The effect of Asulox spraying on the recovery of natural upland grassland after bracken invasion

Waddecar, M.I.

THE EFFECT OF ASULOX SPRAYING ON THE RECOVERY OF NATURAL UPLAND GRASSLAND AFTER BRACKEN INVASION

M.I. WADDECAR

Submitted as part of the requirements for the degree of Master of Science (Advanced Course in Ecology) at the University of Durham, 1993.

ACKNOWLEDGEMENTS

Thanks to Dr. P.E Hulme, Department of Biological Sciences, without whose advice, support, expertise and tact, this study would not have been completed.
Thanks also to Ian Findlay, Warden, Upper Teesdale NNR, for assistance and guidance at the fieldwork site.
I am indebted to colleagues in the M.Sc. Ecology class for their unfailing good humour, which was a constant source of encouragement.

CONTENTS

ABSTRACT

Bracken (*Pteridium aquilinum*) spreads rapidly as a response to the removal of forest and woodland, invading land cleared for agriculture. In Upper Teesdale bracken has encroached into a juniper woodland and may be preventing regeneration of this species. Recovery of vegetation after the removal of bracken has been examined by considering the nature, abundance and distribution of all species. Shading by the bracken canopy, the accummulation of bracken litter and the grazing by rabbits and sheep all influence the recovery of vegetation along a gradient of successive herbicide spraying of the bracken. The persisitence of the bracken litter layer is important in the recovery of the shade-intolerant species which flourish where bracken has been cleared, since there is generally a time-lag between removal of the bracken canopy and establishment of the grass land community. Areas of high and low bracken density behave differently when cleared, but in terms of abundance, rather than range, of species.

List of Figures.

List of Tables.

1. INTRODUCTION

1.1 BRACKEN.

Pteridium aquilinum L.(Kuhn) is an ancient plant which has survived virtually unchanged for millions of years. It can be found in both hemispheres and even north of the Arctic Circle. It is an extremely invasive plant, capable of taking over from other forms of vegetation given the least opportunity. Man's management of land over the past few hundred years has encouraged the spread of bracken (Anon, 1990).

Bracken can spread in the sporophyte and the gametophyte stage. Release of spores from sori on the abaxial surface of the pinnae can facilitate dispersal over tremendous distances but development of the prothallus in the wild is rare (Kirkwood & Hinshalwood, 1985). The sporophyte spreads largely as result of growth of the rhizome system, which advances as a front, and is protected from winter frost by the litter layer lying on the soil. The rhizome acts as a store of carbohydrate which is utilised by developing buds and fronds. Killing the fronds above the ground is not very helpful, except that it depletes future carbohydrate stores in the rhizomes: rather the rhizomes and buds need eliminating. There are two types of frond - storage and frond-bearing (Lowday, 1987). The latter is much less than the former, and carries the buds which develop into mature fronds. Active buds produce fronds in the next growing season but dormant buds can contain several years supply of fronds. The frond network can be extensive: mature bracken plants vary in diameter from 20m to 390m, and can be as old as 1600 years (Sheffield *et al*, 1989).

Before the arrival of man, when Britain was a wooded and forested country, bracken was a species of open woodland and forest margins. Removal of the forest canopy enables the plant to spread rapidly, and it becomes more aggressive and dominating. Open conditions permit greater spore output than shade, and spores germinate best in virgin soil conditions i.e. those produced by burning off other vegetation. Burning also removes competitors, as does heavy selective grazing by sheep and rabbits (Page, 1982).

Acid peat is unsuitable for bracken growth, but free draining slopes of brown soil such as are found on lower hill faces are ideal (MacLeod, 1982). For example in Scotland bracken grows on well-drained mineral soil under the light shade of scattered birch trees, often dominating the potentially most productive hill land (Scragg,1982). Bracken has even colonised deforested land in Brazil (Taylor, 1986 [ii]).

Bracken stands are generally poor floristically, perhaps only 4-6 species m^{-2} underneath a bracken canopy, except where they protect a relict, woodland vernal flora (Pakeman & Marrs, 1992). Generally speaking, further spread of bracken will lead to the loss of many areas of other habitats with high conservation value e.g. lowland heath, moorland. However, bracken can harbour a number of rare plant species, can provide cover and bedding material for some mammals, and some birds nest preferentially in bracken.

Although several estimates agree that bracken is encroaching at the rate of 1-3% per annum (Taylor, 1986 [i]), a recent postal survey revealed that farmers in Less Favoured Areas have a different perception: in Wales they reported a perceived decline of 1.8%, and in England a perceived increase of 2.5% over the previous 10 years (Varvarigos & Lawton,1991). Loss of land to bracken is comparable with other major land use changes, since 10,360 ha p.a. are lost to bracken, 15,000-20,000 ha p.a. are lost to urban development and between 5,000 and 20,000 ha p.a. are acquired by the Forestry Commission (Taylor, 1986 [ii]).

As well as compet~~e~~ing with other vegetation and harbouring pararsites, it is known that bracken can exert toxic effects in animals and man via five pathways: 7

i) consumption of croziers and fronds
ii) consumption of rhizomes
iii) consumption of spores
iv) leachates in rainwater
v) milk pathways.

Young bracken croziers are eaten as a delicacy in Japan, being compared with asparagus, and associated with a high incidence of gastric cancer (Antice Evans *et al,* 1982). Pigs, horses, cattle and sheep will directly consume bracken fronds or rhizomes in small quantities if no other food is available, or consume spores adhering to grass (Fenwick, 1988). The effects are varied: vitamin B deficiency, acute haemorrhagic syndrome, bovine enzootic haematuria, progressive retinal atrophy, and carcinoma of the digestive tract and urinary bladder. Sheep are less susceptible than cattle (Hopkins, 1990). It is possible that compounds present in bracken may act as immunosuppressive agents in the first years of an animal's life (Jarrett, 1982). It is possible that leachates from bracken-infested land could contaminate springs and wells (Fenwick, 1988; Antice Evans *et al,* 1982). Unusually high incidence of gastric cancer also occur in N Wales, where it is linked with exposure to bracken carcinogens via inhalation of bracken spores (Galpin *et al,* 1990). Exposure to bracken is also linked, in N Wales, to consumption of buttermilk by children and adults on farms, and this could be transferring carcinogens from bracken to humans via dairy cows.

Bracken is the favoured habitat of the sheep-tick, *Ixodes ricinus,* which is a vector of *Borrelia burgdorferi,* the cause of Lyme disease in man (Trotter, 1990). This disorder has only lately been recognised and the incidence would appear quite low currently, but these infections are easily confused with others. *I. ricinus* is also an ecto-parasite of sheep and grouse, and transmits a number of diseases such as louping-ill, tick-borne fever and tick pyaemia (Hudson, 1986). This can lead to financial loss for hill farmers and grouse-shooting interests. The ticks require a humid habitat in which to survive and this is provided by the thick mat of bracken litter associated with rough moorland grasses.

It was mainly during the last century that pastures became heavily invaded by bracken. Before this fronds were cut regularly and put to good use as thatch, bedding for animals - and humans, fuel for heating and cooking, and as a source of potash for soap-making (Lowday & Marrs, 1992 [ii]) When no longer required for such purposes, bracken was still cut or crushed, either by labourers with scythes or by machines specially constructed to cut, slash or bruise the bracken, to maintain the usefulness of the land for agriculture. Bracken control was widespread up to the fifties with grant-aided schemes reaching a peak,depending on scythe men cutting under contract. With mounting wages and the slow rate of cutting, such schemes became unprofitable in the sixties. Maintaining a regime of twice-yearly cutting e.g. mid-June and late July, has been found to be the most effective treatment for bracken reduction. Even so the rhizomes can persist for up to 12 years (Marrs *et al,* 1992; Lowday & Marrs, 1992 [i]). This leads to predictions of 19-21 years for total eradication by cutting. The policy of 'set-aside' means farmers no longer have an incentive to clear bracken from marginal land, so it encroaches faster (Trotter, 1990). Cutting could again become viable if bracken could be used as a biofuel, with the added advantage that summer cutting would lead to rhizome depletion and vulnerability to frost due to removal of the litter material (McCreath, 1982). In the meantime chemical control of bracken has become the norm.

1.2 ASULOX

The extensive rhizome system of bracken, with abundant food reserves and numerous dormant buds, is a difficult target for a foliage applied translocated herbicide. Only in the 1970's was a suitable herbicide made available and subjected to numerous trials: asulam is the only herbicide officially recommended for bracken control, and is applied as an aqueous solution of the sodium salt, marketed as 'Asulox'. Optimal application conditions are when the frond are sufficiently opened to present a large target area, but still with unthickened cuticle on the pinnae so as not to inhibit uptake, Asulox is translocated with the products of photosynthesis to the rhizome where it accumulates in frond buds (Veerasekaran *et al*, 1976).

Warm, moist conditions and freedom from rain in the following 24 hours are the best application conditions. Spraying can be carried out aerially, by tractor operated boom or droplet sprayers, or by knapsack spraying. Wetters increase the uptake of Asulox and improve translocation, and emulsifiable oils prevent droplet evaporation during spraying (Cook *et al,* 1982). Rope wick application can be used to smear concentrated herbicide directly onto taller scattered fronds achieving selectivity (Lowday, 1985). Some fronds may appear in the year after the initial spraying, and 'spot spraying' is recommended as a follow-up one or two years after the original blanket spray.

Asulox is safe to animals, has low persistence in the soil, and there is no evidence of accumulation in food chains (Heywood, 1982).

1.3 VEGETATION RECOVERY

Since bracken invades land which is useful for agriculture and forestry, as well as areas of importance for wildlife, two aspects of vegetation recovery are examined:

i) recovery of vegetation previously on the site before bracken encraochment, whether or not assisted by additional seeding, and

ii) recovery of bracken itself, as a competitor with naturally occuring or sown species.

Grassland, woodland and heathland restoration fall into the first category, while forestry plantations fall into the second. Seeding will assist vegetation recovery in some instances where restoration of grassland or heath has been the aim (Marrs & Lowday, 1992). Species with a competitive advantage on fertile soil may be favoured since bracken litter enriches soils, so litter removal may be necessary (Marrs *et al,* 1992). If removal of bracken allows undesirable species to flourish e.g. birch seedlings in *Calluna* heath, additional control methods to remove these will be necessary (Marrs, 1987). Grant aid for bracken clearance has been conditional upon subsequent addition of fertilizer but many areas of bracken infestation benefit by recovery of vegetation from removal of bracken alone (Martin & Sparke, 1982).

Forestry land requires that bracken is removed before small trees are planted, and then that it is kept under control until the trees are large enough to limit availability of light to the bracken. Bracken can also be a fire hazard, and can cause physical damage by pressing down on new trees in the winter (Biggin, 1982). As long as the bracken is kept at bay for 2-3 years the trees will become established safely.

1.4 AIMS OF STUDY.

On Holwick Fell, Upper Teesdale, there is a well-known juniper woodland which has been causing concern for some years (Piggott, 1955). The juniper trees range from 40 to 300 years in age i.e. there are no new juniper seedlings flourishing to make good the inevitable decline. There are two possible reasons for this:

a) seedling germination hampered by the bracken, either the canopy or the litter

b) grazing of seedlings by rabbits and sheep.

There is an exclosure already at the site to explore the effect of removing, or at least reducing, grazing pressure, and within it the bracken is extensive and vigourous.

The aim of this study was to explore the recovery of vegetation when the bracken canopy is removed, in general terms rather than specifically with regard to the regeneration of juniper. To do this, information has collected about the nature, distribution and abundance of bracken, grasses and dicotyledons to establish how the vegetation changes over a temporal sequence of recovery from Asulox spraying.

2. MATERIALS AND METHODS

2.1 THE SITE

The Teesdale National Nature Reserve includes, at its easternmost margin, an extensive juniper woodland on the south bank of the River Tees (grid reference NY 887283). A similar woodland exists north of the river on the Raby Estate outside the boundary of the NNR. In the Reserve, the Warden has trialled the use of Asulox on one slope, which was therefore selected for this study. The slope runs gently from south to north and so is north-facing, but it is unshaded and of open aspect. The northern boundary is the public footpath through the Reserve (a portion of the Pennine Way), and the southern edge of the study area is delineated by the transition to open moorland at the top of the slope.

