Experimental cutting of the shrub layer did not improve capercaillie *Tetrao urogallus* breeding success during wet summers in Scots pine forests, Strathspey, UK

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SUMMARY

Understanding factors causing the low breeding success of capercaillies *Tetrao urogallus* is important for the conservation of this species. Here we investigate possible causes of spatial variation in breeding success in two neighbouring Scots pine *Pinus sylvestris* woods in Scotland, Abernethy Forest and Craigmore Wood. Breeding success declined with increasing June rainfall at both sites, but there was a stronger effect at Abernethy. Average productivity (chicks/female) during 2000-2011 was 1.61 (95% C.I. 1.08-2.41) times greater at Craigmore than Abernethy. It was possible that the difference was due to increased wetting of chicks by vegetation during and after rain at Abernethy, where the vertical density of the shrub and grass layer was greater than at Craigmore. Wet chicks may then die. To test this hypothesis, 2 m wide routes were cut through tall heather *Calluna vulgaris* at Abernethy, so that broods could move between bilberry *Vaccinium myrtillus* feeding areas without having to brush against tall dense vegetation. However, there was no improvement in breeding success in the treated area compared to a control area. Possible explanations are that the capercaillies did not use the cut routes, that cutting did not provide sufficiently short vegetation, that rain affects capercaillie chicks in other ways (e.g. through insect availability), or that broods shelter from rain using pine thickets.

BACKGROUND

The capercaillie *Tetrao urogallus* is a large woodland grouse, generally associated with old conifer woodland, (Rolstad & Wegge 1989) that has declined in numbers across most of its European range (Storch 2007). In Scotland, the capercaillie population had declined to 1,285 (95% C.I. 822-1,882) birds (Ewing *et al*. 2012). Poor breeding success and increased mortality due to collisions with forest fences have contributed to the decline (Moss *et al*. 2000). Whilst fence removal and marking have now largely been put in place to reduce mortality of adult birds (Summers & Dugan 2001), measures to improve breeding success have proved less tractable.

In Fennoscandia and Scotland, correlative studies across woods, or over time at a single wood, have identified several factors related to breeding success. These include a negative effect of June rainfall (Slagsvold & Grasaas 1979, Moss 1986, Summers *et al*. 2004), the phenology of spring warming (Moss *et al*. 2001), a positive effect of bilberry *Vaccinium myrtillus* abundance (Baines *et al*. 2004) and a negative effect of predation (Baines *et al*. 2004). There is also experimental evidence for the impact of predation (Marcström *et al*. 1988, Summers *et al*. 2004).

In the present study, we focus on the issue of summer rainfall. Rainfall may be deleterious to small game bird chicks because insect food is less available (Potts 1973), or because chicks either die from hypothermia (Marjoniemi *et al.* 1995) or call more to be brooded, thereby alerting predators (Wegge & Kastadalen 2007). Vegetation may aggravate wetting when chicks and females brush against tall wet vegetation, such as heather *Calluna vulgaris* (Summers *et al*. 1999), as they forage. Therefore, it is possible that the wetting effect of summer rainfall could be mitigated by managing the structure of the shrub layer.

This study was based in two contrasting forests in Scotland, a Caledonian Scots pine *Pinus sylvestris* wood and a Scots pine plantation. The study had three stages. Firstly, the relationship between capercaillie productivity and rainfall was confirmed at the two forests. Secondly, the difference in productivity between the woods was investigated in relation to the structure of the shrub layer, to examine whether rainfall and the vegetation interact to determine variation in breeding success. Thirdly, an experiment tested the hypothesis that clearing pathways through tall shrubs would increase capercaillie breeding success in wet weather.

ACTION

Study areas: The study was carried out at Abernethy Forest (57°15'N, 3°40'W) and neighbouring Craigmore Wood (57 °18'N, 3°38'W) in Strathspey, Scotland, from 2000-2011. Abernethy Forest is about 38 km^2 and the trees are almost entirely Scots pines, consisting of either old-growth Caledonian pinewood or plantations of younger trees (Steven & Carlisle 1959, Summers *et al*. 2008). The study was carried out in stands of primarily Caledonian pinewood with a shrub layer of heather, bilberry and cowberry *Vaccinium vitis-idaea*. Craigmore Wood is about 1.5 km away from Abernethy and 6.5 km^2 in extent, and composed primarily of Scots Pine plantation but also some old-growth pinewood. Both woods contain capercaillies. Abernethy Forest had 170 (95% C.I. 110-280) individuals in winter 2004-2005 (Summers *et al*. 2010). Numbers at Craigmore have not been assessed, although a median of ten males occurred at the only lek during 2000-2011.

