.H.A., Veenendaal E.M., Fijen T.P.M. (2017) Artificial night lighting inhibits feeding in moths. *Biology Letters*, 13, 20160874.

4.2. Change turbine colour to reduce insect attraction

- We found no studies that evaluated the effects of changing turbine colour to reduce attraction to butterflies and moths.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Like all insects, butterflies and moths are attracted to colours, but show greater attraction to some colours than others (Kevan 1983). Common wind turbine colours (white and grey) have been found to attract more insects, including butterflies and moths, than other colours such as purple (Long *et al.* 2011). Therefore, painting turbines in less attractive colours may reduce the disturbance caused to butterfly and moth behaviour.

Kevan P.G. (1983) Floral colors through the insect eye: what they are and what they mean. In: Jones C.E., Little R.J. (eds) Handbook of experimental pollination biology. Van Nostrand, New York, pp 3–25, Scientific and Academic Additions.

Long C.V., Flint J.A. & Lepper P.A. (2011) Insect attraction to wind turbines: does colour play a role? *European Journal of Wildlife Research,* 57, 323–331.

4.3. Reduce the size of surface features when prospecting for or extracting underground products

- **One study** evaluated the effects on butterflies and moths of reducing the size of surface features when prospecting for or extracting underground products. This study was in Canada[1].

COMMUNITY RESPONSE (1 STUDY)

- **Richness/diversity (1 study):** One replicated, site comparison study in Canada[1] found that narrow corridors used for prospecting for oil had a lower species richness of butterflies than wide corridors, but were similar to undisturbed forest.

POPULATION RESPONSE (1 STUDY)

- **Abundance (1 study):** One replicated, site comparison study in Canada[1] found that narrow corridors used for prospecting for oil had a lower abundance of butterflies than wide corridors, but were similar to undisturbed forest.

BEHAVIOUR (0 STUDIES)

Background

Prospecting for underground products, such as oil and gas, can require the destruction of habitat on the surface. Minimizing the footprint of these operations may reduce the disturbance to sensitive species. Note that smaller individual disturbances may require more patches of disturbance across the landscape, and therefore may not reduce the total area disturbed (Riva *et al.* 2018).

Riva F., Acorn J.H. & Nielsen S.E. (2018) Localized disturbances from oil sands developments increase butterfly diversity and abundance in Alberta's boreal forests. *Biological Conservation*, 217, 173–180.

A replicated, site comparison study in 2015 in a boreal forest in Alberta, Canada (1) found that narrow corridors used for prospecting for oil had a lower abundance and species richness of butterflies than wide corridors, but were more similar to undisturbed forest. In narrow, 3-m-wide corridors, the abundance (31 individuals/site) and species richness (8 species/site) of butterflies was lower than in 9-m-wide corridors (abundance: 95 individuals/site; richness: 15 species/site). However, narrow corridors were similar to undisturbed forest (abundance: 21 individuals/site; richness: 7 species/site). From 2000–2005, corridors (3 or 9 m wide) were cleared of trees to prospect for oil in a 25-km^2 area of previously undisturbed forest. From June–August 2015, butterflies were surveyed 11 times on five 200-m transects in corridors of each width, and in undisturbed forest patches which had received no wildfire or anthropogenic disturbance within 50 m for >80 years.

(1) Riva F., Acorn J.H. & Nielsen S.E. (2018) Localized disturbances from oil sands developments increase butterfly diversity and abundance in Alberta's boreal forests. *Biological Conservation*, 217, 173–180.

4.4. Restore or create new habitats after mining and quarrying

- **Four studies** evaluated the effects on butterflies and moths of restoring or creating new habitats after mining and quarrying. Two studies were in the Czech Republic[2,4], and one was in each of the UK[1] and New Zealand[3].

COMMUNITY RESPONSE (2 STUDIES)

- **Community composition (1 study):** One replicated, paired, site comparison study in the Czech Republic[4] found that 15% of 380 invertebrate species (including 208 moth species) were only found on flattened spoil heaps, compared to 30% which were only found on unflattened heaps.
- **Richness/diversity (2 studies):** One replicated, paired, site comparison study in the Czech Republic[2] found that technically restored quarries had a lower species richness of butterflies and day-flying moths than quarries left to restore naturally. One replicated, paired, site comparison study in the Czech Republic[4] found that flattened spoil heaps had a lower species richness of moths than unflattened spoil heaps.

POPULATION RESPONSE (2 STUDIES)

- **Abundance (2 studies):** One replicated, randomized, controlled study in the UK[1] found that on slate waste tips trees where fertilizer was applied had a similar abundance of caterpillars to trees that were unfertilized. One site comparison study in New Zealand[3] found that a peat bog restored after mining supported a similar density of Fred the thread moth caterpillars to undisturbed bogs.
- **Condition (1 study):** One site comparison study in New Zealand[3] found that a peat bog restored after mining supported Fred the thread moth caterpillars of a similar size to caterpillars on undisturbed bogs.

BEHAVIOUR (0 STUDIES)

Background

Former mining and quarrying sites are often hostile environments for butterflies and moths, as large areas of bare ground may remain sparsely vegetated for many decades (Rowe *et al.* 2006). However, many former extraction sites have been turned into important nature reserves over time since their abandonment (e.g. Turner *et al.* 2009). Restoration of such sites may involve a number of different actions, such as introducing soil or nutrients, planting desired vegetation communities, flooding areas or landscaping new features. A common approach for the restoration of post-mining sites is "technical reclamation", whereby the uneven surface is flattened by heavy machinery, before fertile soil is added and sown with grasses and herbs, and planted with trees. However, by accelerating succession, such an approach can reduce habitat availability for species which depend on disturbed, early successional habitats (Moradi *et al.* 2018).

Moradi J., Potocký P., Kočárek P., Bartuška M., Tajovský K., Tichánek F., Frouz J. & Tropek R. (2018) Influence of surface flattening on biodiversity of terrestrial arthropods during early stages of brown coal spoil heap restoration. *Journal of Environmental Management*, 220, 1–7.

Rowe E.C., Healey J.R., Edwards-Jones G., Hills J., Howells M. & Jones D.L. (2006) Fertilizer application during primary succession changes the structure of plant and herbivore communities. *Biological Conservation*, 131, 510–522.

Turner E.C., Granroth H.M.V., Johnson H.R., Lucas C.B.H., Thompson A.M., Froy H., German R.N. & Holgate R. (2009) Habitat preference and dispersal of the Duke of Burgundy butterfly (*Hamearis lucina*) on an abandoned chalk quarry in Bedfordshire, UK. *Journal of Insect Conservation*, 13, 475–486.

A replicated, randomized, controlled study in 2000–2001 in a former slate quarry in North Wales, UK (1) found that applying fertilizer to trees on slate waste tips did not increase the abundance of caterpillars. On fertilized birch and willow trees in a former quarry, the number of caterpillars (1.3 individuals/m^2 leaf) was not significantly different from the number on unfertilized trees in the quarry (1.0 individuals/m^2 leaf) or on trees in undisturbed woodland (2.0 individuals/m^2 leaf). Twenty birch *Betula* spp. and 20 willow *Salix* spp. trees were selected in an area of nutrient-poor slate waste which had been partly colonized by trees over 40–100 years since quarrying. The site was grazed by sheep at low density (0.1 ewes/ha). On 23 May 2000 and 2001, fertilizer (175 kg nitrogen/ha, 53 kg phosphorus/ha, 188 kg potassium/ha) was applied to a 2.25 m^2 plot around 10 trees of each species. In May, June and July 2000 and 2001, a small branch (4–5 mm diameter) from the top of each birch tree was enclosed in a bag and cut, and the caterpillars collected in the bag were counted. In 2001 only, caterpillars were sampled from willow trees using the same method. Each year, caterpillars were also sampled from 10 trees of the same species from an adjacent, undisturbed woodland.

A replicated, paired, site comparison study in 2007 in five former limestone quarries in the Bohemian Karst, Czech Republic (2) found that technically restored quarries had a lower species richness of butterflies and day-flying moths than quarries left to restore naturally. In technically restored quarries, the species richness of all butterflies and day-flying moths (17 species/plot) was lower than in naturally restored quarries (24 species/plot). In addition, the species richness of xeric habitat specialists, and species of conservation concern, was also lower in technically restored quarries (xeric: 5–6; conservation: 0–2 species/plot) than in naturally restored quarries (xeric: 8–15; conservation: 3–7 species/plot). Five pairs of plots (0.2–0.3 ha, 0–150 m apart) were monitored in five quarries which had been abandoned for 10–60 years. In each pair, one plot had been "technically restored" (site covered with topsoil, fast-growing herbs sown, trees planted) and the other had been left to develop naturally ("spontaneous succession"). From May–August 2007, butterflies and day-flying moths were surveyed five times along two perpendicular transects through each plot (50 m/5 min).

A site comparison study in 2013 in a restored peat mine and three native peat bogs in Waikato region, New Zealand (3) found that a peat bog restored after mining supported a similar density of Fred the thread moth caterpillars *Houdinia flexilissima* to three undisturbed bogs, and caterpillars were a similar size at each site. Eleven to 15 years after restoration from mining, a restored peat bog had a similar density of Fred the thread caterpillars (1–2 caterpillars/m of stem) to three undisturbed sites (1–2 caterpillars/m of stem). The caterpillars were a similar size in the restored (9–11 mm) and undisturbed bogs (5–10 mm). Within a 150-ha peat mine, mined strips (45 m wide, 950 m long) had been restored 11–15 years earlier by creating raised islands of processed peat (5 m diameter, 30 cm high, 30 m apart) which were seeded with mānuka *Leptospermum scoparium*, which was eventually outcompeted by bamboo rush *Sporadanthus ferrugineus*. The islands reached 100% vegetation cover in two years. The restored areas were adjacent to 40 ha of unmined peat. From March–April 2013, twenty 60-cm-long sections of bamboo rush stems were collected from a 33-cm-diameter plot on each of two islands (20 m apart, 600 m from unmined peat) in each of three restored strips, and from 6–14 plots in each of three undisturbed bogs (114–10,201 ha). Stems were dissected in the lab to count caterpillars.

A replicated, paired, site comparison study in 2014 in an open-cast mine spoil heap in Sokolov district, Czech Republic (4) found that areas left to regenerate without flattening had more species of moth than flattened areas. The species richness of moths in unflattened areas (16 species/plot) was higher than in flattened areas (10 species/plot). However, the only endangered species recorded, purple tiger *Rhyparia purpurata*, did not show a preference for unflattened or flattened areas (data not presented). Of 380 species of invertebrate recorded (including 208 species of moth), 30% were only found in unflattened areas, and 15% were only found in flattened areas. From 1996–2009, most of a spoil heap was flattened by bulldozing, but patches were left with 1-m-high piles in rows, ~6 m apart. No topsoil was added to the site. Four pairs of unflattened and flattened 1-ha plots (~250 m apart) of a similar age were selected. Pairs were ~1 km apart. From May–September 2014, moths were sampled once/fortnight using two UV light traps/plot, set 50 m apart.

(1) Rowe E.C., Healey J.R., Edwards-Jones G., Hills J., Howells M. & Jones D.L. (2006) Fertilizer application during primary succession changes the structure of plant and herbivore communities. *Biological Conservation*, 131, 510–522.

(2) Tropek R., Kadlec T., Karesova P., Spitzer L., Kocarek, Petr, Malenovsky I., Banar P., Tuf I.H., Hejda M. & Konvicka M. (2010) Spontaneous succession in limestone quarries as an effective restoration tool for endangered arthropods and plants. *Journal of Applied Ecology*, 47, 1, 139–147.
(3) Watts C., Thornburrow D., Clarkson B. & Dean S. (2013) Distribution and abundance of a threatened stem-boring moth, *Houdinia flexilissima* (Lepidoptera: Batrachedridae) in New Zealand peat bogs. *Journal of Research on the Lepidoptera*, 46, 81–89.
(4) Moradi J, Potocký P., Kočárek P., Bartuška M., Tajovský K., Tichánek F., Frouz J. & Tropek R. (2018) Influence of surface flattening on biodiversity of terrestrial arthropods during early stages of brown coal spoil heap restoration. *Journal of Environmental Management*, 220, 1–7.

5. Threat: Transportation and service corridors

Background

Transportation and service corridors, such as roads, railways and power lines, pose a number of threats to butterflies and moths, from the fragmentation of important habitat to the risk of direct mortality with vehicle traffic. However, the design and location of transportation and service corridors, and the subsequent management of the land immediately under or adjacent to them, may provide opportunities to minimize these threats. Further threats from transportation and service corridors include the destruction of habitat and pollution. Actions in response to these threats are described in '*Habitat restoration and creation*' and '*Threat: Pollution*'.

5.1. Design the route of roads to maximize habitat block size

- We found no studies that evaluated the effects on butterflies and moths of designing the route of roads to maximize habitat block size.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

The construction of new roads can not only destroy tracts of habitat, but fragment remaining areas into smaller, more isolated blocks. However, more careful planning may allow impacts to be reduced by routing new roads around, rather than through, important habitat. This could conserve larger patches of habitat for butterflies and moths.

5.2. Restore or maintain species-rich grassland along road/railway verges

- **Eight studies** evaluated the effects on butterflies and moths of restoring or maintaining species-rich grassland along road or railway verges. Three studies were in the USA[3,6,8] and one was in each of Germany[1], the UK[2], Finland[4], Poland[5], and Canada[7].

COMMUNITY RESPONSE (6 STUDIES)

- **Richness/diversity (6 studies):** Four replicated, site comparison studies (including one paired study) in Germany[1], the UK[2,] the USA[3] and Finland[4] found that restored roadside prairies[3], verges sown with native wildflowers[1], with more butterfly species' larval food plants[2], with more species of plants[4] and with more plants in flower[2] had a higher species richness[1,2,3] and diversity[2] of butterflies[1,2,3], day-flying moths[1], burnet moths[2] and meadow-specialist moths[4] than verges dominated by non-native vegetation[1,3] or with fewer butterfly species' larval food plants[2], fewer plant species[4], and fewer plants in flower[2]. However, one of these studies also found that verges sown with more plant species did not have higher species richness of meadow-specialist butterflies[4]. One replicated, site comparison study in Canada[7] found that road verges and land under power lines managed by mowing once or twice a year, or not at all, had a similar species richness of butterflies to remnant prairies. One replicated, site comparison study in Poland[5] found that wide road verges had a higher species richness of butterflies than narrow road verges.

POPULATION RESPONSE (7 STUDIES)

- **Abundance (5 studies):** Two of three replicated, site comparison studies (including one paired study) in the UK[2], the USA[3] and Finland[4] found that restored roadside prairies[3] and verges sown with more butterfly species' larval food plants[2] had a greater abundance of butterflies[2,3] and burnet moths[2] than verges dominated by non-native vegetation[3] or with fewer butterfly species' larval food plants[2]. However, one of these studies also found that verges with more plants in flower did not have a greater abundance of butterflies and burnet moths than verges with fewer plants in flower[2]. The other study found that verges sown with more plant species did not have a greater abundance of meadow-specialist butterflies or moths[4]. One replicated, site comparison study in Canada[7] found that road verges and land under power lines managed by mowing once or twice a year, or not at all, had a similar abundance of butterflies to remnant prairies. One replicated, site comparison study in Poland[5] found that wide road verges had a greater abundance of butterflies than narrow road verges.
- **Survival (3 studies):** One of two replicated, site comparison studies (including one paired study) in the USA[3,8] found that restored prairie road verges had a lower mortality risk for butterflies than verges dominated by non-native grasses[3]. The other study found more dead butterflies and moths on roads with tall meadow verges than on roads with frequently mown, non-native, short grass verges or wooded verges[8]. This study also found more dead butterflies and moths on roads with habitat in the central reservation than on roads without habitat in the central reservation[8]. One replicated, site comparison study in Poland[5] found that less frequently mown road verges, and verges mown later in the summer, had fewer dead butterflies than verges which were mown more frequently or earlier in the summer.
- **Condition (1 study):** One replicated, site comparison study in the USA[6] found that monarch caterpillars living on road verges mown once or twice a year had a similar number of parasites to caterpillars living in mown and unmown prairies.

BEHAVIOUR (0 STUDIES)

Background

Grass verges beside transportation corridors may offer an opportunity to provide habitat patches in their own right, as well as to connect larger areas of grassland across the landscape (Munguira & Thomas 1992), although the butterfly community found in remnant habitat along road verges may differ from that found in large blocks of native habitat (Davis *et al.* 2008). However, roads pose a risk of mortality due to collision with vehicles, a risk which may be higher for smaller species (Skórka *et al.* 2013). Road verges with more native plant species have a greater abundance and species richness of native butterflies (Skórka *et al.* 2013, Leston & Koper 2016), although this can also increase the number of butterflies which fly into the road (Zielin *et al.* 2016). However, the number of individuals killed on the road may be lower next to verges which have a higher species richness of plants (Skórka *et al.* 2013). This suggests that restoring or maintaining species-rich grassland may provide an opportunity to conserve butterflies and moths along transportation corridors.

For studies on reducing collision risk on roads, see "*Use infrastructure to reduce vehicle collision risk along roads*". For management options for road verges, see "*Residential and commercial development – Alter mowing regimes for greenspaces and road verges*" and "*Pollution – Stop using herbicides on pavements and road verges*". For other studies on habitat connectivity, see "*Habitat protection – Retain connectivity between habitat patches*" and "*Habitat restoration and creation – Restore or create habitat connectivity*".

Munguira M.L. & Thomas J.A. (1992) Use of road verges by butterfly and burnet populations, and the effect of roads on adult dispersal and mortality. *Journal of Applied Ecology*, 29, 316–329.

Davis J.D., Hendrix S.D., Debinski D.M. & Hemsley C.J. (2008) Butterfly, bee and forb community composition and cross-taxon incongruence in tallgrass prairie fragments. *Journal of Insect Conservation*, 12, 69–79.

Skórka P., Lenda M., Moroń D., Kalarus K. & Tryjanowski P. (2013) Factors affecting road mortality and the suitability of road verges for butterflies. *Biological Conservation*, 159, 148–157.

Leston L. & Koper N. (2016) Urban Rights-of-Way as Reservoirs for Tall-Grass Prairie Plants and Butterflies. *Environmental Management*, 57, 543–557.

Zielin S.B., Littlejohn J., de Rivera C.E., Smith W.P. & Jacobson S.L. (2016) Ecological investigations to select mitigation options to reduce vehicle-caused mortality of a threatened butterfly. *Journal of Insect Conservation*, 20, 845–854.

A replicated, site comparison study in 1992–1996 in urban road verges in Baden-Württemberg, Germany (1) reported that road verges sown with native wildflowers had a greater species richness of butterflies and day-flying moths than verges with non-native vegetation. Results were not tested for statistical significance. Over four years, eight butterfly and moth species were recorded on two verges sown with wildflowers, compared to none on verges with non-native plants. Only one species, small white *Pieris rapae*, occurred every year in the sown verges. Two road verges (1,100–1,500 m^2, up to 5–35 m wide) on busy roads in the centre of Stuttgart were sown with annual and biennial native wildflowers including white stonecrop *Sedum album*, common self-heal *Prunella vulgaris*, greater knapweed *Centaurea scabiosa* and wild carrot *Daucus carota*. For comparison, an unspecified number of vegetated road verges that contained non-native bearberry cotoneaster *Cotoneaster dammeri*, scarlet firethorn *Pyracantha ccoccinea* and cultivated roses were also surveyed. From April–August 1992–1994 and 1996, butterflies and day-flying moths were surveyed 6–10 times/year on each verge, and plants were occasionally searched for caterpillars.

A replicated, site comparison study in 1989 along 12 road verges in Dorset and Hampshire, UK (2) found that there was higher butterfly and burnet moth abundance, species richness and diversity along verges containing more species' larval food plants, and higher butterfly and burnet moth species richness and diversity, but not abundance, along verges with more plants in flower. There was higher abundance, species richness and diversity of butterflies/burnet moths along verges containing more plant species that represented larval food plants for more species. There was also higher species richness and diversity of butterflies/burnet moths along verges with more plants in flower, but this did not affect the total abundance of butterflies. Additionally, there was higher butterfly/burnet moth abundance and species richness, but not diversity, along wider verges. All data are presented as model results. Weekly from June–September 1989, butterflies and burnet moths were surveyed along a 100 x 2 m transect at each of 12 A-road verges in Dorset and Hampshire. Plants in flower were recorded along a 50 cm strip along the 100-m transect. A verge was considered to contain a species' larval food plant if there were 30 examples of it at the site.

A replicated, paired, site comparison study in 1998 in 12 road verges in Iowa, USA (3) found that restored roadside prairies where herbicide application was restricted had a higher abundance and species richness of habitat-sensitive butterflies than verges dominated by non-native weeds or grasses with no herbicide restrictions. On restored roadside prairies, both the abundance (2.3 individuals/plot) and species richness (1.6 species/plot) of habitat-sensitive butterflies was higher than on roadsides dominated by non-native weeds (abundance: 1.4 individuals/plot; richness: 0.9 species/plot) or grasses (0.5 individuals/plot; 0.7 species/plot), and not significantly different from remnant prairies (1.6 individuals/plot; 1.7 species/plot). In addition, mortality risk was lower on prairie or weedy road verges than on non-native grass verges (data presented as model results). On eight well-established, restored prairie road verges (>0.5 km long) and four native (never ploughed) prairie verges dominated by native prairie vegetation, the use of herbicides was restricted. Roadside vegetation (>6 m wide) within 1.6 km of the 12 prairies was classified as "weedy" (>20% non-native legumes) or "grassy" (dominated by non-native grasses). From June–August 1998, butterflies were surveyed nine times in 1–3 plots/habitat (restored prairie, native prairie, weedy, grassy) at each of 12 sites. Plots were 50 × 5 m, >50 m apart and >500 m from a different verge habitat. In addition, three plots in each of four native prairie remnants (2–16 ha) were surveyed. Roadkill butterflies were surveyed six times along both road edges next to each plot.

A replicated, site comparison study in 2002–2003 along 51 road verges in South Karelia, Finland (4) found that meadow-specialist moth, but not butterfly, species richness was higher along road verges with higher plant species richness, but plant species richness did not affect meadow-specialist butterfly or moth abundance. Richness of all butterfly and moth species and meadow-specialist butterfly species, and abundance of all individuals and meadow-specialist butterflies and moths were not affected by plant species richness, but meadow-specialist moth species richness was higher along verges with higher plant species richness. In additional, total species richness and species richness and abundance of meadow-specialist moths were not affected by the abundance of nectar-bearing plants, but abundance of all butterflies and moths, and meadow-specialist butterfly species richness and abundance, were higher along verges with a higher abundance of nectar-bearing plants. No raw data was provided. In June–August 2002–2003, butterflies and day-flying moths were surveyed weekly along thirteen 250-m transects on 51 verges of highways, urban roads and rural roads on the route from Lappeenranta to Imatra in south-eastern Finland. Plant species were recorded monthly June–August in ten 1-m^2 quadrats every 25 m along transects and the number of plants in flower was converted to an index of nectar abundance.

A replicated, site comparison study in 2010 in 60 road verges in southern Poland (5) found that less frequently or later mown road verges had fewer individuals and a lower species diversity of dead butterflies than more frequently or earlier mown verges, and wide road verges attracted a higher abundance and species richness of butterflies than narrower road verges. Both the number of individual butterflies and number of species killed by traffic were lower on verges mown less frequently, or later in the summer, than on more frequently or earlier mown verges (data presented as model results). In addition, both the abundance and species richness of butterflies on wider road verges was higher than on narrow verges, and higher on verges with a greater species richness of plants (data presented as model results). Sixty roads, >2 km apart, with verges of similar width and vegetation on each side, were selected. Between roads, verges differed in the frequency and timing at which they were mown. From April–September 2010, butterflies were surveyed 12 times on two 100-m transects along each side of each road. Dead butterflies were collected from the asphalt and the first metre of verge next to the road. Live butterflies were counted within 2.5 m of the road edge.

A replicated, site comparison study in 2012 along three highways and in three prairies in Oklahoma, USA (6) found that monarch *Danaus plexippus* caterpillars living on managed road verges had a similar number of parasites to caterpillars on lightly managed prairies. There was no significant difference in the rate of infection with parasitic flies *Lespesia archippivora* or protists *Ophryocystis elektroscirrha* between caterpillars from road verges (*L. archippivora*: 28%; *O. elektroscirrha*: 28% infected) and prairies (*L. archippivora*: 42%; *O. elektroscirrha*: 24% infected). A total of 47 caterpillars were collected from road verges, and 76 from prairies. Between April and October 2012, the verges of three highways were mown once or twice and sprayed with herbicide, and three managed prairies (0.07–0.19 km^2) were mown once or not at all. From April–May and September–October 2012, every milkweed *Asclepias viridis* plant in three 1,000 × 40 m survey areas (2 km apart) along each highway, and on the whole area of each prairie, was inspected 2–4 times/week and all large monarch caterpillars were collected and reared in the lab. The number of *L. archippivora* parasites which emerged from caterpillars or pupae were counted, and adult monarchs were checked for the presence of *O. elektroscirrha* spores.

A replicated, site comparison study in 2007–2008 along 52 road verges and power lines (collectively "transmission lines") in Manitoba, Canada (7) found that managed grassland along transmission lines had a similar overall abundance and species richness of butterflies to remnant prairie fragments, but there were differences for individual species. The abundance and species richness of native butterflies along transmission lines (10–14 individuals/visit; 21–32 species) was statistically similar to remnant tall-grass prairie fragments (12 individuals/visit; 20 species). The abundance of native skippers (Hesperiidae) was higher on transmission lines cut once/year without haying (0.8 individuals/visit) than on native prairie (0.12 indiviuals/visit). The abundance of northern pearl crescent *Phyciodes morpheus* and pearl crescent *Phyciodes tharos* was higher on unmown transmission lines (2.7 individuals/visit) than on remnant prairie (0.4 individuals/visit), but lower on transmission lines mown twice/year (0.1 individuals/visit). There were also fewer fritillaries on transmission lines mown twice/year (0.1 individuals/visit) than on prairie remnants (0.5 individuals/visit). The abundance of monarch *Danaus plexippus* on all transmission lines (1–2 individuals/visit) was lower than on remnant prairie (5 individuals/visit). See paper for other species results. Fifty-two road verges and power lines (>30 m wide, >400 m long) were managed in one of four ways: 21 were neither mown nor sprayed with herbicide, but some trees were removed; 10 were mown once/year with cuttings left on site and sprayed infrequently with herbicide; seven were mown once/year with cuttings baled and removed with no spraying; 14 were mown twice/year with cuttings left on site and sprayed frequently with herbicide. Four similarly-sized remnant tall-grass prairie fragments (two urban, two rural) were managed by prescribed burning on a >3-year rotation. From 15 June–15 August 2007–2008, butterflies were surveyed on one 400- or 500-m transect at each site 2–4 times/year.

A replicated, site comparison study in 2015 on 30 roads in Delaware, Maryland and Pennsylvania, USA (8) found that more butterflies and other insects including moths were killed on roads with meadow verges than on roads bordered by mown, non-native grasses or woods, and mortality was higher on roads with habitat in the central reservation. The number of dead butterflies on roads with meadow verges (2.9–10.0 individuals/site) was higher than on roads with mown grass verges (1.0–3.9 individuals/site) or wooded verges (0.3–0.8 individuals/site). In addition, the number of dead butterflies was higher on roads with habitat in the central reservation (0.8–10.0 individuals/site) than on roads with no habitat in the central reservation (0.3–2.9 individuals/site). The results for other insects, including moths, were similar (see paper for details). Thirty road sections, 200 m long, >400 m apart, with speed limits between 70–105 km/h and high traffic volumes, were classified to three habitat categories: meadow verges dominated by wildflowers and tall grass; frequently mown, short, non-native grass verges; and wooded verges dominated by trees and shrubs. Roads were further split by the presence or absence of a vegetated central reservation. In June 2015, all dead insects were initially removed from the road edge on both sides of the road. From June–July 2015, all dead insects were collected from the road edge five times, at weekly intervals, and identified to species.

(1) Schwenninger H.R. & Wolf-Schwenninger K. (1998) Modifiying landscaped verges for conservation: new urban habitats for bees and butterflies? *Natur und Landschaft*, 73, 386–392.

(2) Munguira M.L. & Thomas J.A. (1992) Use of road verges by butterfly and burnet populations, and the effect of roads on adult dispersal and mortality. *Journal of Applied Ecology*, 29, 316-329.

(3) Ries L., Debinski D.M. & Wieland M.L. (2001) Conservation value of roadside prairie restoration to butterfly communities. *Conservation Biology*, 15, 401–411.

(4) Saarinen K., Valtonen A., Jantunen J., Saarnio S. (2005) Butterflies and diurnal moths along road verges: Does road type affect diversity and abundance? *Biological Conservation*, 123(3), 403-412.

(5) Skórka P., Lenda M., Moroń D., Kalarus K. & Tryjanowski P. (2013) Factors affecting road mortality and the suitability of road verges for butterflies. *Biological Conservation*, 159, 148–157.

(6) Mueller E.K. & Baum K.A. (2014) Monarch-parasite interactions in managed and roadside prairies. *Journal of Insect Conservation*, 18, 847–853.
(7) Leston L. & Koper N. (2016) Urban Rights-of-Way as Reservoirs for Tall-Grass Prairie Plants and Butterflies. *Environmental Management*, 57, 543–557.
(8) Keilsohn W., Narango D.L. & Tallamy D.W. (2018) Roadside habitat impacts insect traffic mortality. *Journal of Insect Conservation*, 22, 183–188.

5.3. Minimize road lighting to reduce insect attraction

- We found no studies that evaluated the effects on butterflies and moths of minimizing road lighting to reduce insect attraction.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Illuminating roads at night is an important part of traffic and pedestrian safety, but poses a risk to moths which are attracted to artificial lights, and therefore disrupted from their natural behaviours such as feeding and reproduction. Minimizing lighting on roads, either by reducing the number or intensity of lights, restricting the timing of lighting, or using motion-sensitive lighting which only activates when required, may help to reduce the impacts on moth populations.

For studies on reducing the impacts of lighting generally, see actions under "*Threat: Pollution*".

5.4. Use infrastructure to reduce vehicle collision risk along roads

- **One study** evaluated the effects on butterflies and moths of using infrastructure to reduce vehicle collision risk along roads. This study was in the USA[1].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (0 STUDIES)

BEHAVIOUR (1 STUDY)

- **Behaviour change (1 study):** One controlled study in the USA[1] reported that "altitude guide" netting, and poles topped with bright colours or flowers (attractive features), did not alter the behaviour of Oregon silverspot around roads.

Background

Collisions with vehicles on roads represent a serious mortality risk for butterflies and moths, especially for low-flying species which rarely go above the height of standard cars. For example, between 1 and 11% of 95 road crossings by Oregon silverspot *Speyeria zerene hippolyta* resulted in mortality (Zielin *et al.* 2016). Artificial structures may be used to try to encourage butterflies and moths to fly higher before crossing the road, therefore reducing the chances of collisions with vehicles.

Zielin S.B., Littlejohn J., de Rivera C.E., Smith W.P. & Jacobson S.L. (2016) Ecological investigations to select mitigation options to reduce vehicle-caused mortality of a threatened butterfly. *Journal of Insect Conservation*, 20, 845–854.

A controlled study in 2012 on a disused road in Oregon, USA (1) reported that "altitude guide" netting, and poles topped with bright colours or flowers, did not alter the behaviour of Oregon silverspot *Speyeria zerene hippolyta* butterflies. Results were not tested for statistical significance. Of 54 Oregon silverspots which encountered a net erected next to a road, only 10 flew over it, compared to 29 which flew around it, two which walked through it, and 13 which turned around. Of the 39 butterflies which flew over or around the net, 10 subsequently landed on the road. When the net was not present, 35 out of 60 butterflies flew between the net poles, nine turned around, and only four butterflies landed on the road. In a second experiment, of 41 Oregon silverspot that flew within one metre of poles topped with bright colours or flowers (attractive features), none ascended to the top. In 2012, a decommissioned road was divided into ten 8 × 7 m^2 sections, spanning the 4-m-wide road and 2 m either side. Six trials, consisting of four 15-minute observation periods, were conducted on different sections. For two periods/trial, a 3-m-tall, 2-cm mesh net was stretched between two pairs of poles (7 m apart) on each side of the road, and for the other two periods the nets were absent. No further details provided. On 25 August and 1 September 2012, seven 1-m-high poles topped with attractive features: a bright colour (red: 3 poles, yellow: 2 poles) or flowers (2 poles), were observed for a total of 90 minutes. No further details provided.

(1) Zielin S.B., Littlejohn J., de Rivera C.E., Smith W.P. & Jacobson S.L. (2016) Ecological investigations to select mitigation options to reduce vehicle-caused mortality of a threatened butterfly. *Journal of Insect Conservation*, 20, 845–854.

5.5. Manage land under power lines for butterflies and moths

- **Six studies** evaluated the effects on butterflies and moths of managing land under power lines for butterflies and moths. Two studies were in each of the USA[1,2] and Finland[4,5], and one was in each of the UK[3] and Canada[6].

COMMUNITY RESPONSE (3 STUDIES)

- **Richness/diversity (3 studies):** Two replicated, site comparison studies (including one paired study) in Finland[4,5] found that land under power lines managed by mechanical cutting had a higher species richness of butterflies than unmanaged land[4], and butterfly species richness was highest 2–4 years after scrub and trees were cleared[5]. One replicated, site comparison study in Canada[6] found that the species richness of butterflies was similar under power lines and on road verges mown once or twice a year, or left unmown.

POPULATION RESPONSE (6 STUDIES)

- **Abundance (6 studies):** One of two replicated, site comparison studies (including one paired study) in Finland[4] and Canada[6] found that land under power lines managed by mechanical cutting had a higher abundance of butterflies than unmanaged land[4]. The other study found that land under power lines and on road verges managed by mowing had a lower abundance of pearl crescent and northern pearl crescent butterflies, and a similar abundance of other butterflies, to those left unmown[6]. Two of three site comparison studies (including two replicated studies) in the USA[1], the UK[3] and Finland[5] found that the time since management under power lines did not affect the abundance of Karner blue butterflies[1] or small pearl-bordered fritillaries[3], but chequered skipper abundance was higher in areas cleared ≤2 years ago than in areas cut ≥4 years earlier[3]. The other study found that power lines cleared of trees and scrub 2–4 years earlier had a higher abundance of butterflies than power lines cleared 1 year or 6–8 years earlier[5]. Two site comparison studies in the USA[1,2] found that land under power lines managed by cutting or herbicide application[1], and by mowing or cutting[2], had a similar abundance of Karner blue butterflies[1] and six other butterfly species[2], but the abundance of frosted elfin was higher under power lines managed by mowing than those managed by cutting[2].

BEHAVIOUR (1 STUDY)

- **Use (1 study):** One replicated, site comparison study in the UK[3] reported that pearl-bordered fritillaries used areas under power lines where scrub had been cleared one or two years earlier, but not under power lines cleared three or more years ago[3].

Background

Land under power lines offers a number of conservation opportunities. Management must maintain early successional habitats by suppressing the growth of woody species, to prevent interference with the electric lines. This could have benefits for butterflies and moths, which often favour these lightly disturbed habitats (Forrester *et al.* 2005). In addition, by running across the landscape, power lines may provide connectivity between other patches of suitable habitat. However, the methods used to control vegetation – primarily herbicide application or cutting – may affect the quality of the habitat created (Smallidge *et al.* 1996), while the frequency of management may be important for maintaining stretches of habitat in optimal conditions (Ravenscroft 2006).

For other studies on retaining or managing habitat connectivity along linear features, see "*Restore or maintain species-rich grassland along road/railway verges*" and "*Habitat protection – Retain connectivity between habitat patches*".

Forrester J.A., Leopold D.J. & Hafner S.D. (2005) Maintaining critical habitat in a heavily managed landscape: Effects of power line corridor management on Karner blue butterfly (*Lycaeides melissa samuelis*) habitat. *Restoration Ecology*, 13, 488–498.

Ravenscroft N. (2006) Management for invertebrates in North Argyll and Lochaber: the effects of cyclical clearance of wayleaves on butterflies. *Scottish Natural Heritage Commissioned Report* No. 162 (ROAME No. F04LG01).

Smallidge P.J., Leopold D.J. & Allen C.M. (1996) Community characteristics and vegetation management of Karner blue butterfly (*Lycaeides melissa samuelis*) habitats on rights-of-way in east-central New York, USA. *Journal of Applied Ecology*, 33, 1405–1419.

A site comparison study in 1990 along 16 power line rights-of-way in New York State, USA (1) found that the type of management used under power lines did not affect Karner blue butterfly *Lycaeides melissa samuelis* abundance. Karner blue population size was similar along power lines managed by cutting vegetation and those managed by applying herbicide (data presented as model results). The average number of years since management was not significantly different between sites with a large (3.3 years), small (3.0 years) or no Karner blue population (4.6 years). Sixteen power line rights-of-way were managed by applying herbicides or cutting vegetation on 3–8-year cycles, and data on at least the last two methods used at each site were available. Karner blue butterflies were surveyed at each site in 1990, and the maximum number seen during a visit was used as an estimate of population size. Sites were classified as having a large (>20 individuals), small (1–20 individuals) or no population of Karner blue butterflies.

A site comparison study in 1988–1996 along two power line rights-of-way in Wisconsin, USA (2) found that one out of seven butterflies was more abundant on a right-of-way managed by mowing than on a right-of-way managed by cutting. Frosted elfin *Callophrys irus* were more abundant along a mown power line right-of-way (4 individuals/hour) than on a right-of-way managed by unintensive cutting (0 individuals/hour). Six other species (Olympia marble *Euchloe olympia*, Karner blue *Lycaeides melissa samuelis*, gorgone checkerspot *Chlosyne gorgone*, Persius duskywing *Erynnis persius*, Leonard's skipper *Hesperia leonardus leonardus*, dusted skipper *Atrytonopsis hianna*) had a similar abundance on the mown and cut right-of-way (see paper for details). One power line right-of-way through pine barrens was managed by mowing, and a second was managed by unintensive cutting. Between 1988–1996, butterflies were surveyed on transects at each site, but not in every year.

A replicated, site comparison study in 2005 along 24 power lines through woodland in North Argyll and Lochaber, UK (3) found that land under power lines managed within the last two years had more chequered skipper *Carterocephalus palaemon* than areas managed over four years ago, but numbers of small pearl-bordered fritillary *Boloria selene* were similar across time since management. In areas cut ≤2 years ago, there were more chequered skippers (1.4–1.7 individuals/minute) than in areas cut ≥4 years earlier (0.1 individuals/minute), and numbers were higher on 16–24-m-wide power lines (2.0 individuals/minute) than on 10–16-m-wide (1.3 individuals/minute) or 25–31-m-wide (1.0 individuals/minute) power lines. The number of small pearl-bordered fritillary was similar in areas cleared ≤1 year ago (1.4 individuals/minute) and 2–3 years ago (1.2 individuals/minute). Pearl-bordered fritillaries *Boloria euphrosyne* occurred at all four power lines cleared ≤1 year ago (0.8 individuals/minute), but at only two of 13 power lines cleared 2 years ago (0.2 individuals/minute), and were absent from ≥3-year-old clearances (statistical significance not assessed). Scrub under 24 power lines was normally cut in autumn or winter, and areas were last cut between 2000/01 and 2004/05. From May–June 2005, butterflies were surveyed weekly along one or more timed 100-m transects under each power line.

A replicated, paired, site comparison study in 2004–2006 in 15 drained pine mires under a power line in central Finland (4, same experimental set-up as 5) found that land under power lines managed by mechanical cutting had a higher abundance and species richness of butterflies than nearby unmanaged land, and was similar to natural mires. In managed land under power lines, the abundance and species richness of both butterflies which depend on mires (abundance: 13–56 individuals/transect; richness: 4–5 species/transect) and other butterflies (abundance: 14–284 individuals/transect; richness: 6–9 species/transect), were higher than in nearby unmanaged areas (mire species: 3–8 individuals/transect, 1–2 species/transect; others: 4–50 individuals/transect, 3–4 species/transect). The abundance and species richness under power lines was also similar to natural mires (mire species: 17–43 individuals/transect, 3–5 species/transect; others: 18–107 individuals/transect, 4–5 species/transect). For 50 years, vegetation was cut every six years to maintain open, treeless habitat on drained mires under a 65-m-wide powerline, but was unmanaged next to the power line where forest developed. From June–August 2004 and June–July 2006, butterflies were surveyed every 5–10 days on paired 250-m transects within and 70 m outside the power line at 15 sites (1.5–4 ha, 0.5–18 km apart). Butterflies were also surveyed at five 2–6 ha undrained mires, 0.5–2 km from the drained mires. Butterflies which feed on plants that predominantly grow in mires were classified as mire-dependent species.

A replicated, site comparison study in 2004–2008 in 17 drained mires under a power line in central Finland (5, same experimental set-up as 4) found that clearing trees and shrubs from under power lines increased the abundance and species richness of butterflies. Two–four years after clearing, the abundance of both mire-dependent (25–29 individuals/transect) and non-mire-dependent butterflies (103–126 individuals/transect) was higher than both one year after clearing (mire: 19 individuals/transect; non-mire: 61 individuals/transect) and 6–8 years after clearing (mire: 5–16 individuals/transect; non-mire: 6–47 individuals/transect). The species richness of non-mire butterflies was higher 1–3 years after clearing (7.4–8.1 species/transect) than 6–8 years after clearing (4.4–5.9 species/transect), but time since clearing did not affect the species richness of mire-dependent species (1–3 years: 4.0–4.4 species/transect; 6–8 years: 3.4–4.1 species/transect). See paper for individual species results. Between winter 1996–1997 and 2003–2004, seventeen drained mires (0.5–18 km apart) under a 65-m-wide power line were mechanically cleared of trees and shrubs. Ten of these sites were cleared again between winter 2004–2005 and 2007–2008. In June–July 2004 and 2006–2008, butterflies were recorded along one 250-m transect/site, 3–8 times/year at 5–10-day intervals. Two sites were only monitored in 2007 and 2008. Butterflies which feed on plants that predominantly grow in mires were classified as mire-dependent species.

A replicated, site comparison study in 2007–2008 along 52 power lines and road verges (collectively "transmission lines") in Manitoba, Canada (6) found that unmown transmission lines had more northern pearl crescent *Phyciodes morpheus* and pearl crescent *Phyciodes tharos* butterflies than lines mown twice/year, but mowing regime did not affect the abundance or species richness of other butterflies. There were more crescent butterflies on unmown transmission lines (2.7 individuals/visit) than on lines mown twice/year (0.1 individuals/visit). However, the abundance and species richness of other native butterflies was not significantly different between transmission lines which were not mown (abundance: 11 individuals/visit; richness: 32 species), mown once/year and not hayed (11 individuals/visit; 27 species), mown once/year and hayed (14 individuals/visit; 21 species), mown twice/year and sprayed with herbicide (10 individuals/visit; 21 species), and remnant tall-grass prairie fragments (12 individuals/visit; 20 species). See paper for species results. Fifty-two power lines and road verges (>30 m wide, >400 m long) were managed in one of four ways: 21 were neither mown nor sprayed with herbicide, but some trees were removed; 14 were mown twice/year with cuttings left on site and sprayed frequently with herbicide; 10 were mown once/year with cuttings left on site and sprayed infrequently with herbicide; seven were mown once/year with cuttings baled and removed with no spraying. Four similarly-sized remnant tall-grass prairie fragments (two urban, two rural) were managed by prescribed burning on a >3-year rotation. From 15 June–15 August 2007–2008, butterflies were surveyed on one 400- or 500-m transect at each site 2–4 times/year.

(1) Smallidge P.J., Leopold D.J. & Allen C.M. (1996) Community characteristics and vegetation management of Karner blue butterfly (*Lycaeides melissa samuelis*) habitats on rights-of-way in east-central New York, USA. *Journal of Applied Ecology*, 33, 1405–1419.
(2) Swengel A.B. & Swengel S.R. (1997) Co-occurrence of prairie and barrens butterflies: applications to ecosystem conservation. *Journal of Insect Conservation*, 1, 131–144.
(3) Ravenscroft N. (2006) Management for invertebrates in North Argyll and Lochaber: the effects of cyclical clearance of wayleaves on butterflies. *Scottish Natural Heritage Commissioned Report* No. 162 (ROAME No. F04LG01).
(4) Lensu T., Komonen A., Hiltula O., Paivinen J., Saari V. & Kotiaho J.S. (2011) The role of power line rights-of-way as an alternative habitat for declined mire butterflies. *Journal of Environmental Management*, 92, 2539–2546.
(5) Komonen A., Lensu T. & Kotiaho J.S. (2013) Optimal timing of power line rights-of-ways management for the conservation of butterflies. *Insect Conservation and Diversity*, 6, 522–529.
(6) Leston L. & Koper N. (2016) Urban Rights-of-Way as Reservoirs for Tall-Grass Prairie Plants and Butterflies. *Environmental Management*, 57, 543–557.

6. Biological resource use

Background

This chapter includes actions designed to mitigate the threat posed by the use or exploitation of biological resources, including direct exploitation of butterflies and moths, and harvesting of their habitats.

Historically, the collecting of butterflies and moths was a popular activity, and may have contributed to the decline of some species (Collins & Morris 1985, Duffey 1968). Although this is a much less common practice today, the threat posed by collecting, particularly of rare species with small population sizes, remains large. On the other hand, well-managed, sustainable harvesting of abundant but popular species can provide an important community income, which may incentivise conservation (Gordon & Ayiemba 2003, Hutton 1985).

Timber plantations are a valuable source of income around the world, and have historically replaced not only native forest, but a range of other habitat types, such as grassland, peatland and wetland, through active afforestation. Plantation monocultures typically have little value for butterflies and moths, as they lack the diversity of resources which species require. However, plantations covering large areas can be managed with native habitat patches preserved or restored, for example with native forest along riparian strips, or grassland along access roads (New Generation Plantations Platform 2017). Within a plantation, especially of native trees, management can also work to increase structural diversity through variation in felling times, or by planting a mix of profitable native species instead of a single species monoculture.

Collins N.M. & Morris M.G. (1985) Threatened Swallowtail Butterflies of the World: The IUCN Red Data Book. IUCN, Gland, Switzerland & Cambridge, UK, pg 155–180.

Duffey E. (1968) Ecological studies on the large copper butterfly *Lycaena dispar* (Haw.) *batavus* (Obth.) at Woodwalton Fen National Nature Reserve, Huntingdonshire. *Journal of Applied Ecology*, 5, 69–96.

Gordon I. & Ayiemba W. (2003) Harnessing Butterfly Biodiversity for Improving Livelihoods and Forest Conservation: The Kipepeo Project. *The Journal of Environment & Development*, 12, 82–98.

Hutton A.F. (1985) Butterfly farming in Papua New Guinea. *Oryx*, 19(3), 158–162.

New Generation Plantations Platform (2017) Plantations for people, planet and prosperity: 10 years of the New Generation Plantations platform 2007–2017. https://newgenerationplantations.org/multimedia/file/ff98c77e-77cb-11e3-92fa-005056986314/

Hunting & collecting

6.1. Legally protect butterflies and moths

- We found no studies that evaluated the effects of legally protecting butterflies and moths.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Historically, the widespread collection of butterflies and moths by private collectors was a popular activity, and may have contributed to the decline of some rarer species (Collins & Morris 1985, Duffey 1968). Today, collecting is illegal in many parts of the world, and rarer species are often subject to specific legal protection. However, it should be noted that for understudied species, carefully regulated collection for scientific research can yield valuable insights into species' diversity, ecology and conservation. This action is for studies testing the impact of legal protection on wild populations of butterflies and moths, either across all species, or using species-specific legislation.

Collins N.M. & Morris M.G. (1985) Threatened Swallowtail Butterflies of the World: The IUCN Red Data Book. IUCN, Gland, Switzerland & Cambridge, UK, pg 155–180.

Duffey E. (1968) Ecological studies on the large copper butterfly *Lycaena dispar* (Haw.) *batavus* (Obth.) at Woodwalton Fen National Nature Reserve, Huntingdonshire. *Journal of Applied Ecology*, 5, 69–96.

6.2. Use education programmes and local engagement to reduce persecution or exploitation of species

- We found no studies that evaluated the effects of using education programmes and local engagement to reduce persecution or exploitation of butterflies and moths.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Although many species of butterflies and moths are among the most popular insects, others are maligned as crop pests or clothes-eaters, or misunderstood simply because they are nocturnal. Increasing public understanding of the importance and beauty of butterflies and moths can counteract this, reducing the frequency of negative behaviours towards them, or even raising funds for their conservation. On the other hand, some rare species of butterfly and moth are still threatened by collecting, and in this case, education may be used to raise awareness of the species' plight with the aim of changing behaviour. This action is for studies which test the impact of either type of education programmes on butterfly and moth populations.

Logging & wood harvesting

6.3. Legally protect large native trees

- We found no studies that evaluated the effects on butterflies and moths of legally protecting large native trees.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Trees, in particular large, old individuals of native species, provide a range of important resources for butterflies and moths. Many species feed on trees as caterpillars, or nectar from them as adults, and trees also provide perches from which they can defend territories, or shelter where they can rest (Thomas & Lewington 2016). However, trees may take 100 years or more to reach large sizes, making them functionally irreplaceable components of the landscape. Therefore, when harvesting trees for commercial use, legally mandating the protection of large, native individuals may have a disproportionate impact on the conservation of butterflies and moths which rely on them.

Thomas J.A. & Lewington R. (2016) *The Butterflies of Britain and Ireland*. Third edition, Bloomsbury Publishing, London, UK.

6.4. Strengthen cultural traditions such as sacred groves that prevent timber harvesting

- We found no studies that evaluated the effects on butterflies and moths of strengthening cultural traditions that prevent timber harvesting.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Forests have important cultural value in many societies around the world, which has led to many areas being protected under local tradition or law. As the surrounding forest is logged or managed, these cultural sites may become increasingly important for conservation, as they preserve intact, primary forest. However, national Governments or logging companies which do not respect local traditions may seek to exploit these sites and, if offered enough money or improvements to their livelihoods, local people may agree or be forced to accept this. Strengthening cultural traditions which protect forests, either within local communities or by lobbying national Governments, may help to prevent exploitation of these important sites.

6.5. Use selective or reduced impact logging instead of conventional logging

- **Four studies** evaluated the effects on butterflies and moths of using selective or reduced impact logging instead of conventional logging. Two studies were in Brazil[3,4] and one was in each of Sweden[1] and the USA[2].

COMMUNITY RESPONSE (3 STUDIES)

- **Community composition (1 study):** One replicated, site comparison study in Brazil[4] found that forests managed by reduced impact logging at different intensities had a different community composition of fruit-feeding butterflies to pristine forest.
- **Richness/diversity (3 studies):** One replicated, controlled, before-and-after study in the USA[2] found that forests harvested by single tree selection had a similar species richness of moths to forests managed by group selection harvesting or clearcutting, but a lower species richness than unharvested forest. One site comparison study in Brazil[3] found that a forest managed by reduced impact logging had a similar species richness and diversity of butterflies to primary forest. One replicated, site comparison study in Brazil[4] found that forests managed by reduced impact logging at different intensities had a similar species richness of fruit-feeding butterflies.

POPULATION RESPONSE (3 STUDIES)

- **Abundance (3 studies):** One replicated, randomized, paired, controlled study in Sweden[1] found that selectively logged forests had a higher abundance of exposed moth caterpillars, but a similar abundance of concealed moth caterpillars, to clearcut forests, and a similar abundance of all moth caterpillars to undisturbed forests. One site comparison study in Brazil[3] found that a forest managed by reduced impact logging had a higher abundance of butterflies than primary forest. One replicated, site comparison study in Brazil[4] found that forests managed by reduced impact logging at intermediate intensity had a higher abundance of fruit-feeding butterflies than forests managed by high or low intensity reduced impact logging.

BEHAVIOUR (0 STUDIES)

Background

Harvesting timber within forests can be carried out by clearcutting sites or by various methods of harvesting a proportion of trees. Selective logging is the removal of selected trees within a forest based on criteria such as diameter, height, or species. Remaining trees are left in the stand, as opposed to conventional clearcutting where all trees are felled. Reduced impact logging is a sustainable harvesting and management method that aims to minimize ecological disturbance. It involves selective logging as well as other practices such as mapping large target trees prior to felling, limiting the number of trees which can be felled/hectare, pre-cutting heavy vines and controlling the direction in which trees fall to minimize collateral damage, and planning the routes of access roads to reduce disturbance (Montejo-Kovacevich *et al.* 2018, Ribeiro & Freitas 2012). The aim is to preserve the integrity of the forest structure, which may also be termed “continuous cover forestry” if the canopy remains intact.

For other options for harvesting timber, see "*Harvest groups of trees or use thinning instead of clearcutting*", "*Use patch retention harvesting instead of clearcutting*", "*Use leave-tree harvesting instead of clearcutting*", "*Use shelterwood harvesting instead of clearcutting*" and "*Retain riparian buffer strips during timber harvest*".

Montejo-Kovacevich G., Hethcoat M.G., Lim F.K.S., Marsh C.J., Bonfantti D., Peres C.A. & Edwards D.P. (2018) Impacts of selective logging management on butterflies in the Amazon. *Biological Conservation*, 225, 1–9.

Ribeiro D.B. & Freitas A.V.L. (2012) The effect of reduced-impact logging on fruit-feeding butterflies in Central Amazon, Brazil. *Journal of Insect Conservation*, 16, 733–744.

A replicated, randomized, paired, controlled study in 1992 in three boreal forests in Lapland, Sweden (1) found that bilberry *Vaccinium myrtillus* plants in selectively logged forests had a higher abundance of exposed moth caterpillars, but not concealed caterpillars, than clearcut forests. The abundance of exposed caterpillars (Geometridae and Noctuidae, which crawl on leaves while feeding) in selectively logged forests (2.3–3.5 individuals/m^2) was higher than in clearcut forests (0.3–1.3 individuals/m^2), and similar to undisturbed forests (3.0–5.7 individuals/m^2). However, the abundance of concealed caterpillars (Tortricidae and Pyralidae, which spin leaves together and live between them) was not significantly different in selectively logged (0 individuals/m^2), clearcut (0–0.3 individuals/m^2) and undisturbed (0–1.3 individuals/m^2) forests. Three forests were each divided into three 20-ha stands, which were randomly assigned to three treatments: selective logging (30% of trees and 45–50% of tree volume removed), clearcutting (all trees removed, followed by soil scarification and artificial regeneration), and undisturbed. Felling was staggered between winter 1987/88 and 1991/92. From late June–early July 1992, caterpillars feeding on bilberry were counted in three randomly placed 0.1-m^2 plots in each of 10 sites within each stand.

A replicated, controlled, before-and-after study in 2007–2009 in three hardwood forests in Indiana, USA (2) found that timber harvesting method, including selective logging, did not affect the number of moth species, but all harvested forest stands had fewer species than unharvested stands. One year after harvesting, there was no significant difference in the number of moth species between stands subjected to single-tree harvesting (39 species), group-selection harvesting (40 species) or shelterwood harvesting and clearcutting (46 species, data not separated), but all harvested stands had fewer species than unharvested stands (56 species). One year before harvesting, all stands had a similar number of moth species (single-tree: 85; group-selection: 100; shelterwood/clearcutting: 96; unharvested: 90 species). In 2008, forest stands (3–5 ha, 150–350 m apart) in three watersheds (500 ha, 10 km apart) were logged. In one watershed, four stands had random single trees removed, and four stands were harvested by group-selection (80% of trees removed). In a second watershed, three stands were shelterwood harvested (15% of trees removed), two stands were clearcut (100% of trees removed), and three stands were unharvested (no trees removed). In the third watershed, all four stands were unharvested. All stands had been clearcut around 60 years earlier. From June–August 2007 and 2009, moths were surveyed every 14 nights (five times/year) from 8pm–7am using a black-light trap placed 2 m above the ground in the centre of each forest stand.

A site comparison study in 2007 in a rainforest in Amazon State, Brazil (3) found that forests managed by reduced impact logging had a higher abundance, but similar species richness and diversity, of butterflies than unlogged, primary forest. In a forest managed by reduced impact logging, the abundance of butterflies (644 individuals) was higher than in an unlogged forest (447 individuals), but the species richness was not significantly different between reduced impact logging (62 species) and unlogged (54 species) forest. The diversity of butterflies was also similar between forest types (data presented as model results). See paper for individual species results. An 8,100-ha area of forest was managed under reduced impact logging for three years. Trees of 70 valuable species, >50 cm diameter at breast height, were selected and harvested by directional felling. A maximum of six trees/ha could be felled every 30 years. A 7,500-ha primary forest, which had never been logged, was also studied. From July–November 2007, butterflies were sampled for 14 days/month using 50 baited traps/forest. Traps were placed in groups of ten, 900 m apart. Within each group, traps were 100 m apart and alternated between the understorey (1.5 m above ground) and the canopy (20 m above ground). Traps were visited every 48 hours to replace bait and collect captured butterflies.

A replicated, site comparison study in 2015–2016 in 40 tropical forest sites in Rondônia, Brazil (4) found that intermediate intensity reduced impact logging (RIL) produced higher fruit-feeding butterfly (Nymphalidae) abundance, but not species richness, compared to low or high intensity RIL. Three to five years after logging, RIL sites logged at intermediate intensity had a higher abundance of butterflies (7.7 individuals/site/48 hours) than RIL sites logged at low (2.9 individuals/site/48 hours) or high (3.0 individuals/site/48 hours) intensity. Species richness was similar at intermediate (1.9 species/site/48 hours), low (1.7 species/site/48 hours) and high (1.7 species/site/48 hours) intensity RIL sites. However, community composition at logged sites was different to pristine forest (data presented as model results). From 2011–2012, reduced impact logging was conducted at 40 sites (>100 m apart, >250 m from roads or rivers). All timber trees >40 cm diameter were mapped prior to logging, and pre-felling vine cutting and directional felling were used to minimize disturbance. Logging intensity ranged from 0 (low) to 36.9 (high) m^3 timber/ha (0–6 trees/ha), with intermediate logging at 18.6 m^3 timber/ha. In the 2015 and 2016 dry seasons, fruit-feeding butterflies were sampled in 50-m radius plots at 40 logged sites and 20 pristine forest sites. Three baited cylindrical traps/plot were suspended 15–25 m apart, 1 m above the ground, and the surrounding undergrowth was cleared. Traps were open for 12 consecutive days, and visited every 48 hours to replace bait and record butterflies.

(1) Atlegrim O. & Sjöberg K. (1996) Effects of clear-cutting and single-tree selection harvests on herbivorous insect larvae feeding on bilberry (*Vaccinium myrtillus*) in uneven-aged boreal *Picea abies* forests. *Forest Ecology and Management*, 87, 139–148.
(2) Summerville K.S. (2011) Managing the forest for more than the trees: effects of experimental timber harvest on forest Lepidoptera. *Ecological Applications*, 21, 806–816.
(3) Ribeiro D.B. & Freitas A.V.L. (2012) The effect of reduced-impact logging on fruit-feeding butterflies in Central Amazon, Brazil. *Journal of Insect Conservation*, 16, 733–744.

(4) Montejo-Kovacevich G., Hethcoat M.G., Lim F.K.S., Marsh C.J., Bonfantti D., Peres C.A. & Edwards D.P. (2018) Impacts of selective logging management on butterflies in the Amazon. *Biological Conservation*, 225, 1–9.

6.6. Harvest groups of trees or use thinning instead of clearcutting

- **Three studies** evaluated the effects on butterflies and moths of harvesting groups of trees or using thinning instead of clearcutting. All three studies were in the USA[1–3].

COMMUNITY RESPONSE (3 STUDIES)

- **Richness/diversity (3 studies):** One controlled, before-and-after study in the USA[3] found that the species richness of macro-moths was higher after a forest was harvested by thinning, than after harvest by patch-cutting or clearcutting, and the richness in the thinned forest was similar to an unharvested forest. One replicated, controlled, before-and-after study in the USA[1] found that forests managed by group selection harvesting had a similar species richness of moths to forests managed by single tree harvesting or clearcutting, but a lower species richness than unharvested forest. One replicated, controlled, before-and-after study in the USA[2] found that moth species richness recovered at a similar rate after management by group selection harvesting or clearcutting, but recovery in both was slower than after shelterwood harvesting.

POPULATION RESPONSE (0 STUDIES)

BEHAVIOUR (0 STUDIES)

Background

Harvesting of timber within forests can be carried out by clearcutting sites or by various methods of harvesting a proportion of trees. Forests naturally undergo disturbances such as storms and lightning that can create open patches. Similarly, group selection harvesting and thinning are harvest methods designed to reduce the density of trees within a forest, without removing substantial areas of canopy cover, and may create a mix of different habitats which suit different species of butterflies and moths.

Note that by thinning, rather than felling a whole forest, larger areas would need to be managed in order to achieve the same timber harvest, though some degree of forest cover can be retained over that area.

For other options for harvesting timber, see "*Use selective or reduced impact logging instead of conventional logging*", "*Use patch retention harvesting instead of clearcutting*", "*Use leave-tree harvesting instead of clearcutting*", "*Use shelterwood harvesting instead of clearcutting*" and "*Retain riparian buffer strips during timber harvest*".

A replicated, controlled, before-and-after study in 2007–2009 in three hardwood forests in Indiana, USA (1, same experimental set-up as 2) found that timber harvesting method, including group-selection harvesting, did not affect the number of moth species, but all harvested forest stands had fewer moths than unharvested stands. One year after harvesting, there was no significant difference in the number of moth species between stands subjected to group-selection harvesting (40 species), single-tree harvesting (39 species) or shelterwood harvesting and clearcutting (46 species, data not separated), but all harvested stands had fewer species than unharvested stands (56 species). One year before harvesting, all stands had a similar number of moth species (group-selection: 100; single-tree: 85; shelterwood/clearcutting: 96; unharvested: 90 species). In 2008, forest stands (3–5 ha, 150–350 m apart) in three watersheds (500 ha, 10 km apart) were logged. In one watershed, four stands were harvested by group-selection (80% of trees removed) and four stands had random single trees removed. In a second watershed, three stands were shelterwood harvested (15% of trees removed), two stands were clearcut (100% of trees removed), and three stands were unharvested (no trees removed). In the third watershed, all four stands were unharvested. All stands had been clearcut around 60 years earlier. From June–August 2007 and 2009, moths were surveyed every 14 nights (five times/year) from 8pm–7am using a black-light trap placed 2 m above the ground in the centre of each forest stand.

A replicated, controlled, before-and-after study in 2007–2011 in two hardwood forests in Indiana, USA (2, same study as 1) found that after group-selection harvesting, the number of moth species did not recover faster than after clearcutting, and both were slower to recover than after shelterwood harvesting. Three years after group-selection harvesting, the total number of moth species (52 species/stand) was similar to after clearcutting (48 species/stand), and both were lower than before harvesting (group-selection: 100; clearcutting: 98 species/stand) or after shelterwood harvesting (73 species/stand). After group-selection harvesting, the number of specialist species (8 species/stand) was lower than before harvest (19 species/stand), or after shelterwood harvesting (23 species/stand). However, the number of herbaceous-feeding species was higher after group-selection harvesting (10 species/stand) and clearcutting (16 species/stand) than before harvesting (group-selection: 3; clearcutting: 4 species/stand), but remained similar after shelterwood harvesting (after: 6; before: 4 species/stand). In 2008, forest stands (3–5 ha, 350–750 m apart) in two watersheds (500 ha, 10 km apart) were logged. In one watershed, four stands were harvested by group-selection (80% of trees removed) and four stands were unharvested. In a second watershed, three stands were shelterwood harvested (15% of trees removed), two stands were clearcut (100% of trees removed), and three stands were unharvested. All stands had been clearcut around 60 years earlier. From June–August 2007 and 2009–2011, moths were surveyed every 14 nights (five times/year) from 8pm–7am using a black-light trap placed 2 m above the ground in the centre of each forest stand.

A controlled, before-and-after study in 2007–2014 in two hardwood forest blocks in Indiana, USA (3) found that thinned areas had more macro-moth species than patch-cut or clearcut areas, and a similar number to unharvested areas. One–six years after management, the species richness of macro-moths in thinned areas (40–68 species/site) was higher than in patch-cut (30–52 species/site) or clearcut (34–54 species/site) areas, and was similar to shelterwood harvested (53–75 species/site) and unharvested areas (56–84 species/site). Before harvesting, all areas had similar species richness (thinned: 84; patch-cut: 99; clearcut: 96;

shelterwood: 95; unharvested: 90 species/site). However, after management, the total species richness in the thinned and patch-cut block was 122–162 species, compared to 144–190 species in the shelterwood and clearcut block, whereas before management richness was similar (thinned/patch-cut: 203; shelterwood/clearcut: 198 species; statistical significance not assessed). Two ~100 ha regenerated forest blocks were managed in autumn 2008. In one "uneven-aged" block, two 2.0-ha, two 1.2-ha and four 0.4-ha areas were patch-cut, and the remaining area was thinned by single-tree selection. In one "even-aged" block, two 4.1-ha areas were clearcut, two 4.1-ha areas were shelterwood harvested (midstory and understory cleared), and the remaining area was not harvested. From May–August 2007 and 2009–2014, macro-moths were sampled on five nights/year (once/fortnight) using 12 W black-light traps. Traps were placed in the centre of 16 patches: four patch-cut and four thinned sites within the uneven-age block, and two clearcut, three shelterwood and three unharvested sites within the even-age block. Species represented by fewer than three individuals were excluded.

(1) Summerville K.S. (2011) Managing the forest for more than the trees: effects of experimental timber harvest on forest Lepidoptera. *Ecological Applications*, 21, 806–816.
(2) Summerville K.S. (2013) Forest lepidopteran communities are more resilient to shelterwood harvests compared to more intensive logging regimes. *Ecological Applications*, 23, 1101–1112.
(3) Murray B.D., Holland J.D., Summerville K.S., Dunning J.B., Saunders M.R. & Jenkins M.A. (2017) Functional diversity response to hardwood forest management varies across taxa and spatial scales. *Ecological Applications*, 27, 1064–1081.

6.7. Use patch retention harvesting instead of clearcutting

- We found no studies that evaluated the effects on butterflies and moths of using patch retention harvesting instead of clearcutting.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Harvesting of timber within forests can be carried out by clearcutting sites or by various methods of harvesting a proportion of trees. Patch retention harvesting may be used as an alternative to a total clearcutting in commercial forests. Typically, around 10% of trees are retained in patches within a clearcut area. These retained patches can help maintain characteristic forest species and act as reservoirs for recolonization by forest dependent species.

For other options for harvesting timber, see "*Use selective or reduced impact logging instead of conventional logging*", "*Harvest groups of trees or use thinning instead of clearcutting*", "*Use leave-tree harvesting instead of clearcutting*", "*Use shelterwood harvesting instead of clearcutting*" and "*Retain riparian buffer strips during timber harvest*".

6.8. Use leave-tree harvesting instead of clearcutting

- We found no studies that evaluated the effects on butterflies and moths of using leave-tree harvesting instead of clearcutting.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Harvesting of timber within forests can be carried out by clearcutting sites or by various methods of harvesting a proportion of trees. Leave-tree harvest retains a low density of high-quality trees uniformly through the forest stand. Trees can be retained in groups or dispersed and may contain trees with structural characteristics important to wildlife. Compared to clearcutting, this type of management can help maintain forest species.

For other options for harvesting timber, see "*Use selective or reduced impact logging instead of conventional logging*", "*Harvest groups of trees or use thinning instead of clearcutting*", "*Use patch retention harvesting instead of clearcutting*", "*Use shelterwood harvesting instead of clearcutting*" and "*Retain riparian buffer strips during timber harvest*".

6.9. Use shelterwood harvesting instead of clearcutting

- **Three studies** evaluated the effects on butterflies and moths of using shelterwood harvesting instead of clearcutting. All three studies were in the USA[1–3].

COMMUNITY RESPONSE (3 STUDIES)

- **Richness/diversity (3 studies):** One controlled, before-and-after study in the USA[3] found that the species richness of macro-moths was higher after a forest was managed by shelterwood harvesting, than after harvest by patch-cutting or clearcutting, and the richness in the shelterwood harvested forest was similar to a thinned forest and an unharvested forest. One replicated, controlled, before-and-after study in the USA[1] found that forests managed by shelterwood harvesting had a similar species richness of moths to forests managed by single tree harvesting, group selection harvesting or clearcutting, but a lower species richness than unharvested forest. One replicated, controlled, before-and-after study in the USA[2] found that moth species richness recovered faster after shelterwood harvesting than after group selection harvesting or clearcutting.

POPULATION RESPONSE (0 STUDIES)

BEHAVIOUR (0 STUDIES)

Background

Harvesting of timber within forests can be carried out by clearcutting sites or by various methods of harvesting a proportion of trees. Shelterwood harvesting is a management technique designed to obtain even-aged timber without clearcutting. It involves harvesting trees in a series of partial cuttings, with trees removed uniformly over the plot, which allows new seedlings to grow from the seeds of older trees. This can help maintain characteristic forest species and increase structural diversity of stands.

For other options for harvesting timber, see "*Use selective or reduced impact logging instead of conventional logging*", "*Harvest groups of trees or use thinning instead of clearcutting*", "*Use patch retention harvesting instead of clearcutting*", "*Use leave-tree harvesting instead of clearcutting*" and "*Retain riparian buffer strips during timber harvest*".

A replicated, controlled, before-and-after study in 2007–2009 in three hardwood forests in Indiana, USA (1, same study as 2) found that timber harvesting method, including shelterwood harvesting, did not affect the number of moth species, but all harvested forest stands had fewer moths than unharvested stands. One year after harvesting, there was no significant difference in the number of moth species between stands subjected to shelterwood harvesting and clearcutting (46 species, data not separated), single-tree harvesting (39 species) or group-selection harvesting (40 species), but all harvested stands had fewer species than unharvested stands (56 species). One year before harvesting, all stands had a similar number of moth species (shelterwood/clearcutting: 96; single-tree: 85; group-selection: 100; unharvested: 90 species). After harvesting, the community composition of shelterwood and unharvested stands in one forest were more similar to an unharvested forest than to two nearby clearcut stands (data presented as model results). In 2008, forest stands (3–5 ha, 150–350 m apart) in three watersheds (500 ha, 10 km apart) were logged. In one watershed, three stands were shelterwood harvested (15% of trees removed), two stands were clearcut (100% of trees removed), and three stands were unharvested (no trees removed). In a second watershed, four stands had random single trees removed, and four stands were harvested by group-selection (80% of trees removed). In the third watershed, all four stands were unharvested. All stands had been clearcut around 60 years earlier. From June–August 2007 and 2009, moths were surveyed every 14 nights (five times/year) from 8pm–7am using a black-light trap placed 2 m above the ground in the centre of each forest stand.

A replicated, controlled, before-and-after study in 2007–2011 in two hardwood forests in Indiana, USA (2, same study as 1) found that after shelterwood harvesting, the number of moth species recovered faster than after group-selection harvesting or clearcutting. Three years after shelterwood harvesting, the total number of moth species (73 species/stand) and the number of specialist species (23 species/stand) was similar to before harvesting (total: 96; specialist: 23 species/stand). Numbers of species had not recovered following group-selection harvesting (total: after: 52; before: 100; specialist: after: 8; before: 19 species/stand) or clearcutting (total: after: 48; before: 98 species/stand; data for specialists not presented). However, the number of herbaceous-feeding species was higher after group-selection harvesting (10 species/stand) and clearcutting (16 species/stand) than before harvesting (group-selection: 3; clearcutting: 4 species/stand), but remained similar after shelterwood harvesting (after: 6; before: 4 species/stand). In 2008, forest stands (3–5 ha, 350–750 m apart) in two watersheds (500 ha, 10 km apart) were logged. In one watershed, three stands were shelterwood harvested (15% of trees removed), two stands were clearcut (100% of trees removed), and three stands were unharvested. In a second watershed, four stands were harvested by group-selection (80% of trees removed) and four stands were unharvested. All stands had been clearcut around 60 years earlier. From June–August 2007 and 2009–2011, moths were surveyed every 14 nights (five times/year) from 8pm–7am using a black-light trap placed 2 m above the ground in the centre of each forest stand.

A controlled, before-and-after study in 2007–2014 in two hardwood forest blocks in Indiana, USA (3) found that shelterwood harvested areas had more macro-moth species than clearcut areas, and a similar number to unharvested forest. One–six years after management, the species richness of macro-moths in shelterwood harvested areas (53–75 species/site) was higher than in clearcut (34–54 species/site) or patch-cut (30–52 species/site) areas, and was similar to thinned (40–68 species/site) or unharvested areas (56–84 species/site). Before harvesting, all areas had similar species richness (shelterwood: 95; clearcut: 96; patch-cut: 99; thinned: 84; unharvested: 90 species/site). After management, the total species richness in the shelterwood and clearcut block was 144–190 species, compared to 122–162 species in the thinned and patch-cut block, whereas before management richness was similar (shelterwood/clearcut: 198; thinned/patch-cut: 203 species; statistical significance not assessed). Two ~100 ha regenerated forest blocks were managed in autumn 2008. In one "even-aged" block, two 4.1-ha areas were shelterwood harvested (non-oak midstory and understory cleared), two 4.1-ha areas were clearcut, and the remaining area was not harvested. In one "uneven-aged" block, two 2.0-ha, two 1.2-ha and four 0.4-ha areas were patch-cut, and the remaining area was thinned by single-tree selection. One block was left unharvested. From May–August 2007 and 2009–2014, macro-moths were sampled on five nights/year (once/fortnight) using 12 W black-light traps. Traps were placed in the centre of 16 patches: three shelterwood, two clearcut and three unharvested sites within the even-age block; four patch-cut and four thinned sites within the uneven-age block. Species represented by fewer than three individuals were excluded.

(1) Summerville K.S. (2011) Managing the forest for more than the trees: effects of experimental timber harvest on forest Lepidoptera. *Ecological Applications*, 21, 806–816.
(2) Summerville K.S. (2013) Forest lepidopteran communities are more resilient to shelterwood harvests compared to more intensive logging regimes. *Ecological Applications*, 23, 1101–1112.
(3) Murray B.D., Holland J.D., Summerville K.S., Dunning J.B., Saunders M.R. & Jenkins M.A. (2017) Functional diversity response to hardwood forest management varies across taxa and spatial scales. *Ecological Applications*, 27, 1064–1081.

6.10. Retain riparian buffer strips during timber harvest

- We found no studies that evaluated the effects on butterflies and moths of retaining riparian buffer strips during timber harvest.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Retaining riparian forest buffer strips along water courses or around ponds can help to shield waterways from the negative impacts of tree harvesting, such as sedimentation, by reducing soil erosion. It can also help to mitigate the effects of habitat loss and disturbance for forest butterflies and moths by retaining suitable habitat patches and favourable microclimates. Retained habitat strips can also provide corridors for dispersal through a disturbed landscape (see "*Habitat protection – Retain connectivity between habitat patches*").

For other options for harvesting timber, see "*Use selective or reduced impact logging instead of conventional logging*", "*Harvest groups of trees or use thinning instead of clearcutting*", "*Use patch retention harvesting instead of clearcutting*", "*Use leave-tree harvesting instead of clearcutting*" and "*Use shelterwood harvesting instead of clearcutting*".

6.11. Create or retain deadwood in forest management

- **One study** evaluated the effects on butterflies and moths of creating or retaining deadwood in forest management. This study was in Sweden[1].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (1 STUDY)

- **Abundance (1 study):** One replicated, site comparison study in Sweden[1] found that sites where deadwood had been left for many years had a higher abundance of *Scardia boletella* moths than conventionally managed sites in one of two regions, but the occurrence of *Archinemapogon yildizae* moths was similar across all sites.

BEHAVIOUR (0 STUDIES)

Background

In conventionally managed forests deadwood is often cleared out, either to use, or for safety, accessibility or aesthetic reasons. Although most butterflies and moths will not use deadwood directly, woodlands managed in a more natural way, with deadwood retained or added, may support a more diverse ecosystem. For example, the presence of deadwood should encourage a greater abundance and diversity of fungi, on which some species of moth depend (Bury *et al.* 2014).

Bury J., Hołowiński M., Jaworski T., Mleczak M., Zajda W. & Zamorski R. (2014) Notes of the occurrence in Poland of the rare tineid moth *Scardia boletella* (Fabricius, 1794) (Lepidoptera: Tineidae). *Fragmenta Faunistica*, 57, 131–139.

A replicated, site comparison study in 1992–1995 in 25 forests in Uppland and Östergötland, Sweden (1) found that sites where deadwood had been left for many years supported more *Scardia boletella* moths than conventionally managed sites in one of two regions, but the occurrence of *Archinemapogon yildizae* moths was similar across all sites. In one of two regions, the proportion of tinder fungus *Fomes fomentarius* fruiting bodies in which *Scardia boletella* was found was higher at sites with a long history of deadwood presence (33–36% of 133 fruiting bodies) than at sites with a short history of deadwood presence (0–10% of 177 fruiting bodies) or with little deadwood (0% of 28 fruiting bodies), but there was no significant difference in the other region (long: 0–54% of 172 fruiting bodies; short: 0–38% of 260 fruiting bodies; no sites with little deadwood). The proportion of red-belted conk *Fomitopsis pinicola* and tinder fungus fruiting bodies on which *A. yildizae* moths were found was not significantly different at sites with a long (conk: 3–17% of 239 fruiting bodies; tinder: 0–29% of 305 fruiting bodies) or short (conk: 1–6% of 628 fruiting bodies; tinder: 0–10% of 437 fruiting bodies) history of deadwood presence, or with little deadwood (conk: 0–3% of 104 fruiting bodies; tinder: 7% of 28 fruiting bodies). Twenty-five forests were managed with one of three strategies based on the availability of deadwood: 10 sites had large amounts of deadwood which was likely to have been continuously available for >100 years; 12 sites had large amounts of deadwood which was not likely to have been available 100 years earlier; and three sites were managed conventionally for timber production, with little deadwood available. From 1992–1995, a total of 976 fruiting bodies of red-belted conk were collected from 11 sites, and 770 fruiting bodies of tinder fungus were collected from 20 sites. These were collected by walking a random route through each site, and sampling 1–8 fruiting bodies from every second tree trunk which contained some. Fungi were kept in sealed boxes with a glass vial inserted to collect emerging insects, and kept outdoors from September to February to experience natural temperatures.

(1) Jonsell M. & Nordlander G. (2002) Insects in polypore fungi as indicator species: A comparison between forest sites differing in amounts and continuity of dead wood. *Forest Ecology and Management*, 157, 101–118.

6.12. Re-plant native trees in logged areas

- **One study** evaluated the effects on butterflies and moths of replanting native trees in logged areas. The study was in Ghana[1].

COMMUNITY RESPONSE (1 STUDY)

- **Richness/diversity (1 study):** One site comparison study in Ghana[1] found that nine years after an area was replanted with native trees after logging it had similar species richness but lower diversity for two of three metrics compared to naturally regenerating secondary forest.

POPULATION RESPONSE (0 STUDIES)

BEHAVIOUR (0 STUDIES)

Background

Logging of native forest or plantations causes a dramatic change in the structure of the landscape. Planting native trees in logged areas of natural forest may help to speed up the process of succession and redevelopment of the forest structure, while planting native trees in logged plantations may encourage the restoration of native forest in the area. Note that many species of butterfly and moth do well in early successional woodland after disturbance, but these species may represent a different community to those found in established, pristine forest.

A site comparison study in 2007 and 2009 in an area of moist forest in the Central Region, Ghana (1) found that after nine years, an area replanted with native trees after logging had similar butterfly species richness to, but lower community diversity than, an area clear-cut one year before and naturally regenerated secondary forest, and lower species richness and community diversity than primary forest. Species richness was similar in nine-year-old replanted forest (54), naturally regenerated secondary forest (51) and a clear-cut area (53), all of which had fewer species than primary forest (62). However, using statistical models, replanted forest had lower estimated species richness (66–75) than the clear-cut area (66–75 vs 77–128). Butterfly community diversity was lower in all three diversity metrics in replanted forest than clear-cut or primary forest, and in two of three metrics than secondary forest (data presented as diversity indices). Differences between habitat types were not tested statistically. Butterfly community compositions in the replanted forest, naturally regenerated secondary forest and primary forest were more similar to each other than to the clear-cut area, but replanted forest and naturally regenerated secondary forest community were more similar to each other than to the primary forest (data presented as similarity index results). Four habitat patches were surveyed, all within a 40 ha area and ~250 m apart from each other, on the boundary of Kakum National Park: young forest planted nine years ago with *Ceiba pentandra, Chlorophora excelsa, Terminalia ivoriensis* and *Khaya ivoriensis*, middle-aged naturally regenerated secondary forest, old primary forest and an area which was previously primary forest but was clear cut one year prior to the first surveying year. Patch size was not given. Eight banana-baited traps were established 30 m apart in each of the sampled patches, and operated for 12 consecutive days, three times each in 2007 and 2009. Butterflies were collected from traps daily.

(1) Sáfián S., Csontos G. & Winkler D. (2011) Butterfly community recovery in degraded rainforest habitats in the Upper Guinean Forest Zone (Kakum forest, Ghana). Journal of Insect Conservation, 15, 351–359.

6.13. Encourage natural regeneration in former plantations or logged forest

- **Four studies** evaluated the effects on butterflies and moths of encouraging natural regeneration in former plantations or logged forest. One study was in each of Côte d'Ivoire[1], Japan[2], Ghana[3] and Uganda[4].

COMMUNITY RESPONSE (4 STUDIES)

- **Community composition (3 studies):** One site comparison study in Côte d'Ivoire[1] found that rarer species of fruit-feeding butterfly were more frequently caught in a naturally regenerating forest than in a forest still managed by thinning. One replicated, site comparison study in Japan[2] found that the moth community was different between naturally regenerating forests of different ages. One site comparison study in Ghana[3] found that a naturally regenerating forest had a butterfly community more similar to forest replanted nine years ago than a primary forest or a clear-cut area.
- **Richness/diversity (4 studies):** One site comparison study in Côte d'Ivoire[1] found that a naturally regenerating forest had a similar species richness and diversity of fruit-feeding butterflies to a forest still managed by thinning. One replicated, site comparison

study in Japan[2] found that naturally regenerating forests had a greater species richness of moths than plantations. One site comparison study in Ghana[3] found that a naturally regenerating forest had lower butterfly species richness than a primary forest, but similar richness to a clear-cut area and a nine-year old replanted forest, and lower community diversity than a primary forest and a clear-cut area. One replicated, site comparison study in Uganda[4] found that naturally regenerating forests had a similar species richness of butterflies to pristine forests, but richness was highest 12–25 years after felling.

POPULATION RESPONSE (3 STUDIES)

- **Abundance (3 studies):** One site comparison study in Côte d'Ivoire[1] found that a naturally regenerating forest had a similar abundance of fruit-feeding butterflies to a forest still managed by thinning. One replicated, site comparison study in Japan[2] found that naturally regenerating forests had a greater abundance of moths than plantations. One replicated, site comparison study in Uganda[4] found that naturally regenerating forests had a similar abundance of butterflies to pristine forests, but abundance was highest 12–25 years after felling.

BEHAVIOUR (0 STUDIES)

Background

Logging of native forest or plantations causes a dramatic change in the structure of the landscape. Encouraging natural woodland regeneration in logged forest may enable the redevelopment of the forest structure, while encouraging natural regeneration in former plantations may encourage the restoration of native forest in the area. This action includes studies comparing naturally regenerating forest to plantations, continually managed natural forests, or pristine forests (which represent the end goal of regeneration). Note that many species of butterfly and moth do well in early successional woodland after disturbance, but these species may represent a different community to those found in established, pristine forest.

A site comparison study in 1996 in a logged tropical rainforest in south-east Côte d'Ivoire (1) found that the abundance, species richness and diversity of fruit-feeding butterflies (Nymphalidae) were similar in naturally regenerating forest and forest managed by thinning, but rarer species were caught more frequently in regenerating forest. Naturally regenerating forest had a similar abundance (56 individuals/trap), species richness (71 species) and diversity (data presented as model results) of butterflies to forest managed by thinning (abundance: 54 individuals/trap; richness: 76 species). However, species with smaller geographic ranges were caught more frequently in naturally regenerating forest (data presented as model results). See paper for individual species results. From 1960–1990, a 216 km^2 forest was selectively logged. From 1992 the forest was protected, and two management options were implemented: natural regeneration (no management) and liberation thinning. Liberation thinning was designed to promote the growth of commercial timber species, and included cutting of lianas and climbers, and killing some non-commercial trees. Rare trees and important fruit trees were protected. From January–March 1996, butterflies were sampled in 30 ha of naturally regenerating forest, and 30 ha of thinned forest, using 28 banana-baited traps in each habitat. Traps were set 1 m above ground, 100 m apart, for six consecutive days, and checked daily.

A replicated, site comparison study in 2001–2002 in 18 forest stands in Ibaraki Prefecture, Japan (2) reported that naturally regenerating forests had a higher abundance and species richness of moths than plantations, and found that the moth community changed with forest age. In naturally regenerating forests, 286–979 individuals of 121–220 species/stand were recorded, compared to 68–672 individuals of 50–192 species/stand in plantations (statistical significance not assessed). In naturally regenerating forests, the abundance and species richness of moths was similar between young (abundance: 344–849 individuals/stand; richness: 132–177 species/stand), mature (abundance: 375–979 individuals/stand; richness: 125–220 species/stand) and old (abundance: 286–682 individuals/stand; richness: 121–171 species/stand) forests, but the species community was different (data presented as model results). Six species were associated with young, 71 with mature, and 43 with old naturally regenerating forest. In mature plantations, the abundance (151–672 individuals/stand) and species richness (84–192 species/stand) of moths was higher than in young plantations (abundance: 68–271 individuals/stand; richness: 50–117 species/stand). Ten forest stands (2.5–32.5 ha) had been naturally regenerating for 1–178 years, and eight conifer plantations (2.6–14.3 ha) were planted 1–74 years ago. Forests were divided into three age classes (young: <20 years old; mature: 20–100 years old; old: >100 years old (natural regeneration stands only)). In August 2001–2002, moths were sampled on two nights/year using one 6 W black-light trap in each plantation forest (in 2001) and naturally regenerating stand (in 2002). Species with fewer than three individuals in each forest type were excluded.

A site comparison study in 2007 and 2009 in an area of rainforest in the Central Region, Ghana (3) found that naturally regenerated secondary forest had lower observed butterfly species richness than primary forest and similar richness to a clear-cut area and forest replanted nine years ago, and lower butterfly community diversity than primary forest and the clear-cut area. Similar numbers of species were recorded in secondary forest (51) to a clear-cut area (53) and nine-year-old replanted forest (54), all of which had fewer species than primary forest (62). However, when taking into consideration the number of rare and common butterflies seen, for all four indices calculated, secondary forest had lower estimated richness (62–73) than the clear-cut area (77–128). Butterfly community diversity was lower in secondary forest than primary and clear-cut forest (data presented as diversity indices). Differences between habitat types were not tested statistically. Butterfly community compositions in the naturally regenerated secondary forest, replanted forest and primary forest were more similar to each other than to the clear-cut area, but naturally regenerated secondary forest was more similar to replanted forest than primary forest (data presented as similarity index results). Four habitat patches were surveyed, all within a 40 ha area and ~250 m apart from each other, on the boundary of Kakum National Park: young forest planted nine years ago with *Ceiba pentandra*, *Chlorophora excelsa*, *Terminalia ivoriensis* and *Khaya ivoriensis*, middle-aged naturally regenerated secondary forest, old primary forest and an area which was previously primary forest but was clear cut one year prior to the first surveying year. Patch sizes were not given. Eight banana-baited traps were established 30 m apart in each of the patches, and operated for 12 consecutive days, three times each in 2007 and 2009. Butterflies were collected from traps daily.

A replicated, site comparison study in 2011–2012 in a tropical rainforest in Uganda (4) found that naturally regenerating forest had a similar abundance and species richness of butterflies to pristine forest, but abundance and richness were highest 12–25 years after felling. Two former plantations which were clearcut 12–25 years earlier and left to regenerate naturally had a similar abundance (18–21 individuals/trap) and species richness (31–34 species/trap) of butterflies to one pristine forest site (abundance: 24 individuals/trap; richness: 32 species/trap). However, those three sites had a greater abundance and species richness than both a second pristine site (abundance: 12 individuals/trap; richness: 24 species/trap) and four other sites which were clearcut 7–12 years earlier (abundance: 8–10 individuals/trap; richness: 20–23 species/trap) or were heavily logged 42–44 years earlier and left to regenerate naturally (abundance: 7–10 individuals/trap; richness: 22–24 species/trap). In 1968–1969, two areas of forest (347–622 ha) were heavily logged (40–50% basal area reduction, one area treated with arboricide) and left to regenerate naturally. From 1987–2004, four former conifer plantations (60–171 ha) were clearcut and left to regenerate naturally for 7–10, 10–12, 12–17 and 17–25 years. Two areas of intact pristine forest (282–754 ha) were also studied. From May 2011–April 2012, butterflies were caught from 0800–1600 hours on three consecutive days/month in 8–13 banana-baited white cylindrical butterfly traps (125 × 35 cm, hung at 40–50 cm height) in each area.

(1) Fermon H., Waltert M., Larsen T.B., Dall'Asta U. & Muehlenberg M. (2000) Effects of forest management on diversity and abundance of fruit-feeding nymphalid butterflies in south-eastern Cote d'Ivoire. *Journal of Insect Conservation*, 4, 173–189.
(2) Taki H., Yamaura Y., Okochi I., Inoue T., Okabe K. & Makino S. (2010) Effects of reforestation age on moth assemblages in plantations and naturally regenerated forests. *Insect Conservation and Diversity*, 3, 257–265.
(3) Sáfián S., Csontos G. & Winkler D. (2011) Butterfly community recovery in degraded rainforest habitats in the Upper Guinean Forest Zone (Kakum forest, Ghana). *Journal of Insect Conservation*, 15, 351–359.
(4) Nyafwono M., Valtonen A., Nyeko P. & Roininen H. (2014) Butterfly Community Composition Across a Successional Gradient in a Human-disturbed Afro-tropical Rain Forest. *Biotropica*, 46, 210–218.

6.14. Reduce planting density to create warmer woodlands

- We found no studies that evaluated the effects on butterflies and moths of reducing planting density to create warmer woodlands.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Although many species of butterfly and moth are associated with woodland, they often prefer openings within the forest where sunlight penetrates the canopy and creates warmer patches for basking. Replanted woodlands, whether young plantations or native forests, often have trees planted at very high density, which may be unsuitable for warmth-loving butterflies and moths. Reducing the density at which trees are planted may provide habitat for more butterfly and moth species in woodlands.

7. Threat: Human intrusions and disturbance

Background

Due to their exacting habitat requirements and limited dispersal ability, some species of butterfly and moth are extremely sensitive to human disturbance. For example, trampling of grassland or flower-rich woodland rides may reduce the suitability of the sward structure for basking, roosting or breeding, and vehicle wheels may destroy sensitive host plants. For small populations, their entire area of suitable habitat could be damaged by a small number of disturbance events. This chapter covers actions which aim to prevent or reduce disturbance to butterfly and moth habitats.

7.1. Use signs and access restrictions to reduce disturbance

- We found no studies that evaluated the effects on butterflies and moths of using signs and access restrictions to reduce disturbance.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

People can deliberately or unintentionally damage important habitats by straying from footpaths in sensitive areas, allowing animals such as dogs to roam freely, or by driving vehicles off-road. Introducing signs or imposing access restrictions may reduce unintentional, careless actions, as well as discouraging deliberate acts of vandalism by indicating that a site is being monitored.

7.2. Restrict recreational activities to particular areas

- We found no studies that evaluated the effects on butterflies and moths of restricting recreational activities to particular areas.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Many outdoor areas, particularly those with public access, are managed for a variety of recreational activities alongside nature conservation. This may include walking, cycling or riding trails, adventure sports or camping. These activities are likely to have a detrimental effect on many species of butterfly and moth, by increasing disturbance and making some areas of habitat unsuitable. Restricting recreational activities to specific areas of a park or reserve may help to minimize these impacts, by limiting the area of disturbance and allowing species to survive in the remaining, undisturbed areas.

8. Threat: Natural system modifications

Background

Natural system modifications include alterations to ecosystem processes, such as changes in fire frequency or the damming or straightening of rivers. In many parts of the world, infrequent fires may have been part of natural disturbance processes, which helped to maintain open habitats, such as grassland, alongside grazing, browsing and flooding, but their frequency has been greatly increased by people (Anderson 2006, Russell 1997). However, while many open habitat plants are adapted to cope with fire, the response of insects such as butterflies and moths is much more variable, and many are threatened by too frequent or widespread fires which directly kill individuals or remove critical resources (New *et al.* 2010). These adverse responses are particularly common in specialist species (Cleary & Grill 2004). Natural wildfires tend to have different properties to anthropogenic fires, included less frequent burns over larger areas, scattered with unburned patches or "skips", which may be more beneficial to butterflies and moths than prescribed burning (Swengel 1998). However, natural fires are often suppressed due to the threat posed to human health and property, or because the land is used for grazing livestock or recreation. Elsewhere, fire may be deliberately or unintentionally started in habitats where natural fires rarely occur. The restoration and management of natural or semi-natural habitats for butterflies and moths may require reductions in burning, including the complete cessation of fire, and where fires are used, the exact frequency, timing, intensity and area of the burn are all likely to affect whether the results are beneficial or detrimental to individual species (New *et al.* 2010).

Anderson R.C. (2006) Evolution and origin of the Central Grassland of North America: climate, fire, and mammalian grazers. *Journal of the Torrey Botanical Society*, 133(4), 626–647.

Cleary D.F.R & Grill A. (2004) Butterfly response to severe ENSO-induced forest fires in Borneo. *Ecological Entomology*, 29, 666–676.

New T.R., Yen A.L., Sands D.P.A., Greenslade P., Neville P.J., York A. & Collett N.G. (2010) Planned fires and invertebrate conservation in South East Australia. *Journal of Insect Conservation*, 10, 567–574.

Russell E.W.B. (1997) People and the Land Through Time: Linking Ecology and History. *Yale University Press*, New Haven and London.

Swengel A.B. (1998) Effects of management on butterfly abundance in tallgrass prairie and pine barrens. *Biological Conservation*, 83, 77–89.

Fire & fire suppression

8.1. Use prescribed fire to maintain or restore disturbance in forests

- **Five studies** evaluated the effects on butterflies and moths of using prescribed fire to maintain or restore disturbance in forests. Four studies were in the USA[1,2,4,5] and one was in Australia[3].

COMMUNITY RESPONSE (4 STUDIES)

- **Richness/diversity (4 studies):** Three of four studies (including one replicated study, one paired study, two controlled studies, two before-and-after studies, and one site comparison study) in the USA[1,2,4,5] found that coniferous forest restored 1–2 years ago by burning (in combination with thinning)[1,5] or burned once within the last 20 years[4], had a higher species richness of butterflies than unburned forest. The fourth study[2] found that mixed forest and shrubland sites which had been burned the year before had similar butterfly species richness to unburned sites.

POPULATION RESPONSE (3 STUDIES)

- **Abundance (3 studies):** Two studies (including one controlled, before-and-after study and one site comparison study) in the USA[1,5] found that pine forest restored 1–2 years ago by burning (in combination with thinning) had a higher abundance of butterflies than unburned forest. One replicated, before-and-after study in Australia[3] reported that in the spring after selective burning of eucalyptus forest there were fewer Eltham copper caterpillars than before.

BEHAVIOUR (0 STUDIES)

Background

Although many species of butterflies and moths are found in woodland, most prefer areas with open glades or a sparse understorey, where light can penetrate and enable flowering plants to grow, as well as providing areas for basking. One option for opening up dense areas of woodland is to use prescribed burning. Although destructive in the short-term, with likely loss of butterflies and moths through direct mortality or reductions in food availability (Glaves *et al.* 2013), burning may have long-term benefits by creating a more favourable, open habitat (Bubová *et al.* 2015). However, the impact of fires can vary depending on their exact characteristics, such as the frequency, temperature, ground surface intensity, time and size of burning compared to the surrounding unburned areas (Swengel 2001, Tucker 2003, New *et al.* 2010), and caution should be taken before instigating fire in place of alternative management options such as grazing or cutting.

For studies using prescribed burning in naturally open habitats, see "*Use prescribed fire to maintain or restore disturbance in grasslands or other open habitats*". For other options for reducing the density of woodlands, see "*Habitat restoration and creation – Clear or open patches in forests*", "*Habitat restoration and creation – Coppice woodland*", "*Habitat restoration and creation – Thin trees* *within forests*" and "*Habitat restoration and creation – Create young plantations within mature woodland*".

Bubová T., Vrabec V., Kulma M. & Nowicki P. (2015) Land management impacts on European butterflies of conservation concern: a review. *Journal of Insect Conservation*, 19, 805–821.

Glaves D.J., Morecroft M., Fitzgibbon C., Lepitt P., Owen M. & Phillips S. (2013) Natural England Review of Upland Evidence 2012 - The effects of managed burning on upland peatland biodiversity, carbon and water. *Natural England Evidence Review*, Number 004 (NEER004).

New T.R., Yen A.L., Sands D.P.A., Greenslade P., Neville P.J., York A. & Collett N.G. (2010) Planned fires and invertebrate conservation in South East Australia. *Journal of Insect Conservation*, 10, 567–574.

Swengel A.B. (2001) A literature review of insect responses to fire, compared to other conservation managements of open habitat. *Biodiversity and Conservation*, 10, 1141–1169.

Tucker G. (2003) Review of the impacts of heather and grassland burning in the uplands on soils, hydrology and biodiversity (ENRR550). Natural England (English Nature) report.

A site comparison study in 1998 in two pine forests in Arizona, USA (1) found that a forest restored by prescribed burning and thinning young trees had a higher abundance and species richness of butterflies than an unrestored forest. Two years after burning and thinning, the restored forest had a higher abundance (6–46 individuals/visit) and species richness (3–11 species/visit) of butterflies than the unrestored forest (abundance: 0–7 individuals/visit; richness: 0–4 species/visit). One species, the checkered white *Pieris protodice*, was only found in the restored forest, but another, the California sister *Limenitis bredowii*, was only found in the unrestored forest. In 1996, a 40-acre ponderosa pine *Pinus ponderosa* forest was burned and thinned (pole-sized trees removed) to reopen the dense understorey. An adjacent forest was not restored. From May–July 1998, butterflies were surveyed six times (every two weeks) along a single 450-m transect in each forest.

A replicated, paired, before-and-after, site comparison study in 1996–1998 in 12 mixed forest and shrubland sites in Nevada, USA (2) found that butterfly species richness was similar between burned and unburned plots. Butterfly species richness was similar between plots that had been burned and plots that had not, and between plots before and after they were burned (data presented as model results). Additionally, the difference in butterfly community composition between two years in which plots had been burned was similar to between two years in plots which had not been burned in the first year but had been burned in the second year (data presented as community composition indices). Five plots (7–17 ha each) were burned in October 1996 or April 1997 and surveyed in 1997–1998. Two of the burn plots had paired unburned plots, similar in size, topography and pre-burning vegetation, but they too were burned in November 1997 and became burn plots thereafter. Five additional unburned plots (55–127 ha each) were surveyed in 1996–1998. In survey years at each plot, butterflies were identified via walking transects every two weeks from June–September.

A replicated, before-and-after study in 1998–1999 in two Eucalyptus forest sites in Victoria, Australia (3) reported that in the following spring after selective habitat burning there were fewer Eltham copper Paralucia pyrodiscus lucida caterpillars than before. One week after burning, 580 caterpillars were counted at the western colony (numbers for the eastern colony not provided), indicating some had survived the fire. By the following spring, caterpillars were found in both the burnt and unburnt patches but in lower numbers than in the previous year (data not provided). In the spring and summer following the burning, adult butterflies were found in both burnt and unburnt areas of both sites, but at one site (the eastern colony), they were mostly concentrated in the unburnt areas. Two forested sites with populations of the Eltham copper were partially burned in April 1998 (50% of the eastern colony and 75% of the western colony). Individual Bursaria spinosa plants (the sole larval food plant), on which caterpillars had been found prior to burning, were marked and avoided by the burning. Burning was planned for as late as possible in the summer to increase the likelihood that caterpillars would be well-fed and not suffer from the removal of vegetation prior to overwintering. Numbers of caterpillars and butterflies were surveyed at the two sites a week after the fire and in the following spring and summer (further survey timings not provided).

A replicated, controlled study in 1998–1999 in two upland coniferous forest reserves in Oregon and California, USA (4) found that sites subjected to prescribed burning had more species of butterfly than unburned sites. In forest patches which had been burned once in the last 1–19 years, there were more species of butterfly (11–14 species/patch) than in patches not burned for at least 20 years (4–7 species/patch). There were also more species in burned "fuel-break" corridors (16 species/site) than in unburned corridors (1 species/site) and in riparian strips burned in the last 1–13 years (25 species/site) than in unburned strips (10 species/site). Butterfly species diversity was 0.5–8 times higher in the burned habitats than the unburned habitats (see paper for details). In Oregon, five upland forest patches were burned once between 1991 and 1997, and five patches were unburned since at least 1978. Five wide, shaded, corridors of thinned vegetation ("fuel breaks") were burned and four were unburned (no dates given). In California, five upland forest patches were burned once between 1980 and 1998, and seven patches were unburned. Four riparian strips were burned once from 1986–1998, and five strips were unburned (no date given). Butterflies were surveyed along one 240-m transect/site, six times from late June–August 1998 in Oregon, and five times from late June–August 1999 in California.