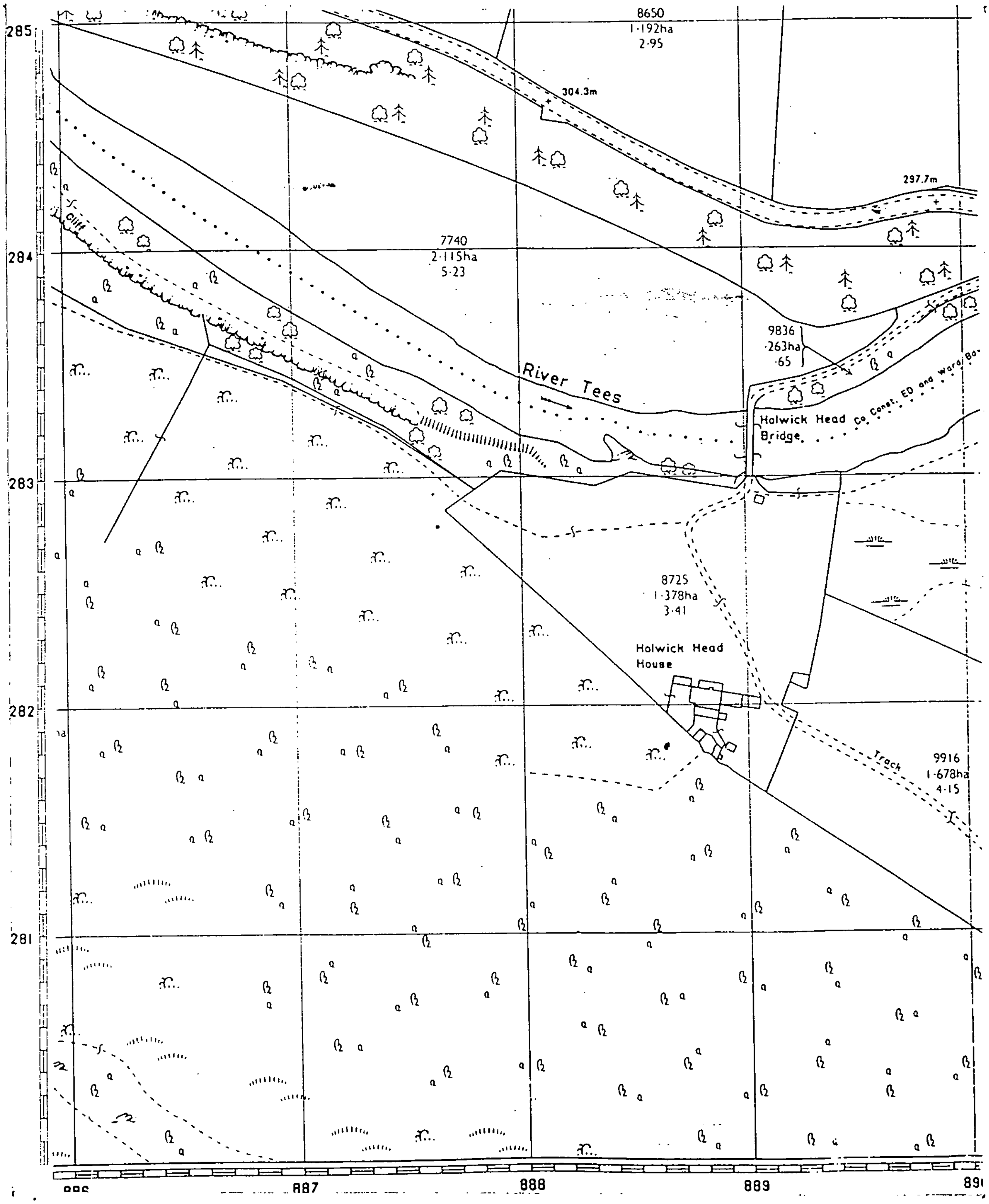
Prior to Asulox treatment, dense bracken covered this slope from the open moorland, where the soil is thin, down to the footpath, and grew in summer to a height of over 1 metre. Spraying has been carried out sequentially in 1990, 1991 and 1992, in swathes 15 to 40 metres wide running east-west across the slope. It was intended to spray further bracken stands higher up the slope in 1993 after this study had been completed. This strategy has produced an easily visible series of vegetation bands perpendicular to a bracken/Asulox treatment gradient, from untreated bracken stands at the top, southern edge of the slope, through several years of spraying, to a turf sprayed 3 years previously at the bottom, northern edge of the slope. There is also an east-west difference on the site, with much denser bracken stands to the east than to the west. This is not apparent early in the season before the bracken croziers come through, so the positioning of the boundary relied on evidence from the Warden.

Sheep and rabbits freely graze the slope, both species feeding up the slope away from the public footpath, and rabbits mainly grazing within 20 metres of the path: rabbits crop turf shorter than sheep. It would be difficult to measure the effect of this grazing pressure. Rabbits were also responsible for disturbance of soil by burrowing.

A control area could not be located in the Reserve, as sites selected as possible areas of natural grazed upland grassland soon displayed evidence of bracken encroachment. Eventually permission was obtained to use an area of farmland adjoining the Reserve, where bracken had been eliminated some years previously, and which was grazed by rabbits only.

Holwick Fell, High Force

Upper Teesdale



2.2 SELECTION OF PLOTS AND EXPERIMENTAL DESIGN

Permanent 2 metre quadrats were set up on the site to cover the 5 treatments, at both high and low bracken density where feasible. There were 5 replicates for each, as follows:

Quadrat	Bracken density	Treatment
1F - K	NIL	grazed moorland
2A - E	high	unsprayed bracken
2F - K	low	unsprayed bracken
3A - E	high	1992 spraying
3F - K	low	1992 spraying
4A - E	high	1991 spraying
4F - K	low	1991 spraying
5F - K	low	1990 spraying
6F - K	NIL	grazed inbye land

N.B. For treatments 1, 5 and 6, it was not possible to locate equivalent sites of high bracken density.

The replicates for each treatment were set out as far as possible at the same altitude, and regularly spaced about 15 metres apart. Generally the quadrats were positioned so as to lie on a transect along the treatment/bracken gradient down the slope. Care was taken to avoid excessively damp, disturbed, trampled or rocky areas, and for treatments 5 and 6, to keep at least 10 metres from the public footpath in an attempt to avoid interference with the pegs. The north-east corner of each quadrat was marked with a small wooden peg painted white which was concealed from the path by a pile of stones or piece of turf. The position of each peg was carefully measured and noted, to allow location of the quadrat this year, should the peg be disturbed by passersby or animals, and next year, should the peg be concealed by vegetation.

When examining vegetation, each quadrat corner was marked with a 1 metre bamboo pole after measuring the quadrat sides with a metric tape and orienting the quadrat with a navigational compass. Additional poles laid on the ground were used to subdivide each quadrat into 4 sections as required.

2.3 TECHNIQUES

2.3a. Point quadrats.

This method involves the use of a narrow diameter metal pin, calibrated in centimetres, to collect information about the identity, abundance and height of the plant species present in the quadrat. Two pins were used, one about 40cm high for short vegetation, and one about 60cm high for the taller vegetation. Each pin was calibrated with clear centimetre-calibrated adhesive tape, with the addition of narrow strips of coloured tape to mark the 5cm and 10cm divisions. The tape needed renewing after prolonged use, although a coating of varnish or similar could improve durability. The calibrations commenced 5cm from the insertion point of the pin, to permit the pin to stand without support when placed in the ground perpendicular to the vegetation. The top end of the pin was bent over at right angles to assist with removal from the ground.

The pin is inserted into the ground through the vegetation with minimal disturbance. The point of the pin will not be visible in dense turf, but noting the position on the scale of one arbitrary leaf when the pin first touches the soil, as felt by a change in resistance, facilitates the insertion of the pin to the correct depth - in this case, by an increase in the arbitrary reading of 5cm. When the pin is inserted, the identity of the species touching the pin on all sides is recorded and the number of touches of each species at each height interval is also recorded as a tally. It is generally found that starting recording at the greatest height and working downwards into the vegetation will produce the least disturbance and distortion of results.

In each 2m quadrat, the pin was placed randomly 40 times. The quadrat was divided into quarters by laying bamboo poles on the gound, and 10 pins placed in each section. The accuracy of the technique can be improved by placing more pins in each quadrat. It was found that random placing of the pin could be influenced by visual cues, so an approximation to a grid pattern was followed in each quarter. In quadrats where vegetation was tall and dense, particular care had to be taken to prevent damage and at the same time ensure that the full area of the quadrat was sampled.

Problems arose with the recording of number of touches of bracken in regions of dense bracken litter: after some thought it was decided to record an arbitrary value of 10 touches per centimetre in these instances, which was denoted by 'L' (for litter) on the record sheet.

For each quadrat, the data from the 40 pins can be summated to give a picture of the species adundance and the architecture or 'shape' of the vegetation. The height categories in which the vegetation touches are recorded are chosen with this in mind: here touches were recorded every centimetre up to 5cm, to accommodate the turf species and litter, then every 5cm up to 30cm, to pick up the taller herbaceous species, and finally every 10cm up to 50cm with a 50cm-plus category, to allow recording of the bracken canopy. Two classes of results can be obtained: either for the total biomass, expressed as number of touches, for each height interval, or for the biomass of each species, both in a height distribution or in relation to other species in the sample.

Species of which there are very small numbers present in the quadrat could be missed by this method, so it is important to record percentage vegetation cover with the Domin scale as well.

Point quadrat data and Domin scale scores were collected three times at approximately monthly intervals - May, June, July - to explore the development of the vegetation, with particular reference to the effect of bracken canopy, past and present, on other species.

2.3b. Frond growth.

The annual growth of the new bracken after the winter die-back was considered for two reasons, to discover if bracken flourishes as an even-aged stand, and to give some measure of the success or otherwise of the Asulox spraying on the site. Thirty 1 metre quadrat samples were taken randomly in each of the treatment areas (excluding treatment 6, where bracken had been eliminated some years ago, and treatment 1, where bracken had never grown) and the number of bracken fronds was recorded. The intention was to record frond numbers in 3 categories: a) croziers, the small tightly-curled emergent fronds b) upright unopened fronds and c) fully unfurled fronds. This data was collected once, during June. e/ e/ were/

2.3c. Bracken litter depth.

The point quadrat data will give measurements of dead bracken biomass which will be related to depth of bracken litter: to obtain a direct measure of bracken litter depth, a 10cm soil core was taken from every quadrat. The proportion of bracken litter was measured by the depth of litter floating at the surface after thoroughly mixing the soil sample with an equal volume of water in a measuring cylinder and allowing the heavier particles to settle out.

3. RESULTS

3. RESULTS

Analysis of data has been conducted on

a) log transformation of number of touches of vegetation from point quadrats for biomass

b) log transfomation of numbers of fronds for frond regrowth

c) log transformation of numbers for species numbers

d) ranks of Shannon-Weaver Diversity Indices

e) raw data for litter depth

In the original layout of the replicates, Treatment 1:grazed upland grassland was difficult to site: an area selected at the top of the slope on open moorland was judged unsuitable after one sampling, due to the range of species being typical of poor moorland soils rather than of grassland. This explains why Treatment 1 data does not feature in consideration of results.

3.1 HOMOGENEITY OF REPLICATES.

Data for each treatment ~~was~~ were collected from 5 replicates: homogeneity of these was determined by considering the percentage of species common to 4 or more of the replicates in each treatment (Table 1).

Table 1. Homogeneity of replicates

Replicate	Treatment (year of spray)	Bracken density	May	June	July
2A-E	NONE	HIGH	50%	80%	50%
2F-K	NONE	LOW	67%	61%	72%
3A-E	1992	HIGH	30%	32%	44%
3F-K	1992	LOW	56%	74%	57%
4A-E	1991	HIGH	63%	58%	53%
4F-K	1991	LOW	61%	63%	55%
5F-K	1990	LOW	50%	41%	43%
6F-K	NONE	NIL	50%	54%	66%

Generally, for each treatment, 50% or more of the species are common to 4 or more replicates, with the exception of replicates 3A-E and 5F-K, which is quite satisfactory. The 3A-E replicates are situated in an area of formerly high bracken density, which was sprayed with Asulox 12 months previously i.e. in 1992. The spraying has been quite successful at preventing regrowth of bracken, with very few fronds appearing in the current growing season, so this area represents a transition between the former very shaded circumstances and the current open and much lighter situation. It is reasonable to suppose that vegetation change consequent to such an environmental change will be very varied in terms of the number and distribution of the newly occuring species, hence the low value for homogeneity.