Data on June rainfall were obtained from Dorback (57°15'N, 3°32'W) for Craigmore, and Grianan (57°14'N, 3°42'W) for Abernethy. The proximity of the two woods meant that they receive similar weather, with highly correlated June rainfall during 2000-2011 ($r = 0.91$, $n = 12$, $p < 0.001$).

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Carrion crows *Corvus corone*, hooded crows *Corvus cornix* and red foxes *Vulpes vulpes* were controlled in both woods, although a later study found crow numbers were higher and fox and numbers lower in Craigmore than Abernethy (Summers *et al*. 2015). Pine marten *Martes martes* numbers were also lower at Craigmore (Summers *et al*. 2015).

Breeding success: Brood counts were carried out during late July and early August by a team of people with dogs to locate female capercaillies and any associated chicks, which are well-grown at this stage. Breeding success was expressed as the average number of chicks per female (total number of chicks/total number of females). To examine the effect of rain on capercaillie breeding success, a Poisson regression was used, with the number of chicks produced each year at each of the two woods as the dependent variable, and the number of hens (log-transformed) as an offset variable (Crawley 1993). Site was included as a fixed effect, and rainfall in June a continuous variable. Overdispersion was accounted for using a scale parameter.

Three different measures of breeding success were compared between Abernethy and Craigmore. Firstly, the number of chicks produced each year at each of the two woods was fitted as a dependent variable, with number of hens (log-transformed) as an offset variable. Year and wood were both fixed effects, a Poisson error distribution was assumed, a log link function applied and overdispersion accounted for. Secondly, brood sizes for the two woods were compared using the same model structure. Thirdly, we compared the proportion of females with broods in the two woods using a binomial error model, with the number of broods as the response variable and the number of hens as the binomial denominator (trials). A logit link function was used. All the analyses were carried out using SAS (SAS Inst. 2000).

Habitat at brood locations. During brood searches in late July and early August in 2003 to 2006, 10-figure grid references of 37 brood locations (19 at Abernethy and 18 at Craigmore) were recorded using a GPS, allowing each location to be revisited in August to describe the habitat. A 10 x 10 m square containing a 2 m grid of 36 points was set across each brood location, and the percentage cover of heather, bilberry, and grasses (species lumped) within 1 m radius of each point was recorded. The maximum height of each of these plants within 5 cm of the sample point was also recorded. The vertical density of the vegetation was measured by estimating the percentage non-visible at various height sections of a 2 cm wide measuring stick placed vertically on the ground and held at arm's length at each of the 36 points. For the first 20 cm above the ground, estimates were made for each 5 cm section. Between 20 cm and 150 cm above the ground, sections were 10 cm long. All recording was carried out by one person for consistency. Means of the 36 measurements for each habitat variable were calculated to obtain a single value for each variable per brood location. For each brood location, the density of Scots pines within a 15 m radius was also determined.

Habitat data for the brood locations in Abernethy and Craigmore were compared using Mann-Whitney U tests, because the distribution of some variables was skewed.

The shrub cutting experiment: Two plots of woodland at Abernethy that were regularly used by capercaillie broods were selected for the shrub-cutting trial. The plots were separated by a 1 km wide buffer, which included a fast-running river 5 m wide, a smaller stream and unsuitable habitat for capercaillies. These features minimised the possibility of movements by capercaillie broods between the two areas. One area was selected at random as the treatment area (399 ha east of the river) and the other was a control (338 ha west of the river).

Vegetation was monitored in the treatment and control areas during August and September 2006 before the treatment cutting, and during August and September 2007-2009 after the two phases of cutting. Vegetation was surveyed at 50 m intervals along parallel east-west transects 100 m apart. The total length of transects was 39,850 m for the treatment area and 33,800 m for the control, providing 1,473 sampling points. The same vegetation measures were taken as at the brood locations. In 2007-2009 in the treatment area, sample points that fell within and outside cut areas were analysed separately.

In winters 2006-2007 and 2007-2008, heather-dominated vegetation in the treatment area was cut using a handheld strimmer with a metal blade and a tractor-mounted swipe. The latter made a 2 m wide route. Cutting was targeted at areas with tall (over 30 cm) heather and heather cover over 50%. In 2006, 279 out of the total of 797 sample points in the experimental area met these criteria. Therefore, 35% or 140 ha of the shrub layer was deemed suitable for treatment.

