Annals of Botany **85** (Supplement B): 31–35, 2000
doi:10.1006/anbo.1999.1083, available online at http://www.idealibrary.com on IDEAL®

Follow-up Methods for Bracken Control Following an Initial Glyphosate Application: The Use of Weed Wiping, Cutting and Reseeding

P. PETROV† and R. H. MARRS*‡

†*Institute of Upland Stockbreeding and Agriculture, Troyan 5600, Bulgaria and* ‡*School of Biological Sciences, University of Liverpool, PO Box 147, Liverpool L69 3BX, UK*

Received: 20 July 1999 Returned for revision: 14 September 1999 Accepted: 28 October 1999

Between 1990 and 1996 a range of follow-up strategies were applied to a permanent meadow in Bulgaria infested with bracken (*Pteridium aquilinum*), which was recovering after initial control using glyphosate. The initial glyphosate treatment (4·3 kg ha^{-1}) reduced both the bracken infestation and the underlying weedy vegetation, and facilitated the recovery of pasture species. However, there was rapid bracken recovery within 5 years where no follow-up treatment was applied. Cutting twice yearly slowed recovery, but the most effective treatments were where (1) there had been a single follow-up weed wiping application of glyphosate plus cutting twice yearly, or (2) where *Festuca rubra* and *Vicia cassubica* were sown. Reseeding on its own or combined with cutting twice yearly provided good bracken control and a high forage quality over the 5 year period.

Key words: Bracken, herbicidal control, grassland management, forage production, glyphosate, weed wiping, *Pteridium*.

INTRODUCTION

Bracken infestation is a major constraint of the productivity of permanent meadows in mountain regions (Taylor, 1995). The grass in bracken-infested areas is of poor nutritional value and the bracken canopy (Page, 1986; Petrov, 1991) hinders the access of grazing animals to forage and interferes with stock management. Traditionally bracken has been controlled either by mechanical means or through the use of herbicides (Lowday and Marrs, 1992*a*,*b*). Several herbicides have been shown to give successful control of bracken. The most commonly used herbicides for the control of bracken are asulam and glyphosate, but amidosulfuron, chlorsulfuron, metsulfuron-methyl and tribenuron-methyl have also been shown to give effective control (West and Butler, 1992; West *et al*., 1995). However, there is often rapid recovery unless the initial treatment is repeated or followed up with other weed control measures (Williams, 1980; Robinson, 1986; Petrov, 1988; West, 1992). Moreover, chemical control may be difficult to use in areas subject to conservation measures (Tyler, 1988; Marrs *et al*., 1992; Pakeman and Marrs, 1992; Warren, 1993). Alternative, 'biological' control methods, either on their own or in combination with reduced herbicide use, could be a valuable alternative technique to aid bracken control (Page, 1986).

One method to assist in follow-up bracken control which has received relatively little attention, is to harness biological mechanisms to reduce bracken vigour. Biological control *sensu stricto*, where parasites, phytopathogens or predators of bracken are introduced have been tested in the laboratory (Lawton, 1986, 1988; Lawton *et al*., 1988; Cock and Lawton, 1989; Fowler, 1993; Womack and Burge, 1993), but have not been developed for commercial use. An alternative approach may be to introduce appropriate plant species to compete with the bracken and prevent its recovery. This has been done in some experimental situations where grass species or *Calluna vulgaris* have been seeded with the aim of hindering bracken recovery after treatment (Marrs *et al*., 1988; Lowday and Marrs, 1992*a*), essentially imposing the 'Inhibition model of succession' (Connel and Slatyer, 1997).

In this study, three different strategies for follow-up control of bracken after an initial application of glyphosate were tested: (1) cutting on its own; (2) application of a second glyphosate application by weed wiper plus cutting; and (3) biological control, where a mixture of productive plant species were sown.