Replicates 5F-K have rather low values. This is an area of formerly low bracken density sprayed with Asulox 3 years previously i.e. in 1990. Although it could not be referred to as 'transitional' vegetation, there are several newly but infrequently occurring grassland species in this area which could account for the lower homogeneity (Appendix 2).

3.2 BRACKEN.

This is considered in two categories:

a) live bracken	i) bracken frond biomass
	ii) frond regrowth
b) dead bracken	i) dead bracken biomass
	ii) litter depth

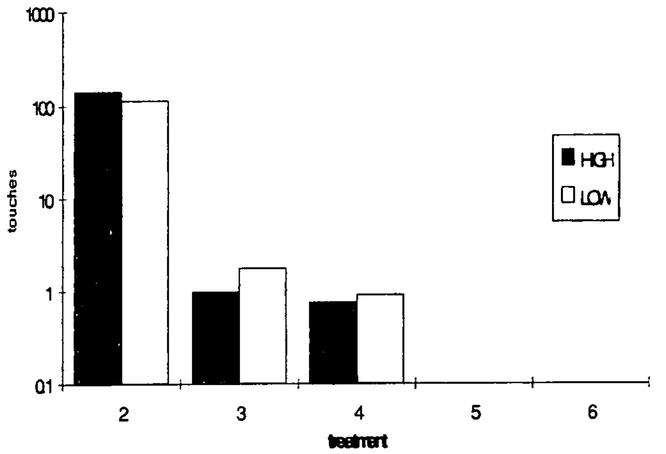
There is no bracken in treatment 6:grazed only.

3.2a. Live bracken.

i) Bracken frond biomass

Two-way analysis of variance of all treatments shows significant differences between treatments ($F_{(7,96)}$= 112.31, p<0.001) and between seasons ($F_{(2,96)}$= 7.27, p<0.01) for bracken frond biomass. Treatment 5:1991 spray has no touches of fronds at all over the 3 months. Treatment 4:1991 spray at high bracken density has a fall to zero in frond biomass from May to June and July: this reflects the very low incidence of fronds and consequent sampling error in these replicates (Fig.1).

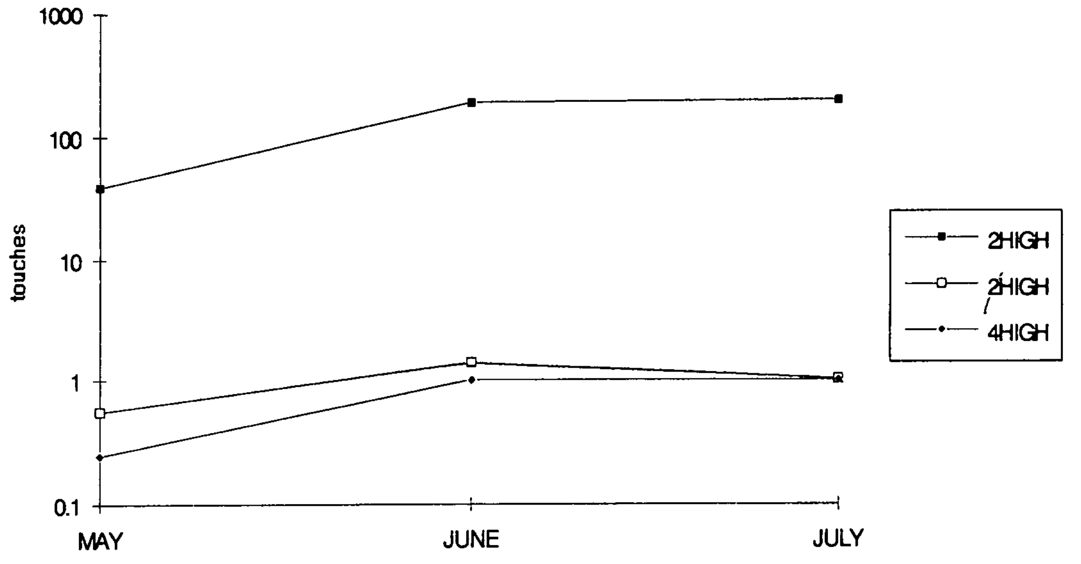
Fig. 1. Frond biomass as touches per quadrat in high and low density bracken replicates.



Frond biomass is less in treatments 3:1992 spray and 4:1991 spray than in treatment 2:no spray at both high and low bracken densities. Use of t-tests shows that differences between areas of different bracken density are not significant for any of these treatments at any of the three monthly samples.

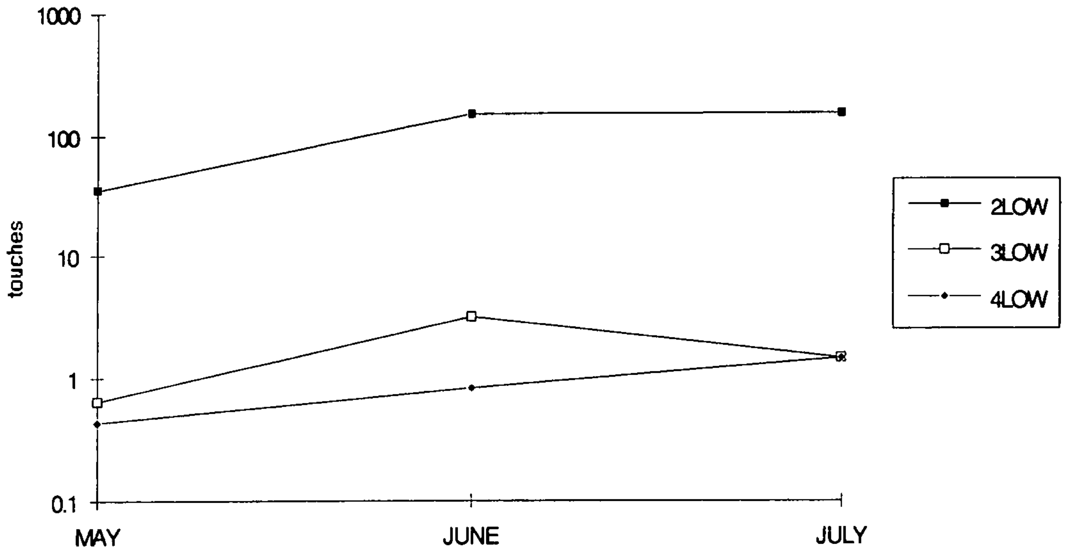
Where there is appreciable frond biomass (treatment 2), there is an increase from May to June: thereafter the value remains almost steady (Figs. 2a and 2b).

Fig. 2a. Seasonal change in frond biomass in high bracken density replicates.



3?

Fig.2b. Seasonal change in frond biomass in low bracken density replicates.

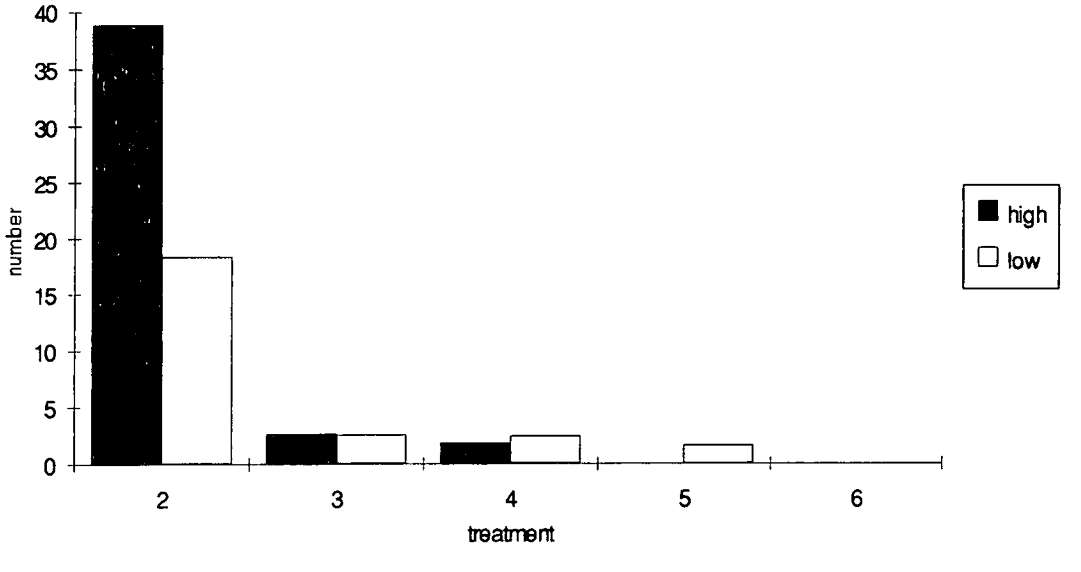


The rise in frond biomass in treatment 4:1991 spray at low bracken density indicates that the spraying regime has not been completely effective at preventing regrowth of bracken fronds. Discussion with the Reserve Warden reveals that spraying cannot always be carried out under optimal conditions i.e. when the fronds are at their most receptive to the uptake of Asulox, due to inclement weather. However these are very small values and the variation may be due to sampling error.

ii) Frond regrowth.

One-way analysis of variance shows significant difference in frond numbers between all treatments ($F_{(6,203)}$= 182.57, p<0.001) as does separate consideration of high bracken density ($F_{(2,87)}$= 449.07, p<0.001) and low bracken density areas ($F_{(3,116)}$= 111.69, p<0.001). There is a general decrease in frond numbers along the treatment gradient from treatment 2:no spray to treatment 5:1990 spray. It is generally the case that numbers are greater in high bracken density areas than in low bracken density areas (Fig. 3).

Fig. 3. Numbers of fronds m^{-2} in high and low bracken density replicates.



Use of t-tests shows that there is no significant difference in frond number in treatments 4;1991 spray and 5:1990 spray, but that the difference is significant in treatment 2:no spray ($p<0.001$).

The difference between treatments for both frond biomass and frond regrowth reflects the spraying regime, and indicates considerable success since the values for both are so low in the sprayed areas. The value is smaller in areas of low bracken density, and decreases with increase in recovery time. By mid-June the bracken canopy in treatment 2 replicates was well-developed, providing extensive shade to the vegetation beneath.

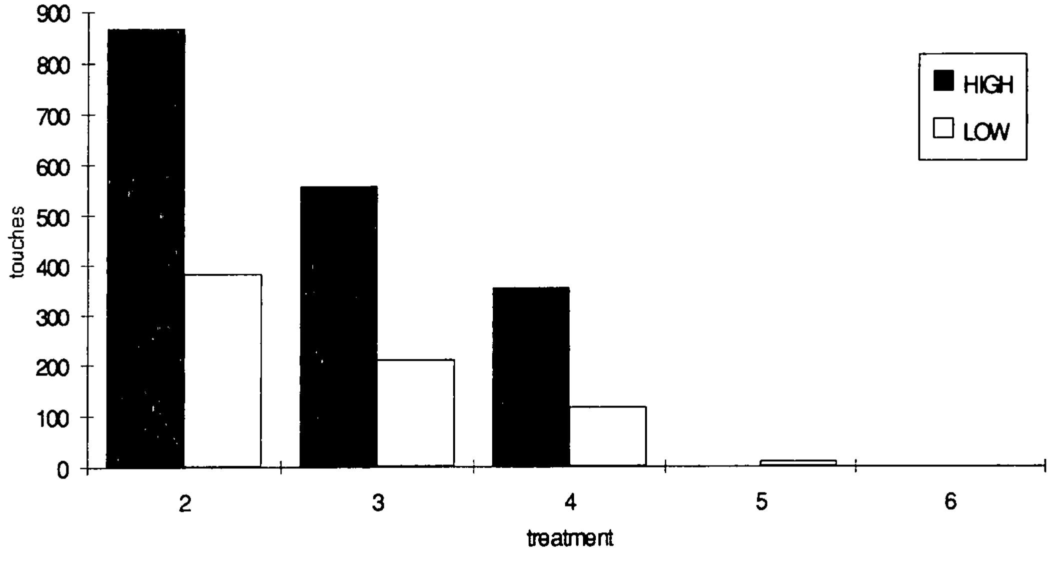
3.2b. Dead bracken

i) Dead bracken biomass.

