Effectiveness of chemical and mechanical bracken *Pteridium aquilinum* control treatments in northern coastal heathlands on the island of Lygra, Hordaland, Norway

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SUMMARY

In a 7-year field experiment undertaken in western Norway, the efficiency of four bracken control measures on a heathland was investigated: application of two herbicides i) Asulox®- and ii) Gratil®- with follow-up annual cutting; iii) annual cutting; and iv) biannual cutting. Assessments were also made as to what extent the characteristic species composition and vegetation structure of heathlands were restored, and effects of the herbicides on non-target plant species commonly found on heaths. Fastest reduction in bracken cover resulted from herbicide application, but cutting proved equally efficient in the longer term; Asulox and biannual cutting both reduced bracken cover from over 70% to below 10% in 2 years, while annual cutting achieved this in 5 years. Gratil failed to have long-term effects. Species composition progressed towards a desirable heathland vegetation community, but successional trajectories differed, and Asulox had minor unintended effects on a number of heathland plants, including heather *Calluna vulgaris*, several grasses, herbs and mosses. These effects could not be predicted by functional group or other simple species characteristics. However, any short-term detrimental effects of Asulox application were considered to be outweighed by the beneficial longer term effects of reduced bracken cover, which allowed re-establishment of the heathland flora.

BACKGROUND

The lowland heathlands of Europe are man-made, cyclic vegetation systems where secondary succession is manipulated by management such as grazing by livestock or cutting and removal of vegetation. However, due to land use change, lowland heaths are endangered habitats of considerable conservation value (Farrell 1989, Gimingham 1992, Aarrestad *et al*. 2001) and are now protected under EU Habitats Directive (92/43/EEC). Norway harbours the northern one third of Europe's coastal heathlands, characterized by long and unbroken management history. Interestingly, in contrast to most of their more southerly European counterparts, these Norwegian heaths completely lack conservation management schemes.

Major threats to both Norwegian and other European heathlands include development, especially roads and housing, leading to fragmentation, pollution and loss of biodiversity, and abandonment due to changes in agricultural policies leading to woodland encroachment or invasion by alien species and bracken *Pteridium aquilinum*. The rapid spread of bracken in particular, has been recognised as a serious threat to the unique qualities of heathlands, as due to its tall, vigorous growth it can out-compete and eliminate characteristic ericaceaous shrubs such as heather *Calluna vulgaris*, herbs and grasses (Watt 1955, Gimingham 1972, Marrs & Watt 2006).

One of the main keys to bracken control lays in exhausting the underground rhizomes of carbohydrates (Pakeman & Marrs 1994). Today, the chemical asulam commonly applied as Asulox® (a herbicide formulated for control of bracken) is the most widely applied bracken

control measure (e.g. asulam treatment is commonly employed in the UK); it is effective in reducing bracken density by killing the above-ground fronds, consequently leading to depletion of carbohydrate reserves in the rhizomes. However, an increasing focus on organic farming (bracken may also invade marginal farmland habitats) as well as nature conservation, call for alternative approaches to chemical control. This study documents a 7-year field experiment undertaken on the island of Lygra, southwest Norway, which compared the efficiency of four bracken control measures, in terms of reducing bracken density, on a heathland. The treatments tested were application of Asulox® (active ingredient (a.i.) asulam), application of Gratil® (a.i. Amidosulfuron); annual cutting, and biannual cutting.

ACTION

Study area: The island of Lygra (60°42' N, 5°05' E) is situated in the Lurefjorden fjord basin, approximately 40 km northwest of Bergen, southwest Norway. Hard and slowly eroding acidic bedrock gives rise to nutrient-poor soils. The climate is oceanic with relatively small differences between June (12.0 ^{0}C) and January (2.0 ^{0}C) mean temperatures; the annual 1,600 mm of precipitation is relatively evenly distributed throughout the year and there is a long growing season (around 220 days). Parts of the semi-natural rangeland on the island have been under continuous historical management regimes (burning, grazing, and turf and heather cutting) up until the present day, creating a mosaic of heathland of different successional stages (Vandvik *et al*. 2005). The area is grazed (since 1992) by 0.1 cow/ha in summer and by 0.8 sheep/ha in winter. However, in recent years bracken has increased as a result of changes in traditional management and by 2004 it had invaded about 30% of the area. As a consequence of the increasing bracken cover, it was decided to undertake a series of experimental bracken control measures using both chemical (herbicide application) and mechanical (cutting) techniques.