MATERIALS AND METHODS

The study was conducted between 1990 and 1996 at the Institute of Uplands Stock Breeding and Agriculture, Troyan, Bulgaria (25° E, 43° N). The study site was a permanent meadow, weakly infested with bracken (10–15 fronds m^{-2}) at an altitude of 600 m, on a grey, forest soil type (42% clay and 2·5% humus; pH 4·5). The vegetation was dominated by *Agrostis capillaris* and *Festuca fallax*. Other species present included *Cirsium arvense*, *Convolvulus arvensis*, *Rubus* spp., *Achillea millefolium*, *Rumex acetosella*, *Centaurea stobe* and a small amount of other grasses such as *Festuca rubra*, *Poa pratensis* and *Holcus lanatus*; there were no legumes present (Petrov, 1984).

In August 1990, glyphosate was applied (as Roundup, 36% a.i.) at 4·3 kg a.i. ha^{-1} to an area (20 × 30 m) using a

* For correspondence. Fax 0151 794 4240, e-mail calluna@liv.ac.uk

0305-7364/00/0B0031 + 05 $35.00/00

Tecnoma Super pulsar-7 plot sprayer. This was set at 1 bar working pressure to apply 800 litres ha^{-1} (Petrov, 1984). Four areas (5 × 5 m) were retained as unsprayed 'controls'—denoted treatment number 1.

Five follow-up treatments were then applied to 5 × 5 m plots arranged in four replicate blocks; these were; treatment number 2—no seeding of grass mixture or cutting of frond regrowth; treatment number 3—no seeding treatment but bracken cut twice yearly; treatment number 4—no seeding treatment, a follow-up glyphosate treatment applied in August 1991 by weed wiper (1 : 1 herbicide : water ratio, 45 d after the full development of bracken fronds, height approx. 85 cm) plus cutting twice yearly; treatment number 5—seeding treatment alone, no cutting; and treatment number 6—seeding treatment plus cutting twice yearly. The seeding treatment involved sowing *Festuca rubra* (1·5 g m^{-2}) and *Vicia cassubica* (10 g m^{-2}) using a standard agricultural seed-drill in April 1991 on ground which had been prepared by removing the surface litter from the site. In treatments 3, 4 and 6 the hay plus bracken fronds were cut manually using a scythe; treatments 1, 2 and 5 remained uncut. The timing of the hay cuts reflected normal practices used in the mountain regions of Bulgaria (450–600 m asl), although the exact cutting was modified each year to account for the prevailing weather at the time. The first cut was applied in June, when the legumes were flowering, and the second cut was applied in late July–early August, when grass seeds were present.

The effect of treatment on the bracken infestation was recorded non-destructively before the first harvest each year. The fronds were counted in four 50 × 50 cm quadrats in each experimental plot, and mean frond height measured. The percentage cover of grasses, legumes and other dicotyledons was also estimated before the first harvest.

Analysis of variance was used to detect significant effects of treatment on frond density and frond height through time. A randomized blocks model was applied to the data for each year, and the effect of time was assessed using repeated measures (SAS, 1988). Analyses were performed using both untransformed and transformed ($\sqrt{x}$) data. As transformation improved the distribution of residuals only the transformed analyses are discussed here. Differences between treatment means were assessed using the Bonferonni test.

RESULTS

The only significant differences due to blocks were found in 1994 and 1995 ($P < 0{\cdot}01$) for frond density (Table 1). Significant treatment effects ($P < 0{\cdot}001$) were found for both frond density and frond height in all years (Table 1). There were significant differences through time ($P < 0{\cdot}001$) and its interaction with treatment ($P < 0{\cdot}001$), but not with blocks.

The untreated plots showed fluctuations in density and to a lesser extent frond height between 1991 and 1996; frond densities ranged between 9 and 15·5 m^{-2} and a mean frond height of approx. 170 cm. In 1991, the year after herbicide treatment, there was a large reduction in both density and height of fronds, with no significant difference between the treatments applied (Table 1, Fig. 1). Thereafter there were differential responses between the control treatments. Where there was neither seeding nor follow-up treatment

TABLE 1. *Summary results from the analyses of variance for the effects of bracken control treatments on bracken frond density and frond height (both $\sqrt{x}$ transformed) for each year*