A replicated, randomized, paired, controlled, before-and-after study in 1997–2001 in a pine forest in Arizona, USA (5) found that forests restored by prescribed burning and thinning had a higher abundance and species richness of butterflies than unrestored forests. One and two years after burning and thinning, restored forests had a higher butterfly abundance (48–132 individuals/unit) and species richness (7–16 species/unit) than unrestored forests (abundance: 10–42 individuals/unit; richness: 4–10 species/unit). Before restoration, there was no significant difference between forest marked for restoration (abundance: 23–50 individuals/unit; richness: 8–12 species/unit) and unrestored forest (abundance: 10–41 individuals/unit; richness: 5–13 species/unit). These results were primarily due to the abundance of species of blue (Lycaenidae) and white (Pieridae) butterflies (see paper for details). In 1997, four blocks within a 5,000-

ha ponderosa pine *Pinus ponderosa* forest were each divided into two units (≤40-ha each). In autumn/winter 1999–2000, one randomly assigned unit/block was burned and thinned. The other units were not restored. From May–August 1997, 1998, 2000 and 2001, butterflies were surveyed six times/year (two-week intervals) along two or three 300-m transects/unit.

(1) Waltz A.E.M. & Covington W.W. (1999) Butterfly richness and abundance increase in restored ponderosa pine ecosystem (Arizona). *Ecological Restoration*, 17, 244–246.
(2) Fleishman E. (2000) Monitoring the Response of Butterfly Communities to Prescribed Fire. *Environmental Management*, 26, 685-695.
(3) New T. R., Van Praagh B. D. & Yen A. L. (2000) Fire and the management of habitat quality in an Australian Lycaenid butterfly, *Paralucia pyrodiscus lucida* Crosby, the Eltham copper. *Metamorphosis*, 11(3), 154-163.
(4) Huntzinger M. (2003) Effects of fire management practices on butterfly diversity in the forested western United States. *Biological Conservation*, 113, 1–12.
(5) Waltz A.E.M. & Covington W.W. (2004) Ecological Restoration Treatments Increase Butterfly Richness and Abundance: Mechanisms of Response. *Restoration Ecology*, 12, 85–96.

8.2. Use prescribed fire to maintain or restore disturbance in grasslands or other open habitats

- **Thirteen studies** evaluated the effects on butterflies and moths of using prescribed fire to maintain or restore disturbance in grasslands or other open habitats. Eight studies were in the USA[2,4,6,8,9,10,12,13], three were in the UK[1,3,7], one was in South Africa[5] and one was a review across Europe[11].

COMMUNITY RESPONSE (3 STUDIES)

- **Community composition (1 study):** One replicated, site comparison study in the USA[12] found that pastures managed by patch-burning had a similar butterfly community to rotationally or continuously grazed pastures.
- **Richness/diversity (3 studies):** Two replicated, before-and-after studies (including one randomized, controlled study and one paired sites, site comparison study) in the USA[4,9] found that shrubland plots[4] and grass field margins[9] managed by burning had a similar species richness of butterflies to those which were unburned. One replicated, site comparison study in the USA[12] reported that pastures managed by patch-burning had a lower species richness of butterflies than rotationally grazed pastures, a similar richness to rotationally grazed and mown pastures, and a higher species richness than continuously grazed pastures.

POPULATION RESPONSE (12 STUDIES)

- **Abundance (12 studies):** Four of nine studies (including six replicated studies, two randomized studies, two paired sites studies, three controlled studies, two before-and-after studies, and five site comparison studies) in the UK[1,3,7], South Africa[5] and the USA[6,8,9,,10,13] found that the abundance of heath fritillary adults[1], marsh fritillary caterpillar webs[3] and Fender's blue caterpillars and eggs[6,13] was higher (sometimes after initial reductions in abundance[1,13]) on heathland[1], fen meadows[3] and prairies[6,13] one or more years after management by burning than before burning[1], or compared to unburned[3,6,13] or grazed[3] land, although the total population of Fender's blue declined in adjacent burned and unburned areas[13]. Three studies found that the abundance of Brenton blue butterfly eggs and adults[5], rosy marsh moth caterpillars[7] and regal fritillary adults[8] was lower on a bog[7] and prairies[5,8] managed by burning than on unburned land, at least one[5,8] and five[7] years after burning. One study found that grass field margins managed by burning had a similar abundance of butterflies to unburned field margins[9]. The seventh study found that abundance of Powershiek skipperling to burning, along with haying and idling, depended on the site's vegetation characteristics[10]. Two replicated, site comparison studies in the USA[2,12] found that two prairie specialists (regal fritillary and arogos skipper)[2] and three out of nine butterfly species[12] were less abundant in prairies[2] or pastures[12] managed by burning than in prairies managed by haying[2] or grazed pastures[12]. These studies also found that the abundance of generalist and migrant species[2], and of purplish copper[12], was higher in burned prairies[2] or pastures[12] than hayed prairies[2] or grazed pastures[12]. One review across Europe[11] reported that occasional burning on grassland benefitted 10 out of 67 butterfly species of conservation concern.

- **Survival (1 study):** One replicated, paired sites, controlled study in the USA[6] found that in prairie plots burned one year before, Fender's blue butterfly caterpillars had lower survival than in unburned plots.

BEHAVIOUR (1 STUDY)

- **Use (1 study):** One replicated, site comparison study in the UK[3] found that a similar proportion of fen meadows were occupied by marsh fritillary caterpillars whether they were managed by burning, grazing or were unmanaged.

Background

Open habitats, such as grassland, heathland, peatland and fynbos, require disturbance processes to prevent them undergoing succession to scrub or woodland. One option for preventing succession and opening up areas of habitat is to use prescribed burning. Although destructive in the short-term, with likely loss of butterflies and moths through direct mortality or reductions in food availability (Glaves *et al.* 2013), burning may have long-term benefits by creating a more favourable, open habitat (Bubová *et al.* 2015), with increases in structural diversity (Glaves *et al.* 2013) or flower density (Vogel *et al.* 2010). In particular, fires which move quickly across the site and burn some areas more than others may be important for creating a diverse habitat structure (Kwilosz & Knutson 1999). However, the impact of fires can vary depending on their exact characteristics, such as the frequency, temperature, ground surface intensity, time and size of burning compared to the surrounding unburned areas (Swengel 2001, Tucker 2003, New *et al.* 2010) and caution should be taken before instigating fire in place of alternative management options such as grazing or cutting.

For studies on further manipulations to burning regimes, including using different frequencies or timing of prescribed burning, see "*Use rotational burning*", "*Change season/timing of prescribed burning*" and "*Leave some areas unburned during prescribed burning*". For studies using prescribed burning in forests, see "*Use prescribed fire to maintain or restore disturbance in forests*".

Bubová T., Vrabec V., Kulma M. & Nowicki P. (2015) Land management impacts on European butterflies of conservation concern: a review. *Journal of Insect Conservation*, 19, 805–821.

Glaves D.J., Morecroft M., Fitzgibbon C., Lepitt P., Owen M. & Phillips S. (2013) Natural England Review of Upland Evidence 2012 - The effects of managed burning on upland peatland biodiversity, carbon and water. *Natural England Evidence Review*, Number 004 (NEER004).

Kwilosz J.R. & Knutson R.L. (1999) Prescribed fire management of Karner blue butterfly habitat at Indiana Dunes National Lakeshire. *Natural Areas Journal*, 19, 98–108.

New T.R., Yen A.L., Sands D.P.A., Greenslade P., Neville P.J., York A. & Collett N.G. (2010) Planned fires and invertebrate conservation in South East Australia. *Journal of Insect Conservation*, 10, 567–574.

Swengel A.B. (2001) A literature review of insect responses to fire, compared to other conservation managements of open habitat. *Biodiversity and Conservation*, 10, 1141–1169.

Tucker G. (2003) Review of the impacts of heather and grassland burning in the uplands on soils, hydrology and biodiversity (ENRR550). Natural England (English Nature) report.

Vogel J.A., Koford R.R. & Debinski D.M. (2010) Direct and indirect responses of tallgrass prairie butterflies to prescribed burning. *Journal of Insect Conservation*, 14, 663–677.

A before-and-after study in 1980–1989 on a heathland on Exmoor, UK (1) reported that prescribed burning increased the number of heath fritillary *Mellicta athalia*. Results were not tested for statistical significance. Seven years after burning, over 5,500 adult heath fritillary were recorded at the site, compared to 280 adults two years before burning. However, in the summer after burning, no heath fritillaries were seen, and only 17 were recorded the following year. The author noted that these adults may have recolonized from a neighbouring site 500 m away. In March 1982, most of a 9-ha heathland was burned. In 1980, and from 1982–1989, butterflies were surveyed annually on timed counts along a zig-zag route covering the known flight area.

A replicated, site comparison study in 1992–1993 in 42 tall-grass prairies in Missouri, USA (2) found that two prairie specialist butterflies were less abundant, but generalist and migrant species were more abundant, in burned than in hayed prairies. At sites managed by burning, the abundance of two prairie specialists (regal fritillary *Speyeria idalia* and arogos skipper *Atrytone arogos*; 2–21 individuals/hour) was lower than at sites managed by haying (68–81 individuals/hour). However, generalist and migrant species were more abundant at burned sites (18–24 individuals/hour) than hayed sites (6–19 individuals/hour). See paper for some individual species results. Of 42 sites (6–571 ha), some were managed by cool-season burning covering 5–99% of the site, and the rest by summer haying on a 1–3 year rotation with occasional cattle grazing (number of sites in each management not given). In June 1992–1993, butterflies were surveyed at least once/year at most sites, either along a transect (35 sites) or from a single point (7 sites, recording only regal fritillary). Sixteen species observed >49 times and at >5 sites were included, and divided into "prairie specialists" (only found on prairies), "grassland species" (found in prairies and other grasslands), "generalists" (found in grasslands and other habitats) and "migrants" (only present in the study area during the growing season).

A replicated, site comparison study in 1993 in 34 fen meadows in Glamorgan, UK (3) found that managing grassland by burning did not affect site use by marsh fritillary *Eurodryas aurinia* compared to grazed or unmanaged grassland. There was no significant difference in the proportion of burned (5/8 sites), cattle-grazed (3/9), horse-grazed (2/6), sheep-grazed (0/2), mown (0/1) and unmanaged (4/8) sites that had >20 caterpillar webs recorded. However, the three largest populations (>200 caterpillar webs) were on sites burned in early spring. Caterpillar webs were present on 28/34 sites where adults had been recorded in May/June. In 1993, eight grasslands were burned, nine were cattle-grazed, six were horse-grazed, two were sheep-grazed, one was mown and eight were unmanaged. Sites were separated by >1 km of unoccupied grassland, or >0.5 km of unsuitable habitat. From late August–mid-October 1993, caterpillar webs were surveyed on 34 fen grasslands. On sites <2 ha, all devil's bit scabious *Succisa pratensis* were searched in 2-m-wide parallel strips until the whole area had been searched. On larger sites, 2-m-wide strips at 10-m intervals were searched, and areas around caterpillar webs were then searched comprehensively.

A replicated, paired, before-and-after, site comparison study in 1996–1998 in 12 mixed shrubland and forest sites in Nevada, USA (4) found that butterfly species richness was similar between burned and unburned plots. Butterfly species richness was similar between plots that had been burned and plots that had not, and between plots before and after they were burned (data presented as model results). Additionally, the difference in butterfly community composition between two years in which plots had been burned was similar to between two years in plots which had not been burned in the first year but had been burned in the second year (data presented as community composition indices). Five plots (7–17 ha each) were burned in October 1996 or April 1997 and surveyed in 1997–1998. Two of the burn plots had paired unburned plots, similar in size, topography and pre-burning vegetation, but they too were burned in November 1997 and became burn plots thereafter. Five additional unburned plots (55–127 ha each) were surveyed in 1996–1998. In survey years at each plot, butterflies were identified via walking transects every two weeks from June–September.

A site comparison study in 2000–2002 in one shrubland site in the Western Cape province, South Africa (5) reported that after prescribed burning and some management of bracken fern *Pteridium aquilinium* there were fewer Brenton blue butterfly *Orachrysops niobe* eggs and adults during the laying and flight season in areas that had been burned. There were fewer Brenton blue eggs found in areas that had been burned (0.4–1.3 eggs/100 m^2) than unburned areas (14.3–70.0 eggs/100 m^2). Additionally, fewer adult males (November: 69%, February: 31.1%) and females (November: 22.2%, February: 10.6%) were found in the burned areas (64% of the area surveyed) compared to unburned areas (males November: 31.0%, February: 68.9%; females November: 77.8%, February: 89.4%). In September 2000, a 2,700 m^2 area of reserve was burned. Prior to the burn, in over 1,000 m^2 of the area bracken fern was cut and 0.2 m of topsoil was turned over ("skoffeled"). In that area and another 1,400 m^2, natural succession was allowed after the burn. In another 300 m^2 of the burned area, bracken fern was removed manually for 6 months after the burn. In a 1,500 m^2 area of reserve that was not burned, paths were cut with shears in July 2001, avoiding trees, large bushes and *Indigofera erecta* plants, and thereafter new bracken ferns were removed manually. In November 2001 and January–February 2002, all *Indigofera erecta* plants identified in the burned and unburned areas were checked for eggs and larvae. In October–November 2001 and January–February 2002 walking transects (9 times/season) and fixed-point surveys (7–8 times/season) were conducted to count and sex adult butterflies (it is not specified how many were in the burned and unburned areas).

A replicated, paired sites, controlled study in 1994–1997 in eight grassland prairies in Oregon, USA (6) found that in burned plots there were more Fender's blue butterfly *Icaricia icarioides fenderi* eggs, but caterpillars had lower survival, than in unburned plots. There were more eggs found/butterfly seen in burned plots (0.03 eggs/butterfly/m^2) than in unburned plots (0.01 eggs/butterfly/m^2). However, there was a lower percentage of caterpillars the following year compared to eggs found in the previous year (caterpillar survivorship) in burned plots (0.36%) than unburned plots (9.4%). In 1994, five experimental sites were established, three containing a paired 120-m^2 burn plot and 40-m^2 non-burn plot, and two containing only a 120-m^2 burn plot. Burn plots were burned in autumn 1994 and 1996. Fender's blue eggs, caterpillars and adults were counted in spring 1995–1997.

A site comparison study in 1988–2003 in a raised bog in Ceredigion, UK (7) reported that a burned bog had fewer rosy marsh moth *Coenophila subrosea* caterpillars than an unburned bog. Results were not tested for statistical significance. For 2–5 years after burning, caterpillars were scarce in the burned area (0–3 individuals/year) compared to the unburned area (6–24 individuals/year). From 6–9 years after burning, numbers were similar in burned (5–13 individuals/year) and unburned (6–15 individuals/year) areas. From 10–14 years after burning, the burned area had 6–24 individuals/year compared to 2–17 individuals/year on the unburned area. From 16–17 years after burning, the burned area had 16–38 individuals/year compared to 33–50 individuals/year on the unburned area. From 1968, fire frequency was reduced on a raised bog, and the last burn occurred in 1974. In February 1986, two-thirds of the bog was accidentally burned. In late May 1988–2003, caterpillars were counted once/year, at night, in seven 15 × 1 m plots in the burned area and seven in the unburned area.

A replicated, site comparison study in 2005 in 87 remnant prairies in Kansas, USA (8) found that recently burned prairies had fewer regal fritillaries *Speyeria idalia* than prairies which had not been burned for at least a year. There were fewer regal fritillaries on prairies which had been burned since the last growing season (0.9 individuals/100 m) than on prairies which were unburned in that time (3.2 individuals/100 m). However, the presence of fritillaries at a site was similar between burned (16/21 sites) and unburned (54/66 sites) prairies. Eighty-seven tallgrass prairie remnants (0.9–53.9 ha) were managed by either burning (usually in April), cutting once/year in July, or grazing. In June 2005, signs of recent fire were used to classify sites at recently burned (since autumn 2004) or unburned in that time. In June 2005, regal fritillaries were surveyed along transects (130–1,300 m long), >30 m from the edge of the prairie.

A replicated, randomized, controlled, before-and-after study in 2007–2009 on a mixed farm in Mississippi, USA (9) found that burning grass field margins did not increase the abundance or species richness of either disturbance-tolerant or grassland butterflies. The abundance and species richness of 18 disturbance-tolerant butterfly species was similar on burned (abundance: 4–11 individuals; richness: 6–7 species) and undisturbed (abundance: 4–14 individuals; richness: 6–8 species) grass field margins. The abundance and species richness of 14 grassland butterfly species also remained similar in burned (abundance: 0.3–1.3 individuals; richness: 1–3 species) and undisturbed (abundance: 0.5–1.3; richness: 1–3 species) margins. See paper for details of individual species. In spring 2004, grass margins were sown with a seed mix of common prairie species. Ten fields (containing 26 margins) were randomly assigned to one of two treatments: burning and no disturbance. Within each burning field, one margin was burned in spring 2008 and a different margin was burned in spring 2009. From June–August 2007–2009, butterflies were surveyed six times/year along three 50-m transects in the centre of each margin.

A replicated, site comparison study in 1988–1997 in 37 tallgrass prairies in Iowa, Minnesota and North Dakota, USA (10) found that after burning, haying and idling management, Powershiek skipperling *Oarisma poweshiek* abundance differed depending on site vegetation characteristics. In undegraded uplands with diverse vegetation, by one type of average (mean) Poweshiek skipperling abundance was higher at sites managed with burning (17 butterflies/km) than haying (4 butterflies/km) or those left idling (3 butterflies/km), but by another type of average (median) abundance was lower at sites with burning (0 butterflies/km) than haying (2 butterflies/km) or idling (3 butterflies/km). However, in undegraded moist prairie, abundance was lower at sites with burning (0–7 butterflies/km) than haying (2–11 butterflies/km) (no data was provided for idling sites). In undegraded uplands with burning management, abundance was highest two to six years after burning (22–36 butterflies/km), and lowest in the year of burning up to three years after burning (0–3 butterflies/km). Butterfly and habitat management surveys were conducted at 37 sites in northern Iowa, western Minnesota and eastern Dakota in June–August 1988–1997. Not all sites were surveyed for the whole period or every year. Surveys were of varying lengths and conducted simultaneously along one set of parallel transects (5–10 m apart) in each site. These butterfly counts were combined with a butterfly survey dataset from another researcher team, which overlapped in location, and adjusted to account for differences in survey methods (survey details and sites for this dataset were not provided).

A review in 2015 of 126 studies in Europe (11) reported that occasional burning on grassland benefitted 10 out of 67 butterfly species of conservation concern. Results were not tested for statistical significance. The review reported that seven studies found that occasional burning benefitted 10 butterfly species (large heath *Coenonympha tullia*, woodland grayling *Hipparchia fagi*, rock grayling *Hipparchia hermione*, tree grayling *Hipparchia statilinus*, Iolas blue *Iolana iolas*, large blue *Phengaris arion*, scarce large blue *Phengaris teleius*, zephyr blue *Plebejus pylaon*, Piedmont anomalous blue *Polyommatus humedasae*, Kolev's anomalous blue *Polyommatus orphicus*). The authors suggested that negative short-term impacts of burning can be reduced by leaving small areas of land unburned, and by burning in winter or early spring (data not presented). Meadows were burned in different patterns and at different times of year. The review focussed on 67 butterfly species of conservation concern. The available information was biased towards studies in Northern and Western Europe.

A replicated, site comparison study in 2015–2016 in two grassland reserves in North Dakota, USA (12) found that burning patches of pasture did not affect butterfly community composition, but did affect the species richness and abundance of individual species, compared to management by rotational grazing, rotational grazing with mowing, and season-long grazing. Patch-burning did not affect butterfly community composition compared to other management (data presented as model results). One out of nine species (purplish copper *Lycaena helloides*) was more abundant in patch-burned pastures, while three species (meadow fritillary *Boloria bellona*, regal fritillary *Speyeria idalia* and small pearl-bordered fritillary *Boloria selene*) were less abundant in patch-burned pastures than other management, and five species had a similar abundance between management types (see paper for details). Twenty-six butterfly species were recorded in patch-burned grazed pastures, compared to 30 species in rotationally grazed pastures, 25 species in rotationally grazed pastures with mowing and 22 species in season-long grazed pastures (statistical significance not assessed). Eight pastures (54–484 ha) managed under one of four management practices (patch-burn grazing, rotational grazing, rotational grazing with lowland mowing, season-long grazing) were selected. One-third of each patch-burn pasture was burned in the dormant season, but prior to April 2015 these sites were rotationally grazed. All other sites had the same management for at least a decade. Rotational pastures were sub-divided into four paddocks, each grazed twice/season. In mown pastures, sedge-dominated patches were cut once/summer. On season-long pastures cattle were free to select grazing areas. Pastures were stocked with cattle (0.5–0.75 cow-calf pairs/ha) from May–October. From June–August 2015 and 2016, butterflies were surveyed three times/year along twelve 100-m transects/pasture.

A replicated, randomized, paired, controlled study in 2011–2014 in four upland prairies in Oregon, USA (13) found that prescribed burning in autumn initially reduced the amount of Fender's blue caterpillar damage, but then the number of eggs and amount of caterpillar damage in burned areas was higher than in unburned areas for two years after burning, although the overall population decreased in both areas. In the first spring after burning, fewer Kincaid's lupine *Lupinus oreganus* and spur lupine *Lupinus arbustus* plants had damage from Fender's blue caterpillars, /egg found the previous June, in burned plots (0.1 leaves/egg) than in unburned plots (0.3 leaves/egg). However, the following year, there were more damaged leaves in burned (1.2 leaves/egg) than unburned (0.7 leaves/egg) plots, but there was no difference by the third year after burning (burned: 0.3 leaves/egg; unburned: 0.3 leaves/egg). For two years after burning, there were also more eggs in June, /caterpillar found in April, in burned plots (67–68 eggs/caterpillar) than in unburned plots (48–49 eggs/caterpillar), but by the third year after burning the number was similar in burned (26 eggs/caterpillar) and unburned (25 eggs/caterpillar) plots. However, the population declined by 78% in the burned areas and 83% in the unburned areas (statistical significance not assessed). In October 2011, half of each of four prairies was burned (0.07–0.21 ha burned), and the remaining area was not burned. In June 2011–2014, Fender's blue eggs were surveyed in twenty 1-m^2 plots/patch (160 plots total) with ≥30% cover of lupine. In April 2012–2014, the number of caterpillars was estimated by counting the number of lupine leaves with characteristic Fender's blue feeding damage.

(1) Warren M.S. (1991) The successful conservation of an endangered species, the heath fritillary butterfly *Mellicta athalia*, in Britain. *Biological Conservation*, 55, 37–56.
(2) Swengel A.B. (1996) Effects of fire and hay management on abundance of prairie butterflies. *Biological Conservation*, 76, 73–85.
(3) Lewis O.T. & Hurford C. (1997) Assessing the status of the marsh fritillary butterfly (*Eurodryas aurinia*): an example from Glamorgan, UK. *Journal of Insect Conservation*, 1, 159–166.
(4) Fleishman E. (2000) Monitoring the Response of Butterfly Communities to Prescribed Fire. *Environmental Management*, 26, 685-695.
(5) Edge D.A. (2002) Some ecological factors influencing the breeding success of the Brenton Blue butterfly, Orachrysops niobe (Trimen) (Lepidoptera: Lycaenidae). *Koedoe*, 45(2), 19-34.
(6) Schultz C.B., Crone E.E. (2002) Burning Prairie to Restore Butterfly Habitat: A Modeling Approach to Management Tradeoffs for the Fender's Blue. *Restoration Ecology*, 6(3), 244-252.
(7) Fowles A.P., Bailey M.P. & Hale A.D. (2004) Trends in the recovery of a rosy marsh moth *Coenophila subrosea* (Lepidoptera, Noctuidae) population in response to fire and conservation management on a lowland raised mire. *Journal of Insect Conservation*, 8, 149–158.
(8) Powell A.F.L.A., Busby W.H. & Kindscher K. (2007) Status of the regal fritillary (*Speyeria idalia*) and effects of fire management on its abundance in northeastern Kansas, USA. *Journal of Insect Conservation*, 11, 299–308.
(9) Dollar J.G., Riffell S.K. & Burger L.W. (2013) Effects of managing semi-natural grassland buffers on butterflies. *Journal of Insect Conservation*, 17, 577–590.
(10) Swengel A.B. and Swengel S.R. (2014) Paradoxes of Poweshiek Skipperling (*Oarisma poweshiek*) (Lepidoptera: Hesperiidae): Abundance Patterns and Management of a Highly Imperiled Prairie Species. *International Scholarly Research Notices*, 2014.
(11) Bubová T., Vrabec V., Kulma M. & Nowicki P. (2015) Land management impacts on European butterflies of conservation concern: a review. *Journal of Insect Conservation*, 19, 805–821.
(12) Bendel C.R., Hovick T.J., Limb R.F. & Harmon J.P. (2018) Variation in grazing management practices supports diverse butterfly communities across grassland working landscapes. *Journal of Insect Conservation*, 22, 99–111.
(13) Warchola N., Crone E.E. & Schultz C.B. (2018) Balancing ecological costs and benefits of fire for population viability of disturbance-dependent butterflies. *Journal of Applied Ecology*, 55, 800–809.

8.3. Use rotational burning

- **Seventeen studies** evaluated the effects on butterflies and moths of using rotational burning. Twelve studies were in the USA[1–6, 8-15,17], one was in South Africa[7] and one was in Japan[16].

COMMUNITY RESPONSE (5 STUDIES)

- **Community composition (1 study):** One replicated, site comparison study in the USA[9] found that prairies managed by rotational burning (every 1–6 years) and grazing had a different community composition of butterflies to prairies managed by rotational burning or grazing alone.

- **Richness/diversity (5 studies):** Two replicated, site comparison studies in the USA[6] and Japan[16] found that pine-oak barrens[6] and semi-natural grasslands[16] managed by rotational burning every 2 years[16] or 2–5 years[6] (sometimes combined with rotational mowing[16]) had a higher species richness of butterflies than unmanaged sites[6,16] or sites managed by annual burning or mowing[16]. However, one of these studies also found that the species richness of grassland butterflies was lower in prairies managed by rotational burning than in unmanaged prairies in one of two regions[6]. Two replicated, site comparison studies in the USA[6,10] found that the species richness of butterflies was higher on prairies burned more than one[6] or four[10] years ago than on prairies burned in the last one[6] or two[10] years under rotational burning management. One replicated, site comparison study in the USA[7] found that prairies managed by rotational burning (every 1–6 years) and grazing had a similar species richness of butterflies to prairies managed by rotational burning or grazing alone, but a lower diversity of butterflies than sites managed by rotational burning only. One replicated, randomized, controlled study in the USA[12] found that species richness of butterflies did not differ between prairies managed with annual rotational burning or complete burning.

POPULATION RESPONSE (15 STUDIES)

- **Abundance (15 studies):** Four replicated studies (including one paired, controlled study and three site comparison studies) in the USA[1,6,8,10] found that under rotational burning management the total abundance of prairie specialist[1,6], grassland[6] and all[10] butterflies, and of most insects including butterflies and moths[8], was higher on prairies burned more than one[6], two[8] or four[10] years ago, or longer ago[1], than on prairies burned in the last one[6] or two[8,10] years, or recently[1]. One of these studies also found that the abundance of grassland and generalist butterflies was highest in the third year after burning, and migrant butterflies in the first year after burning[1]. Two of these studies[6,8], and an additional replicated, site comparison study in the USA[9] found that the total abundance of butterflies[6,9], and of most insects including butterflies and moths[8], was higher in pine-oak barrens[6] and prairies[8,9] managed by rotational burning every 2–5 years[6], 2–3 years[8] or 1–6 years[9] than at unmanaged sites[6,8] or sites managed by rotational burning or grazing alone[9]. One of these studies also found that the abundance of butterflies was lower in prairies managed by rotational burning than in unmanaged prairies in one of two regions[6]. Five of six replicated studies in the USA (including five site comparison studies[2,3,4,11,14] and one randomized, controlled study[12]) found that rotational burning in prairies[2,4,11,12], pine barrens[4,11] and grasslands[11] had mixed effects on butterflies, compared to unmanaged, hayed, grazed, mowed or completely burned sites. The third study found that prairies managed by rotational burning had more strongly declining populations of grass-skipper butterflies than unmanaged pine barrens or lightly managed fields[14]. The fourth study found that for three fritillary species rotational burning in prairies did not affect abundance, but for three others, in at least one region surveyed, abundance was lower in prairies managed by rotational burning, sometimes in combination with haying, grazing and/or mowing, than in prairies managed with only haying or grazing, or in unmanaged prairies[3]. One replicated, site comparison study in the USA[5] reported that Karner blue butterfly abundance was similar in rotationally burned and unmanaged oak savannas and prairies. One site comparison study in the USA[15] reported that regal fritillary abundance was higher in grasslands and oak barrens managed by rotational burning every three years (following restoration by seeding) than on unmanaged sites or remnant prairies. One replicated, site comparison study in the USA[17] found that the abundance of regal fritillary was higher in rotationally burned prairies four years after the last burn than one or eight years after the last burn. One replicated, randomized, paired, controlled study in the USA[13] found that, in June, the abundance of regal fritillaries in prairies burned on rotation that spring was lower than in prairies burned 1–2 years ago, but in July the abundance was higher in recently burned prairies.

- **Survival (1 study):** One replicated study in South Africa[7] found that populations of Karkloof blue persisted for at least a year following rotational burning.

BEHAVIOUR (0 STUDIES)

Background

Open habitats, such as grassland, heathland, peatland and fynbos, require disturbance processes to prevent them undergoing succession to scrub or woodland. One option for preventing succession and opening up areas of habitat is to use prescribed burning. However, burning is likely to be destructive in the short-term, because of either direct mortality or a reduction in food availability for butterflies and moths (Glaves *et al.* 2013). Rotational burning, where sites are burned once every few years, may allow time for habitat patches to recover to the optimal condition for butterflies and moths in the period between burns, while maintaining a dynamic patchwork of suitable habitat across a site. However, the impact of fires can vary depending on their exact characteristics, such as the frequency, temperature, ground surface intensity, time and size of burning compared to the surrounding unburned areas (Swengel 2001, Tucker 2003, New *et al.* 2010) and caution should be taken before instigating fire in place of alternative management options such as grazing or cutting.

For studies on the impact of single prescribed burns, see "*Use prescribed fire to maintain or restore disturbance in grasslands or other open habitats*". For studies of other changes to the burning regime, see "*Change season/timing of prescribed burning*" and "*Leave some areas unburned during prescribed burning*".

Glaves D.J., Morecroft M., Fitzgibbon C., Lepitt P., Owen M. & Phillips S. (2013) Natural England Review of Upland Evidence 2012 - The effects of managed burning on upland peatland biodiversity, carbon and water. *Natural England Evidence Review*, Number 004 (NEER004).

New T.R., Yen A.L., Sands D.P.A., Greenslade P., Neville P.J., York A. & Collett N.G. (2010) Planned fires and invertebrate conservation in South East Australia. *Journal of Insect Conservation*, 10, 567–574.

Swengel A.B. (2001) A literature review of insect responses to fire, compared to other conservation managements of open habitat. *Biodiversity and Conservation*, 10, 1141–1169.

Tucker G. (2003) Review of the impacts of heather and grassland burning in the uplands on soils, hydrology and biodiversity (ENRR550). Natural England (English Nature) report.

A replicated, site comparison study in 1988–1993 in 51 tall-grass prairies in Illinois, Iowa, Minnesota and Wisconsin, USA (1) found that the abundance of prairie specialist butterflies in burned prairies increased with time since the last fire, but the abundance of other species was highest sooner after burning. At sites burned >4 years ago, the total abundance of six prairie specialists (75 individuals/hour) was higher than at sites burned the previous winter (10 individuals/hour). However, the abundance of grassland species and generalists was higher in the third year after burning (100–130 individuals/hour) than in the first or second year (50–100 individuals/hour) or fourth or fifth year (60–90 individuals/hour). The abundance of migrant species was higher in the year immediately after burning (770 individuals/hour) than in any subsequent year (10–40 individuals/hour). See paper for individual species results. Fifty-one sites (1–445 ha) were primarily managed by cool-season fire covering 5–99% of the site. From June–August 1988–1993, butterflies were surveyed 1–4 times/year on a transect through most sites (only Minnesota and Wisconsin in 1988–1989). Transects were sub-divided by the most recent management. Thirty-two species observed >49 times and at >5 sites were included, and divided into "prairie specialists" (6 species, only found on prairies), "grassland species" (13 species, found in prairies and other grasslands), "generalists" (10 species, found in grasslands and other habitats) and "migrants" (3 species, only present in the study area during the growing season).

A replicated, site comparison study in 1988–1996 on 17 upland prairies in Missouri, Minnesota, North Dakota and Wisconsin, USA (2, same experimental set-up as 3 and 5) found that prairies managed by rotational burning had a lower abundance of six out of seven specialist butterfly species than prairies managed by haying or grazing, or unmanaged areas. Of seven prairie specialist butterfly species, three (gray copper *Lycaena dione*, regal fritillary *Speyeria idalia*, arogos skipper *Atrytone arogos*) were less abundant in rotationally burned areas than in unmanaged areas, and four were less abundant in burned areas than in hayed (regal fritillary, Pawnee skipper *Hesperia leonardus pawnee*, Dakota skipper *Hesperia dacotae*) or grazed (Gorgone checkerspot *Chlosyne gorgone*) prairies. Poweshiek skipperling *Oarisma poweshiek* abundance in burned prairies was not significantly different from in hayed, grazed or unmanaged areas. See paper for individual species data. Across 17 prairies (16 to >120 ha), eight areas were managed by burning on rotation, six by haying (often in rotation), three by burning and haying, two by grazing, and two were unmanaged. From 1988–1996, butterflies were surveyed on transects through different management areas at each site. Sites were not surveyed in every year.

A replicated, site comparison study in 1988–1996 in 106 tallgrass prairies in Illinois, Iowa, Wisconsin, North Dakota, Minnesota and Missouri, USA (3) found that rotational burning, either alone or in combination with other managements, was associated with lower butterfly abundances for three of six fritillary butterfly species in at least one of the studied regions. In all regions where present, variegated fritillary *Euptoieta claudia*, great spangled fritillary *Speyeria cybele* and small pearl-bordered fritillary *Boloria selene* abundances were not affected by management type. Aphrodite fritillary *Speyeria aphrodite* abundance was lower in sites managed with burning or burning and mowing than in unmanaged and grazed sites in the Eastern Upper Midwest, but not in the Western Upper Midwest. Regal fritillary *Speyeria idalia* abundance was lower in sites with burning than grazing in the Upper Eastern Midwest, in sites with burning than haying in the Western Upper Midwest and in sites with burning or burning and haying than in sites with haying alone in southwestern Missouri. Meadow fritillary *Boloria bellona* abundance was lower in sites with burning or burning and mowing than in unmanaged sites in the Eastern Upper Midwest. All other management comparisons were not significantly different or had insufficient data for comparisons. Raw data were not provided. Butterfly surveys were conducted in June–September 1988–1996 in the Eastern Upper Midwest (northern Illinois, eastern Iowa and southwestern Wisconsin), Western Upper Midwest (eastern North Dakota, western Minnesota and western Iowa) and southwestern Missouri in tallgrass prairie sites with no management (7 sites), unknown management (4 sites) or managed by rotational burning (49 sites, mostly with a 2–5 year interval), rotational haying (24 sites, mostly with a 2–3 year interval), grazing (1 site) or a combination of burning and haying (20 sites) or burning and mowing (1 site). Not all sites were surveyed for the whole period or every year. Surveys were of varying lengths and conducted simultaneously along one set of parallel transects (5–10 m apart) in each site. Not all butterflies were found in all regions.

A replicated, site comparison study in 1986–1995 in 104 tallgrass prairies and 141 pine barrens in Illinois, Iowa, Minnesota, Missouri, North Dakota and Wisconsin, USA (4, same experimental set-up as 2 and 5) found that rotationally burned grasslands or barrens had a higher abundance of two of 16 specialist butterfly species, but a lower abundance of seven specialist species, than either unmanaged sites or sites managed by grazing or mowing. Of 16 prairie or pine barren specialist butterfly species, two (ottoe skipper *Hesperia ottoe* and dusted skipper *Atrytonopsis hianna*) were more abundant in sites managed by rotational burning than grazed, mown or unmanaged sites. Seven species were less abundant in rotationally burned sites than in sites managed by haying (Dakota skipper *Hesperia dacotae*, pawnee skipper *Hesperia leonardus pawnee*), mowing (Persius duskywing *Erynnis persius*), cutting (cobweb skipper *Hesperia metea*), grazing and haying (arogos skipper *Atrytone arogos*, regal fritillary *Speyeria idalia*), or unmanaged sites (arogos skipper *Atrytone arogos*, Poweshiek skipper *Oarisma poweshiek*). Seven species had similar abundance between management types. See paper for individual species data. Of 104 prairies (1–2,024 ha), 61 were managed by cool-season burning on a 2–5-year rotation, of which 21 were additionally mown or hayed; 27 were hayed in summer on a 1–2-year rotation, of which two were also grazed occasionally with cattle; 10 were grazed; and six had not been managed for many years. Of 141 pine barrens, some were burned by wildfires, some were used for off-road vehicle trails, and some were power line rights-of-way (no further detail provided). From April–September 1986–1995, butterflies were surveyed on transects at each site. Most sites were surveyed more than once/year, and in >1 year.

A replicated, site comparison study in 1993–1997 in five oak savannas and prairies in Indiana, USA (5) reported that sites burned on rotation had a similar abundance of Karner blue butterfly *Lycaeides melissa samuelis* to unburned sites. Results were not tested for statistical significance. Over 2–3 years, at two sites managed by rotational burning, the maximum number of Karner blue adults recorded increased from 159–288 to 296–725. Over 1–2 years, at two unburned sites, the abundance increased from 45–103 to 71–184. At a third unburned site, there were 104 adults in 1994 and 103 in 1997. Within a 6,000-ha reserve, two sites were each divided into four units. At a 177-ha site, one unit was burned annually in autumn or spring from 1993–1996, and adjacent units were not burned in consecutive years. At a 59-ha site, one unit/year was burned in autumn

1995–1996. Within the burned units, multiple 50–300-m^2 patches with high Karner blue and wild lupine *Lupinus perennis* densities were left unburned. Three sites (areas not given) were not burned during the study. Butterflies were surveyed along a fixed 1.5–6.5-km transect/site, passing through all units. The highest number recorded at each site was taken as an annual population estimate. In July 1994, two surveys were conducted at each of two sites (one burned and one unburned). In June–August 1995–1997, three–nine surveys were conducted at each of 4–5 sites/year. Surveys were conducted 1–10 days apart.

A replicated, site comparison study in 1990–1997 in 86 tallgrass prairies and 32 pine-oak barrens in Illinois, Iowa, Minnesota, Missouri, North Dakota and Wisconsin, USA (6, same experimental set-up as 2 and 3) found that barrens had a higher abundance and species richness of specialist and grassland butterflies after more recent burning, but that prairies had a lower abundance and species richness of butterflies after more recent burning. In pine-oak barrens, the abundance and species richness of specialist and grassland butterflies was higher in recently burned areas than in unmanaged areas. However, in the first year after prairies had been burned, the abundance and species richness of specialist and grassland butterflies was lower than in areas which had not been burned in the last year. In addition, in Illinois, Wisconsin and eastern Iowa, the abundance of specialists, and the abundance and richness of grassland species, was lower in burned prairies of any age than in unmanaged prairies. However, apart from in the first year since burning, there were no differences between burned and unmanaged prairies in western Iowa, Minnesota and North Dakota. All data were presented as models results. A total of 77 prairies and 20 barrens were managed by rotational burning (every 2–5 years) in the cool-season, although some areas had not been burned for eight years. Nine prairies and 12 barrens had been unmanaged for many years. From May–September 1990–1997, butterflies were surveyed on parallel transects (5–10 m apart) at each site. Most sites were surveyed more than once/year, and in >1 year. Butterflies were classified as "specialists" (of native plants), "grassland" (occurring widely in open habitat) and "generalist" (occurring in a range of habitats).

A replicated study in 1998–1999 in three mistbelt grasslands in KwaZulu-Natal province, South Africa (7) reported that populations of Karkloof blue butterfly *Orachrysops ariadne* persisted for at least a year following prescribed burning. In 1999, after prescribed fires in 1998, the authors recorded adults at Stirling, 90 hatched eggs at The Start and adults and 170 hatched eggs at Wahroonga. In March–June 1999, vegetation was searched for eggs at three mistbelt grasslands – Stirling (1–2 ha of Karkloff blue habitat), The Start (1 ha of habitat) and Wahroonga (10 ha of habitat).). Each egg was marked with a tag and a serial number so its hatching progress could be recorded. Details of adult butterfly recording were not provided. All three sites were in long term prescribed rotational burning regimes. Half of The Start was burned in July 1998, all of Wahroonga was burned in August 1998, and most of Stirling was burned in October 1998. No burning happened in 1999. Additionally, at The Start 50 *Indigofera woodii H. Bol.* var *laxa* saplings were planted in November 1998 and bramble was controlled with herbicide in January 1999. Stirling was cattle grazed each summer.

A replicated, paired, controlled study in 1992–1997 in 21 tallgrass prairie remnants in Illinois, Indiana and Wisconsin, USA (8) found that most insect populations (including butterflies and moths) which initially declined after burning recovered within a year and had higher abundance on burned than unburned sites. One year after burning, the abundance of 68% of insect populations which initially declined had recovered to match the abundance at unburned sites, and all recovered within two years. Moreover, 84% of these populations recovered to higher abundance in recently burned than unburned areas. Species which increased (26%) or did not change (34%) in abundance immediately after fire were not considered further. See paper for individual species results. Twenty-one prairies (2–600 ha) were divided into two or more units, and from 1992–1997 either 0 or 1 unit/prairie was burned each year in March–April. Recently burned units were left unburned for 2–3 years. Insects of 151 species were sampled in burned and unburned areas in a variety of ways. From May–October 1992–1997, random sweep samples were conducted at each site. In autumn 1992–1997, adhesive-coated plastic plates were placed to catch leafhoppers (Cicadellidae). Six moth caterpillars were sampled from 100–4,700 plant stems on 28 occasions. On three nights in 1997, black-light traps were used at two sites to sample three moth species. From June–July 1995–1997, butterflies were surveyed along transects and on 5-minute counts from random points at seven sites.

A replicated, site comparison study in 2004–2005 in two remnant prairies and adjacent land in Iowa, USA (9, same experimental set-up as 8) found that prairies which were rotationally burned and grazed had a higher abundance, but not species richness, of butterflies than prairies which only received burning or grazing, but the three management practices supported different species. The abundance of butterflies in burned and grazed prairies (31.5 individuals/unit) was higher than in prairies which were only burned (20.2 individuals/unit) or only grazed (27.8 individuals/unit). Species richness of butterflies was similar in prairies managed by burning and grazing (8.5 species/unit), only burning (8.6 species/unit) and only grazing (7.4 species/unit). Butterfly diversity was higher in prairies managed by burning only than in prairies managed by grazing only or grazing and burning (data presented as model results). However, each management practice supported different species (see paper for details). Across two remnant prairie reserves (320 and 1,800 ha) and surrounding land, 28 management units (10–167 ha) were managed consistently for ≥4 years. Ten units were burned during autumn or spring every 1–6 years. Six units were lightly grazed on rotation (1 cow-calf pair/4 ha). Twelve units were burned and grazed. From June–August 2004–2005, butterflies were surveyed for 30 minutes twice/year at 69 sites (50 × 50 m, >150 m apart) across the 28 units.

A replicated, site comparison study in 2004–2005 in two remnant prairies and adjacent land in Iowa, USA (10, same experimental set-up as 7) found that recently burned sites had lower abundance and species richness of butterflies than sites burned longer ago. At sites burned 7–25 months before surveying, the abundance and species richness of all butterflies (abundance: 6–21 individuals/unit; richness: 4–7 species/unit) and of prairie specialists (abundance: 2–14 individuals/unit; richness: 1–3 species/unit) were lower than at sites burned 43–

61 months before surveying (all: 13–21 individuals/unit; 5–7 species/unit; specialists: 5–15 individuals/unit; 2–3 species/unit). Of 14 individual species, four were less abundant, and three were more abundant, at recently burned sites than at sites burned longer ago (see paper for details). Across two remnant prairie reserves (320 and 1,800 ha) and surrounding land, 22 management units (10–102 ha) were managed consistently for ≥4 years. All units were burned during autumn or spring every 1–6 years. Twelve units were also lightly grazed on rotation (0.25 cow-calf pairs/ha). From June–August 2004–2005, butterflies were surveyed for 30 minutes twice/year at 53 sites (50 × 50 m, >150 m apart) across the 22 units. Butterflies were classified as "specialists" which require native prairie plants as adults or caterpillars, and "generalists" which use a variety of common plants and occur in a range of open habitats.

A replicated, before-and-after, site comparison study in 1979–2009 in prairie, grassland and pine barrens in Illinois, Iowa, Minnesota and Wisconsin, USA (11) found that rotational burning, along with other interventions, had mixed effects on prairie-specialist butterfly abundance. At sites managed by rotational burning, the Ottoe skipper *Hesperia ottoe* declined over time in some sites in two of four states (Minnesota and Wisconsin), and the Poweshiek skipperling *Oarisma poweshiek* and Aphrodite fritillary *Speyeria Aphrodite* declined in sites in one state (Iowa). Regal fritillary *Speyeria idalia* numbers increased at one site in one state (Wisconsin). No changes were found for species monitored in other states. Results are presented as statistical tests. In four areas in Wisconsin designated as butterfly reserves (≤32% burned/year), Karner blue butterfly *Lycaeides melissa samuelis* abundance decreased less (1999: 27 individuals/km; 2009: 20 individuals/km) than at 10 sites where higher levels of burning, as well as timber extraction and public rights-of-way, were allowed (1999: 17 individuals/km; 2009: 2–5 individuals/km). Butterfly counts from 10 separate researcher teams, which overlapped in location, were combined and adjusted to account for differences in survey methods. At each site, 20–35% of the area was burned on average each year, with each section being burned at least every 10 years. Authors reported that sites were also managed with mowing, haying, brush-cutting and herbicides; details of management at each not provided.

A replicated, randomized, controlled study in 2007–2009 in 13 tallgrass prairies in Iowa and Missouri, USA (12) found that butterfly species richness did not differ between pastures with rotational burning and grazing and pastures where the whole area was burned (with or without grazing), but the density of some species differed with management and year. There was no difference in species richness between pastures burned rotationally with grazing (6–7) and pastures with complete burning and grazing (6–7) or no grazing (7). Regal fritillary *Speyeria idalia* densities were lower with rotational burning with grazing and complete burning with grazing (both average: 0 individuals/ha) than with complete burning and no grazing (5–7 individuals/ha). The same was seen in the common wood-nymph *Cercyonis pegala* (rotational burning/grazing or complete burning/grazing = 2 individuals/ha; complete burning/no grazing = 21) and the monarch butterfly *Danaus plexippus* (rotational burning/grazing or complete burning/grazing = 1 individuals/ha; complete burning/no grazing = 2) but only in 2009 (the survey after the burn in non-rotational pastures, no difference in 2008).

In 2008 only, eastern tailed-blue *Cupido comyntas* population densities were higher in rotational burning with grazing pastures (124 individuals/ha) than complete burning with (101) or without grazing (55) pastures (no difference in 2009). Other species analysed were not affected by management in either year. Pastures (15–31 ha) were managed in one of three ways: 1) rotational burning, with a third of each pasture burned annually in spring 2007–2009 and grazing May–October annually (five pastures), 2) complete burning in spring 2008 or 2009 and grazing May–October annually (four pastures), or 3) complete burning in spring 2008 or 2009 without grazing (four pastures). Butterflies were surveyed in June–July 2008–2009 along six 100-m transects/pasture.

A replicated, randomized, paired, controlled study in 2005–2007 in four tallgrass prairies in Missouri, USA (13) found that spring burning reduced regal fritillary *Speyeria idalia* abundance in mid-summer, but increased abundance later in the summer. In late June, the number of regal fritillaries in plots burned that spring (3–12 individuals/ha) was lower than in plots burned one (12–22 individuals/ha) or two (7–25 individuals/ha) years earlier. However, by late July, the number was higher in recently burned plots (14–22 individuals/ha) than in plots burned one or two years earlier (1–9 individuals/ha). In early June, fritillary abundance was not significantly different in recently burned plots (5–22 individuals/ha) and those burned in previous years (7–9 individuals/ha). From 2000–2004, four remnant prairies were burned on rotation and occasionally hayed or lightly grazed. In 2005, half of each prairie was randomly assigned to one of two treatments: grazing and rotational burning, or rotational burning only. Each half was sub-divided into three plots (20–34 ha), which were randomly assigned to be burned in either March 2005, 2006 or 2007. The grazed sites were stocked with cattle (2.2 ha/animal unit) annually from April–August. From June–July 2006–2007, butterflies were surveyed three times/year on a transect through each plot.

A replicated, site comparison study in 1988–2013 in 24 prairies, pine-oak barrens and fields in Wisconsin, USA (14) found that prairies managed by rotational burning had more strongly declining populations of grass-skipper butterflies (Hesperiinae) than unmanaged pine barrens or lightly managed fields. In prairies managed by rotational burning, specialist and grassland skipper butterflies had more strongly declining population trends than in pine-oak barrens (specialist and grassland species) or old fields (grassland species only) (data presented as model results). Ten native prairies were managed by cool-season burning, typically on a 2–5-year rotation, with some mowing, cutting and spot herbicide application. Eight pine-oak barrens were last burned by wildfires in 1977 or 1988. Six fields reverting from agriculture were managed by burning, grazing, haying, cutting, herbicide or tilling, but with no more than 10% of a site managed each year. In spring and summer 1988–2013, butterflies were surveyed along transects (2–3 km/hour) at each site, generally at least twice/year and in at least two years/site. Skippers were classified as eight "specialist" (restricted to native grassland habitat) or five "grassland" (occurring widely in open habitat) species.

A site comparison study in 2014 in a restored grassland and oak barren landscape in Indiana, USA (15) reported that regal fritillary *Speyeria idalia* were found across a landscape restored by planting and managed by rotational burning. Results were not tested for statistical significance. Eighteen years after planting and rotational burning began, on four restoration sites with high plant diversity, the abundance of regal fritillaries peaked at 17 butterflies/30-minute transect, compared to 12 butterflies/transect on two remnant prairies and a low plant diversity restoration site, 19 butterflies/transect in an old field, and 0 butterflies/transect in an agricultural field. Prior to restoration, authors reported that regal fritillaries were only found at three small sites in the landscape. Beginning in 1996, over 3,240 ha of agricultural land was restored to native grassland and oak barrens by planting seed mixes containing over 620 native species. In addition, seeds and plugs of arrowleaf violet *Viola sagittata* and bird's-foot violet *Viola pedata* were planted as host plants. The area was managed to control invasive species and, once established, patches were burned on a three-year rotation. From May–September 2014, butterflies were surveyed every two weeks on 30-minute transects at nine sites across the landscape: four restoration sites with high plant diversity, one restoration site with low plant diversity, two remnant prairies, one old field, and one site still in agricultural production, none of which had been burned during the previous year.

A replicated, site comparison study in 2012–2013 in 12 semi-natural grasslands in Nagano Prefecture, Japan (16) found that meadows managed by traditional rotational burning and mowing had a higher species richness and diversity of butterflies than annually burned, annually mown or abandoned meadows. In rotationally managed meadows, the diversity and species richness of threatened (6–7 species/meadow) and common (10–12 species/meadow) butterflies was higher than in annually burned (threatened: 2–3; common: 6 species/meadow), annually mown (threatened: 3; common: 4 species/meadow) or abandoned meadows (threatened: 1–2; common: 1–2 species/meadow) (diversity data presented as model results). Three meadows were managed traditionally: each year half of the meadow was burned in April and mown in September, while the other half was unmanaged, and management rotated each year. An additional three meadows had been burned annually for 7–13 years, three meadows had been mown annually in April or August for 8–9 years and three meadows had been abandoned (unmanaged) for 6–13 years. From May–September 2012–2013, butterflies were surveyed monthly on three 5 × 30 m plots/meadow.

A replicated, site comparison study in 1997–2016 in seven tallgrass prairies in Wisconsin, USA (17) found that burning initially reduced the abundance of regal fritillaries *Speyeria idalia* but then resulted in increased abundance for up to four years. All data were presented as model results. Regal fritillary abundance was reduced immediately after burning, highest four years after burning, and reduced again by eight years after burning. Areas burned within the last 7 years had a higher abundance of regal fritillaries than unburned areas, but fritillary abundance was not significantly higher in more frequently burned areas. The proportion of habitat burned did not affect abundance. From 1997–2016, seven patches of remnant and restored prairie (19–41 ha, 0.25–3.5 km apart) were managed with periodic rotational burning, where 25–93% of each site was left unburned each year. Burned areas always had suitable unburned habitat within

622 m. In July and August 1997–2016, beginning 7–10 days after the first emergence, regal fritillaries were surveyed weekly on 57 permanent transects across the seven sites, with >3 surveys/transect/year. The maximum number of regal fritillaries recorded on a single survey each year was used as the population estimate for each transect.

(1) Swengel A.B. (1996) Effects of fire and hay management on abundance of prairie butterflies. *Biological Conservation*, 76, 73–85.
(2) Swengel A.B. & Swengel S.R. (1997) Co-occurrence of prairie and barrens butterflies: applications to ecosystem conservation. *Journal of Insect Conservation*, 1, 131–144.
(3) Swengel A.B. (1997) Habitat Associations of Sympatric Violet-Feeding Fritillaries (*Euptoieta, Speyeria, Boloria*) (Lepidoptera: Nymphalidae) in Tallgrass Prairie. *The Great Lakes Entomologist*, 30(1&2).
(4) Swengel A.B. (1998) Effects of management on butterfly abundance in tallgrass prairie and pine barrens. *Biological Conservation*, 83, 77–89.
(5) Kwilosz J.R. & Knutson R.L. (1999) Prescribed fire management of Karner blue butterfly habitat at Indiana Dunes National Lakeshire. *Natural Areas Journal*, 19, 98–108.
(6) Swengel A.B. & Swengel S.R. (2001) Effects of prairie and barrens management on butterfly faunal composition. *Biodiversity and Conservation*, 10, 1757–1785.
(7) Lu S. & Samways M.J. (2002) Conservation management recommendations for the Karkloof blue butterfly, *Orachrysops ariadne* (Lepidoptera: Lycaenidae). *African Entomology*, 10(1), 149-159.
(8) Panzer R. (2002) Compatibility of prescribed burning with the conservation of insects in small, isolated prairie reserves. *Conservation Biology*, 16, 1296–1307.
(9) Vogel J.A., Debinski D.M., Koford R.R. & Miller J.R. (2007) Butterfly responses to prairie restoration through fire and grazing. *Biological Conservation*, 140, 78–90.
(10) Vogel J.A., Koford R.R. & Debinski D.M. (2010) Direct and indirect responses of tallgrass prairie butterflies to prescribed burning. *Journal of Insect Conservation*, 14, 663–677.
(11) Swengel S. R., Schlicht D., Olsen F., Swengel A. B. (2011) Declines of prairie butterflies in the midwestern USA. *Journal of Insect Conservation*, 15, 327-339.
(12) Moranz R.A., Debinski D.M., McGranahan D.A., Engle D.M. & Miller J.R. (2012) Untangling the effects of fire, grazing, and land-use legacies on grassland butterfly communities. *Biodiversity and Conservation*, 21, 2719-2746.
(13) Moranz R.A., Fuhlendorf S.D. & Engle D.M. (2014) Making sense of a prairie butterfly paradox: The effects of grazing, time since fire, and sampling period on regal fritillary abundance. *Biological Conservation*, 173, 32–41.
(14) Swengel A.B. & Swengel S.R. (2015) Grass-skipper (Hesperiinae) trends in midwestern USA grasslands during 1988–2013. *Journal of Insect Conservation*, 19, 279–292.
(15) Shuey J., Jacquart E., Orr S., Becker F., Nyberg A., Littiken R., Anchor T. & Luchik D. (2016) Landscape-scale response to local habitat restoration in the regal fritillary butterfly (*Speyeria idalia*) (Lepidoptera: Nymphalidae). *Journal of Insect Conservation*, 20, 773–780.
(16) Uchida K., Takahashi S., Shinohara T. & Ushimaru A. (2016) Threatened herbivorous insects maintained by long-term traditional management practices in semi-natural grasslands. *Agriculture, Ecosystems & Environment*, 221, 156–162.
(17) Henderson R.A., Meunier J. & Holoubek N.S. (2018) Disentangling effects of fire, habitat, and climate on an endangered prairie-specialist butterfly. *Biological Conservation*, 218, 41–48.

8.4. Change season/timing of prescribed burning

- **Two studies** evaluated the effects on butterflies and moths of changing the season or timing of prescribed burning. One study was in each of Australia[1] and the USA[2].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (2 STUDIES)

- **Abundance (2 studies):** One replicated, controlled, before-and-after study in Australia[1] found that management of a tropical savanna and floodplain with early season burning or no burning for 2–5 years increased the abundance of caterpillars, but management with late season burning did not. One replicated, paired, controlled study in the USA[2] found that Karner blue butterfly abundance was similar on grasslands managed by burning in summer or autumn, and on unmanaged grasslands.

BEHAVIOUR (0 STUDIES)

Background

Open habitats, such as grassland, heathland, peatland and fynbos, require disturbance processes to prevent them undergoing succession to scrub or woodland. One option for preventing succession and opening up areas of habitat is to use prescribed burning. Although destructive in the short-term, with the likely loss of butterflies and moths through direct mortality or reductions in food availability (Glaves *et al.* 2013), burning may have long-term benefits by creating a more favourable, open habitat (Bubová *et al.* 2015), with increases in structural diversity (Glaves *et al.* 2013) or flower density (Vogel *et al.* 2010). However, the impact of fires can vary depending on their exact characteristics, such as the frequency, temperature, ground surface intensity, time and size of burning compared to the surrounding unburned areas (Swengel 2001, Tucker 2003, New *et al.* 2010) and caution should be taken before instigating fire in place of alternative management options such as grazing or cutting.

For studies on the impact of single prescribed burns, see "*Use prescribed fire to maintain or restore disturbance in grasslands or other open habitats*". For studies of other changes to the burning regime, see "*Use rotational burning*" and "*Leave some areas unburned during prescribed burning*".

Bubová T., Vrabec V., Kulma M. & Nowicki P. (2015) Land management impacts on European butterflies of conservation concern: a review. *Journal of Insect Conservation*, 19, 805–821.

Glaves D.J., Morecroft M., Fitzgibbon C., Lepitt P., Owen M. & Phillips S. (2013) Natural England Review of Upland Evidence 2012 - The effects of managed burning on upland peatland biodiversity, carbon and water. *Natural England Evidence Review*, Number 004 (NEER004).

New T.R., Yen A.L., Sands D.P.A., Greenslade P., Neville P.J., York A. & Collett N.G. (2010) Planned fires and invertebrate conservation in South East Australia. *Journal of Insect Conservation*, 10, 567–574.

Swengel A.B. (2001) A literature review of insect responses to fire, compared to other conservation managements of open habitat. *Biodiversity and Conservation*, 10, 1141–1169.

Tucker G. (2003) Review of the impacts of heather and grassland burning in the uplands on soils, hydrology and biodiversity (ENRR550). Natural England (English Nature) report.

Vogel J.A., Koford R.R. & Debinski D.M. (2010) Direct and indirect responses of tallgrass prairie butterflies to prescribed burning. *Journal of Insect Conservation*, 14, 663–677.

A replicated, controlled, before-and-after study in 1988–1995 in a tropical savannah and floodplain reserve in Northern Territory, Australia (1) found that management with early season burning or no burning increased the abundance of caterpillars, but late season burning did not. After 2–5 years of burning, the abundance of caterpillars increased at sites with early (before: 1; after: 4 individuals) or no burning (before: 5; after: 8 individuals) but remained similar at sites with late burning (before: 3; after: 3 individuals). From 1990–1994, one of three fire regimes was applied annually to each of nine 15–20 km^2 compartments across a 670-km^2 area: early fires (lit early in dry season in May/June, equivalent to usual conservation management); late fires (lit late in dry season in September/October, equivalent to unmanaged wildfires); and unburned (no fires). Fire was excluded from all plots for 1–2 years prior to the experiment. Caterpillars were sampled by pitfall trapping and sweep-netting. Pitfall traps were set for 48 hours every November and August from 1988–1994, using 15 traps (10 m apart) /40 × 20 m plot, with two plots/compartment, one in poorly-drained woodland and one in well-drained forest. Sweep-netting was conducted every February and May from 1989–1995, using five parallel transects of 20 sweeps each, spaced 5 m apart, over the trapping grid.

A replicated, paired, controlled study in 1993–1997 in 15 oak savannas in Wisconsin, USA (2) found that burning grassland in summer or autumn did not increase Karner blue butterfly *Lycaeides melissa samuelis* abundance compared to either unmanaged or mown grasslands. The density of Karner blue was similar on both summer burned (31–186 individuals/ha) and paired, unburned (35–101 individuals/ha) grasslands, and on autumn burned (22–478 individuals/ha) and paired, unburned (14–179 individuals/ha) grasslands. Karner blue density was also similar on three summer burned (36–213 individuals/ha), three summer mown (46–111 individuals/ha) and three unmanaged (43–119 individuals/ha) grasslands. Fifteen restored oak savannas were burned on average every 3.5 years for 19–33 years prior to 1993. In 1994, four grasslands (1–11 ha) were summer burned in July and two grasslands (0.5–19.2 ha) were autumn burned in November. In winter 1993–1994, woody vegetation was removed with chainsaws on three additional grasslands, and these sites were then cut with a rotary mower in August 1994. Six control grasslands received no burning or mowing. In July–August 1993–1997, butterflies were surveyed three times/grassland/year (>7 days apart) along transects placed 15 m apart.

(1) Andersen A.N. & Müller W.J. (2000) Arthropod responses to experimental fire regimes in an Australian tropical savannah: ordinal-level analysis. *Austral Ecology*, 25, 199–209.

(2) King R.S. (2003) Habitat management for the Karner blue butterfly (*Lycaeides melissa samuelis*): evaluating the short-term consequences. *Ecological Restoration*, 21, 101–106.

8.5. Leave some areas unburned during prescribed burning

- **Two studies** evaluated the effects on butterflies and moths of leaving some areas unburned during prescribed burning. Both studies were in the USA[1,2].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (2 STUDIES)

- **Abundance (2 studies):** One replicated study in the USA[1] reported that the abundance of Karner blue butterflies increased over 2–3 years in oak savannas and prairies where unburned patches were left during prescribed burning. One replicated, site comparison study in the USA[2] found that six out of nine specialist butterfly species were more abundant, one was less abundant, and two had similar abundance in pine barrens and prairies where unburned areas were left during prescribed burning compared to at sites without unburned areas.

BEHAVIOUR (1 STUDY)

- **Use (1 study):** One replicated study in the USA[1] reported that Karner blue butterflies were recorded using all 11 unburned patches which were surveyed within oak savannas and prairies managed by burning.

Background

Open habitats, such as grassland, heathland, peatland and fynbos, require disturbance processes to prevent them undergoing succession to scrub or woodland. One option for preventing succession and opening up areas of habitat is to use prescribed burning. However, burning is likely to be destructive in the short-term, because of either direct mortality or a reduction in food availability for butterflies and moths (Glaves *et al.* 2013). Leaving some areas unburned within a prescribed burn, in particular habitat patches which currently support a high abundance of sensitive species (Kwilosz & Knutson 1999), may help populations to survive the fire and recolonize the newly created habitat over the following weeks, months or years. Unburned patches may be part of the burning rotation, or remain permanently unburned and managed by other, non-fire management options such as grazing or haying.

For studies on the impact of single prescribed burns, see "*Use prescribed fire to maintain or restore disturbance in grasslands or other open habitats*". For studies of other changes to the burning regime, see "*Use rotational burning*" and "*Change season/timing of prescribed burning*".

Glaves D.J., Morecroft M., Fitzgibbon C., Lepitt P., Owen M. & Phillips S. (2013) Natural England Review of Upland Evidence 2012 - The effects of managed burning on upland peatland biodiversity, carbon and water. *Natural England Evidence Review*, Number 004 (NEER004).

Kwilosz J.R. & Knutson R.L. (1999) Prescribed fire management of Karner blue butterfly habitat at Indiana Dunes National Lakeshire. *Natural Areas Journal*, 19, 98–108.

A replicated study in 1993–1997 in two oak savanna and prairie sites in Indiana, USA (1) reported that Karner blue butterfly *Lycaeides melissa samuelis* populations increased where unburned patches were left during prescribed burning, and Karner blues were recorded within the unburned patches. Results were not tested for statistical significance. Over 2–3 years, at two sites managed by rotational burning with unburned patches left within the burn area, the maximum number of Karner blue adults recorded increased from 159–288 to 296–725. Karner blues were recorded in nine of 11 unburned patches within burned units during the first brood after burning, and in all 11 patches during the second brood. Within a 6,000-ha reserve, two sites were each divided into four units. At a 177-ha site, one unit was burned annually in autumn or spring from 1993–1996, and adjacent units were not burned in consecutive years. At a 59-ha site, one unit/year was burned in autumn 1995–1996. Within the burned units, multiple 50–300-m^2 patches with high Karner blue and wild lupine *Lupinus* *perennis* densities were left unburned. Butterflies were surveyed along a fixed 1.5–6.5-km transect/site, passing through all units and 11 unburned patches. The highest number recorded at each site was taken as an annual population estimate. In July 1994, two surveys were conducted at the larger site. In June–August 1995–1997, six–nine surveys/year were conducted 1–10 days apart at each site.

A replicated, site comparison study in 1991–2005 in seven pine barrens and four prairies in Wisconsin, USA (2) found that six out of nine specialist butterfly species were more abundant at sites with unburned areas than at sites without unburned areas. At one pine barren, Karner blue *Lycaeides melissa samuelis* and mottled duskywing *Erynnis martialis* abundance in the unburned refuge were higher 10–17 years after establishment (Karner blue: 10.2–17.3 individuals) than 3–9 years after establishment (2.4–14.9 individuals), while abundance in 10 burned areas remained similar (10–17 years after: 7.1–14.6; 3–9 years after: 4.7–9.2 individuals; data for mottled duskywing not presented). In addition, when the unburned refuge was older, relative abundances of gorgone checkerspot *Chlosyne gorgone* (47% of records in refuge) and dusted skipper *Atrytonopsis hianna* (49% of records) were higher than in 10 burned areas, compared to when the unburned refuge was younger (checkerspot: 9%, skipper: 19% of records in refuge). There was no significant difference in relative abundances between the refuge and burned areas for Olympia marble *Euchloe olympia* (older: 12%; younger: 4% of records in refuge) and Persius duskywing *Erynnis persius* (older: 13%; younger: 0% of records in refuge). At another pine barren, over 13 years, frosted elfin *Callophrys irus* abundance in the refuge increased, but was absent from a site after burning, and abundance decreased at 11 comparison sites (see paper for details). In two prairies, regal fritillary *Speyeria idalia* abundance in unburned refuges (15.9–53.5 individuals) was higher than in burned areas (2.7–11.1 individuals). At the prairie with the most recently established refuge, regal fritillary abundance began to increase once the refuge was 7-years-old. However, Ottoe skipper *Hesperia ottoe* abundance declined at two prairies managed with burning and unburned refuges (data presented as model result). Seven pine barrens (8–48,921 ha) and four prairies (25–4,766 ha) were managed with cool-season rotational burning, mowing, grazing and hand-cutting of woody vegetation, within which areas were unburned for up to eight years. Two barrens contained an unburned refuge (4–14 ha) last burned in 1988 and 2002. Three prairies had long-established unburned refuges (11–35 ha), while the 3-ha refuge at the fourth prairie was last burned in 1991. From May–August 1991–2005, butterflies were surveyed along transects at each site, but sites were not surveyed every year.

(1) Kwilosz J.R. & Knutson R.L. (1999) Prescribed fire management of Karner blue butterfly habitat at Indiana Dunes National Lakeshire. *Natural Areas Journal*, 19, 98–108.
(2) Swengel A.B. & Swengel S.R. (2007) Benefit of permanent non-fire refugia for Lepidoptera conservation in fire-managed sites. *Journal of Insect Conservation*, 11, 263–279.

8.6. Use fire suppression/control

- We found no studies that evaluated the effects of using fire suppression or control on butterflies and moths.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Wildfires are part of a natural disturbance process in many habitats, and help to retain open landscapes such as grasslands and savannas. However, fire is destructive, and in the short-term will destroy habitat and kill butterflies and moths (Glaves *et al.* 2013). In areas occupied by sensitive and range-restricted species, it may therefore be necessary to suppress or control fires – whether natural or anthropogenic – to reduce their impact to small areas. This may be achieved by using herbicides or manual vegetation clearance to reduce the fuel-load in fire-prone areas, or deliberately burning small areas to reduce the risk of large wildfires.

For studies on creating fire breaks to restrict the spread of wildfires, see "*Mechanically remove mid-storey or ground vegetation to create fire breaks*".

Glaves D.J., Morecroft M., Fitzgibbon C., Lepitt P., Owen M. & Phillips S. (2013) Natural England Review of Upland Evidence 2012 - The effects of managed burning on upland peatland biodiversity, carbon and water. *Natural England Evidence Review*, Number 004 (NEER004).

8.7. Mechanically remove mid-storey or ground vegetation to create fire breaks

- **Two studies** evaluated the effects on butterflies and moths of mechanically removing mid-storey or ground vegetation to create fire breaks. One study was in Portugal[1] and the other was in France[2].

COMMUNITY RESPONSE (2 STUDIES)

- **Richness/diversity (2 studies):** One replicated, site comparison study in Portugal[1] found that cork oak woodlands with more recent or more regular mechanical clearance of woody understorey vegetation had a greater species richness of butterflies than woodlands cleared less frequently or longer ago. One replicated, paired, controlled study in France[2] reported that shrublands where trees and/or bushes were mechanically cleared to create firebreaks had a similar species richness of butterflies to a shrubland where grazing was used to suppress vegetation.

POPULATION RESPONSE (1 STUDY)

- **Abundance (1 study):** One replicated, site comparison study in Portugal[1] found that cork oak woodlands with more recent or more regular mechanical clearance of woody understorey vegetation had a higher abundance of butterflies than woodlands cleared less frequently or longer ago.

BEHAVIOUR (0 STUDIES)

Background

Wildfires can spread quickly through dry landscapes, in particular where flammable vegetation has accumulated. This can pose a threat to both wildlife and people. One option for pre-empting the control of wildfires is to create "fire breaks" in the landscape, where vegetation is cleared to prevent future fires from spreading between adjacent areas. Fire breaks may also be created prior to prescribed burning, to contain the burn within a desired area. In addition to any benefits from the reduction in the spread of the fire, breaks may create suitable habitat for butterflies and moths in their own right. Both outcomes are considered in studies in this action.

A replicated, site comparison study in 2005–2006 in 45 cork oak *Quercus suber* woodlands in Serra do Caldeirão, Portugal (1) found that areas with recent or regular mechanical clearance of woody understorey vegetation had a higher abundance and species richness of butterflies than less recently or regularly cleared areas. In the most recently cleared areas, the species richness of butterflies (13–21 species/plot) was higher than areas cleared 10–70 years ago (5–16 species/plot), while the abundance of butterflies was higher in areas cleared two years ago (86–117 individuals/plot) than in areas cleared 10–70 years ago (12–51 individuals/plot). Both species richness and abundance were higher in areas managed 0.6–0.8 times/decade (richness: 11–21 species/plot; abundance: 27–100 individuals/plot) than in areas managed 0.0–0.2 times/decade (richness: 5–16 species/plot; abundance: 13–51 individuals/plot). However, some species were more abundant in areas cleared less frequently or longer ago (see paper for details). Forty-five 1-ha plots in forests with >30% canopy of cork oak were selected. Plots were >800 m apart, and none had been affected by fire. The time since woody understorey clearance, and the number of clearances/decade, in each plot were inferred from aerial photographs (taken in 1958, 1972, 1985, 1995 and 2002), vegetation surveys and landowner interviews in 2004. Butterflies were surveyed on a 10-minute count five times/plot, in June/July, August and September 2005, and April and May 2006.

A replicated, paired, controlled study in 1999–2001 in three Mediterranean shrublands in Eastern Pyrenees, France (2) reported that areas where scrub and trees were mechanically cleared to create fire breaks had a similar species richness of butterflies to areas where grazing was used to suppress vegetation. Results were not tested for statistical significance. Areas where trees and bushes were cleared had 23–50 butterfly species, compared to 18–50 species in areas where only bushes were cleared, and 25–41 species in areas where grazing was used to suppress vegetation. The authors reported that the main associations of species were by site rather than fire management strategy, but at one site species adapted to dry Mediterranean areas were mostly found in the grazed area (data presented as model results). In winter 1999–2000, three shrublands (29–70 ha) were divided into three zones by fencing. One zone (7–15 ha) was totally cleared of trees and bushes, leaving only the herb layer. The second zone (11–12 ha) was cleared of at least two-thirds of bushes, leaving trees in place. The third zone (1–51 ha) was grazed by cows or goats, with no mechanical vegetation clearance. From May–September 2000–2001, butterflies were surveyed with hand nets for 90 minutes once/month in a single 1-ha plot in each management area.

(1) Verdasca M.J., Leitão A.S., Santana J., Porto M., Dias S. & Beja P. (2012) Forest fuel management as a conservation tool for early successional species under agricultural

abandonment: The case of Mediterranean butterflies. *Biological Conservation*, 146, 14–23.

(2) Ricouart F., Cereghino R., Gers C., Winterton P. & Legal L. (2013) Influence of fire prevention management strategies on the diversity of butterfly fauna in the eastern Pyrenees. *Journal of Insect Conservation*, 17, 95–111.

9. Threat: Invasive alien and other problematic species

Background

Alien, or non-native, species of animals and plants have been accidentally or deliberately introduced around the world by humans. Where these species survive and breed well in their new environment, they can rapidly become invasive, often due to release from their natural predators or competitors. Similarly, where human activities have driven species (often apex predators) to extinction, or modified habitats in ways which adversely affect most species but favour a few, even native species can become problematic.

Invasive or problematic native species can affect butterflies and moths in numerous ways. Some, such as deer or domestic livestock, may alter habitat structure by overgrazing or browsing. Other animals may become problematic predators, or herbivorous competitors, of native species, while invasive plants may outcompete native species on which butterflies and moths rely.

While habitats across the world are already invaded by non-native species, conservation actions can include efforts to reduce the risk of future species' invasions, as well as actions to minimize, mitigate or remove the impacts of species which are already present.

Predation

9.1. Remove or control non-native predators

- We found no studies that evaluated the effects on butterflies and moths of removing or controlling non-native predators.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Non-native predators, introduced outside of their natural range, can cause problems for native prey species, such as butterflies and moths, which are not adapted to cope with the additional predation pressure. The ideal conservation outcome is often to entirely remove non-native species, but this may not be possible if the species has become too widespread or abundant, or is difficult to catch and kill. However, where removal is not possible, on-going control of the non-native species may allow native butterflies and moths to persist alongside them.

9.2. Remove, control or exclude native predators

- **Five studies** evaluated the effects on butterflies and moths of removing, controlling or excluding native predators. Two studies were in each of the UK[1,2] and the USA[4,5] and one was in Kenya[3].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (5 STUDIES)

- **Survival (5 studies):** Three of five replicated studies (including one randomized, paired, controlled study and three paired, controlled studies) in the UK[1], Kenya[3] and the USA[4,5] found that using mesh cages[1,4], net sleeves[3] and sticky resin[4] to exclude predators (including birds and mammals[1] and spiders and ants[4]) increased the survival of large copper caterpillars[1], Boisduval silkworm eggs and caterpillars[3] and Appalachian brown eggs and juveniles[4]. The other two studies found that using cages[2] or water and chemicals[5] to exclude vertebrate[2] or terrestrial predators (mainly ants)[5] did not increase the survival of monarch caterpillars[2,5].

BEHAVIOUR (0 STUDIES)

Background

Native predators of butterflies and moths (such as mammals, birds or other insects), although part of the natural ecosystem, can become problematic for threatened species if either the abundance of the predator has been increased by human activities, or the abundance of the butterfly or moth species has been reduced by human activities. In these scenarios, the removal, control or exclusion of native predators from an important area, such as around host plants used for breeding, may be necessary to enable the focal species to establish or recover.

A replicated, paired, controlled study in 1964–1965 in a fen in Cambridgeshire, UK (1) reported that excluding native predators increased the survival of large copper *Lycaena dispar batavus* caterpillars. Results were not tested for statistical significance. On plants which were caged to exclude birds and mammals, the survival of large copper caterpillars was 73% (79/108 survived), compared to 4% (11/300 survived) on plants without cages. Data from four caged plants were excluded as the caterpillars abandoned them after eating all of the leaves. The author reported that on plants kept in cages which excluded birds, mammals and parasitic insects, 297/354 (84%) caterpillars survived. Four batches of 20 great water dock *Rumex hydrolapathum* plants were selected. In each batch, four plants were >100 cm tall, and 16 were 50 cm high. In May 1964, three or 12 large copper caterpillars were placed onto each plant, and half of the plants in each batch were covered with a 6-mm plastic mesh cage to exclude birds and mammals. In July 1964, all surviving caterpillars and pupae were counted. In 1965, a total of 354 caterpillars were reared in six muslin cages to exclude birds, mammals and parasitic insects (no further details provided).

A replicated study in 1996–1998 in two peatland sites in Wrexham and Shropshire, UK (2) found that when cotton-sedge tussocks *Eriophorum vaginatum* were caged to exclude vertebrate predators, overwinter survival of large heath butterfly *Coenonympha tullia* caterpillars was no higher than when the tussocks they were on were uncaged. There was no difference in survival between caterpillars on caged and uncaged tussocks on Fenn's Moss (1997 caged: 12 of 40, uncaged: 16 of 40) or on Whixall Moss (1997 caged: 24 of 40, uncaged: 26 of 40; 1998 caged: 23 of 40, uncaged: 20 of 40). In winter 1996–1997 one study plot was located at Whixall and one plot at Fenn's, but in 1997–1998 two plots were located at Whixall only. In September 1996 and 1997, twenty captive-reared large heath caterpillars were put on each of four cotton-sedge tussocks in that year's plots (two plots/year and a total of 80 caterpillars/plot). In October 1996 and September 1997, mesh cages of 50 x 50 x 87 cm were placed over two of the four tussocks in each of that year's plots. The mesh had 0.5 cm^2 gaps to exclude vertebrate but not invertebrate predators. In April 1997 and May 1998 the tussocks were searched thoroughly for surviving caterpillars.

A replicated, paired, controlled study in 2005–2007 in two rainforest blocks in western Kenya (3) found that Boisduval silkworm *Anaphe panda* eggs and caterpillars protected with a net had a higher survival rate than unprotected caterpillars. More silkworm egg clusters survived to pupation when they were protected with a net (114/126 clusters, 90%) than when they were unprotected (66/95 clusters, 69%). The survival of individual caterpillars through to pupation was higher when their egg cluster was protected with a net (16,645/25,571 caterpillars, 65%) than when it was unprotected (6,068/32,411 caterpillars, 19%). In 2005–2007, across one 380-ha natural forest containing only native trees, and one 415-ha modified forest containing native and non-native trees, 150 mitzeeri *Bridelia micrantha* trees with ≥2 silkworm egg clusters were chosen. On each tree, one egg cluster was covered with a 1.5 × 1.5 × 2-m net sleeve tied closed on the branches, one egg cluster was left uncovered, and any additional egg clusters were removed. Protected caterpillars were moved to new branches of the same tree 2–3 times during development to maintain their food supply. From June 2005–June 2007, the number of surviving caterpillars in each cluster was counted twice/week. Only groups where some individuals survived to pupation were included in the analysis of individual survival.

A replicated, randomized, paired, controlled study in 2011–2012 in a pine forest in North Carolina, USA (4) found that excluding native predators increased the survival of Appalachian brown *Satyrodes appalachia* eggs, caterpillars and pupae. In plots where predators were excluded, the survival of Appalachian brown eggs (48–94%) and caterpillars and pupae (35–60%) was higher than on plots left open to predators (eggs: 12–74%; caterpillars and pupae: 7–37%). In May 2011, four 30 × 30 m plots in each of four blocks were established. From 15 May–15 June and 7 July–7 August 2012, two potted sedge *Carex mitchelliana* plants were placed in the centre of each plot. To exclude predators, one plant/plot was enclosed in a fine mesh fabric cage, and had a 15-cm band of sticky resin painted on its pot. Each plant had a known number of butterfly eggs, laid by caged wild-caught females prior to placement. The number of eggs on each plant which survived after 48 hours was counted. In addition, in each of six arenas/plot (created from polyethylene food drums), centred on mature sedge, five captive-reared caterpillars (first to third instar) were released and the number of emerging adults was counted. Three arenas were enclosed with tulle netting, and potential predators (mainly spiders and ants) were removed prior to the release of caterpillars.

A replicated, paired, controlled study in 2014 in a managed park in Georgia, USA (5) found that excluding terrestrial predators did not increase the survival of monarch *Danaus plexippus* caterpillars. The survival of monarch caterpillars from first to fifth instar was similar on plants where terrestrial predators were excluded and on plants without predator exclusion (data presented as model results). Swamp milkweed *Asclepias incarnata* plants were grown in greenhouses, and placed outside in July 2014. Plants were paired at 28 locations, six within grassland plots planted with native species, six within grassland plots planted with exotic species, and 16 in open grassland and forest edges. One plant/pair was placed in a 2-litre tub of water with Tanglefoot™ applied to the rim of the pot to exclude non-flying predators (mainly ants) and the other was placed directly on the ground. Each plant was surrounded by fencing to prevent deer browsing. In October 2013, monarch butterflies were collected on migration, and reared for two generations. In July 2014, two to four first-instar caterpillars were placed on each milkweed and monitored daily until they reached the fifth instar.

(1) Duffey E. (1968) Ecological studies on the large copper butterfly *Lycaena dispar* (Haw.) *batavus* (Obth.) at Woodwalton Fen National Nature Reserve, Huntingdonshire. *Journal of Applied Ecology*, 5, 69–96.
(2) Joy J. & Pullin A.S. (2001) Field studies on flooding and survival of overwintering large heath butterfly *Coenonympha tullia* larvae on Fenn's and Whixall Mosses in Shropshire and Wrexham, U.K. *Ecological Entomology*, 24(4), 426-431.
(3) Mbahin N., Raina S.K., Kioko E.N. & Mueke J.M. (2010) Use of sleeve nets to improve survival of the Boisduval silkworm, *Anaphe panda*, in the Kakamega Forest of western Kenya. *Journal of Insect Science*, 10:6, 1–10.
(4) Aschehoug E.T., Sivakoff F.S., Cayton H.L., Morris W.F. & Haddad N.M. (2015) Habitat restoration affects immature stages of a wetland butterfly through indirect effects on predation. *Ecology*, 96 (7), 1761–1767.
(5) Majewska A.A., Sims S., Wenger S.J., Davis A.K. & Altizer S. (2018) Do characteristics of pollinator-friendly gardens predict the diversity, abundance, and reproduction of butterflies? *Insect Conservation and Diversity*, 11, 370–382.

Habitat alteration

9.3. Remove or control non-native or problematic plants

- **Nine studies** evaluated the effects on butterflies and moths of removing or controlling non-native or problematic plants. Five studies were in the USA[4,5,7–9] and one was in each of Poland[1], South Africa[2], Australia[3] and Mauritius[6].

COMMUNITY RESPONSE (2 STUDIES)

- **Richness/diversity (2 studies):** Two studies (including one replicated, paired, site comparison study and one controlled study) in Mauritius[6] and the USA[7] found that sites where invasive plants were removed by weeding[6] or cutting and applying herbicide[7] (in one case along with fencing to exclude non-native pigs and deer[6]) had a greater species richness of butterflies than untreated sites. One of these studies also found that sites where Chinese privet was removed had a similar species richness of butterflies to sites which had not been invaded[7].

POPULATION RESPONSE (8 STUDIES)

- **Abundance (7 studies):** Four of six studies (including three controlled studies, one before-and-after study and two site comparison studies) in Poland[1], South Africa[2], the USA[4,7,8] and Mauritius[6] found that sites where trees and shrubs were removed[1] or invasive plants were cut to a similar height to native plants[4], or removed by weeding[6] or cutting and applying herbicide[7] (in one case along with fencing to exclude non-native pigs and deer[6]), had a greater abundance of Apollo butterflies[1], a higher density of Fender's blue eggs[4], or higher total abundance of butterflies[6,7], compared to before removal[1] or untreated sites[4,6,7]. One of these studies also found that sites where Chinese privet was removed had a similar abundance of butterflies to sites which had not been invaded[7]. The fifth study found that in plots where herbicide was applied to control invasive grasses, the abundance of Columbia silvery blue eggs and caterpillars was similar to unsprayed plots[8]. The sixth study found that, after prescribed burning, an area where bracken fern was also removed had fewer Brenton blue butterfly eggs than an area without removal[2]. One study in Australia[3] reported that a population of purple copper butterfly caterpillars translocated to an area where invasive plants had been removed, along with host plant translocation and other habitat management, increased in number compared to at the time of translocation.
- **Survival (2 studies):** One replicated, randomized, paired, controlled study in the USA[8] found that in plots where herbicide was applied to control invasive grasses, the survival of Columbia silvery blue eggs and caterpillars was similar to unsprayed plots. One replicated, randomized, controlled study in the USA[9] found that one herbicide commonly used to control invasive grasses reduced the survival of snowberry checkerspot caterpillars, but two other herbicides did not affect the survival of snowberry checkerspot, Edith's checkerspot or Baltimore checkerspot caterpillars.

BEHAVIOUR (4 STUDIES)

- **Use (3 studies):** Two of three randomized, controlled studies (including two replicated, paired studies and one before-and-after study) in the USA[4,5,8] found that sites where invasive oat-grass was cut to a similar height to native plants[4], or where Eastern white pine was removed[5], were used more by Fender's blue[4] and frosted elfin[5] butterflies than untreated sites. The third study found that habitat use by Columbia silvery blue butterflies was similar in plots where herbicide was applied to control invasive grasses and in unsprayed plots[8].
- **Behaviour change (1 study):** One before-and-after study in Poland[1] found that removal of trees and shrubs, in addition to the release of captive bred adults and pupae, allowed adults from two previously separated populations of Apollo butterflies to mix.

Background

Invasive or dominant native plant species can alter habitat structure, outcompeting the host plants of butterflies and moths, or making the habitat otherwise unsuitable (Sinclair 2002). Removal of problematic plants may be conducted by hand, with machinery, or by targeted herbicide application (e.g. Glaeser & Schultz 2014). This action includes studies which have tested any of these methods, alone or in combination.

Note that herbicide application may also have negative effects on butterflies and moths (Russell & Schultz 2010) and the choice of which herbicide to use may be important for minimising harms (Schultz *et al.* 2016). For studies testing the effect of reducing herbicide application, see "*Restrict certain pesticides or other agricultural chemicals*" and "*Reduce fertilizer, pesticide or herbicide use generally*".

Glaeser R.M. & Schultz C.B. (2014) Characterizing a contentious management tool: the effects of a grass-specific herbicide on the silvery blue butterfly. *Journal of Insect Conservation*, 18, 1047–1058.

Russell C. & Schultz C.B. (2010) Effects of grass-specific herbicides on butterflies: an experimental investigation to advance conservation efforts. *Journal of Insect Conservation*, 14, 53–63.

Schultz C.B., Zemaitis J.L., Thomas C.C., Bowers M.D. & Crone E.E. (2016) Non-target effects of grass-specific herbicides differ among species, chemicals and host plants in *Euphydryas* butterflies. *Journal of Insect Conservation*, 20, 867–877.

Sinclair L.J. (2002) Distribution and conservation requirements of *Notoreas* sp., an unnamed Geometrid moth on the Taranaki coast, North Island, New Zealand. *New Zealand Journal of Zoology*, 29, 311–322.

A before-and-after study in 1991–1994 in a limestone montane grassland reserve in southern Poland (1) found that removing trees and shrubs, in addition to releasing captive bred adults and pupae, increased Apollo butterfly *Parnassius apollo* numbers, and allowed adults from two previously separated populations to mix. Removing trees and shrubs from an area with two small, separated populations of Apollo butterflies, along with releasing captive bred individuals, increased the total number of adults observed from 22 in 1991 to 60 in 1994. Mark-recapture surveys estimated that the total population increased from 44 adults in 1992 to 67 in 1994, and showed that the previously separated populations were mixing. In 1992, trees and shrubs were removed from an area of scree in the Pieniny Mountains, creating a corridor between the locations of two Apollo butterfly populations. From 1991–1994, captive bred butterflies were also released annually at the site (339 males, 362 females and four pupae in total). Butterfly numbers were recorded each year but survey details are not provided. Mark-recapture surveys were also conducted in 1992–1994 to estimate population size and determine connectivity between the original two populations.

A site comparison study in 2000–2002 in one shrubland site in the Western Cape province, South Africa (2) reported that after prescribed burning there were fewer Brenton blue butterfly *Orachrysops niobe* eggs in an area where bracken fern *Pteridium aquilinium* was removed compared to where it was not removed. In an area that had been burned, there were fewer Brenton blue eggs/*Indigofera erecta* host plant in the section with bracken fern control (November 2001: 0.035 eggs/100 plants; January–February 2002: 0.38 eggs/100 plants) than in the area with no control (November 2001: 0.32 eggs/100 plants; January–February 2002: 0.81 eggs/100 plants). Results were not tested for statistical significance. In September 2000, a 2,700 m^2 area of reserve was burned. Prior to the burn, in over 1,000 m^2 of the area bracken fern was cut and 0.2 m of topsoil was turned over ("skoffeled"). In that area and another 1,400 m^2, natural succession was allowed after the burn. In another 300 m^2 of the burned area, bracken fern was removed manually for 6 months after the burn. In a 1,500 m^2 area of reserve that was not burned, paths were cut with shears in July 2001, avoiding trees, large bushes and *Indigofera erecta* plants, and thereafter new bracken ferns were removed manually. In November 2001 and January–March 2002, all *Indigofera erecta* plants identified in the burned and unburned areas were checked for eggs and larvae.

A study in 2004–2007 in one shrubland in New South Wales, Australia (3) reported that, three years after translocation, a population of purple copper butterfly *Paralucia spinifera* caterpillars that had been moved from land designated for development to an adjacent area of retained habitat and compensatory habitat where invasive plants had been removed, along with host plant translocation and other habitat management, increased in number compared to the time of translocation. A site designated for development and adjacent retained and compensatory habitat initially had an estimated purple copper caterpillar population size of 2,000. After the development, habitat management and translocation of butterflies into the retained and compensatory habitat, the estimated caterpillar population size reduced to 1,600 in the following year but increased to an estimated 1,995 two years and 2,780 three years after translocation. Of the caterpillars found in the third year, 39% were in the compensatory habitat and 61% were in the area of retained original habitat. In 2004–2005, two thirds of an area of purple copper butterfly habitat was cleared for road-building and an area adjacent to the retained third was designated as compensatory habitat. Invasive plants, including hawthorn *Crataegus monogyna*, radiata pine *Pinus radiata*, cotoneaster *Cotoneaster* sp., blackberry *Rubus fruticosus* sp. and briar rose *Rosa rubiginosa* were cleared from the retained and compensatory habitat and caterpillars and their host plant blackthorn *Bursaria spinosa* var. *lasiophylla* were moved from the land about to the cleared to the retained and compensatory habitat. Over 12 nights in December 2004–January 2005, a total of 1,260 caterpillars were moved. In 2005–2007 blackthorn plants in the retained and compensatory habitats were surveyed for caterpillars, signs of their feeding, and their mutualistic ants *Anonychomyrma itinerans*. Estimated caterpillar population sizes were calculated by multiplying the number of caterpillars found by five.

A replicated, randomized, paired, controlled study in 2004 in two upland prairies in Oregon, USA (4) found that plots where non-native tall oat-grass *Arrhenatherum elatius* had been cut were used by Fender's blue *Icaricia icarioides fenderi* more than uncut plots. In plots where oat-grass had been cut, Fender's blue butterflies were more likely to bask (76–80% of 166 butterflies) or lay eggs (69% of 71 females) and less likely to fly straight over (17–24% of 166 butterflies) than in plots where oat-grass had not been cut (bask: 13–49% of 105 butterflies; lay eggs: 13% of 45 females; fly over: 47–87% of 105 butterflies). In cut plots, the density of eggs (2.5 eggs/leaf) was higher than in uncut plots (1.0 eggs/leaf). In May 2004, four pairs of plots (1-m radius, 2.5 m apart) were selected in each of two remnant prairies (1–5 ha). In one plot/pair, oat-grass was cut with shears to the same height as the native Kincaid's lupine *Lupinus sulphureus kincaidii* leaves. In the remaining plots oat-grass was not cut. In May 2004, three pairs of plots/prairie were observed for 50 minutes, and butterflies flying over, basking, or laying eggs in each plot were recorded. In June 2004, all lupines within each plot were searched for eggs.

A randomized, controlled, before-and-after study in 2001–2006 in a heathland in New York, USA (5) found that areas where eastern white pine *Pinus strobus* had been removed were used more by frosted elfin butterflies *Callophrys irus*. In areas where eastern white pine trees were removed, the number of elfins seen after removal (11% of all butterflies recorded) was higher than before removal (3% of all butterflies), but there was no significant change in areas where trees were not removed (before: 12% of all butterflies; after: 8% of all butterflies). After tree removal, there were 12 male territories on a 1-ha dune, compared to nine territories before removal. In May 2002, seventeen white pines growing over lupine plants were selected and, in January 2003, eight were randomly removed. From April–June 2001–2006, frosted elfins were surveyed along a 12-minute transect 10–15 times/year. The location of each butterfly, and each male territory, was mapped, and the number within 3 m of the removed and not removed trees was counted.

A replicated, paired, site comparison study in 1998 in eight lowland forest sites in Mauritius (6) found that areas where invasive plants had been removed, together with fencing to exclude non-native pigs and deer, had a higher abundance and species richness of butterflies than sites where invasive species control had not been conducted. In sites where invasive plants had been removed and exclusion fencing installed, both the abundance (5.9 individuals/100 m) and species richness (9 species) of native butterflies was higher than in sites where no weed removal or fence installation had been conducted (abundance: 0.3 individuals/100 m; richness: 3 species). From 1986–1996, eight Conservation Management Areas (0.4–6.0 ha) were fenced to try to exclude non-native pigs and deer, and were regularly hand-weeded (1–3 times/year) to remove invasive plants, primarily strawberry guava *Psidium cattleianum*, rose apple *Syzygium jambos*, *Ossaea marginata* and Christmas berry *Ardisia crenata*. From April–June 1998, butterflies were surveyed on point counts along four to six 100-m transects in each weeded plot and in adjacent, non-weeded plots with an equivalent number of native canopy trees.

A controlled study in 2005–2012 in seven riparian forests in Georgia, USA (7) found that areas where Chinese privet *Ligustrum sinense* had been removed had a higher abundance and species richness of butterflies than areas infested with privet. Five years after privet removal had finished, removal sites had a higher abundance (121–146 individuals/plot) and species richness (10–12 species/plot) of butterflies than privet-infested sites (abundance: 30 individuals/plot; richness: 4 species/plot). Butterfly abundance and species richness in removal sites were also similar to reference sites with no privet invasion (abundance: 190 individuals/plot; richness: 14 species/plot). In October 2005, Chinese privet was removed from two infested 2-ha plots. At one site, a mulching machine ground up the privet and at the other site privet was hand-cut with chainsaws. Privet stumps were sprayed with herbicide (30% triclopyr or 30% glyphosate) after cutting, and sprouts and seedlings were sprayed with 2% glyphosate in December 2006. Removal sites were compared with two infested sites where privet was not removed, and three reference sites with little or no privet invasion. From March–October 2012, butterflies were sampled for one week/month using five blue and five yellow pan traps/plot. Traps were filled with soapy water and suspended 30 cm above ground.

A replicated, randomized, paired, controlled study in 2013 in an upland prairie in Oregon, USA (8) found that applying herbicide to control invasive grasses in the early spring did not increase use of the habitat by Columbia silvery blue butterflies *Glaucopsyche lygdamus columbia*, or the number or survival of eggs or caterpillars. In sprayed plots, the number of butterfly visits (12 individuals/plot), the time spent in the plot (34–154 seconds/visit), and the proportion of butterflies which landed (18–73%) did not differ significantly from unsprayed plots (visits: 10 individuals/plot; time: 40–98 seconds/visit; landed: 16–67%). Similarly, in sprayed plots, the number of eggs (3.9/subplot), caterpillars (1.3/subplot) and survival of eggs to large caterpillars (15%) did not differ significantly from unsprayed plots (eggs: 4.1/subplot; caterpillars: 1.3/subplot; survival: 14%). In March 2013, thirty-two plots (20 × 20 m) were paired based on equal host plant (Kincaid's lupine *Lupinus oreganus*) cover (>15 m^2/plot). In each pair, one plot was randomly assigned to the herbicide treatment (sprayed in March with 326 g/ha Fusilade DX® grass-specific herbicide and 425 g/ha Nufilm®) and the other was left unsprayed. In May 2013, the time spent in each plot by adult butterflies, and whether or not they landed, was recorded during 15-minute observations in 30 plots. From late April 2013, hatched and unhatched eggs were counted five times, and the number and size of caterpillars was counted eight times, at 4–5 day intervals in each of three 60 × 60 cm subplots/plot, centred on randomly selected flowering lupines.

A replicated, randomized, controlled study in 2013–2014 in a greenhouse in Washington, USA (9) found that one of three herbicides commonly used to control invasive grasses reduced the survival of snowberry checkerspot *Euphydryas colon* caterpillars, but not Edith's checkerspot *Euphydryas editha colonia* or Baltimore checkerspot *Euphydryas phaeton* caterpillars. The survival of snowberry checkerspot caterpillars sprayed with sethoxydom and NuFilm (78%) was lower than caterpillars sprayed with water (98%), but the survival of caterpillars sprayed with clethodim and NuFilm (85%), fluazifop-p-butyl and NuFilm (88%) or NuFilm alone (93%) was not significantly different from those sprayed with water. The survival of caterpillars sprayed with fluazifop-p-butyl and NuFilm (snowberry checkerspot: 51–89%; Edith's checkerspot: 87–88%; Baltimore checkerspot: 91–95%) was not significantly lower than unsprayed caterpillars (snowberry: 55–92%; Edith's: 84–92%; Baltimore: 96–98%). Eggs were collected from wild-caught females (snowberry and Edith's checkerspot) or wild-laid egg clusters (Baltimore checkerspot), and caterpillars were reared on ribwort plantain *Plantago lanceolata*. In August 2014, forty snowberry checkerspot caterpillars were exposed to each of five treatments: one of three herbicides used regularly for prairie restoration (fluazifop-p-butyl, sethoxydim and clethodim) applied using their most common formulations (Fusilade DX®, Poast® and Envoy Plus®, respectively) in combination with a "sticker-spreader" (adjuvant NuFilm IR®); the NuFilm alone; or a water treatment (see paper for details). Caterpillars were kept in containers and fed fresh plantain exposed to the same treatment. In August–September 2013, caterpillars of three species were randomly assigned to two treatments, sprayed with Fusilade and NuFilm or unsprayed, and placed in groups of 20 in 5–6 host plant microcosms/treatment/species. In both experiments, survival to overwintering was recorded.

(1) Witkowski Z., Adamski P., Kosior A. & Plonka P. (1997) Extinction and reintroduction of *Parnassius apollo* in the Pieniny National Park (Polish Carpathians). *Biologia*, 52(2), 199-208.

(2) Edge D.A. (2002) Some ecological factors influencing the breeding success of the Brenton Blue butterfly, *Orachrysops niobe* (Trimen) (Lepidoptera: Lycaenidae). Koedoe, 45(2), 19-34.
(3) Mjadwesch R. & Nally S. (2008) Emergency relocation of a Purple Copper Butterfly colony during roadworks: Successes and lessons learned. Ecological Management & Restoration, 9(2), 100-109.
(4) Severns P.M. (2008) Exotic grass invasion impacts fitness of an endangered prairie butterfly, *Icaricia icarioides fenderi*. *Journal of Insect Conservation*, 12, 651–661.
(5) Pfitsch W.A. & Williams E.H. (2009) Habitat restoration for lupine and specialist butterflies. *Restoration Ecology*, 17, 226–233.
(6) Florens F.B.V., Mauremootoo J.R., Fowler S.V., Winder L. & Baider C. (2010) Recovery of indigenous butterfly community following control of invasive alien plants in a tropical island's wet forests. *Biodiversity and Conservation*, 19, 3835–3848.
(7) Hudson J.R., Hanula J.L. & Horn S. (2013) Removing Chinese privet from riparian forests still benefits pollinators five years later. *Biological Conservation*, 167, 355–362.
(8) Glaeser R.M. & Schultz C.B. (2014) Characterizing a contentious management tool: the effects of a grass-specific herbicide on the silvery blue butterfly. *Journal of Insect Conservation*, 18, 1047–1058.
(9) Schultz C.B., Zemaitis J.L., Thomas C.C., Bowers M.D. & Crone E.E. (2016) Non-target effects of grass-specific herbicides differ among species, chemicals and host plants in *Euphydryas* butterflies. *Journal of Insect Conservation*, 20, 867–877.

9.4. Remove, control or exclude vertebrate herbivores

- **Ten studies** evaluated the effects on butterflies and moths of removing, controlling or excluding vertebrate herbivores. Three studies were in the USA[2,4,5], two were in the UK[1,3], one was in each of Mauritius[6], the Netherlands[7], Canada[8] and Japan[9], and one was a global systematic review[10].