Dead bracken biomass is made up of two components, the small particles of bracken litter which form a layer on the soil surface and the taller remnants of dead fronds from the winter die-back. The latter is considerably less than the former, so this which?
category can be taken as a fair reflection of bracken litter biomass.

Two-way analysis of variance shows significant differences between all treatments ($F_{(7,96)}= 308.24$, $p<0.001$) and between monthly samples ($F_{(2,96)}= 7.27$, $p<0.01$). There is a decrease in dead bracken biomass along the treatment gradient from treatment 2:no spray to treatment 5:1990 spray, and the value is greater in high bracken density areas than in the corresponding low density areas (Fig.4).

Fig. 4. Dead bracken biomass as number of touches in high and low bracken density replicates.



Generally, differences between dead bracken biomass in corresponding high and low density areas were significantly different for all treatments at all monthly samples (Table 2).

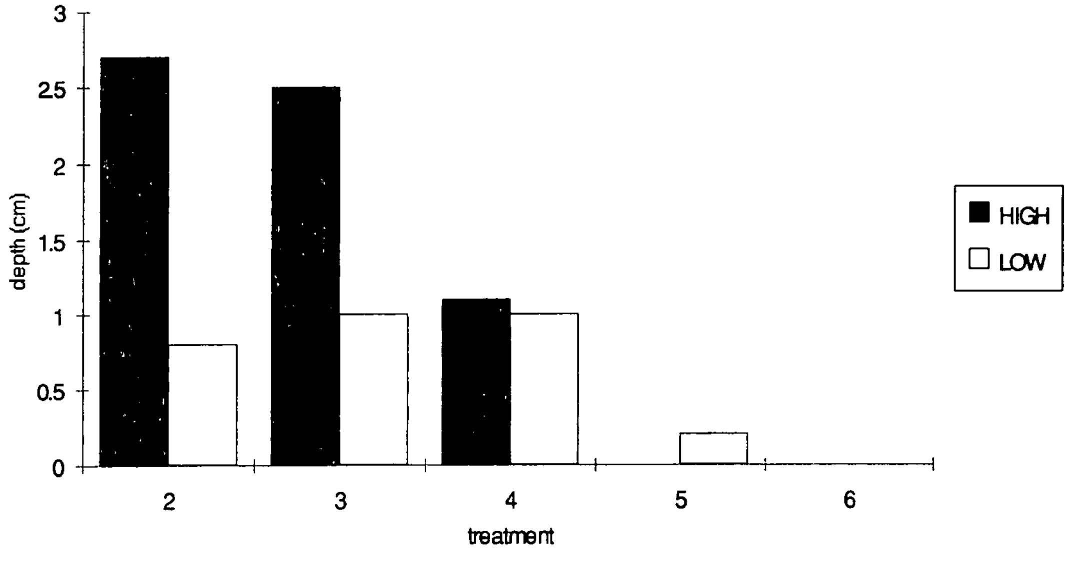
Table 2. Difference between dead bracken biomass in corresponding high and low bracken density plots.

treatment	May	June	July
2:no spray	p<0.05	p<0.05	n.s.
3:1992 spray	p<0.05	p<0.01	n.s.
4:1991 spray	p<0.01	p<0.01	p<0.01

ii) Bracken litter depth.

Two-way analysis of variance revealed a significant difference in litter depth between areas of high bracken density and areas of low bracken density ($F_{(1,24)}= 4.51$, $p<0.05$) but not between years of spraying. There is deeper litter in areas of high bracken density than areas of low density for treatments 2, 3 and 4. Treatment 5:1990 spray, where the litter depth is considerably less, cannot be considered as there were replicates only in the low bracken density area (Fig. 5).

Fig.5. Bracken litter depth in high and low bracken density replicates.



Bracken litter persists for some years after spraying. In the high bracken density areas there is little apparent loss of litter the year immediately after spraying, but a more significant loss after 2 years when the value falls to a level similar to the low bracken density areas. In the low bracken density areas there is little apparent litter loss until 3 years after spraying.

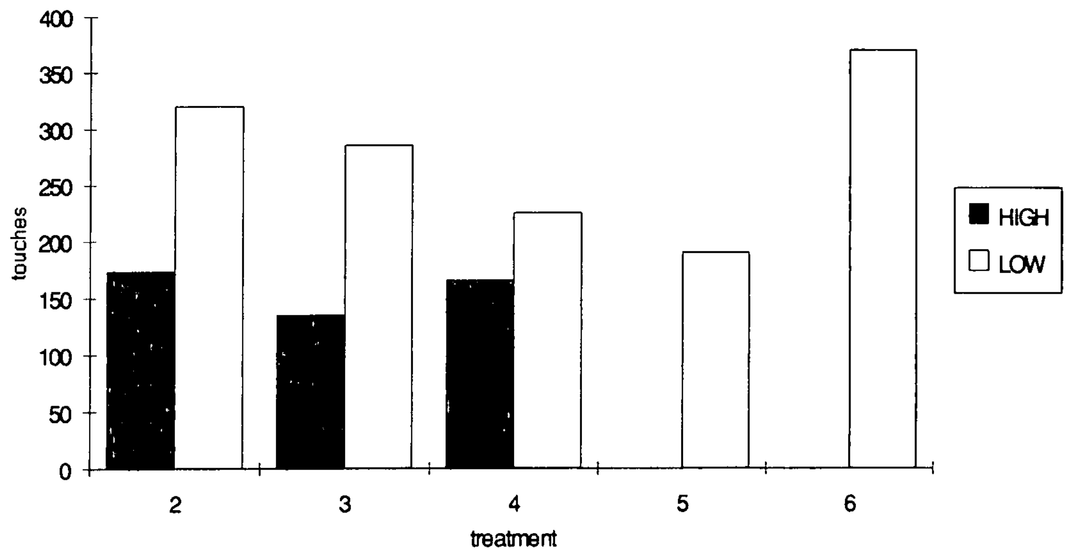
The two techniques for measuring bracken litter give complementary results. There is more bracken litter in areas of high density than low, and the biomass declines with increase in recovery time. Although the frond biomass and number values are very low in the sprayed areas (treatments 2, 3 and 4), these same replicates possess considerable though varying biomass of bracken litter.

3.3. BIOMASS OF GRASS AND DICOTYLEDONS.

a) Grass biomass.

Two-way analysis of variance reveals that all treatments have significantly different grass biomass ($F_{(7,96)}$= 25.37, $p<0.001$): the difference between treatments in high bracken density areas is not significant, while in low bracken density areas the grass biomass is significantly different ($F_{(4,60)}$= 26.23, $p<0.001$). There is a decrease in grass biomass in low bracken density areas along the treatment gradient from treatment 2:no spray to treatment 5:1990 spray, with a rise to treatment 6:grazed only (Fig. 6).

Fig. 6. Grass biomass as number of touches in high and low bracken density replicates.



Grass biomass in low bracken density areas is consistently greater than in high bracken density areas, and use of t-tests shows that this is generally significant (Table 3).

Table 3. Difference in grass biomass between corresponding areas of high and low bracken density.

treatment	MAY	JUNE	JULY
2:no spray	$p<0.05$	$p<0.05$	$p<0.05$
3:1992 spray	$p<0.05$	$p<0.05$	$p<0.001$
4:1991 spray	n.s.	$p<0.05$	$p<0.05$

The difference in monthly samples is significant for all treatments ($F_{(2,96)}= 8.19$, $p<0.001$) and in low bracken density areas ($F_{(2,60)}= 16.48$, $p<0.001$) but not in high bracken density areas (Figs. 7a and 7b). The general pattern is one of seasonal increase.

Fig. 7a. Grass biomass in high bracken density replicates.

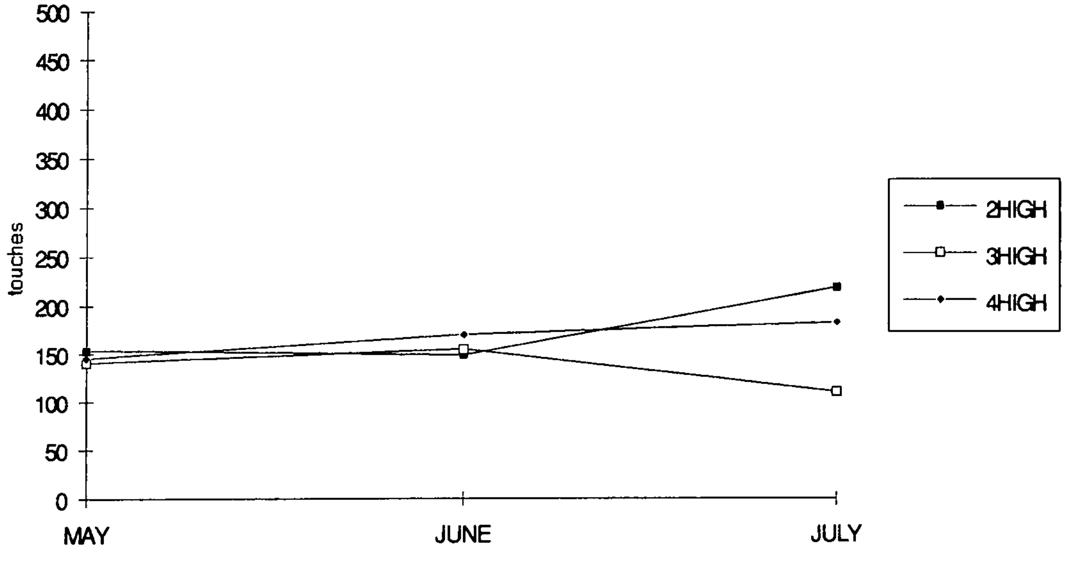
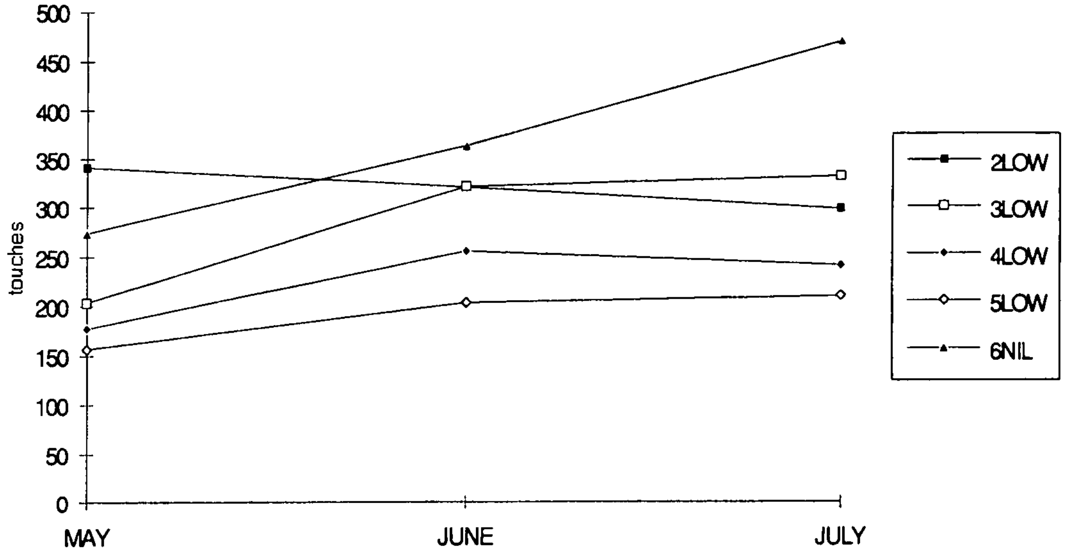


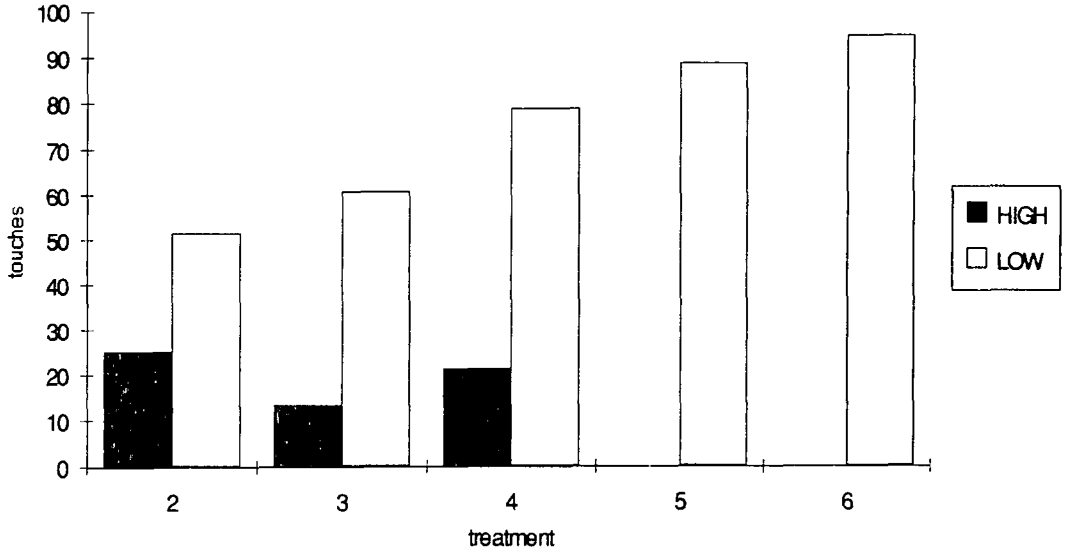
Fig. 7b. Grass biomass in low bracken density replicates.



b) Biomass of dicotyledons.