The cutting design consisted of a network of 2 m wide paths with enlarged areas at intersections of routes. Routes connected large areas of bilberry that remained uncut. This pattern provided chicks with access to bilberry within the cut patches and also allowed broods to move between patches of bilberry. Cutting was restricted to woodland habitat, although it extended out to 20 m beyond the woodland edge. Open areas less than 40 m wide within woodland had routes cut through them.

After the treatment in winters 2006-2007 and 2007-2008, re-surveys of the transects in August and September 2007 and 2008 assessed the area that had been cut. Where a transect crossed cut vegetation, the length of the transect that lay within a cut section was measured and used to calculate percentage of the total transect length that was cut. This was then applied to the total experimental area. Vegetation cover and heights at the transect points within cut sections were analysed separately from uncut sections, to describe the change in the vegetation due to cutting.

As above, a Poisson regression analysis accounting for overdispersion was used to examine the difference in breeding success (number of chicks / female, including zeros) between treatment and control areas from 2000-2011. Year was included as a continuous variable, and the interaction between year and site was used to detect any change in the treatment area over time, relative to the control area. Years when no chicks were found at either site were deleted from the analysis (2004 and 2008). These years provided no information about the relative performance of birds in the two areas of the forest, making it more difficult to detect a difference. Analyses run including these years found no qualitative difference in the significance of the results.

CONSEQUENCES

Breeding success at Abernethy and Craigmore: Between 2000 and 2011 there was a negative relationship between productivity and total June rainfall at both woods (χ^2 = 10.2, p = 0.0014) and a significant difference between woods (χ^2 = 4.44, p = 0.035), but no significant interaction between wood and rainfall (p = 0.89) (Figure 1). Mean productivity for 2000-2011 was 0.55 (S.E. = 0.15) chicks/female at Abernethy and

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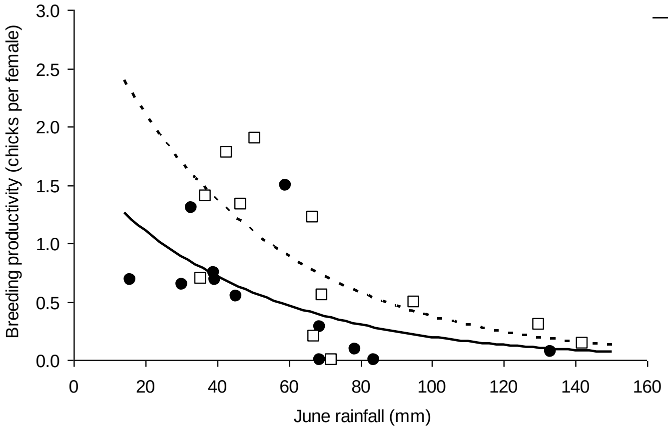

Figure 1. Capercaillie productivity and total June rainfall at Abernethy Forest (●, solid line) and Craigmore Wood (□, dotted line) during 2000-2011. The effects of rain and wood, but not the interaction, were significant.

0.84 (S.E. = 0.20) at Craigmore. Based on the modelled estimates, productivity at Craigmore was 1.61 times higher than at Abernethy (95% C.I. 1.08-2.41, χ^2 = 5.21, p = 0.023). The modal brood size was one chick at both sites. There was no significant difference in mean brood size between Abernethy (2.12, S.E. = 0.16, range 1-6) and Craigmore (2.41, S.E. = 0.27, range 1-8) (χ^2 = 2.99, p = 0.084). On average, significantly fewer females had a brood at Abernethy (26.1%) than at Craigmore (33.7%) (χ^2 = 4.22, p = 0.040).

Habitat at brood locations: There were no significant differences in the characteristics of the shrubs and grasses between brood locations in Abernethy and Craigmore in 2003-2006 (Table 1).

There was a greater vertical density of vegetation at all heights of the shrub/grass layer at Abernethy compared to Craigmore (Figure 2). The greatest difference occurred at a height of 10-15 cm where measures of density between the two woods were statistically significant (Mann-Whitney U = 98.5, p = 0.028). This height also corresponds to the height of the chicks. In addition, Scots pines at Abernethy were less dense (median = 213 trees/ha, interquartile range = 50-630) than at Craigmore (722 /ha, interquartile range = 269-977) (Mann-Whitney U = 101, p = 0.033).

Both the greater vertical density of the shrub/grass layer and the lower density of pines at Abernethy compared to Craigmore could increase the chance of chicks becoming wet, either by brushing against taller wet vegetation or because the smaller canopy cover provides less shelter.