COMMUNITY RESPONSE (6 STUDIES)

- **Richness/diversity (6 studies):** Two of four replicated studies (including three controlled studies and one site comparison study) in the USA[2,4], Mauritius[6] and Canada[8] found that forest plots fenced to exclude[6,8], or reduce the density of[8], non-native pigs[6] and deer[6,8] (in one case along with weeding of invasive plants[6]) had a greater species richness of butterflies[6] and macro-moths[8] than unfenced plots. The other two studies found that forest plots fenced to exclude elk had mixed effects on the species richness of butterflies[4] and arthropods including moths[2] depending on fire intensity and year. One of these studies also found that grassland plots fenced to exclude elk had a similar species richness of butterflies to unfenced plots in all years[4]. One global systematic review[10] found that reducing or removing grazing or browsing by wild or domestic herbivores in temperate and boreal forests did not affect the species richness of butterflies and moths.

POPULATION RESPONSE (10 STUDIES)

- **Abundance (9 studies):** Five of eight studies (including five controlled studies, one before-and-after study, and two site comparison studies) in the UK[1,3], the USA[2,4,5], Mauritius[6], Canada[8] and Japan[9] found that forest[1,5,6,8] and grassland[3] plots fenced to exclude[1,3,5,6,8], or reduce the density of[1,8], deer[1,6,8], sheep[3], pigs[6] and large herbivores[5] (in one case along with weeding of invasive plants[6]) had a higher abundance of butterflies[6], moths[5], caterpillars[1], rare macro-moths[8] and New Forest burnet moths[3] than unfenced plots. One of these studies also found that the total abundance of macro-moths was similar in fenced and unfenced plots[8]. Two studies found that forest plots fenced to exclude elk had mixed effects on the abundance of butterflies[4] and arthropods including moths[2] depending on fire intensity and year. One of these studies also found that grassland plots fenced to exclude elk had a similar abundance of butterflies to unfenced plots in all years[4]. The eighth study found that a forest fenced to exclude sika deer had a similar abundance of all moths, but a lower abundance of tree-feeding moths, than unfenced forest[9]. One global systematic review[10] found that reducing or removing grazing or browsing by wild or domestic herbivores in temperate and boreal forests increased the abundance of butterflies and moths.

- **Survival (1 study):** One paired, controlled study in the Netherlands[7] reported that all Glanville fritillary caterpillar nests survived in grassland fenced to exclude sheep, compared to 88% in a grazed area.
- **Condition (1 study):** One paired, controlled study in the Netherlands[7] found that fewer Glanville fritillary caterpillar nests were damaged in grassland fenced to exclude sheep than in a grazed area.

BEHAVIOUR (0 STUDIES)

Background

Vertebrate herbivores can have a large impact on habitat structure, in turn affecting butterfly and moth communities. This can be particularly pronounced where wild herbivores are able to persist at artificially high densities owing to the absence or control of their predators in the landscape, where domestic herbivores are kept at high density, or where non-native herbivores have been introduced (Sinclair 2002). This intervention includes studies investigating the impact of completely excluding wild or domestic herbivores, or of reducing their population density enough to allow vegetation to recover.

For studies on the control of invertebrate herbivores, see "*Remove, control or exclude invertebrate herbivores*".

Sinclair L.J. (2002) Distribution and conservation requirements of *Notoreas* sp., an unnamed Geometrid moth on the Taranaki coast, North Island, New Zealand. *New Zealand Journal of Zoology*, 29, 311–322.

A replicated, paired, controlled study in 1991–1992 in eight pinewoods in the Scottish Highlands, UK (1) found that excluding red deer *Cervus elaphus* increased the abundance of moth and butterfly caterpillars. In plots where deer were excluded, or present at lower density, the abundance of caterpillars (30–440 individuals/plot) was higher than in forest where deer were present at higher density (10–325 individuals/plot). Two of the four most common species (July highflyer moth *Hydriomena furcata* and twin spot carpet *Perizoma didymata*) were more abundant in exclosures with no deer (July highflyer: 32–44; twin spot: 43–57 individuals/plot) than in forest with deer (July highflyer: 10–11; twin spot: 13–16 individuals/plot), but the abundance of the other two most common species was similar between plots (winter moth *Operophtera brumata* (no deer: 5–20; deer: 4–10 individuals/plot) and grey mountain carpet *Entephria caesiata* (no deer: 2–5; deer: 1–4 individuals/plot)). In each of eight forests, three pairs of plots with different deer densities were monitored. In five forests, deer exclosures (no deer) were compared to open forest (11–16 deer/km), but in the other three forests, plots were compared between sporting estates with different deer management policies (low density: 3–10 deer/km; high density: 11–20 deer/km). Between mid-May and early June 1991 and 1992, caterpillars were sampled by sweep-netting once/plot (125 sweeps covering 10 m^2).

A replicated, controlled study in 1997–1998 in a mixed forest in Arizona, USA (2) found that aspen *Populus tremuloides* stands where elk *Cervus canadensis* were excluded had a higher abundance and species richness of arthropods (including moths) following intense fire, but a lower abundance and species richness following intermediate severity fire. After intense fire, the abundance and species richness of arthropods (including moths) was higher in aspen stands where elk were excluded (abundance: 6 individuals/plot; richness: 4 species/plot) than in browsed stands (abundance: 2 individuals/plot; richness: 1 species/plot), but following intermediate severity fire arthropod abundance and species richness was lower in elk-excluded (abundance: 5 individuals/plot; richness: 3 species/plot) than browsed stands (abundance: 8 individuals/plot; richness: 5 species/plot). The abundance of the most common moth, aspen blotch miner *Lithocolletis tremuloidiella*, did not differ significantly between elk-excluded (2–6 individuals/plot) and browsed stands (0–4 individuals/plot). Following a wildfire in 1996 which burned at high and intermediate intensity, in 1997 two 75-ha elk exclosures were constructed within a mixed ponderosa pine *Pinus ponderosa* and aspen forest. In summer 1998, arthropods (e.g. insects and spiders) were surveyed visually on the tallest aspen shoot in each of six 1-m^2 plots in each of 12 aspen stands (three inside and three outside the exclosures in each of the high and intermediate intensity burned areas).

A before-and-after study in 1990–2004 in a grassland in western Scotland, UK (3) reported that after fencing excluded sheep, a population of New Forest burnet moth *Zygaena viciae* increased. Results were not tested for statistical significance. After seven years of complete sheep exclusion, 264 adults/transect were recorded, and the population was estimated at 8,500–10,200 individuals, compared to 0.1–1.2 adults/transect (estimated population 10–24 individuals) before and in the first six years of fencing (with occasional sheep grazing due to fence damage). The authors reported that this increase followed the spread of the host plant meadow vetchling *Lathyrus pratensis* across the site. In early 1991 a 1-ha grassland, where 12 moths were found in 1990, was fenced to exclude sheep. In early 1994 and 1996, some sheep entered the site following damage to the fence, but from 1997–2004, sheep were completely excluded. In 1990, an intensive search for the moth was conducted. In July 1990–1991 and 1994–2003, moths were surveyed 1–15 times/year along a 5-m-wide, 300-m-long transect across the site, and were separately caught, marked and recaptured to estimate population size.

A replicated, randomized, paired, controlled study in 1997–2002 in a grassland and forest reserve in New Mexico, USA (4) found that forest areas where elk *Cervus elaphus* were excluded had a higher abundance and species richness of butterflies in one out of four years, but the number of butterflies was similar in the remaining years and in all grassland areas. In forest sites where elk were excluded, the abundance (91 individuals/site) and species richness (17 species) of butterflies was higher than in browsed sites in one of four years (abundance: 42 individuals/site; richness: 13 species), but was not significantly different in the other three years (excluded: 2–9 individuals/site/year, 5–6 species/year;

browsed: 2 individuals/site/year, 4–6 species/year). In grassland sites, the abundance and species richness of butterflies was not significantly different between exclusion (abundance: 3–141 individuals/site/year; richness: 5–16 species/year) and browsed sites (abundance: 3–85 individuals/site/year; richness: 4–13 species/year). In 1997–1998, four areas of ponderosa pine *Pinus ponderosa* grassland and five areas of mixed forest were selected, and a 60 × 60 m exclosure was constructed randomly on half of each site. Exclosures were 3 m high with 10-cm wire fencing to exclude elk. Three grassland sites and one forest site were deliberately or accidentally burned during the experiment. In June–August 1999–2002, butterflies were surveyed 2–5 times/year along a 360-m-long zigzag transect through each exclosure and browsed site. Grassland sites were not surveyed in 2002. Skippers (Hesperiidae) were not identified to species.

A replicated, randomized, paired, controlled study in 1999–2004 in a pine forest in Arizona, USA (5) reported that Fendler's ceanothus *Ceanothus fendleri* shrubs protected from large herbivores with exclosures had a higher abundance of moths than unprotected shrubs. Results were not tested for statistical significance. On protected shrubs, 0.03–0.20 individual moths/plant, from three families, were recorded, compared to no moths on unprotected shrubs. In 1998–1999, trees <36 cm diameter were thinned in three experimental units (14–16 ha), and sixty Fendler's ceanothus *Ceanothus fendleri* shrubs/unit (1–25 upright stems, covering <2 m^2) were located. In 1999, thirty shrubs/unit were randomly selected, and had 4-m^2, 1.4-m-high exclosures built around them. Exclosures had a large mesh (5 × 10 cm) on the sides, and open tops. In June 2002–2004, insects including moths were sampled by sweep netting (five sweeps/shrub, 20–50 cm above ground) through a subset of 30–52 shrubs/year (see paper for details), and identified to family level.

A replicated, paired, site comparison study in 1998 in eight lowland forest sites in Mauritius (6) found that areas which were fenced to exclude non-native pigs and deer, together with removal of non-native plants, had a higher abundance and species richness of butterflies than unfenced sites where invasive species control had not been conducted. In fenced sites where invasive plants had been removed, both the abundance (5.9 individuals/100 m) and species richness (9 species) of native butterflies was higher than in unfenced sites where no weed removal had been conducted (abundance: 0.3 individuals/100 m; richness: 3 species). From 1986–1996, eight Conservation Management Areas (0.4–6.0 ha) were fenced to exclude non-native pigs and deer, and were regularly hand-weeded (1–3 times/year) to remove invasive plants, primarily strawberry guava *Psidium cattleianum*, rose apple *Syzygium jambos*, *Ossaea marginata* and Christmas berry *Ardisia crenata*. From April–June 1998, butterflies were surveyed on point counts along four to six 100-m transects in each weeded plot and in adjacent, non-weeded plots with an equivalent number of native canopy trees.

A paired, controlled study in 2009–2010 on a calcareous grassland in the Netherlands (7) found that fewer Glanville fritillary *Melitaea cinxia* caterpillar nests were damaged in a fenced, ungrazed area than in a grazed area. After 10 days of autumn grazing, fewer caterpillar nests had signs of damage in a fenced area (2/24 nests damaged) than nests in a grazed area (15/25 nests damaged). Two months later, the number of nests with signs of damage was similar in fenced

(6/24 nests damaged) and grazed areas (6/25). All 24 nests in the fenced area survived until spring, compared to 22/25 surviving in the grazed area (statistical significance not assessed). In July–August 2009, a grazed 4-ha grassland was searched three times for caterpillar nests. Half of the area with the highest density of nests was fenced to create a 0.15-ha ungrazed area. Twenty-four pairs of the largest, equally sized nests (>1 m apart) in each area were selected, and their location marked on GPS. In September 2009, the unfenced area was grazed by 114 sheep over 1.23 ha for 10 days, after which an expanded 1.76-ha area was grazed by 15 sheep for 50 days. In October and December 2009, nests were checked for damage, and in March 2010 the survival of each nest was recorded.

A replicated, controlled study in 2001–2007 on a forested island in Quebec, Canada (8) found that reducing invasive white-tailed deer *Odocoileus virginianus* density increased the total species richness of macro-moths, and the abundance of rare nocturnal macro-moths, but not total macro-moth abundance. The total species richness of macro-moths, and the abundance of rare species, in areas with no deer (richness: 34 species/exclosure; abundance: 84 individuals) or reduced deer density (7.5–15 deer/km^2: richness: 36 species/exclosure; abundance: 86–113 individuals) was higher than in areas where deer were not controlled (richness: 21 species/exclosure; abundance: 12 individuals). However, the total abundance of macro-moths did not differ significantly between sites (no deer: 113; 7.5 deer/km^2: 139; 15 deer/km^2: 122; uncontrolled: 87 individuals/exclosure). In 2001, fenced deer exclosures were built at three sites across a 7,943-km^2 island. From 2002–2007, at each site, all deer were removed from a 10-ha exclosure (0 deer/km^2), and three deer were stocked in both a 40-ha (7.5 deer/km^2) and a 20-ha (15 deer/km^2) exclosure from early spring to late autumn. An adjacent area with uncontrolled deer (26–57 deer/km^2) was also monitored at each site. Within each exclosure, 70% of the area was harvested for timber just prior to construction in 2001. From June–August 2007, moths were sampled over five 3-day periods, using two Luminoc® traps/exclosure (>100 m apart). Traps were placed 3 m high and fitted with a 1.8 W blue light tube and Vapona® strips.

A site comparison study in 2014 in a deciduous forest in Hokkaido, Japan (9) found that forest where deer were excluded with fencing had a similar abundance of all moths to forest with deer present, but had fewer tree-feeding moths. In an exclosure with no deer, the abundance of moths (320 individuals) was similar to the surrounding forest with deer present (322 individuals), but higher than in an enclosure with high deer density (280 individuals). The abundance of herb- and shrub-feeding species in the exclosure (19 individuals) was also similar to the surrounding forest (20 individuals), but higher than in the enclosure (17 individuals), whereas the abundance of tree-feeding species was lower in the exclosure (51 individuals) than in the surrounding forest (57 individuals) or enclosure (62 individuals). From 2004, sika deer *Cervus nippon* were excluded from a 1.5-ha fenced exclosure (0 deer/km^2), and deer density was maintained at 20 deer/km^2 within a 16.4-ha fenced enclosure. The remaining forest contained approximately 10 deer/km^2. In June, July and September 2014, moths were sampled once/month using three light traps/site. Traps contained a 4 W fluorescent light and a 4 W UV light. Half of the moth species were classified as either herb- and shrub-feeding species, or tree-feeding species.

A systematic review in 2018 of 13 studies in temperate and boreal forests from across the world (10) found that reducing or removing grazing or browsing by wild or domestic herbivores increased the abundance of moths and butterflies, but did not affect species richness. Forest plots where grazers and browsers were excluded or where herbivore density was reduced had a higher abundance of moths and butterflies than more heavily grazed forest, but species richness was not affected (data presented as model results). A total of 144 studies were included in the review, 13 of which reported data on moth and butterfly abundance, and three on species richness. The majority of the 144 studies came from North America (75), Europe (53) and Australia/New Zealand (14). Experimental plot size within studies ranged from 0.5 m^2 to 2,428 ha. The majority of studies were controlled, and some included before-and-after measurements. Studies that were unreplicated, or did not include suitable comparisons, were excluded from the review.

(1) Baines D., Sage R.B. & Baines M.M. (1994) The implications of red deer grazing to ground vegetation and invertebrate communities of Scottish native pinewoods. *Journal of Applied Ecology*, 31, 776–783.
(2) Bailey J.K. & Whitham T.G. (2002) Interactions among fire, aspen, and elk affect insect diversity: Reversal of a community response. *Ecology*, 83, 1701–1712.
(3) Young M.R. & Barbour D.A. (2004) Conserving the New Forest burnet moth (*Zygaena viciae* ([Denis and Schiffermueller])) in Scotland; responses to grazing reduction and consequent vegetation changes. *Journal of Insect Conservation*, 8, 137–148.
(4) Kleintjes Neff P.K., Fettig S.M. & VanOverbeke D.R. (2007) Variable response of butterflies and vegetation to elk herbivory: An exclosure experiment in ponderosa pine and aspen-mixed conifer forests. *Southwestern Naturalist*, 52, 1–14.
(5) Huffman D.W., Laughlin D.C., Pearson K.M. & Pandey S. (2009) Effects of vertebrate herbivores and shrub characteristics on arthropod assemblages in a northern Arizona forest ecosystem. *Forest Ecology and Management*, 258, 616–625.
(6) Florens F.B.V., Mauremootoo J.R., Fowler S.V., Winder L. & Baider C. (2010) Recovery of indigenous butterfly community following control of invasive alien plants in a tropical island's wet forests. *Biodiversity and Conservation*, 19, 3835–3848.
(7) van Noordwijk C.G.E., Flierman D.E., Remke E., WallisDeVries M.F. & Berg M.P. (2012) Impact of grazing management on hibernating caterpillars of the butterfly *Melitaea cinxia* in calcareous grasslands. *Journal of Insect Conservation*, 16, 909–920.
(8) Brousseau P.-M., Hébert C., Cloutier C. & Côté S. (2013) Short-term effects of reduced white-tailed deer density on insect communities in a strongly overbrowsed boreal forest ecosystem. *Biodiversity and Conservation*, 22, 77–92.
(9) Iida T., Soga M., Hiura T. & Koike S. (2016) Life history traits predict insect species responses to large herbivore overabundance: a multitaxonomic approach. *Journal of Insect Conservation*, 20, 295–304.
(10) Bernes C., Macura B., Jonsson B.G., Junninen K., Müller J., Sandström J., Lõhmus A. & Macdonald E. (2018) Manipulating ungulate herbivory in temperate and boreal forests: effects on vegetation and invertebrates. A systematic review. *Environmental Evidence*, 7, UNSP-13.

9.5. Remove, control or exclude invertebrate herbivores

- One study evaluated the effects on butterflies and moths of removing, controlling or excluding invertebrate herbivores. The study was in the UK[1].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (1 STUDY)

- **Abundance (1 study):** One replicated, site comparison study in the UK[1] found that at sites fenced to exclude grazing animals there was a higher density of pearl-bordered fritillary butterflies than at unfenced sites.

BEHAVIOUR (0 STUDIES)

Background

Outbreaks of invertebrate herbivores can cause problems for other species, including butterflies and moths, through the competition for food, induced food plant resistance, increased food plant mortality, or increases in predator, parasitoid or pathogen abundance (Scriber 2004). This intervention includes studies investigating the impact of attempting to exclude, remove, or control the density of invertebrate herbivores to allow vegetation to recover, for the benefit of butterfly or moth populations.

For studies on the control of vertebrate herbivores, see "*Remove, control or exclude vertebrate herbivores*".

Scriber J.M. (2004) Non-target impacts of forest defoliator management options: Decision for no spraying may have worse impacts on non-target Lepidoptera than *Bacillus thuringiensis* insecticides. *Journal of Insect Conservation*, 8, 241–261.

A replicated, site comparison study in 1995–1998 in 28 woodland sites in Argyll, UK (1) found that at sites fenced to exclude grazing animals there was a higher density of pearl-bordered fritillary butterflies *Boloria Euphrosyne* than at unfenced sites. In sites within woodland that were fenced to exclude deer there was a higher density of pearl-bordered fritillaries (6.8 butterflies/hectare) than at sites where deer were not excluded (3.7 butterflies/ha). In woodland edge sites where fencing excluded deer, there was a higher density of pearl-bordered fritillaries (10.7 butterflies/ha) than where deer were not excluded and sheep were grazing (0.1 butterflies/ha). In May and June 1998 mark-release-recapture surveys of pearl-bordered fritillaries were conducted at the 28 sites of woodland and woodland edge in Lochawe. Within this area were two woods designated in 1995–1996 under the Woodland Grant Scheme and fenced to exclude deer (6 sampling sites in woodland, 12 at woodland edge). These were compared to other woodland sites without deer fencing (3 sites) and woodland edge sites without fencing which were also sheep grazed (7 sites).

(1) Feber R. E. & Brereton T. M., Warren M. S. & Oates M. (2011) The impacts of deer on woodland butterflies: the good, the bad and the complex. *Forestry: An International Journal of Forest Research*, 74 (3), 271-276.

9.6. Replant alternative host plants or disease resistant individuals to combat losses to disease

- We found no studies that evaluated the effects on butterflies and moths of replanting alternative host plants or disease resistant individuals to combat losses to disease.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Butterflies and moths rely on particular host plants for the growth and survival of their caterpillars, with some caterpillars able to feed on only one or two plant species. They are therefore vulnerable to sudden declines in the host plant population caused by disease. Planting alternative host plant species (where available) or disease resistant individuals of the affected plant species may help to buffer butterfly and moth populations against the threat of host plant disease.

9.7. Increase biosecurity checks

- We found no studies that evaluated the effects on butterflies and moths of increasing biosecurity checks.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Butterflies and moths may be vulnerable to non-native diseases, parasites, predators or competitors introduced by international trade, in particular of live plants and fresh food. Since many problematic species will themselves be small invertebrates, detecting and removing them after they have been released into a new location is likely to be almost impossible. Therefore, increasing biosecurity checks on shipments may help to identify and remove potentially invasive species before they arrive in new locations, preventing them from having the opportunity to survive and spread.

9.8. Restrict the sale of problem species in garden centres and pet shops

- We found no studies that evaluated the effects on butterflies and moths of restricting the sale of problem species in garden centres and pet shops.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Many non-native species of plant and animal are sold commercially in garden centres and pet shops. If seeds or individuals of non-native species escape into the wild, they may invade native ecosystems, altering habitat structure or directly competing with, predating or parasitizing native butterflies and moths. Regulating the sale of potentially problematic species may help to reduce the number which are accidentally released, and reduce the chances of an invasion happening.

10. Threat: Pollution

Background

A major threat to butterflies and moths comes from environmental pollution, in the form of chemicals (such as pesticides, herbicides and fertilizers) and artificial lighting (particularly at night). With the spread of human activities, including housing, industry and agriculture across the landscape, pollution has become increasingly widespread. Correlations have been drawn between the use of insecticides, and declines in butterfly populations (Gilburn *et al.* 2015). Meanwhile, light pollution disrupts natural light/dark patterns, and disturbs the behaviour of moths (Bruce-White & Shardlow 2011), exacerbating the impact of other threats, such as habitat loss and fragmentation (Frank 2006). This chapter includes actions which address the threat of pollution from agriculture and forestry, industrial and urban areas, and light pollution.

Bruce-White C. & Shardlow M. (2011) A review of the impact of artificial light on invertebrates. *Buglife Report*, ISBN 978-1-904878-99-5

Frank K.D. (2006) Effects of artificial night lighting on moths. In *Ecological consequences of artificial night lighting* (eds Rich C. & Longcore T.), pp. 305–344 Washington DC, Island Press.

Gilburn A.S., Bunnefeld N., Wilson J.M., Botham M.S., Brereton T.M., Fox R. & Goulson D. (2015) Are neonicotinoid insecticides driving declines in widespread butterflies? *PeerJ*, 3:e1402.

Agricultural & forestry pollution

10.1. Introduce legislation to control the use of hazardous substances

- We found no studies that evaluated the effects on butterflies and moths of introducing legislation to control the use of hazardous substances.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Potentially hazardous substances, such as pesticides, herbicides and fertilizers, are sold commercially for use in agriculture as well as privately. This facilitates widespread use over a large area which, even if low level or infrequent, can harm or kill butterflies and moths, and may have contributed to population declines (Gilburn *et al.* 2015). Using legislation to restrict the sale and application of the most dangerous chemicals could reduce their use, and help threatened butterfly and moth populations to recover.

Gilburn A.S., Bunnefeld N., Wilson J.M., Botham M.S., Brereton T.M., Fox R. & Goulson D. (2015) Are neonicotinoid insecticides driving declines of widespread butterflies? *PeerJ* 3:e1402.

10.2. Restrict certain pesticides or other agricultural chemicals

- **Five studies** evaluated the effects on butterflies and moths of restricting the use of certain pesticides or other agricultural chemicals. Three studies were in the UK[1–3], and one was in each of Germany[4] and Italy[5].

COMMUNITY RESPONSE (3 STUDIES)

- **Richness/diversity (3 studies):** Two replicated, site comparison studies in the UK[2] and Italy[5] found that arable field margins[2] and rice field banks[5] which were not sprayed with the herbicide glyphosate had a greater species richness of butterflies than margins and banks sprayed once/year for 1–3 years. One replicated, randomized, controlled study in the UK[3] found that grass strips which were not sprayed with the herbicide fluazifop-P-butyl had a similar species richness of butterflies to strips sprayed once.

POPULATION RESPONSE (5 STUDIES)

- **Abundance (5 studies):** Three replicated, site comparison studies (including two randomized studies) in the UK[1,2] and Italy[5] found that arable field margins[1,2] and rice field banks[5] which were not sprayed with the herbicide glyphosate had a higher total abundance of butterflies[2,5], and of meadow brown[1] and large copper[5] specifically, than margins and banks sprayed once/year for 1–3 years. One controlled study in Germany[4] found that white campion plants sprayed with water had a higher abundance of lychnis moth eggs and caterpillars after one night than plants sprayed with the insecticide Karate Zeon. One replicated, randomized, controlled study in the UK[3] found that grass strips which were not sprayed with the herbicide fluazifop-P-butyl had a similar abundance of butterflies to strips sprayed once.

BEHAVIOUR (0 STUDIES)

Background

In conventional farming, a wide range of chemicals are commonly applied for pest control. Specific pesticides (including insecticides, herbicides or fungicides) vary in their ability to specifically target certain species, and the extent of their wider, detrimental effects on other species, including butterflies and moths (Russell & Schultz 2010, Schultz *et al.* 2016). Therefore, restricting the use of specific, more toxic, chemicals, may benefit species living on farmland.

This action includes studies where the use of a specific, named chemical has been reduced or stopped. For studies on a general reduction of multiple or unnamed chemicals, either without cessation or across a small area, see "*Reduce fertilizer, pesticide or herbicide use generally*". For studies on the complete cessation of chemical applications across an entire farm, see "*Convert to organic farming*".

Russell C. & Schultz C.B. (2010) Effects of grass-specific herbicides on butterflies: an experimental investigation to advance conservation efforts. *Journal of Insect Conservation*, 14, 53–63.

Schultz C.B., Zemaitis J.L., Thomas C.C., Bowers M.D. & Crone E.E. (2016) Non-target effects of grass-specific herbicides differ among species, chemicals and host plants in *Euphydryas* butterflies. *Journal of Insect Conservation*, 20, 867–877.

A replicated, randomized, controlled study in 1989–1991 in Oxfordshire, UK (1, same experimental set-up as 2) found more adult meadow brown *Maniola jurtina* on naturally regenerated field margins that were not sprayed with herbicide than on margins which were sprayed once a year. After 1–2 years of herbicide application, there were more adult meadow brown on cut or uncut margins which were not sprayed (4–10 individuals/50 m) than on uncut sprayed margins (3–4 individuals/50 m). In the first year of herbicide application, there was no difference between unsprayed (7–15 individuals/50 m) and sprayed margins (15 individuals/50 m). In October 1987, two-metre-wide field margins around arable fields were rotovated and left to naturally regenerate. Fifty-metre-long plots were either uncut and unsprayed, subject to one of four different cutting regimes but unsprayed, or uncut but sprayed once/year with herbicide (glyphosate, 3 l/ha Roundup™ in 175 l water) in late June or early July 1989–1991. There were eight replicates of each treatment. From June–September 1989, and April–September 1990–1991, adult meadow brown were monitored weekly.

A replicated, randomized, controlled study in 1989–1991 in Oxfordshire, UK (2, same experimental set-up as 1) found that butterfly abundance and species richness were higher on naturally regenerated field margins that were not sprayed with herbicide than on margins which were sprayed once a year. After one year of herbicide application, both the abundance (39 individuals/50 m) and species richness (8 species/50 m) of butterflies were higher on uncut margins which were not sprayed than on uncut sprayed margins (abundance: 18 individuals/50 m; richness: 6 species/50 m). After two years of herbicide application, there were more butterflies on both cut and uncut margins which were not sprayed (abundance: 17–37 individuals/50 m; richness: 8–9 individuals/50 m) than on uncut sprayed margins (abundance: 12 individuals/50 m; richness: 7 species/50 m). In the first year of herbicide application, there was no difference between unsprayed (abundance: 15–44 individuals/50 m; richness: 6–9 species/50 m) and sprayed margins (abundance: 42 individuals/50 m; richness: 6 species/50 m). Two-metre-wide field margins around arable fields were rotovated in October 1987 and left to naturally regenerate. Fifty-metre-long plots were either uncut and unsprayed, subject to one of four different cutting regimes but unsprayed, or uncut but sprayed once a year with herbicide (glyphosate, 3 l/ha Roundup™ in 175 l water) in late June or early July 1989–1991. There were eight replicates of each treatment. Butterflies were monitored weekly from June–September 1989 and from April–September 1990 and 1991.

A replicated, randomized, controlled study in 2008–2009 on two arable farms in Berkshire, UK (3) found that grass buffer strips which were not sprayed with grass-specific herbicide had a similar abundance and species richness of butterflies to sprayed strips. On unsprayed grass buffer strips, the abundance (3.7 individuals/plot), species richness (3.7 species/plot) and diversity of butterflies was not significantly different to strips which had been sprayed with herbicide (abundance: 2.2 individuals/plot; richness: 2.5 species/plot; diversity presented as model results). Six-metre-wide grass buffer strips were created on two arable farms in 2004 and managed under an Entry Level Stewardship agreement from 2005. In April 2008, three pairs of 25 × 4 m plots were established at each farm. One random plot/pair was sprayed with a grass-specific herbicide ("fluazifop-P-butyl"), and the other was left unsprayed. All plots were cut to 15 cm in autumn, and cuttings left in place. From May–September 2008–2009, butterflies were surveyed twice on each of four days/year on a 25-m transect through the centre of each plot.

A controlled study in 2012 in a field in Landau, Germany (4) found more eggs and caterpillars of the lychnis moth *Hadena bicruris* on white campion *Silene latifolia alba* flowers which had been sprayed with water than on flowers sprayed with insectide. After a single night, flowers sprayed with water had more lychnis moth eggs and caterpillars (18 individuals) than flowers sprayed with insecticide (11 individuals). White campion were grown from seed and cultivated indoors in 10 cm pots before being potted into 2 litre containers and moved outside. In September 2012, after flowering began, six female plants were sprayed with water, six were sprayed with insecticide (Karate Zeon), and all were placed outside, 1 m apart, around the circumference of a 2-m radius circle. Six male plants were sprayed with water and placed in a smaller, 0.75-m radius circle inside the female plants. The plants were exposed to natural pollination overnight. The next morning, each flower was wrapped in gauze to exclude further pollination. Nine days later, the flowers were searched for eggs or caterpillars.

A replicated, site comparison study in 2016 on three rice farms in Pavia province, Italy (5) found that herbicide-free rice field banks had a higher abundance and species richness of butterflies than banks which were sprayed with herbicide. On unsprayed banks, the abundance (1.2–12.2 individuals/100 m) and species richness (0.7–2.6 species/100 m) of butterflies was higher than on banks sprayed with herbicide once/year (abundance: 0.1–2.3 individuals/100 m; richness: 0.1–1.1 species/100 m). Endangered large copper *Lycaena dispar* butterflies were present on more unmanaged banks (48 individuals) than on sprayed banks (10 individuals). See paper for other species results. Banks (1–2 m wide) between paddy fields on three farms were either sprayed with herbicide (Glyphosate) in April, or left unmanaged with permanent herbaceous cover. From April–September 2016, butterflies were surveyed monthly on 160–440-m-long transects on 17 field banks (13 sprayed, four unsprayed).

(1) Feber R.E., Smith H. & Macdonald D.W. (1994) The effects of field margin restoration on the meadow brown butterfly (*Maniola jurtina*). *British Crop Protection Council Monographs*, 58, 295–300.
(2) Feber R.E., Smith H. & Macdonald D.W. (1996) The effects on butterfly abundance of the management of uncropped edges of arable fields. *Journal of Applied Ecology*, 33, 1191–1205.
(3) Blake R., Woodcock B., Westbury D., Sutton P. & Potts S. (2011) New tools to boost butterfly habitat quality in existing grass buffer strips. *Journal of Insect Conservation*, 15, 221–232.
(4) Hahn M., Schotthöfer A., Schmitz J., Franke L.A. & Brühl C.A. (2015) The effects of agrochemicals on Lepidoptera, with a focus on moths, and their pollination service in field margin habitats. *Agriculture, Ecosystems & Environment*, 207, 153–162.
(5) Giuliano D., Cardarelli E. & Bogliani G. (2018) Grass management intensity affects butterfly and orthopteran diversity on rice field banks. *Agriculture, Ecosystems & Environment*, 267, 147–155.

10.3. Reduce fertilizer, pesticide or herbicide use generally

- **Eleven studies** evaluated the effects on butterflies and moths of reducing fertilizer, pesticide or herbicide use generally. Three studies were in the UK[2,4,5], two were in each of the USA[1,9] and Germany[6,7], one was in each of Spain[8], Mexico[10] and Switzerland[11], and one was a systematic review across Europe[3].

COMMUNITY RESPONSE (10 STUDIES)

- **Richness/diversity (10 studies):** Eight studies (including one replicated study, two controlled studies, one randomized study, five site comparison studies, and one systematic review) in the USA[1,9], Europe[3], the UK[2,5], Spain[8], Mexico[10] and Switzerland[11] found that orchards[1], crop edges[2,3], farms[5], vineyards[8], replanted Douglas fir stands[9], coffee plantations[10] and agricultural landscapes[11] managed with less frequent[2], reduced[1,3,5,6–11] or no[1,9] pesticide[1,3,8,10,11], herbicide[1,2,3,8–10], fertilizer[1,10,11] or unspecified chemical[5] input (sometimes along with other agri-environment scheme options[5] or less intensive management[10]) had a greater species richness of adult butterflies[2,3,8,11] and moths[3,5,9], or caterpillars[1,10] (in one case along with other leaf-eating arthropods[1]), than areas with more frequent[2] or conventional chemical applications[1,3,5,6–11,]. However, one of these studies found that species richness was not affected by the number of pesticide applications in the year of study, only in the previous three years[2], and another of the studies also found that vineyards managed with reduced insecticide and herbicide application had a similar species richness of moths to conventionally managed vineyards[8]. Two replicated studies (including one randomized, controlled study and one site comparison study) in the UK[4] and Germany[7] found that unfertilized grassland had a similar species richness of butterflies[4] and moths[7], but greater species richness of specialist moths[7], to fertilized grassland.

POPULATION RESPONSE (9 STUDIES)

- **Abundance (9 studies):** Six studies (including one replicated study, one controlled study, one randomized study, four site comparison studies, and one systematic review) in Europe[3], the UK[2,5], Germany[6], Mexico[10] and Switzerland[11] found that crop edges[2,3], farms[5], a hay meadow[6], coffee plantations[10] and agricultural landscapes[11] managed with less frequent[2], reduced[3,5,10,11] or no[6] pesticide[3,11], insecticide[6,10], fungicide[10], herbicide[2,3,10], fertilizer[10,11] or unspecified chemical[5] input (sometimes along with other agri-environment scheme options[5] or less intensive management[10]) had a higher abundance of adult butterflies[2,3,11] and moths[3,5], or caterpillars[3,6,10], than areas with more frequent[2] or conventional chemical applications[3,5,6,10,11]. However, one of these studies found that abundance was not affected by the number of pesticide applications in the year of study, only in the previous three years[2], and another of these studies also found that a hay meadow with no herbicide applications had a similar abundance of caterpillars to a meadow where herbicide was used, and a meadow with no fertilizer applications had a lower abundance of caterpillars than a meadow where fertilizer was applied in one of two sampling sessions[6]. Three replicated studies (including two randomized, controlled studies and one site comparison study) in the UK[4], Germany[7] and the USA[9] found that unfertilized grassland[4,7] and replanted Douglas fir stands with limited or no herbicide applications[9] had a similar abundance of adult butterflies and caterpillars[4], and adult moths[7,9], to fertilized grassland[4,7] and stands with more herbicide applications[9].

BEHAVIOUR (1 STUDY)

- **Use (1 study):** One replicated, site comparison study in Germany[7] found that unfertilized or lightly fertilized grasslands were preferred to heavily fertilized grasslands by 7 out of 58 species of moth, but 12 of 58 species preferred more heavily fertilized grasslands.

Background

In conventional farming or plantation management, a wide range of chemicals are commonly applied for pest control or fertilization, but these can have lethal or sub-lethal effects on other wildlife, including butterflies and moths (Russell & Schultz 2010, Schultz *et al.* 2016). Therefore, reducing the extent, amount or frequency of chemical application may benefit butterfly and moth populations.

This action includes studies where there has been a general reduction in the use of multiple or unnamed chemicals, either without complete cessation or over a small area. For studies on the reduction or cessation in use of a specific, named chemical, see "*Restrict certain pesticides or other agricultural chemicals*". For studies on restricting chemical applications on field edges, see "*Leave headlands in fields unsprayed (conservation headlands)*". For studies on the complete cessation of chemical applications across an entire farm, see "*Convert to organic farming*". For studies on the reduction of chemical application as part of a general reduction in grassland management intensity, see "*Agriculture and aquaculture – Reduce management intensity on permanent grasslands (several interventions at once)*".

Russell C. & Schultz C.B. (2010) Effects of grass-specific herbicides on butterflies: an experimental investigation to advance conservation efforts. *Journal of Insect Conservation*, 14, 53–63.

Schultz C.B., Zemaitis J.L., Thomas C.C., Bowers M.D. & Crone E.E. (2016) Non-target effects of grass-specific herbicides differ among species, chemicals and host plants in *Euphydryas* butterflies. *Journal of Insect Conservation*, 20, 867–877.

A controlled study in 1984–1988 in three orchards in West Virginia, USA (1) found that orchards managed without pesticides or fertilizer, and with fewer or no herbicides, had more leaf-eating arthropod species, including caterpillars, and greater diversity, than a conventionally managed orchard. Three to five years after establishment, the number of species and diversity of leaf-eating arthropods (e.g. insects and mites) in an unmanaged (23–27 species) and a partially managed (21–33 species) orchard were higher than in a conventionally managed orchard (7–11 species, see paper for diversity data). Over five years, the diversity increased in the reduced management orchards, but in the conventionally managed orchard diversity decreased in the third year and remained low (see paper for details). In spring 1984, three orchards (0.30–0.35 ha) were planted with young trees (1–2 cm diameter). Two reduced management orchards had five apple cultivars at 5 × 4-m spacing. One conventional orchard had one apple cultivar at 5 × 7.5-m spacing. The unmanaged orchard was mown three times/year in 1984–1985, but unmanaged thereafter. The partially managed orchard was pruned commercially, with four annual herbicide applications and monthly mowing. The conventionally managed orchard was pruned and fertilized, mown every 3–4 weeks, and received regular herbicide and pesticide applications, which increased in the third year. From April–September 1984–1988, all leaf-eating arthropods were recorded on 5–10 randomly selected trees/orchard, 4–5 times/year.

A replicated, randomized, site comparison study in 1991 at a farmland and grassland site in Cambridgeshire, UK (2) found that there was higher butterfly abundance and species richness in areas that had been treated less frequently with herbicide in the previous three years, but abundance and species richness were not affected by the number of pesticide applications in the surveying year itself. Butterfly abundance and species richness increased with a decrease in the number of times that the adjacent fields had been treated with herbicide in the previous three years (data presented as statistical results). Peacock butterfly *Inachis io* abundance particularly increased with decreased herbicide applications (data presented as statistical results). However, neither overall butterfly abundance nor richness was affected by the number of pesticide applications in the surveying year itself (1991). See paper for details of the effects on individual butterfly species. From May–September 1991, butterflies were surveyed up to once/month in fine weather on twenty-six 200 m transects along margins between fields of any combination of arable farmland and grassland. Each transect was surveyed 2–4 times in both years. The researchers obtained data on the total number of applications of herbicide in 1989–1991 and pesticide in 1991 in the fields adjacent to the surveyed margins.

A systematic review of 23 controlled studies (3) found that restricting pesticide inputs on crop edges tended to increase moth and butterfly abundance. In six out of 11 studies, moth or butterfly adult or caterpillar abundance was higher where pesticide use was restricted than under normal application (data presented as model results). When both pesticide and herbicide were restricted, both the abundance and species richness of adult moths and butterflies doubled (data presented as model results). In most (9 out of 11) studies, the effect of reducing different pesticides (fungicide, herbicide, insecticide) or the effect of reducing pesticide or fertilizer inputs could not be distinguished from one another. Only controlled studies, comparing areas with higher (or normal) and lower (reduced or no) pesticide input were included. All studies came from Europe.

A replicated, randomized, controlled study in 2002–2006 on four lowland farms in Devon and Somerset, UK (4) found that unfertilized grassland plots had a similar abundance and species richness of butterflies, and abundance of caterpillars, to fertilized plots. On unfertilized plots, the abundance (1–4 individuals/transect) and species richness (1–2 species/transect) of butterflies, and the abundance of caterpillars (0–4 caterpillars/transect) were not significantly different from fertilized plots (butterfly abundance: 0–2 individuals/transect; richness: 0–1 species/transect; caterpillar abundance: 0–4 caterpillars/transect). In April 2002, six experimental plots (50 × 10 m) were established on permanent pastures (>5-years-old) on four farms. All plots were cut to 5 cm twice/year in May and July, and grazed in September. Three plots/farm were fertilized (225 kg nitrogen/ha, 22 kg phosphorus/ha, 55 kg potassium/ha) and three were not fertilized. From June–September 2003–2006, butterflies were surveyed once/month on a 50-m transect through the centre of each plot. In April, June, July and September 2003–2006, caterpillars were counted (but not identified) on two 10-m transects/plot using a sweep net (20 sweeps/transect).

A replicated, paired, site comparison study in 2008 on 36 farms in central Scotland, UK (5) reported that farms managed with reduced chemical inputs (alongside other agri-environment scheme (AES) options) had a greater abundance and species richness of moths than conventionally-managed farms. Results were not tested for statistical significance. On farms managed with reduced chemical input under AES, 390 individuals of 51 species of micro-moth were recorded, compared to 199 individuals of 43 species on conventionally-managed farms. On AES farms, 1,377 individuals of 71 species of all macro-moths, and 159 individuals of 13 species of declining macro-moths, were recorded, compared to conventional farms where 917 individuals of 61 species of all macro-moths and 111 individuals of 17 species of declining macro-moth were recorded. In 2004, eighteen farms enrolled in AES, and were paired with 18 similar but conventionally managed farms, <8 km away. Each AES farm had at least three of four features (hedgerows, sown grass field margins or banks, sown species-rich grassland, >3-m-wide waterway margins) all with reduced chemical inputs and relaxed cutting and grazing regimes compared to similar habitat features on the conventional farms. From June–September 2008, moths were collected for four hours, on one night/farm, using 6 W heath light traps located next to each habitat type (3–4 traps/farm, ≥100 m apart). Paired farms were surveyed on the same night.

A replicated, randomized, paired, controlled study in 2010–2011 in an extensively managed hay meadow in Landau, Germany (6) found that plots without insecticide applied had higher caterpillar abundance than plots with insecticide, but the application of herbicide did not alter caterpillar abundance, and plots without fertilizer had lower caterpillar abundance in one of two sampling sessions. In plots not treated with insecticide, caterpillar abundance (1–2 individuals/plot) was higher than in plots with insecticide applied (0 individuals/plot). However, caterpillar abundance was lower in plots not treated with fertilizer (1–2 individuals/plot) than in plots with fertilizer applied in one of two samples (2–3 individuals/plot). Caterpillar abundance was similar in plots without (1–2 individuals/plot) and with (2 individuals/plot) herbicide applied. The results were mostly due to differences in the numbers of two moth groups (Geometridae and Noctuidae). In 2010, sixty-four plots (8 × 8 m) were assigned to one of eight treatments: no pesticide, herbicide or fertilizer, insecticide-, herbicide- or fertilizer-only, or each combination of two or three chemicals applied. Fertilizer was applied twice/year in April, with a granular nitrate/phosphorus/potassium fertilizer and a calcium carbonate/ammonium nitrate fertilizer two weeks apart. Herbicide (Atlantis WG) was applied once/year in April. Insecticide (Karate Zeon) was applied once/year in late May or early June. On 30 May and 27 June 2011, caterpillars were sampled using sweep nets (80 and 100 sweeps/plot).

A replicated, site comparison study in 2014 in 26 grasslands in Germany (7) found that unfertilized grasslands had a similar abundance, species richness and diversity of moths to fertilized grasslands. Unfertilized grasslands had a similar abundance, species richness and diversity of moths to fertilized grasslands (data presented as model results). However, unfertilized grasslands did support more specialist moth species than fertilized grasslands (data presented as model results). Of 58 individual species monitored, seven preferred unfertilized or lightly fertilized grasslands, and 12 preferred more heavily fertilized grasslands (see paper for individual species data). From 2006, across three regions, eleven grasslands were fertilized with 1–138 kg nitrogen/ha, and 15 were unfertilized. Moths were collected once/month from nine grasslands in each of two regions (May–August 2014), and from eight grasslands in one region (June–July 2014). Each night, a 12 V actinic and black-light trap were placed in the centre of each of three grasslands for 138–317 minutes/night. Moths were classified as specialists based on the number of food plants eaten by their caterpillars.

A replicated, site comparison study in 2013–2014 in 20 vineyards in Catalonia, Spain (8) found that vineyards managed with fewer chemicals had more butterfly species than conventional vineyards, but a similar number of moth species. There were more species of butterfly in vineyards managed with fewer chemicals (30–33 species) than conventionally managed vineyards (22–32 species), but the number of moth species was similar (reduced: 193 species; conventional: 190 species). Ten vineyards were managed with fewer insecticide and herbicide (Glyphosate) applications/year than 10 conventionally-managed vineyards. From April–August 2013–2014, butterflies were surveyed four times/year on two 100-m transects/vineyard in nine vineyards/year. One transect was along crop lines, and the other was along grass strips between crop lines. From April–September 2013–2014, moths were sampled for 3–4 hours after sunset using two light traps, one each on a reduced and conventional farm. The number of nights is not specified, but 18 farms were sampled in 2013 and 20 in 2014.

A replicated, randomized, paired, controlled study in 2011–2013 in eight forests in Oregon, USA (9) found that replanted stands with limited or no herbicide applications had a higher species richness, but similar abundance, of moths to stands with more herbicide applied. In forest stands with limited or no herbicide treatment, the species richness of moths (42 species/stand) was higher than in stands with moderate or intensive herbicide treatments (38 species/stand). However, the abundance of moths was not significantly different between stands with different herbicide applications (none: 144–148; limited: 180–195; moderate: 132–138; intensive: 161–172 individuals/stand). In winter 2009–2010, four 10–19-ha stands within each of eight forest blocks were clearcut, and replanted with Douglas fir *Pseudotsuga menziesii* in spring 2011. Within each block, one stand received each of four herbicide treatments: no herbicide; limited herbicide treatment for herbaceous plants in year two and woody vegetation in year three; moderate treatment prior to planting and for woody vegetation control in years three and four; intensive treatment with the moderate applications plus herbaceous control in years two and three. The moderate treatment reflected standard management practice. From May–August 2012–2013, moths were sampled overnight once/month using three 22 W universal black-light traps/stand. Stands within a block were sampled on the same night.

A site comparison study in 2016 in five coffee plantations in Veracruz, Mexico (10) found that coffee plantations managed less intensively, including with fewer chemical inputs, supported more caterpillars than more intensively managed plantations. On the least intensively managed plantation, both the abundance (212 individuals) and species richness (129 species) of caterpillars was higher than on the most intensively managed plantation (abundance: 47 individuals; richness: 46 species). Both abundance and species richness on the other three plantations were intermediate. In addition, the amount of damage found on coffee leaves was not related to either caterpillar abundance or species richness (data not presented). The management intensity of five coffee plantations was measured based on 10 vegetation characteristics (including canopy cover, epiphyte cover, area of shade trees and presence of herbs) and the frequency of six external inputs (fertilizers, insecticides, herbicides, fungicides, irrigation and ploughing). In July, September and December 2016, all caterpillars were collected by hand from all plants along three 30 × 2-m transects in the centre of each plantation, and reared to adults for species identification.

A replicated, site comparison study in 2010–2014 in 50 agricultural areas in the Swiss Plateau, Switzerland (11) found that landscapes with more semi-natural habitat managed without pesticide and fertilizer had more butterflies than landscapes with less semi-natural habitat managed without chemicals. Agricultural areas with more than 20% of the land managed as semi-natural habitat without chemicals had a higher abundance and species richness of all butterflies than areas with less than 10% semi-natural habitat with no chemicals. The abundance of farmland butterflies, and the species richness of threatened butterflies, was higher in landscapes with more chemical-free semi-natural habitat than in landscapes with less chemical-free semi-natural habitat (all data presented as model results). Fifty mixed farming areas (1 km^2) were selected where 2.5–32.2% of agricultural land was managed under agri-environment schemes (primarily extensive meadows cut or grazed once/year with no fertilizers or pesticides). Butterflies were surveyed seven times along a 2.5-km transect through each 1-km^2 area in one of five years (2010–2014). Species were classified as "farmland species" if they occur in open habitat, and "threatened" species if they were listed as Near Threatened, Vulnerable or Critically Endangered on the Swiss RedList.

(1) Brown M.W. & Welker W.V. (1992) Development of the phytophagous arthropod community on apple as affected by orchard management. *Environmental Entomology*, 21, 485–492.
(2) Sparks T. H. & Parish T. (1995) Factors affecting the abundance of butterflies in field boundaries in Swavesey fens, Cambridgeshire, UK. *Biological Conservation*, 73(3), 221-227.
(3) Frampton G.K. & Dorne J.L.C.M. (2007) The effects on terrestrial invertebrates of reducing pesticide inputs in arable crop edges: a meta-analysis. *Journal of Applied Ecology*, 44, 362–373.
(4) Potts S.G., Woodcock B.A., Roberts S.P.M., Tscheulin T., Pilgrim E.S., Brown V.K. & Tallowin J.R. (2009) Enhancing pollinator biodiversity in intensive grasslands. *Journal of Applied Ecology*, 46, 369–379.
(5) Fuentes-Montemayor E., Goulson D. & Park K.J. (2011) The effectiveness of agri-environment schemes for the conservation of farmland moths: assessing the importance of a landscape-scale management approach. *Journal of Applied Ecology*, 48, 532–542.
(6) Hahn M., Schotthöfer A., Schmitz J., Franke L.A. & Brühl C.A. (2015) The effects of agrochemicals on Lepidoptera, with a focus on moths, and their pollination service in field margin habitats. *Agriculture, Ecosystems & Environment*, 207, 153–162.
(7) Mangels J., Fiedler K., Schneider F.D. & Bluthgen N. (2017) Diversity and trait composition of moths respond to land-use intensification in grasslands: generalists replace specialists. *Biodiversity and Conservation*, 26, 3385–3405.
(8) Puig-Montserrat X., Stefanescu C., Torre I., Palet J., Fàbregas E., Dantart J., Arrizabalaga A. & Flaquer C. (2017) Effects of organic and conventional crop management on vineyard biodiversity. *Agriculture, Ecosystems & Environment*, 243, 19–26.

(9) Root H.T., Verschuyl J., Stokely T., Hammond P., Scherr M.A. & Betts M.G. (2017) Plant diversity enhances moth diversity in an intensive forest management experiment. *Ecological Applications*, 27, 134–142.
(10) Sosa-Aranda I., del-Val E., Hernández-Martínez G., Arroyo-Lambaer D., Uscanga A. & Boege K. (2018) Response of lepidopteran herbivore communities to crop management in coffee plantations. *Agriculture, Ecosystems & Environment*, 265, 37–44.
(11) Zingg S., Grenz J. & Humbert J.-Y. (2018) Landscape-scale effects of land use intensity on birds and butterflies. *Agriculture, Ecosystems & Environment*, 267, 119–128.

10.4. Convert to organic farming

- **Thirteen studies** evaluated the effects on butterflies and moths of converting to organic farming. Six studies were in Sweden[1,3,7,8,9,12], three were in the UK[2,4,5] and one was in each of Canada[6], Switzerland[10], Germany[11] and Taiwan[13].

COMMUNITY RESPONSE (13 STUDIES)

- **Richness/diversity (13 studies):** Seven of 11 replicated, site comparison studies (including five paired studies) in Sweden[1,3,7,8,9], the UK[2,5], Canada[6], Switzerland[10], Germany[11] and Taiwan[13] found that organic arable farms had a greater species richness of butterflies[1,2,3,7,8,11], burnet moths[1,3,8] and all moths[9] than conventionally managed farms. However, three of these studies only found this in intensively managed not in more diverse landscapes[1],only in the first of three study years[2], and in farms managed organically for <6 years but not 15–23 years[9]. Four of the studies found that organic arable[5,6,13] and mixed[10] farms had a similar species richness of macro-moths[6] and butterflies[5,10,13] to conventionally managed farms. Two of these studies also found that on organic and conventionally managed farms within a landscape with a high proportion of organic farms there was higher species richness of butterflies[3,5] and burnet moths[3] than either type of farm in a landscape with a high proportion of conventional farms. One before-and-after study in the UK[4] found that within 4 years after a mixed farm converted to organic management (along with increasing the proportion of grassland and reducing grazing intensity) the species richness of large moths increased. One replicated, site comparison study in Sweden[12] found that organic mixed farms had a more consistent species richness of butterflies across the farm, but a similar consistency through the summer and between years, compared to conventional farms.

POPULATION RESPONSE (12 STUDIES)

- **Abundance (12 studies):** Seven of 11 replicated, site comparison studies (including five paired studies) in Sweden[1,3,7,8,9], the UK[2,5], Canada[6], Switzerland[10], Germany[11] and Taiwan[13] found that organic arable farms had a greater abundance of butterflies[1,2,3,5,7,8],burnet moths[1,3,8], and all moths[9], than conventionally managed farms, and that butterfly abundance increased with time since farms had been converted to organic management[7]. However, three of these studies only found this in intensively managed not in more diverse landscapes[1,3], and in farms managed organically for <6 years but not 15–23 years[9]. One of these studies also found that on organic and conventionally managed farms within a landscape with a high proportion of organic farms there was higher abundance of butterflies than either type of farm in a landscape with a high proportion of conventional farms[5]. The other four found that organic arable[6,11,13] and mixed[10] farms had a similar abundance of macro-moths[6] and butterflies[10,11,13] to conventionally managed farms. One before-and-after study in the UK[4] found that within 4 years after a mixed farm converted to organic management (along with increasing the proportion of grassland and reducing grazing intensity) the total abundance of large moths, and the abundance of lunar underwing moths and 5 out of 23 butterfly species, increased, but the abundance of two butterfly species decreased.

BEHAVIOUR (0 STUDIES)

Background

In conventional farming, a wide range of chemicals are commonly applied for pest control or fertilization, but these can have lethal or sub-lethal effects on farmland wildlife, including butterflies and moths (Russell & Schultz 2010, Schultz *et al.* 2016). Organic farming is an agricultural system that excludes the use of synthetic fertilizers and pesticides, and relies on techniques such as crop rotation, composting and biological pest control to maintain soil fertility and prevent pest outbreaks.

This action includes studies where there has been a complete cessation of chemical applications across an entire farm or substantial farmed area. For studies on a general reduction of multiple or unnamed chemicals, either without cessation or across a smaller area, see "*Reduce fertilizer, pesticide or herbicide use generally*". For studies on the reduction or cessation in use of a specific, named chemical, see "*Restrict certain pesticides or other agricultural chemicals*".

Russell C. & Schultz C.B. (2010) Effects of grass-specific herbicides on butterflies: an experimental investigation to advance conservation efforts. *Journal of Insect Conservation*, 14, 53–63.

Schultz C.B., Zemaitis J.L., Thomas C.C., Bowers M.D. & Crone E.E. (2016) Non-target effects of grass-specific herbicides differ among species, chemicals and host plants in *Euphydryas* butterflies. *Journal of Insect Conservation*, 20, 867–877.

A replicated, paired, site comparison study in 2003–2004 on 24 arable farms in Scania, Sweden (1) found that organic farms had a higher abundance and species richness of butterflies and burnet moths than conventional farms in intensively farmed but not more diverse landscapes. In intensively farmed landscapes, both the abundance (1.7 individuals/50 m) and species richness (0.9 species/50 m) of butterflies and burnet moths on organic farms were higher than on conventional farms (abundance: 0.4 individuals/50 m; richness: 0.3 species/50 m). However, in more diverse landscapes, the abundance (4.5 individuals/50 m) and species richness (1.6 species/50 m) of butterflies and burnet moths on organic farms were not significantly different from conventional farms (abundance: 3.6 individuals/50 m; richness: 1.4 species/50 m). Twelve arable farms with >50% of land under EU-subsidized organic management in 2002 and 12 conventional farms of similar size, crop type and landscape features, were selected. Farm pairs were 3–8 km apart. Six pairs of farms were in diverse landscapes (15% arable land, 19% pasture, small fields), and six pairs were in intensively farmed landscapes (70% arable land, 3% pasture, large fields). From June–August 2003 and May–August 2004, butterflies and burnet moths were surveyed 5–6 times/year along 400–750 m routes along cereal field boundaries. Individuals occurring 5 m into the crop and in adjacent 2-m uncultivated margins were counted.

A replicated, paired sites, site comparison study in 1994–1996 in 34 arable farms in southern England, UK (2) found that organic farms had a higher abundance of butterflies than conventional farms, but higher species richness in only the first of three study years. In all years there were more butterflies on organic farms (average: 24–34 individuals/km) than conventional farms (average: 17–21 individuals/km). See paper for average numbers of individual species. In 1994, there was higher species richness on organic (average: 10–16 species/km) than conventional farms (average: 8–12 species/km), but there was no difference between the two systems in 1995–1996 (1995 average species/km: organic = 12–16, conventional = 8–14; 1996 average species/km: organic = 11–16, conventional = 9–15). Pairs of neighbouring organic and conventional farms were surveyed (eight pairs in 1994, ten in 1995 and five in 1996, of which three were surveyed every year). From April–September 1994–1996, butterflies were surveyed every two weeks on transects of differing lengths, each of which included areas of both organic and conventional farms.

A replicated, paired, site comparison study in 2004–2005 in 16 sites of arable farmland in Skåne, Sweden (3) found that butterfly and burnet moth species richness was higher in organic fields than in conventionally farmed fields, and in either type of field within a landscape with a high proportion of organic fields (organic landscape), whereas butterfly abundance was higher in organic fields than in conventionally farmed fields only when fields were situated within a landscape with a high proportion of conventionally farmed fields (conventional landscape). More species of butterfly were recorded in organic (average: 8) than conventionally farmed fields (average: 7). Both organic and conventionally farmed fields within organic landscapes had more butterfly species (average: 8) than the same type of field in conventional landscapes (average: 7). In conventional landscapes there were more individuals in organic fields (95) than conventionally farmed fields (46), but in organic landscapes the difference in number of individuals between organic (68) and conventionally farmed fields (56) was not statistically significant. Eight pairs of circles of land with a 1 km radius were selected (each termed a "landscape"), where one of the pair contained a high proportion of land under the Swedish agri-environment scheme for organic farming (organic landscape: 31–97% organically farmed fields) and the other had a low proportion of organic farming (conventional landscape: 2–16%). Landscapes in a pair were 2.5–7.5 km apart, with similar field sizes, crop compositions, and percentages of land in ley, pasture and arable. In each landscape, two pairs of two adjacent cereal fields were chosen. In one pair both fields matched the landscape farming practice (organic or conventional), in the other pair one field was organically farmed and one was conventionally farmed. In each field, a 250 m transect was walked five times in June–August 2004 and six times in May–August 2005 to count butterflies Rhopalocera and burnet moths Zygaenidae.

A before-and-after study in 1994–2006 on a mixed farm in Oxfordshire, UK (4) found that following adoption of the Environmentally Sensitive Areas scheme, including stopping the application of fertilizers, herbicides and pesticides, the abundance and species richness of large moths and some species of butterfly increased. After Environmentally Sensitive Area management began, the total abundance (1,000–1,450 individuals) and species richness of large moth species was higher than before (800–1,250 individuals, richness data not presented). One of the five most abundant moth species (lunar underwing *Omphaloscelis lunosa*) and five of 23 butterfly species (meadow brown *Maniola jurtina*, brown argus *Aricia agestis*, common blue *Polyommatus icarus*, small copper *Lycaena phlaeas* and red admiral *Vanessa atalanta*) increased in abundance after the change in management. However, two butterfly species became less abundant (green-veined white *Pieris napi* and large white *Pieris brassicae*, data presented as model results). Overall butterfly abundance and species richness increased over the entire monitoring period, but the increase did not just happen after the management change. In 2002, the farm entered the Environmentally Sensitive Areas agri-environment scheme, and fertilizers, herbicides and pesticides were no longer used. Additionally, the proportion of grassland increased, and the total number of livestock dropped from 180 cows and 1,000 sheep to 120 cows and 850 sheep. Butterflies were monitored weekly from April–September on a fixed 3.6 km transect divided into 13 sections. Moths were monitored nightly from dusk to dawn using a light trap in a fixed position in the middle of the farm.

A replicated, paired sites, site comparison study in 2007–2008 in 16 sites of arable farmland in England, UK (5) found that butterfly abundance, but not species richness, was higher on organic farms than conventional farms and on either farm type within landscapes with relatively high proportions of organic farming. There was higher abundance of butterflies on organic than on conventional farms and on either type of farm within a wider landscape which had a relatively high proportion of organic farming (data presented as model results). However, there was no effect of organic farming at the farm or landscape scale on species richness (data presented as model results). Eight pairs of 10 km^2 landscapes were selected, matched in environmental conditions, where one of the pair contained a high proportion of organic farming (average: 17.2%) and the other had a low proportion of organic farming (average: 1.4%). Within each landscape one organic farm and one conventional farm was selected. Fifteen-minute walking butterfly transects were conducted along the centre and margins of six fields (three arable and three pasture) within each farm. In June–August 2008, seventy-five percent of farms were surveyed twice and 25% once. Surveys were also conducted in some arable fields only in June–August 2007 (number of visits not provided).

A replicated, site comparison study in 2001 on 16 arable farms in Ontario, Canada (6) found that organic farms had a similar abundance and species richness of macro-moths to conventionally managed farms. On organic farms, the total abundance (51–418 individuals/trap) and species richness (8–26 species/trap) of moths were not significantly different to on conventional farms (abundance: 40–359 individuals/trap; richness: 9–21 species/trap). However, more species of the family Notodontidae were found in organic than conventional farms (data not presented). Of 126 species collected only once, 91 were found on organic farms compared to 35 on conventional farms (statistical significance not assessed). See paper for species results. Eight organic farms had no chemical inputs for at least three years. Eight conventional farms had chemical fertilizers and herbicides applied. From June–September 2001, macro-moths were sampled on six nights/site. Each night, one fluorescent UV black-light funnel trap was set halfway along a hedge, and one was set ~50 m away in the middle of the adjacent crop field.

Two organic and two conventional farms were sampled each night, and all sites were sampled within five nights every two weeks.

A replicated, site comparison study in 2009 in 60 arable farms in Uppland and Scania, Sweden (7, same experimental set up as 8) found that butterfly abundance and species richness was higher on organic than conventionally-managed farms, and butterfly abundance, but not richness, increased with the time since a farm had been converted to organic farming. Butterfly abundance was 60% higher on organic (average: 68 individuals) than conventional farms (42 individuals). Species richness was 23% higher on organic (average: 10 species) than conventional farms (8 species). Butterfly abundance increased steadily with years since land was converted from conventionally-managed to organic farming, but time since conversion to organic did not affect species richness (data presented as statistical results). In June–August 2009, butterfly surveys were carried out in 40 organic and 20 conventionally-managed farms. Organic farms varied in time since conversion from conventional management (1–25 years). On each farm, three 250 m transects were completed 5–6 times - one in an uncultivated margin of a cereal field, and two within the field at 50 m and 200 m from the margin transect. Butterflies and burnet moths Zygaenidae were identified to species.

A replicated, site comparison study in 2009 on 60 arable farms in Uppland and Scania, Sweden (8, same experimental set up as 7) found that organic farms had a higher abundance and species richness of butterflies and day-flying moths than conventional farms. Data were not presented. Forty organic and 20 conventional farms (>2 km apart) were selected. Organic farms had been under organic management for 1–25 years. From June–August 2009, butterflies and burnet moths (Zygaenidae) were surveyed 5–6 times on three transects/farm. One 250-m transect was located along an uncropped margin of a cereal field, and two 50-m transects ran perpendicular to the margin into the field.

A replicated, site comparison study in 2010 in 18 arable farms in south-east Sweden (9) found that recently established organic farms had a higher abundance and species richness of moths than older organic farms or conventional farms. On farms which had been managed organically for up to six years, the abundance (357 individuals) and species richness (26 species) of moths was higher than on farms which had been managed organically for over 15 years (abundance: 48 individuals; richness: 11 species) and on conventionally managed farms (abundance: 50 individuals; richness: 12 species). Twelve species of moth were associated with new organic farms (see paper for details), but no species were associated with old organic or conventional farms. Six farms had been in organic management for ≤6 years, six had been in organic management for 15–23 years, and six were still managed conventionally. In early August 2010, moths were sampled for four consecutive days using three bait traps/farm. Traps were placed 50 m apart along one 1.5–3-m-wide, >300-m-long, uncropped field margin/farm, 1.7 m above ground, and baited with sugar saturated red wine.

A replicated, site comparison study in 2009–2011 in 133 mixed farms in the Central Plateau, Switzerland (10) found that organic farms had a similar abundance and species richness of butterflies to conventional farms. On organically managed farms, both the abundance and species richness of butterflies was similar to conventionally managed farms (data presented as model results). Of 133 farms (17–34 ha, 13–91% arable crops), 42 were managed organically, and 91 were managed conventionally. All farms contained "Ecological Compensation Areas" under agri-environment schemes. From May–September 2009–2011, butterflies were surveyed six times on 10–38 transects/farm, totalling 2,500 m/farm. Each transect ran diagonally through a single crop or habitat type, with all available crops and habitats represented. All visits to a farm were completed in a single year, and the species richness was summed across all visits. Total abundance of butterflies was calculated from the number recorded in each habitat, and the availability of each habitat across the farm.

A replicated, site comparison study in 2015 on seven arable farms in Germany (11) found that field margins next to organically managed fields had more butterfly species than field margins next to conventionally managed fields. On margins next to organically managed fields, there were more butterfly species than on margins next to conventionally managed fields (data presented as model results). Overall, 143–542 butterflies of 8–25 species were recorded on each organic farm, and 217–446 butterflies of 10–16 species were recorded on each conventional farm (statistical significance not assessed). Five farms (80–700 ha) were managed organically, and two farms (58–260 ha) were managed conventionally. From June–August 2015, butterflies were surveyed six times along 10 permanent, unsprayed and uncropped arable field margins (≥1 m wide, 50–250 m long) on each farm.

A replicated, site comparison study in 2015–2017 on 19 mixed farms in Scania, Sweden (12) found that organic farms had more consistent butterfly species richness across the farm than conventional farms. Across three field types, butterfly species richness was more consistent on organic than on conventional farms (data presented as model results). However, the consistency of butterfly species richness within a single field type throughout the summer, and between years, was similar on organic and conventional farms. On each of 10 organic and nine conventional farms, three fields were surveyed: a cereal field, a grass ley (rotational, sown, improved grassland), and a semi-natural grassland. From May–August 2015–2017, butterflies were surveyed five times (two weeks apart) along two 100-m transects/field.

A replicated, paired, site comparison study in 2017 in four farms in Hualien County, Taiwan (13) found that organic farms had a similar abundance and species richness of butterflies to conventional farms. On organic farms, the abundance (287 individuals/ha) and species richness (11 species/farm) of butterflies was not significantly different from that on conventional farms (abundance: 191 individuals/ha; richness: 9 species/farm). Within a National Park, 39 ha of farmland remained in production and farmers were encouraged to convert to organic farming. In each of two areas, one organic and one conventional farm were selected (number of years since conversion to organic not given). Farms were 250–3,200 m apart. From May–September 2017, butterflies were surveyed once/month along 150-m transects at each farm (number not specified).

(1) Rundlöf M. & Smith H.G. (2006) The effect of organic farming on butterfly diversity depends on landscape context. *Journal of Applied Ecology*, 43, 1121–1127.

(2) Feber R.E., Johnson P.J., Firbank L.G., Hopkins A. & Macdonald D.W. (2007) A comparison of butterfly populations on organically and conventionally managed farmland. *Journal of Zoology*, 273(1), 30-39.
(3) Rundlöf M., Bengtsson J. & Smith H.G. (2008) Local and landscape effects of organic farming on butterfly species richness and abundance. *Journal of Applied Ecology*, 45(3), 813-820.
(4) Taylor M.E. & Morecroft M.D. (2009) Effects of agri-environment schemes in a long-term ecological time series. *Agriculture, Ecosystems & Environment*, 130, 9–15.
(5) Hodgson J.A., Kunin W.E., Thomas C.D., Benton T.G., Gabriel D. (2010) Comparing organic farming and land sparing: optimizing yield and butterfly populations at a landscape scale. *Ecology Letters*, 13(11), 1358-1367.
(6) Boutin C., Baril A., McCabe S.K., Martin P.A. & Guy M. (2011) The Value of Woody Hedgerows for Moth Diversity on Organic and Conventional Farms. *Environmental Entomology*, 40, 560–569.
(7) Jonason D., Andersson G.K.S., Öckinger E., Rundlöf M., Smith H.G. & Bengtsson J. (2011) Assessing the effect of the time since transition to organic farming on plants and butterflies. *Journal of Applied Ecology*, 48(3), 543-550.
(8) Jonason D., Andersson G.K.S., Öckinger E., Smith H.G. & Bengtsson J. (2012) Field scale organic farming does not counteract landscape effects on butterfly trait composition. *Agriculture, Ecosystems & Environment*, 158, 66–71.
(9) Jonason D., Franzén M. & Pettersson L.B. (2013) Transient peak in moth diversity as a response to organic farming. *Basic and Applied Ecology*, 14, 515–522.
(10) Stoeckli S., Birrer S., Zellweger-Fischer J., Balmer O., Jenny M. & Pfiffner L. (2017) Quantifying the extent to which farmers can influence biodiversity on their farms. *Agriculture, Ecosystems & Environment*, 237, 224–233.
(11) Sybertz J., Matthies S., Schaarschmidt F., Reich M. & von Haaren C. (2017) Assessing the value of field margins for butterflies and plants: how to document and enhance biodiversity at the farm scale. *Agriculture, Ecosystems & Environment*, 249, 165–176.
(12) Carrie R., Ekroos J. & Smith H.G. (2018) Organic farming supports spatiotemporal stability in species richness of bumblebees and butterflies. *Biological Conservation*, 227, 48–55.
(13) Yen S.-C., Pan Y.-C., Wang L.-H. (2018) The Effects of Agricultural Lands Management Strategies for Biodiversity Recovery in Taroko National Park. *Journal of National Park*, 28, 29–43.

10.5. Use genetically modified crops which produce pesticide to replace conventional pesticide application

- **One study** evaluated the effects on butterflies and moths of using genetically modified crops which produce pesticide to replace conventional pesticide application. This study was in a laboratory[1].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (1 STUDY)

- **Survival (1 study):** One controlled study in a laboratory[1] found that pollen from genetically modified maize expressing the *Bacillus thuringiensis* var. *kurstaki* (*Btk*) toxin against European corn borer did not reduce the survival of eastern tiger swallowtail or spicebush swallowtail caterpillars more than pollen from non-genetically modified maize.

- **Condition (1 study):** One controlled study in a laboratory[1] found that pollen from genetically modified maize expressing the *Bacillus thuringiensis* var. *kurstaki* (*Btk*) toxin against European corn borer did not reduce the growth of eastern tiger swallowtail or spicebush swallowtail caterpillars more than pollen from non-genetically modified maize.

BEHAVIOUR (0 STUDIES)

Background

Drift of insecticides with aerial application, such as *Bacillus thuringiensis* (*Bt*), has been recorded as far as 3 km downwind, and spraying reduces the abundance and survival of a wide range of butterflies and moths (Scriber 2004). The use of genetically modified crops, which can produce pesticides themselves, reduces the need for chemical applications, and may result in an overall reduction in the harm caused to non-target species, including butterflies and moths (Scriber 2004).

Note that genetically modified plants which produce pesticides are still harmful to butterflies and moths (see Scriber 2004 for examples).

Scriber J.M. (2004) Non-target impacts of forest defoliator management options: Decision for no spraying may have worse impacts on non-target Lepidoptera than *Bacillus thuringiensis* insecticides. *Journal of Insect Conservation*, 8, 241–261.

A controlled study (year not specified) in a laboratory (location not specified) (1) found that pollen from genetically modified maize expressing the *Bacillus thuringiensis* var. *kurstaki* (*Btk*) toxin against European corn borer *Ostrinia nubilalis* did not reduce the growth and survival of eastern tiger swallowtail *Papilio glaucus* or spicebush swallowtail *P. troilus* caterpillars more than pollen from non-genetically modified maize. The growth and survival of both eastern tiger swallowtail and spicebush swallowtail caterpillars exposed to a large quantity of genetically modified pollen (eastern tiger, survival: 83%, growth: 0.15 mg/mg/day; spicebush, survival: 81%, growth: 0.15) were similar to those exposed to the same quantity of non-genetically modified pollen (eastern tiger, survival: 88%, growth: 0.15 mg/mg/day; spicebush, survival: 83%, growth: 0.14 mg/mg/day), but both were lower than caterpillars which were not exposed to any maize pollen (eastern tiger, survival: 100%, growth: 0.30 mg/mg/day; spicebush, survival: 100%, growth: 0.30 mg/mg/day). The growth rates of caterpillars exposed to smaller quantities of genetically modified or non-genetically modified pollen were similar to those exposed to large quantities (data not presented). Forty-two eastern tiger swallowtail and 28 spicebush swallowtail caterpillars were fed tulip tree *Liriodendron tulipfera* or spicebush *Lindera benzoin* leaves dusted with either genetically modified or non-genetically modified maize pollen, at both 1% and 10% fresh leaf weight, or with no pollen dusting. Survival and growth rate were measured after 48 hours.

(1) Scriber J.M. (2004) Non-target impacts of forest defoliator management options: Decision for no spraying may have worse impacts on non-target Lepidoptera than *Bacillus thuringiensis* insecticides. *Journal of Insect Conservation*, 8, 241–261.

10.6. Leave headlands in fields unsprayed (conservation headlands)

- **Six studies** evaluated the effects on butterflies and moths of leaving headlands in fields unsprayed. Four studies were in the UK[1,3,5,6], and two were in the Netherlands[2,4].

COMMUNITY RESPONSE (2 STUDIES)

- **Richness/diversity (2 studies):** Two replicated, paired, controlled studies in the UK[1] and the Netherlands[4] found that unsprayed headlands in arable fields had a greater species richness of butterflies than headlands sprayed with herbicide[1,4] and insecticide[4].

POPULATION RESPONSE (5 STUDIES)

- **Abundance (5 studies):** Four of five replicated, controlled studies (including one randomized study) in the UK[1,5,6] and the Netherlands[2,4] found that unsprayed headlands in arable[1,2,4] and pasture[6] fields had a greater abundance of butterflies[1,2,4] and caterpillars[6] than headlands sprayed with herbicide[1,2,4,6] and insecticide[2,4]. The other study found that unsprayed headlands in arable fields had a similar abundance of caterpillars to headlands sprayed with herbicide[5].

BEHAVIOUR (1 STUDY)

- **Use (1 study):** One replicated, paired, controlled study in the UK[3] found that large white, small white and green-veined white butterflies spent more time in unsprayed arable headlands than adjacent hedgerows, but more time in the hedgerows when adjacent headlands were sprayed with herbicide. The same study found that gatekeepers spent more time in hedgerows than headlands regardless of whether the headlands were unsprayed or sprayed[3].

- **Behaviour change (1 study):** One replicated, paired, controlled study in the UK[3] found that large white, small white and green-veined white butterflies spent more time feeding and interacting, or had slower flight speeds, in unsprayed arable headlands than in headlands sprayed with herbicide. However, the same study found that male gatekeepers spend less time feeding and interacting, and had faster flight speeds, in unsprayed headlands than in sprayed headlands[3].

Background

In conventional farming, a wide range of chemicals are commonly applied for pest control or fertilization, but these can have lethal or sub-lethal effects on farmland wildlife, including butterflies and moths (Russell & Schultz 2010, Schultz *et al.* 2016). Conservation headland management involves restricted fertilizer, herbicide and insecticide spraying in a margin (usually 6 m wide) of crop at the edge of the field, which may allow butterfly and moth populations to persist within the farm.

For studies on restricting chemical applications across the farm, see "*Reduce fertilizer, pesticide or herbicide use generally*". For studies on removing chemical applications entirely, see "*Convert to organic farming*".

Russell C. & Schultz C.B. (2010) Effects of grass-specific herbicides on butterflies: an experimental investigation to advance conservation efforts. *Journal of Insect Conservation*, 14, 53–63.

Schultz C.B., Zemaitis J.L., Thomas C.C., Bowers M.D. & Crone E.E. (2016) Non-target effects of grass-specific herbicides differ among species, chemicals and host plants in *Euphydryas* butterflies. *Journal of Insect Conservation*, 20, 867–877.

A replicated, paired, controlled study in 1984–1987 on an arable farm in Hampshire, UK (1, same experimental set up as 3), found that the abundance and species richness of butterflies was greater on unsprayed conservation headlands than on conventional sprayed headlands. On unsprayed headlands, the abundance of butterflies (222–472 individuals/km) was higher than on conventional headlands (80–259 individuals/km) in all four years. In total, 29 species of butterfly were recorded, of which 13–21 were found on unsprayed headlands and 13–17 on conventional headlands each year (statistical significance not assessed). On half of 14 fields, a 6-m strip around the edge (headland) was left unsprayed, while the remainder received conventional broadleaved herbicide applications. Spring and summer applications of insecticide were not used anywhere on the farm. From 1984–1987, butterflies were sampled along a transect at least once a week from 14 May to 19 August. Sprayed and unsprayed headlands were paired with similar adjacent habitats.

A replicated, paired, controlled study in 1990–1992 of arable field edges in the Netherlands (2, same experimental set up as 4) found that unsprayed field margins had greater butterfly abundance than sprayed margins. In unsprayed margins, the abundance of butterflies (6–7 individuals/300 m^2) was higher than in sprayed margins (1–2 individuals/300 m^2). Abundance did not differ between 3-m-wide (6 individuals/300 m^2) and 6-m-wide (7 individuals/300 m^2) unsprayed margins. Numbers on adjacent ditch banks were also higher for unsprayed (18–20 individuals/100 m) than sprayed margins (9–11 individuals/100 m). From January 1990 and 1992, margins 3 × 100 m (in 1990) and 6 × 400 m (in 1992) were left unsprayed by herbicides and insecticides and compared to sprayed edges in the same field. From mid-May–July 1992, butterflies were sampled 11 times on 3 m (eight farms) and 6 m (six farms) margins.

A replicated, paired, controlled study in 1985–1987 on an arable farm in Hampshire, UK (3, same experimental set-up as 1) found mixed effects of unsprayed conservation headlands on the behaviour of butterflies. In fields with unsprayed headlands, white butterflies (Pieridae) spent more time in the headland (57–220 seconds) than the adjacent hedgerow (4–40 seconds), whilst in fields with sprayed headlands they spent less time in the headland (5–40 seconds) than the hedgerow (18–72 seconds). However, gatekeepers *Pyronia tithonus* spent more time in the hedgerow (145–900 seconds) than the headland (15–375 seconds) in all fields. Flight and transit speeds of male white butterflies and transits of female green-veined white *Pieris napi* in unsprayed headlands (male flight: 0.56–1.35; male transit: 0.74–0.98; female transit: 0.14 m/s) were slower than in sprayed headlands (male flight: 0.21–1.75; male transit: 1.19–1.66; female transit: 0.57 m/s). However, gatekeeper males (in 1986) moved faster in the unsprayed (flight: 0.70; transit: 0.43 m/s) than the sprayed headlands (flight: 0.51; transit: 0.22 m/s). In unsprayed headlands, male large white *P. brassicae* and small white *P. rapae* spent more time feeding (47–60%) and interacting (20–65%) than in sprayed headlands (feeding: 4–8%; interacting: 23–33%), whereas male gatekeeper spent less time feeding (32%) and interacting (36%) in unsprayed headlands than in sprayed headlands (feeding: 67%; interacting: 71%). Sample sizes were too small for other species and females. On half of 4–8 fields each year, a 6-m strip around the edge (headland) was left unsprayed, while the remainder received conventional broadleaved herbicide applications. Insecticide was not used in spring and summer anywhere on the farm. The behaviour and location (hedgerow or headland) of five butterfly species were observed. Flight speed (distance travelled/time spent in flight) and transit speed (distance travelled/time observed) were calculated.

A replicated, paired, controlled study in 1990–1992 in arable field edges on 12 farms in the Netherlands (4, same experimental set-up as 2) found that unsprayed field margins had a higher abundance and species richness of butterflies than sprayed margins. Butterfly abundance was higher in unsprayed edges of winter wheat in both years (10–12 individuals/100 m^2) and potatoes in 1992 (5 individuals/100 m^2) compared to sprayed edges (wheat: 2–3, potato: 1 individuals/100 m^2). Species richness was also higher in unsprayed winter wheat in both years (3–4 species/100 m^2) and potatoes in 1992 (3 species/100 m^2) compared to sprayed edges (wheat: 1–2, potato: 1 species/100 m^2). All six of the most common species (Meadow brown Maniola *jurtina*, Wall *Lasiommata megera*, Small heath *Coenonympha pamphilus*, Small white *Pieris rapae*, Green-veined white *Pieris napi*, Essex skipper *Thymelicus lineola*) had higher abundance in unsprayed than sprayed edges in one or both years and crops (see paper for data). Strips 6 × 100 m or 400 m along field edges were left unsprayed by herbicides and insecticides and were compared to sprayed edges in the same field. Butterflies were sampled once/week on the crop edges and adjacent ditch banks nine times from mid-May to July in 1990 and 1992.

A replicated, randomized, controlled study in 1989–1991 on an arable farm on the Hampshire–Dorset border, UK (5) found that caterpillar abundance was similar in unsprayed headlands and in headlands receiving autumn herbicide applications. The number of caterpillars was similar in unsprayed (0.1–0.3 individuals/0.5 m^2) and sprayed (0.1–0.4 individuals/0.5 m^2) plots. Two field headlands were divided into 6–8 plots (6 × 100 m), and half were randomly assigned to each treatment each year: sprayed with herbicides in autumn or left unsprayed. No insecticides or fungicides were applied. Caterpillars were surveyed in five samples/plot using a D-Vac insect sampler on five occasions from May–July 1989–1991, in one field each year.

A replicated, randomized, controlled study in 1997–1998 on permanent pasture at three sites in Dumfries and Galloway, UK (6) found that leaving field headlands unsprayed increased the abundance of caterpillars. Field headlands which were not sprayed with herbicide in spring had more caterpillars the following summer than headlands which were sprayed once with herbicide, but numbers were similar one year later (data not presented). From spring 1997, four treatments were carried out in adjacent plots (10 × 50 m long) on the boundaries of seven pasture fields: unsprayed unfenced, unsprayed fenced (May–September), sprayed unfenced, and sprayed fenced (May–September). In sprayed plots, herbicide (6 l glyphosate/ha) was applied in April 1997 to clear strips to trial a method for increasing foraging access for birds. Unfenced plots were grazed by cattle and sheep during summer, and all plots were intermittently grazed by sheep during winter. Insects were sweep net sampled in June and July 1997 and 1998.

(1) Dover J., Sotherton N. & Gobbett K.A.Y. (1990) Reduced pesticide inputs on cereal field margins: the effects on butterfly abundance. *Ecological Entomology*, 15, 17–24.
(2) de Snoo G.R. (1996) The effect of cereal headland treatments on carabid communities. *Arthropod Natural Enemies in Arable Land II - Survival, Reproduction and Enhancement*. Pages 209–219 in: *Acta Jutlandica*.

(3) Dover J.W. (1997) Conservation headlands: effects on butterfly distribution and behaviour. *Agriculture, Ecosystems & Environment*, 63, 31–49.
(4) de Snoo G.R., van der Poll R.J. & Bertels J. (1998) Butterflies in sprayed and unsprayed field margins. *Zeitschrift Fur Angewandte Entomologie*, 122, 157–161.
(5) Moreby S.J. & Southway S.E. (1999) Influence of autumn applied herbicides on summer and autumn food available to birds in winter wheat fields in southern England. *Agriculture, Ecosystems & Environment*, 72, 285–297.
(6) Haysom K.A., McCracken D.I., Roberts D.J. & Sotherton N.W. (2000) Grassland conservation headlands: a new approach to enhancing biodiversity on grazing land. Grazing Management: the Principles and Practice of Grazing, for Profit and Environmental Gain, within Temperate Grassland Systems: *Proceedings of the British Grassland Society Conference*, 29 February-2 March, 2000, Harrogate, UK, 159–160.

10.7. Provide buffer strips to reduce pesticide and nutrient run-off into margins, waterways and ponds

- **One study** evaluated the effects on butterflies and moths of providing buffer strips to reduce pesticide and nutrient run-off into margins, waterways and ponds. This study was in the UK[1].

COMMUNITY RESPONSE (1 STUDY)

- **Richness/diversity (1 study):** One replicated, paired, site comparison study in the UK[1] found that margins next to water bodies managed with restrictions on fertilizer and pesticide use (as well as restrictions on mowing and grazing) had a similar species richness of moths to conventionally managed margins.

POPULATION RESPONSE (1 STUDY)

- **Abundance (1 study):** One replicated, paired, site comparison study in the UK[1] found that margins next to water bodies managed with restrictions on fertilizer and pesticide use (as well as restrictions on mowing and grazing) had a greater abundance of moths than conventionally managed margins.

BEHAVIOUR (0 STUDIES)

Background

In conventional farming, a wide range of chemicals are commonly applied for pest control or fertilization, but these can have lethal or sub-lethal effects on farmland wildlife, including butterflies and moths (Russell & Schultz 2010, Schultz *et al.* 2016). Chemicals can spread easily from farmland into adjacent habitats, either by drifting on the wind during spraying, or by leaching through the soil in water. Providing buffer strips with reduced or no chemical applications may reduce run-off into neighbouring habitats, as well as providing additional habitat in their own right.

For studies on restricting chemical applications at the edge of crops, see "*Leave headlands in fields unsprayed (conservation headlands)*". For studies on restricting chemical applications across the farm, see "*Reduce fertilizer, pesticide or herbicide use generally*". For studies on physically preventing chemicals from spreading to adjacent habitats, see "*Use fencing to reduce pesticide and nutrient run-off into margins, waterways and ponds*".

Russell C. & Schultz C.B. (2010) Effects of grass-specific herbicides on butterflies: an experimental investigation to advance conservation efforts. *Journal of Insect Conservation*, 14, 53–63.

Schultz C.B., Zemaitis J.L., Thomas C.C., Bowers M.D. & Crone E.E. (2016) Non-target effects of grass-specific herbicides differ among species, chemicals and host plants in *Euphydryas* butterflies. *Journal of Insect Conservation*, 20, 867–877.

A replicated, paired, site comparison study in 2008 on 34 farms in central Scotland, UK (1) found that margins next to water bodies managed under agri-environment schemes (AES) had a higher abundance, but not species richness, of moths than conventionally-managed margins. In AES water margins, the abundance of micro-moths (113 individuals) and all macro-moths (498 individuals), and of declining macro-moths specifically (65 individuals), was higher than in conventionally-managed water margins (micro-moths: 58 individuals; all macro-moths: 236 individuals; declining macro-moths: 27 individuals). However, the species richness in AES margins (micro-moths: 25; all macro-moths: 48; declining macro-moths: 7 species) was not significantly different from conventional margins (micro-moths: 24; all macro-moths: 44; declining macro-moths: 12 species). In 2004, seventeen farms enrolled in AES, and were paired with 17 similar but conventionally-managed farms, <8 km away. On AES farms, >3-m-wide margins were established next to water bodies, and managed with restrictions on fertilizer and pesticide use, mowing and grazing. Margins on conventional farms had no management restrictions. From June–September 2008, moths were collected for four hours, on one night/farm, using a 6 W heath light trap located next to one margin on each farm. Paired farms were surveyed on the same night.

(1) Fuentes-Montemayor E., Goulson D. & Park K.J. (2011) The effectiveness of agri-environment schemes for the conservation of farmland moths: assessing the importance of a landscape-scale management approach. *Journal of Applied Ecology*, 48, 532–542.

10.8. Use fencing to reduce pesticide and nutrient run-off into margins, waterways and ponds

- We found no studies that evaluated the effects on butterflies and moths of using fencing to reduce pesticide and nutrient run-off into margins, waterways and ponds.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

In conventional farming, a wide range of chemicals are commonly applied for pest control or fertilization, but these can have lethal or sub-lethal effects on farmland wildlife, including butterflies and moths (Russell & Schultz 2010, Schultz *et al.* 2016). Chemicals can spread easily from farmland into adjacent habitats, either by drifting on the wind during spraying, or by leaching through the soil in water. Physical barriers may be used to reduce the spread of chemicals from farmland on to neighbouring habitats.

For studies on restricting chemical applications next to adjacent habitat, or at the edge of crops, see "*Provide buffer strips to reduce pesticide and nutrient run-off into margins, waterways and ponds*" and "*Leave headlands in fields unsprayed (conservation headlands)*".

Russell C. & Schultz C.B. (2010) Effects of grass-specific herbicides on butterflies: an experimental investigation to advance conservation efforts. *Journal of Insect Conservation*, 14, 53–63.

Schultz C.B., Zemaitis J.L., Thomas C.C., Bowers M.D. & Crone E.E. (2016) Non-target effects of grass-specific herbicides differ among species, chemicals and host plants in *Euphydryas* butterflies. *Journal of Insect Conservation*, 20, 867–877.

Industrial & urban pollution

10.9. Stop using herbicides on pavements and road verges

- **Two studies** evaluated the effects on butterflies and moths of stopping the use of herbicides on pavements and road verges. One study was in the USA[1] and the other was in Canada[2].

COMMUNITY RESPONSE (2 STUDIES)

- **Richness/diversity (2 studies):** One replicated, paired, site comparison study in the USA[1] found that restored roadside prairies where herbicide application was restricted had a greater species richness of butterflies than verges dominated by non-native weeds and grasses with no restrictions on herbicide application. One replicated, site comparison study in Canada[2] found that transmission lines (road verges and power lines) which were neither sprayed with herbicide nor mown had a similar species richness of butterflies to sprayed and mown transmission lines.

POPULATION RESPONSE (2 STUDIES)

- **Abundance (2 studies):** One replicated, paired, site comparison study in the USA[1] found that restored roadside prairies where herbicide application was restricted had a greater abundance of butterflies than verges dominated by non-native weeds and grasses with no restrictions on herbicide application. One replicated, site comparison study in Canada[2] found that transmission lines (road verges and power lines) which were neither sprayed with herbicide nor mown had a greater abundance of northern pearl crescent and pearl crescent butterflies, but similar total butterfly abundance, compared to sprayed and mown transmission lines.
- **Survival (1 study):** One replicated, paired, site comparison study in the USA[1] found that butterflies had a lower mortality risk on restored roadside prairies where herbicide application was restricted than on verges dominated by non-native grasses with no restrictions on herbicide application.

BEHAVIOUR (0 STUDIES)

Background

Plants growing within urban landscapes, such as along pavements or road verges, can provide important habitat for wildlife, including butterflies and moths, but these areas are often subject to intense management, including regular doses of herbicide to control plant growth. However, herbicides can have lethal or sub-lethal effects on butterflies and moths (Russell & Schultz 2010, Schultz *et al.* 2016). Stopping the use of herbicides on pavements and road verges may help to support butterfly and moth populations in urban areas.

For other management options for road verges, see "*Residential and commercial development – Alter mowing regimes for greenspaces and road verges*" and "*Transportation and service corridors – Restore or maintain species-rich grassland along road/railway verges*".

Russell C. & Schultz C.B. (2010) Effects of grass-specific herbicides on butterflies: an experimental investigation to advance conservation efforts. *Journal of Insect Conservation*, 14, 53–63.

Schultz C.B., Zemaitis J.L., Thomas C.C., Bowers M.D. & Crone E.E. (2016) Non-target effects of grass-specific herbicides differ among species, chemicals and host plants in *Euphydryas* butterflies. *Journal of Insect Conservation*, 20, 867–877.

A replicated, paired, site comparison study in 1998 in 12 road verges in Iowa, USA (1) found that restored roadside prairies where herbicide application was restricted had a higher abundance and species richness of habitat-sensitive butterflies than verges dominated by non-native weeds or grasses with no herbicide restrictions. On restored roadside prairies with herbicide restrictions, both the abundance (2.3 individuals/plot) and species richness (1.6 species/plot) of habitat-sensitive butterflies was higher than on roadsides with no herbicide restrictions and dominated by weeds (abundance: 1.4 individuals/plot; richness: 0.9 species/plot) or grasses (0.5 individuals/plot; 0.7 species/plot), and not significantly different from remnant prairies (1.6 individuals/plot; 1.7 species/plot). In addition, mortality risk was lower on prairie or weedy road verges than on non-native grass verges (data presented as model results). On eight well-established, restored prairie road verges (>0.5 km long) and four native (never ploughed) prairie verges dominated by native prairie vegetation, the use of herbicides was restricted. Roadside vegetation (>6 m wide) within 1.6 km of the 12 prairies, but with no restrictions on herbicide use, was classified as "weedy" (>20% non-native legumes) or "grassy" (dominated by non-native grasses). From June–August 1998, butterflies were surveyed nine times in 1–3 plots/habitat (restored prairie, native prairie, weedy, grassy) at each of 12 sites. Plots were 50 × 5 m, >50 m apart and >500 m from a different verge habitat. In addition, three plots in each of four native prairie remnants (2–16 ha) were surveyed. Roadkill butterflies were surveyed six times along both road edges next to each plot.

A replicated, site comparison study in 2007–2008 along 52 road verges and power lines (collectively "transmission lines") in Manitoba, Canada (2) found that transmission lines which were not sprayed with herbicide and left unmown had more northern pearl crescent *Phyciodes morpheus* and pearl crescent *Phyciodes tharos* butterflies than frequently sprayed lines mown twice/year, but herbicide use did not affect the abundance or species richness of other butterflies. There were more crescent butterflies on unsprayed, unmown transmission lines (2.7 individuals/visit) than on frequently sprayed lines mown twice/year (0.1 individuals/visit). However, the abundance and species richness of other native butterflies was not significantly different between transmission lines which were not sprayed or mown (abundance: 11 individuals/visit; richness: 32 species), unsprayed and mown (14 individuals/visit; 21 species), infrequently sprayed and mown (11 individuals/visit; 27 species), or frequently sprayed and mown (10 individuals/visit; 21 species). See paper for species results. Fifty-two road verges and power lines (>30 m wide, >400 m long) were managed in one of four ways: 21 were neither sprayed with herbicide nor mown, but some trees were removed; 14 were sprayed frequently with herbicide and mown twice/year with cuttings left on site; 10 were sprayed infrequently with herbicide and mown once/year with cuttings left on site; seven were not sprayed and were mown once/year with cuttings baled and removed. From 15 June–15 August 2007–2008, butterflies were surveyed on one 400- or 500-m transect at each site 2–4 times/year.

(1) Ries L., Debinski D.M. & Wieland M.L. (2001) Conservation value of roadside prairie restoration to butterfly communities. *Conservation Biology*, 15, 401–411.
(2) Leston L. & Koper N. (2016) Urban Rights-of-Way as Reservoirs for Tall-Grass Prairie Plants and Butterflies. *Environmental Management*, 57, 543–557.

10.10. Stop using pesticides as seed dressings and sprays in flower beds and greenspace

- One study evaluated the effects on butterflies and moths of stopping the use of pesticides as seed dressings and sprays in flower beds and greenspaces. The study was in France[1].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (1 STUDY)

- **Abundance (1 study):** One replicated, site comparison study in France[1] found that gardens where insecticides and herbicides were not used had a higher abundance of butterflies, but gardens where fungicides and snail pellets were not used had a lower abundance of butterflies

BEHAVIOUR (0 STUDIES)

Background

Plants growing within urban landscapes and domestic settings, such as in flower beds and greenspaces, could provide important habitat for wildlife, including butterflies and moths. However, these areas are often subject to intense management, including regular doses of pesticides which can kill butterflies and moths. Managing public areas and private gardens without the use of pesticides may help to support butterfly and moth populations in urban areas.

For other management options for urban greenspaces, see "*Stop using herbicides on pavements and road verges*", "*Residential and commercial development – Plant parks and gardens with appropriate native species*" and "*Residential and commercial development – Alter mowing regimes for greenspaces and road verges*".

A replicated, site comparison study in 2009–2011 in 3,722 private gardens in France (1) found that there was a higher abundance of butterflies in gardens where insecticides and herbicides were not used, compared to where they were, and where there were more natural features, but a lower abundance of butterflies where fungicides and snail pellets were not used compared to where they were. There were significantly more butterflies in gardens that used no pesticides (average: 7) than those with insecticide (average: 6) and herbicide (average: 7) use, but fewer butterflies in gardens that did not use conventional (average: 7) or Bordeaux mixture (average: 7) fungicides or snail pellets (average: 7). There was no difference in abundance between gardens that did and did not use fertilizer. Additionally, there were more butterflies in gardens which had more "natural" features, such as fallow plots, nettles, ivy, brambles and dead trees (data presented as model results). Data was obtained from a citizen monitoring scheme across France. Monthly from March–October participants submitted information about their gardens, including the number of butterflies seen, the presence of fallow plots, nettles, ivy, brambles and dead trees, and whether they use chemicals in gardening.

(1) Muratet A. & Fontaine B. (2015) Contrasting impacts of pesticides on butterflies and bumblebees in private gardens in France. *Biological Conservation*, 182, 148-154.

Light pollution

10.11. Restrict timing of lighting to conserve areas with natural light regimes

- We found no studies that evaluated the effects on butterflies and moths of restricting the timing of lighting to conserve areas with natural light regimes.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Artificial lighting disrupts the activity of nocturnal moths. For example, even when offered a food source, moths spend less time feeding in the presence of artificial light than when kept in complete darkness (van Langevelde *et al.* 2017). Attraction to artificial lights may also limit moths' dispersal ability and mate-finding behaviour. One option to reduce this impact is to protect areas with natural light regimes, by reducing the time that lights are on, or removing unnecessary lights entirely (Gaston *et al.* 2012).

Gaston K.J., Davies T.W., Bennie J., Hopkins J. (2012) Reducing the ecological consequences of night-time light pollution: options and developments. *Journal of Applied Ecology*, 49, 1256–1266.

van Langevelde F., van Grunsven R.H.A., Veenendaal E.M. & Fijen T.P.M. (2017) Artificial night lighting inhibits feeding in moths. *Biology Letters*, 13: 20160874.

10.12. Use low intensity lighting

- **One study** evaluated the effects on butterflies and moths of using low intensity lighting. This study was in Germany[1].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (0 STUDIES)

BEHAVIOUR (1 STUDY)

- **Behaviour change (1 study):** One replicated, paired, controlled study in Germany[1] found that fewer moths were attracted to low intensity lights (which also emitted a narrower range of yellow light with little UV) than to higher intensity lights (which also emitted broader spectra and included UV).

Background

Artificial lighting disrupts the activity of nocturnal moths, for example altering feeding behaviour (van Langevelde *et al.* 2017). Brighter, higher intensity lights are likely to be more attractive, or to disrupt individuals over a wider area as the light reaches further into the darkness. Reducing the intensity of lights used at night may help to minimize the impact on moths, while maintaining lighting for people in key areas (Gaston *et al.* 2012).

Gaston K.J., Davies T.W., Bennie J., Hopkins J. (2012) Reducing the ecological consequences of night-time light pollution: options and developments. *Journal of Applied Ecology*, 49, 1256–1266.

van Langevelde F., van Grunsven R.H.A., Veenendaal E.M. & Fijen T.P.M. (2017) Artificial night lighting inhibits feeding in moths. *Biology Letters*, 13: 20160874.

A replicated, paired, controlled study in 1997 in three sites in a rural built-up area in Rhineland-Palatinate, Germany (1) found that lower intensity yellow lights attracted fewer moths than higher intensity and broader spectrum lights. Under lower intensity yellow lights (high-pressure sodium ellipsoid lamps, HSE), the number of moths caught (2–8 individuals/trap/day) was less than the number caught under higher intensity lights with a broader range of visible and ultra-violet (UV) light (high-pressure mercury-vapour lamp, HME: 8–28 individuals/trap/day; high-pressure sodium-xenon lamp in tube form, HSXT: 8–25 individuals/trap/day), but higher than at a trap with no light (0 individuals/trap/day). At each of three sites, three different light types (HSE: 50–70 W, yellow light with very little UV light; HME: 80 W, visible and UV light; HSXT: 80 W, visible and UV light) were compared to a control without light. From May–September 1997, flying insects (including moths) were sampled for 60 nights using flight eclector traps installed below each lamp.

(1) Eisenbeis G. & Hassel F. (2000) Attraction of nocturnal insects to street lights — a study of municipal lighting systems in a rural area of Rheinhessen (Germany). *Natur und Landschaft*, 75, 145–156.

10.13. Use 'warmer' (red/yellow) lighting rather than other lighting colours

- **Five studies** evaluated the effects on butterflies and moths of using 'warmer' (red/yellow) lighting rather than other lighting colours. Two studies were in the Netherlands[2,4] and one study was in each of Germany[1], Slovenia[3] and the UK[5].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (0 STUDIES)

BEHAVIOUR (5 STUDIES)

- **Behaviour change (5 studies):** Four replicated, controlled studies (including one randomized, paired study and two paired studies) in Germany[1], the Netherlands[2], Slovenia[3] and the UK[5] found that fewer individual moths[1,3,5], and moth species[3], were attracted to yellow[1,3,5], green[2], white[2] or red[2] lights (which in one case also emitted at a lower intensity[1]) than to UV[1], actinic[2], blue[3] or conventional metal halide[3,5] lights. One replicated, randomized, paired, controlled study in the Netherlands[4] found that four moth species spent more time feeding under red lights than under white or green lights, but less time feeding than when in complete darkness.