		Year					
Parameter	d.f.	1991	1992	1993	1994	1995	1996
Frond density							
Blocks	3,15	0·12	3·37	2·85	6·68**	6·79**	1·17
Treatments	5,15	38·01***	50·74***	71·90***	69·12***	83·34***	42·75***
Bonferroni's MSD		0·991	0·787	0·602	0·752	0·720	0·941
Treatment means not		123456	123564	123564	123564	123546	123546
significantly different		abbbbb	abbbb	abbb	abccdd	abcddd	abcc
			ccc	ccc			ddd
				ddd			
Frond height							
Blocks	3,15	0·98	0·26	1·09	0·22	1·98	3·75
Treatments	5,15	24·82***	41·37***	72·48***	65.43***	125·71***	212·91***
Bonferroni's MSD		1·492	1·710	1·341	1·485	1·050	0·921
Treatment means not		142356	123564	123564	123564	213456	123456
significantly different		abbbbb	abcccd	abcc	aabccc	aabcc	aabcdd
				dd		dd	
				ee			

F-ratios for the effects of blocks and bracken control treatments are presented along with an assessment of their significance; ** = $P < 0{\cdot}01$, *** = $P < 0{\cdot}001$. Bonferroni's MSD values are also given for each year and the groups of means not significantly different from each other based on the Bonferroni test. Treatment codes: (1) untreated 'control'; (2) no seeding of grass mixture or cutting of frond regrowth; (3) no seeding treatment but bracken cut twice yearly; (4) no seeding treatment but follow up glyphosate application by weed wiper; (5) seeding treatment alone, no cutting; and (6) seeding treatment plus cutting twice yearly. The seeding treatment involved sowing *Festuca rubra* and *Vicia cassubica*.

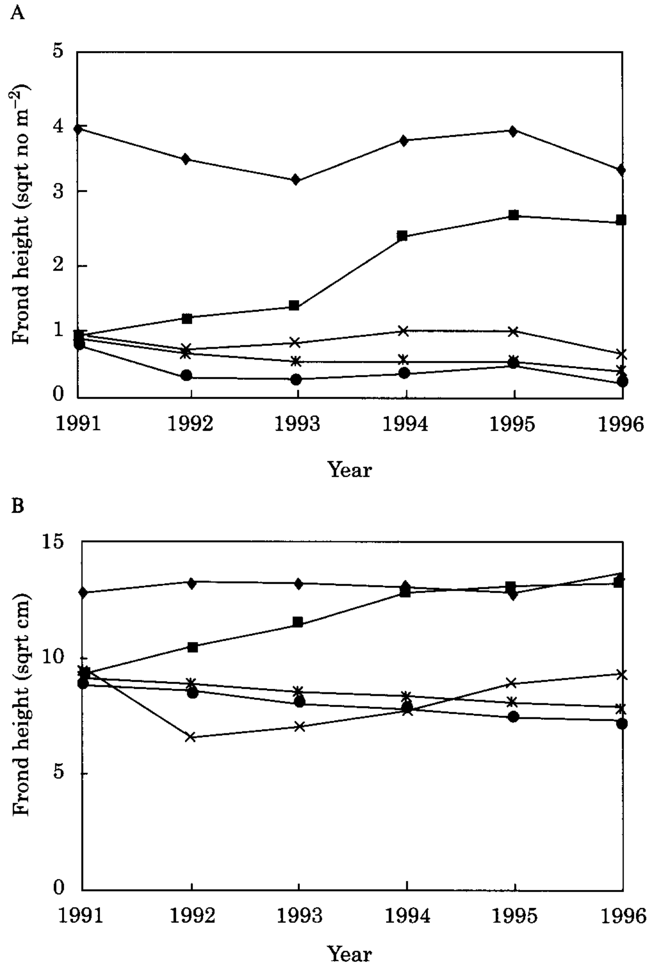

FIG. 1. Effects of various follow-up bracken control treatments applied after glyphosate application on frond density (A) and frond height (B) between 1991 and 1996. Mean values ($n = 4$) of transformed data ($\sqrt{x}$) are presented. Treatment codes: (1) Untreated 'control' (◆); (2) no seeding of grass mixture or cutting of frond regrowth (■); (3) no seeding treatment but bracken cut twice yearly (▲); (4) no seeding treatment but follow-up glyphosate by weed wiper and cutting twice yearly (×); (5) seeding treatment alone, no cutting (⁎); and (6) seeding treatment plus cutting twice yearly (●). The seeding treatment involved sowing *Festuca rubra* and *Vicia cassubica*.