Table 1. Comparison of the height (cm) and cover (%) of the field layer vegetation at brood locations in Abernethy Forest (n = 19) and Craigmore Wood (n = 18). Bonferroni corrections were applied to each individual hypothesis for the shrub layer; α = 0.05/6 = 0.008.

	Abernethy		Craigmore			
	Mean	**S.E.**	**Mean**	**S.E.**	**U**	**p**
Height bilberry	23.2	1.3	26.9	1.7	93.5	0.13
Height live heather	41.2	2.3	37.1	2.9	183	0.30
Height grass	31.6	2.4	31.2	3.6	151	0.59
Total cover bilberry	13.0	3.6	16.2	3.6	144	0.41
Total cover heather	41.7	6.3	25.7	6.1	232	0.06
Total cover grass	16.1	5.8	30.2	6.2	118	0.10

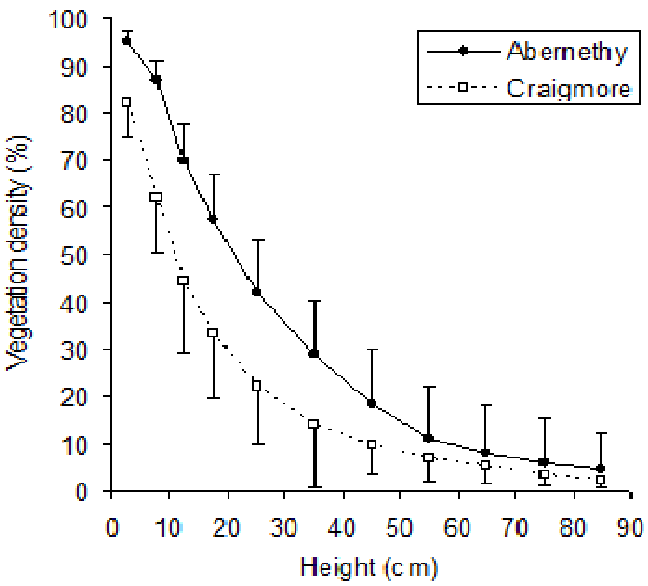

Figure 2. Mean vegetation density of the field layer at different heights at brood locations in Abernethy Forest and Craigmore Wood from 2003-2006. Vertical lines show 95% C.I.s.

The shrub cutting experiment: The initial survey in autumn 2006 showed that before cutting there was more cover of heather (42% (95% C.I. 39-44) versus 30% (95% C.I. 28-32)) and grass (26% (95% C.I. 24-28) versus 20% (95% C.I. 17-23)), but less bilberry (23% (95% C.I. 21-25) versus 29% (95% C.I. 27-31)) in the experimental area compared with the control area. At the final assessment in 2009, the vertical density of the vegetation at the height band 10-20 cm in the uncut parts of the

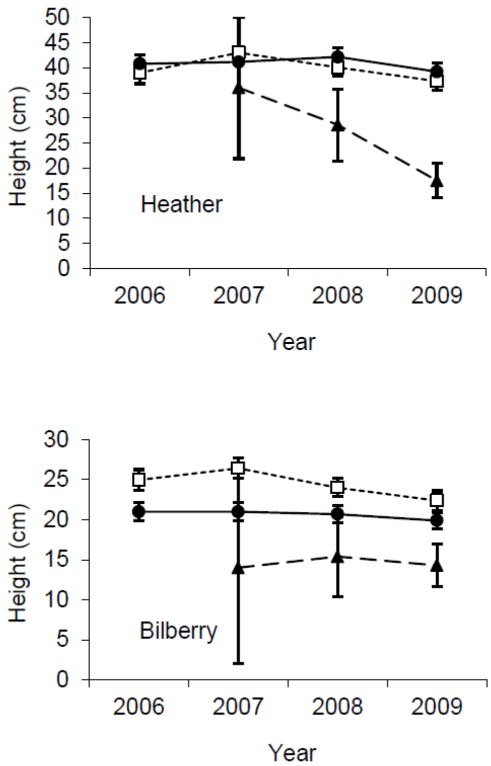

Figure 3. Mean maximum shrub heights (cm) in the control (□) and uncut part of the treatment (●) areas each year. Heights (▲) are also shown for cut sections within the treatment area. Vertical lines show 95% C.I.s.