Background

Artificial lighting disrupts the activity of nocturnal moths. Larger species in particular are more attracted to shorter wavelength light (ultraviolet, blue and green; van Langevelde *et al.* 2011), and some have been shown to have eyes which are particularly sensitive to ultraviolet and green light (Belušič *et al.* 2017). Therefore, replacing nocturnal lighting with longer wavelength lights ('warmer' colours such as red and yellow) may reduce their impact on moths in areas where lighting is necessary (Gaston *et al.* 2012).

Belušič G., Šporar K. & Meglič A. (2017) Extreme polarisation sensitivity in the retina of the corn borer moth *Ostrinia*. *Journal of Experimental Biology*, 220 (11): 2047–2056.

Gaston K.J., Davies T.W., Bennie J., Hopkins J. (2012) Reducing the ecological consequences of night-time light pollution: options and developments. *Journal of Applied Ecology*, 49, 1256–1266.

van Langevelde F., Ettema J., Donners M., WallisDeVries M.F., Groenendijk D. (2011) Effect of spectral composition of artificial light on the attraction of moths. *Biological Conservation*, 144, 2274–2281.

A replicated, paired, controlled study in 1997 in three sites in a rural built-up area in Rhineland-Palatinate, Germany (1) found that yellow lights with a lower intensity attracted fewer individual moths than broader spectrum lights with a higher intensity. Under yellow, lower intensity lights (high-pressure sodium ellipsoid lamps, HSE), the number of moths caught (2–8 individuals/trap/day) was less than the number caught under lights with a broader range of visible and ultra-violet (UV) light at a higher intensity (high-pressure mercury-vapour lamp, HME: 8–28 individuals/trap/day; high-pressure sodium-xenon lamp in tube form, HSXT: 8–25 individuals/trap/day), but higher than at the trap with no light (0 individuals/trap/day). At each of three sites, three different light types (HSE: 50–70 W, yellow light with very little UV light; HME: 80 W, visible and UV light; HSXT: 80 W, visible and UV light) were compared to a control without light. From May–

September 1997, flying insects (including moths) were sampled for 60 nights using flight eclector traps installed below each lamp.

A replicated, controlled study in 2009 in a wet heathland in Noord Brabant, the Netherlands (2) found that light traps with longer wavelength (warmer) bulbs attracted fewer moths and fewer species than those with shorter wavelength (cooler) bulbs. There was no significant difference in the number of moths found in traps with bulbs with wavelengths of 618 nm (average abundance: 1.3), 617 nm (average: 1.1), 597 nm (average: 3.0), 554 nm (average: 2.5) and 534 nm (average: 5.8), but fewer moths were found in these traps than ones with bulbs with a wavelength of 382 nm (average: 13.2). Additionally, lower species richness of moths was found in traps with bulbs with wavelengths at 618 nm (average: 0.9 species) or 617 nm (average: 1.1) than those with 534 nm (average: 4.1) and 382 nm (average: 6.7) bulbs, but there was no significant difference between 618 nm, 617 nm, 597 nm (average: 1.9) and 554 nm (average: 1.9) bulbs. See paper for abundance and species richness of individual types of butterfly. Twice weekly between 12 July and 25 August 2009, eighteen Heath's light traps with 6 Watt T5 fluorescent bulbs were operated at night in a 2.3 ha area of wet heathland. Each used one of six types of bulbs with differing average wavelengths (replicated three times): actinic (382 nm), green phosphor (534 nm), warm white (554 nm), white phosphor (597 nm), and red phosphor either with (618 nm) or without white phosphor (617 nm). Traps were checked for moths one hour after sunrise after each trapping night.

A replicated, paired, controlled study in 2011–2013 in 15 churches in Slovenia (3) found that yellow filtered lights attracted fewer individuals and species of moths than blue filtered lights or conventional lighting. On church walls illuminated with yellow light, both the abundance (12 individuals/year) and species richness of moths (10 species/year) were lower than on walls illuminated with blue light (abundance: 20 individuals/year; richness: 15 species/year) or conventional lighting (abundance: 73 individuals/year; richness: 42 species/year). Fifteen churches in dark, rural areas were grouped into adjacent triplets, and illuminated in one of three ways: blue or yellow metal halide lamps, or the existing light (metal halide or sodium vapour, 70–400 W). Experimental lamps were 70 or 150 W, had custom-made filters to remove wavelengths shorter than 400 nm (blue) or 470 nm (yellow), and blinds to prevent the scattering of light away from the building. The illumination used on each church was rotated within each triplet each year. From May–September 2011–2013, moths were counted for 45 minutes six times/year within a 10 × 3 m area of wall on each church. Churches within a triplet were surveyed on the same night.

A replicated, randomized, paired, controlled study in 2012 in a laboratory in the Netherlands (4) found that four species of moth spent more time feeding under red light than under white or green lights, but less time than when they were in full darkness. Moths were more likely to feed under red light (5–14% of observations) than under white (4–11% of observations) or green (2–8% of observations) lights, but still fed less than in dark conditions (17–34% of observations). Forty compartments (30 × 25 cm, 60-cm-deep), arranged in 10 blocks, were randomly assigned to four light treatments: red, white, green or no light. A 1 W Deco-LED lamp above each compartment was mechanically filtered to the correct wavelength, and covered with layers of cotton to diffuse the light. Light was applied at 15 lux. On three nights in August–September 2012, one moth was placed in each compartment. Each night, 20 compartments contained captive-bred cabbage moth *Mamestra brassicae* of the same age, and 20 contained either straw dot *Rivula sericealis*, small fan-footed wave *Idaea biselata*, or common marbled carpet *Dysstroma truncata* (one night/species), caught from the wild the previous night using light traps placed in mixed forest. All moths were starved for one day before the experiment. Moths were provided with a 1:10 sugar-water soaked piece of cotton wool, and recorded as feeding or not feeding 10 times/hour for six hours.

A replicated, randomized, paired, controlled study in 2014 in 12 woodland edges and hedgerows in southern England, UK (5) found that yellow high-pressure sodium (HPS) and light-emitting diode (LED) street lights caught fewer moths than broad spectrum metal halide lights, and HPS lights caught a lower diversity of insects (including moths) than LED or metal halide lights. The total number of moths caught by HPS (0–8 individuals/light) and LED lights (2–9 individuals/light) was lower than the number caught by metal halide lights (4–55 individuals/light). The diversity of all insects caught by HPS lights (32 families) was lower than the diversity caught by LED (49 families) and metal halide lights (69 families). At each of 12 sites, >100 m from existing artificial lighting, three lights were placed on 5-m-high tripods, 32–35 m apart, along a woodland edge or hedgerow (>170 m long). Three common street light designs were used: high-pressure sodium (50 W), LED (2 × 8 arrays) and metal halide (45 W), housed in matching cases. From July–September 2014, insects were collected overnight using flight intercept traps hung 20 cm below each light on one night/site.

(1) Eisenbeis G. & Hassel F. (2000) Attraction of nocturnal insects to street lights — a study of municipal lighting systems in a rural area of Rheinhessen (Germany). *Natur und Landschaft*, 75, 145–156.
(2) van Langevelde F., Ettema J.A., Donners M., WallisDeVries M.F., Groenendijk D. (2011) Effect of spectral composition of artificial light on the attraction of moths. *Biological Conservation*, 144 (9), 2274-2281.
(3) Verovnik R., Fišer Z. & Zakšek V. (2015) How to reduce the impact of artificial lighting on moths: A case study on cultural heritage sites in Slovenia. *Journal for Nature Conservation*, 28, 105–111.
(4) van Langevelde F., van Grunsven R.H.A., Veenendaal E.M. & Fijen T.P.M. (2017) Artificial night lighting inhibits feeding in moths. *Biology Letters*, 13, 20160874.
(5) Wakefield A., Broyles M., Stone E.L., Harris S. & Jones G. (2018) Quantifying the attractiveness of broad-spectrum street lights to aerial nocturnal insects. *Journal of Applied Ecology*, 55, 714–722.

10.14. Restrict use of polarized light

- We found no studies that evaluated the effects on butterflies and moths of restricting the use of polarized light.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Artificial lighting disrupts the activity of nocturnal moths, and some species of moth have been shown to respond to polarized light more than to non-polarized light of the same intensity (Danthanarayana & Dashper 1986), because their eyes are particularly sensitive to polarized light (Belušič *et al.* 2017). Therefore, restricting the use of polarized light may reduce the impact of artificial lighting on moth populations.

Belušič G., Šporar K. & Meglič A. (2017) Extreme polarisation sensitivity in the retina of the corn borer moth *Ostrinia*. *Journal of Experimental Biology*, 220 (11): 2047–2056.

Danthanarayana W. & Dashper S. (1986) Response of Some Night-Flying Insects to Polarized Light. In: Danthanarayana W. (eds) Insect Flight. *Proceedings in Life Sciences*. Springer, Berlin, Heidelberg.

10.15. Use shielded "full cut-off" lights to remove outwards lighting

- **One study** evaluated the effects on butterflies and moths of using shielded "full cut-off" lights to remove outwards lighting. This study was in Slovenia[1].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (0 STUDIES)

BEHAVIOUR (1 STUDY)

- **Behaviour change (1 study):** One replicated, paired, controlled study in Slovenia[1] found that fewer individual moths and moth species were attracted to lights fitted with blinds to prevent light scattering (along with filters to remove shorter wavelengths) than to conventional lights without blinds or filters.

Background

Artificial lighting disrupts the activity of nocturnal moths. Although some lighting is necessary for human activity and safety, conventional designs allow light to "spill" outwards from the direction in which the light is required, increasing pollution across a larger area. Changing the design of lights to reduce the amount of light which spills outwards ('full cut-off' lighting) may minimize the impact of lights on moths (Gaston *et al.* 2012).

Gaston K.J., Davies T.W., Bennie J., Hopkins J. (2012) Reducing the ecological consequences of night-time light pollution: options and developments. *Journal of Applied Ecology*, 49, 1256–1266.

A replicated, paired, controlled study in 2011–2013 in 15 churches in Slovenia (1) found that lights with blinds to prevent light scattering, which were also colour-filtered, attracted fewer individuals and species of moths than conventional lighting. On church walls illuminated with yellow or blue light with blinds, both the abundance (12–20 individuals/year) and species richness of moths (10–15 species/year) were lower than on walls illuminated with conventional lighting and no blinds (abundance: 73 individuals/year; richness: 42 species/year). Fifteen churches in dark, rural areas were grouped into adjacent triplets, and illuminated in one of three ways: blue or yellow metal halide lamps, or the existing light (metal halide or sodium vapour, 70–400 W). Experimental lamps were 70 or 150 W, had custom-made filters to remove wavelengths shorter than 400 nm (blue) or 470 nm (yellow), and blinds to prevent the scattering of light away from the building. The illumination used on each church was rotated within each triplet each year. From May–September 2011–2013, moths were counted for 45 minutes six times/year within a 10 × 3 m area of wall on each church. Churches within a triplet were surveyed on the same night.

(1) Verovnik R., Fišer Z. & Zakšek V. (2015) How to reduce the impact of artificial lighting on moths: A case study on cultural heritage sites in Slovenia. *Journal for Nature Conservation*, 28, 105–111.

10.16. Use glazing treatments to reduce light spill from inside lit buildings

- We found no studies that evaluated the effects on butterflies and moths of using glazing treatments to reduce light spill from inside lit buildings.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Artificial lighting disrupts the activity of nocturnal moths. For example, even when offered a food source, moths spend less time feeding in the presence of artificial light than when kept in complete darkness (van Langevelde *et al.* 2017). Attraction to artificial lights may also limit moths' dispersal ability and mate-finding behaviour. Reducing the spillover of light through windows may minimize the impact of lights on moths living in urban areas (Gaston *et al.* 2012).

Gaston K.J., Davies T.W., Bennie J., Hopkins J. (2012) Reducing the ecological consequences of night-time light pollution: options and developments. *Journal of Applied Ecology*, 49, 1256–1266.

van Langevelde F., van Grunsven R.H.A., Veenendaal E.M. & Fijen T.P.M. (2017) Artificial night lighting inhibits feeding in moths. *Biology Letters*, 13: 20160874.

11. Threat: Climate change and severe weather

Background

Climate change is perhaps the greatest emerging threat to butterflies and moths, and is already altering species' distributions (Mason *et al.* 2015), phenology (Stefanescu *et al.* 2003, Van Dyck *et al.* 2015) and behaviour (Cormont *et al.* 2011). The impact of climate change is expected to be severe and detrimental for the majority of species (Settele *et al.* 2008). A review of studies on 30 well-studied European butterfly species found that climate change and weather was the joint second most important driver of long-term population trends (after habitat quality) (Thomas *et al.* 2011). This chapter includes actions which aim to mitigate the impacts of climate change and severe weather on butterflies and moths, or which aim to encourage adaptation through, for example, facilitating species range shifts.

Climate change and extreme weather are very large-scale threats. Therefore, most interventions used in response to them are general conservation interventions such as creating additional breeding sites, captive breeding and translocations, which are discussed in '*Habitat restoration and creation*' and '*Species management*'. Climate change is also likely to alter fire regimes, and interventions to address the threat from fire specifically are covered in '*Natural system modifications: Fire & fire suppression*'.

Cormont A., Malinowska A.H., Kostenko O., Radchuk V., Hemerik L., WallisDeVries M.F. & Verboom J. (2011) Effect of local weather on butterfly flight behaviour, movement, and colonization: Significance for dispersal under climate change. *Biodiversity Conservation*, 20, 483–503.

Mason S.C., Palmer G., Fox R., Gillings S., Hill J.K., Thomas C.D. & Oliver T.H. (2015) Geographical range margins of many taxonomic groups continue to shift polewards. *Biological Journal of the Linnean Society*, 115, 586–597.

Settele J., Kudrna O., Harpke A., Kühn I., van Swaay C., Verovnik R., Warren M., Wiemers M., Hanspach J., Hickler T., Kühn E., van Halder I., Veling K., Vliegenthart A., Wynhoff I. & Schweiger O. (2008) *Climatic Risk Atlas of European Butterflies*. Biorisk 1 (Special Issue), Pensoft, Sofia–Moscow.

Stefanescu C., Penuelas J. & Filella I. (2003) Effects of climatic change on the phenology of butterflies in the northwest Mediterranean Basin. *Global Change Biology*, 9, 1494–1506.

Thomas J.A., Simcox D.J. & Hovestadt T. (2011) Evidence based conservation of butterflies. *Journal of Insect Conservation*, 15, 241–258.

Van Dyck H., Puls R., Bonte D., Gotthard K. & Maes D. (2015) The lost generation hypothesis: could climate change drive ectotherms into a developmental trap? *Oikos*, 124(1), 54–61.

Habitat shifting & alteration

11.1. Protect and connect habitat along elevational gradients

- We found no studies that evaluated the effects on butterflies and moths of protecting and connecting habitat along elevational gradients.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Climate change threatens butterfly and moth species by shifting areas of suitable climatic conditions away from species' historic ranges. For montane species, this leads to areas at lower elevations becoming less climatically suitable, and areas at higher elevations becoming more suitable (Franco *et al.* 2006). To survive, butterfly and moth populations must be able to move uphill along elevational gradients, but this movement is hindered by habitat loss and fragmentation. Protecting and connecting habitat along elevational gradients may enable species to move, and adapt their distribution to cope with climate change.

For studies on improving habitat to facilitate latitudinal range shifts, see "*Enhance natural habitat to improve landscape connectivity to allow for range shifts*". For studies on creating habitat refuges for species less able to alter their distribution, see "*Create microclimate and microhabitat refuges*".

Franco A.M.A., Hill J.K., Kitschke C., Collingham Y.C., Roy D.B., Fox R., Huntley B. & Thomas C.D. (2006) Impacts of climate warming and habitat loss on extinctions at species' low-latitude range boundaries. *Global Change Biology*, 12, 1545–1553.

11.2. Enhance natural habitat to improve landscape connectivity to allow for range shifts

- We found no studies that evaluated the effects on butterflies and moths of enhancing natural habitat to improve landscape connectivity and allow for range shifts.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Climate change threatens butterfly and moth species by shifting areas of suitable climatic conditions away from species' historic ranges. For most species, this leads to areas at lower latitudes becoming less climatically suitable, and areas at higher latitudes becoming more suitable (Mason *et al.* 2015). To survive, butterfly and moth populations must be able to move polewards across the landscape, between suitable habitat patches, but this movement is hindered by habitat loss and fragmentation. Enhancing natural habitat to improve landscape connectivity may enable species to move, and adapt their distribution to cope with climate change.

For studies on improving habitat to facilitate elevational range shifts, see "*Protect and connect habitat along elevational gradients*". For studies on creating habitat refuges for species less able to alter their distribution, see "*Create microclimate and microhabitat refuges*".

Mason S.C., Palmer G., Fox R., Gillings S., Hill J.K., Thomas C.D. & Oliver T.H. (2015) Geographical range margins of many taxonomic groups continue to shift polewards. *Biological Journal of the Linnean Society*, 115(3), 586–597.

Droughts

11.3. Manage natural waterbodies in arid areas to prevent desiccation

- We found no studies that evaluated the effects on butterflies and moths of managing natural waterbodies in arid areas to prevent desiccation.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Climate change is altering rainfall patterns globally, leading to increasingly frequent or severe droughts in some areas. Access to water is important for some species of butterfly and moth, including those where the adults gather nutrients by "mud-puddling" (Thomas & Lewington 2016). Droughts can also lead to the desiccation of caterpillar food plants, which in turn may kill caterpillars if the drought coincides with their period of growth and reliance on the plant. Managing natural waterbodies, from small pools to larger areas, may help to protect butterflies and moths by maintaining water availability in the environment.

For studies on the creation of scrapes and pools, see "*Habitat restoration and creation – Create scrapes and pools*".

Thomas J.A. & Lewington R. (2016) *The Butterflies of Britain & Ireland*. Third edition, Bloomsbury Publishing, UK.

Temperature extremes

11.4. Create microclimate and microhabitat refuges

- We found no studies that evaluated the effects on butterflies and moths of creating microclimate and microhabitat refuges.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Climate change threatens butterfly and moth species by shifting areas of suitable climatic conditions away from species' historic ranges. For species with poor dispersal ability, tracking suitable climate across long distances is likely to be difficult, or even impossible. However, landscapes with more diverse microclimates are able to preserve species, by providing cooler climatic refuges (Suggitt *et al.* 2015, 2018). Therefore, increasing microclimate diversity by, for example, creating topographic features or increasing the structural diversity of habitats, may enable temperature sensitive species to persist (Davies *et al.* 2006, Suggitt *et al.* 2018). Improving habitat suitability more generally may also reduce the overall stress on populations, and increase their ability to cope with climatic changes (Walsh 2017). These features may also enable species which are shifting their ranges polewards to colonize new areas more quickly.

For studies on improving habitat to facilitate elevational or latitudinal range shifts, see "*Protect and connect habitat along elevational gradients*" and "*Enhance natural habitat to improve landscape connectivity to allow for range shifts*".

Davies Z.G., Wilson R.J., Coles S. & Thomas C.D. (2006) Changing habitat associations of a thermally constrained species, the silver-spotted skipper butterfly, in response to climate warming. *Journal of Animal Ecology*, 75, 247–256.

Suggitt A.J., Wilson R.J., August T.A., Fox R., Isaac N.J.B., Macgregor N.A., Morecroft M.D. & Maclean I.M.D. (2015) Microclimate affects landscape level persistence in the British Lepidoptera. *Journal of Insect Conservation*, 19, 237–253.

Suggitt A.J., Wilson R.J., Isaac N.J.B., Beale C.M., Auffret A.G., August T., Bennie J.J., Crick H.Q.P., Duffield S., Fox R., Hopkins J.J., Macgregor N.A., Morecroft M.D., Walker K.J. & Maclean I.M.D. (2018) Extinction risk from climate change is reduced by microclimatic buffering. *Nature Climate Change*, 8, 713–717.

Walsh R.O. (2017) Microclimate and biotic interactions affect Karner blue butterfly occupancy and persistence in managed oak savanna habitats. *Journal of Insect Conservation*, 21, 219–230.

Storms & flooding

11.5. Provide shelter habitat against highly adverse weather conditions

- We found no studies that evaluated the effects on butterflies and moths of providing shelter habitat against highly adverse weather conditions.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Climate change is increasing the frequency and intensity of storms and flooding. Such severe weather events pose a threat to the survival of butterflies and moths in all of their four life stages (Joy & Pullin 1997, 1999). Shelter habitat, which provides protection against extreme weather, may include vegetation or banks to protect against wind and rain, raised sites on free-draining soil to protect against flooding, flood defences to protect against tidal surges, or any other habitat created specifically for protection or shelter.

Joy J. & Pullin A.S. (1997) The effects of flooding on the survival and behaviour of overwintering large heath butterfly *Coenonympha tullia* larvae. *Biological Conservation*, 82, 61–66.

Joy J. & Pullin A.S. (1999) Field studies on flooding and survival of overwintering large heath butterfly, *Coenonympha tullia*, larvae on Fenn's and Whixall Mosses in Shropshire and Wrexham, UK. *Ecological Entomology*, 24, 426–431.

11.6. Retain or plant trees to act as windbreaks

- **One study** evaluated the effects on butterflies and moths of retaining or planting trees to act as windbreaks. This study was in Sweden[1].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (0 STUDIES)

BEHAVIOUR (1 STUDY)

- **Use (1 study):** One site comparison study in Sweden[1] reported that sheltered grassland strips were more likely to be used by one of four butterfly species than strips providing nectar resources or no resources.

Background

Even under normal weather conditions many species of butterfly and moth, particularly those which are weak fliers, show a preference for sheltered areas (Hayes *et al.* 2018). However, during extreme weather events, high winds are a particular problem as they prevent adults from being able to fly, and therefore potentially find food, defend territories, or mate. Retaining or planting trees, which act as wind breaks, may enable butterflies and moths to maintain activity during higher winds, reducing the impact of extreme weather events resulting from climate change.

Hayes M.P., Rhodes M.W., Turner E.C., Hitchcock G.E., Knock R.I., Lucas C.B.H. & Chaney P.K. (2018) Determining the long-term habitat preferences of the Duke of Burgundy butterfly, *Hamearis lucina*, on a chalk grassland reserve in the UK. *Journal of Insect Conservation*, 22, 329–343.

A site comparison study in 2003 in a grassland in Uppsala, Sweden (1) reported that grassland strips providing shelter were more likely to be used by one of four butterfly species than strips providing nectar resources or strips with no resources. Results were not tested for statistical significance. Of 27 mazarine blue *Polyommatus semiargus* released on a sheltered strip with few flowers, 11 flew along it, compared to 4/29 on a flower-rich strip with no shelter, and 5/29 on a strip with no shelter and few flowers. Of 27 pearly heath *Coenonympha arcania* released on the sheltered strip, 4 flew along it, compared to 12/31 released on the flower-rich strip and 5/30 on the unsheltered strip with few flowers. The numbers of common blue *Polyommatus icarus* and ringlet *Aphantophus hyperantus* which flew along strips were similar between strip types (see paper for details). Three 30 × 2 m strips of long grass (21–28 cm high) were created in a field. One strip had nectar resources removed but was sheltered by a plantation on one side, one had abundant nectar resources but no shelter, and one had neither shelter nor nectar resources. The surrounding grassland was cut to 2–4 cm. From 27 June–16 July 2003, butterflies were caught in the morning in six grasslands, and transported to the experimental site (<20 km). Each day, 2–4 individuals/species were released, one-by-one, from the north end of each strip. Butterflies were followed for two minutes, and the distance and direction travelled were recorded.

(1) Söderström B. & Hedblom M. (2007) Comparing movement of four butterfly species in experimental grassland strips. *Journal of Insect Conservation*, 11, 333–342.

12. Habitat protection

Background

Habitat protection is a cornerstone of species' conservation, with 14.9% of the world's land surface area protected in 2018, although the reasons for designation, the quality of habitat protected, and the true level of protection afforded may all vary (UNEP-WCMC, IUCN & NGS 2018). The protection of intact habitat is an important tool for butterfly and moth conservation, because many species depend on specific relationships with particular plant species, most notably as caterpillar food sources.

Habitat protection can be through the designation of legally protected areas, using national or local legislation. It can also be through the designation of community conservation areas or similar schemes, which do not provide formal protection but may increase the profile of a site and make its destruction less likely. Alternatively, protection can be of entire habitat types, for example through the European Union's Habitats Directive. On a smaller scale, habitat protection may involve ensuring areas of important habitat are retained during detrimental activities. It can be difficult to measure the effectiveness of legally protected areas as there may be no suitable controls. Monitoring often only begins with the designation of the protected area and they are often in areas that would be less likely to be cleared even if it was not protected.

This chapter includes actions to protect key areas of habitat, as well as the land around and between core sites. Actions on the restoration and creation of habitat are covered in '*Habitat restoration and creation*'.

UNEP-WCMC, IUCN & NGS (2018). Protected Planet Report 2018. UNEP-WCMC, IUCN & NGS: Cambridge UK; Gland, Switzerland; & Washington, D.C., USA.

12.1. Legally protect habitat

- **Ten studies** evaluated the effects on butterflies and moths of legally protecting habitat. Six studies were in the UK[1,2,5–8] and one was in each of Australia[3], Singapore[4] and Ireland[9] and the USA[10]. Three of the studies used data from the same national monitoring scheme across different years[5–7].

COMMUNITY RESPONSE (3 STUDIES)

- **Richness/diversity (3 studies):** One replicated, site comparison study in Singapore[4] found that protected primary or secondary forest reserves had a higher species richness of butterflies than unprotected forest fragments. One replicated, paired, site comparison study in Ireland[9] reported that raised bogs protected as Special Areas of Conservation (where restoration had sometimes taken place) had a similar species richness of moths to unprotected bogs. One replicated, site comparison study in the UK[2] found that, in the first three years after protection as Sites of Special Scientific Interest (SSSI), woodland, grassland and heathland sites lost a similar proportion of 29 threatened butterfly species to unprotected sites.

POPULATION RESPONSE (8 STUDIES)

- **Abundance (7 studies):** Three of five site comparison studies (including four replicated studies and one before-and-after study) in the UK[1,6–8] and Ireland[9] found that sites protected as National Nature Reserves[1] or Sites of Special Scientific Interest (SSSI)[8] (in one case also managed by coppicing[1]), or surrounded by SSSIs[7], had a higher abundance of heath fritillary[1], all butterflies[7] and 30/57 species of butterfly[8] than unprotected sites. However, one of these studies only found the result using one of two sets of sites[7]. The other two studies found that grasslands protected as National Nature Reserves or SSSIs[6] and raised bogs protected as Special Areas of Conservation[9] had a similar total abundance of moths[9], and change in abundance of chalkhill blue butterflies[6], to unprotected sites. However, one of these studies found mixed results for individual moth species[9]. One replicated, site comparison study in the USA[10] found that, at sites with the highest levels of protection, abundances of Karner blue, frosted elfin and Persius duskywing did not change over time, whereas they decreased at sites with lower levels of protection. One replicated, site comparison study in the UK[5] found that protected grasslands assessed as being in "Favourable" habitat condition had worse population trends for 4/8 butterfly species but better for 1/8 species than grasslands in "Unfavourable" condition. One study in Australia[3] reported that after a grassland was designated as a local reserve, populations of golden sun-moth and pale sun-moth persisted for at least four years.

BEHAVIOUR (0 STUDIES)

Background

The legal protection of important habitat is a commonly used conservation tool, and has been suggested as a major action for threatened butterflies and moths at both national and international level (Patrick 2004, van Swaay & Warren 2006). However, the establishment of reserves specifically for invertebrates, including butterflies and moths, is rare (Douglas 2004). Moreover, legally protected habitat may still need to be well managed, and the protection enforced, in order for the area to conserve populations of threatened butterflies and moths (van Swaay *et al.* 2012). In addition to the protection of public reserves, private protection of habitat, alongside suitable management, could improve butterfly and moth conservation.

Douglas F. (2004) A dedicated reserve for conservation of two species of *Synemon* (Lepidoptera: Castniidae) in Australia. *Journal of Insect Conservation*, 8, 221–228.

Patrick B.H. (2004) Conservation of New Zealand's tussock grassland moth fauna. *Journal of Insect Conservation*, 8, 199–208.

van Swaay C.A.M. & Warren M.S. (2006) Prime Butterfly Areas of Europe: an initial selection of priority sites for conservation. *Journal of Insect Conservation*, 10, 5–11.

van Swaay C., Collins S., Dušej G., Maes D., López Munguira M., Rakosy L., Ryrholm N., Šašić M., Settele J., Thomas J.A., Verovnik R., Verstrael T., Warren M., Wiemers M. & Wynhoff I. (2012) Dos and Don'ts for butterflies of the Habitats Directive of the European Union. *Nature Conservation*, 1, 73–153.

A before-and-after, site comparison study in 1980–1989 in two woodlands in Kent, UK (1) reported that a woodland legally protected as a National Nature Reserve and managed by coppicing established a large population of heath fritillary *Mellicta athalia*, while over half of the colonies in a privately owned, unmanaged wood went extinct. Results were not tested for statistical significance. After four years of coppicing in one protected wood, the number of heath fritillaries peaked at 2,000 adults, and stabilized at around 800 adults after nine years, compared to "just a few individuals" when management began. In an unmanaged, unprotected wood, there were 800 adults across nine colonies in 1989, compared to over 10,000 adults across 20 colonies in 1980. From 1980–1989, a woodland protected as a National Nature Reserve was managed by coppicing one or two plots (1–5 ha) each year on a 15–20-year rotation. Plots were connected by wide rides and permanent glades. A nearby, privately owned woodland was not managed. From 1980–1989, butterflies were surveyed most years on timed counts along a zig-zag route covering the known flight areas at each site. The total yearly population at a site was estimated by multiplying the peak population count by three.

A replicated, site comparison study in 1980–1984 in woodland, grassland and heathland sites (number not given) in central southern England, UK (2) found that legally protected Sites of Special Scientific Interest (SSSI) had lost a similar number of threatened butterfly species as unprotected sites. In the first three years after SSSI designation was introduced, the extinction rate of threatened butterflies on protected sites (8.6%/decade) was not statistically different from unprotected sites (11.6%/decade). In 1981, sites containing important species were designated as statutory SSSIs under the Wildlife and Countryside Act. The number of extinctions of 29 threatened butterfly species from individual sites between 1980 and 1984 was recorded (no further details provided).

A study in 1999–2004 in a grassland in Victoria, Australia (3) reported that a newly protected reserve continued to support populations of golden sun-moth *Synemon plana* and pale sun-moth *Synemon selene*. From 1999–2003, around 150–200 golden sun-moths, and 10–15 pale sun-moths, were recorded each year in a recently designated reserve. In February 1999, three Nhill morphs of the pale sun-moth were found on a 4.5-ha grassland known to support the golden sun-moth. The area had never been ploughed or fertilized, but had been sold to 10 separate owners for development. In 2000, the area was designated as a local reserve, and protected from development or human activities under a regional planning scheme. By 2003, most of the land had been purchased. From 2000–2004, information boards, signage and fencing were constructed. Most of the area was mown to 6–8 cm annually, normally in December. From 1999–2004, the number of each species of moth was recorded annually at the site.

A replicated, site comparison study in 2002–2003 in four tropical rainforest reserves and 14 unprotected forest fragments in Singapore (4) found that protected primary or secondary forest reserves had a higher species richness of butterflies than unprotected forest fragments. In protected forest reserves, the species richness of butterflies (8–27 species) was higher than in unprotected forest fragments (1–12 species). Protected forest reserves also had more unique species than unprotected forest fragments (data presented as model results). Four protected forest reserves (54–1,147 ha) consisted of old secondary and primary lowland tropical rainforest and freshwater swamp forest. Fourteen unprotected forest fragments (2–73 ha) contained patches of abandoned plantation and degraded secondary forest. From June 2002–June 2003, butterflies (excluding blues (Lycaenidae) and skippers (Hesperiidae)) were surveyed three times along one to fourteen 100-m transects/site.

A replicated, site comparison study in 1994–2003 on hundreds of grassland reserves across England, UK (5) found that half of threatened or declining grassland butterfly species had worse population trends in protected areas where the habitat condition was assessed as "Favourable" than in protected areas with habitat in unfavourable condition. In protected areas assessed as being in "Favourable" condition, four out of eight threatened or declining grassland butterfly species (dark-green fritillary *Argynnis aglaja*, Duke of Burgundy *Hamearis lucina*, silver-studded blue *Plebeius argus*, small blue *Cupido minimus*) had worse population trends than in protected areas assessed as ""Unfavourable No Change" or "Unfavourable Declining". One species (Adonis blue *Polyommatus bellargus*) had better population trends in protected areas assessed as being in "Favourable" condition than in protected areas assessed as "Unfavourable No Change" or "Unfavourable Declining". Three species had similar population trends in protected areas assessed as being in each condition. Data presented as model results. The habitat condition ("Favourable", "Unfavourable Recovering", "Unfavourable No Change" or "Unfavourable Declining") of each protected area where a species occurred was assessed by English Nature from 1997–2005. Changes in the abundance of eight threatened or declining grassland butterfly species within protected areas between 1994–2003 were obtained from the UK Butterfly Monitoring Scheme, which surveys >1,000 sites/year.

A replicated, site comparison study in 1991–2000 in 152 grassland sites across southern England, UK (6) found that chalkhill blue *Polyommatus coridon* abundance changes were not different in statutory protected sites and sites without statutory protection. There was no difference in the abundance change of chalkhill blues at 111 sites with statutory protected status (Site of Special Scientific Interest or National Nature Reserve) and 41 sites without statutory protection (data not reported). Chalkhill blues were counted annually from 1991 to 2000, at 152 sites across its entire UK range. This was part of the UK Butterfly Monitoring Scheme, which takes weekly transect counts along a set route at each site and follows standardized weather conditions.

A replicated, site comparison study in 2006–2011 in 850 sites across England, UK (7) found that sites surrounded by more habitat legally protected as Sites of Special Scientific Interest had a higher population density of butterflies than sites surrounded by no protected areas in one of two analyses. One analysis, using data from 399 randomly placed transects, found that there were more butterflies on sites with more protected habitat in the surrounding 1 or 3 km than on sites surrounded by no protected areas (data presented as model results). A second analysis, using data from 451 transects that were less likely to pass through farmland, found no difference in the number of butterflies on sites surrounded by protected areas or with no protected areas nearby (data presented as model results). The area of land protected by a Site of Special Scientific Interest designation within 1- or 3-km around each survey site was calculated. From 2006–2011, butterflies were surveyed once/week throughout the flight season (up to 26 weeks) along fixed transects at 451 sites as part of the UK Butterfly Monitoring Scheme. In July–August 2010–2011, butterflies were surveyed at least twice/year on two parallel transects within 399 1-km squares as part of the Wider Countryside Butterfly Monitoring Scheme.

A replicated, site comparison study in 1995–2010 across the UK (8) found that areas legally protected as Sites of Special Scientific Interest had a higher abundance of 53% of butterfly species than areas without legal protection. Thirty out of 57 species of butterfly were more abundant in protected areas than at unprotected sites. No species were significantly less abundant in protected areas than at unprotected sites. See paper for individual species results. Protected areas were defined as Sites of Special Scientific Interest, representing IUCN category IV protection for target species or habitats. From 1995–2010, butterflies were recorded by volunteers on a national recording scheme ("Butterflies for the New Millennium"). Only records with abundance information, recorded at 100 × 100-m resolution or finer, were included. Records were counted as inside a protected area if any part of the 100 × 100 m square was within a protected area.

A replicated, paired, site comparison study in 2011 in 12 bogs in County Offaly, Ireland (9) found that bogs legally protected as Special Areas of Conservation had a similar total abundance and species richness of moths to unprotected bogs, but individual species showed mixed preferences. The total number of moths recorded on protected bogs was 951 individuals of 67 species, compared to 865 individuals of 73 species on unprotected bogs (statistical significance not assessed). Of the 14 most common species, three were more abundant on protected bogs (dark arches *Apamea monoglypha*, large yellow underwing *Noctua pronuba*, dark tussock *Dicallomera fascelina*), three were more abundant on unprotected bogs (map-winged swift *Pharmacis fusconebulosa*, narrow-winged pug *Eupithecia nanata*, spruce carpet *Thera britannica*), and eight showed no difference (data presented as model results). Of 15 bog-associated species of conservation concern, only three (dark tussock, bordered grey *Selidosema brunnearia*, garden tiger *Arctia caja*) were recorded in higher numbers on protected sites than on unprotected sites (statistical significance not assessed). Six raised bogs (74–246 ha) designated as Special Areas of Conservation, and six nearby (1.5–5 km away), highly modified but vegetated undesignated raised bogs (40–578 ha) were selected. At four of the protected sites, restoration work (mostly drain blocking) had taken place. From July–October 2011, moths were sampled five times using a Heath-type actinic 15 W light trap left overnight at each site. Paired sites were sampled on the same night, and all sites were sampled over two nights/visit.

A replicated, site comparison study in 1991–2014 in 40 sites of pine-oak barren in Wisconsin, USA (10) found that at sites with the highest level of habitat protection for populations of Karner blue butterflies *Lycaeides melissa samuelis*, frosted elfin *Callophrys irus* and Persius duskywing *Erynnis persius* abundance did not change in central Wisconsin but Karner blue decreased in northwestern Wisconsin, and in central Wisconsin sites with lower levels of protection populations of all species decreased. At sites in central Wisconsin which were specifically managed to protect and enhance Karner blue habitat ("reserves"), Karner blue, frosted elfin and Persius duskywing numbers did not change from 1991–2014, but at timber management sites ("shifting mosaic" sites) and along uncanopied roadsides and powerline rights-of-way ("permanency of habitat" sites) populations decreased (data presented as statistical results). However, in northwestern Wisconsin Karner blue numbers declined in reserves over the period (data presented as statistical results). Sites termed "shifting mosaic" and "permanency of habitat" were managed "with consideration for the Karner blue butterfly and its habitat", but no further management details are provided. In central Wisconsin, surveys took place in May–June 1991–2014 for frosted elfin and Persius duskywing, and twice during both spring and summer generations of the Karner blue (months not provided) in 10 reserves, 10 shifting mosaic and five permanency of habitat sites. In 1991–2014 in northwestern Wisconsin, surveys took place for the Karner blue only, once a year in their summer generation (month not provided) in 13 reserves, one shifting mosaic and one permanency of habitat sites. There were multiple survey locations/site (numbers not given). Not all sites were surveyed for the whole period or every year. Surveys were of varying lengths and conducted simultaneously along one set of parallel transects (5–10 m apart) in each site.

(1) Warren M.S. (1991) The successful conservation of an endangered species, the heath fritillary butterfly *Mellicta athalia*, in Britain. *Biological Conservation*, 55, 37–56.
(2) Warren M.S. (1993) A review of butterfly conservation in central southern Britain: I. Protection, evaluation and extinction on prime sites. *Biological Conservation*, 64, 25–35.
(3) Douglas F. (2004) A dedicated reserve for conservation of two species of *Synemon* (Lepidoptera: Castniidae) in Australia. *Journal of Insect Conservation*, 8, 221–228.
(4) Koh L.P. & Sodhi N.S. (2004) Importance of reserves, fragments, and parks for butterfly conservation in a tropical urban landscape. *Ecological Applications*, 14, 1695–1708.
(5) Davies H., Brereton T.M., Roy D.B. & Fox R. (2007) Government targets for protected area management: will threatened butterflies benefit? *Biodiversity and Conservation*, 16, 3719–3736.
(6) Brereton T.M., Warren M.S., Roy D.B. & Stewart K. (2008) The changing status of the Chalkhill Blue butterfly *Polyommatus coridon* in the UK: the impacts of conservation policies and environmental factors. *Journal of Insect Conservation*, 12, 629-638.
(7) Oliver T. (2014) Assessing the importance of spatial location of agri-environment options within the landscape to butterflies. *Natural England Commissioned Report*, NECR157.
(8) Gillingham P.K., Alison J., Roy D.B., Fox R. & Thomas C.D. (2015) High Abundances of Species in Protected Areas in Parts of their Geographic Distributions Colonized during a Recent Period of Climatic Change. *Conservation Letters*, 8, 97–106.
(9) Flynn C., Griffin C.T., Coll J. & Williams C.D. (2016) The diversity and composition of moth assemblages of protected and degraded raised bogs in Ireland. *Insect Conservation and Diversity*, 9, 302–319.
(10) Swengel A. B. & Swengel S. R. (2018) Patterns of Long-Term Population Trends of Three Lupine-Feeding Butterflies in Wisconsin. *Diversity*, 10(2), 31.

12.2. Retain connectivity between habitat patches

- **Three studies** evaluated the effects on butterflies and moths of retaining connectivity between habitat patches. One study was in each of the USA[1], the Netherlands[2] and Estonia[3].

COMMUNITY RESPONSE (1 STUDY)

- **Richness/diversity (1 study):** One replicated, paired, site comparison study in Estonia[3] found that well connected cleared patches within a woodland had a similar species richness of butterflies to isolated cleared patches.

POPULATION RESPONSE (0 STUDIES)

BEHAVIOUR (2 STUDIES)

- **Use (1 study):** One replicated, site comparison study in the Netherlands[2] found that low quality habitat patches which were well connected were more likely to retain Alcon large blue populations than less well connected patches, but connectivity did not affect occupancy of high quality patches.
- **Behaviour change (1 study):** One replicated, controlled study in the USA[1] found that common buckeye were more likely to colonize farther away habitat patches if they were released on corridors of suitable habitat than if released in unsuitable habitat, but there was no difference when released close to habitat patches[1].

Background

Habitat connectivity is important for enabling animals to colonize new sites, and can be important for the persistence of a population which exists in fragmented sites across a landscape (Johansson *et al.* 2017, van Langevelde & Wynhoff 2009). Small habitat patches are more likely to be occupied if they are located close to larger, occupied patches (Sinclair 2002, Thomas & Harrison 1992). Fragmented habitats attract fewer butterflies than more intact habitats (Summerville & Crist 2001), and retaining connectivity may increase habitat use by butterflies and moths.

For studies on creating habitat corridors, see "*Habitat restoration and creation – Restore or create habitat connectivity*".

Johansson V., Knape J. & Franzen M. (2017) Population dynamics and future persistence of the clouded Apollo butterfly in southern Scandinavia: The importance of low intensity grazing and creation of habitat patches. *Biological Conservation*, 206, 120–131.

Sinclair L.J. (2002) Distribution and conservation requirements of *Notoreas* sp., an unnamed Geometrid moth on the Taranaki coast, North Island, New Zealand. *New Zealand Journal of Zoology*, 29, 311–322.

Summerville K.S. & Crist T.O. (2001) Effects of experimental habitat fragmentation on patch use by butterflies and skippers (Lepidoptera). *Ecology*, 82, 1360–1370.

Thomas C.D. & Harrison S. (1992) Spatial dynamics of a patchily distributed butterfly species. *Journal of Animal Ecology*, 61, 437–446.

van Langevelde F. & Wynhoff I. (2009) What limits the spread of two congeneric butterfly species after their reintroduction: quality or spatial arrangement of habitat? *Animal Conservation*, 12, 540–548.

A replicated, controlled study in 1997 in three pine plantations in South Carolina, USA (1) found that the number of common buckeye *Junonia coenia* which colonized habitat patches when released from suitable habitat corridors did not change with distance from the patch, but the number which reached habitat patches when released from unsuitable habitat was lower at greater distances. When released in a habitat corridor 128–192 m from a suitable habitat patch, the number of common buckeyes which colonized the patch (1.6 individuals/point) was similar to the number which colonized when released 16–64 m from a patch

(1.5 individuals/point). However, when released in unsuitable forest, the number of butterflies which colonized the patch from 128–192 m (0.8 individuals/point) was lower than from 16–64 m (2.5 individuals/point). In 1994–1995, across three plantations, 13 open patches (128 × 128 m, 256 or 384 m apart) were created by felling trees. Some patches were connected to others by open corridors (32 m wide). In 1997, butterflies were collected >5 km from the experimental patches, marked with a unique code, and released along transects at 16, 32, 64, 128 or 192 m from a patch. Ten transects were along corridors and 10 were within forest (192-m points occurred on only 12 transects). Four butterflies were released from every location within a single plantation on one day in June and one day in July. For four days following releases, marked butterflies were recorded daily by walking eight 128-m transects (16 m apart) across each patch.

A replicated, site comparison study in 1998–1999 on 114 wet heathland sites in the Netherlands (2) found that well connected, lower quality habitat patches were more likely to retain Alcon large blue *Maculinea alcon* populations than less well connected lower quality patches, but connectivity did not affect occupancy of high quality patches. Alcon large blue were more likely to be found in low quality patches if they were well connected to other patches, but connectivity did not affect occupancy of higher quality patches (data presented as model results). A total of 114 wet heathland sites in the Netherlands where Alcon large blue was known to have occurred since 1990 were selected. From mid-July–early September 1998–1999, the size of each habitat patch, area of gentian *Gentiana pneumonanthe*, and number of reproductive gentians were recorded as measures of patch quality. In each of three 10 × 10 m plots/site, all gentians were counted, 15-minute searches were conducted for host ant *Myrmica* spp. nests (also for patch quality), and Alcon large blue eggs were counted to determine butterfly presence.

A replicated, paired, site comparison study in 2012–2015 in 36 clearcut forest patches in eastern Estonia (3) found that cleared patches connected to other open areas had a similar number of butterfly species to isolated cleared patches. In clearcut patches connected to other open areas, the number of "grassland species" (9 species/patch) and "open habitat species" (13 species/patch) was not significantly different to the number in isolated clearcut patches (grassland: 8 species/patch; open habitat: 12 species/patch). Eighteen pairs of clearcut forest patches of similar age (2–10 years since clearcutting) and size (0.3–2.5 ha) were selected. Paired patches were 150–4,720 m apart. Within each pair, one patch was directly connected to a network of open corridors (wide road verges and power line rights-of-way), and one patch was completely isolated by a belt of forest. From June–July 2012–2015, each patch was searched three times for butterflies (30 minutes/ha) within one or two consecutive years. Paired patches were surveyed consecutively. Butterflies were classified as "grassland species" for which semi-natural grasslands are their primary habitat, "open habitat species" which included the grassland species and other species which use a wider range of open habitat, and "forest species" which live mainly in woodland.

(1) Haddad N. (2000) Corridor length and patch colonization by a butterfly, *Junonia coenia*. Conservation Biology, 14, 738–745.

(2) WallisDeVries, M. (2004) A quantitative conservation approach for the endangered butterfly *Maculinea alcon*. *Conservation Biology*, 18, 489–499.
(3) Viljur M.L. & Teder T. (2018) Disperse or die: Colonisation of transient open habitats in production forests is only weakly dispersal-limited in butterflies. *Biological Conservation*, 218, 32–40.

12.3. Retain buffer zones around core habitat

- We found no studies that evaluated the effects on butterflies and moths of retaining buffer zones around core habitat.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

The edges of habitat patches, where they meet heavily modified landscapes such as agricultural fields or urban areas, often suffer from a number of "edge effects". This can include an increase in exposure to pollution, such as noise, light or chemicals, produced and released from human landscapes, or changes to natural rhythms, such as higher or more variable temperatures, which are a result of the more open structure of human landscapes. Retaining buffer zones around core habitat, even if the buffers themselves are of lower quality habitat, may reduce the impact of edge effects on butterfly and moth populations.

For studies testing actions to tackle pollution directly, see "*Pollution*" chapter.

13. Habitat restoration and creation

Background

Large areas of habitat have been degraded or destroyed around the world, leading to widespread declines and extinctions of native butterfly and moth species (Fox 2012). Restoring degraded habitat, and creating new habitat, aims to reverse these trends. However, butterflies and moths often have exacting habitat requirements (Dennis *et al.* 2003), and restoring or creating ideal habitat can be challenging. Maintaining habitat through time is also likely to be important. A review of studies on 30 well-studied European butterfly species found that within-site quality of caterpillar habitat was the most important driver of long-term population trends (Thomas *et al.* 2011).

This chapter includes actions which aim to create, restore or maintain natural habitats through a variety of methods, alone or in combination. Studies describing the effects of actions that involve restoration through processes such as fire and water management are covered in '*Threat: Natural system modifications*'. Actions on the protection of areas of intact habitat can be found in '*Habitat protection*'.

Dennis R.L.H., Shreeve T.G. & Van Dyck H. (2003) Towards a functional resource-based concept for habitat: a butterfly biology viewpoint. *Oikos*, 102, 417–426.

Fox R. (2012) The decline of moths in Great Britain: a review of possible causes. *Insect Conservation and Diversity*, 6, 5–19.

Thomas J.A., Simcox D.J. & Hovestadt T. (2011) Evidence based conservation of butterflies. *Journal of Insect Conservation*, 15, 241–258.

13.1. Replant native vegetation

- **Eleven studies** evaluated the effects on butterflies and moths of replanting native vegetation. Five studies were in the USA[1–3,9,11], two were in New Zealand[4,6], and one was in each of Switzerland[5], Mexico[7], Ecuador[8] and Brazil[10].

COMMUNITY RESPONSE (5 STUDIES)

- **Community composition (3 studies):** One replicated, site comparison study in Ecuador[8] found that native trees planted within recently abandoned pasture and secondary shrubland had a similar community composition of butterflies and moths after 7–8 years, but a subset of communities found on native trees planted within pine plantations, or on saplings regenerating naturally within pristine forest. One replicated, site comparison study in Brazil[10] found that 12–14-year-old replanted and naturally regenerating forests had a different butterfly community to both grazed pasture and remnant forest. One site comparison study in Mexico[7] found that a replanted forest had a different community composition of caterpillars to a naturally regenerating forest.
- **Richness/diversity (5 studies):** Four of five site comparison studies (including four replicated studies) in New Zealand[4], Mexico[7], Ecuador[8], Brazil[10] and the USA[11] found that replanted native shrubs[4], grasses[4,11], non-woody broadleaved plants (forbs)[11] and trees[7,10] had a similar species richness[4,10] or diversity[7,11] of butterflies[4,10], caterpillars[7] and flower-visiting insects (including butterflies and moths)[11] to vineyards[4], pasture[4,10],

naturally regenerating[7] and remnant[10] forests, and remnant prairies[11]. However, one of these studies also found that the species richness of butterflies in replanted native shrubs and grasslands was lower than in remnant native habitat[4]. The fifth study[8] found that, after 7–8 years, native trees planted in pine plantations had a greater species richness of butterflies and moths than trees planted in recently abandoned pasture, but both had a lower species richness than naturally regenerating saplings within pristine forest.

POPULATION RESPONSE (6 STUDIES)

- **Abundance (5 studies):** Four of five site comparison studies (including four replicated studies) in New Zealand[4,6], Mexico[7] and the USA[9,11] found that replanted native shrubs[4], grasses[4,11], non-woody broadleaved plants (forbs)[11], trees[7] and translocated bamboo rush[6] had a similar abundance of butterflies[4], caterpillars[7] and flower-visiting insects (including butterflies and moths)[11], and density of Fred the thread moth caterpillars[6] to vineyards[4], pasture[4], naturally regenerating forest[7], remnant prairies[11] and undisturbed bogs[6]. However, one of these studies also found that replanted native shrubs and grasses had a lower abundance of butterflies than remnant native habitat[4]. The fifth study[9] found that common milkweed planted in meadows had fewer monarch butterfly eggs than milkweed planted in private gardens.
- **Survival (2 studies):** Two replicated studies (including one randomized, controlled study and one site comparison study) in the USA[2,9] found that the survival of common sooty winged skipper[2] and monarch butterfly[9] eggs and caterpillars was similar on planted patches of lamb's-quarters of different sizes[2], and on common milkweed planted in meadows or private gardens[9].
- **Condition (1 study):** One replicated, site comparison study in New Zealand[6] found that Fred the thread moth caterpillars in translocated bamboo rush plants were a similar size to caterpillars in undisturbed bogs.

BEHAVIOUR (3 STUDIES)

- **Use (3 studies):** Three studies in the USA[1,3] and Switzerland[5] reported that planted patches of silver lupine[1], prairie violet[3] and bladder senna[5] were used by wild mission blue[1] and Iolas blue[5] butterflies, and translocated regal fritillaries[3], for at least three[3] or 4–10 years[5] after planting.

Background

The conversion of natural habitat to other land uses leads to the loss of native vegetation. Butterflies and moths often have specific host plant requirements, meaning that if their host species is lost from a site, the population will not be able to survive. This action includes studies testing the effect of specifically planting butterfly and moth host species, as well as planting other native vegetation which may benefit butterflies and moths (Fuentes-Montemayor *et al.* 2015). Caterpillar growth and survival can differ between naturally occurring host plants species (Pocius *et al.* 2017), so the choice of host species for planting may be important. This action includes tests of different methods of replanting (e.g. sowing vs plug planting, or the effect of patch size) as well as the effectiveness of replanting overall, and may be conducted at a small scale, or as large-scale habitat restoration where planting is the only action.

For studies on specifically replacing non-native plant species with native species, see "*Replace non-native species of tree/shrub with native species*". For studies on the restoration of specific habitats by either *multiple actions* (which may include planting) or where the *specific action is not clear*, see "*Restore or create forest or woodland*", "*Restore or create grassland/savannas*", "*Restore or create heathland/shrubland*", "*Restore or create peatland*" and "*Restore or create wetlands and floodplains*".

Fuentes-Montemayor E., Peredo-Alvarez V.M., Watts K. & Park K.J. (2015) Are woodland creation schemes providing suitable resources for biodiversity? Woodland moths as a case study. *Biodiversity and Conservation*, 24, 3049–3070.

Pocius V.M., Debinski D.M., Pleasants J.M., Bidne K.G., Hellmich R.L. & Brower L.P. (2017) Milkweed Matters: Monarch Butterfly (Lepidoptera: Nymphalidae) Survival and Development on Nine Midwestern Milkweed Species. *Environmental Entomology*, 46, 1098–1105.

A study (year not specified) in a mountain grassland and shrubland in California, USA (1) reported that habitat restored by planting and seeding was used by mission blue butterflies *Plebejus icarioides missionensis*. Mission blue butterfly eggs were found on silver lupine *Lupinus albifrons var. collinus* plants growing in an area of restored habitat (no further details provided). From spring 1982, a 14-ha area on San Bruno Mountain was restored by a combination of hydroseeding (using a slurry of seed and mulch) and container planting of native plants (no further details provided). Details of data collection were not provided.

A replicated, randomized, controlled study in 1984 in a field at an ecological research station in Illinois, USA (2) found that the patch size of planted host plants did not affect the survival of common sooty wing skipper *Pholisora catullus* eggs and caterpillars. The survival of common sooty wing skipper eggs and caterpillars was similar in small (7%), medium (2%) and large (5%) patches of its host plant, lamb's-quarters *Chenopodium album*. In 1984, in a recently ploughed field, lamb's-quarters seedlings were planted 30 cm apart in square patches of four (small patch), 16 (medium patch) and 64 (large patch) plants. The centres of patches were 7 m apart. There were 44 small, 11 medium and 10 large patches. The area between patches was mown, and spread with herbicide in July. In August 1984, all skipper eggs were removed from nine small, six medium and five large patches. Three days later, all new eggs in these patches were individually marked (98, 134 and 162 eggs in small, medium and large patches, respectively). The survival of these eggs and their caterpillars was recorded every 3–5 days for one month, while all new eggs were removed.

A study in 1998–2004 on a restored prairie in Iowa, USA (3) reported that replanted native prairie violets *Viola pedatifida* supported a translocated regal fritillary *Speyeria idalia* population. In 2001, the first year after translocation to a prairie where violets had been planted, no butterflies were seen, but in 2002, one year after a second release, 84 adults were recorded. In the following two years, 11–12 fritillaries were observed in planted violet plots and other areas on 1–2 days/year. On 15 days in 2004, between 1–23 fritillaries were seen/day. Three–four years after planting, 73% of violets survived, and nine new plants had grown. In 1998 and 1999, prairie violets were planted at four sites in a 2,083-ha reserve of restored and remnant tallgrass prairie. At each site, five plots of 99 violets were planted in a grid (9 × 11 m), 1 m apart. From 1998–2002, the survival of violets was checked each spring. In July 2000 and August–September 2001, seven female fritillaries were caught and brought to the restored prairie. Fritillaries were placed in mesh cages (0.6 × 0.6 m or 1.8 × 1.8 m) directly over violet plants, and provided with nectar from cut flowers and moved to new violet plants each day. In June–August 2001–2004, butterflies were surveyed or opportunistically recorded across the site.

A replicated, site comparison study in 2008–2009 in six vineyards in Canterbury Province, New Zealand (4) found that planted native vegetation had a similar abundance and species richness of butterflies to amongst the vines or on pasture, but all were lower than in remnant native habitat patches. In planted native vegetation, the abundance (3 individuals/section) and species richness (0.5 species) of butterflies was similar to amongst the grape vines (abundance: 8 individuals/section; richness: 0.3 species) and on pasture fields (abundance: 7 individuals/section; richness: 0.5 species), but lower than in remnant native habitat patches (abundance: 14 individuals/section; richness: 0.7 species). See paper for individual species results. Six vineyards, each containing small (100–200 m^2) areas of planted native shrubs and grasses and areas of remnant native vegetation (typically stands of matagouri *Discaria toumatou* and New Zealand bindweed *Calystegia tuguriorum*), alongside grape vines and grazed pasture, were selected. From October 2008–April 2009, butterflies were surveyed 13 times (once/fortnight) along a fixed transect through the different habitat patches on each vineyard. Transects were split into 9–14 sections based on habitat type for analysis.

A study in 2010 in vineyards in Valais, Switzerland (5) reported that planted bladder senna *Colutea arborescens* were used by Iolas blue butterflies *Iolana iolas*. Four to 10 years after planting, 19 out of 38 patches of planted bladder senna were occupied by Iolas blue, although total butterfly numbers were low (generally <15 individuals/patch). From 2000–2006, a total of 38 patches of 1–12 bladder senna seedlings were planted across a 10 km^2 south-facing hillside at 500–950 m altitude. Seedlings were collected from local shrubs in mid-November, and watered 2–3 times during dry periods in their first year. Prior to planting, two natural patches of bladder senna in the area were known to support Iolas blue butterflies. In 2010, all 38 patches were surveyed at least once/week throughout the flight season. The number of Iolas blue within 5 m of the patch were recorded for 10 minutes.

A replicated, site comparison study in 2013 in three created peat bogs and three native peat bogs in Waikato, New Zealand (6) found that following the translocation of bamboo rush *Sporadanthus ferrugineus* plants, three populations of Fred the thread moth *Houdinia flexilissima* established and had a similar density of caterpillars to three undisturbed bogs, and the caterpillars were a similar size. Five to seven years after transplanting bamboo rush, created peat bogs had a similar density of Fred the thread caterpillars (1 caterpillar/m of stem) to three undisturbed sites (1–2 caterpillars/m of stem). The caterpillars were a similar size in the created (7–10 mm) and undisturbed bogs (5–10 mm). From 2006–2008, at three sites, existing non-native vegetation was removed, the soil was excavated to 30 cm depth, and the depression was back-filled with peat. Bamboo rush plants

(0.5–1.5 m tall) were transplanted from a peat mine and planted at 0.75 plants/m^2 across 180–270 m^2 at each site. It was assumed that Fred the thread moth caterpillars would be translocated within the bamboo rush plants. From March–April 2013, twenty 60-cm-long sections of bamboo rush stems were collected from each of four 33-cm-diameter plots/site, 2 m inside each corner of each replanted area. Stems were dissected in the lab to count caterpillars.

A site comparison study in 2008 in two forest sites in Jalisco, Mexico (7) found that a forest restored by planting native trees and a naturally regenerated forest had a similar diversity and abundance of caterpillars, but the species present at the two sites differed. In a forest restored by planting, the diversity and abundance of caterpillars (119 individuals) was similar to a forest which had regenerated naturally (103 individuals; diversity data presented as model results). However, only 27% of species were found at both sites. Three conserved forest sites had an average abundance of 159 caterpillars/plot (statistical significance not assessed). In 2002, one 1-ha abandoned pasture was restored by planting 39 native tree species. A second 1-ha abandoned pasture had been regenerating naturally since 1992, and shared tree species with the restored site. Three conserved forest sites were also surveyed for comparison. From July–November 2008, caterpillars were sampled five times along four parallel 20 × 2-m transects/site, 20 m apart. All leaves in trees up to 2 m high were searched for caterpillars, and in trees >2 m high three branches/tree were searched. Caterpillars were reared in the laboratory to identify the adults.

A replicated, site comparison study in 2003–2012 in southern Ecuador (8) found that native trees planted within pine plantations had a higher moth and butterfly species richness than native trees planted in pasture, but not than native trees planted in shrubland. Seven to eight years after planting, the species richness of moths and butterflies in native tree saplings planted in pine plantations (52 species) was higher than in saplings planted in abandoned pasture (24 species). The species richness in saplings planted in secondary shrubland (35) was not statistically different from pine plantations or pasture. However, all three restoration sites contained fewer species than naturally regenerating saplings in pristine rainforest (81 species). The community composition was similar between saplings in pasture and shrubland, but these communities were a subset of those in pine and natural forest. In 2003–2004, saplings were planted in randomly distributed plots in three habitats: recently abandoned pasture, secondary shrubland, and a 25–30-year-old pine plantation. Plots were 4.0 × 4.0 m (pine) or 10.8 × 10.8 m (pasture and shrub), and contained nine or 25 saplings planted 1.8 m apart. Saplings of Andean cedar *Cedrela montana*, golden trumpet-tree *Tabebuia chrysantha* and majaguillo *Heliocarpus americanus* were raised from locally collected seeds. From October 2010–May 2011 and October 2011–April 2012, between 26 and 47 healthy saplings with at least 15 leaves were sampled in each habitat. Insects were sampled on each sapling five times/year, by visual searching and beating onto a 1 × 1 m^2 sheet. The search time and number of hits were determined based on the leaf area of the sapling (see paper for details).

A replicated, site comparison study in 2009–2010 in five meadows and 20 residential gardens in Pennsylvania, USA (9) found that common milkweed *Asclepias syriaca* planted in meadows had fewer monarch butterflies *Danaus* *plexippus* eggs than milkweed planted in gardens, but caterpillar survival was similar across the sites. Milkweed patches in meadows (7–45 eggs/plot) contained fewer monarch eggs than milkweed patches in gardens (47–109 eggs/plot). Egg and caterpillar survival was similar in meadows (3.9–11.4%) and gardens (6.9–8.7%). In May–June 2009, twenty milkweed plants were planted in each of forty 2-m^2 plots across five minimally managed native meadows and twenty 2-m^2 plots in heavily managed lawns and gardens. In the meadows, 20 plots were located among existing milkweed patches, and 20 were planted >10 m from the nearest milkweed plants. Plants were grown from seed in greenhouses, surrounding vegetation was cut prior to planting, and sites were watered periodically. Plants were searched for eggs and caterpillars nine times from July–September 2009, and six times from 19–29 August 2010. Eggs and caterpillars were removed or marked to avoid double-counting. Monitoring ended if fewer than four healthy plants remained. On half of the plants at each site, survival of marked eggs and caterpillars was monitored over 11–14 days from the third week of August each year.

A replicated, site comparison study in 2011 in a fragmented forest in Paraná, Brazil (10) found that replanted and regenerating forest plots had a similar species richness of butterflies to both grazed pasture and remnant forest, but the species present differed between habitats. The number of butterfly species in replanted (47–102 species) and regenerating (69 species) forest was not significantly different from in pastures (52–59 species) or remnant forest (57–79 species). However, out of 213 butterfly species recorded, 33 were found only on restored sites (replanted or regenerating), compared to 18 species unique to pastures and 66 species unique to remnant forests. Eight sites, all >40 ha, were studied: two former pastures planted with 15–20 species of native trees 12–14 years before the study, one former pasture ungrazed for 14 years and naturally regenerating from the surrounding remnant forest, two grazed open pastures, and three intact forest remnants. In January, March and April 2011, butterflies were sampled once/month. Four baited butterfly traps were placed 1–2 m above ground, 50 m apart, in the centre of each plot, for three consecutive days/month, and checked daily. In addition, butterflies were counted on two 1-hour transects/month at each site.

A replicated, site comparison study in 2013–2015 in five restored and five remnant tallgrass prairies in Kansas, USA (11) found that prairies restored by planting had a similar diversity and abundance of flower-visiting insects (including butterflies and moths) to remnant prairies. The diversity and total abundance of all flower-visiting insects, 14% of which were butterflies and moths, in restored prairies (abundance: 3,155 individuals) was similar to remnant prairies (abundance: 3,315 individuals; diversity data presented as model results). The total abundance of butterflies and moths in restored prairies was 353 individuals of 36 species, compared to 487 individuals of 38 species in remnant prairies (statistical significance not assessed). From 1992–2009, five restored prairies (3.1–7.0 ha) were created on former croplands by sowing 6–12 native grass and 15–121 native non-woody, broadleaved plant (forb) species. They were compared with five remnant prairies (3.5–5.8 ha). All prairies were >5 km apart, managed by periodic burning or haying, and all but one were burned or hayed at least once between 2013 and 2015. From April–July 2013–2015, a 100 × 100 m plot near the centre of each prairie was surveyed 2–4 times/year. On each survey, four 20-m transects/plot were walked twice recording all insects visiting open flowers. The whole plot was then surveyed for an additional 60 minutes recording all flower visitors.

(1) Walsh R.C. (1987) Habitat reclamation for endangered butterflies on San Bruno mountain (California). *Restoration & Management Notes*, 5, 38.

(2) Capman W.C., Batzli G.O. & Simms L.E. (1990) Responses of the Common Sooty Wing Skipper to Patches of Host Plants. *Ecology*, 71, 1430–1440.

(3) Shepherd S. & Debinski D.M. (2005) Reintroduction of regal fritillary (*Speyeria idalia*) to a restored prairie. *Ecological Restoration*, 23, 244–250.

(4) Gillespie M. & Wratten S.D. (2012) The importance of viticultural landscape features and ecosystem service enhancement for native butterflies in New Zealand vineyards. *Journal of Insect Conservation*, 16, 13–23.

(5) Heer P., Pellet J., Sierro A. & Arlettaz R. (2013) Evidence-based assessment of butterfly habitat restoration to enhance management practices. *Biodiversity and Conservation*, 22, 239–252.

(6) Watts C., Thornburrow D., Clarkson B. & Dean S. (2013) Distribution and abundance of a threatened stem-boring moth, *Houdinia flexilissima* (Lepidoptera: Batrachedridae) in New Zealand peat bogs. *Journal of Research on the Lepidoptera*, 46, 81–89.

(7) Hernandez Y., Boege K., Lindig-Cisneros R. & del-Val E. (2014) Lepidopteran herbivory in restored and successional sites in a tropical dry forest. *The Southwestern Naturalist*, 59, 66–74.

(8) Adams M.-O. & Fiedler K. (2015) The value of targeted reforestations for local insect diversity: a case study from the Ecuadorian Andes. *Biodiversity and Conservation*, 24, 2709– 2734.

(9) Cutting B.T. & Tallamy D.W. (2015) An Evaluation of Butterfly Gardens for Restoring Habitat for the Monarch Butterfly (Lepidoptera: Danaidae). *Environmental Entomology*, 44, 1328–1335.

(10) Shuey J., Labus P., Carneiro E., Silva Dias F.M., Leite L.A.R. & Mielke O.H.H. (2017) Butterfly communities respond to structural changes in forest restorations and regeneration in lowland Atlantic Forest, Parana, Brazil. *Journal of Insect Conservation*, 21, 545–557.

(11) Denning K.R. & Foster B.L. (2018) Flower visitor communities are similar on remnant and reconstructed tallgrass prairies despite forb community differences. *Restoration Ecology*, 26, 751–759.

13.2. Restore or create habitat connectivity

- **Six studies** evaluated the effects on butterflies and moths of restoring or creating habitat connectivity. Three studies were in the USA[1,2,6], two were in the UK[4,5] and one was in Sweden[3].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (4 STUDIES)

- **Abundance (4 studies):** Four studies (including one controlled, before-and-after study and one before-and-after study) in the USA[1,6] and the UK[4,5] found that restoring connectivity between lupine[1], bracken[4], pastures[5] or prairie[6] patches increased the abundance of Karner blue[1], high brown fritillary[4], small pearl-bordered fritillary[4], marsh fritillary[5] and regal fritillary[6].

BEHAVIOUR (2 STUDIES)

- **Use (2 studies):** One site comparison study in Sweden[3] reported that grassland strips providing nectar or shelter were each more likely to be used by one of four butterfly species than strips with no resources. One replicated, controlled study in the USA[2] found that common buckeye and variegated fritillary butterflies were more likely to move between connected than unconnected habitat patches.

Background

An important threat to butterflies and moths is the increasing fragmentation of habitat patches by human activity (Cavanzón-Medrano *et al.* 2018). This limits dispersal, especially in species which are poor fliers, and leaves isolated populations vulnerable to local extinction (van Langevelde & Wynhoff 2009). Species richness tends to be higher in better connected habitat patches (Öckinger *et al.* 2010), so restoring habitat connectivity across a landscape may be important for reconnecting isolated populations (Schultz *et al.* 2008). For example, woodland creation projects can be used to increase connectivity between existing woodland fragments, but are most beneficial when they are spatially-targeted (Fuentes-Montemayor *et al.* 2015).

For studies on retaining habitat corridors, see "*Habitat protection – Retain connectivity between habitat patches*".

Cavanzón-Medrano L.E., Machkour-M'Rabet S., Chablé-Iuit L.R., Pozo C., Hénaut Y. & Legal L. (2018) Effect of Climatic Conditions and Land Cover on Genetic Structure and Diversity of Eunica tatila (Lepidoptera) in the Yucatan Peninsula, Mexico. *Diversity*, 10, 79.

Fuentes-Montemayor E., Peredo-Alvarez V.M., Watts K. & Park K.J. (2015) Are woodland creation schemes providing suitable resources for biodiversity? Woodland moths as a case study. *Biodiversity and Conservation*, 24, 3049–3070.

Öckinger E., Schweiger O., Crist T.O., Debinski D.M., Krauss J., Kuussaari M., Petersen J.D., Pöyry J., Settele J., Summerville K.S. & Bommarco R. (2010) Life-history traits predict species responses to habitat area and isolation: a cross-continental synthesis. *Ecology Letters*, 13, 969–979.

Schultz C.B., Russell C. & Wynn L. (2008) Restoration, reintroduction, and captive propagation for at-risk butterflies: A review of British and American conservation efforts. *Israel Journal of Ecology & Evolution*, 54, 41–61.

van Langevelde F. & Wynhoff I. (2009) What limits the spread of two congeneric butterfly species after their reintroduction: quality or spatial arrangement of habitat? *Animal Conservation*, 12, 540–548.

A controlled, before-and-after study in 1998–2001 in two pine plantations in Wisconsin, USA (1) found that connecting patches of lupine *Lupinus perennis* by felling trees increased the abundance of Karner blue butterfly *Lycaeides melissa samuelis*. Two–three years after felling began, the peak abundance of Karner blue butterflies (26–49 individuals/year) was higher than before felling (32 individuals/year). On an unmanaged site, the peak abundance was lower two–three years after felling at the managed site (16–20 individuals/year) than before felling (46 individuals/year). Within a 1.5-ha, seven-year-old red pine plantation containing 0.25-ha of lupine *Lupinus perennis*, >400 trees were removed to create openings and connect corridors between lupine patches. In February and March 1999–2001, patches of trees (20 × 20 and 5 × 20 m) were removed with bow saws, and in autumn 2001 additional patches were felled with chainsaws. A 0.9-ha, six-year-old red pine plantation was not managed. From 1998–2001, Karner blue butterflies were surveyed 5–6 times/year (covering both flight periods) on a 953-m transect through the managed plantation, and an 890-m transect through the unmanaged plantation. The highest number of butterflies counted on a single date in each flight period at each site was used as the abundance for that year.

A replicated, controlled study in 2000–2001 in eight pine plantations in South Carolina, USA (2) found that common buckeye *Junonia coenia* and variegated fritillary *Euptoieta claudia* butterflies were more likely to move between connected habitat patches than unconnected habitat patches. A greater percentage of common buckeye and variegated fritillary butterflies moved between connected (common buckeye 2000: 5%, 2001: 4%; variegated fritillary 2000: 10%, 2001: 11%) than unconnected habitat patches (common buckeye 2000: 3%, 2001: 1%; variegated fritillary 2000: 5%, 2001: 5%). There was a lower density of butterflies in the corridors (common buckeye 2000: 0.29, 2001: 0.28; variegated fritillary 2000: 0.31, 2001: 0.29) than in patches (common buckeye 2000: 1.18, 2001: 0.93; variegated fritillary 2000: 1.86, 2001: 1.38). Eight 50 ha areas of pine plantation each contained one central butterfly habitat patch surrounded by four patches at a distance of 150 m from the centre. One of the surrounding patches was connected by a 25 m-wide corridor. Connected patches were 1.0 ha each and unconnected patches were 1.4 ha each. Patches and corridors were created by harvesting pines, followed by burning. In June–July 2000 and May–June 2001, mark-recapture butterfly surveys were conducted along 12.5 m-wide transects to cover the entirety of patches and corridors. Each patch was surveyed 23 times in 2000 and 39 times in 2001.

A site comparison study in 2003 in a grassland in Uppsala, Sweden (3) reported that grassland strips providing nectar resources or shelter were each more likely to be used by one of four butterfly species than strips with no resources. Results were not tested for statistical significance. Of 31 pearly heath *Coenonympha arcania* released on a flower-rich strip with no shelter, 12 flew along it, compared to 4/27 released on a sheltered strip with few flowers, and 5/30 on a strip with few flowers and no shelter. Of 27 mazarine blue *Polyommatus semiargus* released on the sheltered strip, 11 flew along it, compared to 4/29 on the flower-rich strip, and 5/29 on the unsheltered strip with few flowers. The numbers of common blue *Polyommatus icarus* and ringlet *Aphantophus hyperantus* which flew along strips were similar between strip types (see paper for details). Three 30 × 2 m strips of long grass (21–28 cm high) were created in a field. One strip had abundant nectar resources but no shelter, one had nectar resources removed but was sheltered by a plantation on one side, and one had neither nectar resources nor shelter. The surrounding grassland was cut to 2–4 cm. From 27 June–16 July 2003, butterflies were caught in the morning in six grasslands, and transported to the experimental site (<20 km). Each day, 2–4 individuals/species were released, one-by-one, from the north end of each strip. Butterflies were followed for two minutes, and the distance and direction travelled were recorded.

A before-and-after study in 2002–2011 in an area of woodland, heathland and grassland in South Wales, UK (4) reported that after tree felling to create habitat connectivity, along with coppicing, scrub control and grazing, the number of high brown fritillary *Argynnis adippe* and small pearl-bordered fritillary *Boloria selene* increased. Results were not tested for statistical significance. In 2002, prior to felling, an average of seven high brown fritillary adults/hour were recorded at the site, and seven years after felling began 14 adults/hour were recorded. Small pearl-bordered fritillary also increased in number between 2003 and 2011 (numbers not given). From 2003–2011 large trees were felled to increase connectivity between patches of bracken *Pteridium aquilinum* in the Alun Valley, a 254 ha landscape comprising woodland, heathland and grassland. The area of tree felling was not provided. Coppicing of hazel *Corylus avellana* and gorse *Ulex europaeus* (1999–2011), scrub clearance (2003–2011), and sheep grazing (start date not given–2011) were also conducted in areas of the site. Adult butterflies were counted annually from 2002–2011.

A before-and-after study in 2005-2010 in two pastures in Devon, UK (5) reported that in areas with tree felling to create connectivity corridors between habitats, along with scrub and bracken *Pteridium aquilinum* control and livestock grazing, marsh fritillary *Euphydryas aurinia* populations increased. Results were not tested for statistical significance. Of two pastures where trees were felled, along with scrub and bracken control and livestock grazing, one had one marsh fritillary population in 2005 and in 2010, after management, had two populations, and the other had no population in 2005 but did have a population in 2010. In 2005–2010, small areas of woodland on two pastures were felled, western gorse *Ulex galli*, willow *Salix* spp., soft rush *Juncus effusus*, greater tussocksedge *Carex paniculata* and bracken were controlled, and there was some livestock grazing. In 2005 and 2010 surveyors conducted timed adult marsh fritillary counts during their flight season and caterpillar web counts in the autumn.

A study in 2014 in a restored grassland and oak barren landscape in Indiana, USA (6) reported that regal fritillary *Speyeria idalia* were found across a restored, connected grassland landscape. Results were not tested for statistical significance. Eighteen years after restoration began, the abundance of regal fritillaries in the restored area peaked at 12–19 butterflies/30-minute transect, compared to 12 butterflies/transect on remnant prairies, and 0 butterflies/transect in an agricultural field. In addition, fritillaries were present in ≥17 habitat patches ≤16 km from the restoration area. Prior to restoration, authors reported that regal fritillaries were only found at three small sites in the landscape. Beginning in 1996, over 3,240 ha of agricultural land was restored to native grassland and oak barrens by planting seed mixes containing over 620 native species, to reconnect remnant grasslands and oak barrens. In addition, seeds and plugs of arrowleaf violet *Viola sagittata* and bird's-foot violet *Viola pedata* were planted as host plants. The area was managed to control invasive species and, once established, patches were burned on a three-year rotation. From May–September 2014, butterflies were surveyed every two weeks on 30-minute transects at nine sites across the landscape: five restored sites, two remnant prairies, one old field, and one site still in agricultural production. In 2014–2015, suitable habitat surrounding the restoration area was searched for regal fritillaries.

(1) Kleintjes P.K., Sporrong J.M., Raebel C.A. & Thon S.F. (2003) Habitat type conservation and restoration for the Karner blue butterfly: a case study from Wisconsin. *Ecological Restoration*, 21, 107–115.
(2) Haddad N.M. & Tewksbury J.J. (2005) Low-quality habitat corridors as movement conduits for two butterfly species. *Ecological applications*, 15, 250-257.
(3) Söderström B. & Hedblom M. (2007) Comparing movement of four butterfly species in experimental grassland strips. *Journal of Insect Conservation*, 11, 333–342.
(4) Hobson R. & Smith R. (2012) High Brown Fritillary in the Vale of Glamorgan: saving the last site in Wales In Ellis S., Bourn N. & Bulman C., *Landscape-scale conservation for butterflies and moths: Lessons from the UK*. 52–57.
(5) Plackett J., Bourn N. & Bulman C. (2012) Restoring Marsh Fritillary metapopulations on Dartmoor. In Ellis S., Bourn N. & Bulman C, *Landscape-scale conservation for butterflies and moths: Lessons from the UK*. 10-15.
(6) Shuey J., Jacquart E., Orr S., Becker F., Nyberg A., Littiken R., Anchor T. & Luchik D. (2016) Landscape-scale response to local habitat restoration in the regal fritillary butterfly (*Speyeria idalia*) (Lepidoptera: Nymphalidae). *Journal of Insect Conservation*, 20, 773–780.

Terrestrial habitat

13.3. Maintain or create bare ground

- **Four studies** evaluated the effects on butterflies and moths of maintaining or creating bare ground. Two studies were in the UK[1,3], and one was in each of the Netherlands[2] and the USA[4].

COMMUNITY RESPONSE (1 STUDY)

- **Richness/diversity (1 study):** One replicated, randomized, controlled, before-and-after study in the USA[4] found that after 1–2 years, grass field margins disked to create bare ground had a similar species richness of both grassland butterflies and disturbance-tolerant butterflies to undisturbed margins.

POPULATION RESPONSE (3 STUDIES)

- **Abundance (3 studies):** One replicated, randomized, controlled, before-and-after study in the USA[4] found that after 1–2 years, grass field margins disked to create bare ground had a higher abundance of disturbance-tolerant, but not grassland, butterflies to undisturbed margins. One replicated, site comparison study in the Netherlands[2] found that Alcon large blue occupied a similar proportion of heathlands managed with sod cutting and unmanaged heathlands. However, the same study[2] found that Alcon large blues were less likely to occur on heathlands where sod cutting and grazing were used together. One site comparison study in the UK[1] found that a sand dune plot which had been stripped of turf and soil supported a translocated population of belted beauty moths, but a plot which had been strimmed and raked did not.

BEHAVIOUR (1 STUDY)

- **Use (1 study):** One replicated study in the UK[3] reported that 2-3 years after bare ground plots were created, some were used by caterpillars or adult moths of one or more of the grey carpet, lunar yellow underwing, forester and marbled clover, but none by the basil thyme case-bearer.

Background

Some butterflies and moths show preferences for exposed areas of ground (e.g. Marschalek *et al.* 2017, Vogel *et al.* 2007), which warm up quicker than the surrounding vegetation and can be used for basking/sunning, although other species avoid it (Vogel *et al.* 2007). Exposed ground can also allow less competitive plants to re-establish, which butterflies and moths may rely on as caterpillar food or adult nectar sources (Howe *et al.* 2004). Bare ground can be created in a number of ways, including rotovating (Hearle & Ellis 2012), disking (Dollar *et al.* 2013), turf stripping (Howe *et al.* 2004) or sod cutting (Sedláková & Chytrý 1999), or by the impact of livestock (Elligsen *et al.* 1997) or wild mammals (de Schaetzen *et al.* 2018).

De Schaetzen F., van Langevelde F. & WallisDeVries M.F. (2018) The influence of wild boar (*Sus scrofa*) on microhabitat quality for the endangered butterfly *Pyrgus malvae* in the Netherlands. *Journal of Insect Conservation*, 22, 51–59.

Dollar J.G., Riffell S.K. & Burger L.W. (2013) Effects of managing semi-natural grassland buffers on butterflies. *Journal of Insect Conservation*, 17, 577–590.

Elligsen H., Beinlich B. & Plachter H. (1997) Effects of large-scale cattle grazing on populations of *Coenonympha glycerion* and *Lasiommata megera* (Lepidoptera: Satyridae). *Journal of Insect Conservation*, 1, 13–23.

Hearle S. & Ellis S. (2012) Specialist moths in Breckland: creating bare ground habitat on a landscape-scale. In Ellis S., Bourn N. & Bulman C., *Landscape-scale conservation for butterflies and moths: Lessons from the UK*. 36-41.

Howe M.A., Hinde D., Bennett D. & Palmer S. (2004) The conservation of the belted beauty *Lycia zonaria britannica* (Lepidoptera, Geometridae) in the United Kingdom. *Journal of Insect Conservation*, 8, 159–166.

Marschalek D.A., Faulkner D.K. & Deutschman D.H. (2017) Livestock Grazing Shapes the Vegetation Structure and Subsequent Habitat Use by the Endangered Skipper *Pyrgus ruralis lagunae* (Lepidoptera: Hesperiidae), *Environmental Entomology*, 46, 445–453.

Sedláková I. & Chytrý M. (1999) Regeneration patterns in a Central European dry heathland: effects of burning, sod-cutting and cutting. *Plant Ecology*, 143(1), 77–87.

Vogel J.A., Debinski D.M., Koford R.R. & Miller J.R. (2007) Butterfly responses to prairie restoration through fire and grazing. *Biological Conservation*, 140, 78–90.

A site comparison study in 2000–2003 in a coastal sand dune in Merseyside, UK (1) reported that a plot stripped of turf and soil supported a translocated population of belted beauty moth *Lycia zonaria britannica* one year after release, but a plot that had been strimmed and raked did not. Two years after two grassland plots were cleared, and one year after eggs and caterpillars were released, eight adult moths (7 females, 1 male) were present in a plot which had been stripped of turf and soil, but no adults were present in a plot which had been strimmed and raked. In the summer of the release, caterpillars had been observed feeding in both plots. In winter 2000–2001, vegetation was removed from two 15 × 10 m plots within a 6.5-ha dune grassland. One plot was completely stripped of turf and soil to expose the bare sand, and the other was heavily strimmed to ground level, with cuttings and leaf litter raked off. Both plots were allowed to re-vegetate naturally. In early April 2002, three egg batches and 33 caterpillars were introduced to each plot, and in late April a further 10 caterpillars were added to the stripped plot. Caterpillars were observed in summer 2002, and adults were recorded in April 2003.

A replicated, site comparison study in 1998–1999 on 68 wet heathland sites in the Netherlands (2) found that sod cutting to create bare ground did not increase occupancy by Alcon large blue *Maculinea alcon*. Alcon large blue occupancy at sites with sod cutting (47%) was similar to sites with no management (41%), but was lower when sod cutting and grazing were applied together (26%). Sixty-eight wet heathland sites in the Netherlands where Alcon large blue was known to have occurred since 1990 were selected. Management information for the last five years was obtained by sending questionnaires to land managers. Sod cutting had been used at 57% of sites, normally covering >100 m^2/site (range: 10 m^2 to 2 ha). From mid-July–early September 1998–1999, Alcon large blue eggs were counted in each of three 10 × 10 m plots/site to determine butterfly presence in the plot.

A replicated study in 2008–2011 in 15 grassland sites in Norfolk and Suffolk, UK (3) reported that two to three years after bare ground plots were created using five methods, the adult moths or caterpillars of one or more of the grey carpet *Lithostege griseata*, lunar yellow underwing *Noctua orbona*, forester *Adscita statices* and marbled clover *Heliothis viriplaca* were found on 7–27% of plots, but the basil thyme case-bearer *Coleophora tricolor* was found on none. Results were not tested for statistical significance. Either the adults or larvae of one or more of the grey carpet, lunar yellow underwing, forester and marbled clover were recorded on 28% of rotovation plots, 66% of forest ploughing plots, 83% of agricultural ploughing plots, 75% of disc harrowing plots and 73% of turf stripping plots. Each of these species was found on 7–27% of plots, however the basil thyme case-bearer Coleophora tricolor was not found on any of the plots. See paper for details for individual species. In November 2008–December 2009, fifty-nine bare ground plots were created across 15 sites using one of the five following techniques: rotovating (29 plots at 13 sites), forest ploughing (9 plots at 5 sites), agricultural ploughing (6 plots at 2 sites), disc harrowing (4 plots at 3 sites) and turf stripping (11 plots at 4 sites). Most were 150 m long and 3 m wide but some were larger (dimensions not given). All plots were surveyed for moths in 2009 and 2010 using daytime walking transects (twice annually in April–June and July–September) and night-time torchlight vegetation surveys (November–March). Half of plots were surveyed again in 2011.

A replicated, randomized, controlled, before-and-after study in 2007–2009 on a mixed farm in Mississippi, USA (4) found that disking grass field margins to create bare ground increased the abundance, but not species richness, of disturbance-tolerant butterflies without affecting the abundance or species richness of grassland butterflies. The abundance of 18 disturbance-tolerant butterfly species was higher both one (10–14 individuals) and two (18 individuals) years after disking than on undisturbed (4–14 individuals) margins. However, the species richness of disturbance-tolerant butterflies was similar between disked (7–9 species) and undisturbed (6–8 species) margins. Both the abundance and species richness of 14 grassland butterfly species remained similar in disked (abundance: 0.6–1.4 individuals; richness: 2 species) and undisturbed margins (abundance: 0.5–1.3; richness: 1–3 species). See paper for details of individual species. In spring 2004, grass margins were sown with a seed mix of common prairie species. Ten fields (containing 28 margins) were randomly assigned to one of two treatments: disking and no disturbance. Within each disking field, one margin was disked in autumn 2007, and a different margin was disked in autumn 2008. From June–August 2007–2009, butterflies were surveyed six times/year along three 50-m transects in the centre of each margin.

(1) Howe M.A., Hinde D., Bennett D. & Palmer S. (2004) The conservation of the belted beauty *Lycia zonaria britannica* (Lepidoptera, Geometridae) in the United Kingdom. *Journal of Insect Conservation*, 8, 159–166.
(2) WallisDeVries, M. (2004) A quantitative conservation approach for the endangered butterfly *Maculinea alcon*. *Conservation Biology*, 18, 489–499.
(3) Hearle S. & Ellis S. (2012) Specialist moths in Breckland: creating bare ground habitat on a landscape-scale. In Ellis S., Bourn N. & Bulman C., *Landscape-scale conservation for butterflies and moths: Lessons from the UK*. 36-41.
(4) Dollar J.G., Riffell S.K. & Burger L.W. (2013) Effects of managing semi-natural grassland buffers on butterflies. *Journal of Insect Conservation*, 17, 577–590.

13.4. Restore or create forest or woodland

- **Ten studies** evaluated the effects on butterflies and moths of restoring or creating forest or woodland. Three studies were in the UK[3,4,5], two studies were in Brazil[7,10] and one was in each of the USA[1], Cameroon[2], Mexico[6], Malaysia[8] and Costa Rica[9].

COMMUNITY RESPONSE (6 STUDIES)

- **Community composition (4 studies):** Three site comparison studies (including two replicated studies) in Mexico[6], Costa Rica[9] and Brazil[10] found that naturally generating[6,10] or secondary[9] forest had a different community composition of caterpillars[6], geometrid and arctiine moths[9] and butterflies[10] to replanted forest[6], oil palm plantations[9], pasture[10] or remnant primary forest[9,10]. One site comparison study in Brazil[7] found that a 54-year-old restored forest had a higher proportion of fruit-feeding forest butterfly species than 11–22-year-old restored forests, and a similar community composition to a remnant forest.

- **Richness/diversity (6 studies):** Three replicated, site comparison studies in Cameroon[2], Costa Rica[9] and Brazil[10] found that secondary forest had a similar species richness of butterflies[2,10] and geometrid and arctiine moths[9] to agroforestry plantations[2], pasture[10] and remnant forest[9,10]. Two of these studies also found that secondary forest had a greater species richness of butterflies[2] and geometrid and arctiine moths[9] than cropland[2] or oil palm plantations[9]. One of two site comparison studies (including one replicated study) in Brazil[7] and Malaysia[8] found that a 54-year-old restored forest had a lower species richness of fruit-feeding butterflies than 11–22-year-old restored forests[7]. The other study found that 5–60-year-old restored forests had a greater species richness of butterflies than newly restored forests (<3-years-old), but restored forests had a lower species richness than primary forests[8]. One site comparison study in Mexico[6] found that a forest restored by natural regeneration had a similar diversity of caterpillars to a forest restored by planting.

POPULATION RESPONSE (6 STUDIES)

- **Abundance (6 studies):** Two replicated, site comparison studies in Cameroon[2] and Costa Rica[9] found that secondary forest had a higher abundance of butterflies[2] and geometrid and arctiine moths[9] than cropland[2] or oil palm plantations[9]. One of these studies also found that secondary forest had a similar abundance of butterflies to coffee and cocoa agroforestry[2], and the other study also found that secondary forest had a lower abundance of geometrid and arctiine moths than primary forest[9]. One site comparison study in Mexico[6] found that a forest restored by natural regeneration had a similar abundance of caterpillars to a forest restored by planting. Two of three studies in the UK[3,4,5] reported that where forest had been restored with coppicing, felling and ride management, the number of populations of high brown fritillary[4], pearl-bordered fritillary[5], wood white[5] and grizzled skipper[5] stayed the same[4] or increased[4,5]. The other study found that the number of heath fritillary colonies decreased after management[3].

BEHAVIOUR (3 STUDIES)

- **Use (3 studies):** Two studies (including one paired study) in the USA[1] and the UK[3] found that in forest restored with selective logging[1] or coppicing, felling and ride widening[3] orange sulphur[1] and heath fritillary[3] butterflies, but not pine white butterflies[1], flew into restored areas more than unrestored areas[1] and occupied a greater area than before the sites were restored[3]. One replicated, before-and-after study in the UK[4] reported that in forest restored with coppicing, felling and ride management, high brown fritillary presence was the same or higher than before restoration, and after restoration the butterflies were more likely to be present at sites with high brash and bracken litter coverage.

Background

Woodland creation or restoration can be used to reverse the global loss of forest habitat, and forest-dependent species. However, restored forests can remain structurally different from older forests even 20 years after regeneration (Fuentes-Montemayor *et al.* 2015), which may in turn affect the butterfly and moth community which they can support. Additional management, such as thinning, may be necessary to improve the structural diversity of new forests, as part of the restoration process (Fuentes-Montemayor *et al.* 2015).

This action includes studies where either *multiple actions* have been used to restore or create forests, or where the *specific action used is not clear*, including natural regeneration on abandoned land. For studies of specific actions for creating or managing forests, see "*Replant native vegetation*", "*Replace non-native species of tree/shrub with native species*", "*Clear or open patches in forests*", "*Coppice woodland*", "*Thin trees within forests*", "*Create young plantations within mature woodland*" and "*Natural system modifications – Use prescribed fire to maintain or restore disturbance in forests*". For studies testing the natural regeneration of native forests after forestry/logging operations, see "*Biological resource use – Encourage natural regeneration in former plantations or logged forest*".

Fuentes-Montemayor E., Peredo-Alvarez V.M., Watts K. & Park K.J. (2015) Are woodland creation schemes providing suitable resources for biodiversity? Woodland moths as a case study. *Biodiversity and Conservation*, 24, 3049–3070.

A paired sites study in 1999 in a pine forest in Arizona, USA (1) found that orange sulphur *Colias eurytheme* butterflies, but not pine white *Neophasia menapia* butterflies, flew into areas of ponderosa pine *Pinus ponderosa* forest restored by selective logging more often than into unrestored areas. From both east- and west-facing edges, orange sulphur butterflies flew into an area of forest restored through selective logging more often than they flew into unrestored forest (58–90%). Pine whites did not fly into the restored area more often than expected by chance from either edge (47–57%). In early 1999, 87% of trees in the restoration area were cut and removed. In unrestored areas no trees were cut. In July and August 1999, orange sulphur and pine white butterflies were collected from the study sites and nearby land, and held overnight at 5 °C. Thirty minutes before dawn, butterflies were released at four points 1 m from the east- or west-facing edge between the restored and unrestored areas (two points on the east- and two on the west-facing edge of the restored area). Orange sulphurs were monitored on three mornings and pine whites on one morning. Behaviour was monitored until they moved >10 m from the release point.

A replicated, site comparison study in 2003–2004 in 24 sites in a forested landscape in the Korup Region, Cameroon (2) found that secondary forest had a similar abundance and species richness of butterflies to agroforestry sites, but a higher abundance and species richness than cropland. The abundance of butterflies was similar in secondary forest (310 individuals) and agroforestry (412 individuals), but was higher than in near-primary forest (270 individuals) and cropland (175 individuals). Butterfly species richness was similar in secondary forest (44 species), agroforestry (36 species) and near-primary forest (35 species), but higher than in cropland (17 species). Six out of 119 species were more abundant in secondary forest than in both agroforestry and cropland. However, seven species were less abundant in secondary forest than agroforestry or cropland. Two species were less abundant in secondary forest, agroforestry and cropland than in near-primary forest (see paper for details). Six 50-m radius sample sites, >500 m apart, were established in each of four habitat types: secondary forest, cocoa/coffee plantation (agroforestry), near-primary forest and annual cropland. From late December 2003–early March 2004, butterflies were caught in three baited, cylindrical gauze-traps/site, set for nine days/site.

A study in 2008–2011 in a woodland in Kent, UK (3) reported that in an area managed with coppicing, clear felling and ride widening, populations of heath fritillary *Melitaea athalia* persisted and, during a period when a larger woodland area was managed, the area occupied by heath fritillary increased but the number of colonies decreased. Results were not tested for statistical significance. In woodland already managed with coppicing, clear felling and ride widening, populations of heath fritillary occupied 18 ha in 2008, when management began to be conducted over a larger area, and three years later in 2011 they occupied 28 ha. However, from 2008–2011 the number of colonies decreased from 37 to 23. Blean Woods was managed with coppicing, clear felling and ride widening since at least prior to 1980 (area of management not provided) and from 2008–2011 the area of management was increased (34–54.5 ha/year). Timed butterfly counts were conducted annually.

A replicated, before-and-after study in 2007–2011 in five woodlands in Lancashire and Cumbria, UK (4) reported that at sites with coppicing, tree felling and thinning, and ride management, presence of the high brown fritillary *Argynnis adippe* persisted or increased, and presence was most likely at sites with high brash and bracken *Pteridium aquilinum* litter coverage. Between 2007 and 2011, when there was an increase in coppicing, tree felling and thinning, and ride management, the number of sites within a woodland where high brown fritillaries were recorded increased by between 0% and 40%. High brown fritillaries were significantly more likely to occupy sites with more bracken litter (reported as a frequency, average occupied: 19, not occupied: 7) and higher brash cover (average occupied: 21%, not occupied: 11%). Between 2007 and 2011 the pearl-bordered fritillary *Boloria euphrosyne* colonised two, Duke of Burgundy *Hamearis lucina* one and pyralid moth *Anania funebris* two sites (number of woodlands not provided). Twenty-three sites spread across five woodlands in Lancashire and Cumbria were managed between 2007 and 2011 with a combination of coppicing, tree felling and thinning, and ride management. Butterflies were monitored at each site using transects in 2007 (months not given) and timed counts with an average length of eight minutes in May–July 2011. Bracken litter and brash coverage were assessed in May 2011.

A before-and-after study in 2007–2012 in a woodland in Worcestershire, UK (5) reported that when coppicing, clear-felling, ride management, scrub clearing, scalloping and grazing were being carried out, pearl-bordered fritillary *Boloria euphrosyne*, wood white *Leptidea sinapis* and grizzled skipper *Pyrgus malvae* numbers increased. Results were not tested for statistical significance. Four years after management began, 13 of 21 newly created potential pearl-bordered fritillary breeding sites were occupied. The year before the new management regime began, there were 10 small and six medium pearl-bordered fritillary populations, occupying 27 ha, compared to 16 small, three medium and 11 large populations, occupying 52 ha three years afterwards. Over the same period, a wood white population increased and an additional population was established (numbers not given). Grizzled skipper numbers also increased (numbers not given). From 2008–2012 coppicing, clear-felling, ride management (including scalloping), scrub clearing and grazing were conducted in at least 58 locations in the Wyre Forest. Woodland management was conducted prior to this time, at least from 2002, but details are not given. Butterfly transects were conducted annually at two sites and timed counts at at least 10 sites. Populations of pearl-bordered fritillary were defined as small (≤20 individuals), medium (21 – 49) or large (≥ 50) based on butterflies seen during timed counts.

A site comparison study in 2008 in two forest sites in Jalisco, Mexico (6) found that a naturally regenerated forest and a forest restored by planting native trees had a similar diversity and abundance of caterpillars, but the species present at the two sites differed. In a forest which had regenerated naturally, the diversity and abundance of caterpillars (103 individuals) was similar to a forest restored by planting (119 individuals; diversity data presented as model results). However, only 27% of species were found at both sites. Three conserved forest sites had an average abundance of 159 caterpillars/plot (statistical significance not assessed). One 1-ha abandoned pasture was allowed to regenerate naturally from 1992. In 2002, a second 1-ha abandoned pasture was restored by planting 39 native tree species which were shared with the naturally regenerating site. Three conserved forest sites were also surveyed for comparison. From July–November 2008, caterpillars were sampled five times along four parallel 20 × 2-m transects/site, 20 m apart. All leaves in trees up to 2 m high were searched for caterpillars, and in trees >2 m high three branches/tree were searched. Caterpillars were reared in the laboratory to identify the adults.

A site comparison study in 2009 in four forest fragments in São Paulo, Brazil (7) found that an old restored forest had fewer species and a lower diversity of fruit-feeding butterflies (Nymphalidae) than younger restored forests, but the proportion of forest species and overall species community at the older site was the most similar to a remnant forest. A 54-year-old restored forest had fewer species (25) and lower diversity of butterflies than 11–22-year-old restored forests (29–35 species) or remnant forest (28 species; diversity data presented as model results). However, the proportion of forest species in the 54-year-old forest (79% of individuals; 72% of species) was higher than in the younger forests (36–46% of individuals; 60–65% of species), and more similar to the remnant forest (92% of individuals; 89% of species). The species community in the old forest was most similar to the remnant forest (data presented as model results). In 1955, 1987 and 1998, three areas of forest (30–50 ha) were restored using seedlings of >70 native tree species and some non-native species. From January–April 2009, butterflies were surveyed in three plots (200 m apart) in each restored forest, and in a 245-ha remnant forest. At each plot, five baited Van Someren-Rydon traps were placed 30 m apart. Traps were left open for 8 days/month. Every 48 hours, butterflies were identified and released, and bait was replaced. Butterfly species were classified according to habitat preference as “forest”, “edge” or “grassland”.

A replicated, site comparison study in 2003–2006 around a tropical rainforest reserve in Sarawak, Malaysia (8) found that butterfly species richness was higher in older forest regeneration plots than in newly regenerating plots, but that regenerating areas had lower species richness than primary forest. Butterfly species richness was higher at sites which had been regenerating naturally for >5 years (5–13 years: 10–18 species; 20–60 years: 12–22 species) than at newly regenerating sites (<3 years: 6–7 species). However, species richness in all regenerating sites was lower than in isolated (20–40 species) or intact (48–66 species) primary rainforest. In August 2003, twenty-one open plots (two × 100 m^2 each) on the edge of five types of forest stand (2,772–4,917 m^2) were selected. Six plots were next to old regenerating forest, where 20–60 years had passed since the land was last cultivated; three were next to young regenerating forest where 5–13 years had passed since cultivation; three were next to newly regenerating forest where one year had passed since cultivation; six were next to isolated primary forest stands, and three were next to intact primary forest. Butterflies were surveyed twice/plot in August 2003, September 2003, January 2005 and June 2006.