Two-way analysis of variance showed that the significant difference in dicotyledon biomass is between treatments ($F_{(7,96)}$= 22.77, $p<0.001$) rather than between seasons. This is also true when considering the high bracken density areas ($F_{(2,36)}$= 3.39, $p<0.05$) separately from the low bracken density areas ($F_{(4,60)}$= 5.65, $p<0.001$). In low bracken density areas, there is an increase in value from treatment 2:no spray to treatment 6:grazed only (Fig.8).

Fig. 8. Biomass of dicotyledons as number of touches in high and low bracken density replicates.



Using t-tests to investigate the biomass of dicotyledons in high and low bracken density areas of the same treatment revealed that the difference was significant for all three months in treatments 3 and 4 (1992 and 1991 spray respectively) but not for treatment 2:no spray (Table 4).

Table 4. Difference in dicotyledon biomass between corresponding areas of high and low bracken density.

treatment	MAY	JUNE	JULY
2:no spray	$p<0.001$	n.s.	n.s.
3:1992 spray	$p<0.01$	$p<0.001$	$p<0.05$
4:1991 spray	$p<0.01$	$p<0.001$	$p<0.001$

For treatment 2:no spray the difference was significant only in May, when the biomass of dicotyledons was greater in the low density area. As the months pass and the fronds unfurl, the shading by bracken canopy in both areas of treatment 2 appears very similar, and this could explain the similarity in dicotyledon biomass.

The response of grasses and dicotyledons to the regime of treatments is

a) similar, in that the biomass of each is greater in the low density than the high density bracken areas, and

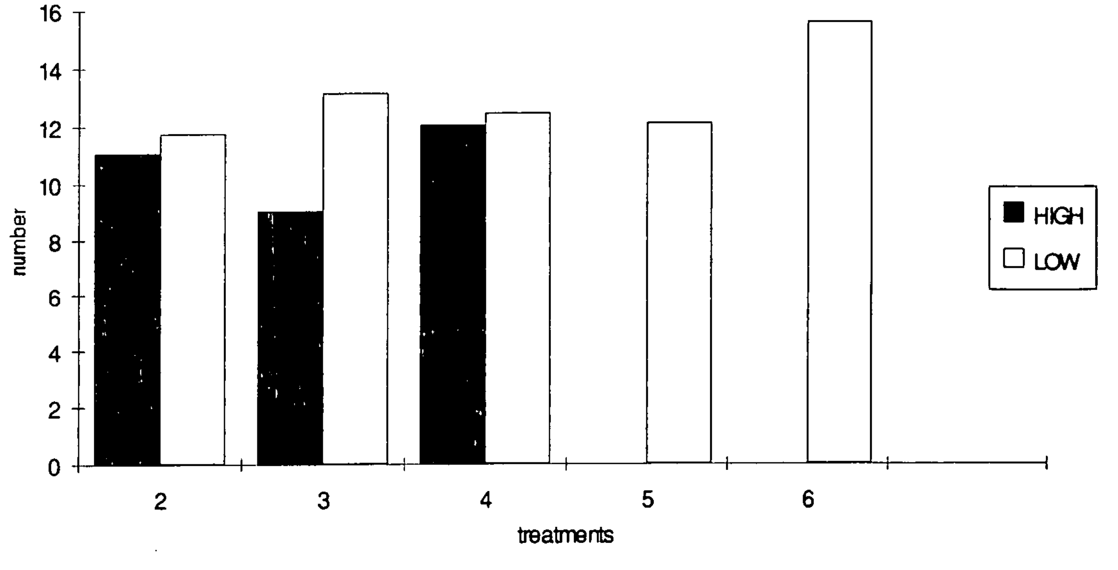
b) different, in that the biomass of grass decreases with increase in recovery time, while the biomass of dicotyledons increases.

3.4 NUMBERS OF SPECIES.

a) All species

Two-way analysis of variance shows that the number of all species is significantly different between all treatments ($F_{(7,96)}$= 8.11, $p<0.01$) but not between monthly samples. This is also true when considering high bracken density areas ($F_{(2,36)}$= 3.95, $p<0.05$) separate from low bracken density areas($F_{(4,60)}$= 9.69, $p<0.001$). The number is greater in low bracken density areas (Fig. 9).

Fig. 9. Number of all species.

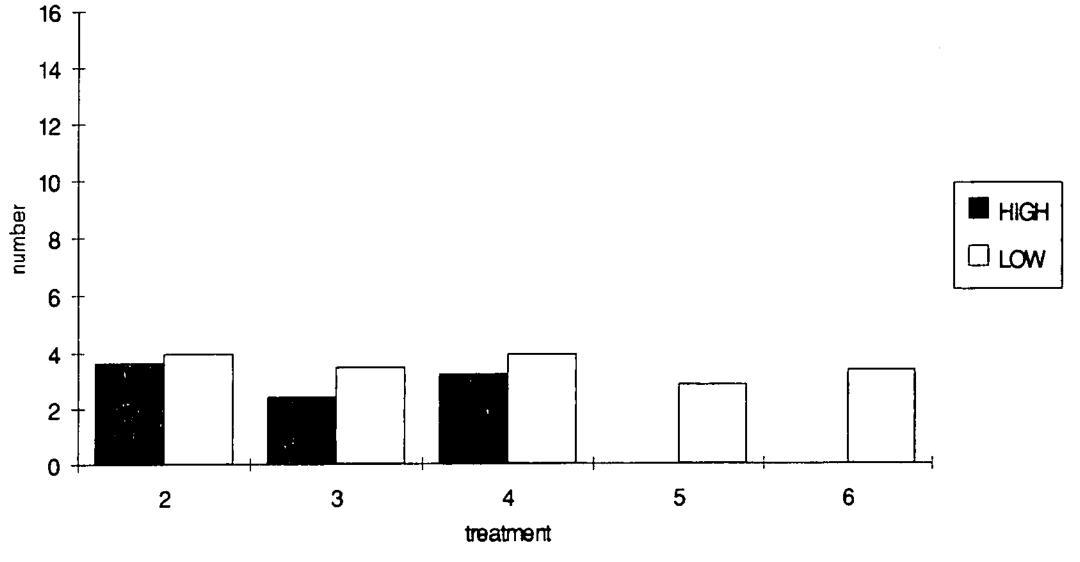


b) Grass species.

Two-way analysis of variance shows that the number of grass species is significantly different between all treatments ($F_{(7,96)}$= 5.53, $p<0.001$) but not between seasons.

This also holds true when considering low bracken density areas ($F_{(4,60)}$= 7.15, p<0.001) separate from high bracken density areas ($F_{(2,36)}$= 4.99, p<0.05). The number is greater in low bracken density areas (Fig. 10).

Fig. 10. Number of grass species.

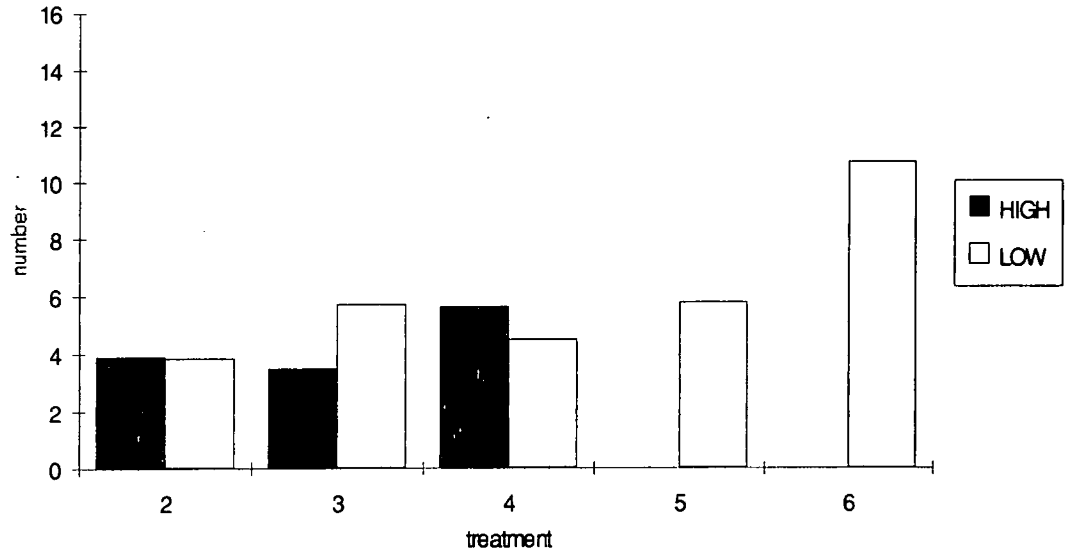


c) Dicotyledon species.

Two-way analysis of variance reveals that there is significant difference in the number of dicotyledon species between all the treatments ($F_{(7,96)}$= 18.42, p<0.001) but that seasonal differences are not significant. This is also true when considering high bracken density areas ($F_{(2,36)}$= 6.09, p<0.01) separate from low bracken density areas ($F_{(4,60)}$= 31.92, p<0.001).

There is a general increase in the number of dicotyledon species along the treatment gradient from treatment 2:no spray to treatment 6:grazed only (Fig. 11). Treatment 3:1992 spray i.e. transition area, shows a dip in the number of dictyledon species in the high bracken density replicates and a peak in the low bracken density replicates.

Fig. 11. Number of dicotyledon species.



There are more grass and dicotyledon species in areas where bracken has been cleared the longest, and where the bracken density was originally low. However the number of grass species is not significantly different between corresponding areas of high and low bracken density, and the number of dicotyledon species is significantly different in treatment 3 only, where the value is higher in the low bracken density replicates.

3.5. DIVERSITY INDICES.

The Shannon-Weaver Diversity Index was calculated for all replicates for each of the monthly samples (Appendix 1). One-way analysis of variance was carried out on ranks of the indices to investigate differences between treatments, differences between monthly samples and differences between high and low bracken density areas of the same treatments. No significant differences were apparent: the larger part of the vegetation being accounted for by grass biomass made any other outcome unlikely. Comparison of diversity indices for dicotyledons only, to remove the influence of the number and abundance of grass species, may have been informative.

3.6. INDICATOR SPECIES.

The median of the Domin scores for the 5 replicates of each treatment at each month was drawn up, and used to select possible indicator species (Appendix 2). The intention was to consider in more detail:

a) species which were shade-tolerant
b) species which were shade-intolerant
c) species which occurred universally but with varying abundance.