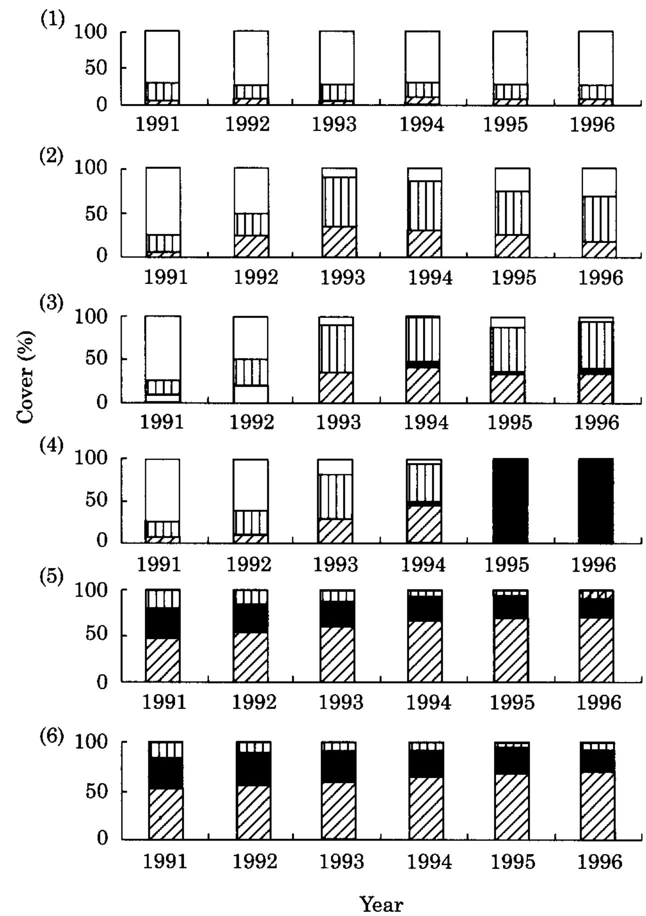

FIG. 2. Effects of various follow-up bracken control treatments applied after glyphosate application on vegetation composition between 1991 and 1996. The vegetation composition classes are as follows: (□) bare ground; (▥) dicotyledons; (■) legumes; and (▨) grass. Treatment codes: (1) untreated 'control'; (2) no seeding of grass mixture or cutting of frond regrowth; (3) no seeding treatment but bracken cut twice yearly; (4) no seeding treatment but follow-up glyphosate by weed wiper and cutting twice yearly; (5) seeding treatment alone, no cutting; and (6) seeding treatment plus cutting twice yearly. The seeding treatment involved sowing *Festuca rubra* and *Vicia cassubica*.

of the bracken (treatment 2), control was poorest, with a sustained reduction in density for only 2 years, and an almost linear recovery in height. By 1996 there was still a significant reduction in density compared to the untreated plots but not in height (Table 1, Fig. 1). Most successful control was achieved with either the follow-up glyphosate treatment applied by weed wiper plus cutting (treatment 4), or treatments involving seeding (treatments 5 and 6), which all produced a good reduction in frond density and height (especially treatments 5 and 6). Where cutting alone was applied (treatment 3) frond recovery gave an intermediate response (Table 1, Fig. 1).

The initial glyphosate treatment reduced the cover of weeds such as *Cirsium arvense*, *Convolvulus arvensis*, *Achillea millefolium* and all grasses growing beneath the bracken, and facilitated the colonization of pasture species from the seed bank. Colonists included *Dactylis glomerata*, *Poa pratensis*, *Festuca rubra*, *Agrostis vulgaris*, *Holcus lanatus*, as well as of some dicotyledons such as *Achillea millefolium*, *Rumex acetosella*, *Centaurium umbelatum* and *Centaurea stobe*. Initially the herbicide almost completely destroyed the vegetation, and where no seed was added there was a considerable amount of bare ground in the year after application, and recovery was relatively slow, with the speed depending on treatment (Fig. 2). The poorest vegetation development occurred on the untreated plots, which maintained a high proportion of bare ground throughout (Fig. 2). On all other plots where there was no seeding, the vegetation achieved a cover of >80% by the third year, but some plots still retained bare patches until 1996. In all these treatments there was a considerable dicotyledon component. The application of glyphosate by weed wiper and cutting (treatment 4) had little impact on vegetation development. Where the seeding treatment was applied there was a rapid increase in vegetation development within 1 year and there was a substantial grass and legume component throughout the 6 years (Fig. 2).