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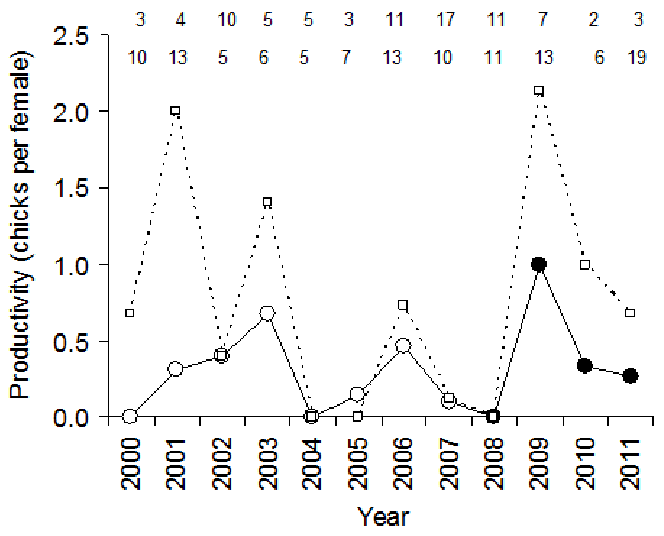

Figure 4. The breeding success (mean chicks per female, including brood-less females) of capercaillies in the treatment (solid line) and control (dotted line) areas in Abernethy Forest prior to (2000-2006) and after treatment in winters 2006/07 and 2007/08. The filled circles show breeding success in the experimental area after treatment. Numbers of females located in each area are shown, with control area values above experimental.

experimental area was 22% (95% C.I. 19-24) but reduced to 1% (95% C.I. 0-3) in the cut parts, whilst the density in the control area was 16% (95% C.I. 14-18). Heather height was similar for the two areas, although bilberry was taller in the control area (Figure 3).

Of the 39,850 m of transect lines within the experimental area, 1,358 m (3.4%) crossed cut sections in 2007 and 3,478 m (8.7%) in 2008. Therefore, approximately 14 ha was cut in winter 2006/07 and a further 21 ha cut in winter 2007/08. The 35 ha of cut vegetation represented about 25% of the suitable habitat (tall heather-dominated shrub). Live heather cover was 12% (95% C.I. 9-14) in cut areas compared to 29% (95% C.I. 27-31) in uncut areas, but dead heather cover was 9% (95% C.I. 6-11) in cut areas compared to 2% (95% C.I. 2-3) in uncut areas. The amount of bilberry was similar in cut (12%, 95% C.I. 9-16) and uncut (13%, 95% C.I. 11-14) areas. Cutting was therefore successful in reducing heather cover as well as reducing the height of the shrubs (Figure 3).

Breeding success showed no significant trend from 2000 to 2011 (χ^2 = 0.34, p = 0.56), nor any difference between the treatment and control areas (χ^2 = 3.25, p = 0.071). More importantly, there was no significant interaction between year and treatment, showing that there was no improvement in breeding success in the treatment area relative to the control area after the cutting took place (χ^2 = 0.18, p = 0.67) (Figure 4). All years after treatment had some wet weather in June (59 mm in 2009, 39 mm in 2010 and 69 mm in 2011), allowing the experiment to be realistically tested.

DISCUSSION

Abernethy Forest and Craigmore Wood are neighbouring woods, with similar weather. Capercaillie productivity varied depending on rainfall, with productivity higher at Craigmore than Abernethy for all amounts of rainfall during 2000-2011 (Figure 1). The vertical density of the field layer vegetation was greater at brood locations in Abernethy compared with Craigmore (Figure 2), potentially causing chicks to become wetter. However, cutting routes through the tall heather did not lead to improvement in capercaillie breeding success. It was predicted that there would be an immediate improvement in breeding success, because the cut routes would have allowed broods to move around the forest floor without brushing against tall wet vegetation. Therefore, the negative effect of June rainfall on capercaillie breeding success does not appear to be mitigated by cutting tall heather. It is possible that the vegetation was not cut short enough, so that although the mean maximum vegetation height was reduced from 20-40 cm to about 15 cm for the remaining vegetation (Figure 3), this was still too high to provide benefits for capercaillie chicks.

We are left with an unexplained difference in breeding success between Abernethy and Craigmore. Possible explanations include a difference in predator abundance (Summers *et al*. 2015) or food availability of invertebrates on bilberry (Storch 1994, Baines *et al*. 2004). However, the latter seems unlikely because the amount (cover and height) of bilberry was similar in both woods (Table 1). The other differing habitat characteristic was tree density, which was more than three times greater at Craigmore than at Abernethy, perhaps giving greater canopy cover from rain. Stands of high tree density in Abernethy tend not to occur in the old-growth stands where brood counts were carried out. The mix of different stand types at Abernethy may be at too large a scale to allow broods to move between them, making it difficult for broods to exploit areas rich in bilberry and still seek cover from the rain in denser stands.

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