A replicated, site comparison study in 2013 in 15 forest sites in southwest Costa Rica (9) found that secondary forests had a greater abundance and species richness of geometrid (Geometridae) and arctiine (Arctiinae) moths than oil palm plantations, and a similar species richness but lower abundance than old-growth forest. In young secondary forest, the species richness of both geometrid (90 species) and arctiine (96 species) moths was higher than in oil palm plantations (geometrids: 31; arctiines: 35 species), but not significantly different to old-growth forest (geometrids: 113; arctiines: 81 species). The abundance of geometrid moths was higher in secondary forest (314 individuals) than in oil palm (135 individuals), but lower than in old-growth forest (570 individuals). The abundance of arctiine moths was similar between habitat types (secondary forest: 668; oil palm: 529; old-growth forest: 581 individuals). Species composition was different in the three habitats (see paper for details). Fifteen sites, >200 m apart, were selected: five 3–10-year-old secondary forests; five even-aged oil palm plantations (>1 ha); and five old-growth primary or 80-year-old secondary forests. From February–July 2013, moths were sampled overnight once/month, using an 8 W, UV-emitting funnel trap installed 1–2 m above ground at up to three sites/night in different habitats.

A replicated, site comparison study in 2011 in a fragmented forest in Paraná, Brazil (10) found that regenerating and replanted forest plots had a similar species richness of butterflies to both grazed pasture and remnant forest, but the species present differed between habitats. The number of butterfly species in regenerating (69 species) and replanted (47–102 species) forest was not significantly different from in pastures (52–59 species) or remnant forest (57–79 species). However, out of 213 butterfly species recorded, 33 were found only on restored sites (regenerating or replanted), compared to 18 species unique to pastures and 66 species unique to remnant forests. Eight sites, all >40 ha, were studied: one former pasture ungrazed for 14 years and naturally regenerating from the surrounding remnant forest, two former pastures planted with 15–20 species of native trees 12–14 years before the study, two grazed open pastures, and three intact forest remnants. In January, March and April 2011, butterflies were sampled once/month. Four baited butterfly traps were placed 1–2 m above ground, 50 m apart, in the centre of each plot, for three consecutive days/month, and checked daily. In addition, butterflies were counted on two 1-hour transects/month at each site.

(1) Meyer C.L. and Sisk T.D. (2001) Butterfly Response to Microclimatic Conditions Following *Ponderosa* Pine Restoration. *Restoration Ecology*, 9(4), 435-461.
(2) Bobo K.S., Waltert M., Fermon H., Njokagbor J. & Muhlenberg M. (2006) From forest to farmland: butterfly diversity and habitat associations along a gradient of forest conversion in Southwestern Cameroon. *Journal of Insect Conservation*, 10, 29–42.
(3) Bourn N., Brereton T., Bulman C. and Kelly C. (2012) The Heath Fritillary in the Blean Woods: a low input large output landscape project. In Ellis S., Bourn N. & Bulman C., *Landscape-scale conservation for butterflies and moths: Lessons from the UK*. 42-47.
(4) Ellis S., Wainwright D. & Wain M. (2012) Conserving the High Brown Fritillary on the Morecambe Bay Limestones. In Ellis S., Bourn N. & Bulman C, *Landscape-scale conservation for butterflies and moths: Lessons from the UK.* 16-23.
(5) Joy J. & Ellis S. (2012) The impact of management on Pearl-bordered Fritillary populations in the Wyre Forest. In Ellis S., Bourn N. & Bulman C., *Landscape-scale conservation for butterflies and moths: Lessons from the UK*. 30–35.
(6) Hernandez Y., Boege K., Lindig-Cisneros R. & del-Val E. (2014) Lepidopteran herbivory in restored and successional sites in a tropical dry forest. *The Southwestern Naturalist*, 59, 66–74.
(7) Sant'Anna C.L.B., Ribeiro D.B., Garcia L.C. & Freitas A.V.L. (2014) Fruit-feeding butterfly communities are influenced by restoration age in tropical forests. *Restoration Ecology*, 22, 480–485.
(8) Itioka T., Takano K.T., Kishimoto-Yamada K., Tzuchiya T., Ohshima Y., Katsuyama R., Yago M., Yata O., Nakagawa M. & Nakashizuka T. (2015) Chronosequential changes in species richness of forest-edge-dwelling butterflies during forest restoration after swidden cultivation in a humid tropical rainforest region in Borneo. *Journal of Forest Research*, 20, 125–134.

(9) Alonso-Rodríguez A., Finegan B. & Fiedler K. (2017) Neotropical moth assemblages degrade due to oil palm expansion. *Biodiversity and Conservation*, 26, 2295–2326.
(10) Shuey J., Labus P., Carneiro E., Silva Dias F.M., Leite L.A.R. & Mielke O.H.H. (2017) Butterfly communities respond to structural changes in forest restorations and regeneration in lowland Atlantic Forest, Parana, Brazil. *Journal of Insect Conservation*, 21, 545–557.

13.5. Replace non-native species of tree/shrub with native species

- **One study** evaluated the effects on butterflies and moths of replacing non-native species of tree/shrub with native species. This study was in Panama[1].

COMMUNITY RESPONSE (1 STUDY)

- **Richness/diversity (1 study):** One replicated, site comparison study in Panama[1] found that established plantations of native trees had a similar species richness of butterflies to plantations of exotic trees, but a greater species richness than old growth forest.

POPULATION RESPONSE (1 STUDY)

- **Abundance (1 study):** One replicated, site comparison study in Panama[1] found that established plantations of native trees had a similar abundance of butterflies to plantations of exotic trees, but a higher abundance than old growth forest.

BEHAVIOUR (0 STUDIES)

Background

The conversion of natural habitat to other land uses often leads to the replacement of native vegetation with non-native species. Native trees and shrubs often support a greater abundance and species richness of caterpillars than non-native trees (Clem & Held 2018). Therefore, replacing non-native species with native ones may improve native butterfly and moth populations.

Clem C.S. & Held D.W. (2018) Associational interactions between urban trees: are native neighbors better than non-natives? *Environmental Entomology*, 47, 881–889.

A replicated, site comparison study in 2014 in 15 tropical forest plantations in Colon Province, Panama (1) found that established plantations of native trees had a similar abundance and species richness of butterflies to plantations of exotic trees. In plantations of native trees, both the abundance (17 individuals) and species richness (6 species) of butterflies were similar to plantations of non-native trees (abundance: 5–20 individuals; richness: 1–7 species). However, plantations generally had a higher abundance (16 individuals) and species richness (5 species) of butterflies than old growth forest (abundance: 11 individuals; richness: 4 species). Five established (>20 years old) single species plantations (average size 4.3 ha) of each of three tree species were surveyed: Cedro espino *Pachira quinata* (native), teak *Tectona grandis* (non-native) and *Terminalia ivorensis* (non-native). During 2014, butterflies were surveyed in four months (March: wet season; and May, September, November: all dry season). Each month, 10 surveys were conducted along a 100-m trail in each plantation, and three surveys were conducted along ten 500-m trails in old growth forest.

(1) Basset Y., Barrios H., Ramirez J.A., Lopez Y., Coronado J., Perez F., Arizala S., Bobadilla R. & Leponce M. (2017) Contrasting the distribution of butterflies and termites in plantations and tropical forests. *Biodiversity and Conservation*, 26, 151–176.

13.6. Clear or open patches in forests

- **Fourteen studies** evaluated the effects on butterflies and moths of clearing or opening patches in forests. Five studies were in the UK[1,2,8,9,10], two were in each of Finland[3,4] and Japan[7,13] one was in each of Sweden[5], the USA[6] and Canada[14] and the Czech Republic[12], and one was a review across Europe[11].

COMMUNITY RESPONSE (6 STUDIES)

- **Community composition (1 study):** One replicated, site comparison study in the UK[10] found that wider woodland rides (and coppiced woodland) contained more unique species of macro-moth than standard width rides or mature forest.
- **Richness/diversity (6 studies):** Three replicated studies (including one controlled study, one site comparison study and one paired sites, controlled study) in the UK[2], Japan[7] and the Czech Republic[12] found that cleared patches in forests had a greater species richness of butterflies[2,7,12] but a lower species richness of moths[12] than unmanaged patches[2,7], coppiced woodland[2] or closed canopy forest[12]. One of these studies also found that the species richness of butterflies declined over the first three years after clearing[7]. One of two replicated, site comparison studies in the UK[10] and Canada[14] found that larger, but not smaller, cleared patches supported a higher species richness of butterflies than undisturbed forest[14]. The other study found that both wider and standard width rides had a similar species richness of macro-moths to mature forest[10]. One replicated, site comparison study in Japan[13] found that cleared forest patches had a similar species richness of butterflies to semi-natural grassland, although six species were only observed in cleared patches, compared to 15 species only observed in grassland.

POPULATION RESPONSE (10 STUDIES)

- **Abundance (10 studies):** Five studies (including one replicated, controlled, before-and-after study, one replicated, controlled study and one replicated, site comparison study and two before-and-after studies) in the UK[2,9], Finland[4], Sweden[5] and Japan[7] found that cleared patches in forests, which were also managed with coppicing and grazing[9], had a higher abundance of butterflies generally[2,7], and chequered blue[4], woodland brown[5], high brown fritillary[9] and small pearl-bordered fritillary[9] specifically, than before management[4,5,9], or than unmanaged[2,5,7] or coppiced[2] areas. One of these studies also found that the abundance of butterflies declined over the first three years after clearing[7]. One of two replicated, site comparison studies in the UK[10] and Canada[14] found that larger, but not smaller, cleared patches had a higher abundance of butterflies than undisturbed forest[14]. The other study found that wider rides had a lower abundance of macro-moths than standard width rides or mature forest[10]. One replicated, site comparison study in the UK[1] found that patches cleared 2–4 years ago had a greater abundance of heath fritillary than patches cleared 7–11 years ago or patches in their first year after clearance. One study in Finland[3] reported that, in an area with selected clearance of pines, a translocated population of baton blue butterflies increased in number over two years. One review across Europe[11] reported that clearing small patches in forests benefitted 19 out of 67 butterfly species of conservation concern.

- **Survival (1 study):** One study in Finland[3] reported that, in an area with selected clearance of pines, a translocated population of baton blue survived for at least two years.

BEHAVIOUR (2 STUDY)

- **Use (2 studies):** One paired sites study in the USA[6] found that orange sulphur butterflies, but not pine whites, flew into areas with selective clearance of pines more often than other areas. One replicated, before-and-after, site comparison study in the UK[8] reported that in cleared patches in forests, which were also managed with cutting, grazing and ride widening, pearl-bordered fritillary and Duke of Burgundy breeding sites increased compared to before management.

Background

Although many species of butterflies and moths live within woodland, many are reliant upon open glades, where sunlight can reach the understorey and create warm habitat patches and encourage the growth of flowers. Traditional woodland management, such as small scale wood harvesting, which created these habitats has declined, leading to the closure of woodland canopies (Bubová *et al.* 2015). Opening up patches within the forest may create new habitat for these species. However, some species, especially in tropical and sub-tropical regions, are dependent on the shade provided by continuous forest cover, and may be adversely affected by canopy clearance, so caution should be taken when applying this action.

Bubová T., Vrabec V., Kulma M. & Nowicki P. (2015) Land management impacts on European butterflies of conservation concern: a review. *Journal of Insect Conservation*, 19, 805–821.

A replicated, site comparison study in 1980–1984 in 12 woodlands in Kent, UK (1) found that woodland patches cleared two to four years ago had a higher abundance of heath fritillary *Mellicta athalia* than areas cleared more recently or longer ago. The number of heath fritillary recorded 2–4 years after a site had been cleared (108–410 individuals/site) was higher than in the first year after clearance (9 individuals/site), or 7–11 years after clearance (2–17 individuals/site). Some populations became extinct nine years after management. Twelve woodlands were managed by clearing patches to plant conifers, 1–11 years before surveying. From 1980–1984, the number of adult heath fritillary at each site was estimated from a combination of counts on regular transects throughout the season, single counts around the peak flight period, and mark-recapture of individuals.

A replicated, site comparison study In 1986 in a mixed woodland in Dorset, UK (2) found that managed clearings within a woodland had a higher abundance and species richness of butterflies than other areas of the wood. In managed clearings, both the abundance (89 individuals/km) and species richness (19 species) of butterflies were higher than in coppiced woodland (abundance: 25 individuals/km; richness: 16 species), unmanaged broadleaved woodland (abundance: 2 individuals/km; richness: 4 species), or conifer plantations (abundance: 5 individuals/km; richness: 2 species). See paper for individual species results. The woodland contained patches managed in four ways: managed clearings (30–50 m wide and 100–150 m long) which were cleared of scrub every three years; open woodland with coppiced hazel; unmanaged broadleaved woodland with unmanaged hazel coppice; and conifer plantation. In July–August 1986, butterflies were surveyed six times on each of twenty-two 200-m transects: four in managed clearings, eight in open, coppiced wood, six in unmanaged wood and four in conifer plantation.

A study in 1992–1996 in a forest in Ruokolahti, Finland (3) reported that, in an area with selected clearance of Scots pine *Pinus sylvestris*, a translocated population of baton blue *Pseudophilotes baton schiffermuelleri* butterflies increased in size and survived for at least two years. One year after a population of 10 baton blue females were released, 24 butterflies were captured, and two years after release, 46 butterflies were captured. The 230 x 70-m Scots pine-covered site in Ruokolahti was divided into 10-m^2 study plots. In 1992, pines were selectively logged, and in 1996 some additional saplings were removed. In Säkylänharju, in June 1994, ten female baton blues were captured and marked before being translocated 315 km east to Ruokolahti where they were released into different 10-m^2 plots. In June 1995 and June and July 1996, surveys were conducted twice/day along the longitudinal boundaries of all plots, during which butterflies were captured, marked and released, and egg-laying and mating sightings were recorded.

A before-and-after study in 1987–1999 on a rocky island in South Karelia, Finland (4) reported that following selected clearance of pine trees, chequered blue butterfly *Scolitantides orion* numbers increased. No statistical tests were carried out. In the three years prior to clearance around two chequered blue butterflies were recorded annually, later in the year of clearance none were recorded, and in the nine years after clearance 0–25 were recorded annually. In 1990, pines were selectively logged on the rocky outcrops and slopes of an island on Lake Saimaa, creating a patchy, open habitat. In 1990–1996 and 1998–1999 chequered blue abundance was estimated on long (2–5 hours) and short (≤ 30 minutes) surveys 1–3 times annually on days with good weather during the peak flight period. In June 1997, butterflies were monitored by an eight-day mark-recapture study. Authors reported that butterflies were also observed annually in 1987–1989 but provided no survey details.

A replicated, controlled, before-and-after study in 1992–1997 in 18 deciduous woods in Östergötland, Sweden (5) found that clearing new woodland glades increased the population size of woodland brown *Lopinga achine* butterflies in five out of six woods. Over 4–5 years after glades were created, the population of woodland brown increased by 93–97% in five woods where glades were created, but decreased by 19–25% in nine woods where no glades were created. However, in a sixth wood cleared later, the population decreased by 27% in the first two years after glades were created, compared to a 9% decrease over the same time period in three other woods where no glades were created. The authors noted that populations only occurred at sites with >60% canopy cover, but sites with 70–75% canopy cover had the highest population density. From 1992–1995, irregularly-shaped glades (10–30 m long) were created in six woodlands (20 in one wood, and 5–6 in each of the others). Where possible, the longest side had a south-west to north-east orientation to maximize sun exposure. In July 1992–

1997, the adult population size of woodland brown butterflies was estimated in six woods where glades were created, and in 12 woods where no glades had been created.

A paired sites study in 1999 in a pine forest in Arizona, USA (6) found that orange sulphur *Colias eurytheme* butterflies, but not pine white *Neophasia menapia* butterflies, flew into areas with selective clearance of ponderosa pine *Pinus ponderosa* more often than into areas without selective clearance. From both east- and west-facing edges, orange sulphur butterflies flew into an area of forest restored through selective logging more often than they flew into unrestored forest (58–90%). Pine whites did not fly into the restored area more often than expected by chance from either edge (47–57%). In early 1999, eighty-seven percent of trees in the restoration area were cut and removed. In unrestored areas no trees were cut. In July and August 1999, orange sulphur and pine white butterflies were collected from the study sites and nearby land, and held overnight at 5 °C. Thirty minutes before dawn, butterflies were released at four points 1 m from the east- or west-facing edge between the restored and unrestored areas (two points on the east- and two on the west-facing edge of the restored area). Orange sulphurs were monitored on three mornings and pine whites on one morning. Behaviour was monitored until they moved >10 m from the release point.

A replicated, controlled study in 2001–2004 in an urban evergreen forest in the Kansai region, Japan (7) found that small cleared patches in the forest had a higher abundance and species richness of butterflies than the forest interior, but both abundance and species richness decreased with time since clearing. Two to three years after clearing, the abundance (56–142 individuals) and species richness (14–19 species) of butterflies in cleared patches was higher than in uncleared patches in the forest interior (abundance: 11 individuals; richness: 9 species). However, in the four patches cleared in the first year, abundance and species richness were higher in the year after clearing (abundance: 161 individuals; richness: 20 species) than three years after clearing (abundance: 76 individuals; richness: 18 species). In 2001 and 2002, four patches/year (15 × 15 m each) were cleared within a mature ring-cupped oak *Quercus glauca* and Japanese bay tree *Machilus thunbergi* forest (0.16–0.20 trees/m^2). From April–September 2004, butterflies were surveyed three times/month in each cleared patch, and in four nearby patches of forest interior, for 10 minutes/plot. The four patches cleared in 2001 were surveyed in the same way in 2001.

A replicated, before-and-after, site comparison study in 2006–2011 in woodlands in Hampshire, Wiltshire and Kent, UK (8) reported that in areas where patches of forest were cleared, along with cutting, grazing and ride-widening, the number of pearl-bordered fritillary *Boloria euphrosyne* and Duke of Burgundy *Hamearis lucina* breeding sites increased, whereas in a nearby area with no management pearl-bordered fritillary breeding sites decreased. In 2006, there were five pearl-bordered fritillary breeding sites in Tytherley Woods, and in 2011, after habitat management, there were 12 sites, and most populations were stable or increasing (details not provided). However, in nearby woodland without management there were 10 pearl-bordered fritillary breeding sites in 2006 and seven in 2011. In Denge Woods in 2007 there were 11 Duke of Burgundy butterflies recorded across two sites, and in 2010 after habitat management there were 173 butterflies across 10 sites (although two of these sites had not been surveyed in 2007). Results were not tested for statistical significance. In 2007–2011 habitat management was conducted in Tytherley Woods, Hampshire/Wiltshire and Denge Woods, Kent, which included clearing derelict coppice, felling non-native conifer plantations, cutting and grazing clearings and widening rides. Butterfly surveys were conducted in 2006–2010 in sites which pearl-bordered fritillary and Duke of Burgundy butterflies were known to occupy and in other suitable habitat patches.

A before-and-after study in 2002–2011 in an area of woodland, heathland and grassland in South Wales, UK (9) reported that after tree felling and scrub clearance was conducted, along with coppicing and grazing, the numbers of high brown fritillary *Argynnis adippe* and small pearl-bordered fritillary *Boloria selene* butterflies increased. Results were not tested for statistical significance. In 2002, prior to felling and scrub control, an average of seven high brown fritillary adults/hour were recorded at the site, and seven years after felling and scrub clearance began 14 adults/hour were recorded. Small pearl-bordered fritillary also increased in number between 2003 and 2011 (numbers not given). From 2003–2011 some large trees were felled and some patches of bracken *Pteridium aquilinum*, bramble *Rubus fruticosus* agg., honeysuckle *Lonicera periclymenum* and tree saplings were cut back in the Alun Valley, a 254 ha landscape comprising woodland, heathland and grassland. Coppicing of hazel *Corylus avellana* and gorse *Ulex europaeus* (1999–2011) and sheep grazing (start date not given–2011) were also conducted in areas. Adult butterflies were counted annually from 2002–2011.

A replicated, site comparison study in 2010 in six deciduous woodlands in Hampshire and Wiltshire, UK (10) found that wide woodland rides had a lower abundance, but similar species richness, of macro-moths than standard rides and mature forest. In wide woodland rides, the abundance of macro-moths (1,926 individuals) was lower than in standard rides (2,513 individuals) and mature forest (2,479 individuals). Species richness was similar between wide (175 species) and standard (176 species) rides and mature forest (180 species). However, wide rides and coppiced woodland supported 49 species not found in standard rides or mature forest, and 124 species were more abundant in wide rides and coppiced woodland than in standard rides and mature forest, especially 'common but severely declining' species (see paper for details). Only 22 species were found in standard rides or mature forest but not wide rides or coppiced woodland. Within six woodlands (8–711 ha), six areas under each of six management types were studied: young (1–2 years), medium (3–6 years) and old (7–9 years) coppice, wide (>20 m) and standard (<10 m) rides, and non-coppiced mature forest. From July–October 2010, macro-moths were sampled nine times/site using a 6 W Heath actinic light trap, over 27 nights (two sites/management type sampled/night).

A review in 2015 of 126 studies in Europe (11) reported that maintaining sparse forest stands by clearing small patches benefitted 19 out of 67 butterfly species of conservation concern. Results were not tested for statistical significance. The review reported that 23 studies found that clearing and maintaining open areas in woodland benefitted 19 butterfly species. See paper for information on individual species. Clearings were created and maintained by felling trees, suppressing the growth of seedlings in glades, grazing forests, and coppicing. The review focussed on 67 butterfly species of conservation concern. The available information was biased towards studies in Northern and Western Europe.

A replicated, paired sites, controlled study in 2011–2012 in six oak/hornbeam forests in South Moravia, Czech Republic (12) found that partially-cleared plots had higher butterfly but lower moth species richness than plots of closed-canopy forest, and species richness of butterflies and moths was affected by distance of the plot to the woodland edge. Butterfly species richness was higher in partially-cleared forest plots connected to the forest edge (16) and naturally open forest plots (14) than partially-cleared plots >20 m from the edge (10), which in turn had higher richness than closed-canopy forest plots (2). However, whilst moth species richness was higher in partially-cleared forest plots connected to the edge (97) and naturally open forest plots (111) than partially-cleared plots >20 m from the edge (81), all three had lower richness than plots of closed-canopy forest (130). In February 2011 and 2012, four 40-m^2 plots were established at six forest sites: a partial clearing at a forest edge connected to a meadow, a partial clearing >20 m from forest edges, closed-canopy forest, naturally open forest. A few trees were left in the two clearings to replicate open forest. In the May–September after plot establishment, adult butterflies were surveyed five times for seven minutes/plot, and moths were captured once/month using one light trap/plot.

A replicated, site comparison study in 2016 in 10 grasslands and forest clearings in Honshū, Japan (13) found that clearcut forest patches attracted a similar number of butterfly species as semi-natural grasslands. In clearcut patches, the total number of butterfly species (22 species/site) and the number of threatened butterfly species (2 species/site) were not significantly different to semi-natural grasslands (total: 26 species/site; threatened: 6 species/site). However, 15 butterfly species (including five threatened species) were observed only in grassland, compared to six species (none threatened) which occurred only in clearcuts (statistical significance not assessed). From 2008–2012, five plantation patches (aged 27–88 years, 3.1–14.7 ha, >1.8 km apart) were clearcut. Two years after cutting, larch *Larix kaempferi* seedlings were planted at each site, with some broadleaved deciduous and evergreen coniferous trees. For 3–5 years after planting, summer mowing was used to suppress surrounding vegetation. Five semi-natural grasslands (15–1,900 ha, >3.5 km apart) were managed by burning in early spring (three sites) or had been abandoned since the 1950s (two sites). From May–October 2016, butterflies were surveyed once/month on three 200-m transects/site (six transects on the largest grassland).

A replicated, site comparison study in 2015 in a boreal forest in Alberta, Canada (14) found that larger cleared patches in forests had a higher abundance and species richness of butterflies than undisturbed forest, but smaller cleared patches did not. The abundance and species richness of butterflies in large clearings (abundance: 65 individuals/site; richness: 13 species/site) and wide corridors (abundance: 95 individuals/site; richness: 15 species/site) was higher than in undisturbed forest (abundance: 21 individuals/site; richness: 7 species/site). However, narrow corridors (abundance: 31 individuals/site; richness: 8 species/site) were similar to undisturbed forest. Of 43 species observed, 41 had a higher abundance in cleared sites than in undisturbed forest (statistical significance of individual species results not presented, see paper for details). From 2000–2005, clearings (60 × 60 m) and corridors (3 or 9 m wide) were created in a 25-km^2 area of previously undisturbed forest by removing trees. From June–August 2015, butterflies were surveyed 11 times on five 200-m transects in each type of clearing, and in undisturbed forest patches which had received no wildfire or anthropogenic disturbance within 50 m for >80 years.

(1) Warren M.S. (1987) The ecology and conservation of the heath fritillary butterfly, *Mellicta athalia*. III. Population dynamics and the effect of habitat management. *Journal of Applied Ecology*, 24, 499–513.
(2) Robertson P.A., Woodburn M.I.A. & Hill D.A. (1988) The effects of woodland management for pheasants on the abundance of butterflies in Dorset, England. *Biological Conservation*, 45, 159–167.
(3) Marttila O., Saarinen K. & Jantunen J. (1997) Habitat restoration and a successful reintroduction of the endangered Baton Blue butterfly (*Pseudophilotes baton schiffermuelleri*) in SE Finland. *Annales Zoologici Fennici*, 34(3), 177-185.
(4) Marttila O., Saarinen K. & Marttila P. (2000) Six years from passing bell to recovery: Habitat restoration of the threatened Chequered Blue Butterfly (*Scolitantides orion*) in SE Finland. *Entomologica Fennica*, 11(2), 113–117.
(5) Bergman K.O. (2001) Population dynamics and the importance of habitat management for conservation of the butterfly *Lopinga achine*. *Journal of Applied Ecology*, 38, 1303–1313.
(6) Meyer C.L. and Sisk T.D. (2001) Butterfly Response to Microclimatic Conditions Following *Ponderosa* Pine Restoration. *Restoration Ecology*, 9(4), 435-461.
(7) Yamamoto K. & Tuhara Y. (2004) The change of butterfly assemblages after artificial gap formation in an urban park. *Journal of The Japanese Institute of Landscape Architecture*, 68, 585–588.
(8) Hoare D., Dent K., Kelly C., McLellan L., Thompson F. & Wheatley S. (2012) Landscape-scale woodland restoration for multiple species in the South East Woodlands In Ellis S., Bourn N. & Bulman C., *Landscape-scale conservation for butterflies and moths: Lessons from the UK.* 66–75.
(9) Hobson R. & Smith R. (2012) High Brown Fritillary in the Vale of Glamorgan: saving the last site in Wales In Ellis S., Bourn N. & Bulman C., *Landscape-scale conservation for butterflies and moths: Lessons from the UK*. 52–57.
(10) Merckx T., Feber R.E., Hoare D.J., Parsons M.S., Kelly C.J., Bourn N.A.D. & Macdonald D.W. (2012) Conserving threatened Lepidoptera: Towards an effective woodland management policy in landscapes under intense human land-use. *Biological Conservation*, 149, 32–39.
(11) Bubová T., Vrabec V., Kulma M. & Nowicki P. (2015) Land management impacts on European butterflies of conservation concern: a review. *Journal of Insect Conservation*, 19, 805–821.
(12) Sebek P., Bace R., Bartos M., Benes J., Chlumska Z., Dolezal J., Dvorsky M., Kovar J., Machac O., Mikatova B., Perlik M., Platek M., Polakova S., Skorpik M., Stejskal R., Svoboda M., Trnka F., Vlasin M., Zapletal M. & Cizek L. (2015) Does a minimal intervention approach threaten the biodiversity of protected areas? A multi-taxa short-term response to intervention in temperate oak-dominated forests. *Forest Ecology and Management*, 358, 80-89.
(13) Ohwaki A., Koyanagi T.F. & Maeda S. (2018) Evaluating forest clear-cuts as alternative grassland habitats for plants and butterflies. *Forest Ecology and Management*, 430, 337–345.
(14) Riva F., Acorn J.H. & Nielsen S.E. (2018) Localized disturbances from oil sands developments increase butterfly diversity and abundance in Alberta's boreal forests. *Biological Conservation*, 217, 173–180.

13.7. Coppice woodland

- **Ten studies** evaluated the effects on butterflies and moths of coppicing woodland. Eight studies were in the UK[1–8] and one was in each of France[9] and Germany[10].

COMMUNITY RESPONSE (4 STUDIES)

- **Community composition (3 studies):** Two replicated, site comparison studies in the UK[5] and France[9] found that coppiced woodland of different ages supported different communities of moths[5] and butterflies[9]. One replicated, site comparison study in the UK[8] found that coppiced woodland contained more unique species of macro-moth than mature forest.
- **Richness/diversity (4 studies):** One of two replicated, site comparison studies in the UK[2,8] found that coppiced woodland had a greater species richness of butterflies than unmanaged woodland[2]. The other study found that coppiced woodland had a lower species richness of macro-moths than mature forest, and there was no change in species richness with the age of coppice[8]. One of two replicated, site comparison studies in the UK[5] and France[9] found that woodland coppiced two years ago had a greater species richness of butterflies than woodland coppiced >15 years ago[9]. The other study found that the species richness of moths was similar in woodland coppiced 1–4, 5–8 and 12–20 years ago[5].

POPULATION RESPONSE (10 STUDIES)

- **Abundance (9 studies):** Two of four site comparison studies (including three replicated studies and one before-and-after study) in the UK[2–4,8] found that coppiced woodland (in one case also legally protected[3]) had a higher abundance of butterflies generally[2], and of heath fritillary[3] specifically, than unmanaged woodland. One study found that pearl-bordered fritillary and small pearl-bordered fritillary populations were more likely to persist for up to 20 years in coppiced woodland (or woodland with young plantations) than in mature conifer woodland[4]. The fourth study found that the abundance of macro-moths was lower in coppiced woodland than in mature forest, and there was no change in abundance with the age of coppice[8]. Three of four replicated, site comparison studies (including one before-and-after study) in the UK[1,5], France[9] and Germany[10] found that the abundance of butterflies generally[9], heath fritillary specifically[1], and eastern eggar moth and scarce fritillary caterpillar webs[10], was higher in woodland coppiced two[9], two–four[1], five–seven[10] or 12–15[10] years ago than in woodland coppiced 5–11[1] or >15[9,10] years ago. The fourth study reported that the abundance of moths was similar in woodland coppiced 1–4, 5–8 and 12–20 years ago[5]. One before-and-after study in the UK[7] reported that after coppicing, along with scrub control, tree felling and grazing, high brown fritillary and small pearl-bordered fritillary abundance increased.
- **Reproductive success (1 study):** One before-and-after study in the UK[6] reported that pearl-bordered fritillaries released into coppiced woodland bred at least once.

BEHAVIOUR (0 STUDIES)

Background

Coppicing is a traditional woodland management technique, used to harvest the young, fast-growing stems of particular tree species, such as hazel. It involves repeatedly felling trees at the base and allowing them to regrow for a number of years. Coppicing removes some of the canopy, allowing light in to the woodland floor, replicating the natural creation of woodland clearings. This may benefit butterflies and moths by encouraging the growth of food plants on the woodland floor, or by creating sheltered, sunny sites for basking and territory defence.

A replicated, site comparison study in 1980–1984 in 24 woodlands in Kent, UK (1, same experimental set-up as 3) found that recently coppiced woodland patches had a higher abundance of heath fritillary *Mellicta athalia* than areas coppiced longer ago. The number of heath fritillary recorded 2–4 years after a site had been coppiced (96–2,187 individuals/site) was higher than 5–11 years after coppicing (0–46 individuals/site). Populations in vigorous coppice became extinct six years after management if no further coppicing was conducted, but some populations in poor coppice survived for nine years after management. At one site, where new 1–3 ha areas of wood were coppiced annually from 1979, the number of heath fritillary was 1,100 in 1985, compared to <20 in 1980 (statistical significance not assessed). Twenty-four woodlands were coppiced intermittently, 1–11 years before surveying. From 1980–1984, the number of adult heath fritillary at each site was estimated from a combination of counts on regular transects throughout the season, single counts around the peak flight period, and mark-recapture of individuals.

A replicated, site comparison study in 1986 in a mixed woodland in Dorset, UK (2) found that open, coppiced areas within a woodland had a higher abundance and species richness of butterflies than unmanaged broadleaf woodland or conifer plantation, but fewer butterflies than managed clearings. In open, coppiced woodland, both the abundance (25 individuals/km) and species richness (16 species) of butterflies were higher than in unmanaged broadleaved woodland (abundance: 2 individuals/km; richness: 4 species) or conifer plantations (abundance: 5 individuals/km; richness: 2 species). However, the most butterflies were recorded in managed clearings (abundance: 89 individuals/km; richness: 19 species). See paper for individual species results. The woodland contained patches managed in four ways: open woodland with coppiced hazel; unmanaged broadleaved woodland with unmanaged hazel coppice; conifer plantation; and managed clearings (30–50 m wide and 100–150 m long) which were cleared of scrub every three years. In July–August 1986, butterflies were surveyed six times on each of twenty-two 200-m transects: eight in open, coppiced wood, six in unmanaged wood, four in conifer plantation and four in managed clearings.

A before-and-after, site comparison study in 1980–1989 in two woodlands in Kent, UK (3, same experimental set-up as 1) reported that a protected woodland managed by coppicing established a large population of heath fritillary *Mellicta athalia*, while over half of the colonies in a privately owned, unmanaged wood went extinct. Results were not tested for statistical significance. After four years of coppicing in one protected wood, the number of heath fritillaries peaked at 2,000 adults, and stabilized at around 800 adults after nine years, compared to "just a few individuals" when management began. In an unmanaged, unprotected wood, there were 800 adults across nine colonies in 1989, compared to over 10,000 adults across 20 colonies in 1980. From 1980–1989, a woodland protected as a National Nature Reserve was managed by coppicing one or two plots (1–5 ha) each year on a 15–20-year rotation. Plots were connected by wide rides and permanent glades. A nearby, privately owned woodland was not managed. From

1980–1989, butterflies were surveyed most years on timed counts along a zig-zag route covering the known flight areas at each site. The total yearly population at a site was estimated by multiplying the peak population count by three.

A replicated, site comparison study in 1990–1991 in 52 woods in southern England, UK (4) found that populations of pearl-bordered fritillary *Boloria euphrosyne* and small pearl-bordered fritillary *Boloria selene* were more likely to persist for up to 20 years in woodland containing more actively coppiced areas or young plantations. Woodlands with larger areas of active coppicing or young plantations were more likely to have retained populations of either fritillary species than woodlands with larger areas of mature conifer (data presented as model results). Butterfly records from six data sources were used to identify 52 woods which had contained fritillary populations since 1970. The area of four habitat types was mapped in each wood: established coppice cut within the last four years, young plantation on a previously wooded site, mature deciduous woodland and mature conifers. In 1990–1991, all but one of the woods were visited to record whether fritillary populations were still present.

A replicated, site comparison study in 2002–2004 in a woodland in West Sussex, UK (5) found that coppiced woodland of different ages supported different moth communities. The moth community in young coppice (1–4 years old) was different from that in mid-aged coppice (5–8 years old), and both were different from old coppice (12–20 years old) (data presented as model results). No further statistical tests were conducted. Over three years, in young coppice, 109–256 individuals/trap and 20–31 species/trap were caught, compared to 100–218 individuals/trap and 26–27 species/trap in mid-aged coppice, and 186–342 individuals/trap and 28–44 species/trap in older coppice. Fifty-one species were only caught in young coppice, compared to 14 in mid-aged coppice, and 31 in old coppice. In 2003, the number of scarce species of conservation concern was 15–23 in young coppice, compared to 11–17 in mid-aged coppice, and 21–24 in old coppice. See paper for individual species results. A 200-ha sweet chestnut *Castanea sativa* wood was managed by coppicing 0.25–4 ha patches every 12–16 years. Eight patches, last cut between 1984–2001, were studied. In late June–early July 2002–2004, moths were surveyed on two nights/year using a 125 W mercury vapour ‘Robinson’ trap placed in the centre of each patch.

A before-and-after study in 2007–2011 in a woodland in East Sussex, UK (6) reported that captive bred pearl-bordered fritillary *Boloria euphrosyne* released into woodland where a coppicing regime had been reinstated bred at least once. Results were not tested for statistical significance. In 2011, one year after the release of captive-bred adult pearl-bordered fritillaries into an area where a coppicing regime had been reinstated, their offspring were recorded at the site. At some time between 2007 and 2010 surveys showed that there was no longer a population of pearl-bordered fritillary in Rother Woods, so during this time coppicing management was reinstated (management dates not provided). Captive-bred adults (numbers not provided) were released into the site in 2010 and a survey in 2011 recorded adults of the next generation.

A before-and-after study in 1998–2011 in an area of woodland, heathland and grassland in South Wales, UK (7) reported that after coppicing, along with scrub control, tree felling and grazing, the number of high brown fritillary *Argynnis adippe* and small pearl-bordered fritillary *Boloria selene* increased. Results were not tested for statistical significance. In 1998, prior to management, an average of four high brown fritillary adults/hour were recorded at the site, and 12 years after management started, 14 adults/hour were recorded. Authors reported that small pearl-bordered fritillary *Boloria selene* also increased in number between 2003 and 2011 (numbers not given). In 1999, coppicing of trial plots of hazel *Corylus avellana* and gorse *Ulex europaeus* (number and area not given) was started in the Alun Valley, a 254 ha landscape comprising woodland, heathland and grassland. Coppicing was then regularly maintained from 2003 until at least 2011 (it is unclear whether coppicing took place in 2000–2002 and whether it expanded outside the trial plots). From 2003–2011, scrub clearance and tree felling was also conducted in areas, and sheep grazing was present for the whole period in some areas of the site. Adult butterflies were counted annually from 1998–2011.

A replicated, site comparisonstudy in 2010 in six deciduous woodlands in Hampshire and Wiltshire, UK (8) found that coppiced woodland had a lower abundance and species richness of macro-moths than non-coppiced mature forest, but more unique species. Both the abundance and species richness of macro-moths were similar in young (1,248 individuals; 160 species), mid-age (1,433 individuals; 167 species) and old coppice (2,071 individuals; 162 species) and wide rides (1,926 individuals; 175 species), but were lower than in non-coppiced mature forest (2,479 individuals; 180 species) and standard rides (2,513 individuals; 176 species). However, coppiced woodland and wide rides supported 49 species not found in mature forest or standard rides, and 124 species were more abundant in coppiced woodland and wide rides than in mature forest and standard rides, especially 'common but severely declining' species (see paper for details). Only 22 species were found in mature forest or standard rides but not coppiced woodland or wide rides. Within six woodlands (8–711 ha), six areas under each of six management types were studied: young (1–2 years), medium (3–6 years) and old (7–9 years) coppice, wide (>20 m) and standard (<10 m) rides, and non-coppiced mature forest. All coppiced sites had been actively managed for at least 20 years. From July–October 2010, macro-moths were sampled nine times/site using a 6 W Heath actinic light trap, over 27 nights (two sites/management type sampled/night).

A replicated, site comparison study in 2010 in five woodlands in the Alsacian Hardt, France (9) found that recently coppiced woodland had a higher abundance and species richness of butterflies than older coppiced woodland, and that coppiced woodland of different ages had distinct groups of species. Two years after coppicing, woodland had a higher abundance and species richness of resident (abundance: 6 individuals/100 m^2; richness: 11 species/plot) and threatened (abundance: 1.8 individuals/100 m^2; richness: 4 species/plot) butterflies than woodland which had not been coppiced for >15 years (resident: 1 individual/100 m^2; 4 species/plot; threatened: 0.2 individuals/100 m^2; 1 species/plot). Coppiced woodland had a higher abundance of migratory butterflies one (1.2 individuals/100 m^2) and two years (1.1 individuals/100 m^2) after coppicing than >15 years after coppicing (0.2 individuals/100 m^2). However, all five ages of coppiced plots held distinct groups of species (data presented as model results). Across five woodlands (140–1,303 ha), 37 coppiced plots (1–3 ha, 31–41-year coppice cycle) in one of five stages (first year, second year, 3–7 years, 8–15 years and >15 years after coppicing) were surveyed. From May–August 2010, butterflies were surveyed seven times in a 20 × 25 m area in the centre of each plot.

A replicated, before-and-after, site comparison study in 2000–2016 in 10 coppiced forests in Bavaria, Germany (10) found that the number of webs of Eastern eggar moth *Eriogaster catax* and scarce fritillary *Euphydryas maturna* caterpillars was higher in recently coppiced woodland than in older woodland. Eastern eggar moth caterpillars were most often found in patches 5–10 years after the last coppice, and their abundance peaked after 5–7 years (data presented as model results). Scarce fritillary caterpillars were most often found in patches 10–12 years after the last coppice, and their abundance peaked after 12–15 years (data presented as model results). Coppicing commenced in 2005 at nine sites (23–310 ha), and in 2012 at a tenth site (80 ha) under a Government-funded scheme. From 2000–2016, caterpillars of Eastern eggar moth and scarce fritillary were surveyed in early May and late July–early August, respectively, by counting their silk-woven webs, in both coppiced and non-coppiced areas at each site. Each site was surveyed 0–5 times before coppicing (2000–2004) and 1–12 times after coppicing (2005–2016).

(1) Warren M.S. (1987) The ecology and conservation of the heath fritillary butterfly, *Mellicta athalia*. III. Population dynamics and the effect of habitat management. *Journal of Applied Ecology*, 24, 499–513.
(2) Robertson P.A., Woodburn M.I.A. & Hill D.A. (1988) The effects of woodland management for pheasants on the abundance of butterflies in Dorset, England. *Biological Conservation*, 45, 159–167.
(3) Warren M.S. (1991) The successful conservation of an endangered species, the heath fritillary butterfly *Mellicta athalia*, in Britain. *Biological Conservation*, 55, 37–56.
(4) Clarke S.A. & Robertson P.A. (1993) The relative effects of woodland management and pheasant *Phasianus colchicus* predation on the survival of the pearl- bordered and small pearl-bordered fritillaries *Boloria euphrosyne* and *B. selene* in the south of England. *Biological Conservation*, 65, 199–203.
(5) Broome A., Clarke S., Peace A. & Parsons M. (2011) The effect of coppice management on moth assemblages in an English woodland. *Biodiversity and Conservation*, 20, 729–749.
(6) Hoare D., Dent K., Kelly C., McLellan L., Thompson F. & Wheatley S. (2012) Landscape-scale woodland restoration for multiple species in the South East Woodlands In Ellis S., Bourn N. & Bulman C., *Landscape-scale conservation for butterflies and moths: Lessons from the UK*. 66–75.
(7) Hobson R. & Smith R. (2012) High Brown Fritillary in the Vale of Glamorgan: saving the last site in Wales In Ellis S., Bourn N. & Bulman C., *Landscape-scale conservation for butterflies and moths: Lessons from the UK*. 52–57.
(8) Merckx T., Feber R.E., Hoare D.J., Parsons M.S., Kelly C.J., Bourn N.A.D. & Macdonald D.W. (2012) Conserving threatened Lepidoptera: Towards an effective woodland management policy in landscapes under intense human land-use. *Biological Conservation*, 149, 32–39.
(9) Fartmann T., Müller C. & Poniatowski D. (2013) Effects of coppicing on butterfly communities of woodlands. *Biological Conservation*, 159, 396–404.
(10) Dolek M., Kőrösi Á & Freese-Hager A. (2018) Successful maintenance of Lepidoptera by government-funded management of coppiced forests. *Journal for Nature Conservation*, 43, 75–84.

13.8. Thin trees within forests

- **Six studies** evaluated the effects on butterflies and moths of thinning trees within forests and woodland. Three studies were in the USA[1,3,4] and one was in each of Côte d'Ivoire[2], Finland[5] and the Czech Republic[6].

COMMUNITY RESPONSE (5 STUDIES)

- **Community composition (1 study):** One site comparison study in Côte d'Ivoire[2] found that rarer species of fruit-feeding butterfly were less frequently caught in a forest managed by thinning than in an unmanaged, naturally regenerating forest.
- **Richness/diversity (6 studies):** Four studies (including two replicated, paired, controlled, before-and-after studies) in the USA[1,3,4] and Finland[5] found that one[4], two[1,4,5] or four[3] years after management, coniferous woodland which had been thinned, along with either prescribed burning[1,4], mulching[3] or nearby felling[5], had a greater species richness of butterflies[1,3,4], or butterflies, diurnal moths and bumblebees combined[5], than either unmanaged woodland[1,3–5] or before management[4,5]. One site comparison study in Côte d'Ivoire[2] found that a forest managed by thinning had a similar species richness and diversity of fruit-feeding butterflies to an unmanaged, naturally regenerating forest. One replicated, paired sites, controlled study in the Czech Republic[6] found that partially-cleared forest plots had higher butterfly but lower moth species richness than plots of closed-canopy forest.

POPULATION RESPONSE (5 STUDIES)

- **Abundance (5 studies):** Four studies (including two replicated, paired, controlled, before-and-after studies) in the USA[1,3,4] and Finland[5] found that one[4], two[1,4,5] or four[3] years after management, coniferous woodland which had been thinned, along with either prescribed burning[1,4], mulching[3] or nearby felling[5], had a higher abundance of all butterflies[1,3,4], or specialist butterflies[5], than either unmanaged woodland[1,3–5] or before management[4,5]. One site comparison study in Côte d'Ivoire[2] found that a forest managed by thinning had a similar abundance of fruit-feeding butterflies to an unmanaged, naturally regenerating forest.

BEHAVIOUR (0 STUDIES)

Background

Thinning is a forestry practice that involves the selective removal of trees to reduce tree density and improve the growth rate and health of the remaining trees. Thinning has been done historically to maximize timber production but may have ecological benefits. Thinning removes some of the canopy, allowing light in to the woodland floor, replicating the natural creation of woodland clearings. This may benefit butterflies and moths by encouraging the growth of food plants on the woodland floor, or by creating sheltered, sunny sites for basking and territory defence. However, some species spend almost their entire lives in the canopy, and may be adversely affected by the loss of even a few canopy trees, so caution should be taken when applying this action.

For studies that used thinning as part of selective logging methods, see the intervention "*Biological resource use – Harvest groups of trees or use thinning instead of clearcutting*".

A site comparison study in 1998 in two pine forests in Arizona, USA (1) found that a forest restored by thinning young trees and prescribed burning had a higher abundance and species richness of butterflies than an unrestored forest. Two years after thinning and burning, the restored forest had a higher abundance (6–46 individuals/visit) and species richness (3–11 species/visit) of butterflies than the unrestored forest (abundance: 0–7 individuals/visit; richness: 0–4 species/visit). One species, the checkered white *Pieris protodice*, was only found in the restored forest, but another, the California sister *Limenitis bredowii*, was only found in the unrestored forest. In 1996, a 40-acre ponderosa pine *Pinus ponderosa* forest was thinned (pole-sized trees removed) and burned to reopen the dense understorey. An adjacent forest was not restored. From May–July 1998, butterflies were surveyed six times (every two weeks) along a single 450-m transect in each forest.

A site comparison study in 1996 in a logged tropical rainforest in south-east Côte d'Ivoire (2) found that the abundance, species richness and diversity of fruit-feeding butterflies (Nymphalidae) were similar in forest managed by thinning and naturally regenerating forest, but rarer species were caught less frequently in thinned forest. Forest managed by thinning had a similar abundance (54 individuals/trap), species richness (76 species) and diversity (data presented as model results) of butterflies to naturally regenerating forest (abundance: 56 individuals/trap; richness: 71 species). However, species with smaller geographic ranges were caught less frequently in thinned forest (data presented as model results). See paper for individual species results. From 1960–1990, a 216 km^2 forest was selectively logged. From 1992 the forest was protected, and two management options were implemented: liberation thinning and natural regeneration (no management). Liberation thinning was designed to promote the growth of commercial timber species, and included cutting of lianas and climbers, and killing some non-commercial trees. Rare trees and important fruit trees were protected. From January–March 1996, butterflies were sampled in 30 ha of thinned forest and 30 ha of naturally regenerating forest, using 28 banana-baited traps in each habitat. Traps were set 1 m above ground, 100 m apart, for six consecutive days, and checked daily.

A controlled study in 1997–2001 in two piñon pine and juniper woods in New Mexico, USA (3) found that mechanically thinning woodland increased the abundance and species richness of butterflies. Four years after thinning, the abundance (12–20 individuals/transect) and species richness (9–12 species) of butterflies were higher in thinned woodland than in woodland which had not been thinned (abundance: 4 individuals/transect; richness: 5–7 species). The increase in butterflies correlated with an increase in understorey plants in the thinned woodland. In January–March 1997, tree cover in a 40-ha watershed was reduced from 35 to 10%, by removing individual trees <20 cm diameter. Felled trees were applied as rough mulch onto adjacent bare soil. In an adjacent 40-ha watershed, the tree cover was left at 40%. In June–July 1999 and 2001, butterflies were surveyed twice/year on 20 permanent 100-m transects/watershed. Transects were 75–150 m apart, and ran down the slopes, with 10 on each side of each valley.

A replicated, randomized, paired, controlled, before-and-after study in 1997–2001 in a pine forest in Arizona, USA (4) found that forests restored by thinning and prescribed burning had a higher abundance and species richness of butterflies than unrestored forests. One and two years after thinning and burning, restored forests had a higher butterfly abundance (48–132 individuals/unit) and species richness (7–16 species/unit) than unrestored forests (abundance: 10–42 individuals/unit; richness: 4–10 species/unit). Before restoration, there was no significant difference between forest marked for restoration (abundance: 23–50 individuals/unit; richness: 8–12 species/unit) and unrestored forest (abundance: 10–41 individuals/unit; richness: 5–13 species/unit). These results were primarily due to the abundance of species of blue (Lycaenidae) and white (Pieridae) butterflies (see paper for details). In 1997, four blocks within a 5,000-ha ponderosa pine *Pinus ponderosa* forest were each divided into two units (≤40-ha each). In autumn/winter 1999–2000, one randomly assigned unit/block was thinned and burned. The other units were not restored. From May–August 1997, 1998, 2000 and 2001, butterflies were surveyed six times/year (two-week intervals) along two or three 300-m transects/unit.

A replicated, paired, controlled, before-and-after study in 2009–2011 in 15 coniferous forest stands in Vihti and Jokioinen, Finland (5) found that thinning trees near to the edge of woodland, in addition to felling the edge, increased the abundance of specialist butterflies and the total species richness of butterflies, diurnal moths and bumblebees (*Bombus* spp.) combined. Two years after thinning and felling, the abundance of specialist butterflies (2.3 individuals/plot), and the total species richness of butterflies, moths and bumblebees (7.3 species/plot), were higher in thinned areas than in areas which had not been thinned (butterfly abundance: 0.6 individuals/plot; total richness: 3.8 species/plot). Prior to thinning, both butterfly abundance and total species richness were similar in the plots designated for thinning (butterfly abundance: 0.6 individuals/plot; total richness: 4.9 species/plot) and no thinning plots (butterfly abundance: 0.5 individuals/plot; total richness: 5.3 species/plot). In winter 2009–2010, in each of 15 forest stands, a 50-m-long forest edge was logged. Logging comprised felling a 5-m-wide strip at the forest edge, and behind that a 20-m-wide belt was thinned to a basal area of 8 m^2/ha. Trunks were removed, but other debris was left on the ground. A second 50 × 25 m area at each site, within 8–61 m of the logged area, was left unlogged. From late May–August 2009–2011, butterflies, diurnal moths and bumblebees were surveyed seven times/year in each thinned and unthinned area, at two-week intervals.

A replicated, paired sites, controlled study in 2011–2012 in six oak/hornbeam forests in South Moravia, Czech Republic (6) found that partially-cleared plots had higher butterfly but lower moth species richness than plots of closed-canopy forest. Butterfly species richness was higher in partially-cleared forest plots connected to the forest edge (16) and naturally open forest plots (14) than partially-cleared plots >20 m from the edge (10), which in turn had higher richness than closed-canopy forest plots (2). However, whilst moth species richness was higher in partially-cleared forest plots connected to the edge (97) and naturally open forest plots (111) than partially-cleared plots >20 m from the edge (81), all three had lower richness than plots of closed-canopy forest (130). In February 2011 and 2012, four 40-m^2 plots were established at six forest sites: a partial clearing at a forest edge connected to a meadow, a partial clearing >20 m from forest edges, closed-canopy forest, naturally open forest. A few trees were left in the two clearings to replicate open forest. In the May–September after plot establishment, adult butterflies were surveyed five times for seven minutes/plot, and moths were captured once/month using one light trap/plot.

(1) Waltz A.E.M. & Covington W.W. (1999) Butterfly richness and abundance increase in restored ponderosa pine ecosystem (Arizona). *Ecological Restoration*, 17, 244–246.
(2) Fermon H., Waltert M., Larsen T.B., Dall'Asta U. & Muehlenberg M. (2000) Effects of forest management on diversity and abundance of fruit-feeding nymphalid butterflies in south-eastern Cote d'Ivoire. *Journal of Insect Conservation*, 4, 173–189.
(3) Kleintjes P.K., Jacobs B.F. & Fettig S.M. (2004) Initial response of butterflies to an overstory reduction and slash mulching treatment of a degraded piñon-juniper woodland. *Restoration Ecology*, 12, 231–238.
(4) Waltz A.E.M. & Covington W.W. (2004) Ecological restoration treatments increase butterfly richness and abundance: mechanisms of response. *Restoration Ecology*, 12, 85–96.
(5) Korpela E.-L., Hyvonen T. & Kuussaari M. (2015) Logging in boreal field-forest ecotones promotes flower-visiting insect diversity and modifies insect community composition. *Insect Conservation and Diversity*, 8, 152–162.
(6) Sebek P., Bace R., Bartos M., Benes J., Chlumska Z., Dolezal J., Dvorsky M., Kovar J., Machac O., Mikatova B., Perlik M., Platek M., Polakova S., Skorpik M., Stejskal R., Svoboda M., Trnka F., Vlasin M., Zapletal M. & Cizek L. (2015) Does a minimal intervention approach threaten the biodiversity of protected areas? A multi-taxa short-term response to intervention in temperate oak-dominated forests. *Forest Ecology and Management*, 358, 80-89.

13.9. Create young plantations within mature woodland

- **One study** evaluated the effects on butterflies and moths of creating young plantations within mature woodland. This study was in the UK[1].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (1 STUDY)

- **Abundance (1 study):** One replicated, site comparison study in the UK[1] found that pearl-bordered fritillary and small pearl-bordered fritillary populations were more likely to persist for up to 20 years in woodlands with larger areas of young plantations (or coppicing) than in mature coniferous (both species) or deciduous (pearl-bordered fritillary only) woodland.

BEHAVIOUR (0 STUDIES)

Background

Although many species of butterflies and moths live within woodland, many are reliant upon open areas with a diverse habitat structure, which are sheltered by the surrounding trees. Traditional woodland management, such as small scale wood harvesting, which created these habitats has declined, leading to the closure of woodland canopies (Bubová *et al.* 2015). Creating young plantations within mature woodland may help to temporarily open up patches within the forest, and create new habitat for butterflies and moths by encouraging the growth of food plants on the woodland floor, or by creating sheltered, sunny sites for basking and territory defence.

Bubová T., Vrabec V., Kulma M. & Nowicki P. (2015) Land management impacts on European butterflies of conservation concern: a review. *Journal of Insect Conservation*, 19, 805–821.

A replicated, site comparison study in 1990–1991 in 52 woods in southern England, UK (1) found that populations of pearl-bordered fritillary *Boloria euphrosyne* and small pearl-bordered fritillary *Boloria selene* were more likely to persist for up to 20 years in woodland containing more young plantations or actively coppiced areas. Woodlands with larger areas of young plantations or active coppicing were more likely to have retained populations of either fritillary species than woodlands with larger areas of mature conifer (data presented as model results). For pearl-bordered fritillary, woodlands with larger areas of young plantations were more likely to have retained populations than woodlands with larger areas of mature conifer wood or mature deciduous wood. Butterfly records from six data sources were used to identify 52 woods which had contained fritillary populations since 1970. The area of four habitat types was mapped in each wood: young plantation on a previously wooded site, established coppice cut within the last four years, mature deciduous woodland and mature conifers. In 1990–1991, all but one of the woods were visited to record whether fritillary populations were still present.

(1) Clarke S.A. & Robertson P.A. (1993) The relative effects of woodland management and pheasant *Phasianus colchicus* predation on the survival of the pearl-bordered and small pearl-bordered fritillaries *Boloria euphrosyne* and *B. selene* in the south of England. *Biological Conservation*, 65, 199–203.

13.10. Manage woodland edges for maximum habitat heterogeneity

- **Two studies** evaluated the effects on butterflies and moths of managing woodland edges for maximum habitat heterogeneity. One study was in Belgium[1] and the other was in Finland[2].

COMMUNITY RESPONSE (1 STUDY)

- **Richness/diversity (1 study):** One replicated, paired, controlled, before-and-after study in Finland[2] found that two years after felling 5-m-wide woodland edges, and thinning 20-m-wide adjacent forest, the combined species richness of butterflies, diurnal moths and bumblebees was higher than before management or in unmanaged woodland edges.

POPULATION RESPONSE (2 STUDIES)

- **Abundance (2 studies):** One replicated, site comparison study in Belgium[1] found that scalloped woodland edges had a higher abundance of brown hairstreak eggs than straight woodland edges. One replicated, paired, controlled, before-and-after study in Finland[2] found that two years after felling 5-m-wide woodland edges and thinning 20-m-wide adjacent forest, the abundance of specialist butterflies was higher than before management or on unmanaged woodland edges.

BEHAVIOUR (0 STUDIES)

Background

Adult butterflies and moths, and their caterpillars, often have different habitat requirements but poor dispersal ability, and therefore creating a varied habitat structure is important for producing habitat suitable for each life stage within a small area (Schultz *et al.* 2008). Where woodland meets adjacent, open habitat, hard, straight edges provide little habitat diversity for butterflies and moths. Creating a more varied structure to the woodland edge, by felling some trees, encouraging scrub growth, or "scalloping" to increase the length of the edge, may be beneficial to a range of butterfly and moth species.

Schultz C.B., Russell C. & Wynn L. (2008) Restoration, reintroduction, and captive propagation for at-risk butterflies: A review of British and American conservation efforts. *Israel Journal of Ecology & Evolution*, 54, 41–61.

A replicated, site comparison study in 2001–2005 in 63 woodland edges and hedgerows in an agricultural landscape in Flanders, Belgium (1) found that scalloped woodland edges contained more brown hairstreak *Thecla betulae* eggs than woodland edges with straight borders. There were more brown hairstreak eggs on blackthorn *Prunus spinosa* bushes in scalloped woodland edges than in straight woodland edges (data presented as model results). Woodland edges and hedgerows (1–250 m long, 2,260 m total) containing blackthorn were divided into 10-m sections (335 woodland sections), and categorized as "scalloped", "oval", "boxed" or "with gaps" (exact descriptions not provided). Each winter from 2001–2005, all blackthorn bushes were systematically searched for brown hairstreak eggs.

A replicated, paired, controlled, before-and-after study in 2009–2011 in 15 coniferous forest stands in Vihti and Jokioinen, Finland (2) found that felling trees at the woodland edge, in addition to thinning the adjacent woodland, increased the abundance of specialist butterflies and the total species richness of butterflies, moths and bumblebees (*Bombus* spp.) combined. Two years after felling and thinning, the abundance of specialist butterflies (3.5 individuals/plot), and the total species richness of butterflies, moths and bumblebees (10.7 species/plot), were higher in felled forest edges than in forest edges which had not been felled (butterfly abundance: 0.5 individuals/plot; total richness: 3.6 species/plot). Prior to felling, both butterfly abundance and total species richness were similar in the plots designated for felling (butterfly abundance: 0.5 individuals/plot; total richness: 6.4 species/plot) and no felling plots (butterfly abundance: 0.7 individuals/plot; total richness: 6.2 species/plot). In winter 2009–2010, in each of 15 forest stands, a 50-m-long forest edge was logged. Logging comprised felling a 5-m-wide strip at the forest edge, and behind that a 20-m-wide belt was thinned to a basal area of 8 m^2/ha. Trunks were removed, but other debris was left on the ground. A second 50 × 25 m area at each site, within 8–61 m of the logged area, was left unlogged. From late May–August 2009–2011, butterflies, diurnal moths and bumblebees were surveyed seven times/year in each logged and unlogged area, at two-week intervals.

(1) Merckx T. & Berwaerts K. (2010) What type of hedgerows do brown hairstreak (Thecla betulae L.) butterflies prefer? Implications for European agricultural landscape conservation. *Insect Conservation and Diversity*, 3, 194–204.

(2) Korpela E.-L., Hyvonen T. & Kuussaari M. (2015) Logging in boreal field-forest ecotones promotes flower-visiting insect diversity and modifies insect community composition. *Insect Conservation and Diversity*, 8, 152–162.

13.11. Restore or create grassland/savannas

- **Six studies** evaluated the effects on butterflies and moths of restoring or creating grassland or savanna. Three studies were in the USA[1,4,6], two were in the UK[2,3] and one was in Italy[5].

COMMUNITY RESPONSE (1 STUDY)

- **Richness/diversity (1 study):** One replicated, paired, site comparison study in Italy[5] found that created semi-natural grasslands had a greater diversity of butterflies than adjacent conifer forests, but a lower diversity than species-rich pastures.

POPULATION RESPONSE (4 STUDIES)

- **Abundance (4 studies):** Two site comparison studies (including one replicated, paired study) in Italy[5] and the USA[6] found that created semi-natural grasslands[5] and restored grasslands and oak barrens[6] had a higher abundance of butterflies[5] and regal fritillaries[6] than adjacent conifer forests[5], species-rich pastures[5] or unmanaged or remnant prairies[6]. One site comparison study in the USA[4] found that prairies restored 5–10 years ago by seeding with native species, mowing, and weeding or applying herbicide, had a greater abundance of Fender's blue eggs than a prairie restored 1–2 years ago, and a similar abundance to remnant prairies. One study in the USA[1] reported that restored prairie supported a translocated population of regal fritillaries for at least three years after restoration.

BEHAVIOUR (3 STUDIES)

- **Use (2 studies):** One of two replicated, before-and-after studies in the UK[2,3] reported that following grassland restoration the area occupied by small pearl-bordered fritilliaries increased. The other study reported that following grassland restoration the number of marsh fritillary populations at each site remained the same or increased.
- **Behaviour change (1 study):** One site comparison study in the USA[4] found that Fender's blue butterflies spent a similar proportion of time laying eggs in prairies restored 5–10 years ago by seeding with nectar species, mowing, and weeding or applying herbicide, and in remnant prairies.

Background

In many parts of the world, vast areas of native grassland have been lost or degraded. Recreating or restoring these grasslands, by re-planting native species, removing invasive, non-native species, or reintroducing disturbance regimes such as grazing, mowing or burning, aims to create the habitat necessary to restore or boost native butterflies and moths, and return communities to those found in remnant, undisturbed grasslands (Denning & Foster 2018, O'Dwyer & Attiwell 2000).

For studies on restoring wet grasslands, fenland and floodplains, see "*Restore or create wetlands and floodplains*". For studies on restoring dry heathland and shrubland, see "*Restore or create heathland/shrubland*".

This action includes studies where either *multiple actions* have been used to restore or create grasslands, or where the *specific action used is not clear*. For studies of specific actions for creating or restoring grasslands, see "*Replant native vegetation*", "*Change mowing regime on grassland*" and "*Natural system modifications – Use prescribed fire to maintain or restore disturbance in grasslands or other open habitats*". For studies on restoring species-rich grassland within a farmland context, see "*Agriculture and aquaculture – Restore arable land to permanent grassland*", "*Agriculture and aquaculture – Restore or create species-rich, semi-natural grassland*", "*Agriculture and aquaculture – Reduce grazing intensity on grassland by reducing stocking density*", "*Agriculture and aquaculture – Reduce grazing intensity on grassland by seasonal removal of livestock*", "*Agriculture and aquaculture – Reduce cutting frequency on grassland*" and "*Agriculture and aquaculture – Reduce management intensity on permanent grasslands (several interventions at once)*".

Denning K.R. & Foster B.L. (2018) Flower visitor communities are similar on remnant and reconstructed tallgrass prairies despite forb community differences. *Restoration Ecology*, 26, 751–759.

O'Dwyer C. & Attiwell P.M. (2000) Restoration of a native grassland as habitat for the golden sun moth *Synemon plana* Walker (Lepidoptera; Castniidae) at Mount Piper, Australia. *Restoration Ecology*, 8, 170–174.

A study in 1998–2004 on former cropland in Iowa, USA (1) reported that restored prairie supported a translocated regal fritillary *Speyeria idalia* population. In 2001, the first year after translocation to a restored prairie, no butterflies were seen, but in 2002, one year after a second release, 84 adults were recorded. In the following two years, 11–12 fritillaries were observed in planted violet plots and other areas on 1–2 days/year. On 15 days in 2004, between 1–23 fritillaries were seen/day. Within a 2,083-ha reserve, 1,250 ha of former cropland were restored to tallgrass prairie (no further detail provided). The remaining land contained scattered remnant prairie patches. In 1998 and 1999, prairie violets *Viola pedatifida* were planted in five plots at each of four sites across the reserve. Each plot contained 99 violets planted in a grid (9 × 11 m), 1 m apart. In July 2000 and August–September 2001, seven female fritillaries were caught and brought to the restored prairie. Fritillaries were placed in mesh cages (0.6 × 0.6 m or 1.8 × 1.8 m) directly over violet plants, and provided with nectar from cut flowers and moved to new violet plants each day. In June–August 2001–2004, butterflies were surveyed or opportunistically recorded across the site.

A replicated, before-and-after study in 2002–2009 in six grassland sites in County Durham, UK (2) reported that following scrub and bracken control, mowing, planting of marsh violet *Viola palustris* and common dog-violet *Viola riviniana*, grazing management and shelterbelt planting, the area occupied by small pearl-bordered fritillary *Boloria selene* increased. Results were not tested for statistical significance. In 2000, two years before management, small pearl-bordered fritillary were recorded as occupying 1.10 ha at 4 of 4 surveyed sites. Seven years after management started they were recorded across 5.99 ha over 6 of 6 surveyed sites, although 2.95 ha of this across three sites were not surveyed in 2000. Of the four sites that were surveyed in their entirety in 2000, the area occupied by small pearl-bordered fritillary increased in three of them. From 2002, scrub and bracken were controlled and grass was mowed at all sites (frequency not given). Grazing compartments of an average of 1.2 ha were installed at five sites but they remained ungrazed or lightly grazed by sheep until after 2009. At two sites, either 0.06 ha or 0.09 ha of violets were planted. Six areas of shelterbelt were planted at one site. Butterfly transects were conducted annually in 2000–2009, except at one site where weekly transects were conducted from 2004 (annual surveying months not given). The total area surveyed in each year is not given.

A replicated, before-and-after study in 2005–2010 in seven pastures in Devon, UK (3) reported that in areas with scrub and bracken *Pteridium aquilinum* control, along with some planting of devil's bit scabious *Succisa pratensis*, tree felling and livestock grazing, the number of marsh fritillary *Euphydryas aurinia* populations at each site either remained the same or increased. Results were not tested for statistical significance. Five pastures had one population of marsh fritillary in 2005 and were managed with scrub and bracken control (and a mixture of devil's bit scabious planting, tree felling and livestock grazing), after which three still had one population and two had two populations in 2010. Another two similarly managed sites did not have a population in 2005 but did in 2010. In 2005–2010, western gorse *Ulex galli*, willow *Salix* spp., soft rush *Juncus effusus*, greater tussocksedge *Carex paniculata* and bracken were managed in seven pastures. In the same period, trees were felled in two of the pastures, devil's bit scabious was planted in one pasture and all pastures had some livestock grazing. In 2005 and 2010, surveyors conducted timed adult marsh fritillary counts during their flight season and caterpillar web counts in the autumn.

A site comparison study in 2009–2010 in three restored fields in Oregon, USA (4) found that older restored prairie had a higher density of Fender's blue butterfly *Plebejus icarioides fenderi* eggs than recently restored prairie. Five to 10 years after restoration, the host plant Kincaid's lupine *Lupinus oreganus* had more butterfly eggs (0.04–0.16 eggs/leaf) than 1–2 years after restoration (0.002–0.004 eggs/leaf), but similar numbers to intact habitat (0.09–0.13 eggs/leaf). Lupine density was also higher 5–10 years after restoration (5.1–9.0 leaves/m^2) than 1–2 years after restoration (0.3–1.3 leaves/m^2), but lower than in intact prairie (54.5 leaves/m^2). The time spent laying eggs by females was similar in older restored habitat (3–10%) and intact habitat (11%). From 2000, 2004 and 2008, three former fields (0.1–0.6 ha) were restored by seeding with native Fender's blue nectar species and Kincaid's lupine for 1–4 years. Restoration sites were adjacent to 3.5 ha of intact prairie. Restored areas were mown, and either hand weeded or treated with herbicide to reduce the spread of non-native plants. At the end of the 2009 and 2010 flight seasons, the number of lupine leaves and the number of Fender's blue eggs were sampled in the restored and intact prairie. In May–June 2009, female butterflies were observed in restored (38 females) and intact (116 females) prairie, and the percentage of time spent laying eggs was recorded.

A replicated, paired, site comparison study in 2010 three alpine grassland and forest sites in the Aosta Valley, Italy (5) found that created semi-natural grasslands had a higher abundance and diversity of butterflies than adjacent conifer forest, and a higher abundance but lower diversity of butterflies than nearby species-rich pastures. On created grasslands, the total number of butterflies recorded (1,133 individuals) was higher than on pastures (759 individuals) or in forests (1,060 individuals). However, species diversity on created grasslands was lower than on pastures but higher than in forests (data presented as model results). Created semi-natural grassland strips (>15-years-old) were occasionally grazed by cattle in summer, and used as ski-pistes in winter. Species-rich pastures were grazed annually by cattle. From 20 July–20 August 2010, butterflies were surveyed on twenty 300-m transects in each of three habitats: created grassland, adjacent coniferous forest, and nearby pastures.

A site comparison study in 2014 in a restored grassland and oak barren landscape in Indiana, USA (6) reported that regal fritillary *Speyeria idalia* were found across a landscape restored by planting and rotational burning. Results were not tested for statistical significance. Eighteen years after restoration began, on four restoration sites with high plant diversity, the abundance of regal fritillaries peaked at 17 butterflies/30-minute transect, compared to 12 butterflies/transect on two remnant prairies and a low plant diversity restoration site, 19 butterflies/transect in an old field, and 0 butterflies/transect in an agricultural field. Prior to restoration, authors reported that regal fritillaries were only found at three small sites in the landscape. Beginning in 1996, over 3,240 ha of agricultural land was restored to native grassland and oak barrens by planting seed mixes containing nearly all known locally native species (>620 species). In addition, seeds (<1 ounce/year) and plugs (<1,000 plants/year) of arrowleaf violet *Viola sagittata* and bird's-foot violet *Viola pedata* were planted as host plants. The area was managed to control invasive species and, once established, patches were burned on a three-year rotation. From May–September 2014, butterflies were surveyed every two weeks on 30-minute transects at nine sites across the landscape: four restoration sites with high plant diversity, one restoration site with low plant diversity, two remnant prairies, one old field, and one site still in agricultural production, none of which had been burned during the previous year.

(1) Shepherd S. & Debinski D.M. (2005) Reintroduction of regal fritillary (*Speyeria idalia*) to a restored prairie. *Ecological Restoration*, 23, 244–250.
(2) Ellis S. & Wainwright D. (2012) Restoring very small fragmented landscapes for the Small Pearl-bordered Fritillary in the Durham Coalfield Pennine Fringe. In Ellis S., Bourn N. & Bulman C., *Landscape-scale conservation for butterflies and moths: Lessons from the UK*. 48-51.
(3) Plackett J., Bourn N. & Bulman C. (2012) Restoring Marsh Fritillary metapopulations on Dartmoor. In Ellis S., Bourn N. & Bulman C, *Landscape-scale conservation for butterflies and moths: Lessons from the UK*. 10-15.
(4) Carleton A. & Schultz C.B. (2013) Restoration action and species response: oviposition habits of *Plebejus icarioides fenderi* (Lepidoptera: Lycaenidae) across a restoration chronosequence in the Willamette Valley, Oregon, USA. *Journal of Insect Conservation*, 17, 511–520.
(5) Rolando A., Negro M., D'Entreves P.P., Balletto E. & Palestrini C. (2013) The effect of forest ski-pistes on butterfly assemblages in the Alps. *Insect Conservation and Diversity*, 6, 212–222.
(6) Shuey J., Jacquart E., Orr S., Becker F., Nyberg A., Littiken R., Anchor T. & Luchik D. (2016) Landscape-scale response to local habitat restoration in the regal fritillary butterfly (*Speyeria idalia*) (Lepidoptera: Nymphalidae). *Journal of Insect Conservation*, 20, 773–780.

13.12. Employ areas of semi-natural habitat for rough grazing (includes salt marsh, lowland heath, bog, fen)

- **Nine studies** evaluated the effects on butterflies and moths of employing areas of semi-natural habitat for rough grazing. Three studies were in Germany[5,6,9], two were in each of the UK[1,4] and the Netherlands[2,3], and one was in each of China[7] and Canada[8].

COMMUNITY RESPONSE (5 STUDIES)

- **Community composition (1 study):** One controlled study in Germany[9] found that after 16–18 years of sheep grazing, lightly grazed and ungrazed saltmarshes had a different community of micro-moths to heavily grazed saltmarsh.
- **Richness/diversity (4 studies):** Two replicated, site comparison studies (including one paired study) in the Netherlands[2] and Canada[8] found that calcareous coastal dunes[2] and shrubsteppe[8] managed by cattle[2,8] or pony[2] grazing for 4–13[2] or 6–40[8] years had a similar species richness of butterflies (in one case combined with all pollinators[8]) to unmanaged land[2,8] or dunes managed by cutting[2]. One controlled study in Germany[5] found that saltmarsh managed by light sheep grazing for 15–18 years had a greater species richness of micro-moths than moderately or heavily grazed marsh, but a similar species richness to ungrazed marsh. One replicated, site comparison study in the UK[4] found that upland rough grassland managed by livestock grazing had a greater species richness of butterflies than permanently or partially grazed improved grassland.

POPULATION RESPONSE (7 STUDIES)

- **Abundance (7 studies):** Two of four studies (including two controlled studies, one before-and-after study and two site comparison studies) in the UK[1], the Netherlands[2], China[7] and Canada[8] found that fenland[1] and calcareous coastal dunes[2] managed by cattle[1,2] or pony[2] grazing for two[1] or 4–13[2] years had a higher abundance of large copper eggs[1] and four of 13 species of butterfly[2] than unmanaged land[1,2] or dunes managed by cutting[2]. One study found that meadow steppe grazed by cattle, goats or sheep for 1–5 years had a lower abundance of butterflies and moths than ungrazed steppe[7]. The fourth study found that shrubsteppe grazed by cattle for 6–40 years had a similar abundance of pollinators (including butterflies) to ungrazed shrubsteppe[8]. Two controlled studies (including one replicated, paired study) in Germany[5,6] found that saltmarsh managed by light sheep grazing for 15–18[5] or 19–22[6] years had a higher total abundance of micro-moths[5], and of two out of seven caterpillars[6], than moderately[5] or heavily[5,6] grazed or ungrazed[6] marsh. However, one of these studies also reported that the abundance of four other caterpillars was lower in lightly or heavily grazed marsh than in ungrazed marsh[6]. One replicated, site comparison study in the UK[4] found that upland rough grassland managed by livestock grazing had a higher abundance of butterflies than permanently or partially grazed improved grassland.

BEHAVIOUR (2 STUDIES)

- **Use (2 studies):** Two replicated, site comparison studies in the Netherlands[2,3] found that calcareous coastal dunes[2] and heathland[3] managed by cattle or pony[2] or year-round horse and sheep[3] grazing for five[3] or 4–13[2] years were more likely to be occupied by brown argus[2] and Alcon large blue[3] than unmanaged land or habitat managed by cutting[2], grazing and sod cutting[3], or summer-only cattle and sheep grazing[3].

Background

Low intensity, rough grazing can be used to maintain open habitats in an early successional state. It can be enclosed (with limited stocking levels) or unenclosed. This action involves grazing semi-natural habitats that are not an integral part of modern farming practice, such as areas of peat bog, or other undrained wetland, lowland heath, saltmarsh and sand dunes. It does not include management of species-rich grasslands, wet meadows or wood pasture. For studies on the use of grazing to maintain these habitats, see "*Agriculture and aquaculture – Maintain species-rich, semi-natural grassland*", "*Agriculture and aquaculture – Maintain or restore traditional water meadows and bogs*", "*Agriculture and aquaculture – Maintain or restore native wood pasture and parkland*".

For other management options for open, semi-natural habitats, see "*Change mowing regime on grassland*", "*Manage heathland by cutting*" and "*Natural system modifications – Use prescribed fire to maintain or restore disturbance in grasslands or other open habitats*".

A controlled, before-and-after study in 1971–1973 in a fen in Cambridgeshire, UK (1) reported that after grazing by cattle, large copper butterflies *Lycaena dispar batava* laid more eggs/plant than either before grazing or than in ungrazed fens. Results were not tested for statistical significance. In the first two years after grazing commenced, the number of eggs (2.1–3.1 eggs/plant) was higher than in either the year before grazing on the same fen (0.1 eggs/plant) or in two ungrazed fens (0.1–1.7 eggs/plant). From late May–early August 1972–1973, one 4.2-ha fen was grazed by six bulls for 9 weeks/year, while two adjacent fens (2.3–3.3 ha) were not grazed. In summer 1972, a total of 137 male and 65 female adult butterflies were released from two cages, one in each ungrazed fen, to supplement the local population. In summer 1973, another 93 males and 70 females were released in one of the ungrazed fens. In August 1972, the vegetation height in the grazed fen (0.6–1.0 m) was lower than in the ungrazed fens (1.2–2.0 m). In the first week of August 1971–1973, all great water dock *Rumex hydrolapathum* plants in each site were examined, and the number of eggs counted.

A replicated, site comparison study in 1992–1996 in 22 calcareous coastal dunes in the Netherlands (2) found that grazed sites had a higher abundance of some butterfly species than unmanaged sites or areas managed by cutting, but management type did not affect species richness. In 1996, the abundance of two out of 13 species was higher at grazed sites (small copper *Lycaena phlaeas*: 14 individuals/site; Queen of Spain fritillary *Issoria lathonia*: 62 individuals/site) than at unmanaged (small copper: 4; Queen of Spain fritillary: 23 individuals/site) or cut sites (small copper: 1; Queen of Spain fritillary: 4 individuals/site). Two other species were more abundant at grazed (small tortoiseshell *Aglais urticae*: 4; painted lady *Vanessa cardui*: 22 individuals/site) or unmanaged sites (small tortoiseshell: 5; painted lady: 22 individuals/site) than at sites managed by cutting (small tortoiseshell: 1; painted lady: 2 individuals/site). Brown argus *Aricia agestis* occurred more frequently in grazed (34% of sites) than in unmanaged (19%) or cut (11%) sites. The remaining eight species had similar abundances in grazed, unmanaged and cut sites (data not presented). Species richness was also similar between grazed (17 species/site), unmanaged (17 species/site) and cut (15 species/site) areas. Over four years, the total abundance of the 20 most common butterflies (out of 35 recorded) increased in grazed and unmanaged sites, but decreased in sites managed by cutting (data not presented). Eleven coastal dunes had been grazed year-round by cattle or ponies at low density (0.05–0.26 animals/ha/year) since 1983–1992, an additional four dunes were cut once/year in late July and a further seven were unmanaged. From April–October 1992–1996, butterflies were surveyed weekly along a 1-km transect at each site.

A replicated, site comparison study in 1998–1999 on 68 wet heathland sites in the Netherlands (3) found that sites grazed year-round by horses and sheep had higher Alcon large blue *Maculinea alcon* occupancy than sites under other grazing regimes or ungrazed sites. Alcon large blue occupancy was higher in grazed plots (68%) than in ungrazed plots (41%), but was lowest in plots where grazing was combined with sod cutting (26%). Among grazed plots, occupancy was highest under year-round grazing by horses and sheep (77%), intermediate under year-round grazing by horses or sheep with summer grazing by cattle (56%), and lowest under summer grazing by cattle and sheep (29%). Sixty-eight wet heathland sites in the Netherlands where Alcon large blue was known to have occurred since 1990 were selected. Management information for the last five years was obtained by sending questionnaires to land managers. Grazing had been used at 44% of sites, with different livestock and regimes, but always equivalent to about 50 kg/ha/year (further details not provided). From mid-July–early September 1998–1999, Alcon large blue eggs were counted in each of three 10 × 10 m plots/site to determine butterfly presence in the plot.

A replicated, site comparison study in 2005–2007 at an upland site in the UK (exact location not given) (4) found that cattle-grazed semi-natural upland rough grassland had a higher abundance and species richness of butterflies than permanently or partially grazed improved pasture. In semi-natural rough grassland, the abundance (905–1,938 individuals) and species richness (15–17 species) of butterflies was higher than either permanently grazed (abundance: 42–156 individuals; richness: 7–11 species) or partially grazed (abundance: 15–67 individuals; richness: 5–10 species) improved pasture. Eight butterfly species were found exclusively on the semi-natural grassland. Six semi-natural plots dominated by purple moor grass *Molinia caerulea* were grazed from June–September. Ten plots of improved perennial rye grass *Lolium perenne*/white clover *Trifolium repens* were grazed throughout the growing season by livestock. Ten similar plots were grazed in spring and autumn, but had livestock excluded from May–September and one silage cut taken. Butterfly transect counts were conducted weekly from mid-April to mid-September 2005–2007.

A controlled study in 1991–2009 in a saltmarsh in Schleswig-Holstein, Germany (5, same experimental set-up as 6, 9) found that lightly grazed and ungrazed saltmarsh supported more micro-moths than more intensively grazed saltmarsh. After 15–18 years of grazing, both the abundance and species richness of moths on a lightly grazed (abundance: light trap: 65.5, emergence trap: 7.1 individuals/trap; richness: light trap: 7.7, emergence trap: 1.3 species/trap) and an ungrazed marsh (abundance: light trap: 88.6, emergence trap: 6.0 individuals/trap; richness: light trap: 6.2, emergence trap: 1.8 species/trap) were higher than on a moderately grazed (abundance: light trap: 25.4, emergence trap: 2.3 individuals/trap; richness: light trap: 3.8, emergence trap: 0.6 species/trap) or heavily grazed marsh (abundance: light trap: 9.0, emergence trap: 0.2

individuals/trap; richness: light trap: 1.5, emergence trap: 0.1 species/trap). In 1991, four paddocks were established on a 1,050-ha saltmarsh and assigned to four grazing treatments: light (1–2 sheep/ha), moderate (3–4 sheep/ha) or heavy grazing (10 sheep/ha), and ungrazed (0 sheep/ha). From June–September 2006–2009, micro-moths were sampled using one 12 V actinic light trap/paddock on 6–9 nights/year (31 nights total). From April–October 2007–2009, micro-moths were sampled using a 1-m^2 steel emergence trap in each of three 150 × 20 m plots/paddock (>250 m apart). Traps were emptied weekly and repositioned every three weeks, therefore sampling 10 m^2/plot/year.

A replicated, paired, controlled study in 1988–2010 in three saltmarshes in Schleswig-Holstein, Germany (6, same experimental set-up as 5, 9) reported that lightly grazed saltmarsh had a higher abundance of two moth caterpillars, but a lower abundance of four caterpillars, than ungrazed saltmarsh, and heavily grazed marsh had a lower abundance of all species. Results were not tested for statistical significance, and data were not presented. In lightly grazed saltmarsh, two caterpillars (wormwood case-bearer *Coleophora artemisiella* and saltern-rush case-bearer *Coleophora adjunctella*) were more abundant than in heavily grazed or ungrazed marsh. Four species (maritime bell *Eucosma lacteana*, saltmarsh bell *Eucosma tripoliana*/pale saltern bell *E. rubescana*, common sea groundling *Scrobipalpa nitentella*, netted bagworm *Whittleia retiella*) were more abundant in ungrazed marsh than in grazed marshes, and one species (saltmarsh case-bearer *Coleophora atriplicis*) occurred in similar numbers in all marshes. None of the seven species recorded were more abundant in heavily grazed saltmarsh than in lightly grazed or ungrazed marsh. In 1988–1991, three heavily grazed (10 sheep/ha) saltmarshes were each divided into three paddocks (11–15 ha) and assigned to either heavy (10 sheep/ha), light (3–4 sheep/ha) or no (0 sheep/ha) grazing. The marshes were grazed from May–October, with sheep removed only during flooding events. In September 2010, moth caterpillars were sampled in sixteen 30-cm diameter points/paddock. In lightly grazed paddocks, eight points were in taller vegetation and eight in short vegetation. Caterpillars were collected by suction sampling (30 seconds), followed by removing and sieving all vegetation above 3 cm, and another 30-second suction sample.

A replicated, randomized, paired, controlled study in 2007–2008 in a meadow steppe grassland in Jilin Province, China (7) found that moderately grazed plots had a lower abundance of butterflies and moths than ungrazed plots. After a year and a half of grazing, the abundance of butterflies and moths on plots grazed by cattle (2–7 individuals/plot), goats (3–7 individuals/plot) or sheep (3–6 individuals/plot) was lower than on ungrazed plots (6–22 individuals/plot). Nine 0.3-ha blocks were each divided into four fenced, 0.05-ha plots, 18–20 m apart, to which four grazing treatments were randomly assigned. From July 2007 and 2008, plots were either grazed by two cattle, eight goats, or eight sheep, or left ungrazed. Grazing was conducted for two hours each morning and evening, until 60% of forage was removed (10–15 days/month, number of months not given). From July–October 2008, insects were surveyed four times by walking two 25-m-long transects/plot, twice/day, and taking 15 sweeps/transect through the vegetation with a 40-cm diameter net. All adult insects were identified to species.

A replicated, paired, site comparison study in 2010 in eight shrubsteppe sites in British Columbia, Canada (8) found that grazed shrubland did not support a higher abundance, species richness or diversity of pollinators (including butterflies) than ungrazed shrubland. On grazed shrubland, the total abundance (469–1,188 individuals), species richness (82–124 species) and diversity (data presented as model results) of pollinators, including butterflies, were all similar to ungrazed shrubland (abundance: 576–925 individuals; richness: 86–113 species). Four pairs of sites (20–1,850 ha), similar in topography and vegetation, were selected. Within each pair, one site was grazed with cattle for 4–6 weeks between April and June annually or biannually, at 14–160 cows/ha/month, while the other site had been ungrazed for 6–40 years. From April–July 2010, pollinating insects were sampled eight times (bi-weekly) by setting 30 yellow, white and blue 12-oz pan-traps for 8.5 hours at 3-m intervals diagonally across a 1-ha plot at each site. Paired sites were always sampled on the same day.

A controlled study in 1991–2009 in a saltmarsh in Schleswig-Holstein, Germany (9, same experimental set-up as 5, 6) found that a lightly grazed and an ungrazed saltmarsh had a different species community of micro-moths compared to a heavily grazed marsh. After 16–18 years of grazing, the moth community in a lightly grazed and an ungrazed saltmarsh was different from that in a heavily grazed saltmarsh (data presented as model results). See paper for individual species results. Until 1990, a 1,050-ha saltmarsh was grazed at 10 sheep/ha. From 1991, four paddocks (100–256 ha) were lightly (1–2 sheep/ha), moderately (3–4 sheep/ha) or heavily grazed (10 sheep/ha), or left ungrazed (0 sheep/ha). The marsh was grazed from May–October, with sheep removed only during flooding events. From April–October 2007–2009, micro-moths were sampled using a 1-m^2 steel emergence trap in each of three 150 × 20 m plots/paddock (>250 m apart). Traps were emptied weekly and repositioned every three weeks, therefore sampling 10 m^2/plot/year.

(1) Duffey E. (1977) The re-establishment of the large copper butterfly *Lycaena dispar batava* obth. on Woodwalton Fen National Nature Reserve, Cambridgeshire, England, 1969-73. *Biological Conservation*, 12, 143–158.
(2) WallisDeVries M.F. & Raemakers I. (2001) Does extensive grazing benefit butterflies in coastal dunes? *Restoration Ecology*, 9, 179–188.
(3) WallisDeVries, M. (2004) A quantitative conservation approach for the endangered butterfly *Maculinea alcon*. *Conservation Biology*, 18, 489–499.
(4) Fraser M.D., Evans J.G., Davies D.W.R. & Vale J.E. (2008) Effect of sward type and management on butterfly numbers in the uplands. *Aspects of Applied Biology*, 85, 15–18.
(5) Rickert C., Fichtner A., van Klink R. & Bakker J.P. (2012) α- and β-diversity in moth communities in salt marshes is driven by grazing management. *Biological Conservation*, 146, 24–31.
(6) van Klink R., Rickert C., Vermeulen R., Vorst O., WallisDeVries M.F. & Bakker J.P. (2013) Grazed vegetation mosaics do not maximize arthropod diversity: Evidence from salt marshes. *Biological Conservation*, 164, 150–157.
(7) Zhu H., Wang D., Guo Q., Liu J. & Wang L. (2015) Interactive effects of large herbivores and plant diversity on insect abundance in a meadow steppe in China. *Agriculture, Ecosystems & Environment*, 212, 245–252.
(8) Elwell S.L., Griswold T. & Elle E. (2016) Habitat type plays a greater role than livestock grazing in structuring shrubsteppe plant-pollinator communities. *Journal of Insect Conservation*, 20, 515–525.
(9) Rickert C., Fichtner A. & van Klink R. (2018) Livestock grazing disrupts plant-insect interactions on salt marshes. *Insect Conservation and Diversity*, 11, 152–161.

13.13. Change mowing regime on grassland

- **Three studies** evaluated the effects on butterflies and moths of changing mowing regimes on grassland. Two studies were in the USA[1,2] and one was in the UK[3].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (3 STUDIES)

- **Abundance (3 studies):** One replicated, paired, controlled, before-and-after study in the UK[3] found that mowing coastal grassland in August reduced the abundance of Fisher's estuarine moth caterpillars, whereas mowing in November or leaving sites unmown did not reduce abundance. One replicated, site comparison study in the USA[1] found that prairies managed by haying had a higher abundance of prairie specialist butterflies, but a lower abundance of generalist and migrant butterflies, than prairies managed by burning, and the abundance of prairie specialists was higher in the first year after haying than in the second year. One replicated, paired, controlled study in the USA[2] found that the abundance of Karner blue butterflies on oak savannas managed by mowing was similar to unmanaged savannas or savannas managed by burning.

BEHAVIOUR (0 STUDIES)

Background

In the absence of wild or domestic grazing animals, mowing or haying can be used to maintain open grasslands or savannas, and prevent scrub encroachment. However, mowing causes a sudden change in the habitat structure, removing nectar plants and potentially injuring or killing eggs, caterpillars or pupae living within the sward (Humbert et al. 2010, Morris 2000). The timing and frequency of mowing may be important for avoiding these short-term negative impacts on butterflies and moths (Morris 2000). This action includes studies comparing different mowing regimes, as well as studies comparing mowing to other options for grassland management, such as burning.

For studies on the creation or restoration of grasslands by either *multiple actions* (which may include mowing) or where the *specific action is not clear*, see "*Restore or create grassland/savannas*". For studies on other actions for grassland management and restoration, see "*Natural system modifications – Use prescribed fire to maintain or restore disturbance in grasslands or other open habitats*", "*Agriculture and aquaculture – Maintain species-rich, semi-natural grassland*" and "*Agriculture and aquaculture – Restore or create species-rich, semi-natural grassland*". For studies on diversifying mowing regimes on productive grasslands, see "*Agriculture and aquaculture – Use rotational mowing*" and "*Agriculture and aquaculture – Delay cutting or first grazing date on grasslands to create variation in sward height*".

Humbert J.Y., Ghazoul J., Sauter G.J. & Walter T. (2010) Impact of different meadow mowing techniques on field invertebrates. *Journal of Applied Entomology*, 134, 592–599.

Morris M.G. (2000) The effects of structure and its dynamics on the ecology and conservation of arthropods in British grasslands. *Biological Conservation*, 95, 129–142.

A replicated, site comparison study in 1992–1993 in 42 tall-grass prairies in Missouri, USA (1) found that prairie specialist butterflies were more abundant in hayed than burned prairies. In the year following haying, the abundance of prairie specialist butterflies (81 individuals/hour) was higher than two years after haying (68 individuals/hour), and both were higher than at sites the year after burning (2 individuals/hour), or two years after burning (21 individuals/hour). However, generalist and migrant species were less abundant at hayed sites (6–19 individuals/hour) than burned sites (18–24 individuals/hour). See paper for individual species results. Among 42 sites (6–571 ha), some were primarily managed by summer haying on a 1–2 year rotation with occasional cattle grazing, and some were managed by cool-season fire covering 5–99% of the site. In June 1992–1993, butterflies were surveyed at least once/year at most sites, either along a transect (35 sites) or from a single point (7 sites, recording only regal fritillary *Speyeria idalia*). Transects were sub-divided by the most recent management. Sixteen species observed >49 times and at >5 sites were included, and divided into "prairie specialists" (only found on prairies), "grassland species" (found in prairies and other grasslands), "generalists" (found in grasslands and other habitats) and "migrants" (only present in the study area during the growing season).

A replicated, paired, controlled study in 1993–1997 in nine oak savannas in Wisconsin, USA (2) found that mowing grasslands in summer did not increase Karner blue butterfly *Lycaeides melissa samuelis* abundance compared to either burned or unmanaged grasslands. On three summer mown grasslands, the density of Karner blue (46–111 individuals/ha) was similar to three summer burned (36–213 individuals/ha) and three unmanaged (43–119 individuals/ha) grasslands. Nine restored oak savannas were burned on average every 3.5 years for 19–33 years prior to 1993. In winter 1993–1994, woody vegetation was removed with chainsaws on three grasslands, and these sites were then cut with a rotary mower in August 1994. In July 1994, three grasslands were burned. Three control grasslands received no mowing or burning. In July–August 1993–1997, butterflies were surveyed three times/grassland/year (>7 days apart) along transects placed 15 m apart.

A replicated, paired, controlled, before-and-after study in 2000–2002 in a coastal grassland in Essex, UK (3) found that mowing in August reduced the abundance of Fisher's estuarine moth *Gortyna borelii lunata* caterpillars, but mowing in November and not mowing did not affect caterpillar numbers. One–two years after mowing in August, the number of hog's fennel *Peucedanum officinale* plants showing signs of caterpillar feeding was lower than before mowing (0.26–0.29 fewer plants/m^2). However, the number of plants with feeding signs after mowing in November was not significantly lower than before mowing (0.10–0.24 fewer plants/m^2). In unmown areas, the number of plants with feeding signs was not significantly different one (0.04 fewer plants/m^2) or two (0.10 more plants/m^2) years after mowing at the other sites compared to before mowing. A grassland behind a sea wall was divided into three blocks, each sub-divided into three 84-m^2 areas. In 2000–2002, areas were either mown with a tractor-drawn mower in late August, cut with a hand-held strimmer in November, or left unmown. Grass was cut to 10 cm with the cuttings left on site. No mowing had been conducted for >5 years prior to the experiment. In May–August 2000–2002, caterpillar feeding signs were recorded monthly on plants in two randomly-placed 1-m^2 plots/treatment.

(1) Swengel A.B. (1996) Effects of fire and hay management on abundance of prairie butterflies. *Biological Conservation*, 76, 73–85.
(2) King R.S. (2003) Habitat management for the Karner blue butterfly (*Lycaeides melissa samuelis*): evaluating the short-term consequences. *Ecological Restoration*, 21, 101–106.
(3) Ringwood Z., Hill J. & Gibson C. (2004) Conservation management of *Gortyna borelii lunata* (Lepidoptera: Noctuidae) in the United Kingdom. *Journal of Insect Conservation*, 8, 173–183.

13.14. Restore or create heathland/shrubland

- **Three studies** evaluated the effects on butterflies and moths of restoring or creating heathland or shrubland. Two studies were in the UK[1,3] and one was in the Netherlands[2].

COMMUNITY RESPONSE (2 STUDIES)

- **Community composition (1 study):** One replicated, paired, site comparison study in the UK[1] found that the moth community on restored moorland was more similar to that on established heather moorland than on degraded moorland.
- **Richness/diversity (1 study):** One replicated, site comparison study in the Netherlands[2] found that in heathlands restored by topsoil removal butterfly species richness was lower than in the surrounding landscape.

POPULATION RESPONSE (2 STUDIES)

- **Abundance (2 studies):** One replicated, site comparison study in the Netherlands[2] found that in heathlands restored by topsoil removal butterfly species richness was lower than in the surrounding landscape but at restored sites abundance was higher in areas where heather litter had also been spread than where it had not. One study in the UK[3] reported that a population of silver-studded blue butterflies released into a site which was managed for heathland restoration increased in abundance over 11 years.

BEHAVIOUR (1 STUDY)

- **Use (1 study):** One study in the UK[3] reported that a population of silver-studded blue butterflies released into a site where heathland was being restored expanded its range beyond its initial release area.

Background

The loss of heathland or shrubland may occur due to a range of factors, including too many grazing animals inhibiting regeneration of shrubs, too few grazing animals or fire suppression leading to reversion to woodland, or invasion by non-native species. Shrubland restoration or creation may benefit butterflies and moths associated with the habitat.

Habitats within this action include dry heathland, shrubland and moorland. For studies on restoring wet heathland and raised bogs, see "*Restore or create peatland*". For studies on restoring dry grassland, see "*Restore or create grassland/savannas*".

This action includes studies where either *multiple actions* have been used to restore or create heathland or shrubland, or where the *specific action used is not clear*. For studies of specific actions for creating, restoring, or managing heathland and shrubland, see "*Replant native vegetation*", "*Employ areas of semi-natural habitat for rough grazing (includes salt marsh, lowland heath, bog, fen)*", "*Manage heathland by cutting*" and "*Natural system modifications – Use prescribed fire to maintain or restore disturbance in grasslands or other open habitats*".

A replicated, paired, site comparison study in 2003 on eight moorlands in northern England and Scotland, UK (1) found that the moth community on restored moorland was more similar to that on established heather moorland than on degraded moorland. Compared to degraded moorland (0%) and established heather moorland (100%), restored moorland sites had moth communities that were 54–95% similar to established sites 6–13 years after restoration commenced. Sites restored by grazing exclusion were 63–95% similar to established sites 6–13 years after restoration, while sites restored by herbicide application and re-seeding were 54–75% similar to established sites 8–11 years after restoration (statistical significance not assessed). Restoration of eight moors commenced from 1990–1997. On four moors, restoration was conducted by grazing exclusion. At the other four moors, herbicide application and reseeding was used, sometimes with burning of dead vegetation and scarification of the ground. On each moor, 18 sample locations were established over 1–4 km: six each in restored sites (recreated dominance of heather *Calluna vulgaris*), degraded sites (acid grassland dominated by purple moor-grass *Molinia caerulea* or matgrass *Nardus stricta*), and established heather moorland. On 44 nights from June–September 2003, moths were caught in 2–3 Skinner light traps/night in different habitats, and identified to species at dawn.

A replicated, site comparison in 2002–2003 in eight restored heathlands in Groningen, Friesland and Drenthe, the Netherlands (2) found that butterfly abundance and species richness was lower in heathlands restored by topsoil removal than in the surrounding landscape, but abundance was higher in an area where heather litter had also been spread than where it had not. There was lower abundance and species richness of both heathland specialist and generalist butterflies in the areas restored through topsoil removal (abundance: specialist = 4, generalist = 14; species richness: specialist = 3, generalist = 5) than in the surrounding 1 km^2 (abundance: specialist = 5, generalist = 16; species richness: specialist = 13, generalist = 12). At a site with some heather litter spreading as well, there was higher abundance of specialist and generalist species where the heather had been spread (specialist = 39, generalist = 46). than where it had not (specialist = 5, generalist = 32). See paper for details of individual species. In 1990–1994, up to 50 cm of topsoil was removed from eight former agricultural sites to restore them to heathland. Heather cuttings were spread on the ground at part of one site. Five restoration sites had 12–40 ha of heathland in the surrounding 1 km^2, and three were surrounded only by agricultural land. In April–September 2002–2003, butterflies were surveyed at each site along walking transects of >500 m, with one transect in each restored site and one in the corresponding surrounding 1 km^2 habitat (heathland for five and agricultural land for three), resulting in 16 transects which were surveyed at least four times annually. At the site with heather spreading half the transect was within the spreading area and half outside it.

A study in 2007–2018 in a heathland in Suffolk, UK (3) reported that a population of silver-studded blue *Plebejus argus* translocated into a site with ongoing habitat management, survived for at least 11 years, increased in number and expanded its range. The highest single day count increased from 60 butterflies released in 2007 to 160 in 2013. Along a fixed transect, the annual butterfly 'population index' was 41 a year after release and 662 ten years later. Authors report that the area the butterflies were recorded in increased over time. In 2007, sixty butterflies were translocated to Blaxhall Common from two existing colonies in Suffolk. From 2007–2018, areas of bell heather *Erica cinerea* were forage harvested to create young patches, silver birch was controlled and areas of gorse *Ulex* spp. and other scrub were cleared. For 2007–2013 a daily peak count figure was provided from fixed point counts and for 2008–2018 a population index figure was calculated from recording butterflies along a fixed transect (number of counts and transects/year not given).

(1) Littlewood N.A., Dennis P., Pakeman R.J. & Woodin S.J. (2006) Moorland restoration aids the reassembly of associated phytophagous insects. *Biological Conservation*, 132, 395–404.
(2) Wallis De Vries M.F. & Ens S.H. (2010) Effects of habitat quality and isolation on the colonization of restored heathlands by butterflies. *Restoration Ecology*, 18(3), 390-398.
(3) Parker R. (2018) Still working at re-establishment of the silver-studded blue Plebejus argus – real progress from 2007 to 2018. *British Journal of Entomology and Natural History*, 31(4), 217-223.