DISCUSSION

The efficiency of glyphosate for initial bracken control has confirmed the findings of Williams (1980). However, in the absence of follow-up control measures, bracken recovers speedily. Here the most effective follow-up control was achieved either when a follow-up glyphosate treatment by weed wiper was applied followed by cutting twice yearly, or when a seed mixture of *Festuca rubra* and *Vicia cassubica* was sown. The follow-up with glyphosate gave superior control to cutting, and there was no additional benefit to combining cutting with the sowing treatment.

Follow-up treatments are therefore necessary after initial glyphosate treatment for the management of pastures where the outcome is hay production. Two strategies are effective. The first is to apply a second application of glyphosate by weed wiper, here combined with cutting. The use of a weed wiper allows the taller bracken fronds to be treated, yet leaving the shorter grassland species unaffected. Good control was achieved for 5 years, but it is possible that the bracken will recover and further follow-up glyphosate treatments might be needed. The second is to sow a mixture of grass and legume species, essentially as a biological control method. This has been demonstrated to give effective follow-up control, and is especially suitable for those areas where the aim is to produce improved forage for livestock. Where the aim is not to provide improved forage, it might be worth considering sowing a 'break-crop' for a medium-term period to reduce the bracken infestation as far as possible. This approach does, however, require considerable research to develop the most appropriate species and the time required to 'eliminate' the bracken.

The choice of *Vicia cassubica* was based on observations that it grows with bracken under natural conditions, and that where *Vicia cassubica* grows well, the density of bracken is low and the fronds show signs of suppressed growth, a situation analogous to that of bracken *vs. Calluna* (Watt, 1955). When bracken is removed, *Vicia cassubica* develops very quickly and suppresses bracken recovery (Petrov, unpubl. res.). *Festuca rubra* was chosen as a result of tests of potential effects of bracken on a number of meadow grass species, where it was found to be highly resistant (Petrov and Mitev, 1988*a*,*b*, 1989; Petrov *et al*., 1989). These species are thus suitable for central European conditions, but presumably other species could be selected for use elsewhere.

The results discussed here were derived from an experimental situation, where the effects of grazing animals were ignored. It is quite possible that the incorporation of aftermath grazing into this system may alter the competitive balance between the pasture species and different effects may result. This needs to be tested in future work.

LITERATURE CITED

Cock MJW, Lawton JH. 1989. Biological control of bracken. In: Brockman JS, ed. *Weeds, pests and diseases of grassland and herbage legumes*. Croydon: BCPC, 275–276.

Connel JH, Slatyer RD. 1977. Mechanisms of succession in natural communities and their role in community stability and organization. *Am Nat* **111**: 1119–1144.

Fowler SV. 1993. The potential for control of bracken in the UK using introduced herbivorous insects. *Pesticide Science* **37**: 393–397.

Lawton JH. 1986. Biological control of bracken plants and possibilities. In: Smith RT, Taylor JA, eds. *Bracken, ecology, land use and control technology*. Carnforth: Parthenon Press, 447–454.

Lawton JH. 1988. Biological control of bracken in Britain: constraints and opportunities. *Philosophical Transactions of the Royal Society B* **318**: 335–355.

Lawton JH, Rashbrock VK, Compton SG. 1988. Biocontrol of British bracken; the potential of two moths from Southern Africa. *Annals of Applied Biology* **112**: 479–490.

Lowday JE, Marrs RH. 1992*a*. Control of bracken and the restoration of heathland. I. Control of bracken. *Journal of Applied Ecology* **29**: 195–203.