Treatments and experimental design: Two experimental areas of 25 m² were established in two heathland areas, one invaded by bracken (A) and the other with no bracken present (B). Both areas were grazed by cattle from May to September and by sheep of Old Norse breed from September to May (0.1 cow/ha in summer and by 0.8 sheep/ha in winter) each year throughout the duration of the experiment (1997-2004). Plots within each area (A and B) were laid at least 10 m apart, creating a buffer zone so as to avoid effects of any herbicide subject to spray drift; herbicide was applied by knapsack sprayer on dry days with low wind speed. In all cutting treatments bracken stems were cut approximately 20-30 cm above ground, thus not affecting the shorter non-target vegetation, and newly cut bracken fronds were removed. After initial testing of different cutting techniques (motorised vs. scythes) a long handled scythe was selected as the most efficient tool for bracken clearance in the study area. The final experimental setup was a balanced BACI (before-after, control-impact) design with 12 replicate quadrats per treatment. The treatments are summarised in Table 1.

Table 1. Overview of treatments applied to area A (60-90% bracken cover before treatment), and area B (without bracken), four replicates of each treatment x area, a total of 32 plots (96 quadrats). The experimental design was expanded successively over the first three years.

Treatment	Area	Year treatment initiated	Treatment details
Asulam	A*, B	1997/ 98	Sprayed with 4 kg a.i./ha Asulox® on 31July; sheep and cattle excluded for 90 days after spraying
Annual cutting	A	1997/ 98	Bracken cut (cuttings removed) annually in late July
No treatment	A, B	1997/ 98	No treatment applied
[1]Biannual cutting	A	1999	Bracken cut (cuttings removed) biannually in mid June and late July each year
[1]Gratil	A*, B	1999	Sprayed with 0.06-0.08 kg a.i./ha Gratil on 1 August; sheep and cattle excluded for 7 days after spraying

Note: [1]Gratil and biannual cutting undertaken over 5-years only. *Bracken regrowth cut annually in late July following the methods of Lowday & Marrs (1992a).

Monitoring: Three 0.25 m² permanent quadrats were randomly distributed within each of the treatment and control plots. Percentage coverage of all vascular plants, bryophytes and lichens were recorded before treatment initiation in 1997, and subsequently in July/August yearly until 2004.

CONSEQUENCES

Treatment effects on bracken: All bracken control treatments in area A significantly reduced bracken cover in the year following treatment application (Fig. 1). Herbicide application resulted in the fastest reduction in bracken: the Asulox treatment reduced bracken cover by 99% over the first year after treatment (Fig. 2), and the effect persisted throughout the seven years of the experiment. Although the Gratil treatment was equally efficient in the first year, reducing cover by 98%, bracken recovered quickly and cover was up to 55% after 5 years even though this treatment also included annual cutting, as for the Asulox treatment. Due to its obvious inefficiency for controlling bracken long-term, the Gratil treatment is not considered further.

Effects of cutting appeared more slowly, but were equally efficient in the long run: Cutting twice yearly reduced bracken cover by 75% in the first year, but was indistinguishable from the Asulox treatment from the second year onwards. Significant effects of cutting once yearly did not appear until the second year after treatment, but increased gradually over time and paralleled that of Asulox after 5 years. Control sites only showed small non-significant variations in the cover of bracken over the seven years of recording.