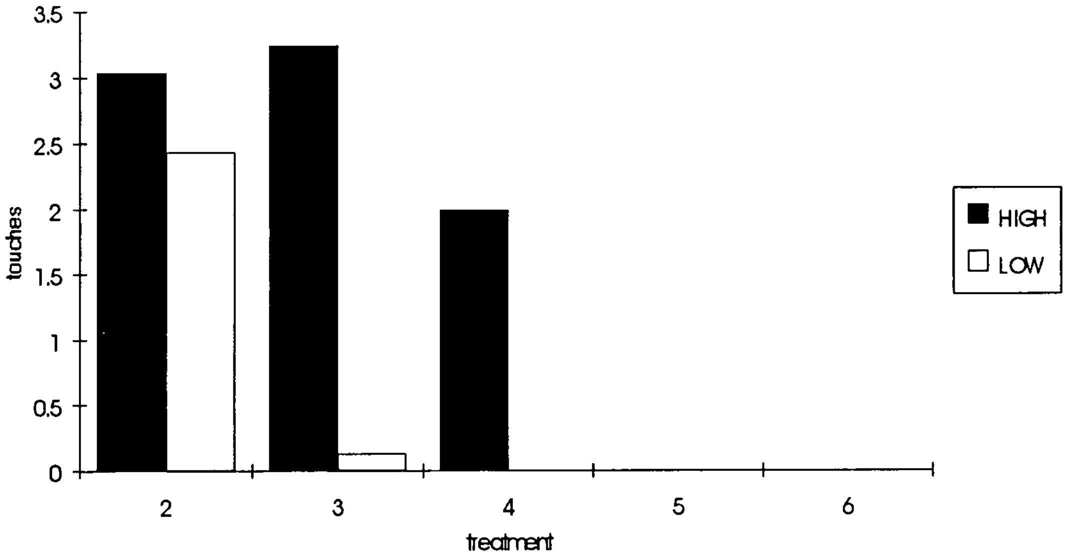
The following were selected:

a) shade-tolerant:	*Oxalis acetosella*
b) shade-intolerant:	*Galium saxatile*
c) universal:	i) *Potentilla erecta*
	ii) *Viola riviniana*
	iii) *Rhytidiadelphus squarrossus*
	iv) *Festuca ovina*

3.6a. *Oxalis acetosella*

Two-way analysis of variance reveals significant differences in biomass between treatments ($F_{(7,96)}$= 8.22, p<0.001) but not between monthly samples. The same is evident when low bracken density areas are considered alone ($F_{(4,60)}$= 22.52, p<0.001), but in high bracken density areas there is no significant difference between either treatments or monthly samples. In low bracken density areas there is a decrease in biomass along the treatment gradient from treatment 2:no spray to treatment 4:1991 spray (Fig. 12).

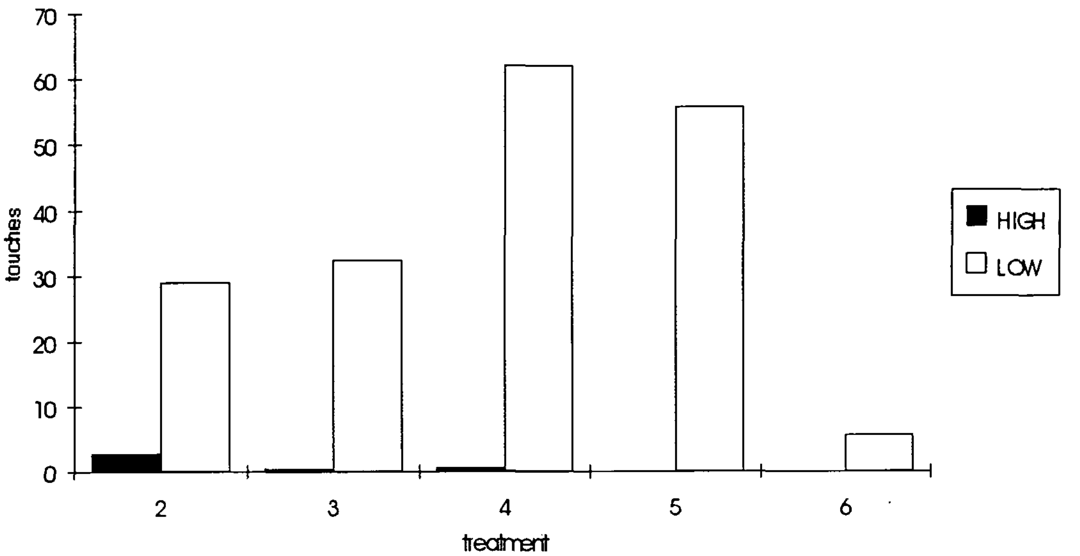
Fig. 12. Biomass of *Oxalis acetosella* as number of touches in high and low bracken density replicates.



3.6b *Galium saxatile*

Two-way analysis of variance shows significant difference in biomass between all treatments ($F_{(7,96)}$= 24.12, p<0.001) but not between monthly samples. This is true also for high bracken density areas ($F_{(2,36)}$= 3.68,p<0.05) when considered separately from low density areas ($F_{(4,60)}$= 6.74, p<0.001). The values in the low bracken density areas are consistently greater than those in the high bracken density areas (Fig. 13).

Fig. 13. Biomass of *Galium saxtile* as number of touches in high and low bracken density replicates.

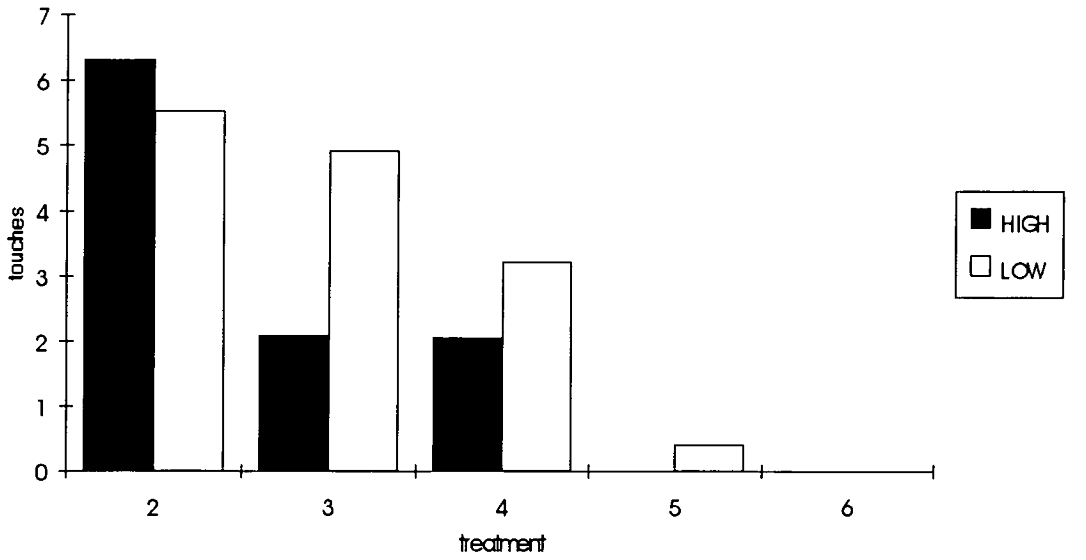


In the high bracken density areas the biomass is very small,and in low bracken density areas there is an increase in biomass with increase in length of recovery time.

3.6c.i) *Potentilla erecta*

Two-way analysis of variance shows significant difference in biomass between treatments ($F_{(7,96)}$= 7.70, p< 0.001) but not between monthly samples. In low bracken density areas considered separately from high density areas the difference between treatments was significant ($F_{(4,60)}$= 12.47, p<0.001) but not in high density areas. The biomass was generally greater in low bracken density areas than in the corresponding high density areas, but not significantly so (Fig. 14).

Fig. 14. Biomass of *Potentilla erecta* as number of touches in high and low bracken density replicates.

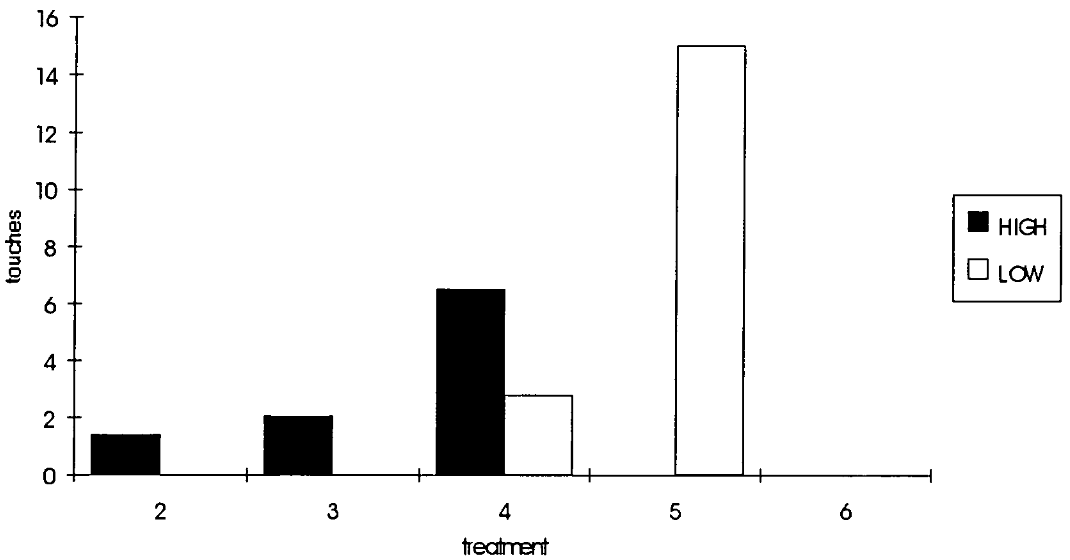


There is a general decline in biomass with increase in length of recovery time since spraying in both high and low bracken density areas.

3.6c.ii) *Viola riviniana.*

Two-way analysis of variance shows significant difference between treatments ($F_{(7,96)}$= 22.43, p<0.001) but not between monthly samples.The same is true when high bracken density areas ($F_{(2,36)}$= 6.10, p<0.01) are considered separately from low bracken density areas ($F_{(4,60)}$= 43.87, p<0.001): the species does not occur in all treatments. There is an increase in biomass with increase in recovery time (Fig. 15).

Fig. 15. Biomass of *Viola riviniana* as number of touches in high and low bracken density replicates.



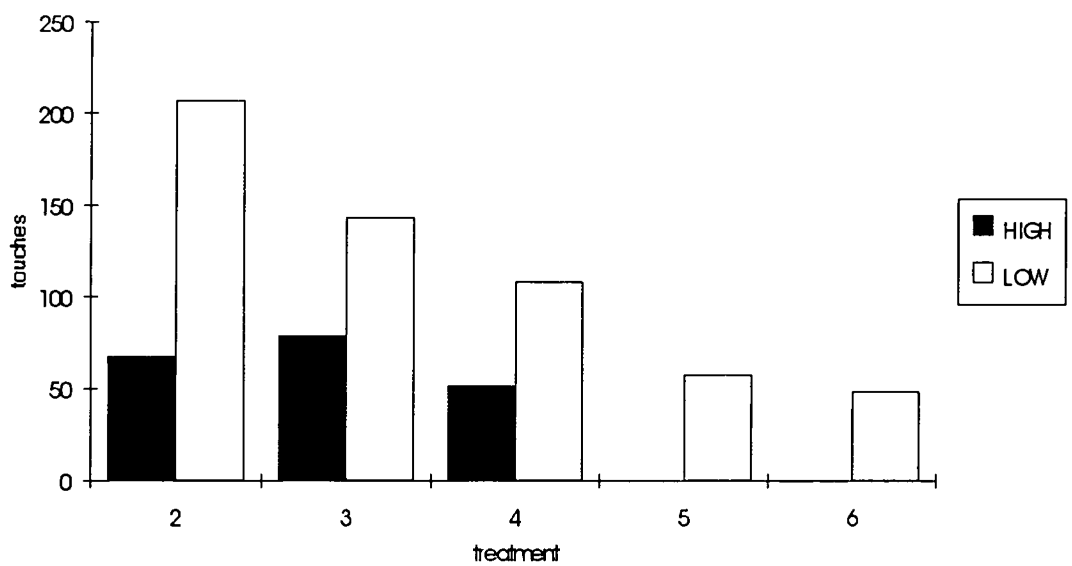
Although the difference between monthly samples was not significant it was noted that in the shade i.e. treatment 2 replicates, the biomass increased seasonally, while in the open i.e. all other replicates, the biomass decreased seasonally.