Lowday JE, Marrs RH. 1992*b*. Control of bracken and the restoration of heathland. III. Bracken litter disturbance and heathland restoration. *Journal of Applied Ecology* **29**: 212–217.

Marrs RH, Frost AJ, Plant RA, Lunnis P. 1992. Aerial applications for asulam: a bioassay technique for assessing buffer zones to protect sensitive sites in upland Britain. *Biological Conservation* **59**: 19–23.

Marrs RH, Johnson SW, Le Duc MG. 1998. Control of bracken and the restoration of heathland. VI. The response of bracken fronds to 18 years of continued bracken control or 6 years of control followed by recovery. *Journal of Applied Ecology* **35**: 401–490.

Page CN. 1986. The strategies of bracken as a permanent ecological opportunist. In: Smith RT, Taylor JA, eds. *Bracken, ecology, land use and control technology*. Carnforth: Parthenon Press, 173–181.

Pakeman RJ, Marrs RH. 1992. Vegetation development and moorland after control of *Pteridium aquilinum* with asulam. *Journal of Vegetation Science* **3**: 707–710.

Petrov P. 1984. The effect of glyphosate treatment on bracken in relation to the time of application. *International Symposium on Classification and Utilization of Soils in the Mountain Regions, Sofia, Bulgaria*.

Petrov P. 1988. Restoration of bracken after asulam treatment. *Plant Science* **6**: 99–102.

Petrov P. 1991. *The problem of bracken: theoretically based systems for reclamation of bracken infested natural meadows and pastures*. PhD Thesis, Institute of Plant Protection, Sofia, Bulgaria.

Petrov P, Mitev D. 1988*a*. Allelopathy in bracken. I. Allelopathic effect of water extract from mature leaves of bracken on the germination of seeds of some grasses. *Plant Physiology* **1**: 35–41.

Petrov P, Mitev D. 1988*b*. Allelopathy in bracken. III. Allelopathic effect of bracken root water extract on the germination of some meadow grass seeds. *Plant Physiology* **4**: 79–84.

Petrov P, Mitev D. 1989. Effect of ripe bracken leaf water extract on the growth of some perennial cereal and leguminous grass species sown on meadow soil. *Plant Physiology* **3**: 48–53.

Petrov S, Petrov P, Mitev D. 1989. Allelopathy in bracken. IV. Allelopathic effect of water extract of ripe leaves, roots and the soil under bracken on the cell division in root meristem of some grass species. *Plant Physiology* **1**: 52–58.

Robinson RC. 1986. Practical herbicide use for bracken control. In: Smith RT, Taylor JA, eds. *Bracken, ecology, land use and control technology*. Carnforth: Parthenon Press, 331–340.

SAS. 1988. *SAS/STAT user's guide, release 6·03 edition*. Cary, NC, USA: SAS Institute Inc.

Taylor JA. 1995. Coming to terms with the bracken problem. *International bracken conference*, Aberystwyth, 1994.

Tyler SJ. 1988. *Birds and bracken in Wales: an inter-agency report on its status in the principality with recommendations*. Peterborough: Nature Conservancy Council.

Warren M. 1993. Hot-spot for invertebrates. *Enact* **1**: 6.

Watt AS. 1955. Bracken versus heather: a study in plant sociology. *Journal of Ecology* **43**: 490–506.

West TM. 1992. Response of bracken plants from different sites to potential new herbicide treatments. *Aspects of Applied Biology* **29**: 451–456.

West TM, Butler RC. 1991. Potential new herbicides for bracken control in grassland and hill pastures. *Proceedings of the Brighton Crop Protection Conferences—Weeds.* Fareham: BCPC, 661–668.

West TM, Lawrie J, Cromack T. 1995. Responses of bracken and its understorey flora to some sulfonylurea herbicides and asulam. *Proceedings of the Brighton Crop Protection Conference—Weeds.* Fareham: BCPC, 997–1002.

Williams G. 1980. *Bracken control: a review of progress, 1974–1979.* West of Scotland Agriculture College Research and Development Publication No 12. Auchincruive: SAC.

Womack JG, Burge MN. 1993. Mycoherbicide formulation and the potential for bracken control. *Pesticide Science* **37**: 337–341.