13.15. Manage heathland by cutting

- **Three studies** evaluated the effects on butterflies and moths of managing heathland by cutting. Two studies were in the USA[1,2] and one was in the UK[3].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (3 STUDIES)

- **Abundance (3 studies):** One site comparison study in the USA[2] found that a pine barren managed for 13 years by mechanical cutting had a higher abundance of Karner blue butterflies than barrens managed by rotational burning or unburned refuges. One before-and-after study in the USA[1] found that the abundance of five butterfly species did not change after the management of a pine barren was changed from rotational burning to unintensive cutting. One before-and-after study in the UK[3] reported that the abundance of high brown fritillary and small pearl-bordered fritillary increased after scrub cutting, along with tree felling, coppicing and grazing.

BEHAVIOUR (0 STUDIES)

Background

Heathland, like other open habitats, requires some disturbance to maintain habitat favourable to specialist species of butterflies and moths. Management by cutting is one option for creating this disturbance, but cutting causes a sudden change in the habitat structure, potentially removing nectar resources or injuring or killing eggs, caterpillars or pupae living within the heath (Humbert et al. 2010, Morris 2000). Therefore, the timing and frequency of cutting may be important for avoiding these short-term negative impacts on butterflies and moths (Morris 2000). This action includes studies comparing different cutting regimes, as well as studies comparing cutting to other options for heathland management, such as burning.

For studies on the creation or restoration of heathland or shrubland by either *multiple actions* (which may include cutting) or where the *specific action is not clear*, see "*Restore or create heathland/shrubland*". For studies on other actions for heathland and shrubland management and restoration, see "*Replant native vegetation*", "*Employ areas of semi-natural habitat for rough grazing (includes salt marsh, lowland heath, bog, fen)*" and "*Natural system modifications – Use prescribed fire to maintain or restore disturbance in grasslands or other open habitats*".

Humbert J.Y., Ghazoul J., Sauter G.J. & Walter T. (2010) Impact of different meadow mowing techniques on field invertebrates. *Journal of Applied Entomology*, 134, 592–599.

Morris M.G. (2000) The effects of structure and its dynamics on the ecology and conservation of arthropods in British grasslands. *Biological Conservation*, 95, 129–142.

A before-and-after study in 1988–1996 on a pine barren in Wisconsin, USA (1) found that the abundance of five butterfly species did not change following the initiation of unintensive cutting instead of burning management. In the first three years after cutting commenced, the abundance of frosted elfin *Callophrys irus* (1.3 individuals/hour), Olympia marble *Euchloe olympia* (18 individuals/hour), Karner blue *Lycaeides melissa samuelis* (120 individuals/hour), Persius duskywing *Erynnis persius* (1.8 individuals/hour), and dusted skipper *Atrytonopsis hianna* (1 individual/hour) were all similar to under the previous burning regime (frosted elfin: 0; Olympia marble: 6; Karner blue: 135; Persius duskywing: 0.7; dusted skipper: 0 individuals/hour). In April 1988 and 1991, an area of pine barren was burned. In April 1994, the area was not burned, and unintensive cutting management commenced. Between 1988–1996, butterflies were surveyed along a transect at the site multiple times/year (no further details provided).

A site comparison study in 1992–2005 in a pine barren in Wisconsin, USA (2) found that an area managed by mechanical cutting supported more Karner blue butterflies *Lycaeides melissa samuelis* than areas managed by rotational burning. Over 13 years, in an area managed by cutting, Karner blue abundance (28–32 individuals/year) was higher than in areas managed by rotational burning (9–11 individuals/year) or rotational burning and cutting (8–10 individuals/year). An unburned refuge supported a similar abundance of Karner blue (11–14 individuals/year). Within a 12,180-ha pine barren, six areas with a similar abundance of wild lupine *Lupinus perennis* were compared. One area was managed by mechanical cutting, one was managed with cool-season rotational burning, three were managed by burning and cutting, and one area was left as a 14-ha unburned refuge (last burned in 1988). From May–July 1992–1995 and 1997–2005, butterflies were surveyed once/year along transects in each area.

A before-and-after study in 2002–2011 in an area of heathland, woodland and grassland in South Wales, UK (3) reported that after scrub cutting was conducted, along with tree felling, coppicing and grazing, the number of high brown fritillary *Argynnis adippe* and small pearl-bordered fritillary *Boloria selene* increased. Results were not tested for statistical significance. In 2002, prior to scrub control, an average of seven high brown fritillary adults/hour were recorded at the site, and seven years after scrub clearance began, 14 adults/hour were recorded. Small pearl-bordered fritillary also increased in number between 2003 and 2011 (numbers not given). From 2003–2011 some patches of bracken *Pteridium aquilinum*, bramble *Rubus fruticosus* agg., honeysuckle *Lonicera periclymenum* and tree saplings were cut back in the Alun Valley, a 254 ha landscape comprising heathland, woodland and grassland. Tree felling (2003–2011), coppicing of hazel *Corylus avellana* and gorse *Ulex europaeus* (1999–2011) and sheep grazing (start date not given–2011) were also conducted in areas of the site. Adult butterflies were counted annually from 2002–2011.

(1) Swengel A.B. & Swengel S.R. (1997) Co-occurrence of prairie and barrens butterflies: applications to ecosystem conservation. *Journal of Insect Conservation*, 1, 131–144.

(2) Swengel A.B. & Swengel S.R. (2007) Benefit of permanent non-fire refugia for Lepidoptera conservation in fire-managed sites. *Journal of Insect Conservation*, 11, 263–279.

(3) Hobson R. & Smith R. (2012) High Brown Fritillary in the Vale of Glamorgan: saving the last site in Wales In Ellis S., Bourn N. & Bulman C., *Landscape-scale conservation for butterflies and moths: Lessons from the UK*. 52–57.

Aquatic, wetland and riparian habitat

13.16. Restore or create peatland

- **Six studies** evaluated the effects on butterflies and moths of restoring or creating peatland. Two studies were in each of Finland[4,6] and the UK[1,2], and one was in each of the Netherlands[3] and Ireland[5].

COMMUNITY RESPONSE (3 STUDIES)

- **Community composition (1 study):** One replicated, paired, site comparison study in Finland[4] found that mires restored by filling ditches and cutting trees had a moth community which was intermediate between drained and pristine mires.
- **Richness/diversity (2 studies):** One replicated, paired, controlled, before-and-after study in Finland[6] found that after mires were restored by raising the water table and removing large trees, they had a higher species richness of mire specialist butterflies than before restoration or than unrestored, drained mires, and a similar species richness to pristine mires. One replicated, paired, site comparison study in Ireland[5] reported that protected bogs re-wetted by blocking drains had a similar species richness of moths to unrestored and unprotected bogs.

POPULATION RESPONSE (5 STUDIES)

- **Abundance (4 studies):** Two before-and-after studies (including one replicated, paired, controlled study) in the UK[2] and Finland[6] found that bogs re-wetted by blocking drains[2] and mires restored by raising the water table and removing large trees[6] had a higher abundance of rosy marsh moth caterpillars[2] and mire specialist butterflies[6] than before restoration[2,6] or than unrestored mires[6], and a similar abundance to pristine mires[6]. Two replicated, paired, site comparison studies in Finland[4] and Ireland[5] found that mires restored by filling ditches and cutting trees[4] and bogs restored by blocking drains (along with legal protection)[5] had mixed effects on moth abundance compared to unrestored sites depending on species.

- **Survival (1 study):** One replicated study in the UK[1] found that where water levels had risen due to peatland restoration, large heath butterfly caterpillars had lower winter survival than in areas where water levels had not risen.

BEHAVIOUR (1 STUDY)

- **Use (1 study):** One replicated, site comparison study in the Netherlands[3] found that wet heathland where water levels had been recently raised were less frequently occupied by Alcon large blue than sites where the water level had not been raised.

Background

Large areas of peatland have been deliberately or unintentionally drained (for example extracting drinking water from below ground lowers the water table over a large area) for human activities. Drained peat can be too dry and chemically unsuitable for peatland plants (Lamers *et al.* 2002), reducing the suitability of habitat for specialist butterflies and moths. Peatland restoration typically involves raising the water table to rewet the surface peat. This creates more suitable conditions for recolonization by peatland plants (Money & Wheeler 1999; Ritzema et al. 2014), such as bog myrtle *Myrica gale*, which could benefit butterflies and moths which depend upon them as a caterpillar food source (Fowles *et al.* 2004). However, the rate at which water levels are raised may need to be controlled, so as not to submerge overwintering caterpillars (Joy & Pullin 1997, 1999). It may also be necessary to rewet the area around a peatland (creating a 'hydrological buffer zone') to prevent water simply draining away from the peatland.

A range of techniques may be used to raise the water table to restore peatlands, for example blocking drainage ditches, planting flood-resistant vegetation to slow water flow, blocking underground channels, building raised embankments to retain water, inserting dams below the peat surface to slow subsurface drainage, switching off drainage pumps, felling trees, or restoring inflows. These interventions are all considered in this action. For studies of specific actions for creating, restoring, or managing peatlands, see "*Replant native vegetation*" and "*Employ areas of semi-natural habitat for rough grazing (includes salt marsh, lowland heath, bog, fen)*".

Habitats within this action include peatland, bogs, mires, and wet heathland, where the water table is close to the ground surface. For studies on restoring wet grasslands, fenland and floodplains, see "*Restore or create wetlands and floodplains*". For studies on restoring dry heathland and shrubland, see "*Restore or create heathland/shrubland*".

Fowles A.P., Bailey M.P. & Hale A.D. (2004) Trends in the recovery of a rosy marsh moth *Coenophila subrosea* (Lepidoptera, Noctuidae) population in response to fire and conservation management on a lowland raised mire. *Journal of Insect Conservation*, 8, 149–158.

Joy J. & Pullin A.S. (1997) The effects of flooding on the survival and behaviour of overwintering large heath butterfly *Coenonympha tullia* larvae. *Biological Conservation*, 82, 61–66.

Joy J. & Pullin A.S. (1999) Field studies on flooding and survival of overwintering large heath butterfly, *Coenonympha tullia*, larvae on Fenn's and Whixall Mosses in Shropshire and Wrexham, UK. *Ecological Entomology*, 24, 426–431.

Lamers L.P., Smolders A.J.P. & Roelofs J.G.M. (2002) The restoration of fens in the Netherlands. *Hydrobiologia*, 478, 107–130.

Money R.P. & Wheeler B.D. (1999) Some critical questions concerning the restorability of raised bogs. *Applied Vegetation Science*, 2, 107–116.

Ritzema H., Limin S., Kusin K., Jauhiainen J. & Wösten H. (2014) Canal blocking strategies for hydrological restoration of degraded tropical peatlands in Central Kalimantan, Indonesia. *Catena*, 114, 11–20.

A replicated study in 1996–1998 in two peatland sites in Wrexham and Shropshire, UK (1) found that where water levels had risen due to peatland restoration, large heath butterfly *Coenonympha tullia* caterpillars had lower winter survival than in areas where water levels had not risen. Caterpillars on cotton-sedge tussocks *Eriophorum vaginatum* in plots with high water levels resulting from restoration activities had lower winter survival (0–35%) than caterpillars on tussocks where the restoration had not affected water levels (54–63%). Prior to the study (years not given) drains were blocked at Fenn's and Whixall Mosses to raise water levels as part of a site restoration programme to create wetter areas of the sites. In winter 1996–1997 one dry study plot was located at Whixall and one wet plot at Fenn's, but in 1997–1998 both the wet and dry plots were located at Whixall. In September 1996 and 1997, twenty captive-reared large heath caterpillars were put on each of four low-lying cotton-sedge tussocks in that year's plots (two plots/year and a total of 80 caterpillars/ plot).

A before-and-after study in 1988–2003 in a raised bog in Ceredigion, UK (2) reported that a re-wetted bog supported a larger population of rosy marsh moth *Coenophila subrosea* caterpillars than before drains were blocked. Results were not tested for statistical significance. One to five years after the last drains were blocked, 27–88 caterpillars/year were recorded, compared to 8–27 caterpillars/year in the preceding 10 years. From the mid-1980s, large drains surrounding a raised bog were dammed. In 1993 and 1998, shallow peat-cuttings were also blocked, raising the water table at the site from 42 cm to 48 cm over 15 years. In late May 1988–2003, caterpillars were counted once/year, at night, in fourteen 15 × 1 m plots along a transect across the bog.

A replicated, site comparison study in 1998–1999 on 68 wet heathland sites in the Netherlands (3) found that raising water levels reduced occupancy by Alcon large blue *Maculinea alcon*. Fewer recently flooded sites were occupied by Alcon large blue (48%) than non-flooded sites (85% occupancy), and sites where measures had been taken to raise the water level were more likely to be flooded (68%) than sites without such measures (35%). Sixty-eight wet heathland sites in the Netherlands where Alcon large blue was known to have occurred since 1990 were selected. Management information for the last five years was obtained by sending questionnaires to land managers. Changes in management designed to raise water levels had been used at 31% of sites (further details not provided). From mid-July–early September 1998–1999, Alcon large blue eggs were counted in each of three 10 × 10 m plots/site to determine butterfly presence in the plot.

A replicated, paired, site comparison study in 2007 in nine boreal mires in Central Finland and Northern Karelia, Finland (4, same experimental set-up as 5) found that mires restored by ditch-filling and tree cutting had moth communities which were intermediate between those found on drained and pristine mires. One–three years after restoration, the moth community on restored mires was intermediate between the communities found on drained and pristine mires (data presented as model results). One of three mire specialist micro-moths (rush marble *Bactra lancealana*) and one of two specialist macro-moths (Manchester treble-bar *Carsia sororiata*) were more numerous in restored than drained sites, but were most abundant in pristine sites. However, one specialist micro-moth (*Crambus alienellus*) and one specialist macro-moth (*Arichanna melanaria*) were more abundant in the drained sites than restored sites. A third specialist micro-moth (pearl-band grass-veneer *Catoptria margaritella*) did not differ in abundance between restored, drained and pristine sites (see paper for details). In the 1960s and 1970s, parts of nine mires were drained for forestry. From 2003–2006, some drained areas were restored by filling ditches with peat, damming the ends with logs and peat, and cutting trees. Each mire also contained a pristine, undrained area. In 2007, moths were sampled along two 250-m transects in each restored, drained and pristine area (six transects/mire). From May–August, micro-moths were sampled weekly using 100 sweeps/transect of a 28-cm diameter net at all nine mires. From May–July, macro-moths were counted weekly along each transect at five of the mires.

A replicated, paired, site comparison study in 2011 in 12 bogs in County Offaly, Ireland (5) found that protected bogs, some of which had been re-wetted, had a similar total abundance and species richness of moths to unprotected bogs, but individual species showed mixed preferences. The total number of moths recorded on protected bogs was 951 individuals of 67 species, compared to 865 individuals of 73 species on unprotected bogs (statistical significance not assessed). Of the 14 most common species, three were more abundant on protected bogs (dark arches *Apamea monoglypha*, large yellow underwing *Noctua pronuba*, dark tussock *Dicallomera fascelina*), three were more abundant on unprotected bogs (map-winged swift *Pharmacis fusconebulosa*, narrow-winged pug *Eupithecia nanata*, spruce carpet *Thera britannica*), and eight showed no difference (data presented as model results). Of 15 bog-associated species of conservation concern, only three (dark tussock, bordered grey *Selidosema brunnearia*, garden tiger *Arctia caja*) were recorded in higher numbers on protected sites than on unprotected sites (statistical significance not assessed). Six raised bogs (74–246 ha) designated as Special Areas of Conservation, and six nearby (1.5–5 km away), highly modified but vegetated undesignated raised bogs (40–578 ha) were selected. At four of the protected sites, restoration work (mostly drain blocking) had taken place. From July–October 2011, moths were sampled five times using a Heath-type actinic 15 W light trap left overnight at each site. Paired sites were sampled on the same night, and all sites were sampled over two nights/visit.

A replicated, paired, controlled, before-and-after study in 2003–2014 in 19 boreal mires in Finland (6, same experimental set-up as 3) found that restoring mires by raising the water table and removing large trees increased the abundance and species richness of mire specialist butterflies. On restored mires, the abundance (1.8 individuals) and species richness of mire specialist butterflies was higher than on drained mires (0.8 individuals), and similar to pristine mires (2.9 individuals; data for species richness not presented). Prior to restoration, abundance and species richness were similar in sites to be restored (1.4 individuals) and drained sites (1.7 individuals), but higher on pristine sites (3.6 individuals). See paper for individual species results. Each of 19 mires comprised three habitats: drained sites which were restored during the study, drained sites that remained in forestry use throughout the study, and undrained pristine sites. At restored sites, tall trees were removed and the water table was raised. Nine mires were restored between 2004 and 2006, and 10 were restored from 2011–2013. Six 250-m transects were established in each mire (2 transects/habitat, 80 m apart). Beginning in May, butterflies were surveyed weekly in years before (2003 or 2010) and after (2007 or 2014) restoration at each mire (7–15 visits/site/year), and divided into specialists (species which predominantly occur on mires) and generalists (species which predominantly occur in other habitats).

(1) Joy J. & Pullin A.S. (2001) Field studies on flooding and survival of overwintering large heath butterfly Coenonympha tullia larvae on Fenn's and Whixall Mosses in Shropshire and Wrexham, U.K. *Ecological Entomology*, 24(4), 426-431.
(2) Fowles A.P., Bailey M.P. & Hale A.D. (2004) Trends in the recovery of a rosy marsh moth *Coenophila subrosea* (Lepidoptera, Noctuidae) population in response to fire and conservation management on a lowland raised mire. *Journal of Insect Conservation*, 8, 149–158.
(3) WallisDeVries, M. (2004) A quantitative conservation approach for the endangered butterfly *Maculinea alcon*. *Conservation Biology*, 18, 489–499.
(4) Noreika N., Kotiaho J.S., Penttinen J., Punttila P., Vuori A., Pajunen T., Autio O., Loukola O.J. & Kotze D.J. (2015) Rapid recovery of invertebrate communities after ecological restoration of boreal mires. *Restoration Ecology*, 23, 566–579.
(5) Flynn C., Griffin C.T., Coll J. & Williams C.D. (2016) The diversity and composition of moth assemblages of protected and degraded raised bogs in Ireland. *Insect Conservation and Diversity*, 9, 302–319.
(6) Noreika N., Kotze D.J., Loukola O.J., Sormunen N., Vuori A., Päivinen J., Penttinen J., Punttila P. & Kotiaho J.S. (2016) Specialist butterflies benefit most from the ecological restoration of mires. *Biological Conservation*, 196, 103–114.

13.17. Restore or create wetlands and floodplains

- **Three studies** evaluated the effects on butterflies and moths of restoring or creating wetlands and floodplains. Two studies were in the USA[1,3] and one was in Sweden[2].

COMMUNITY RESPONSE (1 STUDY)

- **Richness/diversity (1 study):** One replicated, site comparison study in Sweden[2] found that wetland creation increased macroinvertebrate diversity (including butterflies and moths), and that species richness increased with wetland age and was similar to mature ponds.

POPULATION RESPONSE (2 STUDIES)

- **Abundance (1 study):** One site comparison study in the USA[3] found that wetland prairie restored by seeding willow dock and seasonal flooding had a higher abundance of great copper eggs than degraded, unflooded prairie.
- **Survival (1 study):** One site comparison study in the USA[1] found that the survival of great copper eggs and caterpillars was lower in wetland prairie restored by planting native seed mixes and flooding annually than in degraded, unflooded prairie.

BEHAVIOUR (1 STUDY)

- **Use (1 study):** One site comparison study in the USA[1] found that wetland prairie restored by planting native seed mixes and flooding annually was used more by adult great copper than degraded, unflooded prairie.

Background

Wetland habitats are often drained or degraded during the development of agriculture or expansion of urban areas or other land uses. Restoration of these habitats can help to recover specialist butterfly and moth populations. Restoration of wetlands may involve a combination of interventions, such as removing invasive and emergent plants, maintaining bankside vegetation and trees, planting native species, and raising water levels or reinstating seasonal flooding.

Habitats within this action include wet grassland, fenland and floodplains. For studies on restoring dry grassland, see "*Restore or create grassland/savannas*". For studies on restoring peatland, bogs, mires and wet heathland, see "*Restore or create peatland*". For studies on the creation of smaller areas of water, see "*Create scrapes and pools*".

This action includes studies where either *multiple actions* have been used to restore or create wetlands and floodplains, or where the *specific action used is not clear*. For studies of specific actions for creating, restoring, or managing wetlands and floodplains, see "*Replant native vegetation*", "*Manage wetlands or ponds by grazing or cutting to prevent succession*" and "*Natural system modifications – Use prescribed fire to maintain or restore disturbance in grasslands or other open habitats*".

A site comparison study in 2004–2005 in three wetland prairies in Oregon, USA (1, same experimental set up as 3) found that restored wetland prairies were used by adult great copper *Lycaena xanthoides* more than degraded prairies, but egg survival was lower in restored areas. In two restored wetlands, the proportion of marked butterflies which were recaptured in the area (26 out of 32 butterflies) was higher than at an unrestored site (3 out of 16 butterflies). However, the survival of eggs to large caterpillars in restored, flooded sites (2 out of 84 eggs) was lower than in unrestored, unflooded sites (7 out of 46 eggs). In the late 1990s, two wetland prairies (16–26 ha) were partially restored by planting a wetland prairie vernal pool native seed mix, and flooded annually. Unrestored parts of both sites, and a third, 76-ha, unrestored site, remained dominated by non-native grasses and did not flood. From late summer 2004–June 2005, eggs on 24 willow dock *Rumex salicifolius* plants in either restored, flooded areas or unrestored, unflooded areas, were revisited monthly to record survival to large caterpillars.

From July–August 2005, every 3–4 days, butterflies were caught, marked, released and recaptured in a 1–2.9 ha area with a high density of willow dock at each site.

A replicated, site comparison study in 2004 in a lowland agricultural region in southwest Sweden (2) found that wetland creation increased macroinvertebrate diversity, including butterflies and moths. From 0–8 years after creation, wetlands contained 6–51 aquatic macroinvertebrate species, and the estimated addition to regional species richness ranged from 1–33 species/created wetland. Species richness increased with wetland age (data presented as model results). Species richness in created wetlands (32 species/pond; 176 species total) was similar to existing mature ponds (37 species/pond; 178 species total). From 1996–2004, about 300 ha of wetlands (each <2 ha) were created in natural depressions of former pasture, crop or fallow land by soil excavations and damming existing waterways or drainage systems. In three sub-regions with low, moderate and high densities of created wetlands, 15% (i.e. 13, 8, and 15 wetlands) were surveyed in May 2004, by sweeping a D-shaped hand-net twice at 15 points along each wetland margin. Sampled wetlands were all permanent, flow-through water bodies. Ten mature ponds (>50-years-old) in the region had been sampled at intervals in April 1996–2003.

A site comparison study in 2007 in two wetland prairies in Oregon, USA (3, same experimental set up as 1) found that great copper *Lycaena xanthoides* laid more eggs on willow dock *Rumex salicifolius* plants in restored, seasonally flooded wetlands than in degraded, unflooded areas, but egg survival was lower in restored wetlands than in unflooded habitats. In restored, seasonally flooded wetlands, great copper eggs were present on more of the available willow dock plants (10 out of 14 plants) than in degraded, unflooded areas where plants were surrounded by tall, non-native grasses (6 out of 37 plants), and the number of eggs/plant was higher (restored: 0–9 eggs/plant; degraded: 0–3 eggs/plant). However, the authors noted that egg survival was lower in flooded areas than in unflooded habitat (see 1 - Severns et al. 2006). In the late 1990s, several thousand willow dock were seeded in two 0.8-ha, seasonally flooded, restored wetlands. Each restored area was surrounded by degraded, unrestored, unflooded habitat. In August 2007, every willow dock plant at each site was searched for great copper eggs. Plants were categorized as growing in either flooded or unflooded habitat.

(1) Severns P.M., Boldt L. & Villegas S. (2006) Conserving a wetland butterfly: quantifying early lifestage survival through seasonal flooding, adult nectar, and habitat preference. *Journal of Insect Conservation*, 10, 361–370.
(2) Thiere G., Milenkowski S., Lindgren P.E., Sahlén G., Berglund O. & Weisner S.E.B. (2009) Wetland creation in agricultural landscapes: Biodiversity benefits on local and regional scales. *Biological Conservation*, 142, 964–973.
(3) Severns P.M. (2011) Habitat restoration facilitates an ecological trap for a locally rare, wetland-restricted butterfly. *Insect Conservation and Diversity*, 4, 184–191.

13.18. Manage wetlands or ponds by grazing or cutting to prevent succession

- **Three studies** evaluated the effects on butterflies and moths of managing wetlands or ponds by grazing or cutting. Two studies were in the Netherlands[1,3] and one was in Switzerland[2].

COMMUNITY RESPONSE (1 STUDY)

- **Richness/diversity (1 study):** One replicated, site comparison study in Switzerland[2] found that fens managed by mowing had a greater species richness of butterflies than fens managed by cattle grazing.

POPULATION RESPONSE (2 STUDIES)

- **Abundance (1 study):** One replicated, site comparison study in the Netherlands[1] found that recently cut fens had fewer large copper eggs than uncut fens.
- **Survival (2 studies):** Two replicated, site comparison studies in the Netherlands[1,3] found that large copper caterpillar survival was lower in recently cut fens[1], and fens cut in autumn or winter[3], than in uncut fens.

BEHAVIOUR (0 STUDIES)

Background

Wetlands support a number of specialist butterfly and moth species, but this habitat requires some form of disturbance to prevent succession into scrub or woodland. In natural systems, this may have been provided by seasonal flooding and wild grazing animals, but flooding may not be possible in wetlands constrained by surrounding human land use. Cutting or mowing wetlands, or grazing with domestic livestock, may be able to replace natural disturbance regimes, but the frequency and timing of management may be important for benefitting, or avoiding harm to, particular species.

For studies on the creation or restoration of wetlands by either *multiple actions* (which may include grazing or cutting) or where the *specific action is not clear*, see "*Restore or create wetlands and floodplains*". For studies on other actions for wetland management and restoration, see "*Replant native vegetation*" and "*Natural system modifications – Use prescribed fire to maintain or restore disturbance in grasslands or other open habitats*".

For studies on the using of grazing and mowing to manage other semi-natural habitats, see "*Employ areas of semi-natural habitat for rough grazing (includes salt marsh, lowland heath, bog, fen)*", "*Change mowing regime on grassland*" and "*Manage heathland by cutting*".

A replicated, site comparison study in 1994–1996 in a fenland in Overijssel, the Netherlands (1) found that three recently cut fen habitats had fewer large copper *Lycaena dispar batavus* eggs and lower caterpillar survival than two uncut fen habitats. There were fewer large copper eggs on plants in cut fen meadows (0.2–0.3 eggs/plant) than on plants in cut (0.3–0.8 eggs/plant) or uncut (1.8–1.9 eggs/plant) watersides, and the most eggs were found in uncut fen edges (4.2–5.7 eggs/plant). No eggs were found in cut reed fields. In addition, no caterpillars were found in cut fen meadows (from 70 eggs), and caterpillar survival was only marginally higher in cut watersides (11–13 caterpillars from 102 eggs) than in uncut watersides (11–23 caterpillars from 280 eggs) or uncut fen edges (13–31 caterpillars from 425 eggs). Five fenland habitats with different management were surveyed. Fen meadows were cut in patches in August–September; watersides were split into cut (in the preceding year) or uncut areas; fen edges along old ditches were uncut; and reed fields were cut commercially in winter. In August 1994 and 1995, the number of eggs were counted on every water dock *Rumex hydrolapathum* encountered 1 m either side of 2–5 transects/year (40–200 m long) through each habitat type. In late May 1995 and early June 1996, the number of surviving caterpillars were counted on the same plants.

A replicated, site comparison study in 1996 in 24 montane fens in Switzerland (2) found that fens managed by mowing had more species of butterfly than fens managed by cattle grazing. The species density of butterflies was higher on mown fens (8.9 species/transect) than on grazed fens (7.7 species/transect). Twelve of 23 fens (0.8–15.4 ha) were managed by mowing, and 11 by cattle grazing. From July–August 1996, butterflies were surveyed once on a 10-minute walk along each of three 540-m transects/fen.

A replicated, site comparison study in 1996–1998 in nine fens in Overijssel, the Netherlands (3) found that fens cut in autumn or winter had lower large copper *Lycaena dispar batavus* caterpillar survival than uncut fens. The overwinter survival of large copper caterpillars in fens cut in autumn or winter (2–3%/year: 5/176 caterpillars found) was lower than in unmanaged fens (15–20%/year: 36/222 caterpillars found). In 1996–1998, four fens within a 3,500-ha lowland bog in the Netherlands were cut in autumn or winter, and five fens were not cut. In 1996–1997, wild large copper eggs were counted on every great water dock *Rumex hydrolapathum* plant encountered along a transect through each site. Plants were revisited three weeks later, and in April the following year, to record caterpillar survival.

(1) Pullin A.S. (1997) Habitat requirements of *Lycaena dispar batavus* and implications for re-establishment in England. *Journal of Insect Conservation*, 1, 177–185.
(2) Wettstein W. & Schmid B. (1999) Conservation of arthropod diversity in montane wetlands: effect of altitude, habitat quality and habitat fragmentation on butterflies and grasshoppers. *Journal of Applied Ecology*, 36, 363–373.
(3) Nicholls C.N. & Pullin A.S. (2000) A comparison of larval survivorship in wild and introduced populations of the Large Copper butterfly (*Lycaena dispar batavus*). *Biological Conservation*, 93, 349–358.

13.19. Create scrapes and pools

- We found no studies that evaluated the effects on butterflies and moths of creating scrapes and pools.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Access to water or damp environments is important for some species of butterfly and moth, including those where the adults gather nutrients by "mud-puddling", or where caterpillars depend on host plants which grow in damp conditions (Thomas & Lewington 2016). Creating small areas of temporary or permanent water, such as scrapes and pools, may benefit these species.

For studies on the creation of large, permanent wetlands, see "*Restore or create wetlands and floodplains*". For studies on managing waterbodies to prevent desiccation, see "*Climate change and severe weather – Manage natural waterbodies in arid areas to prevent desiccation*".

Thomas J.A. & Lewington R. (2016) *The Butterflies of Britain & Ireland*. Third edition, Bloomsbury Publishing, UK.

13.20. Remove tree canopy to reduce pond or waterway shading

- **One study** evaluated the effects on butterflies and moths of removing tree canopy to reduce pond or waterway shading. This study was in the USA[1].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (1 STUDY)

- **Survival (1 study):** One replicated, randomized, paired, controlled study in the USA[1] found that removing trees to reduce stream shading reduced the survival of Appalachian brown caterpillars and pupae, but did not affect egg survival.

BEHAVIOUR (0 STUDIES)

Background

The edges of ponds and waterways provide open, sunny habitats favoured by many species, including both wetland specialists and more generalist butterflies and moths. However, management of tree growth along waterways may be necessary to prevent the habitat becoming enclosed, leading to increased shading and a loss of important habitat patches.

A replicated, randomized, paired, controlled study in 2011–2012 in a pine forest in North Carolina, USA (1) found that removing trees to reduce stream shading reduced the survival of Appalachian brown *Satyrodes appalachia* caterpillars and pupae, but did not affect egg survival. In plots where trees were removed, the survival of Appalachian brown eggs (12–36%) was not significantly different to plots where trees remained (56–74%), but the survival of caterpillars and pupae was lower (trees removed: 7%; trees remained: 20%). In plots where trees were removed and artificial dams were installed, both egg (33–42%) and caterpillar and pupal (14%) survival were similar to plots where trees remained and artificial dams were not installed (egg: 56–74%; caterpillars and pupae: 20%). In May 2011, four 30 × 30 m plots in each of four blocks were randomly assigned to four treatments: manual removal of 90% of trees, installation of temporary dams, tree removal and dam installation, and no manipulation. The 0.5-m high dams spanned the downstream edge of their plot. From 15 May–15 June and 7

July–7 August 2012, a potted sedge *Carex mitchelliana* plant was placed in the centre of each plot. Each plant had a known number of butterfly eggs, laid by caged wild-caught females prior to placement. The number of eggs on each plant which survived after 48 hours was counted. In addition, in each of three arenas/plot (created from polyethylene food drums), centred on mature sedge, five captive-reared caterpillars (first to third instar) were released and the number of emerging adults was counted.

(1) Aschehoug E.T., Sivakoff F.S., Cayton H.L., Morris W.F. & Haddad N.M. (2015) Habitat restoration affects immature stages of a wetland butterfly through indirect effects on predation. *Ecology*, 96 (7), 1761–1767.

Ecosystem engineering

13.21. Reintroduce mammals as ecosystem engineers

- **One study** evaluated the effects on butterflies and moths of reintroducing mammals as ecosystem engineers. This study was in Italy[1].

COMMUNITY RESPONSE (1 STUDY)

- **Richness/diversity (1 study):** One replicated, site comparison study in Italy[1] found that olive groves with wild boar present had a lower species richness of butterflies than groves without wild boar.

POPULATION RESPONSE (1 STUDY)

- **Abundance (1 study):** One replicated, site comparison study in Italy[1] found that olive groves with wild boar present had a lower total abundance of butterflies, and a lower abundance of six individual species, but a higher abundance of two species, than groves without wild boar.

BEHAVIOUR (0 STUDIES)

Background

Large mammals can act as ecosystem engineers, altering the habitat around them. This often takes the form of disturbance: by grazing, browsing, uprooting or felling dominant plant species (Hess *et al.* 2014). This creates new habitats (such as bare ground, deadwood, or open water), which may benefit butterfly and moth species directly, or allow the establishment of less competitive plant species on which butterflies and moths depend (de Schaetzen *et al.* 2018). Common examples of mammals considered to be ecosystem engineers include elephants, wild boar (de Schaetzen *et al.* 2018), bison (Hess *et al.* 2014) and beavers.

de Schaetzen F., van Langevelde F. & WallisDeVries M.F. (2018) The influence of wild boar (*Sus scrofa*) on microhabitat quality for the endangered butterfly *Pyrgus malvae* in the Netherlands. *Journal of Insect Conservation*, 22, 51–59.

Hess A.N., Hess R.J., Hess J.L.M., Paulan B. & Hess J.A.M. (2014) American Bison influences on lepidopteran and wild blue lupine distribution in an oak savanna landscape. *Journal of Insect Conservation*, 18, 327–338.

A replicated, site comparison study in 2011–2012 in 10 olive groves in Campania, Italy (1) found that groves with wild boar *Sus scrofa* present had a lower abundance, species richness and diversity of butterflies than groves where boar were absent. The abundance, species richness and diversity of butterflies in olive groves with wild boar were lower than in groves without boar (data not presented). Habitat specialist species were 83% less abundant in groves with wild boar than groves without boar, whereas habitat generalist species were 27% less abundant where boar were present. Although two species (clouded yellow *Colias croceus* and common blue *Polyommatus icarus*) were more abundant in groves with boar than groves without boar, six species (brown argus *Aricia agestis*, tree grayling *Hipparchia statilinus*, wall *Lasiommata megera*, Italian marbled white *Melanargia arge*, southern gatekeeper *Pyronia cecilia* and Lulworth skipper *Thymelicus acteon*) were less abundant in groves with boar (see paper for full species results). Five olive groves with signs of heavy wild boar disturbance, and five groves with no signs of wild boar, were selected. From April–September 2011–2012, butterflies were surveyed 2–3 times/month on one 200-m transect in each grove. Butterflies were classified as "habitat specialists" or "habitat generalists" according to their habitat preferences.

(1) Scandurra A., Magliozzi L., Fulgione D., Aria M. & D'Aniello B. (2016) Lepidoptera Papilionoidea communities as a sentinel of biodiversity threat: the case of wild boar rooting in a Mediterranean habitat. *Journal of Insect Conservation*, 20, 353–362.

13.22. Install artificial dams in streams to raise water levels

- **One study** evaluated the effects on butterflies and moths of installing artificial dams in streams to raise water levels. This study was in the USA[1].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (1 STUDY)

- **Survival (1 study):** One replicated, randomized, paired, controlled study in the USA[1] found that installing artificial dams in streams did not increase the survival of Appalachian brown butterfly eggs, caterpillars or pupae.

BEHAVIOUR (0 STUDIES)

Background

In natural wetland habitats in northern temperate regions, streams and rivers are dammed by beavers, reducing the flow of water and creating wetlands and pools which are used by many other species. This rise in water levels may be important for the reproductive cycle of other species, including wetland specialist butterflies and moths. However, in many regions, beavers have been extirpated or reduced to very small populations by hunting, leading to a loss of this important wetland habitat. Where the reintroduction of beavers is unfeasible, installing artificial dams may replicate the rise in water levels associated with wild beavers.

A replicated, randomized, paired, controlled study in 2011–2012 in a pine forest in North Carolina, USA (1) found that installing artificial dams in headwater streams to raise water levels did not increase the survival of Appalachian brown *Satyrodes appalachia* eggs, caterpillars or pupae. In plots where dams were installed, the survival of Appalachian brown eggs (23–43%) and caterpillars and pupae (37%) was not significantly different from plots where dams were not installed (eggs: 56–74%; caterpillars and pupae: 20%). In plots where artificial dams were installed and trees were removed, both egg (33–42%) and caterpillar and pupal (14%) survival were also similar to plots where dams were not installed and trees remained (egg: 56–74%; juvenile: 20%). In May 2011, four 30 × 30 m plots in each of four blocks were randomly assigned to four treatments: installation of temporary dams, manual removal of 90% of trees, tree removal and dam installation, and no manipulation. The 0.5-m high dams spanned the downstream edge of their plot. From 15 May–15 June and 7 July–7 August 2012, a potted sedge *Carex mitchelliana* plant was placed in the centre of each plot. Each plant had a known number of butterfly eggs, laid by caged wild-caught females prior to placement. The number of eggs on each plant which survived after 48 hours was counted. In addition, in each of three arenas/plot (created from polyethylene food drums), centred on mature sedge, five captive-reared caterpillars (first to third instar) were released and the number of emerging adults was counted.

(1) Aschehoug E.T., Sivakoff F.S., Cayton H.L., Morris W.F. & Haddad N.M. (2015) Habitat restoration affects immature stages of a wetland butterfly through indirect effects on predation. *Ecology*, 96 (7), 1761–1767.

14. Species management

Background

Many species of butterfly and moth have become extinct across large parts of their former range, and now persist in small, isolated habitat patches. These species often have poor dispersal ability, and are unlikely to naturally recolonize their former range, even if suitable habitat is created. Moreover, small remnant populations are vulnerable to sudden changes in their environment, such as extreme weather events or disease, as well as further destruction of their habitat. Captive breeding aims to increase a species' population size quicker than would occur in the wild, by rearing individuals in optimal conditions and protecting them from predators and parasitoids. The release of captive-bred individuals back to the wild, or the translocation of wild individuals from extant colonies to uninhabited sites, may provide the only viable option for enabling butterflies and moths to recolonize large areas.

Translocation

14.1. Translocate to re-establish populations in known or believed former range

- **Sixteen studies** evaluated the effects of translocating butterflies and moths to re-establish populations within their former range. Seven studies were in the UK[2–4,7–9,16], two were reviews across the UK and Ireland[1,5], two studies were in Finland[6,15] and one study was in each of the USA[10], Australia[11], the Netherlands[12], Belgium and the Netherlands[13] and the UK and Sweden[14].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (16 STUDIES)

- **Abundance (13 studies):** Eight studies in the UK[3,9,16], Finland[6], the USA[10], Australia[11], the Netherlands[12] and Belgium and the Netherlands[13] reported that translocated populations of adult butterflies[3,6,10,11,12,13,16] and Fisher's estuarine moth eggs[9] persisted for 2–12 years and increased in abundance[3,6,9,11,12,16] (sometimes in areas where coppicing[3], selective felling[6], planting[9,10], fencing[9], host plant translocation[11], invasive plant removal[11], sheep grazing[13], scrub clearance[16] or unspecified habitat restoration[10] were conducted before or after release). Three studies (including two replicated studies) in the UK[4,8] and Finland[15] reported that some translocated populations of silver-studded blue[4] and clouded Apollo[15] adults, and belted beauty moth eggs and caterpillars[8], persisted for 1–49 years (in one case where vegetation had been removed before release[8]), increased in abundance[15] and colonized new sites[4,15], but other populations died out within 0–7 years. One of two reviews across the UK and Ireland[1,5] found that 25% of translocated and released captive-bred butterfly populations survived for at least three years, but 38% died out in that time, and only 8% were known to have survived for more than 10 years[5]. The other review[1] reported that translocated populations of large copper adults and/or caterpillars (sometimes to areas planted with great water dock or where bushes had been cleared, or alongside the release of captive-bred individuals) survived for up to 38 years, but ultimately died out or had to be supplemented by further releases.

- **Survival (2 studies):** Two site comparison studies (including one replicated, paired study) in the UK[2,7] found that the survival of large blue caterpillars was higher when translocated into *Myrmica sabuleti* nests without queen ants present than with queens present[2], and the survival of translocated large copper caterpillars was higher than the survival of released, captive-bred caterpillars[7].
- **Condition (1 study):** One site comparison in the UK and Sweden[14] found that 19 years after translocation, large blue butterflies in the UK had similar genetic diversity to their Swedish source population.

BEHAVIOUR (0 STUDIES)

Background

Many species of butterfly and moth have severely declined or gone extinct in parts of their former range, particularly in areas where high rates of habitat conversion have occurred (Fox *et al.* 2010, Maes & Van Dyck 2001, van Swaay 1990). Given the poor dispersal ability of many species, and the highly fragmented nature of many landscapes, the transportation of individuals to suitable sites may be the only means by which a species is able to recolonize. Releases could be composed of translocated animals (caught in the wild at another site) or captive-bred animals (bred from captive populations over one or more generations, see "*Rear declining species in captivity*" and "*Release captive-bred individuals to the wild*"), and individuals at any life stage (adult, egg, caterpillar or pupa) may be used for capture and release.

Note that restoring habitat quality prior to the release of translocated butterflies and moths is likely to be an important factor determining the success of reintroduction projects (Schultz *et al.* 2008). Furthermore, for parasitic species such as the large blues *Phengaris* (*Maculinea*) spp., which rely on specific hosts (ants *Myrmica* spp.) for survival, the translocation of ant colonies from the same source site as the butterflies may increase caterpillar survival (Witek *et al.* 2016).

CAUTION: Before translocating butterflies and moths, the impact of the removal of individuals from the donor site must be considered, to avoid harming existing populations.

For studies on the release of butterflies and moths outside of their known range, see "*Translocate to establish populations outside of known range*".

Fox R., Warren M.S., Brereton T.M., Roy D.B. & Robinson A. (2010) A new Red List of British butterflies. *Insect Conservation and Diversity*, 4, 159–172.

Maes D. & Van Dyck H. (2001) Butterfly diversity loss in Flanders (north Belgium): Europe's worst case scenario? *Biological Conservation*, 99, 263–276.

Schultz C.B., Russell C. & Wynn L. (2008) Restoration, reintroduction, and captive propagation for at-risk butterflies: A review of British and American conservation efforts. *Israel Journal of Ecology & Evolution*, 54, 41–61.

van Swaay C.A.M. (1990) An assessment of the changes in butterfly abundance in The Netherlands during the 20th Century. *Biological Conservation*, 52, 287–302.

Witek M., Ślipiński P., Trigos Peral G. & Csata E. (2016) Consequences of the arms race between *Maculinea teleius* social parasite and *Myrmica* host ants for myrmecophilous butterfly conservation. *Journal of Insect Conservation*, 20, 887–893.

A review from 1909–1964 in fens in Cambridgeshire and Norfolk, UK, and Tipperary, Ireland (1) reported that five translocated populations of large copper *Lycaena dispar* survived for up to 38 years, but ultimately died out or required additional releases to survive. Three populations of *Lycaena dispar rutilus* released as adults and/or caterpillars survived for zero, 23 and two years. One population of *Lycaena dispar batavus* survived for 38 years, but was supplemented by additional releases of captive-bred individuals, and 'wild' caterpillars were regularly reared in cages. Another *L. d. batavus* population died out 13 years after release. In 1909, *L. d. rutilus* caterpillars (number not given) were released at Wicken Fen, Cambridgeshire. In May 1913, following planting of great water dock *Rumex hydrolapathum* on a bog in Greenfields, Tipperary, 120 *L. d. rutilus* caterpillars from Germany were released. The following year, 400 adults raised from 700 caterpillars collected in Germany were released at the same site. In 1926, a total of 550 pupae from Tipperary were placed in cages in Woodbastwick Marshes, Norfolk, and the adults released as they emerged. In 1926, an 8.8-ha area of Woodwalton Fen, Cambridgeshire, was cleared of bushes and great water dock was planted. In 1927, thirteen female and 25 male *L. d. batavus* from the Netherlands were released at the site. This population was supplemented with captive-bred caterpillars or adults when numbers were low, and from the 1930s, 'wild' caterpillars were routinely reared in muslin cages to protect them from predation. In 1942, *L. d. batavus* (number not given) from Woodwalton were released in Tipperary.

A site comparison study (years not given) in two grasslands in Devon and Dorset, UK (2) found that translocated large blue *Maculinea arion* caterpillars were more likely to survive in *Myrmica sabuleti* nests without queen ants than in nests with queens present. The survival of caterpillars in nests without queen ants (8 out of 12 caterpillars) was higher than in nests with queen ants present (5 out of 20 caterpillars). In August, one locally caught caterpillar was placed near each of 21 ant nests in Devon, and one caterpillar collected in Dordogne, France, was placed near each of 11 ant nests in Dorset. Adoption of each caterpillar into the nests was observed. Two weeks later, nests in Dorset were excavated to measure survival. In Devon, adults were caught in emergence traps the following year and, after emergence, nests were excavated and the number of queen ants present in each nest was counted.

A study in 1987–1989 in a woodland in Essex, UK (3) reported that translocated heath fritillary *Mellicta athalia* released into a coppiced woodland survived and the population increased. Results were not tested for statistical significance. Two years after the release of 38 adult heath fritillaries, the population was around 200 adults. In 1987, a total of 38 adult heath fritillaries (20 females, 18 males) were translocated from a nearby population (which had been established from captive-bred butterflies in 1984), and released into a 30-ha wood with 0.5 ha of coppicing. In 1988–1989, butterflies were surveyed annually on timed counts along a zig-zag route covering the known flight area. The total yearly population was estimated by multiplying the peak population count by three.

A replicated study in 1983–1990 in four heathlands and three limestone grasslands in North Wales, UK (4) reported that three of seven translocated populations of silver-studded blue *Plebejus argus* successfully established new colonies. One population of silver-studded blue released onto heathland, and two released onto limestone grassland, survived for at least 8–49 years. By 41–48 years after release, the oldest population had spread 2.5 km along a valley, colonizing 17/20 patches of suitable habitat (0.04–2.2 ha in size). Seven years after release, the newest population had colonized one new patch, 100 m from the release site, but 14 patches 210–2,000 m away remaining unoccupied. Two populations released on heathland persisted for 2–7 years before disappearing. The other two populations did not survive the first year after release. The authors reported that this was because butterflies were released into a different habitat type from that in which they were captured. In 1942, ninety female silver-studded blues were released on a limestone grassland site. From 1978–1983, groups of 5–30 female silver-studded blues (in one instance including some males) were released on two further grasslands and four heathlands. In 1983 and 1990, all suitable habitat patches at each site were surveyed for >20 minutes/patch to record silver-studded blue presence.

A review from pre-1900–1988 across the UK and Ireland (5) found that at least a quarter of reintroduced butterfly populations survived for over three years, but only 8% were known to survive for more than 10 years after release. Of 274 documented reintroductions of native butterflies, 68 populations (25%) were known to have survived for more than three years, and 21 (8%) were known to survive for more than 10 years. However, 103 populations (38%) died out within three years of release. The remaining reintroductions were either poorly documented (73 releases) or occurred too recently to determine success (30 releases). Twenty-five releases which aimed to reinforce existing populations were not included. Records of all documented releases of butterflies in the UK and Ireland were compiled by Oates & Warren (1990), and their success up to 10 years after release was updated by this study. At least 29% of releases were of captive-bred butterflies. No further details were provided.

A study in 1992–1996 in a forest in Ruokolahti, Finland (6) reported that a translocated population of baton blue *Pseudophilotes baton schiffermuelleri* butterflies (released into a site where areas of Scots pine *Pinus sylvestris* had also been selectively felled two years earlier) increased in size and survived for at least two years. One year after a population of 10 baton blue females were released, 24 butterflies were captured, and two years after release, 46 butterflies were captured. The 230 x 70-m Scots pine-covered site in Ruokolahti was divided into 10-m^2 study plots. In 1992, pines were selectively logged, and in 1996 some additional saplings were removed. In Säkylänharju, in June 1994, ten female baton blues were captured and marked before being translocated 315 km east to Ruokolahti where they were released into different 10-m^2 plots. In June 1995 and June and July 1996, surveys were conducted twice/day along the longitudinal boundaries of all plots, during which butterflies were captured, marked and released, and egg-laying and mating sightings were recorded.

A replicated, paired, site comparison study in 1997–1998 in a fen in Norfolk, UK (7) found that translocated large copper *Lycaena dispar batavus* caterpillars had higher overwinter survival rates than released captive-bred caterpillars. The overwinter survival of translocated caterpillars (8 of 95 caterpillars found) was higher than the overwinter survival of released captive-bred caterpillars (1 of 95 caterpillars found). In September 1997, wild-laid eggs were collected from a 3,500-ha lowland bog in the Netherlands, and captive-laid eggs were obtained from a 25-year-old glasshouse-reared colony at Woodwalton Fen. Eggs from both sources were reared to overwintering in the laboratory. A total of 95 wild and 95 captive-bred caterpillars were placed on 19 pairs of great water dock *Rumex hydrolapathum* (5 caterpillars/plant) in an open fen in Norfolk. In May 1998, after late flooding, surviving caterpillars were counted on each plant.

A study in 2002–2003 in a coastal sand dune in Merseyside, UK (8) reported that one of two disturbed plots where belted beauty moth *Lycia zonaria britannica* eggs and caterpillars were released had a small adult population the following year. Two years after two grassland plots were cleared, and one year after eggs and caterpillars were released, eight adult moths (7 females, 1 male) were present in a plot which had been stripped of turf and soil, but no adults were present in a plot which had been strimmed and raked. In the summer of the release, caterpillars had been observed feeding in both plots. In winter 2000–2001, vegetation was removed from two 15 × 10 m plots within a 6.5-ha dune grassland. One plot was completely stripped of turf and soil to expose the bare sand, and the other was heavily strimmed to ground level, with cuttings and leaf litter raked off. Both plots were allowed to re-vegetate naturally. In early April 2002, three egg batches and 33 caterpillars were introduced to each plot, and in late April a further 10 caterpillars were added to the stripped plot (source population not specified). Caterpillars were observed in summer 2002, and adults were recorded in April 2003.

A study in 2000–2003 in a coastal grassland in Essex, UK (9) reported that a translocated population of Fisher's estuarine moth *Gortyna borelii lunata* survived for at least three years. One–three years after the translocation of 300 eggs, 50–54% of 24 established hog's fennel *Peucedanum officinale* plants had signs of caterpillar feeding. The proportion of plants with signs of caterpillars feeding in the roots was 29% after one year, 38% after two years, and 42% after three years. In February 2000, twenty-five mature hog's fennel plants were translocated to a 125-m^2 unimproved coastal grassland, and one was planted every 4 m^2. A rabbit-proof fence was erected around the site. In October 2000, around 300 moth eggs were placed in two clusters at the site. In July 2001–2003, the number of plants with signs of caterpillars feeding was recorded.

A study in 2000–2004 on a restored prairie in Iowa, USA (10) reported that translocated regal fritillary *Speyeria idalia* butterflies survived and bred for three years. In 2001, the first year after translocation, no butterflies were seen at the release site, but in 2002, one year after a second release, 84 adults were recorded. In the following two years, 11–12 fritillaries were observed in planted violet plots and other areas on 1–2 days/year. On 15 days in 2004, between 1–23 fritillaries were seen/day. In 1998 and 1999, prairie violets *Viola pedatifida* were planted at four sites in a 2,083-ha reserve of restored and remnant tallgrass prairie. At each site, five plots of 99 violets were planted in a grid (9 × 11 m), 1 m apart. In July 2000 and August–September 2001, seven female fritillaries were caught in two prairies (118–500 ha), placed in a cooler, and transported to the restored prairie within two hours. Fritillaries were placed in mesh cages (0.6 × 0.6 m or 1.8 × 1.8 m) directly over violet plants, and provided with nectar from cut flowers and moved to new violet plants each day. Translocated females survived for 3–20 days. In June–August 2001–2004, butterflies were surveyed or opportunistically recorded across the site.

A study in 2004–2007 in one shrubland in New South Wales, Australia (11) reported that, three years after translocation, along with habitat management and host plant translocation, a population of purple copper butterfly *Paralucia spinifera* caterpillars had persisted and increased in number. A site designated for development and adjacent retained and compensatory habitat initially had an estimated purple copper population of 2,000 caterpillars. After the development, and habitat management of and translocation of butterflies into the retained and compensatory habitat, the estimated caterpillar population size reduced to 1,600 in the following year but increased to an estimated 1,995 two years and 2,780 three years after translocation. Of the caterpillars found in the third year, 61% were in the area of retained original habitat and 39% were in the compensatory habitat. In 2004–2005, two thirds of an area of purple copper butterfly habitat was cleared for road-building and an area adjacent to the retained third was designated as compensatory habitat. Invasive plants were cleared from the compensatory habitat and caterpillars and their host plant blackthorn *Bursaria spinosa* var. *lasiophylla* were moved from the land about to the cleared to the retained and compensatory habitat. Over 12 nights in December 2004–January 2005, one thousand two hundred and sixty caterpillars were moved. In 2005–2007 blackthorn plants in the retained and compensatory habitats were surveyed for caterpillars, signs of their feeding, and their mutualistic ants *Anonychomyrma itinerans*. Estimated caterpillar population sizes were calculated by multiplying the number of caterpillars found by five.

A study in 1990–2000 in a wet grassland reserve in Noord-Brabant, the Netherlands (12) reported that translocated scarce large blue *Maculinea teleius* and dusky large blue *Maculinea nausithous* populations increased in size and survived for 10 years. Results were not tested for statistical significance. Five to seven years after the release of 86 scarce large blue, the population consisted of ≥126–296 individuals/year. Five to six years after the release of 70 dusky large blue, the population consisted of ≥592–751 individuals/year. Ten years after reintroduction, the scarce large blue was only found at the release site, despite having occupied another site shortly after reintroduction. The dusky large blue had colonized two other sites (a railway embankment and a road verge), but was no longer present at the release site. In July 1990, seventy dusky large blue (22 males, 48 females) and 86 scarce large blue (33 males, 53 females) were caught in the Wisla Valley, Poland. Butterflies were placed in groups of three in paper boxes in a car-refrigerator, driven to Moerputten in two days, and released into a 116-ha reserve on a warm evening. Details of the translocation taken from Wynhoff (1998). In most years from 1990–1997, butterflies were captured and marked to estimate population size. From 1991–2000, occupied sites were visited at least once/week during each species' flight period, and after the peak period all road verges and ditch sides were searched for butterflies.

A study in 1997–2009 in two calcareous grasslands in Belgium and the Netherlands (13) reported that two introduced populations of Glanville fritillary *Melitaea cinxia* survived for two and 12 years. At one site, 41 caterpillar nests were present 12 years after reintroduction, and at a second site 120 nests were present two years after the reintroduction of 14 nests (no further details provided). In 1997, Glanville fritillaries were reintroduced to a 4-ha grassland in Belgium, managed by low density rotational sheep grazing from April to October. In 2007, fourteen caterpillar nests from that site were reintroduced to a network of grasslands 10 km away in the Netherlands, managed by high density sheep grazing in spring and autumn, and lower density grazing over winter. In the first year after introduction, part of the grassland containing the most caterpillar nests was fenced off during autumn grazing. No further details were provided. In July–August 2009, both grasslands were searched three times for caterpillar nests.

A site comparison study in 2010–2011 in 12 grasslands in Somerset, UK and Öland, Sweden (14) found that large blue butterflies *Maculinea arion* reintroduced to the UK in 1991 survived for at least 19 generations and had similar levels of genetic diversity to the Swedish source population. Nineteen generations after release, the translocated population had similar genetic diversity to the source population (data presented as standardised allelic richness and expected heterozygosity). Low levels of inbreeding were also found amongst the UK populations (data presented as inbreeding coefficients). In 1991, as part of a wider reintroduction, 281 large blue caterpillars were translocated from 11 sites in Sweden to a single site in the Polden Hills, UK. Following natural dispersal and three further translocations from the first release site, large blues spread to 25 sites in the Polden Hills. In 2010 and 2011 hindwing clippings were taken from 128 adult butterflies at seven sites in Sweden, and 59 whole caterpillars were taken from five sites in the Polden Hills, for genetic analysis.

A replicated study in 2000–2013 in two semi-natural grasslands in Uusimaa district, Finland (15) reported that one of two translocated populations of clouded Apollo *Parnassius mnemosyne* increased in abundance and colonized new habitat. Results were not tested for statistical significance. From 11–13 years after the release of 20 mated females, the population at one release site was estimated to be 250–650 butterflies, and all 11 suitable habitat patches within 2 km had been colonized and were estimated to have an additional 451 butterflies in 2013. At the other site, no clouded Apollos were seen in the first summer after translocation, or in later years. The authors suggested that the higher abundance of host plants and surrounding forest cover enclosing the successful site may have been important (see paper for details). In June 2000, forty mated female butterflies were caught from four areas in a large population, stored in a cool box, and translocated to two unoccupied sites 25 km apart, and 105 and 130 km from the nearest known populations. Half of the butterflies were translocated on each of two days, one week apart, during the peak flight season. From 2000–2001, both sites were visited several times to monitor survival. From 2001–2003, the successful site was monitored for 5–6 days/year. From 2004–2013, all 11 suitable habitat patches within 2 km of the release site were also monitored on 7–24 days/year.

A study in 2007–2018 in a heathland in Suffolk, UK (16) reported that a population of silver-studded blue *Plebejus argus* translocated into a site with ongoing habitat management, survived for at least 11 years, increased in number and expanded its range. The highest single day count increased from 60 butterflies released in 2007 to 160 in 2013. Along a fixed transect, the annual butterfly 'population index' was 41 a year after release and 662 ten years later. Authors reported that the area the butterflies were recorded in increased over time. In 2007, sixty butterflies were translocated to Blaxhall Common from two existing colonies in Suffolk. From 2007–2018, areas of bell heather Erica cinerea were forage harvested to create young patches, silver birch was controlled and areas of gorse *Ulex* spp. and other scrub were cleared. For 2007–2013 a daily peak count figure was provided from fixed point counts and for 2008–2018 a population index figure was calculated from recording butterflies along a fixed transect (number of counts and transects/year not given).

(1) Duffey E. (1968) Ecological studies on the large copper butterfly *Lycaena dispar* (Haw.) *batavus* (Obth.) at Woodwalton Fen National Nature Reserve, Huntingdonshire. *Journal of Applied Ecology*, 5, 69–96.
(2) Thomas J.A. & Wardlaw J.C. (1990) The effect of queen ants on the survival of *Maculinea arion* in *Myrmica* ant nests. *Oecologia*, 85, 87–91.
(3) Warren M.S. (1991) The successful conservation of an endangered species, the heath fritillary butterfly *Mellicta athalia*, in Britain. *Biological Conservation*, 55, 37–56.
(4) Thomas C.D. & Harrison S. (1992) Spatial dynamics of a patchily distributed butterfly species. *Journal of Animal Ecology*, 61, 437–446.
(5) Pullin A.S. (1996) Restoration of butterfly populations in Britain. *Restoration Ecology*, 4, 71–80.
(6) Marttila O., Saarinen K. & Jantunen J. (1997) Habitat restoration and a successful reintroduction of the endangered Baton Blue butterfly (*Pseudophilotes baton schiffermuelleri*) in SE Finland. *Annales Zoologici Fennici*, 34(3), 177-185.
(7) Nicholls C.N. & Pullin A.S. (2000) A comparison of larval survivorship in wild and introduced populations of the Large Copper butterfly (*Lycaena dispar batavus*). *Biological Conservation*, 93, 349–358.
(8) Howe M.A., Hinde D., Bennett D. & Palmer S. (2004) The conservation of the belted beauty *Lycia zonaria britannica* (Lepidoptera, Geometridae) in the United Kingdom. *Journal of Insect Conservation*, 8, 159–166.
(9) Ringwood Z., Hill J. & Gibson C. (2004) Conservation management of *Gortyna borelii lunata* (Lepidoptera: Noctuidae) in the United Kingdom. *Journal of Insect Conservation*, 8, 173–183.
(10) Shepherd S. & Debinski D.M. (2005) Reintroduction of regal fritillary (*Speyeria idalia*) to a restored prairie. *Ecological Restoration*, 23, 244–250.
(11) Mjadwesch R. & Nally S. (2008) Emergency relocation of a Purple Copper Butterfly colony during roadworks: Successes and lessons learned. *Ecological Management & Restoration*, 9(2), 100-109.
(12) van Langevelde F. & Wynhoff I. (2009) What limits the spread of two congeneric butterfly species after their reintroduction: quality or spatial arrangement of habitat? *Animal Conservation*, 12, 540–548.
(13) van Noordwijk C.G.E., Flierman D.E., Remke E., WallisDeVries M.F. & Berg M.P. (2012) Impact of grazing management on hibernating caterpillars of the butterfly *Melitaea cinxia* in calcareous grasslands. *Journal of Insect Conservation*, 16, 909–920.
(14) Andersen A., Simcox D.J., Thomas J.A., Nash D.R. (2014) Assessing reintroduction schemes by comparing genetic diversity of reintroduced and source populations: A case study of the globally threatened large blue butterfly (*Maculinea arion*). *Biological Conservation*, 175, 34-41.

(15) Kuussaari M., Heikkinen R.K., Heliölä J., Luoto M., Mayer M., Rytteri S. & von Bagh P. (2015) Successful translocation of the threatened Clouded Apollo butterfly (*Parnassius mnemosyne*) and metapopulation establishment in southern Finland. *Biological Conservation*, 190, 51–59.
(16) Parker R. (2018) Still working at re-establishment of the silver-studded blue *Plebejus argus* – real progress from 2007 to 2018. *British Journal of Entomology and Natural History*, 31(4), 217-223.

14.2. Translocate to establish populations outside of known range

- **Four studies** evaluated the effects of translocating butterflies and moths to establish populations outside of their known range. Two studies were in the USA[1,3] and one was in each of the Czech Republic[2] and the UK[4].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (4 STUDIES)

- **Abundance (3 studies):** Two of three studies in the USA[1,3] and the UK[4] reported that populations of Gillette's checkerspot[3], small skipper[4] and marbled white[4] translocated outside of their native range as eggs[3] or adults[4] (in one case including captive-bred individuals[3]) persisted and increased in abundance over eight[4] and 28[3] years. The third study reported that a population of Gillette's checkerspot adults, eggs and caterpillars translocated outside their native range died out within one year[1].
- **Condition (1 study):** One study in the Czech Republic[2] found that 69 years after translocation, an introduced population of the small mountain ringlet butterfly had similar genetic diversity to its source population, and higher genetic diversity than a small native population.

BEHAVIOUR (0 STUDIES)

Background

Climate change is increasingly reducing the suitability of habitat within species' historic ranges, while a combination of habitat fragmentation and poor dispersal ability can limit species' ability to colonize new areas which have become more climatically suitable. Translocation of butterflies and moths to areas outside of their previously recorded range could be used to seed new populations in more climatically suitable areas, which species may struggle to colonize on their own (Willis *et al.* 2009). This action includes translocations to areas outside of a species' native range, whether or not done explicitly for climate change adaptation, but only if the translocation was within the same biogeographic region (e.g. translocations between continents are not included).

CAUTION: Before translocating butterflies and moths, the impact of the removal of individuals from the donor site must be considered, to avoid harming existing populations.

For studies on the translocation of butterflies and moths to areas within their known range, see "*Translocate to re-establish populations in known or believed* *former range*". For studies on the release of captive-bred butterflies and moths, see "*Release captive-bred individuals to the wild*".

Willis S.G., Hill J.K., Thomas C.D., Roy D.B., Fox R., Blakeley D.S. & Huntley B. (2009) Assisted colonization in a changing climate: a test-study using two U.K. butterflies. *Conservation Letters*, 2, 46–52.

A study in 1979–1980 in an alpine meadow in Colorado, USA (1, same experimental set up as 3) reported that a population of Gillette's checkerspot *Euphydryas gillettii* translocated outside the species' native range died out within a year. Immediately after the release of 8,000 eggs and caterpillars, 85–90% of egg masses hatched and began feeding, and at least a third grew to a good size. Ten months later, 14 caterpillars were found feeding on plants where individuals were released, and 85% of bearberry honeysuckle *Lonicera involucrata* bushes had extensive feeding damage. However, only one adult female and a single egg cluster were found in July, and the egg cluster later disappeared. A later study confirmed that the population did not survive (2 - Boggs *et al.* 2006). In July 1979, eggs and mated adult females were collected in Wyoming. On 10 July 1979, seventeen females were released in an alpine meadow. A week later, ~8,000 eggs and newly-hatched caterpillars were released on to bearberry honeysuckle at the same site. Egg clusters were taped to the leaves, and caterpillars were released in paper cups. Large plants which were not at risk of flooding were specifically chosen. In May 1980, the site was surveyed for surviving caterpillars, and in June and July it was monitored for adults and egg clusters. A second, successful translocation reported by this study is summarized in 2 - Boggs et al. 2006.

A study in 2001–2002 in one subalpine grassland site in northern Czech Republic (2) found that 69 years after translocation, an introduced population of the small mountain ringlet butterfly *Erebia epiphron silesiana* had similar genetic diversity to its source population, and higher genetic diversity than a small native population. The mean genetic diversity of adult butterflies from the translocated population (expected heterozygosity (HE): 11.6%) was not significantly different from that of the source population (HE: 10%), and higher than that of a small native population close to the source population (HE: 5.5%). In 1932–1933, about 50 female butterflies were translocated from a native population in the Jeseniky Mountains to a site in the Krkonose Mountains where they had not previously been recorded. In July 2002, researchers collected 81 butterflies from two locations within the range of the translocated population. For comparison, in July 2001 and 2002, they collected 120 butterflies from three locations within the range of the large native source population (>10,000 individuals) and 46 butterflies from a smaller native population (5,000 individuals), both within the Jeseniky Mountains. DNA from these samples was used to measure genetic diversity.

A study in 1977–2005 in an alpine meadow in Colorado, USA (3, same experimental set up as 1) reported that a translocated and captive-bred population of Gillette's checkerspot *Euphydryas gillettii* released outside the species' native range survived for 28 years, but only increased in size and colonized new sites after 22–25 years. For 21 years after the release of 83 egg clusters, the population size fluctuated between 24 and 143 adults, and remained confined to the release site. However, four years later, the population was estimated at >3,000 adults, and covered 70.4 ha. After a further three years, the population had declined to 150 adults at the release site, but two other habitat patches (0.3 and 0.6 ha) remained occupied (13–153 adults/ha). In July 1977, eggs and adult females were collected in Wyoming, and kept in a laboratory where more eggs were laid. In July–August 1977, eighty-three wild- and captive-laid egg and caterpillar clusters (~10,000 individuals from ~40 females) were released on to bearberry honeysuckle *Lonicera involucrata* in a 2.25-ha meadow. Details of the translocation taken from 1 - Holdren & Ehrlich (1981). In June–July 1978–1989 and 2002–2005, adult butterflies at the release site were caught and uniquely marked every 1–7 days. Recapture rates of marked butterflies were used to estimate the population size in years with sufficient data (1981–1986, 2002–2005). In 1978–1989, 2002 and 2004–2005, egg clusters and/or caterpillar webs were counted throughout the season at the release site, and in 2003–2005 at two newly colonized sites. The relationship between number of egg clusters and adult population was used to estimate the population size in the remaining years. From 1978–1987, areas surrounding the release site were searched for egg clusters or caterpillar webs, and from 2002–2005 a larger area was searched for adults.

A study in 1999–2008 in two limestone grasslands in Durham and Northumbria, UK (4) reported that translocated populations of small skipper *Thymelicus sylvestris* and marbled white *Melanargia galathea* survived and spread for eight years after release into climatically suitable areas north of their current range. Six years after release, the distribution of small skipper was 3.64 ha, compared to 0.17 ha in the first year, and the distribution of marbled white was 17.8 ha, compared to 7.2 ha in the first year. Six years after release, the abundance of marbled white was 14 butterflies/km, compared to 6 butterflies/km one year after release. However, most individuals of both species remained within 1 km of their release site. Eight years after release, both populations were still present. In July–August 1999, about 400 adult small skipper were collected from sites in North Yorkshire, and released in a quarry in Northumberland the following day, ~35 km north of the natural range. In July 2000, a further 200 small skipper were translocated to the same site, and ~500 adult marbled white were caught in North Yorkshire and released in a quarry in Durham, ~65 km north of their natural range. Roughly equal numbers of males and females were released. From 2001–2006, extensive searches of each release site and all suitable habitat within 3–4 km were conducted regularly to record adults during their flight period. In 2007–2008, more limited surveys were conducted. Marbled white were also recorded along a 1,550-m transect through their release site every 3–4 days during the flight period (years not given).

(1) Holdren C.E. & Ehrlich P.R. (1981) Long range dispersal in checkerspot butterflies: transplant experiments with *Euphydryas gillettii*. *Oecologia*, 50, 125–129.

(2) Schmitt T., Cizek O. & Konvicka M. (2005) Genetics of a butterfly relocation: large, small and introduced populations of the mountain endemic *Erebia epiphron silensiana*. *Biological Conservation*, 123(1), 11–18.

(3) Boggs C.L., Holdren C.E., Kulahci I.G., Bonebrake T.C., Inouye B.D., Fay J.P., McMillan A.N.N., Williams E.H., Ehrlich P.R. (2006) Delayed population explosion of an introduced butterfly. *Journal of Animal Ecology*, 75, 466–475.

(4) Willis S.G., Hill J.K., Thomas C.D., Roy D.B., Fox R., Blakeley D.S. & Huntley B. (2009) Assisted colonization in a changing climate: a test-study using two U.K. butterflies. *Conservation Letters*, 2, 46–52.

14.3. Introduce mated females to increase genetic diversity

- We found no studies that evaluated the effects on butterflies and moths of introducing mated females to increase genetic diversity.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Small, remnant populations of butterflies and moths, which are isolated from other populations, may begin to suffer from reduced genetic diversity arising from inbreeding. The release of mated females from other populations should introduce more genetic diversity into a small population, and this may reduce the extinction risk of the focal population.

CAUTION: Remnant populations can benefit from local genetic adaptation to their environment, and the introduction of genetic diversity from other populations may dilute the local adaptation. Individuals from other populations may also carry diseases or parasites to the remnant population. Both factors could put the remnant population at risk, so care should be taken when considering this action. In addition, before translocating butterflies and moths, the impact of the removal of individuals from the donor site must be considered, to avoid harming existing populations.

For studies on the release of translocated or captive-bred butterflies and moths to areas where the species does not occur, see "*Translocate to re-establish populations in known or believed former range*", "*Translocate to establish populations outside of known range*" and "*Release captive-bred individuals to the wild*".

Captive-breeding, rearing & releases (ex-situ conservation)

14.4. Rear declining species in captivity

- **Twenty-two studies** evaluated the effects of rearing declining species of butterfly and moth in captivity. Seven studies were in each of the UK[1–3,11,12,18,20] and South Africa[6,7,8,9,13,14,15], two were in the USA[16,21], one was in each of the UK and France[4], Spain[5], Belgium[17], Poland[19] and Israel[22], and one was a review[10].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (22 STUDIES)

- **Abundance (6 studies):** Three studies in the UK[11,12] and the USA[21] reported that populations of large copper[11], large white[12] and monarch[21] butterflies were successfully reared in captivity for 12 generations[21] or >25 years[11,12]. One study in the UK[18] reported that a captive population of marsh fritillary increased in size over two years. One study in Poland[19] reported that all captive-reared scarce large blue caterpillars died within 35 days. One review[10] reported that attempts to rear caterpillars of four species of large blue had mixed success.
- **Reproductive success (5 studies):** One controlled study in the UK[2] reported that female large copper laid more eggs, and these eggs had a higher hatching success, in a cage kept in a greenhouse than in a cage kept outside. One study in South Africa[6] reported that a Dickson's copper butterfly laid eggs in captivity in the presence of black cocktail ants from the site where she emerged but not from 10 km away. One study in the UK[12] found that female large white from a population kept in captivity for >25 years laid more eggs than females from a population in its third generation in captivity. One study in the UK[20] reported that Fisher's estuarine moths successfully bred in captivity. One study in South Africa[7] reported that wild-caught, gravid scarce mountain copper butterflies laid eggs but none hatched.
- **Survival (14 studies):** Five of six studies (including one replicated, controlled study, four controlled studies and one site comparison study) in the UK[1,3], the UK and France[4], Spain[5], Belgium[17] and Poland[19] found that large copper[1], large blue[3], mountain Alcon blue[5], cranberry fritillary[17] and scarce large blue[19] caterpillars had higher survival rates when reared on plants[1] or in ant nests[5] at a lower than higher density, in ant nests without queens[3] or with winged females[5] present than with queens[3] or without winged females[5], when reared at 20 °C than 25 °C[17], and when reared with ants collected from sites where parasitic butterfly species occur than from sites where parasites do not occur[19]. The sixth study[4] found that mountain Alcon blue caterpillars had a similar survival rate in ant nests with or without queens present. Two of these studies, and one replicated, randomized, paired, controlled study in the USA[21], found that the survival of large blue[3], mountain Alcon blue[4] and monarch[21] caterpillars differed when reared in ant nests of different species[3,4] or on different species of milkweed[21]. Two site comparison studies in the UK[11] and the USA[16] found that large copper[11] and Puget blue[16] eggs had a similar survival rate to the caterpillar[11] and adult[16] stage whether they were laid in captivity or collected from the wild and reared in captivity. One of these studies also found that Puget blue caterpillars kept in refrigerators while overwintering had a lower survival than caterpillars kept in environmental chambers or outside[16]. Three of four studies in South Africa[8,13,15] and the UK[20] reported that some wild-collected Brenton blue butterfly[8], Karkloof blue butterfly[13] and Fishers' estuarine[20] moth eggs hatched[8,13,15,20], survived as caterpillars for three months[13] or to adulthood[8,20], bred in captivity[20] and the resulting captive population survived for at least eight generations[20]. The other study reported that wild-collected Brenton blue butterfly eggs hatched in captivity and those caterpillars reared with only *Pyllanthus incurvatus* leaves died whereas all caterpillars also given *Indigofera erecta* leaves survived to the fourth instar of development[15]. One study in South Africa[9] reported that wild-caught final instar Cape Peninsula butterfly caterpillars reared in an artificial pugnacious ant nest successfully pupated and became adults, but captive-hatched first instar Cape Peninsula and Riley's skolly butterfly caterpillars placed next to a nest did not survive to pupation.
- **Condition (5 studies):** Two studies (including one controlled study) in the UK[12] and the USA[16] found that adult large white from a population kept in captivity for >25 years were heavier, and had smaller wings, than individuals from a population in its third generation

in captivity[12], and captive-reared Puget blue adults were smaller than wild-caught butterflies[16]. One of these studies also found that Puget blue caterpillars raised in environmental chambers or outdoor enclosures reached a similar size as adults[16]. One replicated, controlled study in Spain[5] found that mountain Alcon blue caterpillars reared in ant colonies with winged females were lighter than caterpillars reared in colonies without winged females. One replicated, controlled study in Israel[22] found that spring webworm caterpillars fed vegetation from cattle-grazed pasture had a similar growth rate to caterpillars fed vegetation from an ungrazed paddock. One study in South Africa[14] reported that Brenton blue butterfly caterpillars reared on *Indigofera erecta* leaves with no ants became dwarf adults, but those reared on whole Indigofera plants with an ant colony became full-sized adults.

BEHAVIOUR (0 STUDIES)

Background

Captive-breeding can be an important method for boosting small population sizes, or for ensuring the continued persistence of a species while its habitat is restored to a suitable condition in the wild (Schultz *et al.* 2008). It is likely to be more successful if founding individuals are taken from large populations, and the size of the captive population remains stable over time (Crone *et al.* 2007).

CAUTION: Before removing butterflies and moths from the wild to take into captivity, the impact of the removal of individuals from the donor site must be considered, to avoid harming existing populations.

For studies on the release of captive-bred butterflies and moths into the wild, see "*Release captive-bred individuals to the wild*".

Crone E.E., Pickering D. & Schultz C.B. (2007) Can captive rearing promote recovery of endangered butterflies? An assessment in the face of uncertainty. *Biological Conservation*, 139, 103–112.

Schultz C.B., Russell C. & Wynn L. (2008) Restoration, reintroduction, and captive propagation for at-risk butterflies: A review of British and American conservation efforts. *Israel Journal of Ecology & Evolution*, 54, 41–61.

A replicated, paired, controlled study in 1964 in a fen in Cambridgeshire, UK (1) reported that semi-wild large copper *Lycaena dispar batavus* caterpillars reared at high density on small great water dock *Rumex hydrolapathum* plants had lower survival than caterpillars reared at lower density or on larger plants. Results were not tested for statistical significance. On small plants, the survival of large copper caterpillars reared in groups of 12/plant was 35% (67/192 survived), compared to 65% (31/48 survived) for caterpillars in groups of three/plant. However, on large plants the survival of caterpillars in groups of 12/plant was 81% (39/48 survived) compared to 75% (9/12 survived) for caterpillars in groups of three/plant. The author reported that small plants with 12 caterpillars/plant were abandoned after all the leaves had been eaten, before the caterpillars were fully grown. In a fen with a semi-wild large copper colony, four batches of 10 great water dock plants were selected. In each batch, eight plants were 50 cm tall (3 leaves/plant) and two were >100 cm high (9–20 leaves/plant). In May 1964, three or 12 large copper caterpillars were placed onto each plant, and the plants were covered with a 6-mm plastic mesh cage to exclude birds and mammals. In July 1964, all surviving caterpillars and pupae were counted.

A controlled study in 1968 at a research station in Cambridgeshire, UK (2) reported that large copper butterflies *Lycaena dispar batava* laid more eggs in a cage kept in a greenhouse than in a cage kept outside, and eggs in the greenhouse had a higher hatching success. Results were not tested for statistical significance. The number of eggs laid in a cage kept in a greenhouse (498 eggs) was higher than the number laid in a cage kept outside (126 eggs). In addition, the proportion of eggs which hatched was higher in the greenhouse (91%) than outside (40%). In summer 1968, two cages (5.40 × 1.65 × 1.80 m) were constructed from 1 × 1 cm mesh. One was kept in a greenhouse and the other was placed outside. Each cage contained 15 female and 23 male large coppers, and 20 potted great water dock *Rumex hydrolapathum* plants. From 17 May–14 August 1968, the mean maximum temperature in the greenhouse cage (23.8°C) was higher than in the outside cage (16.8°C), but the mean minimum temperature was similar (greenhouse: 8.7°C; outside: 8.6°C). Eggs were counted daily.

A controlled study in 1979–1980 in a laboratory in the UK (3) found that large blue *Maculinea arion* caterpillars reared in ant *Myrmica* spp. nests without a queen present were more likely to survive than caterpillars reared in nests with a queen. The survival of caterpillars in nests without queen ants (10 out of 26 caterpillars) was higher than in nests with queen ants present (6 out of 39 caterpillars). The authors reported that caterpillars in *Myrmica scabrinodis* nests had lower survival than caterpillars in nests of the other species (data not presented). In 1979 and 1980, a total of 65 *Myrmica* ant colonies were established, containing 20–1,137 workers/colony depending on nest design (see paper for details). In each of 26 nests, 1–6 queen ants (depending on colony size) were present, and the other 39 nests did not contain queens. Most nests were *Myrmica sabuleti*, but four colonies were established with each of *Myrmica rubra*, *Myrmica ruginodis* and *Myrmica scabrinodis*. After >1 week, one newly moulted caterpillar was introduced to each nest. Caterpillar survival was monitored for >2 weeks.

A controlled study (years not given) in a laboratory in the UK or France (location not clear) (4) found that the survival of mountain Alcon blue *Maculinea rebeli* caterpillars reared in captivity differed between ant *Myrmica* spp. species, but not between colonies with or without queens present. Mountain Alcon blue caterpillars reared with *Myrmica schencki* (10 out of 99 survived to pupation) had higher survival rates than caterpillars reared with *Myrmica sabuleti* (4/78 survived), *Myrmica scabrinodis* (2/43 survived), *Myrmica rubra* (1/112 survived), *Myrmica ruginodis* (4/71 survived) or *Myrmica sulcinodis* (1/24 survived). The survival of caterpillars reared for three weeks in colonies with queens was 31–89%, compared to 43–78% without queens (statistical significance not assessed, see paper for details on each ant species). Over five years, >800 mountain Alcon blue caterpillars were introduced to 120 ant colonies kept in small plastic "Brian" nests (no further details provided). Colonies were collected from France and England, fed fruit flies *Drosophila* spp. and sucrose, and kept at a constant temperature which was adjusted weekly to mimic natural temperatures. Caterpillars were collected on their food plant, and placed into the foraging areas of the ants after emergence. Caterpillar survival was monitored for between three weeks and 10 months (to pupation) in the ant nests.

A replicated, controlled study (years not given) in a laboratory in Spain (5) found that mountain Alcon blue *Maculinea rebeli* caterpillars reared in ant *Myrmica rubra* nests at low density had higher survival rates than caterpillars reared at higher densities. The survival of mountain Alcon blue caterpillars reared at low density (five caterpillars/nest: 18 of 20 caterpillars survived) was higher than for caterpillars reared at higher densities (10 caterpillars/nest: 29/40 survived; 25 caterpillars/nest: 22/100 survived). At higher densities, more caterpillars survived in ant nests founded from a colony containing winged females (10: 19/20 survived; 25: 17/50 survived) than from a colony without winged females (10: 10/20 survived: 25: 5/50 survived), but surviving individuals were lighter in colonies with winged females (22–27 mg) than without them (37–50 mg). Caterpillars reared at low density weighed 39–46 mg. Two *Myrmica rubra* nests in the Pyrenees were excavated and used to establish 12 colonies, each containing 50 workers and 10 ant larvae. Colonies were kept in “Brian” nests with abundant food (no further details provided). When excavated, one nest contained a large number of winged females while the other contained none. In August, on the evening of their final moult, 160 mountain Alcon blue caterpillars were collected from the same site, and introduced to the ant colonies at three densities: five, 10 and 25 caterpillars/colony. From October–March, nests were overwintered in a cool room, after which caterpillars grew for another eight weeks until pupation. The survival and weights of caterpillars were recorded before pupation.

A study in 1994 in Cape Town, South Africa (6) reported that a female Dickson’s copper *Oxychaeta dicksoni* butterfly laid eggs in captivity in the presence of black cocktail ants *Crematogaster perengueyi* collected from the site where she emerged, but not in the presence of ants from 10 km away. The female laid ~100 eggs in captivity over 10 days when she was placed with ants that had been collected from the same site as her, but when these ants were swapped for others collected from a site 10 km away she stopped laying. When these ants were replaced with others from the original site, she laid another 20 eggs. Thirteen out of 20 eggs kept in captivity hatched 18–20 days after being laid but none of the larvae survived to adulthood. A freshly emerged female Dickson’s copper was collected from the wild after she was observed mating. She was placed in a small container (dimensions not provided), covered with a nylon net, containing *Phylica* stems and two black cocktail ants from either the same site or a site 10km away. Ten of the resulting larvae were placed in a container with a small ants’ nest taken from the same site as the female butterfly and a potted Phylica plant. The other three larvae were placed in a petri dish with two black cocktail ants and some dry twigs.

A study in 1995 in a captive setting in the Western Cape, South Africa (7) reported that two wild-caught, gravid female scarce mountain copper butterflies *Argyrocupha malagrida* brought into captivity laid eggs, but none hatched. Two gravid females of the scarce Table Mountain copper subspecies *Argyrocupha malagrida maryae* and *Argyrocupha malagrida paarlensis*, collected from the wild, laid eggs in captivity (approximately 12 each). Time from capture to laying is not reported. Eight months after laying no eggs had hatched but dissection revealed the larvae inside were still alive. In January 1995, one *Argyrocupha malagrida maryae* was caught near Bredasdorp and one *Argyrocupha malagrida paarlensis* on the Perdeberg mountain. They were each placed in their own container covered with netting and containing pieces of buchu plant *Agathosma* sp. And three common pugnacious ants Anoplolepis custodiens from where the butterflies were caught. Six weeks after laying, the eggs were exposed to direct sunlight for short periods daily, but this was stopped after 3–4 days. Eggs were misted with water once every two months. An egg was dissected at three, six and eight months after hatching.

A study in 1995–1996 in a captive setting in the Western Cape, South Africa (8) reported that 27% of wild-caught Brenton blue butterfly *Orachrysops niobe* eggs developed into adults. Of 15 eggs collected from the wild and kept in captivity, four developed into adult butterflies. However, captive reared adults were smaller (18–20 mm wingspan) than average wild-reared adults (26–30 mm). Some caterpillars died from a fungal infection (numbers not provided). In November 1995, researchers observed Brenton blue butterflies ovipositing at the Brenton Blue Butterfly Reserve near Knysna and collected 15 freshly-laid eggs to be reared in captivity. Eggs were placed in small air-tight plastic containers and provided with a sprig of Indigofera porrecta every 3–4 days throughout development. Eggs, all caterpillar instars, pupae and adults were measured. Survival data is only provided for adults.

A study in 1996–1997 in a captive setting in the Western Cape, South Africa (9) reported that wild-caught final instar Cape Peninsula butterfly *Thestor yildizae* caterpillars placed in an artificial pugnacious ant *Anoplolepsis custodiens* nest successfully pupated and eclosed, but captive-hatched first instar Cape Peninsula and Riley's skolly butterfly *Thestor rileyi* caterpillars placed next to an artificial ant nest did not survive to pupation. Three wild-caught final instar Cape Peninsula butterfly caterpillars were placed inside an artificial ant nest, were fed by ants with oral fluids, and survived to adulthood. However, first instar caterpillars of Cape Peninsula and Riley's skolly butterflies (numbers not provided), which hatched from eggs laid in captivity and were placed next to the artificial ant nest, were not observed being fed by ants, and died before pupation. Final instar Cape Peninsula caterpillars were collected from the wild and three were placed inside an artificial pugnacious ant nest attached to a glass arena. Adult female Cape Peninsula and Riley's skolly butterflies were also collected in the wild and put in containers to oviposit (numbers not given). Some of the hatching first instar caterpillars were placed in the arena next to the nest. In both experiments ant feeding behaviour, and caterpillar development times and survival were observed.

A review in 1998 (10) reported that four species of large blue butterfly *Maculinea* spp. were bred in captivity using ant *Myrmica* spp. colonies, with varying success. Alcon blue *Maculinea alcon* and mountain alcon blue *Maculinea rebeli* caterpillars were successfully reared in captive ant colonies on different occasions over 20 years (data not presented). Large blue *Maculinea arion* caterpillars were sometimes reared successfully using two methods, but 13 other nest designs failed (data not presented). Scarce large blue *Maculinea teleius* caterpillars were reared for up to eight months, using common red ant *Myrmica* *rubra* and *Myrmica scabrinodis* in two nest designs. Wild butterfly eggs were collected on flowering stems of food plants (gentian *Gentiana* spp., wild thyme *Thymus* spp., oregano *Origanum* spp., great burnet *Sanguisorba officinalis*). Ant colonies (see paper for six species) were collected by excavating nests. Caterpillars were introduced to ant colonies after they dropped from the flower heads. A variety of rearing methods were used, with different nest box designs (see paper for details).

A site comparison study in 1997–1998 in a laboratory in the UK (11) found that wild- and captive-laid large copper *Lycaena dispar batavus* eggs and caterpillars had similar survival in captivity. Both the survival to overwintering of wild-laid eggs (19 of 20 caterpillars), and the overwinter survival of these caterpillars (4 of 19 caterpillars), were statistically similar to the survival to overwintering (15 of 20 caterpillars) and overwinter survival (3 of 15 caterpillars) of captive-laid eggs. In September 1997, twenty wild-laid eggs were collected from a lowland bog in the Netherlands, and 20 captive-laid eggs were obtained from a 25-year-old glasshouse-reared colony at Woodwalton Fen. Eggs were reared to overwintering under controlled conditions (10 hours light, 14 hours dark, 20°C) in a laboratory. Immediately before overwintering, caterpillars were transferred to great water dock *Rumex hydrolapathum* pot plants and maintained in an overwinter environment (10 hours light, 14 hours dark, 5°C) for 20 weeks. Emergence was stimulated by increasing light by 15 minutes, and increasing temperature by 2°C, every two days for eight days, and survival was recorded.

A study (year not specified) in two captive-rearing facilities in Warwickshire and Oxfordshire, UK (12) reported that large white *Pieris brassicae* were successfully reared in captivity for >25 years, but found some morphological changes occurred. A population of large white were bred in captivity for >25 years (100–150 generations). However, long-term captive-bred butterflies were heavier (1.9 g) than butterflies in their third generation in captivity (1.8 g), and had smaller, shorter and broader wings (see paper for details). Captive-bred females laid more eggs (340 eggs/female) than females new to captivity (30 eggs/female). Caterpillars in a long-term captive population, originally caught in southern England >25 years ago, were reared on a synthetic diet at 23–25°C. Adults were kept in cages (45 × 80 × 48 cm) with 150–200 adults/cage. Wild egg batches were collected in Glamorgan, UK, and reared through two generations in captivity in the same conditions. Data were collected on the number of eggs laid in the first 16 days after emergence by 15 females kept with 15 males of each group, and the weight and wing size of freshly emerged adults (number not specified).

A study in 1999 in a captive setting in the KwaZulu-Natal province, South Africa (13) reported that 93% of wild-caught Karkloof blue butterfly *Orachrysops ariadne* eggs hatched and survived for up to three months in the presence of their host plant *Indigofera woodii* Bolus var. *laxa*, but none of the caterpillars survived to adulthood. Of 30 Karkloof blue butterfly eggs collected from the wild, 28 successfully hatched. Of the 18 resulting caterpillars that were kept in the laboratory, all were recorded feeding on the host plant and survived for up to three months, moulting two or three times, before dying from an unidentified fungal infection. In May–June 1999, 30 eggs were collected from three grassland reserves in the KwaZulu-Natal province and taken into captivity. Upon hatching each caterpillar was placed in a small container with fresh *Indigofera* shoots that were replaced every 1–2 days. Eighteen caterpillars were monitored until death for feeding behaviour, moulting occurrence and presence of fungal patches. Ten were returned to the field but not monitored.

A study in 2003 in a laboratory in the Western Cape Province, South Africa, (14) reported that Brenton blue butterfly *Orachrysops niobe* caterpillars reared on stems of their larval host plant *Indigofera erecta* with no ants became dwarf adults, but one of two larvae reared on a whole *Indigofera erecta* plant, with a *Camponotus baynei* ant colony, became a full-sized adult. Brenton blue caterpillars that were reared on cut stems of *Indigofera erecta* emerged as dwarf adults (average 10–13 mm forewings, number of individuals not provided). Of the two larvae that were reared on a full *Indigofera erecta* plant with an ant colony, one emerged as a full-sized adult (17 mm) and one died before pupation. No statistics were conducted. For the cut stem treatment, *Indigofera erecta* stems containing eggs found at the Brenton Blue Butterfly Reserve were cut and placed in containers. After hatching, fresh stems were provided every few days throughout larval development. Measurements of surviving caterpillars were taken at each instar and during and after pupation. For the whole plant and ant colony treatment, two caterpillars were each placed in connecting containers with an *Indigofera erecta* plant each. These containers were linked to another compartment containing an ant nest collected from the wild. The surviving caterpillar was measured as an adult.

A study (years not given) in a captive setting in the Western Cape, South Africa (15) reported that wild-collected Brenton blue butterfly *Orachrysops niobe* eggs hatched and caterpillars kept with only *Phyllanthus incurvatus* leaves died before completing the first instar of development but all caterpillars also given *Indigofera erecta* leaves developed normally through to the fourth instar. Caterpillars in captivity were seen feeding on the leaves of Indigofera erecta but not Phyllanthus incurvatus. No data on number of eggs collected or number of caterpillars in each treatment are provided. Cuttings were taken from *Phyllanthus incurvatus* plants in the wild where Brenton blue butterflies had laid eggs, and the cutting and eggs were placed in air-tight plastic containers. Some containers were left with only their original *Phyllanthus incurvatus* cutting, whereas an *Indigofera erecta* cutting was placed in others once the eggs had hatched. Feeding behaviour and survival to the fourth instar was recorded.

A controlled study in 2003–2006 in two captive-breeding facilities in Washington, USA (16) found that captive-reared Puget blue butterflies *Icaricia icarioides blackmorei* were smaller than wild-born individuals, and caterpillars kept in refrigerators overwinter had lower survival than other treatments. There was no significant difference between the survival to adulthood of eggs collected from the wild (17/200 eggs) and eggs laid in captivity (39/548 eggs), or of caterpillars kept in environmental chambers (49/514 caterpillars) or outdoor enclosures (49/450) overwinter. However, all 308 caterpillars kept in refrigerators overwinter died. Captive-reared butterflies were smaller than wild-caught butterflies, but adult size was similar between all captive treatments (see paper for details). In June 2003, forty-eight female butterflies were collected from the wild and 39 laid 1,879 eggs in captivity. Overwinter, surviving caterpillars were kept in one of three treatments: a refrigerator, an environmental chamber with light, humidity and temperature approximating optimal rearing conditions, or an outdoor enclosure experiencing ambient conditions (see paper for housing details). In 2004, surviving caterpillars were reared on netted sickle-keeled lupine *Lupinus albicaulis*. In spring 2005, sixty female butterflies were collected from a second site and 51 laid 548 eggs in captivity. In addition, lupine leaves with 200 wild-laid eggs were collected and reared in captivity. All caterpillars overwintered in outdoor enclosures. In 2004–2006, captive-reared and wild-caught adults were weighed and measured.

A replicated, controlled study (years not given) in a laboratory in Belgium (17) found that cranberry fritillary *Boloria aquilonaris* caterpillars reared at 20 °C had higher survival to pupation than those reared at 25 °C, but there was no effect on survival of the amount of sphagnum moss *Sphagnum* spp. that caterpillars were reared with. Ninety percent of 68 cranberry fritillary caterpillars kept at 20 °C survived to become pupae, compared to 65% of 68 kept at 25 °C. However, the number of pieces of sphagnum moss that caterpillars were kept with did not significantly affect survival (1 piece = 70–94% survival, 6 pieces = 60–85%). One-hundred-and-thirty-six first, second and third instar wild-collected caterpillars were kept individually in petri dishes with small cranberry *Vaccinium oxycoccus* leaves. All caterpillars were kept at 10 °C at night, but half were kept at 20 °C during the day, and half at 25 °C. Within each temperature regime, half were kept with one piece of sphagnum moss and half with six pieces. This was primarily done to manipulate humidity, since the enclosures with one piece of sphagnum moss were less humid than those with six pieces. Every two days the petri dishes were cleaned and small cranberry leaves and sphagnum moss pieces were replaced. Survival to pupation was recorded.

A study in 2004–2007 in six captive-breeding sites in Cumbria, UK (18) reported that a captive population of marsh fritillary *Euphydryas aurinia* increased in size over two years. Results were not tested for statistical significance. Two years after 250 caterpillars were taken into captivity, the captive population was estimated at 50,000 caterpillars. In September 2004, the only two caterpillar webs (containing 155 individuals) remaining locally were taken into captivity. In addition, 95 caterpillars from 19 populations (five from each location) in west Scotland were collected. Caterpillars were checked for infection with the parasitoid *Cotesia melitaearum*. Caterpillars were kept at six separate locations, and reared in natural conditions using large netted cages and pot-grown devil's-bit scabious *Succisa pratensis*, supplemented with garden varieties of honeysuckle *Lonicera* spp., snowberry *Symphoricarpos albus* and wild honeysuckle *Lonicera periclymenum*. The number of caterpillars in the captive population was estimated in spring 2007.

A replicated, site comparison study in 2014 in a laboratory in Poland (19) found that scarce large blue *Maculinea teleius* caterpillars reared by ants *Myrmica scabrinodis* from sites where the butterfly occurs survived longer than caterpillars raised by ants from sites where the butterfly does not occur, but all caterpillars ultimately died. The survival of scarce large blue caterpillars raised in ant colonies collected from sites where scarce large blue occurs was higher than in colonies collected from sites where scarce large blue does not occur (data presented as model results). However, no caterpillars survived >35 days. In August 2014, ten ant colonies were collected from each of four wet meadows, 110–470 km apart: two where scarce large blue and other ant parasites occurred and two where they did not. Each colony (50 old and 50 young workers with 15 ant larvae) was placed in a plastic box (20 × 12 × 7 cm) containing a patch of wet plaster covered by a flowerpot saucer with an entrance notch. Great burnet *Sanguisorba officinalis* stems were collected from one site, and placed in water with the flowerheads bagged in eight bunches of 25 stems. Bunches were shaken each morning to collect fourth instar caterpillars, and one caterpillar was placed in each ant colony. Fifteen ant larvae were added to each colony each week as food. The survival of caterpillars was checked every 1–2 days until all caterpillars had died.

A study in 2008–2016 in a zoo in Essex, UK (20) reported that Fisher's estuarine moth *Gortyna borelii lunata* eggs collected from the field successfully survived to adulthood, bred successfully in captivity and the resulting captive population continued for at least eight generations. Data on survival and breeding success were not provided. In 2008, ten batches of Fisher's estuarine moth eggs were collected from a natural population and placed in 2 m3 stainless steel mesh cages. In April–May, post-hatching, caterpillars were placed in cages containing one or two potted hog's fennel *Peucedanum officinale* plants, with 1–2 caterpillars/cage. In September–October, as adults, they were placed in cages containing a potted hog's fennel plant and coarse grass to mate and lay eggs (numbers/cage not provided). In March, some eggs were placed in pots in a cold frame until they hatched and used to continue the captive breeding programme and some were translocated to six sites in Essex as part of a reintroduction plan (proportions of eggs kept and reintroduced not provided). Every three years after 2008, eggs were collected from the original donor site to supplement the captive-bred population (numbers of eggs not provided).

A replicated, randomized, paired, controlled study in 2014–2016 in a greenhouse in Iowa, USA (21) reported that monarch butterflies *Danaus plexippus* were successfully reared in captivity for 12 generations, and found that caterpillar survival differed between milkweed *Asclepias* species. A population of monarchs was bred in captivity for 12 generations. However, more caterpillars fed on butterfly milkweed *Asclepias tuberosa* (75%) or poke milkweed *Asclepias exaltata* (72%) survived to adulthood than caterpillars fed on tall green milkweed *Asclepias hirtella* (31%) or prairie milkweed *Asclepias sullivantii* (36%). In May–June 2014, a total of 253 wild monarch eggs and young caterpillars were collected. Caterpillars were fed on common milkweed *Asclepias syriaca* in the summer, and a tropical milkweed *Asclepias curassavica* in the autumn and winter. Adults were tested for parasites *Ophryocystis elektroscirrha* before being allowed to mate. In the 13th generation, individual, newly hatched caterpillars were placed on an 8-week-old milkweed plant grown from seed. Thirty-six blocks, each containing one plant of nine milkweed species (butterfly, poke, tall green, prairie, common, swamp *Asclepias incarnata*, showy *Asclepias speciosa*, whorled *Asclepias verticillata* and honeyvine *Cynanchum leave* milkweed), were placed in a pop-up cage (57 × 37 × 55 cm) and netting in a greenhouse. From day 12, cages were checked daily, and pupae were moved to a laboratory until emergence.

A replicated, randomized, controlled study in 2014–2015 on a farm in Galilee, Israel (22) found that captive spring webworm *Ocnogyna loewii* caterpillars fed vegetation from grazed paddocks had a similar growth rate to caterpillars fed vegetation from ungrazed paddocks. Over five days, the growth rate of caterpillars fed on vegetation from cattle-grazed paddocks (0.12 mg/mg/day) was similar to caterpillars fed vegetation from ungrazed pastures (0.11 mg/mg/day). Sixty wild, fourth instar caterpillars were collected and weighed, and placed in individual plastic containers (12 cm diameter, 8 cm height) with a perforated lid. Caterpillars were randomly divided into six groups, and fed daily with fresh plants from one of six paddocks (three grazed, three ungrazed). Caterpillars were re-weighed after five days, and their growth rate calculated.