Use of t-tests shows that there is no significant difference in biomass between high and low density replicates at any of the monthly samples for treatment 4:1991 spray, the only treatment where *Viola riviniana* is present at both bracken densities.

3.6c.iii). *Rhytidiadelphus squarrosus.*

Two-way analysis of variance shows significant differences in biomass between all treatments ($F_{(7,96)}$= 10.53, p<0.001) and between monthly samples ($F_{(2,96)}$= 3.53, p<0.05): the same is true in low bracken density areas (treatments: $F_{(4,60)}$= 10.37, p<0.001 and monthly samples: $F_{(2,60)}$= 3.46, p<0.05). In high bracken density areas the significant difference is between treatments ($F_{(2,36)}$= 4.57, p<0.05) but not between monthly samples. In the low bracken density areas the biomass decreases along the treatment gradient from treatment 2:no spray to treatment 6:grazed only (Fig. 16).

Fig. 16. Biomass of *Rhytidiadelphus squarrosus* as number of touches in high and low bracken density replicates.



The values are higher in the low bracken density areas than in the corresponding high density areas. Use of t-tests shows significant differences in biomass of this moss between corresponding areas of high and low bracken density for all treatment at all monthly samples except treatment 3 in July (Table 5).

Table 5. Differences in biomass of *Rhytidiadelphus squarrosus* between corresponding areas of high and low bracken density.

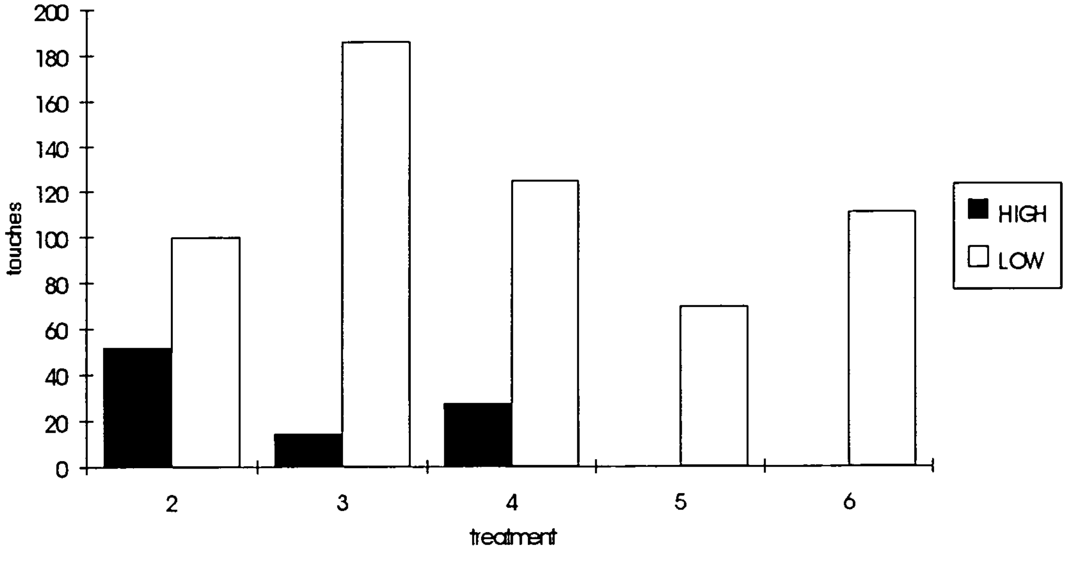
treatment	MAY	JUNE	JULY
2:no spray	$p<0.05$	$p<0.01$	$p<0.01$
3:1992 spray	$p<0.001$	$p<0.05$	n.s.
4:1991 spray	$p<0.01$	$p<0.05$	$p<0.01$

In the high bracken density areas no seasonal pattern is clear. In the low bracken density areas there is an increase in biomass over the three month period, particularly in treatments with the shortest recovery time i.e. 3:1992 spray and 4:1991 spray.

3.6c.iv). *Festuca ovina.*

Two-way analysis of variance shows significant difference in biomass between all treatments ($F_{(7,96)}$= 7.12, p<0.001) but not between monthly samples. This is also true in low bracken density areas ($F_{(4,60)}$= 3.60, p<0.05) but in high bracken density areas there is no significant difference between either treatments or monthly samples. In the areas without a bracken canopy i.e. all except treatment 2, there is a general decrease in biomass with increase in recovery time (Fig. 17).

Fig. 17. Biomass of *Festuca ovina* as number of touches in high and low bracken density replicates.



The values in the low bracken density areas are greater than in the corresponding high density areas, but these differences are not significant.

4. DISCUSSION

4.1 BRACKEN

The values for all measures of live and dead bracken decrease along the gradient from treatment 2:no spray, as would be expected in circumstances where sequential spraying to prevent regrowth of bracken has been carried out. The nature of the decline in values for live bracken is different from the decline in bracken litter, and again this is not unexpected.

Bracken frond numbers and biomass decline sharply from unsprayed to sprayed areas, and the values are greater in high bracken density areas than in low density areas. However, in the unsprayed areas, the significant difference is between frond numbers not frond biomass. This gives the impression that although the number of fronds in the low density area <u>is</u> less than in the high density area, those fronds are in some way more productive or robust in that they produce numbers of touches in the point quadrat data, and presumably levels of shading, similar to the high bracken density areas.

That this has come about during the current growing season, rather than in previous growing seasons, can be deduced by considering bracken litter. Both of the bracken litter values for these low bracken density replicates are different from the values in the high density areas, and comparable with the values in low density replicates of other treatments. The conclusion that last year the low density replicates in treatment 2:no spray had a lower frond biomass than in this current year seems reasonable. The observed increase in frond biomass could be due to the ability of unaffected rhizomes to utilise food reserves from connecting rhizomes in sprayed areas, where the buds will not be developing into fronds. There are two types of rhizome: long storage shoots which lie deep in the ground, and short frond-producing shoots which lie nearer the surface, branching from the storage rhizomes (Burge & Kirkwood, 1992). Storage rhizomes persist in spite of treatment with herbicide for at least two years, after which time they become shrunken and less turgid (Lowday, 1987).

The bracken litter values show that the litter is deeper in the high bracken density areas, and that it decreases with recovery time, but this decline is <u>not</u> as steep as for frond values, but more gradual. The litter releases nutrients to the soil as it decomposes and the consequent soil enrichment can be important with regard to vegetation recovery and colonisation. Although decomposition of bracken litter improves the mineral content and physical structure of the soil, bracken-infested land is often not suitable for arable cultivation, but can be used for grazing or forestry (Burge & Kirkwood, 1992). At the same time chemicals leached from bracken act against potential plant competitors, inhibiting seedling germination and seedling establishment.

4.2 BIOMASS OF GRASS AND DICOTYLEDONS.

Consideration of biomass of species other than bracken gives different viewpoints. Grass biomass decreases across the treatment gradient from treatment 2 to treatment 5, while dicotyledon biomass increases. For both variables treatment 6 has the highest value. The value is significantly greater in low bracken density areas than corresponding high bracken density areas. This could be taken to indicate that biomass of grass and dicotyledons can be affected, adversely or advantageously, by shading due to the bracken canopy.

However, the biomass of grass is not significantly different in the high bracken density replicates whether they are currently shaded by a bracken canopy i.e. treatment 2, or were shaded in past years i.e. treatments 3 and 4. The strong implication is that the response is subject to a time-lag, it is in some way historic. This historic factor could be the depth of the persisting litter layer: there is at least a 2 year time-span before the litter decreases to any degree. Dense bracken litter has been found to have a smothering effect and prevent the recovery of vegetation (Taylor, 1986 [ii]). It has been established that a deep litter layer inhibits the germination of *Calluna*, and that removal or disturbance of the litter might accelerate re-establishment of the species (Lowday & Marrs, 1992 [ii]). This study does include replicates with a three year recovery time but they are sited only in low bracken density areas so it is not possible to make more precise comments.

In low bracken density areas, the biomass of grass declines with increase in recovery time. Grass is quite heavily grazed by sheep and rabbits, neither of which will attempt to feed under a bracken canopy, so the bracken can offer some degree of protection for the attenuated grass in treatment 2. It has been found that *Festuca* and *Agrostis* ssp. do better under a bracken canopy rather than in open areas, but only at the boundary of a bracken colony. These grasses become suppressed further within the colony, due to the increase in bracken litter depth (Taylor, 1986 [ii]).

The larger value for grass biomass in treatment 6 compared with treatment 5 could be due to lighter grazing, as only rabbits graze here, not sheep and rabbits as in the other replicates.

The bracken litter values do not explain the significant difference in biomass of dicotyledons between the high bracken density areas, so perhaps the difference is due to some response to shading by the bracken canopy. It could be that treatment 2 has a substantial biomass of shade-tolerant species under the bracken canopy, treatment 4 of shade-intolerant species due to the longer recovery time, while treatment 3 has a much smaller biomass of either or both types of species since it is a transition area.

The dicotyledon biomass at low bracken density increases with increase in recovery time. Some shade-intolerant species would already be established to a greater or lesser degree and so would flourish when the bracken canopy is removed. In high bracken density areas such species were unlikely to colonise immediately after removal of the bracken canopy, the shade-tolerant species being more abundant: these would decline in the first year of recovery, hence the drop in biomass in treatment 3:1992 spray. The increase in dicotyledon biomass in treatment 4:1991 spray could be ascribed to the colonisation by shade-intolerant species after two years recovery.

4.3 NUMBERS OF SPECIES AND DIVERSITY INDICES

Numbers of species, whether categorised as 'all' , 'grass' or 'dicotyledon' are significantly different between the treatments but not between the monthly samples. The number is generally greater, but not significantly so, in low bracken density areas.

In treatment 3, the most recently sprayed area, there is a significant difference in number of dicotyledon species between high and low density bracken areas. The number is greater in low density replicates, which could be due to the presence of a greater number of shade-intolerant species before the bracken canopy was sprayed with Asulox. The high density replicates, with the heavier bracken canopy and shading, would lose shade-tolerant species, but it takes more than one growing season for the shad-intolerant species to become established.

In treatment 6:grazed only, there is a sharp increase in the number of dicotyledon species, demonstrating that although treatment 5:1990 spray has recovered with respect to biomass of dicotyledons, the full range of upland grassland species has yet to become established.

There is a trend of increase in the number of dicotyledon species as recovery time increases, especially if treatment 3 is discounted as the transition area. This trend follows the bracken litter depth pattern, since litter depth decreases with increase in recovery time. To find that litter depth appears to be the determining factor in increase in numbers of species in sprayed areas is not surprising: not many species can grow through a thick inhospitable litter layer.

The number of dictyledon species is the same in both high and low density replicates of treatment 2, as is the value for frond biomass, so it appears that bracken shading rather than bracken litter is the determining factor in unsprayed areas.

The ingress of new species when bracken is removed could be due to the interaction between renewed grazing pressure and herbicide use, rather than just the herbicide alone (Marrs, 1985). Certainly the removal of bracken does not necessarily result in a reversion to the original flora: it may result in an abundance of grasses and weeds such as docks, nettles, thistles and foxgloves, although groun-cover species which have been resticted by the invasion of bracken may re-emerge years later when the bracken canopy is removed (Brown, 1986).

Diversity indices show no significant difference between treatments, monthly samples or bracken densities. As indicated earlier this is to be expected in vegetation where biomass is very largely accounted for by high abundance of a relatively small number of species.

4.4 INDICATOR SPECIES

a) shade-tolerant : *Oxalis acetosella*

This species is typically found in dry shady places, woodlands or sheltered by rocks, and its distribution in this study conforms to that. In treatment 2:no spray the biomass is not significantly different in high and low bracken density areas, which supports the view that the previously low bracken density area has developed a much denser bracken stand in this current year.