Vegetation responses: During the study 61 taxa of vascular plants, 23 bryophytes and two lichens were recorded in the quadrats. All bracken control treatments affected vegetation composition, inducing a desirable shift towards more open and species-rich communities, dominated by grasses, herbs and heathers (Fig. 3). More species were found to benefit from the removal of bracken than suffering from the treatments. Succession towards heathland may have been facilitated by sheep and cattle grazing, leading to a slower recovery rate of bracken, caused by trampling and foraging activity.

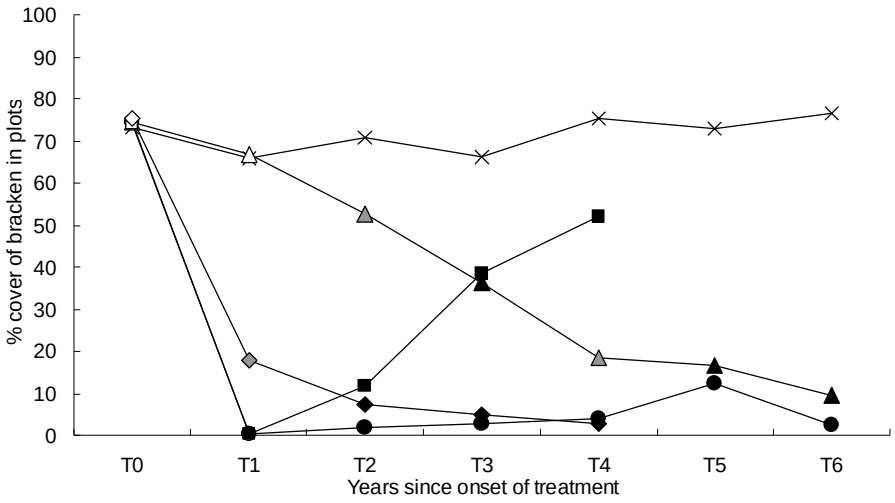

Figure 1. Mean cover (%) of bracken in experimental plots over time. Within each year, filled symbols signify treatments that are significantly different from untreated plots, and different shades signify that the treatment is significantly different from treatments above and below it in the graph at that point in time. Treatments: x = Control, ● = Asulox + annual cutting, ■ = Gratil + annual cutting, ♦ = Cut twice yearly, ▲ = Cut once yearly.

Figure 2. Bracken cover in the year of Asulox application (above) and the following year (below) on bracken invaded heathland at Lygra, southwest Norway.

Effects of herbicides on non-target species: In the bracken-dominated area, the majority of non-target species were positively affected by Asulox treatment, suggesting that the herbicide has little detrimental effect on plant diversity. However, this effect confounds two causal factors: the herbicide *per se* and its effect through the removal of bracken fronds. In area B (no bracken present) the majority of the plant species present were negatively affected, as manifested by a decrease in cover. Such species included; common bent *Agrostis capillaris*, sweet vernal *Anthoxantum odoratum*, heath speedwell *Veronica officinalis*, heath bedstraw *Galium saxatile*, heath rush *Juncus squarrosus*, marsh thistle *Cirsium palustre*, bird's-foot trefoil *Lotus corniculatus*, meadow buttercup *Ranunculus acris*, marsh violet *Viola palustris*, Yorkshire fog *Holcus lanatus*, globe flower *Trientalis europaea*, tormentil *Potentilla erecta*, and the moss *Hylocomium splendens*, suggesting that asulam (the acitive ingredient in Asulox) has negative effects on diversity of the non-target communities. Two important characteristic heath component species showed differing responses; bilberry *Vaccinium myrtillus* was negatively affected, but *Calluna* responded in a slightly positively manner. The negatively affected species belonged to different taxonomic and functional groups. In both areas, there was a significant compositional response to spraying in the first year after treatment, an effect that weakened and disappeared within 2-5 years. This calls for caution in herbicide application (Måren *et al*. 2008).