(1) Duffey E. (1968) Ecological studies on the large copper butterfly *Lycaena dispar* (Haw.) *batavus* (Obth.) at Woodwalton Fen National Nature Reserve, Huntingdonshire. *Journal of Applied Ecology*, 5, 69–96.
(2) Duffey E. (1977) The re-establishment of the large copper butterfly *Lycaena dispar batava* obth. on Woodwalton Fen National Nature Reserve, Cambridgeshire, England, 1969-73. *Biological Conservation*, 12, 143–158.
(3) Thomas J.A. & Wardlaw J.C. (1990) The effect of queen ants on the survival of *Maculinea arion* in *Myrmica* ant nests. *Oecologia*, 85, 87–91.
(4) Elmes G.W., Thomas J.A. & Wardlaw J.C. (1991) Larvae of *Maculinea rebeli*, a large-blue butterfly, and their *Myrmica* host ants: wild adoption and behaviour in ant nests. *Journal of Zoology*, 223, 447–460.
(5) Thomas J.A., Elmes, G.W. & Wardlaw J.C. (1993) Contest competition among *Maculinea rebeli* butterfly larvae in ant nests. *Ecological Entomology*, 18, 73–76.
(6) Heath A. & Brinkman A. K. (1995) Aspects of the life history, distribution and population fluctuations of *Oxychaeta dicksoni* (Gabriel) (Lepidoptera, Lycaenidae). *Metamorphosis*, 6(3), 117-127.
(7) Heath A. & Brinkman A. K. (1995) Notes on the early stages of *Argyrocupha malagrida* maryae (Wallengren) (Lepidoptera, Lycaenidae). *Metamorphosis*, 6(4), 167-173.
(8) Edge D.A. & Pringle E.L. (1996) Notes on the natural history of the Brenton blue *Orachrysops niobe* (Trimen) (Lepidoptera: Lycaenidae). *Metamorphosis* 7(3), 109-122.
(9) Claassens A.J.M. & Heath A. (1997) Notes on the myrmecophilous early stages of two species of Thestor Hübner (Lepidoptera: Lycaenidae) from South Africa. *Metamorphosis*, 8(2), 56-61.
(10) Wardlaw J.C., Elmes G.W. & Thomas J.A. (1998) Techniques for studying *Maculinea* butterflies: I. Rearing *Maculinea* caterpillars with *Myrmica* ants in the laboratory. *Journal of Insect Conservation*, 2, 79–84.
(11) Nicholls C.N. & Pullin A.S. (2000) A comparison of larval survivorship in wild and introduced populations of the Large Copper butterfly (*Lycaena dispar batavus*). *Biological Conservation*, 93, 349–358.
(12) Lewis O.T. & Thomas C.D. (2001) Adaptations to captivity in the butterfly *Pieris brassicae* (L.) and the implications for ex situ conservation. *Journal of Insect Conservation*, 5, 55–63.
(13) Lu S. & Samways M. J. (2001) Life history of the threatened Karkloof blue butterfly, *Orachrysops ariadne*. *African Entomology*, 9(2), 137-151.
(14) Edge D.A. & van Hamburg H. (2003) Larval feeding behaviour and myrmecophily of the Brenton Blue, *Orachrysops niobe* (Trimen) (Lepidoptera: Lycaenidae). *Journal of Research on Lepidoptera*, 42, 21-33.
(15) Edge D.A. (2008) Adult behaviour of *Orachrysops niobe* (Trimen) (Lepidoptera:Lycaenidae). *Metamorphosis*, 19(3), 116-126.
(16) Schultz C.B., Dzurisin J.D. & Russell C. (2009) Captive rearing of Puget blue butterflies (*Icaricia icarioides blackmorei*) and implications for conservation. *Journal of Insect Conservation*, 13, 309–315.
(17) Turlure C., Choutt J., Baguette M. & van Dyck H. (2010) Microclimatic buffering and resource-based habitat in a glacial relict butterfly: significance for conservation under climate change. *Global Change Biology*, 16(6), 1883-1893.

(18) Porter K. & Ellis S. (2011) Securing viable metapopulations of the Marsh Fritillary butterfly, *Euphydryas aurinia*, (Lepidoptera: Nymphalidae) in Northern England. *Journal of Insect Conservation*, 15, 111–119.
(19) Witek M., Ślipiński P., Trigos Peral G. & Csata E. (2016) Consequences of the arms race between *Maculinea teleius* social parasite and *Myrmica* host ants for myrmecophilous butterfly conservation. *Journal of Insect Conservation*, 20, 887–893.
(20) Gardiner T., Ringwood Z., Fairweather G., Perry R. & Woodrow P.L. (2017) Introductions of two insect species threatened by sea-level rise in Essex, United Kingdom: Fisher's estuarine moth *Gortyna borelii lunata* (Lepidoptera: Noctuidae) and Mottled grasshopper *Myrmeleotettix maculatus* (Orthoptera: Acrididae). *International Zoo Yearbook*, 51(1), 69-78.
(21) Pocius V.M., Debinski D.M., Pleasants J.M., Bidne K.G., Hellmich R.L. & Brower L.P. (2017) Milkweed Matters: Monarch Butterfly (Lepidoptera: Nymphalidae) Survival and Development on Nine Midwestern Milkweed Species. *Environmental Entomology*, 46, 1098–1105.
(22) Berman T.S., Ben-Ari M., Henkin Z. & Inbar M. (2018) Immediate and long-term facilitative effects of cattle grazing on a polyphagous caterpillar. *Agriculture, Ecosystems & Environment*, 261, 45–53.

14.5. Release captive-bred individuals to the wild

- **Thirteen studies** evaluated the effects of releasing captive-bred butterflies and moths into the wild. Nine studies were in the UK[1–3,6–8,11-13] and one was in each of the UK and Ireland[4], the UK and the Netherlands[5], the USA[9] and Poland and Slovakia[10].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (12 STUDIES)

- **Abundance (10 studies):** Six studies (including one before-and-after study) in the UK[2,3,11,13], the USA[9] and Poland and Slovakia[10] reported that captive-bred butterfly populations released as eggs[9,13], caterpillars[2,9,11], pupae[2] and adults[3,10] (sometimes into managed habitat[3,11] or alongside translocated individuals[9]) persisted for 2–28 years and increased in abundance (sometimes with continued captive-rearing of wild-laid caterpillars[2] or supplemented by further releases[10,13]). Two studies (including one review) in the UK[1,7] reported that captive-bred large copper[1] and belted beauty moth[7] populations released as caterpillars (sometimes into managed habitat[1]) died out one[7], two[1] or 12[1] years after release, or required further releases to survive[1]. One replicated study in the UK[8] reported that three of 10 captive-bred barberry carpet moth populations released as caterpillars (and in one case as adults) established, and at least one persisted for five years. One review across the UK and Ireland[4] found that 25% of captive-bred and translocated butterfly populations survived for >3 years, but 38% died out in that time, and only 8% were known to have survived for >10 years.

- **Reproductive success (2 studies):** One study in the UK[2] reported that after the release of a captive-bred population of large copper, the number of eggs laid/female increased over the first three years. One before-and-after study in the UK reported captive-bred adult pearl-bordered fritillaries released into coppiced woodland successfully bred at least once[12].

- **Survival (3 studies):** Three studies (including two replicated, site comparison studies and one review) in the UK[1,6] and the UK and the Netherlands[5] found that released, captive-bred large copper caterpillars had a lower survival rate than captive[1], wild[5] or translocated[6] caterpillars.

BEHAVIOUR (0 STUDIES)

Background

Many species of butterfly and moth have severely declined or gone extinct in parts of their former range, particularly in areas where high rates of habitat conversion have occurred (Fox *et al.* 2010, Maes & Van Dyck 2001, van Swaay 1990). Given the poor dispersal ability of many species, and the highly fragmented nature of many landscapes, the transportation of individuals to suitable sites may be the only means by which a species is able to recolonize. Releases could be composed of captive-bred animals (bred from captive populations over one or more generations) or translocated animals (caught in the wild at another site, see "*Translocate to re-establish populations in known or believed former range*" and "*Translocate to establish populations outside of known range*"), and individuals at any life stage (adult, egg, caterpillar or pupa) may be used for capture and release.

Note that restoring habitat quality prior to the release of captive-bred butterflies and moths is likely to be an important factor determining the success of reintroduction projects (Schultz *et al.* 2008). Furthermore, for parasitic species such as the large blues *Phengaris* (*Maculinea*) spp., which rely on specific hosts (ants *Myrmica* spp.) for survival, the presence of a healthy population of the host species will be required at the release site.

For studies on the process of captive-breeding butterflies and moths, see "*Rear declining species in captivity*".

Fox R., Warren M.S., Brereton T.M., Roy D.B. & Robinson A. (2010) A new Red List of British butterflies. *Insect Conservation and Diversity*, 4, 159–172.

Maes D. & Van Dyck H. (2001) Butterfly diversity loss in Flanders (north Belgium): Europe's worst case scenario? *Biological Conservation*, 99, 263–276.

Schultz C.B., Russell C. & Wynn L. (2008) Restoration, reintroduction, and captive propagation for at-risk butterflies: A review of British and American conservation efforts. *Israel Journal of Ecology & Evolution*, 54, 41–61.

van Swaay C.A.M. (1990) An assessment of the changes in butterfly abundance in The Netherlands during the 20th Century. *Biological Conservation*, 52, 287–302.

A review in 1929–1966 in three fens in Cambridgeshire and Norfolk, UK (1) reported that released large copper *Lycaena dispar batavus* caterpillars had lower survival rates than captive caterpillars, and three released populations ultimately died out or required additional releases to survive. Results were not tested for statistical significance. One population of captive-bred large copper survived for 12 years after release, until the fen was drained, but a second population died out two years after release. A third population was maintained for over 30 years by continued releases. In this population, survival from the egg stage to caterpillars in spring in the released population was 4.4%, compared to 5.1% in the captive population, but the survival of caterpillars from spring to pupation was 15.1% in the released population, compared to 79.1% in the captive population. In winter 1929–1930, a 3-ha fen in Cambridgeshire was cleared and planted with great water dock *Rumex hydrolapathum*. In May 1930, 'a sufficient number' of large copper caterpillars were placed on marked plants, and a second release was conducted in 1931 or 1932. In 1942 the fen was drained. In June–July 1949, eighty adults were released on a fen in Norfolk. From the 1930s–1966, a semi-wild population was maintained at a second Cambridgeshire fen, by regular (becoming annual) releases of captive-bred caterpillars. From 1961–1966, the survival of released and captive caterpillars was estimated each year.

A study in 1970–1976 in a fen in Cambridgeshire, UK (2) reported that after the release of captive-bred large copper butterflies *Lycaena dispar batava*, the number of eggs laid/female and the number of caterpillars emerging after hibernation increased over three years, and the population survived for at least six years. Results were not tested for statistical significance. One year after the first release of adult butterflies, 111 caterpillars emerged from hibernation. In the second year, 427 caterpillars emerged, and in the third year 1,344 caterpillars emerged. The number of eggs laid/female increased from 4.85 in the first year to 89–100 in the fourth year. Six years after the first release, eggs were widely distributed across the site. In late summer 1970, caterpillars and pupae from two captive-bred populations were placed in muslin cages across a fenland nature reserve, from which 517 males and 551 females were released. In spring 1971–1973, wild-hatched caterpillars were collected and reared to pupation in muslin cages, and additional releases from captive stock were made (344–554 males/year, 208–446 females/year). Wild-hatched caterpillars were reared in cages again in later years. No details are given on how the eggs and caterpillars were counted and collected.

A study in 1984–1989 in a woodland in Essex, UK (3) reported that captive-bred heath fritillary *Mellicta athalia* released into a coppiced woodland survived and the population increased. Results were not tested for statistical significance. Two years after the release of 53 adult heath fritillaries, the population was nearly 3,000 adults (when the extent of breeding habitat was at its maximum), but stabilized at around 500 adults after five years. In 1984, a total of 53 captive-bred adult heath fritillaries (31 females, 22 males) were released into a coppiced woodland (coppicing commenced in 1980) containing around 4 ha of host plant (common cow-wheat *Melampyrum pratense*). From 1985–1989, butterflies were surveyed annually on timed counts along a zig-zag route covering the known flight areas. The total yearly population was estimated by multiplying the peak population count by three.

A review from pre-1900–1988 across the UK and Ireland (4) found that at least a quarter of reintroduced butterfly populations survived for over three years, but only 8% were known to survive for more than 10 years after release. Of 274 documented reintroductions of native butterflies, 68 populations (25%) were known to have survived for more than three years, and 21 (8%) were known to survive for more than 10 years. However, 103 populations (38%) died out within three years of release. The remaining reintroductions were either poorly documented (73 releases) or occurred too recently to determine success (30 releases). Twenty-five releases which aimed to reinforce existing populations are not included. Records of all documented releases of butterflies in the UK and Ireland were compiled by Oates & Warren (1990), and their success up to 10 years after release was updated by this study. At least 29% of releases were of captive-bred butterflies. No further details were provided.

A replicated, site comparison study in 1995–1998 in three fens in Norfolk, UK and nine in Overijssel, the Netherlands (5, same study as 6) found that released, captive-bred large copper *Lycaena dispar batavus* caterpillars had lower overwinter survival rates than wild caterpillars. The overwinter survival of released captive-bred caterpillars in the UK (0–7%/year: 30/1,440 caterpillars found) was lower than the overwinter survival of a wild population in the Netherlands (19–42%/year: 41/139 caterpillars found). Post-winter survival to pupation of released captive-bred caterpillars in the UK was 49–56% (215/420 caterpillars found). A captive population of large copper was maintained for >25 years. From September–October 1995–1997, captive-bred caterpillars were released in seven 50 × 50 m plots across three sites in Norfolk. Five caterpillars were placed on each of 7–40 randomly chosen great water dock *Rumex hydrolapathum* plants/plot/year (total: 1,440 caterpillars). In April–May 1996–1998 plants were searched for surviving caterpillars. In April–May 1996 and 1997 a further 15–70 caterpillars/plot/year (total: 420 caterpillars) were released, and monitored through to pupation. In 1996–1997, at nine fens within a 3,500-ha lowland bog in the Netherlands, wild large copper eggs were counted on every water dock encountered along a transect through each fen. Plants were revisited three weeks later, and in April the following year, to record caterpillar survival.

A replicated, paired, site comparison study in 1997–1998 in a fen in Norfolk, UK (6, same study as 5) found that released captive-bred large copper *Lycaena dispar batavus* caterpillars had lower overwinter survival rates than translocated wild caterpillars. The overwinter survival of released captive-bred caterpillars (1 of 95 caterpillars found) was lower than the overwinter survival of translocated wild caterpillars (8 of 95 caterpillars found). In September 1997, captive-laid eggs were obtained from a 25-year-old glasshouse-reared colony at Woodwalton Fen, and wild-laid eggs were collected from a 3,500-ha lowland bog in the Netherlands. Eggs from both sources were reared to overwintering in the laboratory. A total of 95 captive-bred and 95 wild caterpillars were placed on to 19 pairs of great water dock *Rumex hydrolapathum* (5 caterpillars/plant) in an open fen in Norfolk. In May 1998, after late flooding, surviving caterpillars were counted on each plant.

A study in 2002–2003 in a coastal sand dune in Caernarvonshire, UK (7) reported that a population of captive-bred belted beauty moth *Lycia zonaria britannica* did not survive the first year after release. One year after the first release of caterpillars, no adults were found at the site. Results for the second year were not presented. In April 2002 and 2003, three to eight gravid females were collected from an 89-ha sand dune system. Their eggs were kept, and the caterpillars were reared on bird's-foot trefoil *Lotus corniculatus*. In late May 2002 and 2003, a total of 2,030 caterpillars were released (number/year not specified) at 22 locations across a 7.4-ha sand dune (21.5 km from the capture site), most of which was managed as a nature reserve. In spring 2003, the release site was searched for emerging adults. The authors also reported that two releases of small numbers of caterpillars to a site in Merseyside, UK, in the early 1990s, were unsuccessful (no further details provided).

A replicated study in 1987–early 2000s (exact year not given) in 10 woodlands and hedgerows in England, UK (8) reported that three out of 10 released populations of captive-bred barberry carpet moth *Pareulype berberata* established in the wild. At three sites where hundreds of barberry carpet moth caterpillars, and in one case adults, were released, self-maintaining populations were established. One population had survived for five years. However, at one site where thousands of caterpillars were released in multiple attempts, some breeding took place but the population died out after three generations. The author suggested that common barberry *Berberis vulgaris* bushes needed to be trimmed to generate new growth. At another site where thousands of caterpillars were released on to cultivated barberry (*Berberis thunbergii* and *Berberis ottawensis*), the population failed to establish, despite caterpillars using these species in captivity. From 1987, but especially from the late 1990s, small numbers of barberry carpet moths (adults and caterpillars) were collected from the wild. Captive-bred caterpillars were released in multiple batches at 10 sites in Wiltshire, Northamptonshire, Lincolnshire, Suffolk, Cambridgeshire and Norfolk with established barberry bushes. At one site adults were also released. No monitoring details were provided.

A study in 1977–2005 in an alpine meadow in Colorado, USA (9) reported that a captive-bred and translocated population of Gillette's checkerspot *Euphydryas gillettii* released outside the species' native range survived for 28 years, but only increased in size and colonized new sites after 22–25 years. For 21 years after the release of 83 egg clusters, the population size fluctuated between 24 and 143 adults, and remained confined to the release site. However, four years later, the population was estimated at >3,000 adults, and covered 70.4 ha. After a further three years, the population had declined to 150 adults at the release site, but two other habitat patches (0.3 and 0.6 ha) remained occupied (13–153 adults/ha). In July 1977, eggs and adult females were collected in Wyoming, and kept in a laboratory where more eggs were laid. In July–August 1977, eighty-three wild- and captive-laid egg and caterpillar clusters (~10,000 individuals from ~40 females) were released on to bearberry honeysuckle *Lonicera involucrata* in a 2.25-ha meadow. Details of the translocation taken from Holdren & Ehrlich (1981). In June–July 1978–1989 and 2002–2005, adult butterflies at the release site were caught and uniquely marked every 1–7 days. Recapture rates of marked butterflies were used to estimate the population size in years with sufficient data (1981–1986, 2002–2005). In 1978–1989, 2002 and 2004–2005, egg clusters and/or caterpillar webs were counted throughout the season at the release site, and in 2003–2005 at two newly colonized sites. The relationship between number of egg clusters and adult population was used to estimate the population size in the remaining years. From 1978–1987, areas surrounding the release site were searched for egg clusters or caterpillar webs, and from 2002–2005 a larger area was searched for adults.

A before-and-after study in 1991–2003 in a limestone montane grassland reserve in Poland and Slovakia (10) found that releasing captive-bred Apollo butterflies *Parnassius apollo frankenbergeri* increased both the population size and the number of occupied sites. Eleven years after the release of captive-bred butterflies began, a population of Apollo butterflies contained ~1,000 individuals, compared to 30 individuals the year before the first release. The number of sub-populations increased from one to more than 12. However, when the number of butterflies in a sub-population was high, the sub-population size in a given year was lower when more captive-bred butterflies had been released the previous year (data presented as model results). In 1991, butterflies from a remnant population were taken into captivity and bred (number captured not specified). From 1992–2001, between 22 and 658 butterflies/year were released across four areas (2,917 butterflies released in total). In 1995, the captive population was supplemented with butterflies from another population to increase genetic diversity. The species' host plant, stonecrop *Sedum maximum*, was abundant at the release sites. From 1991–2003, suitable sites were visited twice/week for 1–3 hours during the flight period, and population size was estimated by marking and recapturing all butterflies observed.

A replicated study in 2007–2009 in four wet grasslands in Cumbria, UK (11) reported that three out of four released populations of marsh fritillary *Euphydryas aurinia* increased in size over three years. Results were not tested for statistical significance. Three years after the release of 3,500–22,900 caterpillars/site at three sites, the number of caterpillar webs was 47–240 webs/site, compared to 16–112 webs/site one year after release. However, at a fourth site where 11,000 caterpillars were released, the number of webs remained low (1–10 webs/year). From before 2004, four sites were managed by a combination of scrub control (all sites), removal of trees (one site), reinstating cattle or pony grazing at 0.4 livestock units/ha (all sites), water level management (two sites) and cutting and removal of course grasses (one site) to increase the area of suitable habitat for marsh fritillary (estimated at 7.4–20.0 ha/site in 2007). In March–April 2007, a total of 42,000 caterpillars were released at four sites (3,500–22,900 caterpillars/site). Caterpillars were placed in groups of ~100 on clusters of devil's-bit scabious *Succisa pratensis*. From mid-August 2007–2009, every patch of devil's-bit scabious at each site was searched for caterpillar webs.

A before-and-after study in 2007–2011 in a woodland in East Sussex, UK (12) reported that captive bred pearl-bordered fritillary *Boloria euphrosyne* released into coppiced woodland bred at least once. Results were not tested for statistical significance. In 2011, one year after the release of some captive-bred adult pearl-bordered fritillaries (numbers not provided) into an area where they had previously gone extinct, their offspring were recorded at the site. At some time between 2007 and 2010 surveys showed that there was no longer a population of pearl-bordered fritillary in Rother Woods, so during this time coppicing management was reinstated (exact management dates not provided). Captive-bred adults were released into the site in 2010 and a survey in 2011 recorded adults of the next generation.

A study in 2009–2016 in six coastal grasslands in Essex, UK (13) reported that released captive-bred Fisher's estuarine moths *Gortyna borelii lunata* established populations and bred at all sites, in some cases for seven years. Six populations resulting from the release of captive Fisher's estuarine moths were present for up to seven years, and breeding was confirmed at all sites (sometimes in all seven years). Numbers of individuals and years of confirmed breeding events at each site are not provided. In March–April 2009–2016, blades of grass containing eggs from a captive breeding programme were placed next to hog's fennel *Peucedanum officinale* plants at each of the six sites. Later each year some caterpillars which were not needed for the continuation for the captive breeding programmes were also introduced to each site. Two sites received eggs and caterpillars in two years, and four only in one year (years of release at each site not provided). Between mid-July and mid-August each year hog's fennel plants at each site were searched for distinctive feeding signs to confirm presence of the moth.

(1) Duffey E. (1968) Ecological studies on the large copper butterfly *Lycaena dispar* (Haw.) *batavus* (Obth.) at Woodwalton Fen National Nature Reserve, Huntingdonshire. *Journal of Applied Ecology*, 5, 69–96.
(2) Duffey E. (1977) The re-establishment of the large copper butterfly *Lycaena dispar batava* obth. on Woodwalton Fen National Nature Reserve, Cambridgeshire, England, 1969-73. *Biological Conservation*, 12, 143–158.
(3) Warren M.S. (1991) The successful conservation of an endangered species, the heath fritillary butterfly *Mellicta athalia*, in Britain. *Biological Conservation*, 55, 37–56.
(4) Pullin A.S. (1996) Restoration of butterfly populations in Britain. *Restoration Ecology*, 4, 71–80.
(5) Nicholls C.N. & Pullin A.S. (2000a) A comparison of larval survivorship in wild and introduced populations of the Large Copper butterfly (*Lycaena dispar batavus*). *Biological Conservation*, 93, 349–358.
(6) Nicholls C.N. & Pullin A.S. (2000b) A comparison of larval survivorship in wild and introduced populations of the Large Copper butterfly (*Lycaena dispar batavus*). *Biological Conservation*, 93, 349–358.
(7) Howe M.A., Hinde D., Bennett D. & Palmer S. (2004) The conservation of the belted beauty *Lycia zonaria britannica* (Lepidoptera, Geometridae) in the United Kingdom. *Journal of Insect Conservation*, 8, 159–166.
(8) Waring P. (2004) Successes in conserving the Barberry Carpet moth *Pareulype berberata* (D. & S.) (Geometridae) in England. *Journal of Insect Conservation*, 8, 167–171.
(9) Boggs C.L., Holdren C.E., Kulahci I.G., Bonebrake T.C., Inouye B.D., Fay J.P., McMillan A.N.N., Williams E.H., Ehrlich P.R. (2006) Delayed population explosion of an introduced butterfly. *Journal of Animal Ecology*, 75, 466–475.
(10) Adamski P. & Witkowski Z. (2007) Effectiveness of population recovery projects based on captive breeding. *Biological Conservation*, 140, 1–7.
(11) Porter K. & Ellis S. (2011) Securing viable metapopulations of the Marsh Fritillary butterfly, *Euphydryas aurinia*, (Lepidoptera: Nymphalidae) in Northern England. *Journal of Insect Conservation*, 15, 111–119.
(12) Hoare D., Dent K., Kelly C., McLellan L., Thompson F. & Wheatley S. (2012) Landscape-scale woodland restoration for multiple species in the South East Woodlands. 66–75.
(13) Gardiner T., Ringwood Z., Fairweather G., Perry R. & Woodrow P.L. (2017) Introductions of two insect species threatened by sea-level rise in Essex, United Kingdom: Fisher's estuarine moth *Gortyna borelii lunata* (Lepidoptera: Noctuidae) and Mottled grasshopper *Myrmeleotettix maculatus* (Orthoptera: Acrididae). *International Zoo Yearbook*, 51(1), 69-78.

Non-target species

14.6. Manage host species' populations for the benefit of dependent parasite/mutualist species

- We found no studies that evaluated the effects of managing host species' populations for the benefit of dependent parasite or mutualist species of butterfly or moth.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Some butterflies, in particular the large blues *Phengaris* (*Maculinea*) spp., are parasites of ant colonies of the genus *Myrmica*, and depend upon just one or two host ant species for their caterpillars to develop. Other species of blue butterfly, such as the chalkhill blue *Polyommatus coridon*, have mutualistic relationships with ants, whereby the caterpillar excretes a sugary secretion which is eaten by the ants, which in turn protect the caterpillar (Thomas & Lewington 2016). Therefore, effective conservation for these butterflies depends not just on habitat management for the requirements of the butterfly, but also for the requirements of the *Myrmica* ants and (in some cases) the suppression of the more competitive black ant *Lasius niger* (Wynhoff *et al.* 2011, Wynhoff *et al.* 2017). For example, the translocation of sods from fen meadows to restoration areas encouraged colonization by *Myrmica scabrinodis* (Wynhoff *et al.* 2017). *Myrmica scabrinodis* is further supported by early or late season mowing, while *Myrmica rubra* nests should be undisturbed in summer, and mown in late autumn (Wynhoff *et al.* 2011).

Studies are only included here if they record the outcome *on a species of butterfly or moth*, not just on the host or mutualist species.

Thomas J.A. & Lewington R. (2016) *The Butterflies of Britain & Ireland*. Third edition, Bloomsbury Publishing, UK.

Wynhoff I., van Gestel R., van Swaay C. & van Langevelde F. (2011) Not only the butterflies: managing ants on road verges to benefit *Phengaris* (*Maculinea*) butterflies. *Journal of Insect Conservation*, 15, 189–206.

Wynhoff I., Kolvoort A.M., Bassignana C.F., Berg M.P. & van Langevelde F. (2017) Fen meadows on the move for the conservation of *Maculinea* (*Phengaris*) *teleius* butterflies. *Journal of Insect Conservation*, 21, 379–392.

15. Education and awareness raising

Background

Humans pose many threats to butterflies and moths, through intentionally or unintentionally harmful behaviours, such as the use of pesticides and other chemicals, damage to important habitats, or the release of non-native species into the wild. However, through favourable management of land, such as private gardens, parks or farmland, people also have the opportunity to help butterflies and moths to thrive. This chapter includes actions which aim to raise awareness of butterfly and moth conservation among policy-makers and the general public, and educate people about how their actions can harm, or benefit, butterflies and moths.

15.1. Provide training for land managers, farmers and farm advisers

- One study evaluated the effects on butterflies and moths of providing training for land managers, farmers and farm advisers. The study was in the UK[1].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (0 STUDIES)

BEHAVIOUR (1 STUDY)

- **Behaviour change (1 study):** One study in the UK[1] reported that 82% of landowners that received advice about applying for the Rural Priorities agri-environment scheme submitted applications, there was a 90% application success rate, and >3,000 ha of farmland were managed for the marsh fritillary.

Background

There are a wide variety of actions which may be implemented on farmland to try and improve habitat quality for butterflies and moths (see actions under "*Agriculture & Aquaculture*"), and agri-environment schemes are increasingly including options and packages designed to support pollinators, including butterflies and moths. Even on nature reserves, getting the right balance of habitat management can be difficult. For species with particular habitat requirements which are difficult to achieve, such as a structural diversity of grassland swards, training events for land managers and conservation staff may help to improve habitat quality for butterflies and moths (Parsons 2004).

Parsons M.S. (2004) The United Kingdom Biodiversity Action Plan moths - selection, status and progress on conservation. *Journal of Insect Conservation*, 8, 95–107.

A study in 2008–2011 in 200 farms in western Scotland, UK (1) reported that of the 170 farms that Butterfly Conservation visited to provide advice about applying for the Rural Priorities agri-environment scheme, 140 landowners submitted applications for the scheme, with the help of the organisation, with plans aimed at conserving the marsh fritillary *Euphydryas aurinia* and of these applications there was a 90% success rate and >3,000 ha were managed for the species. Butterfly Conservation contacted 200 landowners with farms containing known marsh fritillary populations and, with the assistance of the Scottish Agricultural College and Agrimony, assisted 140 landowners in developing management plans for conserving the marsh fritillary and submitting applications for the Rural Priorities agri-environment scheme. Ninety percent of applications were successful and >3,000 ha were managed specifically for the marsh fritillary. The marsh fritillary was a priority species for the Scottish Rural Development Programme's Rural Priorities agri-environment scheme. From 2008, the organisations contacted owners of 200 farmland sites in Mid-Argyll and Knapdale, Mull, Lorne and Islay, conducted site visits at 170 of the farms, and provided assistance with devising site-specific management plans and making scheme applications for 140 of these.

(1) Prescott T (2012) Delivering land management advice for Marsh Fritillary in Scotland. In Ellis S., Bourn N. & Bulman C, Landscape-scale conservation for butterflies and moths: Lessons from the UK. 76–79.

15.2. Raise awareness amongst the general public to promote conservation actions

- We found no studies that evaluated the effects of raising awareness amongst the general public to promote conservation actions for butterflies and moths.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Threats to butterflies and moths, as well as actions for their conservation, can come from members of the public. Therefore, raising awareness of the impact of individual actions on species conservation may improve butterfly and moth conservation outcomes. Behaviours and beliefs which create threats, and which awareness raising should aim to minimize, could include the use of insecticides, the release of non-native animals and plants into the wild (for example from gardens), and a general fear of invertebrates or of moths specifically. Conversely, behaviours which awareness raising may wish to encourage could include planting nectar and pollen-rich native plants, or reducing weeding or mowing, in gardens. Awareness raising programmes could include education and outreach events, as well as citizen science projects (Dennis *et al.* 2017, Richter *et al.* 2018).

Dennis E.B., Morgan B.J.T., Brereton T.M., Roy D.B. & Fox R. (2017) Using citizen science butterfly counts to predict species population trends. *Conservation Biology*, 31, 1350–1361.

Richter A. Hauck J., Feldmann R., Kühn E., Harpke A., Hirneisen N., Mahla A., Settele J. & Bonn A. (2018) The social fabric of citizen science—drivers for long-term engagement in the German butterfly monitoring scheme. *Journal of Insect Conservation*, 22, 731–743.

15.3. Increase consideration of butterflies and moths in international, national and local conservation plans

- We found no studies that evaluated the effects of increasing the consideration of butterflies and moths in international, national and local conservation plans.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Conservation planning, particularly at higher levels, traditionally focuses on charismatic vertebrate species. Despite being among the best studied and widely recognized invertebrates, explicit conservation plans for butterflies, and particularly moths, remain rare. The inclusion of butterflies and moths in conservation plans may help to raise awareness of the species, which may be important for stimulating research into their requirements, or funds for the protection and management of important sites for their conservation (Parsons 2004).

Parsons M.S. (2004) The United Kingdom Biodiversity Action Plan moths - selection, status and progress on conservation. *Journal of Insect Conservation*, 8, 95–107.

References

Publications summarized in the evidence synthesis are indicated with an asterisk (*)

* Adams M.-O. & Fiedler K. (2015) The value of targeted reforestations for local insect diversity: a case study from the Ecuadorian Andes. *Biodiversity and Conservation*, 24, 2709– 2734.

* Adamski P. & Witkowski Z. (2007) Effectiveness of population recovery projects based on captive breeding. *Biological Conservation*, 140, 1–7.

* Albrecht M., Duelli P., Muller C., Kleijn D. & Schmid B. (2007) The Swiss agri-environment scheme enhances pollinator diversity and plant reproductive success in nearby intensively managed farmland. *Journal of Applied Ecology*, 44, 813–822.

* Alison J., Duffield S.J., Morecroft M.D., Marrs R.H. & Hodgson J.A. (2017) Successful restoration of moth abundance and species-richness in grassland created under agri-environment schemes. *Biological Conservation*, 213, 51–58.

* Alonso-Rodríguez A., Finegan B. & Fiedler K. (2017) Neotropical moth assemblages degrade due to oil palm expansion. *Biodiversity and Conservation*, 26, 2295–2326.

* Andersen A.N. & Müller W.J. (2000) Arthropod responses to experimental fire regimes in an Australian tropical savannah: ordinal-level analysis. *Austral Ecology*, 25, 199–209.

* Andersen A., Simcox D.J., Thomas J.A., Nash D.R. (2014) Assessing reintroduction schemes by comparing genetic diversity of reintroduced and source populations: A case study of the globally threatened large blue butterfly (*Maculinea arion*). *Biological Conservation*, 175, 34-41.

Anderson R.C. (2006) Evolution and origin of the Central Grassland of North America: climate, fire, and mammalian grazers. *Journal of the Torrey Botanical Society*, 133(4), 626–647.

* Aschehoug E.T., Sivakoff F.S., Cayton H.L., Morris W.F. & Haddad N.M. (2015) Habitat restoration affects immature stages of a wetland butterfly through indirect effects on predation. *Ecology*, 96 (7), 1761–1767.

* Asmah S., Ghazali A., Syafiq M., Yahya M.S., Peng T.L., Norhisham A.R., Puan C.L., Azhar B., Lindenmayer D.B. (2017) Effects of polyculture and monoculture farming in oil palm smallholdings on tropical fruit-feeding butterfly diversity. *Agricultural and Forest Entomology*, 19(1), 70-80.

* Atlegrim O. & Sjöberg K. (1996) Effects of clear-cutting and single-tree selection harvests on herbivorous insect larvae feeding on bilberry (*Vaccinium myrtillus*) in uneven-aged boreal *Picea abies* forests. *Forest Ecology and Management*, 87, 139–148.

* Aviron S., Berner D., Bosshart S., Buholzer S., Herzog F., Jeanneret P., Klaus I., Pozzi S., Schneider K., Schüpbach B. & Walter T. (2005) Butterfly diversity in Swiss grasslands: respective impacts of low-input management, landscape features and region. Pages 340-343 in: R. Lillak, R. Viiralt, A. Linke & V. Geherman (eds.) *Grassland Science in Europe*. 10, Estonian Grassland Society, Tartu.

* Aviron S., Herzog F., Klaus I., Schüpbach B. & Jeanneret P. (2011) Effects of wildflower strip quality, quantity and connectivity on butterfly diversity in a Swiss arable landscape. *Restoration Ecology*, 19 (4), 500–508.

* Aviron S., Jeanneret P., Schüpbach B. & Herzog F. (2007) Effects of agri-environmental measures, site and landscape conditions on butterfly diversity of Swiss grassland. *Agriculture, Ecosystems & Environment*, 122, 295-304.

* Aviron S., Nitsch H., Jeanneret P., Buholzer S., Luka H., Pfiffner L., Pozzi S., Schüpbach B., Walter T. & Herzog F. (2009) Ecological cross compliance promotes farmland biodiversity in Switzerland. *Frontiers in Ecology and the Environment*, 7(5), 247-252.

* Bailey J.K. & Whitham T.G. (2002) Interactions among fire, aspen, and elk affect insect diversity: Reversal of a community response. *Ecology*, 83, 1701–1712.

* Baines D., Sage R.B. & Baines M.M. (1994) The implications of red deer grazing to ground vegetation and invertebrate communities of Scottish native pinewoods. *Journal of Applied Ecology*, 31, 776–783.

* Baker A.M. & Potter D.A. (2018) Colonisation and usage of eight milkweed (*Asclepias*) species by monarch butterflies and bees in urban garden settings. *Journal of Insect Conservation*, 22, 405–418.

* Balmer O. & Erhardt A. (2000) Consequences of succession on extensively grazed grasslands for central European butterfly communities: rethinking conservation practices. *Conservation Biology*, 14, 746–757.

* Barranco-León de las Nieves M., Luna-Castellanos F., Vergara C.H. & Badano E.I. (2016) Butterfly conservation within cities: a landscape scale approach integrating natural habitats and abandoned fields in central Mexico. *Tropical Conservation Science*, 9, 607–628.

* Basset Y., Barrios H., Ramirez J.A., Lopez Y., Coronado J., Perez F., Arizala S., Bobadilla R. & Leponce M. (2017) Contrasting the distribution of butterflies and termites in plantations and tropical forests. *Biodiversity and Conservation*, 26, 151–176.

Bell J.R., Blumgart D. & Shortall C.R. (2020) Are insects declining and at what rate? An analysis of standardised, systematic catches of aphid and moth abundances across Great Britain. *Insect Conservation and Diversity*, 13, 115–126.

Belušič G., Šporar K. & Meglič A. (2017) Extreme polarisation sensitivity in the retina of the corn borer moth *Ostrinia*. *Journal of Experimental Biology*, 220 (11): 2047–2056.

* Bendel C.R., Hovick T.J., Limb R.F. & Harmon J.P. (2018) Variation in grazing management practices supports diverse butterfly communities across grassland working landscapes. *Journal of Insect Conservation*, 22, 99–111.

* Bergman K.O. (2001) Population dynamics and the importance of habitat management for conservation of the butterfly *Lopinga achine*. *Journal of Applied Ecology*, 38, 1303–1313.

* Berman T.S., Ben-Ari M., Henkin Z. & Inbar M. (2018) Immediate and long-term facilitative effects of cattle grazing on a polyphagous caterpillar. *Agriculture, Ecosystems & Environment*, 261, 45–53.

Bernes C., Macura B., Jonsson B.G., Junninen K., Müller J., Sandström J., Lõhmus A. & Macdonald E. (2018) Manipulating ungulate herbivory in temperate and boreal forests: effects on vegetation and invertebrates. A systematic review. *Environmental Evidence*, 7, 13.

Berthinussen A., Richardson O.C. & Altringham J.D. (2014) Bat Conservation: Global evidence for the effects of interventions. Exeter, Pelagic Publishing.

Black H.L. (1974) A north temperate bat community: structure and prey populations. *Journal of Mammology*, 55, 138–157.

Bladon A.J. & Smith R.K. (2019) Effects of conservation interventions on terrestrial and freshwater invertebrates: a protocol for subject-wide evidence synthesis.

* Blake R., Woodcock B., Westbury D., Sutton P. & Potts S. (2011) New tools to boost butterfly habitat quality in existing grass buffer strips. *Journal of Insect Conservation*, 15, 221–232.

* Błoński W. (2016) Preliminary assessment of active protection measures of the Marsh Fritillary *Euphydryas aurinia* (Rottemburg, 1775) habitats in the Świętokrzyski National Park. *Naturalia*, 5, 132–138.

* Bobo K.S., Waltert M., Fermon H., Njokagbor J. & Muhlenberg M. (2006) From forest to farmland: butterfly diversity and habitat associations along a gradient of forest conversion in Southwestern Cameroon. *Journal of Insect Conservation*, 10, 29–42.

* Boggs C.L., Holdren C.E., Kulahci I.G., Bonebrake T.C., Inouye B.D., Fay J.P., McMillan A.N.N., Williams E.H., Ehrlich P.R. (2006) Delayed population explosion of an introduced butterfly. *Journal of Animal Ecology*, 75, 466–475.

* Bonari G., Fajmon K., Malenovský I., Zelený D., Holuša J., Jongepierová I., Kočárek P., Konvička O., Uřičář J. & Chytrý M. (2017) Management of semi-natural grasslands benefiting both plant and

insect diversity: The importance of heterogeneity and tradition. *Agriculture, Ecosystems & Environment*, 246, 243–252.

* Borkhataria R.R., Collazo J.A. & Groom M.J. (2012) Species abundance and potential biological control services in shade vs. sun coffee in Puerto Rico. *Agriculture, Ecosystems & Environment*, 151, 1–5.

* Bosshard A. & Kuster D. (2001) The significance of restored flower-rich hay meadows on set-aside land for butterflies and grasshoppers. *Agrarforschung*, 8, 252–257.

* Boutin C., Baril A., McCabe S.K., Martin P.A. & Guy M. (2011) The Value of Woody Hedgerows for Moth Diversity on Organic and Conventional Farms. *Environmental Entomology*, 40, 560–569.

Boyes D.H., Evans D.M., Fox R., Parsons M.S. & Pocock M.J.O. (2021) Is light pollution driving moth population declines? A review of causal mechanisms across the life cycle. *Insect Conservation and Diversity*, 14, 167–187.

* Bracken F. (2004) The diversity of birds and butterflies in Irish lowland landscapes with special reference to the effects of set-aside management on birds in the breeding season. PhD thesis. University College Dublin. Chapter 4: The diversity of butterflies in different habitat types, pp 147–194.

* Brereton T.M., Warren M.S., Roy D.B. & Stewart K. (2008) The changing status of the Chalkhill Blue butterfly *Polyommatus coridon* in the UK: the impacts of conservation policies and environmental factors. *Journal of Insect Conservation*, 12, 629-638.

* Broome A., Clarke S., Peace A. & Parsons M. (2011) The effect of coppice management on moth assemblages in an English woodland. *Biodiversity and Conservation*, 20, 729–749.

* Brousseau P.-M., Hébert C., Cloutier C. & Côté S. (2013) Short-term effects of reduced white-tailed deer density on insect communities in a strongly overbrowsed boreal forest ecosystem. *Biodiversity and Conservation*, 22, 77–92.

* Brown M.W. & Welker W.V. (1992) Development of the phytophagous arthropod community on apple as affected by orchard management. *Environmental Entomology*, 21, 485–492.

Bruce-White C. & Shardlow M. (2011) A review of the impact of artificial light on invertebrates. *Buglife Report*, ISBN 978-1-904878-99-5

* Bruppacher L., Pellet J., Arlettaz R. & Humbert J.Y. (2016) Simple modifications of mowing regime promote butterflies in extensively managed meadows: Evidence from field-scale experiments. *Biological Conservation*, 196, 196–202.

Bubová T., Vrabec V., Kulma M. & Nowicki P. (2015) Land management impacts on European butterflies of conservation concern: a review. *Journal of Insect Conservation*, 19, 805–821.

* Buhk C., Oppermann R., Schanowski A., Bleil R., Lüdemann J. & Maus C. (2018) Flower strip networks offer promising long term effects on pollinator species richness in intensively cultivated agricultural areas. *BMC Ecology*, 18(55).

* Burghardt K.T., Tallamy D.W. & Shriver W.G. (2008) Impact of native plants on bird and butterfly biodiversity in suburban landscapes. *Conservation Biology*, 23, 219–224.

Bury J., Hołowiński M., Jaworski T., Mleczak M., Zajda W. & Zamorski R. (2014) Notes of the occurrence in Poland of the rare tineid moth *Scardia boletella* (Fabricius, 1794) (Lepidoptera: Tineidae). *Fragmenta Faunistica*, 57, 131–139.

* Canters K.J. & Tamis W.L.M. (1999) Arthropods in grassy field margins in the Wieringermeer: Scope, population development and possible consequences for farm practice. *Landscape and Urban Planning*, 46, 63–69.

* Capman W.C., Batzli G.O. & Simms L.E. (1990) Responses of the Common Sooty Wing Skipper to Patches of Host Plants. *Ecology*, 71, 1430–1440.

* Carleton A. & Schultz C.B. (2013) Restoration action and species response: oviposition habits of *Plebejus icarioides fenderi* (Lepidoptera: Lycaenidae) across a restoration chronosequence in the Willamette Valley, Oregon, USA. *Journal of Insect Conservation*, 17, 511–520.

* Carreck N.L. & Williams I.H. (2002) Food for insect pollinators on farmland: insect visits to flowers of annual seed mixtures. *Journal of Insect Conservation*, 6, 13–23.

* Carrie R., Ekroos J. & Smith H.G. (2018) Organic farming supports spatiotemporal stability in species richness of bumblebees and butterflies. *Biological Conservation*, 227, 48–55.

Cavanzón-Medrano L.E., Machkour-M'Rabet S., Chablé-Iuit L.R., Pozo C., Hénaut Y. & Legal L. (2018) Effect of Climatic Conditions and Land Cover on Genetic Structure and Diversity of Eunica tatila (Lepidoptera) in the Yucatan Peninsula, Mexico. *Diversity*, 10, 79.

* Cizek O., Zamecnik J., Tropek R., Kocarek P. & Konvicka M. (2012) Diversification of mowing regime increases arthropods diversity in species-poor cultural hay meadows. *Journal of Insect Conservation*, 16, 215–226.

* Clarke S.A. & Robertson P.A. (1993) The relative effects of woodland management and pheasant *Phasianus colchicus* predation on the survival of the pearl- bordered and small pearl-bordered fritillaries *Boloria euphrosyne* and *B. selene* in the south of England. *Biological Conservation*, 65, 199–203.

*Claassens A.J.M. & Heath A. (1997) Notes on the myrmecophilous early stages of two species of *Thestor Hübner* (Lepidoptera: Lycaenidae) from South Africa. *Metamorphosis*, 8(2), 56-61.

Cleary D.F.R & Grill A. (2004) Butterfly response to severe ENSO-induced forest fires in Borneo. *Ecological Entomology*, 29, 666–676.

* Clem C.S. & Held D.W. (2018) Associational Interactions Between Urban Trees: Are Native Neighbors Better Than Non-Natives? *Environmental Entomology*, 47, 881–889.

Cohen J. (1960) A coefficient of agreement for nominal scales. *Educational and Psychological Measurement*, 20, 37–46.

* Cole L.J., Pollock M.L., Robertson D., Holland J.P., McCracken D.I. & Harrison W. (2010) The influence of fine-scale habitat heterogeneity on invertebrate assemblage structure in upland semi-natural grassland. *Agriculture, Ecosystems & Environment*, 136, 69-80.

Collen B., Böhm M., Kemp R. & Baillie J.E.M. (2012) *Spineless: Status and trends of the world's invertebrates*. Zoological Society of London, UK.

Collins N.M. & Morris M.G. (1985) Threatened Swallowtail Butterflies of the World: The IUCN Red Data Book. IUCN, Gland, Switzerland & Cambridge, UK, pg 155–180.

Cormont A., Malinowska A.H., Kostenko O., Radchuk V., Hemerik L., WallisDeVries M.F. & Verboom J. (2011) Effect of local weather on butterfly flight behaviour, movement, and colonization: Significance for dispersal under climate change. *Biodiversity Conservation*, 20, 483–503.

* Coulthard E., McCollin D. & Littlemore J. (2016) The use of hedgerows as flight paths by moths in intensive farmland landscapes. *Journal of Insect Conservation*, 20, 345–350.

Crone E.E., Pickering D. & Schultz C.B. (2007) Can captive rearing promote recovery of endangered butterflies? An assessment in the face of uncertainty. *Biological Conservation*, 139, 103–112.

* Cutting B.T. & Tallamy D.W. (2015) An Evaluation of Butterfly Gardens for Restoring Habitat for the Monarch Butterfly (Lepidoptera: Danaidae). *Environmental Entomology*, 44, 1328–1335.

* D'Aniello B., Stanislao I., Bonelli S. & Balletto E. (2011) Haying and grazing effects on the butterfly communities of two Mediterranean-area grasslands. *Biodiversity and Conservation*, 20, 1731–1744.

Danthanarayana W. & Dashper S. (1986) Response of Some Night-Flying Insects to Polarized Light. In: Danthanarayana W. (eds) Insect Flight. *Proceedings in Life Sciences*. Springer, Berlin, Heidelberg.

* Davies H., Brereton T.M., Roy D.B. & Fox R. (2007) Government targets for protected area management: will threatened butterflies benefit? *Biodiversity and Conservation*, 16, 3719–3736.

Davies Z.G., Tyler C., Stewart G.B. & Pullin A.S. (2008) Are current management recommendations for saproxylic invertebrates effective? A systematic review. *Biodiversity Conservation*, 17, 209–234.

Davies Z.G., Wilson R.J., Coles S. & Thomas C.D. (2006) Changing habitat associations of a thermally constrained species, the silver-spotted skipper butterfly, in response to climate warming. *Journal of Animal Ecology*, 75, 247–256.

Davis J.D., Hendrix S.D., Debinski D.M. & Hemsley C.J. (2008) Butterfly, bee and forb community composition and cross-taxon incongruence in tallgrass prairie fragments. *Journal of Insect Conservation*, 12, 69–79.

* Davros N.M., Debinski D.M., Reeder K.F. & Hohman W.L. (2006) Butterflies and continuous conservation reserve program filter strips: Landscape considerations. *Wildlife Society Bulletin*, 34, 936–943.

de Schaetzen F., van Langevelde F. & WallisDeVries M.F. (2018) The influence of wild boar (*Sus scrofa*) on microhabitat quality for the endangered butterfly *Pyrgus malvae* in the Netherlands. *Journal of Insect Conservation*, 22, 51–59.

* de Snoo G.R. (1996) The effect of cereal headland treatments on carabid communities. *Arthropod Natural Enemies in Arable Land II - Survival, Reproduction and Enhancement*. Pages 209–219 in: *Acta Jutlandica*.

* de Snoo G.R., van der Poll R.J. & Bertels J. (1998) Butterflies in sprayed and unsprayed field margins. *Zeitschrift Fur Angewandte Entomologie*, 122, 157–161.

* Delattre T., Vernon P. & Burel F. (2013) An agri-environmental scheme enhances butterfly dispersal in European agricultural landscapes. *Agriculture, Ecosystems & Environment*, 166, 102–109.

* Denning K.R. & Foster B.L. (2018) Flower visitor communities are similar on remnant and reconstructed tallgrass prairies despite forb community differences. *Restoration Ecology*, 26, 751–759.

Dennis E.B., Morgan B.J.T., Brereton T.M., Roy D.B. & Fox R. (2017) Using citizen science butterfly counts to predict species population trends. *Conservation Biology*, 31, 1350–1361.

* Dennis P., Skartveit J., McCracken D.I., Pakeman R.J., Beaton K., Kunaver A. & Evans D.M. (2008) The effects of livestock grazing on foliar arthropods associated with bird diet in upland grasslands of Scotland. *Journal of Applied Ecology*, 45, 279–287.

* Dennis P., Young M.R. & Gordon I.J. (1998) Distribution and abundance of small insects and arachnids in relation to structural heterogeneity of grazed, indigenous grasslands. *Ecological Entomology*, 23, 253–264.

Dennis R.L.H., Shreeve T.G. & Van Dyck H. (2003) Towards a functional resource-based concept for habitat: a butterfly biology viewpoint. *Oikos*, 102, 417–426.

Department of Forestry, Fisheries and the Environment (2021) National Web Based Environmental Screening Tool. Republic of South Africa Department of Forestry, Fisheries and the Environment, https://screening.environment.gov.za/screeningtool/index.html#/pages/welcome

Devictor V., van Swaay C., Brereton T., Brotons L., Chamberlain D., Heliölä J., Herrando S., Julliard R., Kuussaari M., Lindström Å., Reif J., Roy D.B., Schweiger O., Settele J., Stefanescu C., van Strien A., van Turnhout C., Vermouzek Z., WallisDeVries M., Wynhoff I. & Jiguet F. (2012) Differences in the climatic debts of birds and butterflies at a continental scale. *Nature Climate Change*, 2, 121–124.

Dilts T.E., Steele M.O., Engler J.D., Pelton E.M., Jepsen S.J., McKnight S.J., Taylor A.R., Fallon C.E., Black S.H., Cruz E.E., Craver D.R. & Forister M.L. (2019) Host Plants and Climate Structure Habitat Associations of the Western Monarch Butterfly. *Frontiers in Ecology and Evolution*, 7:188.

* Dolek M. & Geyer A. (1997) Influence of management on butterflies of rare grassland ecosystems in Germany. *Journal of Insect Conservation*, 1, 125–130.

* Dolek M., Kőrösi Á & Freese-Hager A. (2018) Successful maintenance of Lepidoptera by government-funded management of coppiced forests. *Journal for Nature Conservation*, 43, 75–84.

* Dollar J.G., Riffell S.K. & Burger L.W. (2013) Effects of managing semi-natural grassland buffers on butterflies. *Journal of Insect Conservation*, 17, 577–590.

* Douglas F. (2004) A dedicated reserve for conservation of two species of *Synemon* (Lepidoptera: Castniidae) in Australia. *Journal of Insect Conservation*, 8, 221–228.

* Dover J.W. (1997) Conservation headlands: effects on butterfly distribution and behaviour. *Agriculture, Ecosystems & Environment*, 63, 31–49.

* Dover J.W., Rescia A., Fungarino S., Fairburn J., Carey P., Lunt P., Arnot C., Dennis R.L.H. & Dover C.J. (2011) Land-use, environment, and their impact on butterfly populations in a mountainous pastoral landscape: individual species distribution and abundance. *Journal of Insect Conservation*, 15, 207–220.

* Dover J., Sotherton N. & Gobbett K.A.Y. (1990) Reduced pesticide inputs on cereal field margins: the effects on butterfly abundance. *Ecological Entomology*, 15, 17–24.

* Dover J.W., Sparks T.H. & Greatorex-Davies J.N. (1997) The importance of shelter for butterflies in open landscapes. *Journal of Insect Conservation*, 1, 89–97.

* Dover J., Sparks T., Clarke S., Gobbett K. & Glossop S. (2000) Linear features and butterflies: the importance of green lanes. *Agriculture Ecosystems & Environment*, 80, 227–242.

Dover J.W., Spencer S., Collins S., Hadjigeorgiou I. & Rescia A. (2011) Grassland butterflies and low intensity farming in Europe. *Journal of Insect Conservation*, 15, 129–137.

* Duffey E. (1968) Ecological studies on the large copper butterfly *Lycaena dispar* (Haw.) *batavus* (Obth.) at Woodwalton Fen National Nature Reserve, Huntingdonshire. *Journal of Applied Ecology*, 5, 69–96.

* Duffey E. (1977) The re-establishment of the large copper butterfly *Lycaena dispar batava* obth. on Woodwalton Fen National Nature Reserve, Cambridgeshire, England, 1969-73. *Biological Conservation*, 12, 143–158.

Dunnett N. & Kingsbury N. (2008) Planting green roofs and living walls. *Timber*, Portland, Oregon, USA. Second edition, ISBN: 0881929115.

Dwan K., Gamble C., Williamson P.R. & Kirkham J.J. (2013) Systematic review of the empirical evidence of study publication bias and outcome reporting bias—an updated review. *PloS ONE*, 8, e66844.

* Edge D.A. (2002) Some ecological factors influencing the breeding success of the Brenton Blue butterfly, *Orachrysops niobe* (Trimen) (Lepidoptera: Lycaenidae). *Koedoe*, 45(2), 19-34.

* Edge D.A. & Pringle E.L. (1996) Notes on the natural history of the Brenton blue *Orachrysops niobe* (Trimen) (Lepidoptera: Lycaenidae). *Metamorphosis* 7(3), 109-122.

* Edge D.A. (2008) Adult behaviour of *Orachrysops niobe* (Trimen) (Lepidoptera:Lycaenidae). *Metamorphosis*, 19(3), 116-126

* Edge D.A. & van Hamburg H. (2003). Larval feeding behaviour and myrmecophily of the Brenton Blue, *Orachrysops niobe* (Trimen) (Lepidoptera: Lycaenidae). *Journal of Research on Lepidoptera*, 42, 21-33.

Eichel S. & Fartmann T. (2008) Management of calcareous grasslands for Nickerl's fritillary (*Melitaea aurelia*) has to consider habitat requirements of the immature stages, isolation, and patch area. *Journal of Insect Conservation*, 12, 677–688.

* Eisenbeis G. & Hassel F. (2000) Attraction of nocturnal insects to street lights — a study of municipal lighting systems in a rural area of Rheinhessen (Germany). *Natur und Landschaft*, 75, 145–156.

Eisenhauer N., Bonn A. & Guerra C.A. (2019) Recognizing the quiet extinction of invertebrates. *Nature Communications*, 10, 50.

Elligsen H., Beinlich B. & Plachter H. (1997) Effects of large-scale cattle grazing on populations of *Coenonympha glycerion* and *Lasiommata megera* (Lepidoptera: Satyridae). *Journal of Insect Conservation*, 1, 13–23.

* Ellis S., Bourn N. & Bulman C. (2012). Landscape-scale conservation for butterflies and moths: Lessons from the UK.

* Elmes G.W., Thomas J.A. & Wardlaw J.C. (1991) Larvae of *Maculinea rebeli*, a large-blue butterfly, and their *Myrmica* host ants: wild adoption and behaviour in ant nests. *Journal of Zoology*, 223, 447–460.

* Elwell S.L., Griswold T. & Elle E. (2016) Habitat type plays a greater role than livestock grazing in structuring shrubsteppe plant-pollinator communities. *Journal of Insect Conservation*, 20, 515–525.

* Ernst L.M., Tscharntke T. & Batary P. (2017) Grassland management in agricultural vs. forested landscapes drives butterfly and bird diversity. *Biological Conservation*, 216, 51–59.

* Facey S.L., Botham M.S., Heard M.S., Pywell R.F. & Staley J.T. (2014) Moth communities and agri-environment schemes: Examining the effects of hedgerow cutting regime on diversity, abundance, and parasitism. *Insect Conservation and Diversity*, 7, 543–552.

* Farruggia A., Dumont B., Scohier A., Leroy T., Pradel P., Garel J.-P. (2011) An alternative rotational stocking management designed to favour butterflies in permanent grasslands. *Grass and Forage Science*, 67(1), 136–149.

* Fartmann T., Müller C. & Poniatowski D. (2013) Effects of coppicing on butterfly communities of woodlands. *Biological Conservation*, 159, 396–404.

* Feber R. E. & Brereton T. M., Warren M. S. & Oates M. (2011) The impacts of deer on woodland butterflies: the good, the bad and the complex. *Forestry: An International Journal of Forest Research*, 74 (3), 271-276.

* Feber R.E. & Hopkins A. (1997) Diversity of plant and butterfly species on organic farmland field margins in relation to management. *British Grassland Society Fifth Research Conference*, University of Plymouth, Devon, UK, 8-10 September 1997, 63–64.

* Feber R.E., Johnson P.J., Firbank L.G., Hopkins A. & Macdonald D.W. (2007) A comparison of butterfly populations on organically and conventionally managed farmland. *Journal of Zoology*, 273(1), 30-39.

* Feber R.E. & Smith H. (1995) Butterfly conservation on arable farmland. pp 84–97 in: Pullin A.S. (ed) *Ecology and Conservation of Butterflies*. Springer, Dordrecht.

* Feber R.E., Smith H. & Macdonald D.W. (1994) The effects of field margin restoration on the meadow brown butterfly (*Maniola jurtina*). *British Crop Protection Council Monographs*, 58, 295–300.

* Feber R.E., Smith H. & Macdonald D.W. (1996) The effects on butterfly abundance of the management of uncropped edges of arable fields. *Journal of Applied Ecology*, 33, 1191–1205.

* Fermon H., Waltert M., Larsen T.B., Dall'Asta U. & Muehlenberg M. (2000) Effects of forest management on diversity and abundance of fruit-feeding nymphalid butterflies in south-eastern Cote d'Ivoire. *Journal of Insect Conservation*, 4, 173–189.

* Fiedler K., Wrbka T. & Dullinger S. (2017) Pluralism in grassland management promotes butterfly diversity in a large Central European conservation area. *Journal of Insect Conservation*, 21, 277–285.

* Field R.G. & Mason C.F. (2005) The utilization of two-metre Countryside Stewardship Scheme grass margins by the gatekeeper *Pyronia tithonus* (L.). *Journal of Natural History*, 39, 1533–1538.

* Field R.G., Gardiner T. & Watkins G. (2007) The use of farmland by butterflies: a study on mixed farmland and field margins. *Entomologist's Gazette*, 58, 3–15.

* Field R.G., Gardiner T., Mason C.F. & Hill J. (2005) Agri-environment schemes and butterflies: the utilisation of 6 m grass margins. *Biodiversity and Conservation*, 14, 1969–1976.

* Field R., Gardiner T., Mason C. & Hill J. (2006) Countryside Stewardship Scheme and butterflies: a study of plant and butterfly species richness. *Biodiversity and Conservation*, 15, 443–452.

* Field R.G., Gardiner T., Mason C.F. & Hill J. (2007) Agri-environment schemes and butterflies: the utilisation of two metre arable field margins. *Biodiversity and Conservation*, 16, 465–474.

* Fleishman E. (2000) Monitoring the Response of Butterfly Communities to Prescribed Fire. *Environmental Management*, 26, 685-695.

* Florens F.B.V., Mauremootoo J.R., Fowler S.V., Winder L. & Baider C. (2010) Recovery of indigenous butterfly community following control of invasive alien plants in a tropical island's wet forests. *Biodiversity and Conservation*, 19, 3835–3848.

* Flynn C., Griffin C.T., Coll J. & Williams C.D. (2016) The diversity and composition of moth assemblages of protected and degraded raised bogs in Ireland. *Insect Conservation and Diversity*, 9, 302–319.

* Forehand L.M., Orr D.B. & Linker H.M. (2006) Insect communities associated with beneficial insect habitat plants in North Carolina. *Environmental Entomology*, 35, 1541–1549.

Forister M.L., Halsch C.A., Nice C.C., Fordyce J.A., Dilts T.E., Oliver J.C., Prudic K.L., Shapiro A.M., Wilson J.K. & Glassberg J. (2021) Fewer butterflies seen by community scientists across the warming and drying landscapes of the American West. *Science*, 371, 1042–1045.

Forrester J.A., Leopold D.J. & Hafner S.D. (2005) Maintaining critical habitat in a heavily managed landscape: Effects of power line corridor management on Karner blue butterfly (*Lycaeides melissa samuelis*) habitat. *Restoration Ecology*, 13, 488–498.

* Fowles A.P., Bailey M.P. & Hale A.D. (2004) Trends in the recovery of a rosy marsh moth *Coenophila subrosea* (Lepidoptera, Noctuidae) population in response to fire and conservation management on a lowland raised mire. *Journal of Insect Conservation*, 8, 149–158.

Fox R. (2012) The decline of moths in Great Britain: a review of possible causes. *Insect Conservation and Diversity*, 6, 5–19.

Fox R., Brereton T.M., Asher J., August T.A., Botham M.S., Bourn N.A.D., Cruickshanks K.L., Bulman C.R., Ellis S., Harrower C.A., Middlebrook I., Noble D.G., Powney G.D., Randle Z., Warren M.S. & Roy D.B. (2015) *The State of the UK's Butterflies*. Butterfly Conservation and the Centre for Ecology & Hydrology, Wareham, Dorset, UK.

Fox R., Dennis E.B., Harrower C.A., Blumgart D., Bell J.R., Cook P., Davis A.M., Evans-Hill L.J., Haynes F., Hill D., Isaac N.J.B., Parsons M.S., Pocock M.J.O., Prescott T., Randle Z., Shortall C.R., Tordoff G.M., Tuson D. & Bourn N.A.D. (2021) *The State of Britain's Larger Moths 2021*. Butterfly Conservation, Rothamsted Research and UK Centre for Ecology & Hydrology, Wareham, Dorset, UK.

Fox R., Warren M.S., Brereton T.M., Roy D.B. & Robinson A. (2010) A new Red List of British butterflies. *Insect Conservation and Diversity*, 4, 159–172.

* Frampton G.K. & Dorne J.L.C.M. (2007) The effects on terrestrial invertebrates of reducing pesticide inputs in arable crop edges: a meta-analysis. *Journal of Applied Ecology*, 44, 362–373.

Franco A.M.A., Hill J.K., Kitschke C., Collingham Y.C., Roy D.B., Fox R., Huntley B. & Thomas C.D. (2006) Impacts of climate warming and habitat loss on extinctions at species' low-latitude range boundaries. *Global Change Biology*, 12, 1545–1553.

Frank K.D. (2006) Effects of artificial night lighting on moths. In *Ecological consequences of artificial night lighting* (eds Rich C. & Longcore T.), pp. 305–344 Washington DC, Island Press.

* Fraser M.D., Evans J.G., Davies D.W.R. & Vale J.E. (2008) Effect of sward type and management on butterfly numbers in the uplands. *Aspects of Applied Biology*, 85, 15–18.

* Fuentes-Montemayor E., Goulson D. & Park K.J. (2011) The effectiveness of agri-environment schemes for the conservation of farmland moths: assessing the importance of a landscape-scale management approach. *Journal of Applied Ecology*, 48, 532–542.

Fuentes-Montemayor E., Peredo-Alvarez V.M., Watts K. & Park K.J. (2015) Are woodland creation schemes providing suitable resources for biodiversity? Woodland moths as a case study. *Biodiversity and Conservation*, 24, 3049–3070.

* Garbuzov M., Fensome K.A. & Ratnieks F.L.W. (2015) Public approval plus more wildlife: twin benefits of reduced mowing of amenity grass in a suburban public park in Saltdean, UK. *Insect* Conservation and Diversity, 8, 107–119.

*Gardiner T., Ringwood Z., Fairweather G., Perry R. & Woodrow P.L. (2017) Introductions of two insect species threatened by sea-level rise in Essex, United Kingdom: Fisher's estuarine moth *Gortyna borelii lunata* (Lepidoptera: Noctuidae) and Mottled grasshopper *Myrmeleotettix maculatus* (Orthoptera: Acrididae). *International Zoo Yearbook*, 51(1), 69-78.

Gaston K.J., Davies T.W., Bennie J., Hopkins J. (2012) Reducing the ecological consequences of night-time light pollution: options and developments. *Journal of Applied Ecology*, 49, 1256–1266.

* Gaston K. J., Smith R. M., Thompson K. & Warren P. H. (2005) Urban domestic gardens (II): experimental tests of methods for increasing biodiversity. *Biodiversity and Conservation*, 14, 395-413.

Gilburn A.S., Bunnefeld N., Wilson J.M., Botham M.S., Brereton T.M., Fox R. & Goulson D. (2015) Are neonicotinoid insecticides driving declines in widespread butterflies? *PeerJ*, 3:e1402.

* Gillespie M. & Wratten S.D. (2012) The importance of viticultural landscape features and ecosystem service enhancement for native butterflies in New Zealand vineyards. *Journal of Insect Conservation*, 16, 13–23.

* Gillingham P.K., Alison J., Roy D.B., Fox R. & Thomas C.D. (2015) High Abundances of Species in Protected Areas in Parts of their Geographic Distributions Colonized during a Recent Period of Climatic Change. *Conservation Letters*, 8, 97–106.

* Glaeser R.M. & Schultz C.B. (2014) Characterizing a contentious management tool: the effects of a grass-specific herbicide on the silvery blue butterfly. *Journal of Insect Conservation*, 18, 1047–1058.

Glaves D.J., Morecroft M., Fitzgibbon C., Lepitt P., Owen M. & Phillips S. (2013) Natural England Review of Upland Evidence 2012 - The effects of managed burning on upland peatland biodiversity, carbon and water. *Natural England Evidence Review*, Number 004 (NEER004).

Goldstein P.Z. (2017) Diversity and Significance of Lepidoptera: A Phylogenetic Perspective. In Foottit R.G. & Adler P.H. (*eds*) *Insect Biodiversity: Science and Society*. Second edition, Wiley Blackwell, UK.

Goodenough A.E. & Sharp M.H. (2016) Managing calcareous grassland for the declining Duke of Burgundy *Hamearis lucina* butterfly: effects of grazing management on Primula host plants. *Journal of Insect Conservation*, 20, 1087–1098.

Gordon I. & Ayiemba W. (2003) Harnessing Butterfly Biodiversity for Improving Livelihoods and Forest Conservation: The Kipepeo Project. *The Journal of Environment & Development*, 12, 82–98.

* Giuliano D., Cardarelli E. & Bogliani G. (2018) Grass management intensity affects butterfly and orthopteran diversity on rice field banks. *Agriculture, Ecosystems & Environment*, 267, 147–155.

* Grill A., Cleary D.F.R., Stettmer C., Bräu M. & Settele J. (2008) A mowing experiment to evaluate the influence of management on the activity of host ants of *Maculinea* butterflies. *Journal of Insect Conservation*, 12, 617–627.

* Haaland C. (2017) How to preserve a butterfly species within an urbanising settlement and its surroundings: a study of the scarce copper (*Lycaena virgaureae* L.) in southern Sweden. *Journal of Insect Conservation*, 21, 917–927.

* Haaland C. & Bersier L. (2011) What can sown wildflower strips contribute to butterfly conservation?: an example from a Swiss lowland agricultural landscape. *Journal of Insect Conservation*, 15, 301–309.

* Haaland C. & Gyllin M. (2010) Butterflies and bumblebees in greenways and sown wildflower strips in southern Sweden. *Journal of Insect Conservation*, 14, 125–132.

* Haddad N. (2000) Corridor length and patch colonization by a butterfly, *Junonia coenia*. Conservation Biology, 14, 738–745.

* Haddad N.M. & Tewksbury J.J. (2005) Low-quality habitat corridors as movement conduits for two butterfly species. *Ecological applications*, 15, 250-257.

Hahn M. & Brühl C.A. (2016) The secret pollinators: an overview of moth pollination with a focus on Europe and North America. *Arthropod-Plant Interactions*, 10, 21–28.

* Hahn M., Schotthöfer A., Schmitz J., Franke L.A. & Brühl C.A. (2015) The effects of agrochemicals on Lepidoptera, with a focus on moths, and their pollination service in field margin habitats. *Agriculture, Ecosystems & Environment*, 207, 153–162.

Hallmann C.A., Sorg M., Jongejans E., Siepel H., Hofland N., Schwan H., Stenmans W., Müller A., Sumser H., Hörren T., Goulson D. & de Kroon H. (2017) More than 75 Percent Decline over 27 Years in Total Flying Insect Biomass in Protected Areas. *PLoS ONE*, 12(10): e0185809.

* Handke K., Otte A. & Donath T.W. (2011) Late mowed stripes of grassland promote invertebrates in floodplain meadows: Results from the nature reserve "Kühkopf-Knoblochsaue". *Naturschutz und Landschaftsplanung*, 43, 280–288.

* Hayes M.J., Jones A.T., Sackville Hamilton N.R., Wildig J. & Buse A. (2001) Hedgerows of the World: Their Ecological Functions in Different Landscapes. *10th Annual Conference of the International Association for Landscape Ecology*, Birmingham, UK, 339.

Hayes M.P., Rhodes M.W., Turner E.C., Hitchcock G.E., Knock R.I., Lucas C.B.H. & Chaney P.K. (2018) Determining the long-term habitat preferences of the Duke of Burgundy butterfly, *Hamearis lucina*, on a chalk grassland reserve in the UK. *Journal of Insect Conservation*, 22, 329–343.

* Haysom K.A., McCracken D.I., Roberts D.J. & Sotherton N.W. (2000) Grassland conservation headlands: a new approach to enhancing biodiversity on grazing land. Grazing Management: the Principles and Practice of Grazing, for Profit and Environmental Gain, within Temperate Grassland Systems: *Proceedings of the British Grassland Society Conference*, 29 February-2 March, 2000, Harrogate, UK, 159–160.

* Heard M.S., Botham M., Broughton R., Carvell C., Hinsley S., Woodcock B., Pywell R.F., Amy S., Bellamy P.E., Hill R.A., Hulmes S., Hulmes L., Meek W.R., Nowakowski M., Peyton J., Redhead J.W., Shore R.F. & Turk A. (2011) Quantifying the effects of Entry Level Stewardship (ELS) on biodiversity at the farm scale: the Hillesden Experiment. *Natural England report*, RP00026.

* Heath A. & Brinkman A. K. (1995) Aspects of the life history, distribution and population fluctuations of *Oxychaeta dicksoni* (Gabriel) (Lepidoptera, Lycaenidae). *Metamorphosis*, 6(3), 117-127.

* Heath A. & Brinkman A. K. (1995) Notes on the early stages of *Argyrocupha malagrida maryae* (Wallengren) (Lepidoptera, Lycaenidae). *Metamorphosis*, 6(4), 167-173.

* Heer P., Pellet J., Sierro A. & Arlettaz R. (2013) Evidence-based assessment of butterfly habitat restoration to enhance management practices. *Biodiversity and Conservation*, 22, 239–252.

* Helbing F., Cornils N., Stuhldreher G. & Fartmann T. (2015) Populations of a shrub-feeding butterfly thrive after introduction of restorative shrub cutting on formerly abandoned calcareous grassland. *Journal of Insect Conservation*, 19, 457–464.

* Henderson R.A., Meunier J. & Holoubek N.S. (2018) Disentangling effects of fire, habitat, and climate on an endangered prairie-specialist butterfly. *Biological Conservation*, 218, 41–48.

* Henning S.F. (1987) Outline of Lepidoptera conservation with special reference to ant associated Lycaenidae. *Proceedings of the first Lepidoptera Conservation Symposium, Roodepoort, South Africa*. 5–7.

Henning G.A., Terblanche R.F. & Ball J.B. (*eds*) (2009) South African Red Data Book: butterflies. *SANBI Biodiversity Series 13*. South African National Biodiversity Institute, Pretoria.

* Hernandez Y., Boege K., Lindig-Cisneros R. & del-Val E. (2014) Lepidopteran herbivory in restored and successional sites in a tropical dry forest. *The Southwestern Naturalist*, 59, 66–74.

Hess A.N., Hess R.J., Hess J.L.M., Paulan B. & Hess J.A.M. (2014) American Bison influences on lepidopteran and wild blue lupine distribution in an oak savanna landscape. *Journal of Insect Conservation*, 18, 327–338.

Hill G.M., Kawahara A.Y., Daniels J.C., Bateman C.C. & Scheffers B.R. (2021) Climate change effects on animal ecology: butterflies and moths as a case study. *Biological Reviews*, 96, 2113–2126.

Hinks A.E., Cole E.F., Daniels K.J., Wilkin T.A., Nakagawa S. & Sheldon B.C. (2015) Scale-dependent phenological synchrony between songbirds and their caterpillar food source. *The American Naturalist*, 186, 84–97.

* Hodgson J.A., Kunin W.E., Thomas C.D., Benton T.G., Gabriel D. (2010) Comparing organic farming and land sparing: optimizing yield and butterfly populations at a landscape scale. *Ecology Letters*, 13(11), 1358-1367.

* Holdren C.E. & Ehrlich P.R. (1981) Long range dispersal in checkerspot butterflies: transplant experiments with *Euphydryas gillettii*. *Oecologia*, 50, 125–129.

* Holland J.M., Smith B.M., Storkey J., Lutman P.J.W. & Aebischer N.J. (2015) Managing habitats on English farmland for insect pollinator conservation. *Biological Conservation*, 182, 215–222.

Hopwood J., Black S.H., Lee-Mäder E., Charlap A., Preston R., Mozumder K. & Fleury S. (2015) Literature review: Pollinator habitat enhancement and best management practices in highway rights-of-way. *Federal Highway Administration report by The Xerces Society for Invertebrate Conservation & ICF International*.

* Howe M.A., Hinde D., Bennett D. & Palmer S. (2004) The conservation of the belted beauty *Lycia zonaria britannica* (Lepidoptera, Geometridae) in the United Kingdom. *Journal of Insect Conservation*, 8, 159–166.

* Hudson J.R., Hanula J.L. & Horn S. (2013) Removing Chinese privet from riparian forests still benefits pollinators five years later. *Biological Conservation*, 167, 355–362.

* Huffman D.W., Laughlin D.C., Pearson K.M. & Pandey S. (2009) Effects of vertebrate herbivores and shrub characteristics on arthropod assemblages in a northern Arizona forest ecosystem. *Forest Ecology and Management*, 258, 616–625.

* Humbert J.Y., Ghazoul J., Sauter G.J. & Walter T. (2010) Impact of different meadow mowing techniques on field invertebrates. *Journal of Applied Entomology*, 134, 592–599.

Humbert J.-Y., Pellet J., Buri P. & Arlettaz R. (2012) Does delaying the first mowing date benefit biodiversity in meadowland? *Environmental Evidence*, 1, 9.

* Huntzinger M. (2003) Effects of fire management practices on butterfly diversity in the forested western United States. *Biological Conservation*, 113, 1–12.

Hutton A.F. (1985) Butterfly farming in Papua New Guinea. *Oryx*, 19(3), 158–162.

* Iida T., Soga M., Hiura T. & Koike S. (2016) Life history traits predict insect species responses to large herbivore overabundance: a multitaxonomic approach. *Journal of Insect Conservation*, 20, 295–304.

* Itioka T., Takano K.T., Kishimoto-Yamada K., Tzuchiya T., Ohshima Y., Katsuyama R., Yago M., Yata O., Nakagawa M. & Nakashizuka T. (2015) Chronosequential changes in species richness of forest-edge-dwelling butterflies during forest restoration after swidden cultivation in a humid tropical rainforest region in Borneo. *Journal of Forest Research*, 20, 125–134.

* Jacot K., Eggenschwiler L., Junge X., Luka H. & Bosshard A. (2007) Improved field margins for a higher biodiversity in agricultural landscapes. *Aspects of Applied Biology*, 81, 277–283.

Jakobsson S., Bernes C., Bullock J.M., Verheyen K. & Lindborg R. (2018) How does roadside vegetation management affect the diversity of vascular plants and invertebrates? A systematic review. *Environmental Evidence*, 7, 17.

* James D.G., Seymour L., Lauby G. & Buckley K. (2015) Beauty with benefits: butterfly conservation in Washington State, USA, wine grape vineyards. *Journal of Insect Conservation*, 19, 341–348.

Janzen D.H. & Hallwachs W. (2021) To us insectometers, it is clear that insect decline in our Costa Rican tropics is real, so let's be kind to the survivors. *Proceedings of the National Academy of Sciences*, 118, e2002546117.

* Jeanneret P., Aviron S., Herzog F., Luka H., Pozzi S. & Walter T. (2005) Temporal trends of arthropod diversity in conventional and low-input meadows. Pages 344–347 in: *Grassland Science in Europe*. 10, Estonian Grassland Society, Tartu.

* Jeanneret P., Schupbach B. & Pfiffner L. (2003) Arthropod reaction to landscape and habitat features in agricultural landscapes. *Landscape Ecology*, 18, 253–263.

* Jeanneret P., Schüpbach B., Steiger J., Waldburger M. & Bigler F. (2000) Evaluation of ecological measures: Spiders and butterflies. *Agrarforschung*, 7, 112–116.

* Jerrentrup J.S., Wrage-Mönnig N., Röver K.-U. & Isselstein J. (2014) Grazing intensity affects insect diversity via sward structure and heterogeneity in a long-term experiment. *Journal of Applied Ecology*, 51, 968–977.

* Johansson V., Knape J. & Franzen M. (2017) Population dynamics and future persistence of the clouded Apollo butterfly in southern Scandinavia: The importance of low intensity grazing and creation of habitat patches. *Biological Conservation*, 206, 120–131.

* Jonason D., Andersson G.K.S., Öckinger E., Rundlöf M., Smith H.G. & Bengtsson J. (2011) Assessing the effect of the time since transition to organic farming on plants and butterflies. *Journal of Applied Ecology*, 48(3), 543-550.

* Jonason D., Andersson G.K.S., Öckinger E., Smith H.G. & Bengtsson J. (2012) Field scale organic farming does not counteract landscape effects on butterfly trait composition. *Agriculture, Ecosystems & Environment*, 158, 66–71.

* Jonason D., Franzén M. & Pettersson L.B. (2013) Transient peak in moth diversity as a response to organic farming. *Basic and Applied Ecology*, 14, 515–522.

* Jonsell M. & Nordlander G. (2002) Insects in polypore fungi as indicator species: A comparison between forest sites differing in amounts and continuity of dead wood. *Forest Ecology and Management*, 157, 101–118.

Jordan M. & Böhm M. (2021) IUCN SSC Butterfly and Moth Specialist Group. Available at https://www.iucn.org/commissions/ssc-groups/invertebrates/butterfly-and-moth, accessed 28 October 2021.

Joy J. & Pullin A.S. (1997) The effects of flooding on the survival and behaviour of overwintering large heath butterfly *Coenonympha tullia* larvae. *Biological Conservation*, 82, 61–66.

* Joy J. & Pullin A.S. (1999) Field studies on flooding and survival of overwintering large heath butterfly, *Coenonympha tullia*, larvae on Fenn's and Whixall Mosses in Shropshire and Wrexham, UK. *Ecological Entomology*, 24, 426–431.

* Kati V., Zografou K., Tzirkalli E., Chitos T. & Willemse L. (2012) Butterfly and grasshopper diversity patterns in humid Mediterranean grasslands: the roles of disturbance and environmental factors. *Journal of Insect Conservation*, 16, 807–818.

* Keilsohn W., Narango D.L. & Tallamy D.W. (2018) Roadside habitat impacts insect traffic mortality. *Journal of Insect Conservation*, 22, 183–188.

Kevan P.G. (1983) Floral colors through the insect eye: what they are and what they mean. In: Jones C.E., Little R.J. (eds) Handbook of experimental pollination biology. Van Nostrand, New York, pp 3–25, Scientific and Academic Additions.

* King R.S. (2003) Habitat management for the Karner blue butterfly (*Lycaeides melissa samuelis*): evaluating the short-term consequences. *Ecological Restoration*, 21, 101–106.

Kleerekoper L., van Esch M. & Salcedo T.B. (2012) How to make a city climate-proof, addressing the urban heat island effect. *Resources, Conservation and Recycling*, 64, 30–38.

* Kleintjes Neff P.K., Fettig S.M. & VanOverbeke D.R. (2007) Variable response of butterflies and vegetation to elk herbivory: An exclosure experiment in ponderosa pine and aspen-mixed conifer forests. *Southwestern Naturalist*, 52, 1–14.

* Kleintjes Neff P., Locke C. & Lee-Mäder E. (2017) Assessing a farmland set-aside conservation program for an endangered butterfly: USDA State Acres for Wildlife Enhancement (SAFE) for the Karner blue butterfly. *Journal of Insect Conservation*, 21, 929–941.

* Kleintjes P.K., Jacobs B.F. & Fettig S.M. (2004) Initial response of butterflies to an overstory reduction and slash mulching treatment of a degraded piñon-juniper woodland. *Restoration Ecology*, 12, 231–238.

* Kleintjes P.K., Sporrong J.M., Raebel C.A. & Thon S.F. (2003) Habitat type conservation and restoration for the Karner blue butterfly: a case study from Wisconsin. *Ecological Restoration*, 21, 107–115.

* Koh L. P. (2008) Can oil palm plantations be made more hospitable for forest butterflies and birds? *Journal of Applied Ecology*, 45(4), 1002-1009.

* Koh L.P. & Sodhi N.S. (2004) Importance of reserves, fragments, and parks for butterfly conservation in a tropical urban landscape. *Ecological Applications*, 14, 1695–1708.

* Komonen A., Lensu T. & Kotiaho J.S. (2013) Optimal timing of power line rights-of-ways management for the conservation of butterflies. *Insect Conservation and Diversity*, 6, 522–529.

* Konvicka M., Benes J. & Polakova S. (2016) Smaller fields support more butterflies: comparing two neighbouring European countries with different socioeconomic heritage. *Journal of Insect Conservation*, 20, 1113–1118.

* Konvicka M., Benes J., Cizek O., Kopecek F., Konvicka O. & Vitaz L. (2008) How too much care kills species: Grassland reserves, agri-environmental schemes and extinction of *Colias myrmidone* (Lepidoptera: Pieridae) from its former stronghold. *Journal of Insect Conservation*, 12, 519–525.

* Kőrösi Á., Szentirmai I., Batáry P., Kövér S., Örvössy N. & Peregovits L. (2014) Effects of timing and frequency of mowing on the threatened scarce large blue butterfly – A fine-scale experiment. *Agriculture, Ecosystems & Environment*, 196, 24–33.

* Korpela E.-L., Hyvonen T. & Kuussaari M. (2015) Logging in boreal field-forest ecotones promotes flower-visiting insect diversity and modifies insect community composition. *Insect Conservation and Diversity*, 8, 152–162.

* Korpela E.-L., Hyvönen T., Lindgren S. & Kuussaari M. (2013) Can pollination services, species diversity and conservation be simultaneously promoted by sown wildflower strips on farmland? *Agriculture, Ecosystems & Environment*, 179, 18–24.

* Kovács-Hostyánszki A., Kőrösi Á., Orci K.M., Batáry P. & Báldi A. (2011) Set-aside promotes insect and plant diversity in a Central European country. *Agriculture, Ecosystems & Environment*, 141, 296–301.

* Kricke C., Bamann T., Betz O. (2014) Influence of Urban Mowing Concepts on the Diversity of Butterflies – Investigations on public green space in the city of Tübingen. *Naturschutz und Landschaftsplanung*, 46, 052–058.

* Kruess A. and Tscharntke T. (2002) Grazing intensity and the diversity of grasshoppers, butterflies, and trap-nesting bees and wasps. Conservation Biology, 16(6), 1570–1580.

* Kulfan J., Strbova E. & Zach P. (2012) Effect of vegetation and management on occurrence of larvae and adults of generalist *Maniola jurtina* L. (Lepidoptera) in meadow habitats. *Polish Journal of Ecology*, 60, 601–609.

* Kuussaari M., Heikkinen R.K., Heliölä J., Luoto M., Mayer M., Rytteri S. & von Bagh P. (2015) Successful translocation of the threatened Clouded Apollo butterfly (*Parnassius mnemosyne*) and metapopulation establishment in southern Finland. *Biological Conservation*, 190, 51–59.

* Kuussaari M., Hyvönen T. & Härmä O. (2011) Pollinator insects benefit from rotational fallows. *Agriculture, Ecosystems & Environment*, 143, 28–36.

* Kwilosz J.R. & Knutson R.L. (1999) Prescribed fire management of Karner blue butterfly habitat at Indiana Dunes National Lakeshire. *Natural Areas Journal*, 19, 98–108.

* Lagerlöf J., Stark J. & Svensson B. (1992) Margins of agricultural fields as habitats for pollinating insects. *Agriculture Ecosystems & Environment*, 40, 117–124.

Lamers L.P., Smolders A.J.P. & Roelofs J.G.M. (2002) The restoration of fens in the Netherlands. *Hydrobiologia*, 478, 107–130.

Leather S.R. (2017) "Ecological Armageddon" – more evidence for the drastic decline in insect numbers. *Annals of Applied Biology*, 172, 1–3.

* Lee L.-H. & Lin J.-C. (2015) Green roof performance towards good habitat for butterflies in the compact city. International Journal of Biology, 7, 103–112.

* Lensu T., Komonen A., Hiltula O., Paivinen J., Saari V. & Kotiaho J.S. (2011) The role of power line rights-of-way as an alternative habitat for declined mire butterflies. *Journal of Environmental Management*, 92, 2539–2546.

* Leston L. & Koper N. (2016) Urban Rights-of-Way as Reservoirs for Tall-Grass Prairie Plants and Butterflies. *Environmental Management*, 57, 543–557.

* Levy J.M. & Connor E.F. (2004) Are gardens effective in butterfly conservation? A case study with the pipevine swallowtail, *Battus philenor*. *Journal of Insect Conservation*, 8, 323–330.

* Lewis O.T. & Hurford C. (1997) Assessing the status of the marsh fritillary butterfly (*Eurodryas aurinia*): an example from Glamorgan, UK. *Journal of Insect Conservation*, 1, 159–166.

* Lewis O.T. & Thomas C.D. (2001) Adaptations to captivity in the butterfly *Pieris brassicae* (L.) and the implications for ex situ conservation. *Journal of Insect Conservation*, 5, 55–63.

* Littlewood N.A. (2008) Grazing impacts on moth diversity and abundance on a Scottish upland estate. *Insect Conservation and Diversity*, 1, 151–160.

* Littlewood N.A., Dennis P., Pakeman R.J. & Woodin S.J. (2006) Moorland restoration aids the reassembly of associated phytophagous insects. *Biological Conservation*, 132, 395–404.

* Liu W, Wang Y. & Xu R. (2006) Habitat utilization by ovipositing females and larvae of the Marsh fritillary (*Euphydryas aurinia*) in a mosaic of meadows and croplands. *Journal of Insect Conservation*, 10, 351–360.

Lomov B., Keith D.A., Britton D.R. & Hochuli D.F. (2006) Are butterflies and moths useful indicators for restoration monitoring? A pilot study in Sydney's Cumberland Plain Woodland. *Ecological Management & Restoration*, 7, 204–210.

Long C.V., Flint J.A. & Lepper P.A. (2011) Insect attraction to wind turbines: does colour play a role? *European Journal of Wildlife Research,* 57, 323–331.

* Luppi M., Dondina O., Orioli V. & Bani L. (2018) Local and landscape drivers of butterfly richness and abundance in a human-dominated area. *Agriculture, Ecosystems & Environment*, 254, 138–148.

* Lu S. & Samways M. J. (2001) Life history of the threatened Karkloof blue butterfly, *Orachrysops ariadne*. *African Entomology*, 9(2), 137-151.

* Lu S. & Samways M.J. (2002) Conservation management recommendations for the Karkloof blue butterfly, *Orachrysops ariadne* (Lepidoptera: Lycaenidae). *African Entomology*, 10(1), 149-159.

Maes D. & Van Dyck H. (2001) Butterfly diversity loss in Flanders (north Belgium): Europe's worst case scenario? *Biological Conservation*, 99(3), 263-276.

* Majewska A.A., Sims S., Wenger S.J., Davis A.K. & Altizer S. (2018) Do characteristics of pollinator-friendly gardens predict the diversity, abundance, and reproduction of butterflies? *Insect Conservation and Diversity*, 11, 370–382.

Mallet J. (2014) The Lepidoptera Taxome Project. Available at https://www.ucl.ac.uk/taxome/, accessed 29 October 2021

* Mangels J., Fiedler K., Schneider F.D. & Bluthgen N. (2017) Diversity and trait composition of moths respond to land-use intensification in grasslands: generalists replace specialists. *Biodiversity and Conservation*, 26, 3385–3405.

* Manil L. & Chagué J. (2014) Differentiated management of alfalfa fields: a positive impact on butterfly populations (Lepidoptera: Rhopalocera). *Revue d'écologie*, 69, 101–111.

Marini L., Fontana P., Battisti A. & Gaston K.J. (2009) Agricultural management, vegetation traits and landscape drive orthopteran and butterfly diversity in a grassland-forest mosaic: a multi-scale approach. *Insect Conservation and Diversity*, 2, 213–220.

Marschalek D.A., Faulkner D.K. & Deutschman D.H. (2017) Livestock Grazing Shapes the Vegetation Structure and Subsequent Habitat Use by the Endangered Skipper *Pyrgus ruralis lagunae* (Lepidoptera: Hesperiidae), *Environmental Entomology*, 46, 445–453.

* Marttila O., Saarinen K. & Jantunen J. (1997) Habitat restoration and a successful reintroduction of the endangered Baton Blue butterfly (*Pseudophilotes baton schiffermuelleri*) in SE Finland. *Annales Zoologici Fennici*, 34(3), 177-185.

* Marttila O., Saarinen K. & Marttila P. (2000) Six years from passing bell to recovery: Habitat restoration of the threatened Chequered Blue Butterfly (*Scolitantides orion*) in SE Finland. *Entomologica Fennica*, 11(2), 113–117.

Martin D., Fraser M.D., Pakeman R.J. & Moffat A.M. (2013) Impact of moorland grazing and stocking rates. *Natural England Evidence Review*, Number 006, Report.

* Mas A.H. & Dietsch T.V. (2004) Linking Shade Coffee Certification to Biodiversity Conservation: Butterflies and Birds in Chiapas, Mexico. *Ecological Applications*, 14(3), 642-654.

Mason S.C., Palmer G., Fox R., Gillings S., Hill J.K., Thomas C.D. & Oliver T.H. (2015) Geographical range margins of many taxonomic groups continue to shift polewards. *Biological Journal of the Linnean Society*, 115, 586–597.

* Matteson K.C. & Langellotto G.A. (2011) Small scale additions of native plants fail to increase beneficial insect richness in urban gardens. *Insect Conservation and Diversity*, 4, 89–98.

* Maudsley M.J., Marshall E.J.P. & West T.M. (2000) Guidelines for hedge management to improve the conservation value of different types of hedge. Defra report.

* Mbahin N., Raina S.K., Kioko E.N. & Mueke J.M. (2010) Use of sleeve nets to improve survival of the Boisduval silkworm, *Anaphe panda*, in the Kakamega Forest of western Kenya. *Journal of Insect Science*, 10:6, 1–10.

* Meek B., Loxton D., Sparks T., Pywell R., Pickett H. & Nowakowski M. (2002) The effect of arable field margin composition on invertebrate biodiversity. *Biological Conservation*, 106(2), 259-271.

* Merckx T. & Berwaerts K. (2010) What type of hedgerows do Brown hairstreak (Thecla betulae L.) butterflies prefer? Implications for European agricultural landscape conservation. *Insect Conservation and Diversity*, 3, 194–204.

* Merckx T., Feber R.E., Dulieu R.L., Townsend M.C., Parsons M.S., Bourn N.A.D., Riordan P. & Macdonald D.W. (2009) Effect of field margins on moths depends on species mobility: field-based evidence for landscape-scale conservation. *Agriculture, Ecosystems & Environment*, 129, 302–309.

* Merckx T., Feber R.E., Hoare D.J., Parsons M.S., Kelly C.J., Bourn N.A.D. & Macdonald D.W. (2012) Conserving threatened Lepidoptera: Towards an effective woodland management policy in landscapes under intense human land-use. *Biological Conservation*, 149, 32–39.

* Merckx T., Feber R.E., Mclaughlan C., Bourn N.A.D., Parsons M.S., Townsend M.C., Riordan P., Macdonald D.W. (2010) Shelter benefits less mobile moth species: The field-scale effect of hedgerow trees. *Agriculture, Ecosystems & Environment*, 138(3-4), 147-151.

* Merckx T., Feber R.E., Parsons M.S., Bourn N.A.D., Townsend M.C., Riordan P. & Macdonald D.W. (2010) Habitat preference and mobility of *Polia bombycina*: are non-tailored agri-environment schemes any good for a rare and localised species? *Journal of Insect Conservation*, 14, 499–510.

* Merckx T., Feber R.E., Riordan P., Townsend M.C., Bourn N.A.D., Parsons M.S. & Macdonald D.W. (2009b) Optimizing the biodiversity gain from agri-environment schemes. *Agriculture, Ecosystems & Environment*, 130, 177–182.

* Merckx T., Marini L., Feber R.E. & Macdonald D.W. (2012) Hedgerow trees and extended-width field margins enhance macro-moth diversity: implications for management. *Journal of Applied Ecology*, 49, 1396–1404.

* Meyer C.L. and Sisk T.D. (2001) Butterfly Response to Microclimatic Conditions Following *Ponderosa* Pine Restoration. *Restoration Ecology*, 9(4), 435-461.

* Mjadwesch R. & Nally S. (2008) Emergency relocation of a Purple Copper Butterfly colony during roadworks: Successes and lessons learned. *Ecological Management & Restoration*, 9(2), 100-109.

Money R.P. & Wheeler B.D. (1999) Some critical questions concerning the restorability of raised bogs. *Applied Vegetation Science*, 2, 107–116.

* Montejo-Kovacevich G., Hethcoat M.G., Lim F.K.S., Marsh C.J., Bonfantti D., Peres C.A. & Edwards D.P. (2018) Impacts of selective logging management on butterflies in the Amazon. *Biological Conservation*, 225, 1–9.

* Moradi J., Potocký P., Kočárek P., Bartuška M., Tajovský K., Tichánek F., Frouz J. & Tropek R. (2018) Influence of surface flattening on biodiversity of terrestrial arthropods during early stages of brown coal spoil heap restoration. *Journal of Environmental Management*, 220, 1–7.

* Moranz R.A., Debinski D.M., McGranahan D.A., Engle D.M. & Miller J.R. (2012) Untangling the effects of fire, grazing, and land-use legacies on grassland butterfly communities. *Biodiversity and Conservation*, 21, 2719-2746.

* Moranz R.A., Fuhlendorf S.D. & Engle D.M. (2014) Making sense of a prairie butterfly paradox: The effects of grazing, time since fire, and sampling period on regal fritillary abundance. *Biological Conservation*, 173, 32–41.

* Moreby S.J. (2002) Permanent and temporary linear habitats as food sources for the young of farmland birds. Pages 327-332 in: D.E. Chamberlain (ed.) *Avian Landscape Ecology: Pure and Applied Issues in the Large-Scale Ecology of Birds*. International Association for Landscape Ecology (IALE(UK)), Aberdeen.

* Moreby S.J. (2007) Invertebrate distributions between permanent field boundary habitats and temporary stubble set-aside. *Aspects of Applied Biology*, 81, 207–212.

* Moreby S.J. & Aebischer N.J. (1992) Invertebrate abundance on cereal fields and set-aside land – implications for wild gamebird chicks. *British Crop Protection Council Monographs*, 50, 181–186.

* Moreby S.J. & Southway S.E. (1999) Influence of autumn applied herbicides on summer and autumn food available to birds in winter wheat fields in southern England. *Agriculture, Ecosystems & Environment*, 72, 285–297.

* Moreby S.J. & Southway S. (2000) Management of stubble-set-aside for invertebrates important in the diet of breeding farmland birds. Aspects of Applied Biology, 62, 39–46.

* Moreby S.J. & Southway S. (2002) Cropping and year effects on the availability of invertebrate groups important in the diet of nestling farmland birds. *Aspects of Applied Biology*, 67, 107–112.

Morris M.G. (2000) The effects of structure and its dynamics on the ecology and conservation of arthropods in British grasslands. *Biological Conservation*, 95, 129–142.

* Mueller E.K. & Baum K.A. (2014) Monarch-parasite interactions in managed and roadside prairies. *Journal of Insect Conservation*, 18, 847–853.

*Munguira M.L. & Thomas J.A. (1992) Use of road verges by butterfly and burnet populations, and the effect of roads on adult dispersal and mortality. *Journal of Applied Ecology*, 29, 316–329.

* Muratet A. & Fontaine B. (2015) Contrasting impacts of pesticides on butterflies and bumblebees in private gardens in France. *Biological Conservation*, 182, 148-154.

* Murray B.D., Holland J.D., Summerville K.S., Dunning J.B., Saunders M.R. & Jenkins M.A. (2017) Functional diversity response to hardwood forest management varies across taxa and spatial scales. *Ecological Applications*, 27, 1064–1081.

* Musters C.J.M., Alebeek F.V., Geers R.H.E.M., Korevaar H., Visser A. & Snoo G.R.D. (2009) Development of biodiversity in field margins recently taken out of production and adjacent ditch banks in arable areas. *Agriculture, Ecosystems & Environment*, 129, 131–139.

* Myers M.C., Hoksch, B.J. & Mason J.T. (2012) Butterfly response to floral resources during early establishment at a heterogeneous prairie biomass production site in Iowa, USA. *Journal of Insect Conservation*, 16, 457–472.

Naef-Daenzer B. & Keller L.F. (2001) The foraging performance of great and blue tits (*Parus major* and *P. caeruleus*) in relation to caterpillar development, and its consequences for nestling growth and fledging weight. *Journal of Animal Ecology*, 68, 708–718.

Navarro-Cano J.A., Karlsson B., Posledovich D., Toftegaard T., Wiklund C., Ehrlén J. & Gotthard K. (2015) Climate change, phenology, and butterfly host plant utilization. *Ambio*, 44, 78–88.

New Generation Plantations Platform (2017) Plantations for people, planet and prosperity: 10 years of the New Generation Plantations platform 2007–2017. https://newgenerationplantations.org/multimedia/file/ff98c77e-77cb-11e3-92fa-005056986314/

New T.R. (2004) Moths (Insecta: Lepidoptera) and conservation: background and perspective. *Journal of Insect Conservation*, 8, 79–94.

* New T. R., Van Praagh B. D. & Yen A. L. (2000) Fire and the management of habitat quality in an Australian Lycaenid butterfly, *Paralucia pyrodiscus lucida* Crosby, the Eltham copper. *Metamorphosis*, 11(3), 154-163.

New T.R., Yen A.L., Sands D.P.A., Greenslade P., Neville P.J., York A. & Collett N.G. (2010) Planned fires and invertebrate conservation in South East Australia. *Journal of Insect Conservation*, 10, 567–574.

* Nicholls C.N. & Pullin A.S. (2000) A comparison of larval survivorship in wild and introduced populations of the Large Copper butterfly (*Lycaena dispar batavus*). *Biological Conservation*, 93, 349–358.

* Noordijk J., Delille K., Schaffers A.P. & Sykora K.V. (2009) Optimizing grassland management for flower-visiting insects in roadside verges. *Biological Conservation*, 142(10), 2097–2103.

* Noreika N., Kotiaho J.S., Penttinen J., Punttila P., Vuori A., Pajunen T., Autio O., Loukola O.J. & Kotze D.J. (2015) Rapid recovery of invertebrate communities after ecological restoration of boreal mires. *Restoration Ecology*, 23, 566–579.

* Noreika N., Kotze D.J., Loukola O.J., Sormunen N., Vuori A., Päivinen J., Penttinen J., Punttila P. & Kotiaho J.S. (2016) Specialist butterflies benefit most from the ecological restoration of mires. *Biological Conservation*, 196, 103–114.

Numa C., van Swaay C., Wynhoff I., Wiemers M., Barrios V., Allen D., Sayer C., López Munguira M., Balletto E., Benyamini D., Beshkov S., Bonelli S., Caruana R., Dapporto L., Franeta F., Garcia-Pereira Karaçetin E., Katbeh-Bader A., Maes D., Micevski N., Miller R., Monteiro E., Moulai R., Nieto A., Pamperis L., Pe'er G., Power A., Šašić M., Thompson K., Tzirkalli E., Verovnik R., Warren M. & Welch H. (2016) *The status and distribution of Mediterranean butterflies*. IUCN, Malaga, Spain.

* Nyafwono M., Valtonen A., Nyeko P. & Roininen H. (2014) Butterfly Community Composition Across a Successional Gradient in a Human-disturbed Afro-tropical Rain Forest. *Biotropica*, 46, 210–218.

Oates M.R. & Warren M.S. (1990) A review of butterfly reintroductions in Britain and Ireland. *Joint Committee for the Conservation of British Insects/World Wildlife Fund*, Godalming, United Kingdom.