Conclusions and discussion: These results demonstrate that three of the four bracken control techniques trialled (Asulox application with follow-up annual cutting, cutting once a year and cutting twice a year) to be largely applicable to the heathlands on Lygra, and therefore probably other northern heathlands as well. The overall vegetation changes were from bracken, grass and moss dominated communities to more species-rich heather, herb and grass dominated communities. For long term reduction of bracken cover in these northern coastal heathlands, management by cutting bracken once or twice yearly or spraying with Asulox in combination with yearly cutting thereafter, was most effective. Cutting twice yearly proved to be a very efficient alternative to spraying, while cutting once a year was efficient after 5 years. Hence, if a rapid reduction in bracken cover is not of utmost importance, cutting once a year will eventually yield the desired results. As a precaution, potential effects on rare or threatened species should be investigated before herbicide application is considered.

Further, the impact of low-level livestock trampling may be an important factor in bracken control, at least in areas where bracken stands are not too dense. Simply controlling bracken by herbicides might therefore not result in development or restoration of heathlands (Pakeman *et al*. 2007). Our use of follow-up treatments (annual cuttings and removal of bracken fronds) may also have increased the rate of success in re-establishing desirable heathland vegetation. In heterogeneous heathlands, as found in northern regions, one can expect these non-target communities to be intermingled with bracken invaded heath (Vandvik *et al*. 2005).

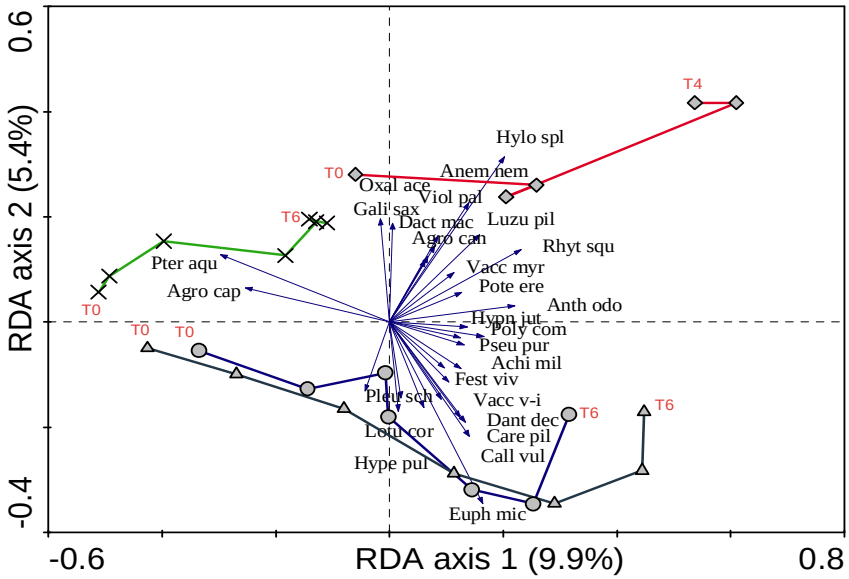

Figure 3. Multivariate redundancy analysis (RDA) ordination diagram of species and bracken control treatments through time for the heathlands at Lygra, Norway. Compositional change within the different treatments over the course of seven years (cut twice; five years) is drawn as trajectories where T0 demarks the year treatment was initiated, and T6 (cut twice; T4) demarks the last year of treatment. Treatments: X = untreated, ● = asulam + annual follow-up cutting, ♦ = cut twice yearly, ▲ = cut once yearly. Species names abbreviations are the four + three first letters of the genus and species names, respectively.

These results show cutting alone to be as efficient as herbicide application plus cutting, in controlling bracken and to be more efficient in restoring northern heathland vegetation over time in terms of cost. This has important implications, especially for organic farming purposes, where alternative bracken control methods aside from herbicide application need to be considered as organic farming may preclude the use of chemical control. We suggest integrated management approaches which emphasize sustainable management methods. Bracken control measures must be developed and implemented to a far greater extent if the heathlands of Northern Europe are to be successfully conserved.

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