Oberndorfer E., Lundholm J., Bass B., Coffman R.R., Doshi H., Dunnett N., Gaffin S., Kohler M., Liu K.K.Y. & Rowe B. (2007) Green roofs as urban ecosystems: ecological structures, functions and services. *BioScience*, 57, 823–833.

* Öckinger E. & Smith H.G. (2007) Semi-natural grasslands as population sources for pollinating insects in agricultural landscapes. *Journal of Applied Ecology*, 44, 50–59.

* Öckinger E., Eriksson A.K. & Smith H.G. (2006) Effects of grassland abandonment, restoration and management on butterflies and vascular plants. *Biological Conservation*, 133, 291–300.

Öckinger E., Schweiger O., Crist T.O., Debinski D.M., Krauss J., Kuussaari M., Petersen J.D., Pöyry J., Settele J., Summerville K.S. & Bommarco R. (2010) Life-history traits predict species responses to habitat area and isolation: a cross-continental synthesis. *Ecology Letters*, 13, 969–979.

O'Dwyer C. & Attiwell P.M. (2000) Restoration of a native grassland as habitat for the golden sun moth *Synemon plana* Walker (Lepidoptera; Castniidae) at Mount Piper, Australia. *Restoration Ecology*, 8, 170–174.

* Ohwaki A., Koyanagi T.F. & Maeda S. (2018) Evaluating forest clear-cuts as alternative grassland habitats for plants and butterflies. *Forest Ecology and Management*, 430, 337–345.

* Oliver T. (2014) Assessing the importance of spatial location of agri-environment options within the landscape to butterflies. *Natural England Commissioned Report*, NECR157.

* Panzer R. (2002) Compatibility of prescribed burning with the conservation of insects in small, isolated prairie reserves. *Conservation Biology*, 16, 1296–1307.

* Parker R. (2018) Still working at re-establishment of the silver-studded blue *Plebejus argus* – real progress from 2007 to 2018. *British Journal of Entomology and Natural History*, 31(4), 217-223.

Parmesan C., Ryrholm N., Stefanescu C., Hill J.K., Thomas C.D., Descimon H., Huntley B., Kaila L., Kullberg J., Tammaru T., Tennent W.J., Thomas J.A. & Warren M. (1999) Poleward shifts in geographical ranges of butterfly species associated with regional warming. *Nature*, 399, 579–583.

Parsons M.S. (2004) The United Kingdom Biodiversity Action Plan moths - selection, status and progress on conservation. *Journal of Insect Conservation*, 8, 95–107.

Patrick B.H. (2004) Conservation of New Zealand's tussock grassland moth fauna. *Journal of Insect Conservation*, 8, 199–208.

* Pérez-Garcia O., Benjamin T.J. & Tobar D.E. (2018) Modern coffee agroecosystems and their relationship with butterflies conservation in fragmented landscapes. *Revista De Biologia Tropical*, 66, 394–402.

* Pfitsch W.A. & Williams E.H. (2009) Habitat restoration for lupine and specialist butterflies. *Restoration Ecology*, 17, 226–233.

Pocius V.M., Debinski D.M., Pleasants J.M., Bidne K.G., Hellmich R.L. & Brower L.P. (2017) Milkweed Matters: Monarch Butterfly (Lepidoptera: Nymphalidae) Survival and Development on Nine Midwestern Milkweed Species. *Environmental Entomology*, 46, 1098–1105.

* Porter K. & Ellis S. (2011) Securing viable metapopulations of the Marsh Fritillary butterfly, *Euphydryas aurinia*, (Lepidoptera: Nymphalidae) in Northern England. *Journal of Insect Conservation*, 15, 111–119.

* Potts S.G., Woodcock B.A., Roberts S.P.M., Tscheulin T., Pilgrim E.S., Brown V.K. & Tallowin J.R. (2009) Enhancing pollinator biodiversity in intensive grasslands. *Journal of Applied Ecology*, 46, 369–379.

* Powell A.F.L.A., Busby W.H. & Kindscher K. (2007) Status of the regal fritillary (*Speyeria idalia*) and effects of fire management on its abundance in northeastern Kansas, USA. *Journal of Insect Conservation*, 11, 299–308.

* Pöyry J., Lindgren S., Salminen J. & Kuussaari M. (2004) Restoration of butterfly and moth communities in semi-natural grasslands by cattle grazing. *Ecological Applications*, 14, 1656–1670.

* Pöyry J., Paukkunen J., Heliölä J. and Kuussaari M. (2009) Relative contributions of local and regional factors to species richness and total density of butterflies and moths in semi-natural grasslands. *Community Ecology*, 160, 577–587.

* Pöyry J., Lindgren S., Salminen J. & Kuussaari M. (2005) Responses of butterfly and moth species to restored cattle grazing in semi-natural grasslands. *Biological Conservation*, 122, 465–478.

* Puig-Montserrat X., Stefanescu C., Torre I., Palet J., Fàbregas E., Dantart J., Arrizabalaga A. & Flaquer C. (2017) Effects of organic and conventional crop management on vineyard biodiversity. *Agriculture, Ecosystems & Environment*, 243, 19–26.

* Pullin A.S. (1996) Restoration of butterfly populations in Britain. *Restoration Ecology*, 4, 71–80.

* Pullin A.S. (1997) Habitat requirements of *Lycaena dispar batavus* and implications for re-establishment in England. *Journal of Insect Conservation*, 1, 177–185.

* Pywell R., Hulmes L., Meek W. & Nowakowski M. (2008) Creation and Management of Pollen and Nectar Habitats on Farmland: Annual report 2007/8.

* Pywell R.F., Meek W.M., Carvell C. & Hulmes L. (2007) The SAFFIE project: enhancing the value of arable field margins for pollinating insects. *Aspects of Applied Biology*, 81, 239–245.

* Pywell R.F., Meek W.R., Hulmes L., Hulmes S., James K.L., Nowakowski M. & Carvell C. (2011) Management to enhance pollen and nectar resources for bumblebees and butterflies within intensively farmed landscapes. *Journal of Insect Conservation*, 15, 853–864.

* Pywell R.F., Shaw L., Meek W., Turk A., Shore R.F. & Nowakowski M. (2007) Do wild bird seed mixtures benefit other taxa? *Aspects of Applied Biology*, 81, 69–76.

Pywell R.F., Warman E.A., Sparks T.H., Greatorex-Davies J.N., Walker K.J., Meek W.R., Carvell C., Petit S. & Firbank L.G. (2004) Assessing habitat quality for butterflies on intensively managed arable farmland. *Biological Conservation*, 118, 313–325.

Ravenscroft N. (2006) Management for invertebrates in North Argyll and Lochaber: the effects of cyclical clearance of wayleaves on butterflies. *Scottish Natural Heritage Commissioned Report* No. 162 (ROAME No. F04LG01).

* Ravetto Enri S., Probo, M., Farruggia A., Lanore L., Blanchetete A. & Dumont B. (2017) A biodiversity-friendly rotational grazing system enhancing flower-visiting insect assemblages while maintaining animal and grassland productivity. *Agriculture, Ecosystems & Environment*, 241, 1–10.

* Reck (1993) Creating new habitats on intensively used farmland, the "Pappelhof" in Saarland — a project supported by the German government. *Natur und Landschaft*, 68, 394–403.

* Revaz E., Schaub M. & Arlettaz R. (2008) Foraging ecology and reproductive biology of the Stonechat *Saxicola torquata*: comparison between a revitalized, intensively cultivated and a historical, traditionally cultivated agro-ecosystem. *Journal of Ornithology*, 149, 301–312.

* Ribeiro D.B. & Freitas A.V.L. (2012) The effect of reduced-impact logging on fruit-feeding butterflies in Central Amazon, Brazil. *Journal of Insect Conservation*, 16, 733–744.

Richter A. Hauck J., Feldmann R., Kühn E., Harpke A., Hirneisen N., Mahla A., Settele J. & Bonn A. (2018) The social fabric of citizen science—drivers for long-term engagement in the German butterfly monitoring scheme. *Journal of Insect Conservation*, 22, 731–743.

* Rickert C., Fichtner A. & van Klink R. (2018) Livestock grazing disrupts plant-insect interactions on salt marshes. *Insect Conservation and Diversity*, 11, 152–161.

* Rickert C., Fichtner A., van Klink R. & Bakker J.P. (2012) α- and β-diversity in moth communities in salt marshes is driven by grazing management. *Biological Conservation*, 146, 24–31.

* Ricouart F., Cereghino R., Gers C., Winterton P. & Legal L. (2013) Influence of fire prevention management strategies on the diversity of butterfly fauna in the eastern Pyrenees. *Journal of Insect Conservation*, 17, 95–111.

* Ries L., Debinski D.M. & Wieland M.L. (2001) Conservation value of roadside prairie restoration to butterfly communities. *Conservation Biology*, 15, 401–411.

* Ringwood Z., Hill J. & Gibson C. (2004) Conservation management of *Gortyna borelii lunata* (Lepidoptera: Noctuidae) in the United Kingdom. *Journal of Insect Conservation*, 8, 173–183.

Ritzema H., Limin S., Kusin K., Jauhiainen J. & Wösten H. (2014) Canal blocking strategies for hydrological restoration of degraded tropical peatlands in Central Kalimantan, Indonesia. *Catena*, 114, 11–20.

* Riva F., Acorn J.H. & Nielsen S.E. (2018) Localized disturbances from oil sands developments increase butterfly diversity and abundance in Alberta's boreal forests. *Biological Conservation*, 217, 173–180.

* Robertson P.A., Woodburn M.I.A. & Hill D.A. (1988) The effects of woodland management for pheasants on the abundance of butterflies in Dorset, England. *Biological Conservation*, 45, 159–167.

Robins J., Henshall S. & Farr A. (2013) The state of brownfields in the Thames Gateway. *Buglife Report*, https://cdn.buglife.org.uk/2019/08/The-State-of-Brownfields-in-the-Thames-Gateway_0_0.pdf.

* Rolando A., Negro M., D'Entreves P.P., Balletto E. & Palestrini C. (2013) The effect of forest ski-pistes on butterfly assemblages in the Alps. *Insect Conservation and Diversity*, 6, 212–222.

* Root H.T., Verschuyl J., Stokely T., Hammond P., Scherr M.A. & Betts M.G. (2017) Plant diversity enhances moth diversity in an intensive forest management experiment. *Ecological Applications*, 27, 134–142.

* Roth T., Amrhein V., Peter B. & Weber D. (2008) A Swiss agri-environment scheme effectively enhances species richness for some taxa over time. *Agriculture, Ecosystems & Environment*, 125, 167–172.

* Rowe E.C., Healey J.R., Edwards-Jones G., Hills J., Howells M. & Jones D.L. (2006) Fertilizer application during primary succession changes the structure of plant and herbivore communities. *Biological Conservation*, 131, 510–522.

* Royal Society for the Protection of Birds (2016) Utility of lenient grazing of agricultural grassland to promote in-field structural heterogeneity, invertebrates and bird foraging [BD5207: Extensive cattle grazing: what is the best approach to improve species-poor pastures for birds and invertebrates? (Phase 2)] - Project BD5206/BD5207 Final Report to DEFRA/Natural England (RP00196). Natural England report.

* Rundlöf M., Bengtsson J. & Smith H.G. (2008) Local and landscape effects of organic farming on butterfly species richness and abundance. *Journal of Applied Ecology*, 45(3), 813-820.

* Rundlöf M. & Smith H.G. (2006) The effect of organic farming on butterfly diversity depends on landscape context. *Journal of Applied Ecology*, 43, 1121–1127.

*Runquist E. (2011) Butterflies, cattle grazing, and environmental heterogeneity in a complex landscape. *Journal of Research on the Lepidoptera*, 44, 61–76.

Russell C. & Schultz C.B. (2010) Effects of grass-specific herbicides on butterflies: an experimental investigation to advance conservation efforts. *Journal of Insect Conservation*, 14, 53–63.

Russell E.W.B. (1997) People and the Land Through Time: Linking Ecology and History. *Yale University Press*, New Haven and London.

* Saarinen K. & Jantunen J. (2005) Grassland butterfly fauna under traditional animal husbandry: contrasts in diversity in mown meadows and grazed pastures. *Biodiversity and Conservation*, 14, 3201–3213.

* Saarinen K., Valtonen A., Jantunen J., Saarnio S. (2005) Butterflies and diurnal moths along road verges: Does road type affect diversity and abundance? *Biological Conservation*, 123(3), 403-412.

* Sáfián S., Csontos G. & Winkler D. (2011) Butterfly community recovery in degraded rainforest habitats in the Upper Guinean Forest Zone (Kakum forest, Ghana). Journal of Insect Conservation, 15, 351–359.

* Sant'Anna C.L.B., Ribeiro D.B., Garcia L.C. & Freitas A.V.L. (2014) Fruit-feeding butterfly communities are influenced by restoration age in tropical forests. *Restoration Ecology*, 22, 480–485.

* Scandurra A., Magliozzi L., Fulgione D., Aria M. & D'Aniello B. (2016) Lepidoptera Papilionoidea communities as a sentinel of biodiversity threat: the case of wild boar rooting in a Mediterranean habitat. *Journal of Insect Conservation*, 20, 353–362.

* Scohier A., Ouin A., Farruggia A. & Dumont B. (2013) Is there a benefit of excluding sheep from pastures at flowering peak on flower-visiting insect diversity? *Journal of Insect Conservation*, 17, 287–294.

* Schmitt T., Cizek O. & Konvicka M. (2005) Genetics of a butterfly relocation: large, small and introduced populations of the mountain endemic *Erebia epiphron silensiana*. *Biological Conservation*, 123(1), 11–18.

* Schtickzelle N., Turlure C. & Baguette M. (2007) Grazing management impacts on the viability of the threatened bog fritillary butterfly *Proclossiana eunomia*. *Biological Conservation*, 136, 651–660.

* Schultz C.B., Crone E.E. (2002) Burning Prairie to Restore Butterfly Habitat: A Modeling Approach to Management Tradeoffs for the Fender's Blue. *Restoration Ecology*, 6(3), 244-252.

* Schultz C.B., Dzurisin J.D. & Russell C. (2009) Captive rearing of Puget blue butterflies (*Icaricia icarioides blackmorei*) and implications for conservation. *Journal of Insect Conservation*, 13, 309–315.

* Schultz C.B., Russell C. & Wynn L. (2008) Restoration, reintroduction, and captive propagation for at-risk butterflies: A review of British and American conservation efforts. *Israel Journal of Ecology & Evolution*, 54, 41–61.

* Schultz C.B., Zemaitis J.L., Thomas C.C., Bowers M.D. & Crone E.E. (2016) Non-target effects of grass-specific herbicides differ among species, chemicals and host plants in *Euphydryas* butterflies. *Journal of Insect Conservation*, 20, 867–877.

* Schwarzwälder B., Lörtscher M., Erhardt A. & Zettel J. (1997) Habitat utilizations by the heath fritillary butterfly, *Mellicta athalia* ssp. *celadussa* (Rott.) (Lepidoptera: Nymphalidae) in montane grasslands of different management. *Biological Conservation*, 82, 157–165.

* Schwenninger H.R. & Wolf-Schwenninger K. (1998) Modifying landscaped verges for conservation: new urban habitats for bees and butterflies? *Natur und Landschaft*, 73, 386–392.

* Scriber J.M. (2004) Non-target impacts of forest defoliator management options: Decision for no spraying may have worse impacts on non-target Lepidoptera than *Bacillus thuringiensis* insecticides. *Journal of Insect Conservation*, 8, 241–261.

* Sebek P., Bace R., Bartos M., Benes J., Chlumska Z., Dolezal J., Dvorsky M., Kovar J., Machac O., Mikatova B., Perlik M., Platek M., Polakova S., Skorpik M., Stejskal R., Svoboda M., Trnka F., Vlasin M., Zapletal M. & Cizek L. (2015) Does a minimal intervention approach threaten the biodiversity of protected areas? A multi-taxa short-term response to intervention in temperate oak-dominated forests. *Forest Ecology and Management*, 358, 80-89.

Sedláková I. & Chytrý M. (1999) Regeneration patterns in a Central European dry heathland: effects of burning, sod-cutting and cutting. *Plant Ecology*, 143(1), 77–87.

Settele J., Kudrna O., Harpke A., Kühn I., van Swaay C., Verovnik R., Warren M., Wiemers M., Hanspach J., Hickler T., Kühn E., van Halder I., Veling K., Vliegenthart A., Wynhoff I. & Schweiger O. (2008) *Climatic Risk Atlas of European Butterflies*. Biorisk 1 (Special Issue), Pensoft, Sofia–Moscow.

* Severns P.M. (2008) Exotic grass invasion impacts fitness of an endangered prairie butterfly, *Icaricia icarioides fenderi*. *Journal of Insect Conservation*, 12, 651–661.

* Severns P.M. (2011) Habitat restoration facilitates an ecological trap for a locally rare, wetland-restricted butterfly. *Insect Conservation and Diversity*, 4, 184–191.

* Severns P.M., Boldt L. & Villegas S. (2006) Conserving a wetland butterfly: quantifying early lifestage survival through seasonal flooding, adult nectar, and habitat preference. *Journal of Insect Conservation*, 10, 361–370.

* Shackleton K. & Ratnieks F.L.W. (2016) Garden varieties: How attractive are recommended garden plants to butterflies? *Journal of Insect Conservation*, 20, 141–148.

* Shepherd S. & Debinski D.M. (2005) Reintroduction of regal fritillary (*Speyeria idalia*) to a restored prairie. *Ecological Restoration*, 23, 244–250.

* Shuey J., Jacquart E., Orr S., Becker F., Nyberg A., Littiken R., Anchor T. & Luchik D. (2016) Landscape-scale response to local habitat restoration in the regal fritillary butterfly (*Speyeria idalia*) (Lepidoptera: Nymphalidae). *Journal of Insect Conservation*, 20, 773–780.

* Shuey J., Labus P., Carneiro E., Silva Dias F.M., Leite L.A.R. & Mielke O.H.H. (2017) Butterfly communities respond to structural changes in forest restorations and regeneration in lowland Atlantic Forest, Parana, Brazil. *Journal of Insect Conservation*, 21, 545–557.

Sinclair L.J. (2002) Distribution and conservation requirements of *Notoreas* sp., an unnamed Geometrid moth on the Taranaki coast, North Island, New Zealand. *New Zealand Journal of Zoology*, 29, 311–322.

* Sjodin N.E., Bengtsson J. & Ekbom B. (2008) The influence of grazing intensity and landscape composition on the diversity and abundance of flower-visiting insects. *Journal of Applied Ecology*, 45, 763–772.

* Skórka P., Lenda M., Moroń D., Kalarus K. & Tryjanowski P. (2013) Factors affecting road mortality and the suitability of road verges for butterflies. *Biological Conservation*, 159, 148–157.

* Skórka P, Settele J, Woyciechowski M (2007) Effects of management cessation on grassland butterflies in southern Poland. *Agriculture, Ecosystems & Environment*, 121(4), 319-324.

* Slamova I., Klecka J. & Konvicka M. (2013) Woodland and grassland mosaic from a butterfly perspective: habitat use by *Erebia aethiops* (Lepidoptera: Satyridae). *Insect Conservation and Diversity*, 6(3), 243–254.

Slancarova J., Bartonova A., Zapletal M., Kotilinek M., Fric Z.F., Micevski N., Kati V. & Konvicka M. (2016) Life history traits reflect changes in Mediterranean butterfly communities due to forest encroachment. *PLoS ONE*, 11(3): e0152026.

* Smallidge P.J., Leopold D.J. & Allen C.M. (1996) Community characteristics and vegetation management of Karner blue butterfly (*Lycaeides melissa samuelis*) habitats on rights-of-way in east-central New York, USA. *Journal of Applied Ecology*, 33, 1405–1419.

Smart M.J. & Winnall R.A. (2006) The biodiversity of three traditional orchards within the Wyre Forest SSSI in Worcestershire: a survey by the Wyre Forest Study Group (ENRR707). *English Nature Research Reports*, No 707.

* Smee M., Smyth W., Tunmore M., ffrench-Constant R. & Hodgson D. (2011) Butterflies on the brink: habitat requirements for declining populations of the marsh fritillary (*Euphydryas aurinia*) in SW England. *Journal of Insect Conservation*, 15, 153–163.

* Söderström B. & Hedblom M. (2007) Comparing movement of four butterfly species in experimental grassland strips. *Journal of Insect Conservation*, 11, 333–342.

* Söderström B., Svensson B., Vessby K. & Glimskär A. (2001) Plants, insects and birds in semi-natural pastures in relation to local habitat and landscape factors. *Biodiversity and Conservation,* 10, 1839-1863.

* Sosa-Aranda I., del-Val E., Hernández-Martínez G., Arroyo-Lambaer D., Uscanga A. & Boege K. (2018) Response of lepidopteran herbivore communities to crop management in coffee plantations. *Agriculture, Ecosystems & Environment*, 265, 37–44.

* Sotherton N.W., Wratten S.D., Price S.B. & White R.J. (1981) Aspects of hedge management and their effects on hedgerow fauna. *Zeitschrift Fur Angewandte Entomologie-Journal of Applied Entomology*, 92, 425–432.

* Sparks T. H. & Parish T. (1995) Factors affecting the abundance of butterflies in field boundaries in Swavesey fens, Cambridgeshire, UK. *Biological Conservation*, 73(3), 221-227.

* Staley J.T., Botham M.S., Amy S.R., Hulmes S. & Pywell R.F. (2018) Experimental evidence for optimal hedgerow cutting regimes for Brown hairstreak butterflies. *Insect Conservation and Diversity*, 11, 213–218.

* Staley J.T., Botham M.S., Chapman R.E., Amy S.R., Heard M.S., Hulmes L., Savage J. & Pywell R.F. (2016) Little and late: How reduced hedgerow cutting can benefit Lepidoptera. *Agriculture, Ecosystems & Environment*, 224, 22–28.

Stefanescu C., Penuelas J. & Filella I. (2003) Effects of climatic change on the phenology of butterflies in the northwest Mediterranean Basin. *Global Change Biology*, 9, 1494–1506.

Stefanescu C., Peñuelas J. & Filella I. (2009) Rapid changes in butterfly communities following the abandonment of grasslands: a case study. *Insect Conservation and Diversity*, 2, 261–269.

Stefanescu C., Puig-Montserrat X., Samraoui B., Izquierdo R., Ubach A. & Arrizabalaga A. (2017) Back to Africa: autumn migration of the painted lady butterfly *Vanessa cardui* is timed to coincide with an increase in resource availability. *Ecological Entomology*, 42, 737–747.

* Steffan-Dewenter I. & Tscharntke T. (1997) Early succession of butterfly and plant communities on set-aside fields. *Oecologia*, 109, 294–302.

* Stoeckli S., Birrer S., Zellweger-Fischer J., Balmer O., Jenny M. & Pfiffner L. (2017) Quantifying the extent to which farmers can influence biodiversity on their farms. *Agriculture, Ecosystems & Environment*, 237, 224–233.

Suggitt A.J., Wilson R.J., August T.A., Fox R., Isaac N.J.B., Macgregor N.A., Morecroft M.D. & Maclean I.M.D. (2015) Microclimate affects landscape level persistence in the British Lepidoptera. *Journal of Insect Conservation*, 19, 237–253.

Suggitt A.J., Wilson R.J., Isaac N.J.B., Beale C.M., Auffret A.G., August T., Bennie J.J., Crick H.Q.P., Duffield S., Fox R., Hopkins J.J., Macgregor N.A., Morecroft M.D., Walker K.J. & Maclean I.M.D. (2018) Extinction risk from climate change is reduced by microclimatic buffering. *Nature Climate Change*, 8, 713–717.

* Summerville K.S. (2011) Managing the forest for more than the trees: effects of experimental timber harvest on forest Lepidoptera. *Ecological Applications*, 21, 806–816.

* Summerville K.S. (2013) Forest lepidopteran communities are more resilient to shelterwood harvests compared to more intensive logging regimes. *Ecological Applications*, 23, 1101–1112.

Summerville K.S. & Crist T.O. (2001) Effects of experimental habitat fragmentation on patch use by butterflies and skippers (Lepidoptera). *Ecology*, 82, 1360–1370.

Sutherland W.J., Pullin A.S., Dolman P.M. & Knight T.M. (2004) The need for evidence-based conservation. *Trends in Ecology & Evolution*, 19, 305–308.

Sutherland W.J., Taylor N.G., MacFarlane D., Amano T., Christie A.P., Dicks L.V., Lemasson A.J., Littlewood N.A., Martin P.A., Ockendon N., Petrovan S.O., Robertson R.J., Rocha R., Shackelford G.E., Smith R.K., Tyler E.H.M. & Wordley C.R.F (2019) Building a tool to overcome barriers in research-implementation spaces: The Conservation Evidence database. *Biological Conservation*, 238, 108199.

* Swengel A.B. (1996) Effects of fire and hay management on abundance of prairie butterflies. *Biological Conservation*, 76, 73–85.

* Swengel A.B. (1997) Habitat Associations of Sympatric Violet-Feeding Fritillaries (*Euptoieta, Speyeria, Boloria*) (Lepidoptera: Nymphalidae) in Tallgrass Prairie. *The Great Lakes Entomologist*, 30(1&2).

* Swengel A.B. (1998) Effects of management on butterfly abundance in tallgrass prairie and pine barrens. *Biological Conservation*, 83, 77–89.

Swengel A.B. (2001) A literature review of insect responses to fire, compared to other conservation managements of open habitat. *Biodiversity and Conservation*, 10, 1141–1169.

* Swengel S. R., Schlicht D., Olsen F., Swengel A. B. (2011) Declines of prairie butterflies in the midwestern USA. *Journal of Insect Conservation*, 15, 327-339.

* Swengel A.B. & Swengel S.R. (1997) Co-occurrence of prairie and barrens butterflies: applications to ecosystem conservation. *Journal of Insect Conservation*, 1, 131–144.

* Swengel A.B. & Swengel S.R. (2001) Effects of prairie and barrens management on butterfly faunal composition. *Biodiversity and Conservation*, 10, 1757–1785.

* Swengel A.B. & Swengel S.R. (2007) Benefit of permanent non-fire refugia for Lepidoptera conservation in fire-managed sites. *Journal of Insect Conservation*, 11, 263–279.

* Swengel A.B. and Swengel S.R. (2014) Paradoxes of Poweshiek Skipperling (*Oarisma poweshiek*) (Lepidoptera: Hesperiidae): Abundance Patterns and Management of a Highly Imperiled Prairie Species. *International Scholarly Research Notices*, 2014.

* Swengel A.B. & Swengel S.R. (2015) Grass-skipper (Hesperiinae) trends in midwestern USA grasslands during 1988–2013. *Journal of Insect Conservation*, 19, 279–292.

* Swengel A. B. & Swengel S. R. (2018) Patterns of Long-Term Population Trends of Three Lupine-Feeding Butterflies in Wisconsin. *Diversity*, 10(2), 31.

* Sybertz J., Matthies S., Schaarschmidt F., Reich M. & von Haaren C. (2017) Assessing the value of field margins for butterflies and plants: how to document and enhance biodiversity at the farm scale. *Agriculture, Ecosystems & Environment*, 249, 165–176.

* Taki H., Yamaura Y., Okochi I., Inoue T., Okabe K. & Makino S. (2010) Effects of reforestation age on moth assemblages in plantations and naturally regenerated forests. *Insect Conservation and Diversity*, 3, 257–265.

* Taylor M.E. & Morecroft M.D. (2009) Effects of agri-environment schemes in a long-term ecological time series. *Agriculture, Ecosystems & Environment*, 130, 9–15.

Terblanche R.F. & Henning G.A. (2009) Threatened butterflies in South Africa: trends since 1989 and a future perspective. In Henning G.A., Terblanche R.F. & Ball J.B. (*eds*) South African Red Data Book: butterflies. *SANBI Biodiversity Series 13*. South African National Biodiversity Institute, Pretoria.

Theng M., Jusoh W.F.A, Jain A., Huertas B., Tan D.J.X., Tan H.Z., Kristensen N.P., Meier R. & Chisholm R.A. (2020) A comprehensive assessment of diversity loss in a well-documented tropical insect fauna: Almost half of Singapore's butterfly species extirpated in 160 years. *Biological Conservation*, 242, 108401.

* Thiere G., Milenkowski S., Lindgren P.E., Sahlén G., Berglund O. & Weisner S.E.B. (2009) Wetland creation in agricultural landscapes: Biodiversity benefits on local and regional scales. *Biological Conservation*, 142, 964–973.

* Thomas C.D. & Harrison S. (1992) Spatial dynamics of a patchily distributed butterfly species. *Journal of Animal Ecology*, 61, 437–446.

Thomas J.A. (1980) Why Did the Large Blue Become Extinct in Britain? *Oryx*, 15, 243–247.

Thomas J.A. (2005) Monitoring change in the abundance and distribution of insects using butterflies and other indicator groups. *Philosophical Transactions of the Royal Society of Biological Sciences*, 360, 339–357.

Thomas J.A. & Lewington R. (2016) *The Butterflies of Britain & Ireland*. Third edition, Bloomsbury Publishing, UK.

* Thomas J.A. & Wardlaw J.C. (1990) The effect of queen ants on the survival of *Maculinea arion* in *Myrmica* ant nests. *Oecologia*, 85, 87–91.

* Thomas J.A., Elmes, G.W. & Wardlaw J.C. (1993) Contest competition among *Maculinea rebeli* butterfly larvae in ant nests. *Ecological Entomology*, 18, 73–76.

Thomas J.A., Simcox D.J. & Clarke R.T. (2009) Successful Conservation of a Threatened *Maculinea* Butterfly. *Science*, 325, 80–83.

Thomas J.A., Simcox D.J. & Hovestadt T. (2011) Evidence based conservation of butterflies. *Journal of Insect Conservation*, 15, 241–258.

* Thomas S.R., Goulson D. & Holland J.M. (2000) The contribution of beetle banks to farmland biodiversity. *Aspects of Applied Biology*, 62, 31–38.

* Tillman P.G. & Carpenter J.E. (2014) Milkweed (Gentianales: Apocynaceae): A Farmscape Resource for Increasing Parasitism of Stink Bugs (Hemiptera: Pentatomidae) and Providing Nectar to Insect Pollinators and Monarch Butterflies. *Environmental Entomology*, 43, 370–376.

* Tobar D.E. & Ibrahim M. (2010) Do live fences help conserve butterfly diversity in agricultural landscapes? *Revista De Biologia Tropical*, 58, 447–463.

* Toivonen M., Herzon I. & Kuussaari M. (2015) Differing effects of fallow type and landscape structure on the occurrence of plants, pollinators and birds on environmental fallows in Finland. *Biological Conservation*, 181, 36–43.

* Toivonen M., Herzon I. & Kuussaari M. (2016) Community composition of butterflies and bumblebees in fallows: niche breadth and dispersal capacity modify responses to fallow type and landscape. *Journal of Insect Conservation*, 20, 23–34.

* Trappe J., Kunz F., Weking S. & Kamp J. (2017) Grassland butterfly communities of the Western Siberian forest steppe in the light of post-Soviet land abandonment. *Journal of Insect Conservation*, 21, 813–826.

* Tropek R., Kadlec T., Karesova P., Spitzer L., Kocarek P., Malenovsky I., Banar P., Tuf I.H., Hejda M., Konvicka M. (2010) Spontaneous succession in limestone quarries as an effective restoration tool for endangered arthropods and plants. *Journal of Applied Ecology*, 47, 139–147.

Tucker G. (2003) Review of the impacts of heather and grassland burning in the uplands on soils, hydrology and biodiversity (ENRR550). Natural England (English Nature) report.

* Turlure C., Choutt J., Baguette M. & van Dyck H. (2010) Microclimatic buffering and resource-based habitat in a glacial relict butterfly: significance for conservation under climate change. *Global Change Biology*, 16(6), 1883-1893.

Turner E.C., Granroth H.M.V., Johnson H.R., Lucas C.B.H., Thompson A.M., Froy H., German R.N. & Holgate R. (2009) Habitat preference and dispersal of the Duke of Burgundy butterfly (*Hamearis lucina*) on an abandoned chalk quarry in Bedfordshire, UK. *Journal of Insect Conservation*, 13, 475–486.

* Uchida K., Takahashi S., Shinohara T. & Ushimaru A. (2016) Threatened herbivorous insects maintained by long-term traditional management practices in semi-natural grasslands. *Agriculture, Ecosystems & Environment*, 221, 156–162.

UNEP-WCMC, IUCN & NGS (2018). Protected Planet Report 2018. UNEP-WCMC, IUCN & NGS: Cambridge UK; Gland, Switzerland; & Washington, D.C., USA.

* Valtonen A. & Saarinen K. (2005) A highway intersection as an alternative habitat for a meadow butterfly: effect of mowing, habitat geometry and roads on the ringlet (*Aphantopus hyperantus*). *Annales Zoologici Fennici*, 42(5), 545-556.

Van Dyck H., Puls R., Bonte D., Gotthard K. & Maes D. (2015) The lost generation hypothesis: could climate change drive ectotherms into a developmental trap? *Oikos*, 124(1): 54–61.

van Klink R., Bowler D.E., Gongalsky K.B., Swengel A.B., Gentile A. & Chase J.M. (2020) Meta-Analysis Reveals Declines in Terrestrial but Increases in Freshwater Insect Abundances. *Science*, 368 (6489): 417–420.

* van Klink R., Rickert C., Vermeulen R., Vorst O., WallisDeVries M.F. & Bakker J.P. (2013) Grazed vegetation mosaics do not maximize arthropod diversity: Evidence from salt marshes. *Biological Conservation*, 164, 150–157.

* van Langevelde F., Ettema J.A., Donners M., WallisDeVries M.F., Groenendijk D. (2011) Effect of spectral composition of artificial light on the attraction of moths. *Biological Conservation*, 144 (9), 2274-2281.

van Langevelde F. & Wynhoff I. (2009) What limits the spread of two congeneric butterfly species after their reintroduction: quality or spatial arrangement of habitat? *Animal Conservation*, 12, 540–548.

van Langevelde F., Ettema J., Donners M., WallisDeVries M.F., Groenendijk D. (2011) Effect of spectral composition of artificial light on the attraction of moths. *Biological Conservation*, 144, 2274–2281.

* van Langevelde F., van Grunsven R.H.A., Veenendaal E.M., Fijen T.P.M. (2017) Artificial night lighting inhibits feeding in moths. *Biology Letters*, 13, 20160874.

* van Noordwijk C.G.E., Flierman D.E., Remke E., WallisDeVries M.F. & Berg M.P. (2012) Impact of grazing management on hibernating caterpillars of the butterfly *Melitaea cinxia* in calcareous grasslands. *Journal of Insect Conservation*, 16, 909–920.

van Strien A.J., van Swaay C.A.M., van Strien-van Liempt W.T.F.H, Poot M.J.M. & WallisDeVries M.F. (2019) Over a century of data reveal more than 80% decline in butterflies in the Netherlands. *Biological Conservation*, 234, 116–122.

van Swaay C.A.M. (1990) An assessment of the changes in butterfly abundance in The Netherlands during the 20th Century. *Biological Conservation*, 52, 287–302.

van Swaay C.A.M. & Warren M.S. (2006) Prime Butterfly Areas of Europe: an initial selection of priority sites for conservation. *Journal of Insect Conservation*, 10, 5–11.

van Swaay C., Collins S., Dušej G., Maes D., López Munguira M., Rakosy L., Ryrholm N., Šašić M., Settele J., Thomas J.A., Verovnik R., Verstrael T., Warren M., Wiemers M. & Wynhoff I. (2012) Dos and Don'ts for butterflies of the Habitats Directive of the European Union. *Nature Conservation*, 1, 73–153.

van Swaay C., Cuttelod A., Collins S., Maes D., López Munguira M., Šašić M., Settele J., Verovnik R., Verstrael T., Warren M., Wiemers M. & Wynhoff I. (2010) *European Red List of Butterflies*. Luxembourg: Publications Office of the European Union.

van Swaay C.A.M., Maes D., Collins S., Munguira M.L., Šašić M., Settele J., Verovnik R., Warren M.S., Wiemers M., Wynhoff I., Cuttelod A. (2011) Applying IUCN criteria to invertebrates: How red is the Red List of European butterflies? *Biological Conservation*, 144(1): 470–478.

* Verdasca M.J., Leitão A.S., Santana J., Porto M., Dias S. & Beja P. (2012) Forest fuel management as a conservation tool for early successional species under agricultural abandonment: The case of Mediterranean butterflies. *Biological Conservation*, 146, 14–23.

* Verovnik R., Fišer Z. & Zakšek V. (2015) How to reduce the impact of artificial lighting on moths: A case study on cultural heritage sites in Slovenia. *Journal for Nature Conservation*, 28, 105–111.

* Viljur M.L. & Teder T. (2018) Disperse or die: Colonisation of transient open habitats in production forests is only weakly dispersal-limited in butterflies. *Biological Conservation*, 218, 32–40.

* Vogel J.A., Debinski D.M., Koford R.R. & Miller J.R. (2007) Butterfly responses to prairie restoration through fire and grazing. *Biological Conservation*, 140, 78–90.

* Vogel J.A., Koford R.R. & Debinski D.M. (2010) Direct and indirect responses of tallgrass prairie butterflies to prescribed burning. *Journal of Insect Conservation*, 14, 663–677.

* Völkl W., Zwölfer H., Romstöck-Völkl M. & Schmelzer C. (1993) Habitat management in calcareous grasslands: effects on the insect community developing in flower heads of Cynarea. *Journal of Applied Ecology*, 30, 307–315.

Wagner D.L., Fox R., Salcido D.M. & Dyer L.A. (2021) A window to the world of global insect declines: Moth biodiversity trends are complex and heterogeneous. *Proceedings of the National Academy of Sciences*, 118(2): e2002549117.

* Wakefield A., Broyles M., Stone E.L., Harris S. & Jones G. (2018) Quantifying the attractiveness of broad-spectrum street lights to aerial nocturnal insects. *Journal of Applied Ecology*, 55, 714–722.

* WallisDeVries, M. (2004) A quantitative conservation approach for the endangered butterfly *Maculinea alcon*. *Conservation Biology*, 18, 489–499.

* Wallis De Vries M.F. & Ens S.H. (2010) Effects of habitat quality and isolation on the colonization of restored heathlands by butterflies. *Restoration Ecology*, 18(3), 390-398.

* WallisDeVries M.F. & Raemakers I. (2001) Does extensive grazing benefit butterflies in coastal dunes? *Restoration Ecology*, 9, 179–188.

* Walsh R.C. (1987) Habitat reclamation for endangered butterflies on San Bruno mountain (California). *Restoration & Management Notes*, 5, 38.

Walsh R.O. (2017) Microclimate and biotic interactions affect Karner blue butterfly occupancy and persistence in managed oak savanna habitats. *Journal of Insect Conservation*, 21, 219–230.

* Waltz A.E.M. & Covington W.W. (1999) Butterfly richness and abundance increase in restored ponderosa pine ecosystem (Arizona). *Ecological Restoration*, 17, 244–246.

* Waltz A.E.M. & Covington W.W. (2004) Ecological Restoration Treatments Increase Butterfly Richness and Abundance: Mechanisms of Response. *Restoration Ecology*, 12, 85–96.

* Warchola N., Crone E.E. & Schultz C.B. (2018) Balancing ecological costs and benefits of fire for population viability of disturbance-dependent butterflies. *Journal of Applied Ecology*, 55, 800–809.

Wardlaw J.C., Elmes G.W. & Thomas J.A. (1998) Techniques for studying *Maculinea* butterflies: I. Rearing *Maculinea* caterpillars with *Myrmica* ants in the laboratory. *Journal of Insect Conservation*, 2, 79–84.

* Waring P. (2004) Successes in conserving the Barberry Carpet moth *Pareulype berberata* (D. & S.) (Geometridae) in England. *Journal of Insect Conservation*, 8, 167–171.

* Warren M.S. (1987) The ecology and conservation of the heath fritillary butterfly, *Mellicta athalia*. III. Population dynamics and the effect of habitat management. *Journal of Applied Ecology*, 24, 499–513.

* Warren M.S. (1991) The successful conservation of an endangered species, the heath fritillary butterfly *Mellicta athalia*, in Britain. *Biological Conservation*, 55, 37–56.

* Warren M.S. (1993) A review of butterfly conservation in central southern Britain: I. Protection, evaluation and extinction on prime sites. *Biological Conservation*, 64, 25–35.

Warren M.S., Maes D., van Swaay C.A.M., Goffart P., Van Dyck H., Bourn N.A.D., Wynhoff I., Hoare D. & Ellis S. (2021) The decline of butterflies in Europe: problems, significance, and possible solutions. *Proceedings of the National Academy of Sciences*, 118(2): e2002551117.

* Watts C., Thornburrow D., Clarkson B. & Dean S. (2013) Distribution and abundance of a threatened stem-boring moth, *Houdinia flexilissima* (Lepidoptera: Batrachedridae) in New Zealand peat bogs. *Journal of Research on the Lepidoptera*, 46, 81–89.

Wepprich T., Adrion J.R., Ries L., Wiedmann J. & Haddad N.M. (2019) Butterfly abundance declines over 20 years of systematic monitoring in Ohio, USA. *PLoS ONE*, 14(7): e0216270.

* Wettstein W. & Schmid B. (1999) Conservation of arthropod diversity in montane wetlands: effect of altitude, habitat quality and habitat fragmentation on butterflies and grasshoppers. *Journal of Applied Ecology*, 36, 363–373.

Whitaker J.O. & Black H. Food habits of cave bats from Zambia, Africa. *Journal of Mammology*, 57, 199–204.

Williams D.R., Pople R.G., Showler D.A., Dicks L.V., Child M.F., zu Ermgassen E.K.H.J. & Sutherland W.J. (2012) Bird Conservation: Global evidence for the effects of interventions. Exeter, Pelagic Publishing.

* Willis S.G., Hill J.K., Thomas C.D., Roy D.B., Fox R., Blakeley D.S. & Huntley B. (2009) Assisted colonization in a changing climate: a test-study using two U.K. butterflies. *Conservation Letters*, 2, 46–52.

Willmer P. (2011) Pollination by Butterflies and Moths. Chapter 14 in Willmer P. (*ed*) *Pollination & Floral Ecology*. Princeton University Press, USA.

Wilson R.J., Gutiérrez D., Gutiérrez J., Martínez D., Agudo R. & Monserrat V.J. (2005) Changes to the elevational limits and extent of species ranges associated with climate change. *Ecology Letters*, 8 (11): 1138–1146.

Wilson R.J., Gutiérrez D., Gutiérrez J. & Monserrat V.J. (2007) An elevational shift in butterfly species richness and composition accompanying recent climate change. *Global Change Biology*, 13(9): 1873–1887.

Witek M., Ślipiński P., Trigos Peral G. & Csata E. (2016) Consequences of the arms race between *Maculinea teleius* social parasite and *Myrmica* host ants for myrmecophilous butterfly conservation. *Journal of Insect Conservation*, 20, 887–893.

* Witkowski Z., Adamski P., Kosior A. & Plonka P. (1997) Extinction and reintroduction of *Parnassius apollo* in the Pieniny National Park (Polish Carpathians). *Biologia*, 52(2), 199-208.

* Woodcock B., Ball S., Amy S., Edwards M., Redhead J., Mountford O., Gregory S., Duffield S., Macgregor N. & Pywell R. (2016) Evaluating the relative importance of site and landscape characteristics for invertebrate communities in grasslands restored through agri-environment schemes. *Natural England Report*, RP01878.

* Woodcock B.A., Bullock J.M., Mortimer S.R., Brereton T., Redhead J.W., Thomas J.A. & Pywell R.F. (2012) Identifying time lags in the restoration of grassland butterfly communities: A multi-site assessment. *Biological Conservation*, 155, 50–58.

* Woodcock B.A., Savage J., Bullock J.M., Nowakowski M., Orr R., Tallowin J.R.B. & Pywell R.F. (2014) Enhancing floral resources for pollinators in productive agricultural grasslands. *Biological Conservation*, 171, 44–51.

Wynhoff I. (1998) Lessons from the reintroduction of *Maculinea teleius* and *M. nausithous* in the Netherlands. *Journal of Insect Conservation*, 2, 47–57.

Wynhoff I., Kolvoort A.M., Bassignana C.F., Berg M.P. & van Langevelde F. (2017) Fen meadows on the move for the conservation of *Maculinea* (*Phengaris*) *teleius* butterflies. *Journal of Insect Conservation*, 21, 379–392.

Wynhoff I., van Gestel R., van Swaay C. & van Langevelde F. (2011) Not only the butterflies: managing ants on road verges to benefit *Phengaris* (*Maculinea*) butterflies. *Journal of Insect Conservation*, 15, 189–206.

* Yamamoto K. & Tuhara Y. (2004) The change of butterfly assemblages after artificial gap formation in an urban park. *Journal of The Japanese Institute of Landscape Architecture*, 68, 585–588.

* Yen S.-C., Pan Y.-C., Wang L.-H. (2018) The Effects of Agricultural Lands Management Strategies for Biodiversity Recovery in Taroko National Park. *Journal of National Park*, 28, 29–43.

* Young M.R. & Barbour D.A. (2004) Conserving the New Forest burnet moth (*Zygaena viciae* ([Denis and Schiffermueller])) in Scotland; responses to grazing reduction and consequent vegetation changes. *Journal of Insect Conservation*, 8, 137–148.

* Zhu H., Wang D., Guo Q., Liu J. & Wang L. (2015) Interactive effects of large herbivores and plant diversity on insect abundance in a meadow steppe in China. *Agriculture, Ecosystems & Environment*, 212, 245–252.

* Zielin S.B., Littlejohn J., de Rivera C.E., Smith W.P. & Jacobson S.L. (2016) Ecological investigations to select mitigation options to reduce vehicle-caused mortality of a threatened butterfly. *Journal of Insect Conservation*, 20, 845–854.

* Zingg S., Grenz J. & Humbert J.-Y. (2018) Landscape-scale effects of land use intensity on birds and butterflies. *Agriculture, Ecosystems & Environment*, 267, 119–128.

Appendix 1: English language journals searched

a) Specialist invertebrate journals (and years) for which new (7 journals) or updated (4 journals) searches were carried out by the authors

An asterisk (*) indicates updated searches. **Bold** indicates new journal searches for this synopsis.

	Journal	Years searched
1.	Acta Oecologica – International Journal of Ecology*	1990–2018
2.	Aquatic Ecosystem Health & Management*	1998–2018
3.	**Ecological Entomology**	1985–2018
4.	**Entomologia Experimentalis et Applicata**	2015–2018
5.	**Environmental Entomology**	1990–2018
6.	**Journal of Insect Science**	2003–2018
7.	**Knowledge and Management of Aquatic Ecosystems** (previously Bulletin Français de la Pêche et de la Pisciculture)	1986–2018
8.	**Limnologica – Ecology and Management of Inland Waters**	1999–2018
9.	Neotropical Entomology*	2001–2018
10.	Revista de Biologia Tropical*	1976–2018
11.	**Riparian Ecology and Conservation**	2013–2017

b) All other journals (and years) searched for the discipline-wide Conservation Evidence database (290 journals)

An asterisk (*) indicates the journals most relevant to this synopsis.

Journal	Years searched	Topic
Acrocephalus	2009–2018	All biodiversity
Acta Chiropterologica	1999–2018	All biodiversity
Acta Herpetologica	2006–2018	All biodiversity
Acta Theriologica Sinica	2000–2018	All biodiversity
African Bird Club Bulletin	2010–2016	All biodiversity
African Journal of Ecology	1963–2016	All biodiversity
African Journal of Herpetology [formerly The Journal of the Herpetological Association of Africa]	1990–2018	All biodiversity
African Journal of Marine Science	1983–2018	All biodiversity
African Primates	1995–2012	Primate conservation
African Zoology	1979–2013	All biodiversity
Agriculture, Ecosystems and Environment*	1983–2017	All biodiversity
Agroforestry Systems	1982–2007	All biodiversity
Ambio	1972–2011	All biodiversity
American Journal of Primatology	1981–2014	Primate conservation
American Naturalist	1867–2018	All biodiversity
Amphibia-Reptilia	1980–2018	All biodiversity
Amphibian and Reptile Conservation	1996–2018	All biodiversity

Animal Biology	2003–2013	All biodiversity
Animal Conservation	1998–2018	All biodiversity
Animal Welfare	1992–2016	Primate and amphibian conservation
Annales Zoologici Fennici	1964–2013	All biodiversity
Annales Zoologici Societatis Zoologicae Botanicae Fennicae Vanamo	1932–1963	All biodiversity
Annual Review of Ecology, Evolution, and Systematics [formerly Annual Review of Ecology and Systematics 1970-2002]	1970–2018	All biodiversity
Antarctic Science	1980–2018	All biodiversity
Anthrozoos	1987–2013	All biodiversity
Apidologie	1958–2009	All biodiversity
Applied Animal Behaviour Science	1988–2014	All biodiversity
Applied Herpetology	2003–2009	Amphibian and reptile conservation
Applied Vegetation Science	1998–2017	All biodiversity
Aquaculture Research	1972–2008	All biodiversity
Aquatic Biology	2007–2018	All biodiversity
Aquatic Botany	1975–2017	All biodiversity
Aquatic Conservation: Marine and Freshwater Ecosystems	1991–2018	All biodiversity
Aquatic Ecology	1968–2018	All biodiversity
Aquatic Invasions	2006–2016	All biodiversity
Aquatic Living Resources (Ressources Vivantes Aquatiques)	1988–2018	All biodiversity
Aquatic Mammals	1972–2018	All biodiversity
Ardeola	1996–2018	All biodiversity
Arid Land Research and Management [formerly Arid Soil Research and Rehabilitation 1987-2000]	1987–2013	All biodiversity
Asian Herpetological Research	2010–2018	All biodiversity
Asiatic Herpetological Research	1993–2008	All biodiversity
Asian Primates	2008–2012	Primate conservation
Auk	1980–2016	Bird conservation
Austral Ecology	1977–2018	All biodiversity
Australasian Journal of Herpetology	2009–2012	Amphibian and reptile conservation
Australian Mammalogy	2000–2018	All biodiversity
Avian Conservation and Ecology	2005–2016	Bird conservation
Basic and Applied Ecology	2000–2018	All biodiversity
Basic and Applied Herpetology	2011–2018	All biodiversity
Behavioral Ecology	1990-2013	All biodiversity
Behaviour	1948-2013	All biodiversity
Bibliotheca Herpetologica	1999–2017	All biodiversity
Biocontrol [formerly Entomophaga until 1998]	1956–2016	All biodiversity

Biocontrol Science and Technology	1991–2016	All biodiversity
Biodiversity and Conservation*	1994–2018	All biodiversity
Biological Conservation*	1981–2018	All biodiversity
Biological Control	1991–2017	All biodiversity
Biological Invasions	1999–2017	All biodiversity
Biology and Environment: Proceedings of the Royal Irish Academy	1993–2017	All biodiversity
Biology Letters	2005–2018	All biodiversity
Biotropica	1990–2018	All biodiversity
Bird Conservation International	1991–2016	Bird conservation
Bird Study	1980–2016	Bird conservation
Boreal Environment Research	1996–2014	All biodiversity
Bulletin of the Herpetological Society of Japan	1999–2008	Amphibian and reptile conservation
Canadian Journal of Fisheries and Aquatic Sciences	1901–2018	All biodiversity
Canadian Journal of Forest Research	1971–2018	All biodiversity
Caribbean Journal of Science	1961–2013	All biodiversity
CCAMLR Science	1985–2016	All biodiversity
Chelonian Conservation and Biology	2006–2016	Amphibian and reptile conservation
Chelonian Research Monographs	1996–2017	All biodiversity
Coastal Engineering	2000–2018	All biodiversity
Collinsorum [formerly Journal of Kansas Herpetology]	2002–2018	All biodiversity
Community Ecology	2000–2012	All biodiversity
Conservation Biology*	1987–2018	All biodiversity
Conservation Evidence*	2004–2018	All biodiversity
Conservation Genetics	2000–2013	All biodiversity
Conservation Letters*	2008–2018	All biodiversity
Contemporary Herpetology	1998–2009	Amphibian and reptile conservation
Contributions to Primatology	1974–1991	Primate conservation
Copeia	1910–2018	All biodiversity
Cunninghamia	1981–2016	All biodiversity
Current Herpetology [formerly Acta Herpetologica Japonica 1964-1971, Japanese Journal of Herpetology 1972–1999]	1964–2018	All biodiversity
Dodo	1977–2001	All biodiversity
Ecological and Environmental Anthropology	2005–2008	Primate conservation
Ecological Applications*	1991–2018	All biodiversity
Ecological Indicators	2001–2007	All biodiversity
Ecological Management and Restoration	2000–2018	All biodiversity
Ecological Restoration*	1981–2018	All biodiversity
Ecology*	1936–2018	All biodiversity
Ecology Letters	1998–2013	All biodiversity

Écoscience	1994–2013	All biodiversity
Ecosystems	1998–2013	All biodiversity
Emu	1980–2016	Bird conservation
Endangered Species Bulletin	1976–2003	Amphibian conservation
Endangered Species Research	2004–2017	All biodiversity
Environmental Conservation*	1974–2018	All biodiversity
Environmental Evidence*	2012–2018	All biodiversity
Environmental Management*	1977–2018	All biodiversity
Environmentalist	1981–1988	All biodiversity
Estuaries and Coasts	2013–2017	All biodiversity
Ethology Ecology & Evolution	1989–2014	All biodiversity
European Journal of Soil Science	1950–2012	Soil fertility
European Journal of Wildlife Research [formerly Zeitschrift für Jagdwissenschaft 1955-2003]	1955–2018	All biodiversity
Evolutionary Anthropology	1992–2014	Primate conservation
Evolutionary Ecology	1987–2014	All biodiversity
Evolutionary Ecology Research	1999–2014	All biodiversity
Fire Ecology	2005–2016	All biodiversity
Fish and Fisheries	2000–2018	All biodiversity
Fisheries	2017–2018	All biodiversity
Fisheries Management and Ecology	1994–2018	All biodiversity
Fisheries Oceanography	1992–2018	All biodiversity
Fisheries Research	1990–2018	All biodiversity
Flora	1991–2017	All biodiversity
Folia Primatologica	1963–2014	Primate conservation
Folia Zoologica	1959–2013	All biodiversity
Forest Ecology and Management	1976–2018	All biodiversity
Freshwater Biology	1975–2017	All biodiversity
Freshwater Science [formerly Freshwater Invertebrate Biology 1982-1985, Journal of the North American Benthological Society 1986-2011]	1982–2018	All biodiversity
Frontiers in Marine Science	2017–2018	All biodiversity
Functional Ecology	1987–2013	All biodiversity
Genetics and Molecular Research	2002–2013	All biodiversity
Geoderma	1967–2012	Soil fertility
Gibbon Journal	2005–2011	Primate conservation
Global Change Biology	1995–2017	All biodiversity
Global Ecology and Biogeography	1991–2014	All biodiversity
Global Ecology and Conservation	2014–2018	All biodiversity
Grass and Forage Science	1980–2017	All biodiversity
Herpetofauna	2003–2007	Amphibian and reptile conservation
Herpetologica	1936–2018	All biodiversity

Herpetological Bulletin	1980–2016	Amphibian and reptile conservation
Herpetological Conservation and Biology	2006–2018	All biodiversity
Herpetological Journal	1985–2014	Amphibian and reptile conservation
Herpetological Monographs	1982–2018	All biodiversity
Herpetological Review	1967–2018	All biodiversity
Herpetology Notes	2008–2018	All biodiversity
Herpetozoa	1988–2018	All biodiversity
Human Wildlife Interactions [formerly Human Wildlife Conflicts]	2007–2017	All biodiversity
Hydrobiologia	2000–2018	All biodiversity
Hystrix, the Italian Journal of Mammalogy	1986–2018	All biodiversity
Ibis	1980–2016	Bird conservation
ICES Journal of Marine Science	1990–2018	All biodiversity
iForest	2008–2016	All biodiversity
Insect Conservation and Diversity*	2008–2018	All biodiversity
Integrative Zoology	2006–2013	All biodiversity
International Journal of Pest Management [formerly PANS Pest Articles & News Summaries 1969-1975, PANS 1976-1979 & Tropical Pest Management 1980-1992]	1969–1979	All biodiversity
International Journal of Primatology	1980–2012	All biodiversity
International Journal of the Commons	2007–2016	All biodiversity
International Journal of Wildland Fire	1991–2016	All biodiversity
International Wader Studies	1970–1972	All biodiversity
International Zoo Yearbook	1960–2015	Management of captive animals
Invasive Plant Science and Management	2008–2016	All biodiversity
Israel Journal of Ecology & Evolution	1963–2013	All biodiversity
Italian Journal of Zoology	1978–2013	All biodiversity
Journal for Nature Conservation	2002–2018	All biodiversity
Journal of Animal Ecology*	1932–2018	All biodiversity
Journal of Apicultural Research	1962–2009	All biodiversity
Journal of Applied Ecology*	1964–2018	All biodiversity
Journal of Aquatic Plant Management [formerly Hyacinth Control Journal]	1962–2016	All biodiversity
Journal of Arid Environments	1993–2017	All biodiversity
Journal of Avian Biology [formerly Ornis Scandinavica 1970-1993]	1980–2016	Bird conservation
Journal of Bat Conservation & Research	2000–2018	All biodiversity
Journal of Cetacean Research and Management	1999–2018	All biodiversity
Journal of Coastal Research	2015–2018	All biodiversity
Journal of Ecology	1933–2018	All biodiversity
Journal of Environmental Management	1973–2018	All biodiversity

Journal of Experimental Marine Biology & Ecology	2000–2012	All biodiversity
Journal of Field Ornithology	1980–2016	Bird conservation
Journal of Forest Research	1996–2018	All biodiversity
Journal of Great Lakes Research	1975–2017	All biodiversity
Journal of Herpetological Medicine and Surgery	2009–2016	Amphibian and reptile conservation
Journal of Herpetology	1968–2016	Amphibian and reptile conservation
Journal of Insect Conservation*	1997–2018	All biodiversity
Journal of Mammalian Evolution	1993–2014	All biodiversity
Journal of Mammalogy	1919–2018	All biodiversity
Journal of Mountain Science	2004–2016	All biodiversity
Journal of Negative Results: Ecology and Evolutionary Biology	2004–2016	All biodiversity
Journal of North American Herpetology	2014–2017	All biodiversity
Journal of Ornithology	2004–2018	All biodiversity
Journal of Primatology	2012–2013	Primate conservation
Journal of Raptor Research	1966–2016	Bird conservation
Journal of Sea Research [formerly Netherlands Journal of Sea Research]	1961–2018	All biodiversity
Journal of the Marine Biological Association of the United Kingdom	1887–2018	All biodiversity
Journal of Threatened Taxa	2009–2013	Plant conservation
Journal of Tropical Ecology	1986–2018	All biodiversity
Journal of Vegetation Science	1990–2017	All biodiversity
Journal of Wetlands Ecology	2008–2012	All biodiversity
Journal of Wetlands Environmental Management	2012–2016	All biodiversity
Journal of Wildlife Diseases	1965–2012	All biodiversity
Journal of Wildlife Management	1945–2018	All biodiversity
Journal of Zoology*	1966–2018	All biodiversity
Jurnal Primatologi Indonesia	2009	Primate conservation
Kansas Herpetological Society Newsletter	1974–2001	All biodiversity
Lake and Reservoir Management	1984–2016	All biodiversity
Land Degradation and Development	1989–2016	All biodiversity
Land Use Policy	1984–2012	Soil fertility
Latin American Journal of Aquatic Mammals	2002–2018	All biodiversity
Lemur News	1993–2012	Primate conservation
Mammal Research [formerly Acta Theriologica until 2000]	1977–2018	All biodiversity
Mammal Review	1970–2018	All biodiversity
Mammal Study	2005–2018	All biodiversity
Mammalia	1937–2018	All biodiversity
Mammalian Biology	2002–2018	All biodiversity
Mammalian Genome	1991–2013	All biodiversity

Management of Biological Invasions	2010–2016	All biodiversity
Mangroves and Saltmarshes	1996–1999	All biodiversity
Marine and Freshwater Research	1980–2018	All biodiversity
Marine Ecology	1980–2018	All biodiversity
Marine Ecology Progress Series	2000–2018	All biodiversity
Marine Environmental Research	1978–2018	All biodiversity
Marine Mammal Science	1985–2018	All biodiversity
Marine Pollution Bulletin	2010–2018	All biodiversity
Marine Turtle Newsletter	1976–2018	All biodiversity
Mires and Peat	2006–2016	All biodiversity
Natural Areas Journal	1992–2017	All biodiversity
Nature Conservation	2012–2018	All biodiversity
NeoBiota	2011–2017	All biodiversity
Neotropical Primates	1993–2014	Primate conservation
New Journal of Botany	2011–2013	Plant conservation
New Zealand Journal of Marine and Freshwater Research	1980–2018	All biodiversity
New Zealand Journal of Zoology	1974–2018	All biodiversity
New Zealand Plant Protection	2000–2016	All biodiversity
Northwest Science	2007–2016	All biodiversity
Oecologia*	1969–2018	All biodiversity
Oikos*	1949–2018	All biodiversity
Ornitologia Neotropical	1990–2018	All biodiversity
Oryx*	1950–2018	All biodiversity
Ostrich	1980–2016	Bird conservation
Pacific Conservation Biology	1993–2018	All biodiversity
Pakistan Journal of Zoology	2004–2013	All biodiversity
Phyllomedusa	2002–2018	All biodiversity
Plant Ecology	1948–2007	All biodiversity
Plant Protection Quarterly	2008–2016	All biodiversity
PLOS	2006–2013	All biodiversity
Polish Journal of Ecology	2002–2013	All biodiversity
Population Ecology	1952–2013	All biodiversity
Preslia	1973–2017	All biodiversity
Primate Conservation	1981–2014	Primate conservation
Primates	1957–2013	All biodiversity
Rangeland Ecology & Management [formerly Journal of Range Management 1948-2004]	1948-2016	All biodiversity
Raptors Conservation	2005–2016	All biodiversity
Regional Studies in Marine Science	2015–2018	All biodiversity
Restoration Ecology*	1993–2018	All biodiversity
Revista Chilena de Historia Natural (RCHN)	2000–2016	All biodiversity
River Research and Applications	1987–2016	All biodiversity
Russian Journal of Ecology	1993–2013	All biodiversity
Russian Journal of Herpetology	1994–2016	Amphibian and reptile conservation

Salamandra	1980–2018	All biodiversity
Slovak Raptor Journal	2007–2016	All biodiversity
Small Ruminant Research	1988–2017	All biodiversity
Soil Biology and Biochemistry	1969–2012	Soil fertility
Soil Use and Management	1985–2012	Soil fertility
South African Journal of Botany	1982–2016	All biodiversity
South African Journal of Wildlife Research	1971–2014	All biodiversity
South American Journal of Herpetology	2006–2018	All biodiversity
Southern Forests	2008–2013	All biodiversity
Systematic Reviews Centre for Evidence-Based Conservation	2004–2017	All biodiversity
Testudo	1978–2017	All biodiversity
The Canadian Field-Naturalist [formerly Ottawa Naturalist]	1987–2018	All biodiversity
The Condor	1980–2016	Bird conservation
The Open Ornithology Journal	2008–2016	All biodiversity
The Rangeland Journal	1976–2016	All biodiversity
The Southwestern Naturalist	1956–2018	All biodiversity
The Wilson Journal of Ornithology [formerly The Wilson Bulletin]	1980–2016	Bird conservation
Trends in Ecology and Evolution*	1986–2017	All biodiversity
Tropical Conservation Science	2008–2018	All biodiversity
Tropical Ecology	1960–2018	All biodiversity
Tropical Grasslands	1967–2010	All biodiversity
Tropical Zoology	1988–2018	All biodiversity
Turkish Journal of Zoology	1996–2014	All biodiversity
Vietnamese Journal of Primatology	2007–2009	Primate conservation
Wader Study Group Bulletin	1970–1977	All biodiversity
Waterbirds [formerly Colonial Waterbirds]	1983–2016	Bird conservation
Weed Biology and Management	2001–2016	All biodiversity
Weed Research	1961–2017	All biodiversity
West African Journal of Applied Ecology	2000–2016	All biodiversity
Western North American Naturalist	2000–2016	All biodiversity
Wetlands	1981–2016	All biodiversity
Wetlands Ecology and Management	1989–2016	All biodiversity
Wildfowl	1948–2018	All biodiversity
Wildlife Biology	1995–2013	All biodiversity
Wildlife Monographs	1958–2013	All biodiversity
Wildlife Research	1974–2018	All biodiversity
Wildlife Society Bulletin	1973–2018	All biodiversity
Zhurnal Obshchei Biologii	1972–2013	All biodiversity
Zoo Biology	1982–2016	All biodiversity
Zookeys	2008–2013	All biodiversity
Zoologica Scripta	1971–2014	All biodiversity
Zoological Journal of the Linnean Society	1856–2013	All biodiversity
Zootaxa	2004–2014	All biodiversity

Appendix 2: Non-English language journals searched

Non-English language journals (and years) searched for the discipline-wide Conservation Evidence database (316 journals in 16 languages).

Journal title	Years searched	Topic	Language
مجلة بغداد للعلوم Baghdad Science Journal	2004–2018	All biodiversity	Arabic
مجلة جامعة الملك عبد العزيز: علوم تصاميم البيئة Journal of King Abdulaziz University: Environmental Design Science	2003–2017	All biodiversity	Arabic
مجلة جامعة الملك عبدالعزيز: الاقتصاد والإدارة Journal of King Abdulaziz University: Economics and Administration	2015–2018	All biodiversity	Arabic
المجلة العربية للبيئات الجافة The Arab Journal for Arid Environments	2009–2018	All biodiversity	Arabic
مجلة علوم البحار والتقنيات البيئية Journal of Marine Sciences and Environmental Techniques	2016–2018	All biodiversity	Arabic
مجلة وقاية النبات العربية Journal of Plant Protection	1993–2018	All biodiversity	Arabic
مجلة آفاق علمية Afak Ilmia Journal	2017–2018	All biodiversity	Arabic
مجلة علوم ذي قار Journal of Thi-Qar Science	2014–2018	All biodiversity	Arabic
مجلة جامعة تشرين للبحوث والدراسات العلمية _ سلسلة العلوم البيولوجية Tishreen University Journal for Research and Scientific Studies: Biological Sciences Series	2001–2018	All biodiversity	Arabic
مجلة جامعة الملك عبدالعزيز: علوم البحار Journal of King Abdulaziz University: Marine Sciences	2000–2018	All biodiversity	Arabic
مجلة العلوم الزراعية والبيئية والبيطرية Journal of Agricultural, Environmental and Veterinary Sciences	2018	All biodiversity	Arabic
西北植物学报 Acta Botanica Boreali-Occidentalia Sinica	2012–2016	All biodiversity	Chinese (simplified)
植物研究 Bulletin of Botanical Research	1959–2017	All biodiversity	Chinese (simplified)
植物分类与资源学报杂志 Plant Diversity and Resources	1975–2017	All biodiversity	Chinese (simplified)
林业科学 Scientia Silvae Sinicae	1955–2017	All biodiversity	Chinese (simplified)

植物保护学报 Acta Phytophylacica Sinica	1962–1966, 1979–2017	All biodiversity	Chinese (simplified)
生态毒理学报 Asian Journal of Ecotoxicology	2006–2017	All biodiversity	Chinese (simplified)
中国微生态学杂志 Chinese Journal of Microecology	1989–2017	All biodiversity	Chinese (simplified)
中国生物防治学报 Chinese Journal of Biological Control	1985–2017	All biodiversity	Chinese (simplified)
水土保持通报 Bulletin of Soil and Water Conservation	1981–2017	All biodiversity	Chinese (simplified)
水土保持学报 Journal of Soil and Water Conservation	1987–2017	All biodiversity	Chinese (simplified)
草业学报 Acta Prataculturae Sinica	2008–2017	All biodiversity	Chinese (simplified)
草业科学 Pratacultural Science	1984–2017	All biodiversity	Chinese (simplified)
土壤学报 Acta Pedologica Sinica	1948–2017	All biodiversity	Chinese (simplified)
土壤 Soils	1958–2017	All biodiversity	Chinese (simplified)
长江流域资源与环境 Resources and Environment in the Yangtze Basin	1992–2017	All biodiversity	Chinese (simplified)
湖泊科学 Journal of Lake Sciences	1989–2017	All biodiversity	Chinese (simplified)
草地学报 Acta Agrestia Sinica	1989–2017	All biodiversity	Chinese (simplified)
山地学报 Journal of Mountain Science	1983–2017	All biodiversity	Chinese (simplified)
湿地科学 Wetland Science	2003–2017	All biodiversity	Chinese (simplified)
中国沙漠 Journal of Desert Research	1981–2017	All biodiversity	Chinese (simplified)
干旱区资源与环境 Journal of Arid Land Resources and Environment	1987–2017	All biodiversity	Chinese (simplified)
世界林业研究 World Forestry Research	1988–2017	All biodiversity	Chinese (simplified)
上海环境科学 Shanghai Environmental Science	1982–2017	All biodiversity	Chinese (simplified)

自然资源学报 Journal of Natural Resources	1986–2016	All biodiversity	Chinese (simplified)
生态学杂志 Chinese Journal of Ecology	1982–2016	All biodiversity	Chinese (simplified)
四川动物 Sichuan Journal of Zoology	1996–2016	All biodiversity	Chinese (simplified)
生物多样性 Biodiversity Science	1993–2016	All biodiversity	Chinese (simplified)
兽类学报 Acta Theriologica Sinica	1981–2016	All biodiversity	Chinese (simplified)
动物学杂志 Chinese Journal of Zoology	1957–2016	All biodiversity	Chinese (simplified)
动物学研究 Zoological Research	1980–2016	All biodiversity	Chinese (simplified)
水生生物学报 Acta Hydrobiologica Sinica	1997–2017	All biodiversity	Chinese (simplified)
资源科学 Resources Science	1977–2016	All biodiversity	Chinese (simplified)
植物学报 Chinese Bulletin of Botany	2006–2016	All biodiversity	Chinese (simplified)
热带亚热带植物学报 Journal of Tropical and Subtropical Botany	1992–2016	All biodiversity	Chinese (simplified)
植物生态学报 Chinese Journal of Plant Ecology [2005-present; formerly Acta Phytoecologica Sinica 1994-2004, Acta Phytoecologica et Geobotanica Sinica 1981-1993, Journal of Plant Ecology pre-1981]	1963–2016	All biodiversity	Chinese (simplified)
植物资源与环境学报 Journal of Plant Resources and Environment	1992–2016	All biodiversity	Chinese (simplified)
中国草地学报 Chinese Journal of Grassland [2008-present; formerly Grassland of China]	1979–2016	All biodiversity	Chinese (simplified)
植物保护 Plant Protection	1963–2016	All biodiversity	Chinese (simplified)
生态学报 Acta Ecologica Sinica	1981–2016	All biodiversity	Chinese (simplified)
应用生态学报 Chinese Journal of Applied Ecology	1990–2016	All biodiversity	Chinese (simplified)

生物学杂志 Journal of Biology	1983–2016	All biodiversity	Chinese (simplified)
水产学报 Journal of Fisheries of China	1965–2017	All biodiversity	Chinese (simplified)
野生动物学报 Chinese Journal of Wildlife	1979–2016	All biodiversity	Chinese (simplified)
动物分类学报 Zoological Systematics	1964–2017	All biodiversity	Chinese (simplified)
生态环境学报 Ecology and Environmental Sciences [2009-present; formerly Ecology and Environment 2002-2008, Soil and Environment pre-2002]	1992–2016	All biodiversity	Chinese (simplified)
动物学报 Current Zoology	1935–2008	All biodiversity	Chinese (simplified)
海洋科学 Marine Sciences	1977–2017	All biodiversity	Chinese (simplified)
水生态学杂志 Journal of Hydroecology [formerly Reservoir Fisheries]	1981–2017	All biodiversity	Chinese (simplified)
生态科学 Ecological Science	1982–2016	All biodiversity	Chinese (simplified)
生命科学 Chinese Bulletin of Life Science	1988–2017	All biodiversity	Chinese (simplified)
生命科学研究 Life Science Research	1997–2016	All biodiversity	Chinese (simplified)
中国农业大学学报 Journal of China Agricultural University	1955–2017	All biodiversity	Chinese (simplified)
中国生态农业学报 Chinese Journal of Eco-Agriculture	1993–2017	All biodiversity	Chinese (simplified)
生态与农村环境学报 Journal of Ecology and Rural Environment [2006-present; formerly Rural Eco-Environnment]	1985–2017	All biodiversity	Chinese (simplified)
农业环境科学学报 Journal of Agro-Environment Science	1981–2017	All biodiversity	Chinese (simplified)
环境科学 Environmental Science	1976–2017	All biodiversity	Chinese (simplified)
中国环境科学 China Environmental Science	1981–2017	All biodiversity	Chinese (simplified)

应用与环境生物学报 Chinese Journal of Applied and Environmental Biology	1995–2017	All biodiversity	Chinese (simplified)
城市环境与城市生态 Urban Environment & Urban Ecology	1988–2016	All biodiversity	Chinese (simplified)
海洋环境科学 Marine Environmental Science	1982–2017	All biodiversity	Chinese (simplified)
海洋科学进展 Advances in Marine Science	1983–2017	All biodiversity	Chinese (simplified)
國家公園學報 Journal of National Park (Taiwan)	1989–2018	All biodiversity	Chinese (traditional)
台灣生物多樣性研究 Taiwan Journal of Biodiversity	1989–2018	All biodiversity	Chinese (traditional)
中華林學季刊 Quarterly Journal of Chinese Forestry (Taiwan)	2004–2018	All biodiversity	Chinese (traditional)
臺灣林業科學 Taiwan Journal of Forest Science	1986–2018	All biodiversity	Chinese (traditional)
生物科學 Chinese Bioscience (Taiwan)	2003–2014	All biodiversity	Chinese (traditional)
臺灣大學生物資源暨農學院實驗林研究報告 Journal of the Experimental Forest of National Taiwan University	2003–2018	All biodiversity	Chinese (traditional)
Fungal Science	1995–2018	All biodiversity	Chinese (traditional)
生物學報 Bio Formosa (Taiwan)	1966–2014	All biodiversity	Chinese (traditional)
農林學報 Journal of Agriculture and Forestry (Taiwan)	2000–2018	All biodiversity	Chinese (traditional)
環境與生態學報 Journal of Ecology and Environmental Sciences (Taiwan)	2008–2012	All biodiversity	Chinese (traditional)
台灣猛禽研究 Raptor Research of Taiwan	2003–2016	All biodiversity	Chinese (traditional)
動物園學報 Taipei Zoo Bulletin	1989–2013	All biodiversity	Chinese (traditional)
野生動物保育彙報及通訊 Notes and Newsletter of Wildlifers (Taiwan)	2005–2012	All biodiversity	Chinese (traditional)
國立臺灣博物館學刊 Journal of the National Taiwan Museum	2005–2018	All biodiversity	Chinese (traditional)
Revue d'Écologie (La Terre et La Vie) Earth and Life	2006–2018	All biodiversity	French

Ecologia Mediterranea: International Journal of Mediterranean Ecology	2000–2018	All biodiversity	French
VertigO	2009–2018	All biodiversity	French
Écoscience Ecological science	2017–2018	All biodiversity	French
Naturae	2017–2018	All biodiversity	French
Alauda	2000–2005	All biodiversity	French
Courrier Scientifique du Parc Naturel Régional du Luberon et de la Réserve de Biosphère Luberon-Lure Scientific Letters from the regional natural Park of Luberon et and the biosphere Reserve Luberon-Lure	1997–2016	All biodiversity	French
Le Naturaliste Canadien The Canadian Naturalist	2008–2018	All biodiversity	French
Travaux Scientifiques du Parc National de la Vanoise Scientific reports of the Vanoise National Park	1986–2009	All biodiversity	French
Bois et Forêts des Tropiques Tropical Woodlands and Forests	2009–2018	All biodiversity	French
Bulletin de la Société Zoologique de France Bulletin of the French Zoology Society	1973–2015	All biodiversity	French
Travaux Scientifiques du Parc National de Port-Cros Scientific reports of the Port-Cros National Park	2000–2018	All biodiversity	French
Biotechnologie, Agronomie, Société et Environnement Biotechnology, Agronomy, Society and Environment	2008–2018	All biodiversity	French
Naturschutz und Landschaftsplanung Conservation and Landscape Planning	2003–2017	All biodiversity	German
Fachzeitschrift für Waldökologie, Landschaftsforschung und Naturschutz Journal for Forest Ecology, Landscape Research and Nature Conservation	2004–2016	All biodiversity	German
Vogelwarte: Zeitschrift für Vogelkunde Bird Observatory: Ornithology Journal	2005–2017	All biodiversity	German
Nyctalus: Internationale Fledermaus-Fachzeitschrift Nyctalus: International Bat Journal	2005–2017	All biodiversity	German
Zeitschrift für Feldherpetologie Journal of Field Herpetology	1994–2017	All biodiversity	German

Tuexenia	1981–2016	All biodiversity	German and English
Freiberg Online Geoscience	1998–2017	All biodiversity	German and English
Allgemeine Forst- und Jagdzeitung Journal for Forestry and Forest Science	2000–2016	All biodiversity	German
Forstarchiv Forestry Archive	2007–2017	All biodiversity	German
Zeitschrift für Jagdwissenschaft Journal of Hunting Science [became European Journal of Wildlife Research in 2004]	1955–2005	All biodiversity	German
Journal für Ornithologie Journal of Ornithology [English only from 2004]	1959–2004	All biodiversity	German
Die Erde The Earth	1952–2004	All biodiversity	German
Pulsatilla: Zeitschrift für Botanik und Naturschutz Pulsatilla: Journal of Botany and Nature Conservation	2000–2007	All biodiversity	German
Insecta	1992–2014	All biodiversity	German
Biodiversität und Naturschutz in Ostösterreich Biodiversity and Conservation Biology in Eastern Austria	2015–2018	All biodiversity	German
ANLiegen Natur: Zeitschrift für Naturschutz und Angewandte Landschaftsökologie Concerning Nature: Journal for Nature Conservation and Applied Landscape Ecology	2006–2017	All biodiversity	German
ABU Info (Arbeitsgemeinschaft Biologischer Umweltschutz im Kreis Soest e.V.) ABU Info (Working Group for Biological Environmental Protection in Soest District)	2006–2017	All biodiversity	German
Auenmagazin (Magazin des Auenzentrums Neuburg a. d. Donau) Floodplains Journal (Magazine of the Auenzentrums Neuburg a. d. Danube)	2010–2017	All biodiversity	German
Botanik und Naturschutz in Hessen Botany and Nature Conservation in Hessen	1987–2018	All biodiversity	German
Inatura Forschung Online Inatura Research Online	1996–2007	All biodiversity	German
RANA - Mitteilungen für Feldherpetologie und Ichthyofaunistik RANA - Communications for Field herpetology and Ichthyofauna	1983–2016	All biodiversity	German

Silva Fera: Wissenschaftliche Nachrichten aus dem Wildnisgebiet Dürrenstein Silva Fera: Scientific News from the Dürrenstein Wilderness Area	2012–2017	All biodiversity	German
Archiv für Forstwesen und Landschaftsökologie Archive for Forestry and Landscape Ecology	2013	All biodiversity	German
Die Bodenkultur: Journal for Land Management, Food und Environment Soil Culture: Journal for Land Management, Food and Environment	2016–2017	All biodiversity	German and English
Ornithologischer Anzeiger Ornithological Journal	1951–2017	All biodiversity	German
Arachnologische Mitteilungen Arachnological Communications	1991–2017	All biodiversity	German and English
Gesunde Pflanzen: Pflanzenschutz, Verbraucherschutz, Umweltschutz Healthy Plants: Crop Protection, Consumer Protection, Environmental Protection	2002–2017	All biodiversity	German and English
Der Zoologische Garten: Zeitschrift für die Gesamte Tiergärtnerei (Neue Folge) The Zoological Garden: Journal for the Entire Zoo	2007–2017	All biodiversity	German
Hercynia	1963–2017	All biodiversity	German
Der Ornithologische Beobachter Ornithological Observer	1950–2017	All biodiversity	German
Bulletin de la Société des Naturalistes Luxembourgeois Bulletin of the Luxemburgian Naturalist Society	1950–2017	All biodiversity	German and French
Mitteilungen des Badischen Landesvereins für Naturkunde und Naturschutz Communications of the Baden Association for Natural History and Nature Conservation	1953–2015	All biodiversity	German
Die Orchidee The Orchid	1949–2016	All biodiversity	German
Natur und Landschaft: Zeitschrift fur Naturschutz und Landschaftspflege Nature and Landscape: Journal for Nature Conservation and Landscape Management	2010–2017	All biodiversity	German
Libellula	1982–2016	All biodiversity	German
Die Vogelwelt: Beiträge zur Vogelkunde Bird Life: Contributions to Ornithology	2005–2017	All biodiversity	German
Salamandra	1965–2018	All biodiversity	German

Mertensiella	1988–2017	All biodiversity	German
Telma	1971–2018	All biodiversity	German
Állattani Közlemények Journal of Zoology	2010–2018	All biodiversity	Hungarian
Botanikai Közlemények Journal of Botany	2010–2018	All biodiversity	Hungarian
Tájökológiai Lapok Journal of Landscape Ecology	2010–2018	All biodiversity	Hungarian
Természetvédelmi Közlemények Journal of Nature Conservation	2010–2018	All biodiversity	Hungarian
Rivista Italiana di Ornitologia Research in Ornithology	2010–2018	All biodiversity	Italian
Picus	2004–2018	All biodiversity	Italian
Hystrix: Italian Journal of Mammalogy	1986–1993	All biodiversity	Italian
Avocetta	2000–2013	All biodiversity	Italian
Alula	1992–2018	All biodiversity	Italian
Biologia Ambientale Environmental Biology	1994–2018	All biodiversity	Italian
Forest @ Rivista di Selvicoltura ed Ecologia Forestale Forest @ Journal of Silviculture and Forest Ecology	2004–2018	All biodiversity	Italian
保全生態学研究 Japanese Journal of Conservation Ecology	1996–2016	All biodiversity	Japanese
日本生態学会誌 Japanese Journal of Ecology	1954–2017	All biodiversity	Japanese
爬虫両棲類学会報 Bulletin of the Herpetological Society of Japan	1999–2008	All biodiversity	Japanese
哺乳類科学 Mammalian Science	1961–2016	All biodiversity	Japanese
哺乳動物学雑誌 Journal of the Mammalogical Society of Japan	1959–1986	All biodiversity	Japanese
動物学雑誌 Doubutsugaku zasshi	1888–1983	All biodiversity	Japanese
日本鳥学会誌 Japanese Journal of Ornithology	1917–2015	All biodiversity	Japanese

ストリクス Strix	1982–2017	All biodiversity	Japanese
応用生態工学 Ecology and Civil Engineering	1998–2017	All biodiversity	Japanese
景観生態学 Landscape Ecology and Management	2005–2016	All biodiversity	Japanese
国際景観生態学会日本支部会報 Bulletin of the International Association for Landscape Ecology-Japan	2002–2003	All biodiversity	Japanese
野生生物保護 Wildlife Conservation Japan	1995–2013	All biodiversity	Japanese
野生生物と社会 Wildlife and Human Society	2013–2017	All biodiversity	Japanese
造園学雑誌 The Journal of the Japanese Landscape Architectural Society	1925–1927	All biodiversity	Japanese
造園雑誌 Journal of the Japanese Institute of Landscape Architects [became Journal of the Japanese Institute of Landscape Architecture]	1934–1993	All biodiversity	Japanese
ランドスケープ研究(オンライン論文集) Landscape Research Japan Online	2008–2017	All biodiversity	Japanese
日本林学会誌 Journal of the Japanese Forestry Society [became Journal of the Japanese Forest Society in 2005]	1985–2004	All biodiversity	Japanese
野生復帰 Reintroduction	2011–2018	All biodiversity	Japanese
한국환경생태학회지 Korean Journal of Environment and Ecology	2001–2018	All biodiversity	Korean
한국산림과학회지(한국임학회지) Journal of Korean Society of Forest Science	2002–2018	All biodiversity	Korean
한국습지학회지 Journal of Wetlands Research	1999–2018	All biodiversity	Korean
환경생물 Korean Journal of Environmental Biology	2002–2018	All biodiversity	Korean
한국조류학회지 Korean Journal of Ornithology	1994–2018	All biodiversity	Korean
نشریه محیط زیست طبیعی Journal of Natural Environment	2010–2017	All biodiversity	Persian
پژوهش های محیط زیست Environmental Research	2010–2017	All biodiversity	Persian
بوم شناسی کاربردی Iranian Journal of Applied Ecology	2012–2017	All biodiversity	Persian

فصلنامه محیط زیست جانوری Journal of Animal Environment	2014–2017	All biodiversity	Persian
پژوهش های جانوری Journal of Animal Research	2013–2017	All biodiversity	Persian
محیط شناسی Journal of Environmental Studies	2009–2017	All biodiversity	Persian
علوم محیطی Journal of Environmental Sciences	2004–2017	All biodiversity	Persian
زیست شناسی جانوری تجربی Experimental Animal Biology	2012–2017	All biodiversity	Persian
مجله منابع طبیعی ایران Iranian Journal of Natural Resources	2002–2009	All biodiversity	Persian
Kulon Stone Curlew	1996–2018	All biodiversity	Polish
Notatki Ornitologiczne Ornithological Notes	2005–2009	All biodiversity	Polish
Ornis Polonica	2010–2018	All biodiversity	Polish
Nietoperze Bats	2000–2011	All biodiversity	Polish
Studia Naturae Nature Studies	1987–2013	All biodiversity	Polish
Chrońmy Przyrodę Ojczystą Let's Protect Our Indigenous Nature	2004–2018	All biodiversity	Polish
Naturalia	2012–2016	All biodiversity	Polish
Nature Conservation [formerly Ochrona Przyrody pre-2000]	2001–2008	All biodiversity	Polish
Parki Narodowe i Rezerwaty Przyrody National Parks and Nature Reserves	2009–2015	All biodiversity	Polish
Przegląd Przyrodniczy Nature Review	2010–2018	All biodiversity	Polish
Natureza & Conservação Brazilian Journal for Nature Conservation	2003–2009	All biodiversity	Portugese
Biodiversidade Brasileira Brazilian Biodiversity	2011–2016	All biodiversity	Portugese
MG Biota	2008–2016	All biodiversity	Portugese
Biota Neotropica Neotropical Biodiversity	2001–2011	All biodiversity	Portugese
Neotropical Biology and Conservation	2006–2017	All biodiversity	Portugese
Revista Brasileira de Gestão Ambiental e Sustentabilidade The Brazilian Journal of Environmental Management and Sustainability	2014–2017	All biodiversity	Portugese

Revista Brasileira de Ecologia Brazilian Journal of Ecology	1997–2009	All biodiversity	Portugese
Revista CEPSUL - Biodiversidade e Conservação Marinha CEPSUL Magazine - Marine Biodiversity and Conservation	2010–2017	All biodiversity	Portugese
Megadiversidade Megadiversity	2005–2009	All biodiversity	Portugese
Floresta	1969–2017	All biodiversity	Portugese
Iheringia: Série Zoologia Iheringia: Zoology Series	2000–2018	All biodiversity	Portugese
Bioikos	1987–2016	All biodiversity	Portugese
Evolução e Conservação da Biodiversidade Evolution and Conservation of Biodiversity	2010–2011	All biodiversity	Portugese
Chiroptera Neotropical Neotropical Chiroptera	1995–2015	All biodiversity	Portugese
Boletim da Sociedade Brasileira de Mastozoologia Bulletin of the Brazilian Society of Mammalogy	1985–2017	All biodiversity	Portugese
Ambiência	2005–2018	All biodiversity	Portuguese
Biodiversidade (UFMT)	2007–2018	All biodiversity	Portuguese
FLORAM - Revista Floresta e Ambiente Brazilian Journal of Forestry and Environment	1994–2018	All biodiversity	Portuguese
Arquipelago - Life and Marine Sciences	1980–2018	All biodiversity	Portuguese
Revista de Ciências Agrárias (SCAP) Journal of Agricultural Sciences	2007–2018	All biodiversity	Portuguese
Portugaliae Acta Biologica	2000–2003	All biodiversity	Portuguese
Revista de Gestão Costeira Integrada Journal of Integrated Coastal Zone Management	2007–2018	All biodiversity	Portuguese
Biotemas	1988–2018	All biodiversity	Portuguese
Biota Amazônica Amazonian Biota	2011–2018	All biodiversity	Portuguese
Revista de Biologia Neotropical Journal of Neotropical Biology	2004–2018	All biodiversity	Portuguese
Revista Nordestina de Biologia Northeastern Journal of Biology	1978–2016	All biodiversity	Portuguese

Boletim do Museu de Biologia Mello Leitão Bulletin of the Mello Leitão Bioogy Museum	2013–2018	All biodiversity	Portuguese
Ciência & Ambiente Science and Environment	1990–2015	All biodiversity	Portuguese
Acta Amazônica	1971–2018	All biodiversity	Portuguese
Известия РАН, серия биологическая Biology Bulletin	1957–2017	All biodiversity	Russian
Бюллетень МОИП, серия биологическая Bulletin of Moscow Society of Naturalists. Biological series	1935–2017	All biodiversity	Russian
Сибирский экологический журнал Contemporary Problems of Ecology	1994–2017	All biodiversity	Russian
Современная герпетология Current Studies in Herpetology	2000–2016	All biodiversity	Russian
Вестник охотоведения Herald of Game Management	2007–2016	All biodiversity	Russian
Вопросы ихтиологии Journal of Ichthyology	1961–2017	All biodiversity	Russian
Поволжский экологический журнал Povolzhsky Journal of Ecology	2002–2016	All biodiversity	Russian
Экология Russian Journal of Ecology	1970–2017	All biodiversity	Russian
Русский орнитологический журнал Russian Journal of Ornithology	1993–2017	All biodiversity	Russian
Зоологический журнал Russian Journal of Zoology	1939–2017	All biodiversity	Russian
Степной бюллетень Steppe Bulletin	1998–2016	All biodiversity	Russian
Заповедная наука Nature Conservation Research	2016–2018	All biodiversity	Russian
Journal of Bat Research and Conservation [formerly Barbastella pre-2017]	2000–2017	All biodiversity	Spanish
Mastozoología Neotropical Neotropical Mammalogy	1994–2017	All biodiversity	Spanish
Therya	2010–2018	All biodiversity	Spanish
Galemys	2011–2017	All biodiversity	Spanish
Mammalogy Notes	2014–2017	All biodiversity	Spanish and English
Ocelotlán	2003–2012	All biodiversity	Spanish
Revista Mexicana de Mastozoología Mexican Journal of Mammology	1995–2017	All biodiversity	Spanish

Boletín de la Sociedad Argentina de Botánica Bulletin of the Argentinean Society of Botany	2013–2018	All biodiversity	Spanish
Ecología Austral Austral Ecology	2001–2018	All biodiversity	Spanish
El Hornero	2003–2017	All biodiversity	Spanish
Cuadernos de Herpetología Herpetology Notes	2010–2018	All biodiversity	Spanish
Edentata	1994–2018	All biodiversity	Spanish
Notulas Faunisticas	2008–2018	All biodiversity	Spanish
Historia Natural Natural History	2011–2018	All biodiversity	Spanish
Semiárida	2013–2018	All biodiversity	Spanish
BioScriba	2008–2017	All biodiversity	Spanish
Quebracho: Revista de Ciencias Forestales Quebracho: Journal of Forest Sciences	2008–2018	All biodiversity	Spanish
Revista Mexicana de Biodiversidad Mexican Journal of Biodiversity	2005–2018	All biodiversity	Spanish
Ecosistemas y recursos agropecuarios Ecosystems and Agropecuary Resources	1984–2018	All biodiversity	Spanish
Huitzil: Revista Mexicana de Ornitología Huitzil: Journal of Mexican Ornithology	2000–2018	All biodiversity	Spanish
Madera y Bosques Wood and Forests	1995–2018	All biodiversity	Spanish
Revista Mexicana de Ciencias Forestales Mexican Journal of Forestry Sciences	2010–2018	All biodiversity	Spanish
Acta Zoológica Mexicana Mexican Zoological Record/Journal	1984–2018	All biodiversity	Spanish
Hidrobiológica Hydrobiology	1991–2018	All biodiversity	Spanish
Revista internacional de contaminación ambiental International Journal of Pollution	1985–2018	All biodiversity	Spanish
Revista Chilena de Ornitología [formerly Boletín Chileno de Ornitología] Chilean Journal of Ornithology	2016–2018	All biodiversity	Spanish
Boletín de Biodiversidad de Chile Biodiversity and Natural History [from 2015]	2009–2014	All biodiversity	Spanish
Gestion Ambiental	1999–2018	All biodiversity	Spanish
Revista Chilena de Historia Natural Chilean Journal of Natural History	1897–2018	All biodiversity	Spanish

Ardeola	1954–2018	All biodiversity	Spanish
Butlletí del Grup Català d'Anellament Bulletin of the Catalan Ring Group	1981–2001	All biodiversity	Spanish
Revista Catalana d'Ornitologia Catalan Journal of Ornithology	2002–2018	All biodiversity	Spanish
A Carriza: Sociedad Gallega de Ornitologia	2009	All biodiversity	Spanish
Revista Espanola de Herpetologia Spanish Journal of Herpetology [became Basic and Applied Herpetology from 2011]	2003–2007	All biodiversity	Spanish
Boletín de la Asociación Herpetológica Española Bulletin of the Spanish Herpetological Association	2004–2018	All biodiversity	Spanish
Anales de Biologia: Universidad de Murcia	1984–2018	All biodiversity	Spanish
Biodiversidad Animal y Conservación: Museo de Ciencias Naturales de Barcelona Animal Biodiversity and Conservation	2001–2018	All biodiversity	Spanish
Arxius de Miscel·lània Zoològica (online name)	2003–2018	All biodiversity	Spanish
Boletín de la Real Sociedad Española de Historia Natural: Sección Biológica Bulletin of the Royal Spanish Society of Natural History: Biological Section	2003–2017	All biodiversity	Spanish
Ecosistemas: Revista Científica de Ecología y Medio Ambiente Ecosystems Journal	2001–2018	All biodiversity	Spanish
Etologia Ethology	1989–2003	All biodiversity	Spanish
Mediterránea: Serie de Estudios Biológicos Mediterranean: Biological Studies Series	1982–2015	All biodiversity	Spanish
Studia Oecologica	1981–1995	All biodiversity	Spanish
Zoologica Baetica	1990–2015	All biodiversity	Spanish
Colombia Forestal	2000–2018	All biodiversity	Spanish
Orinoquia	2003–2018	All biodiversity	Spanish
Boletin Cientifico Centro de Museos Bulletin of the Museum Scientific Center	1996–2018	All biodiversity	Spanish
Caldasia	1940–2018	All biodiversity	Spanish

Ecología Aplicada Applied Ecology	2002–2018	All biodiversity	Spanish
Revista Peruana de Biologia Peruvian Journal of Biology	1974–2018	All biodiversity	Spanish
Folia Amazonica	1988–2018	All biodiversity	Spanish
Agrociencia Uruguay	1997–2017	All biodiversity	Spanish
Bosques Latitud Cero Forests Latitude Zero	2014–2019	All biodiversity	Spanish
CEDAMAZ	2014–2018	All biodiversity	Spanish
Bioma	2012–2016	All biodiversity	Spanish
Revista Nicaraguense de Biodiversidad Nicaraguan Journal of Biodiversity	2015–2018	All biodiversity	Spanish
Centros: Revista Cientifica Universitaria Centros: Scientific Journal of the University	2012–2018	All biodiversity	Spanish
Grupo Jaragua	1997–2011	All biodiversity	Spanish
Novitates Caribaea	1999–2018	All biodiversity	Spanish
Artvin Çoruh Üniversitesi Orman Fakültesi Dergisi Artvin Coruh University Journal of Forestry Faculty	2000–2018	All biodiversity	Turkish
Uluslararasi Doga Bilimleri be Biyoteknoloji Dergisi International Journal of Life Sciences and Biotechnology	2018	All biodiversity	Turkish
Su Ürünleri Dergisi Journal of Fisheries	2000–2018	All biodiversity	Turkish
Akademik Ziraat Dergisi Journal of Academic Agriculture	2012–2018	All biodiversity	Turkish
Bartın Orman Fakültesi Dergisi Journal of Bartin Faculty of Forestry	2000–2018	All biodiversity	Turkish
Orman Bilimleri Dergisi Turkish Journal of Forest Science	2017–2018	All biodiversity	Turkish
Deniz Bilimleri ve Muhendisligi Dergisi Aquatic Sciences and Engineering	2007–2018	All biodiversity	Turkish
Toprak Bilimi ve Bitki Besleme Dergisi Journal of Soil Science and Plant Nutrition	2012–2018	All biodiversity	Turkish
Dumlupınar Üniversitesi Fen Bilimleri Enstitüsü Dergisi Journal of Dumlupınar University Institute of Science	2000–2018	All biodiversity	Turkish

Akdeniz Üniversitesi Ziraat Fakültesi Dergisi Mediterranean Agricultural Sciences	2009–2018	All biodiversity	Turkish
Anadolu Orman Araştırmaları Dergisi Anatolia Journal of Forest Research	2015–2018	All biodiversity	Turkish
Atatürk Üniversitesi Ziraat Fakültesi Dergisi Atatürk University Journal of Agricultural Faculty	2008–2018	All biodiversity	Turkish
Kommagene Biyoloji Dergisi Commagene Journal of Biology	2017–2018	All biodiversity	Turkish
Doğanın Sesi Journal of Nature's Voice	2018	All biodiversity	Turkish
Doğu Coğrafya Dergisi Journal of Eastern Geography	2010–2018	All biodiversity	Turkish
Ege Üniversitesi Ziraat Fakültesi Dergisi Journal of Ege University Faculty of Agriculture	2014–2018	All biodiversity	Turkish
İstanbul Üniversitesi Orman Fakültesi Dergisi Journal of the Faculty of Forestry Istanbul University [became Forestsist in 2018]	2009–2018	All biodiversity	Turkish
Kastamonu Üniversitesi Orman Fakültesi Dergisi Journal of Kastamonu University Faculty of Forestry	2001–2018	All biodiversity	Turkish
Türkiye Ormancılık Dergisi Journal of Turkey Forestry	2000–2018	All biodiversity	Turkish
Trakya University Journal of Natural Sciences	2000–2018	All biodiversity	Turkish
Türk Coğrafya Dergisi Turkish Geographical Review	2000–2018	All biodiversity	Turkish
Türk Tarım - Gıda Bilim ve Teknoloji Dergisi Turkish Journal of Agriculture - Food Science and Technology	2014–2018	All biodiversity	Turkish
Заповідна справа [2013-2016; formerly Заповідна справа в Україні 1995-2012] Nature Conservation [2013-2016; formerly Nature Reserves in Ukraine 1995-2012]	1995–1999; 2001–2016	All biodiversity	Ukrainian
Питання біоіндикації та екології Problems of Bioindication and Ecology	2008–2018	All biodiversity	Ukrainian
Вісник Львівського університету. Серія біологічна Visnyk of Lviv University: Biological series	2005–2018	All biodiversity	Ukrainian

Appendix 3: Conservation reports searched

Conservation reports published by a total of 16 organisations were searched.

a) New searches for this synopsis

Organization	Years searched	Details
Natural England	1986–2018	Access to Evidence – Terrestrial invertebrates
Natural England	2003–2016	Access to Evidence – Freshwater invertebrates

b) All other conservation reports searched for the discipline-wide Conservation Evidence database

An asterisk (*) indicates the reports most relevant to this synopsis.

Organization	Years searched	Details
Amphibian Survival Alliance	1994–2012	Froglog, Vol 9–Vol 104
British Trust for Ornithology	1981–2016	BTO Research Reports 1–687
Convention on the Conservation of Migratory Species of Wild Animals	1998–2018	Technical Series Reports 1–38
International Council for the Exploration of the Sea	2003–2018	16 Working Group on Marine Mammal Ecology Expert Reports
International Council for the Exploration of the Sea	2011–2018	8 Working Group on Bycatch of Protected Species Expert Reports
IUCN-SSC Cetacean Specialist Group	NA	58 dated reports
IUCN-SSC Crocodile Specialist Group	2006–2018	CSG Articles
IUCN SSC Crocodile Specialist Group	2005–2017	CSG Reports
IUCN-SSC Invasive Species Specialist Group	1995–2013	Aliens: The Invasive Species Bulletin, Vol 1–33
IUCN-SSC Marine Mammal Protected Area Specialist Group	2017–2018	16 dated reports
Joint Nature Conservation Committee*	1991–2018	Reports 1–627

National Oceanic and Atmospheric Administration	NA	108 Fisheries Science & Data Resources for whales, dolphins and porpoises, seals and sea lions
Natural England*	1986–2018	Access to Evidence – Species and Habitats
NatureScot*	1999–2018	Reports 1–1080
North Atlantic Marine Mammal Commission	1998–2018	145 dated reports, Vol 1–10
Scientific Committee on Antarctic Research (SCAR)	2014–2018	Expert Group on Birds and Marine Mammals, 4 dated reports and list of 7 selected publications.
Sea Mammal Research Unit (SMRU)	2012–2018	Marine Mammal Scientific Support to Scottish Government (47 dated or numbered reports)
Sea Mammal Research Unit (SMRU)	1990–2018	73 reports for funders
Whale and Dolphin Conservation	2001–2018	55 dated reports

Appendix 4: Literature reviewed for the synopsis

The diagram below shows the total numbers of journals and report series searched for this synopsis, the total number of publications scanned (title and abstract) within those, and the number of publications that were summarized from each source of literature.