The greater values for biomass in high bracken density replicates of treatments 3 and 4, which have been sprayed to prevent regrowth, can be explained by noting the dead bracken fronds in these replicates. In the first year after spraying the dead fronds largely persist and provide some shade and protection for lower growing species.

b) shade-intolerant: *Galium saxatile*

This is a species of open heaths and grasslands, avoiding lime, and also occurring in acid woodlands. Certainly the much lower values for biomass in the high bracken density areas fit this profile. However, in treatment 2, where the bracken frond biomass is not significantly different, the biomass of *Galium saxatile* is different. The response, then, is not just to this growing season's shade but to some other factor. One year ago the treatment 2 low density area had a lighter bracken canopy where *Galium saxatile* would have flourished in moderation, and the effect of an increase in shade has not much reduced the abundance in just one year. Two years after spraying in treatment 4:low bracken density, the biomass is much higher. Bracken litter may play some part in this trend, since it is also at least 2 years after spraying before litter declines appreciably.

The small value in treatment 6:grazed only is probably because this areas has been cultivated, possibly seeded, and trampled by cattle in the past, and the species does not do well in disturbed ground. Alternatively it could be that the area has been limed at some time - *Galium saxatile* does not like lime.

c) universal:

i)*Potentilla erecta*
This is typically found on grasslands, heaths and moors, so it can be assumed that its preference is for open aspect rather than shade, hence the greater value for biomass in the low bracken density areas..

ii) *Viola riviniana*
This species has a wide distribution across woods, hedgebanks, grasslands and mountains - it can flourish in shady and open habitats, as is the case in this study. In treatments 2, 3 and 4, *Viola riviniana* occurs only in high bracken density replicates, which is to be expected of a species found in woodlands. However, the biomass also increases with increase in recovery time i.e. with decrease in shading and litter layer, at both bracken densities: this, and the high value for biomass in treatment 5:1990

spray is typical of an open grassland species. The seasonal change in biomass - increase in shaded replicates, decrease in open replicates - is the response expected of a woodland species.

NB Treatment 6 has no *Viola riviniana*: currently there is a high abundance of *Viola lutea* in these replicates.

iii) *Rhytidiadelphus squarrosus*

This moss occurs in all replicates, both at high and low bracken density. The value for biomass is always greater in low bracken density areas, but decreases with recovery time from the high value in treatment 2:no spray. In high bracken density areas the biomass is similar across treatments 2, 3 and 4. Taken together these patterns suggest that the moss can cope well in bracken litter as long as it is not too deep and not too greatly shaded, i.e. in conditions which may well hamper the success of other species. Excessive litter or shade will reduce the success of the moss but deducing where the boundaries for such variables may lie is beyond the scope of this study. The decline in biomass across the treatment gradient may also be a reflection of grazing pressure.

iv) *Festuca ovina*

This grass is often the dominant species in open upland grassland, and although its productivity is low its nutritional content is good, making a valuable contribution for grazing animals. It also withstands close cutting and heavy grazing.

The values for biomass are higher in low bracken density areas, but the difference is not significant. The change along the treatment gradient is not one of steady increase from treatment 2. The increase from treatment 2:no spray to treatment 3:1992 spray is followed by a decrease to treatments 4:1991 spray and 5:1990 spray. This is attributed to heavier grazing pressure, and a lower grazing pressure explains the increase in treatment 6:grazed only.

4.5 SOME MANAGEMENT IMPLICATIONS.

From this study, it would appear that the parts of a bracken colony adjacent to a cleared area can produce a greater biomass of fronds than formerly, in the growing season following spraying with Asulox, and this may need taking into account when devising a strategy for bracken removal. The carbohydrate in storage rhizomes, which persist for about 2 years after spraying, is presumably utilised by previously dormant rhizome buds to produce more robust, or more, fronds. It should be noted that dormant buds are not severly affected by Asulox, because they have very low requirements for photosynthetic products, and so do not assimmilate any large amounts of chemicals.

It has become apparent that the bracken litter layer, as well as the shading effect of the bracken canopy, is important with regard to the recovery of vegetation. However, the effects are not necessarily deleterious: for example, a covering of bracken litter increased the number of ryegrass and clover seedlings both where bracken had been removed and where there were still developing fronds, early in the growing season (May -July). Later in the growing season (August-October) the bracken litter had no effect, but the frond canopy reduced the establishment of ryegrass seedlings by half (Lee & Cooke, 1989). The litter layer can be beneficial in that it prevents dessication of the soil, and detrimental in that leachates inhibit germination.

Incorporation of bracken litter into the soil provides nutrients for enrichment and soil stability: this enrichment can allow the ingress of species which prefer a more fertile soil rather than the original species present on the site prior to bracken invasion (Marrs *et al*, 1992). Vegetation recovery can be improved by the use of fertiliser and re-seeding (Taylor, 1986 [ii]), but fertiliser should be used only where bracken is completely eradicated since it will encourage the growth of any residual bracken (Biggin, 1982). October removal of litter following July spraying has been shown to be the most effective strategy for reclaiming pasture (Marrs *et al*, 1992).

Combinations of cutting and spraying treatments have been investigated in many studies (Lowday, 1987; Lowday & Lakhani, 1987) but the practical difficulties of spraying, cutting and removing bracken can be extreme in the invaded areas. These tend to be areas of marginal land, steep, rocky and uneven, and often it could be uneconomic to reclaim such land.

Biocontrol of bracken would be most effective via damage to the rhizome system, but no suitable organism has yet ben unearthed. Insects which feed on the aerial portions of the plant are the alternative, and species which defoliate the plant and interfere with its vascular system and growth points are being studied (Lawton *et al*, 1988). Total eradication of bracken is unlikely and undesirable: biocontrol techniques rarely eliminate a species completely.

APPENDICES

Appendix 1

Diversity indices

replicate	MAY	JUNE	JULY
2A	2.1276	2.0300	1.8549
2B	1.8312	1.5970	1.8443
2C	1.9591	1.9228	1.8744
2D	2.1427	1.8537	1.8768
2E	2.2068	1.9710	1.9329
2F	1.9581	1.8024	2.2413
2G	2.1394	2.0567	2.1347
2H	2.1387	2.2088	2.0432
2J	2.2896	2.0793	1.0908
2K	2.1054	2.2127	1.9533
3A	1.5472	1.4315	1.3918
3B	1.2275	1.2244	1.2710
3C	1.9115	1.7154	1.5737
3D	1.9151	1.7050	1.8379
3E	1.4633	1.4569	1.3030
3F	1.9380	1.9517	1.7524
3G	2.2070	1.9364	2.1811
3H	2.0822	1.8914	1.8804
3J	1.7374	2.0008	1.9675
3K	2.0050	1.9924	2.0236
4A	1.5702	1.6281	1.6544
4B	1.8702	1.9784	1.5544
4C	1.9803	1.9811	1.9374
4D	2.0277	2.0045	1.9068
4E	2.0608	1.9819	1.9495
4F	2.0667	1.9957	1.8981
4G	2.0028	1.8228	1.7046
4H	2.2259	2.2282	2.1322
4J	2.1890	2.1527	2.0948
4K	2.1779	2.0810	1.9859
5F	1.7899	1.9122	1.8890
5G	2.1374	1.8256	1.8464
5H	2.0441	1.7660	1.7917
5J	1.6617	1.8582	1.9166
5K	1.9513	1.9772	2.0151
6F	2.2050	2.2570	2.2471
6G	2.2026	2.0717	1.9129
6H	2.0453	1.6279	1.8027
6J	2.0664	2.0344	2.0216
6K	1.9933	1.9903	1.8390

Appendix 2.

Domin scores: median values.

treatment	2A-E:HIGH NO SPRAY			2F-K: LOW NO SPRAY			3A-E:HIGH 1992 SPRAY			3F-K: LOW 1992 SPRAY			4A-E: HIGH 1991 SPRAY			4F-K: LOW 1991SPRAY			5F-K: LOW 1990 SPRAY			6F-K: LOW GRAZED		
sample	May	Jun	Jul	May	Jun	Jul	May	Jun	Jul	May	Jun	Jul	May	Jun	Jul	May	Jun	Jul	May	Jun	Jul	May	Jun	Jul
Achillea millefolium																							1	2
Cardamine hirsuta													1	1	1.5							1		
Carlina vulgaris																			1	2	1			1
Cerastium fontanum	4	1	1	1	1	2	1	1	1	3	1	1.5	1	1	1	4	1	1	3.5	3		1	1.5	2
Cirsium vulgare																			1		1			
Conopodium majus							1.5	1	1	1			1.5	1.5	1	1			1.5	1				
Erica tetralix																								
Euphrasis officinalis																						1	1	2
Galium saxatile	1	1	2	6	5	6	1	1	1	5	6	6	1	2.5	1.5	5	6.5	6	6	6	6	6	6	6
Hieracium sp.																	1	1		1		1	1	1
Myosotis arvensis																						2.5		2
Oxalis acetosella	3	5	4	1	3	2.5	3.5	3.5	3	1	1	1	4	3	1.5									
Plantago lanceolata																						1		1
Potentilla erecta	4	4	4	3	4	5	2	2	2	4	3	4	3	3	1.5	3	3.5	2		2.5	1.5	1		1
Prunella vulgaris																					1	2	1.5	4
Ranunculus repens														1	1							3	3	3.5
Rumex acetosa	1		1	1	1	2	1			1.5	1	1	3	2	1	3	3	1	1	1	1	1	1	1
Scilla verna													1						1					
Senecio jacobea																						4	4	5
Stellaria graminae													1	2		1			1	1	1	1	1	2
Trifolium repens																						4	5	5
Tussilago farfara									1		1	1					1					1	1	1.5
Vaccinium myrtillus	1.5	1	1	4	3	5				3.5	3	3.5	1			1.5	2	1						
Veronica chamaedrys								4	4				2	3.5	2			1	2.5	2.5	1	4	3	5
Veronica officinalis								1	1		4	4					4	4.5		2.5	3	1.5	2	1
Veronica serpyllifolia															1									1
Viola lutea																						4	4	5
Viola riviniana	2	4	4	1	1		3	2	1	4	2	1	4	4	5	4	4	5	5	5	5			1
Agrostis capillaris	4	4	5	4	4.5	6	3.5	2	4	3	2.5	5	5	3	5	4	4	5	5	6	6	6		7
Agrostis stolinifera	4	4		5	4	6	3	2		2	2	2				2.5	2		6	4		5		2
Anthoxanthum odoratum	4	5	5	3	4	5.5	6	6	5	6	6	6	4.5	5	5	5	5	4	5	3	3	4		2
Festuca ovina	6	6	5	6	6	6	6	6	5	7	7	7	6	5.5	4	7	7	7	7	7	6	6	6	6
Holcus mollis			1			2.5	6.5	7	7				4	5	5	3.5	4.5	2.5		5	3	3.5	3	3
Molinia caerulea												1						1						
Carex nigra	1.5	2	1	2.5	2.5	2		1	1.5	1	2	3		2	1	4	2	3	3	3.5	3	1	3	3
Luzula campestris	2	2	2	3	3	1	1	1	1	3.5	2	3	3	2.5	1	4	3	3	4	3	2	3	3	3
Polytrichum				1				1							1			1	1.5	1		1		
Rhytidiadelphus	5	5	5	7	6	6	6	7	6	6	6	6	6	6	6	7	7	6	5	6	6	4.5	4	5
Sphagnum				2																				
Pteridium (dead)	8	8	8	5	6	6	8	8	8	5	7	6	5	7	7	4	5	6		2.5	3			
Pteridium (fronds)	7	10	9	6	8	8	1	1.5	1	1	1	2	1	1	1	1.5	2.5	2		1	1			
Dryopteris pseudomas	3									1	1	1												

BIBLIOGRAPHY

Anon. (1990) Bracken (*Pteridium aquilinum*) Problems and control. *EMBETEC (Rhone-Poulenc Group) Springfield Hose, Kings Road, Harrogate HG1 5JJ.*

Antice Evans, I.., Prorok, J.H., Cole, R.C., Al-Salmani, M.H., Al-Samarrai, A.M.H., Patel, M.C., and **Smith, R.M.M.** (1982) The carcinogenic, mutagenic and teratogenic toxicity of bracken. *Proceedings of the Royal Society of Edinburgh.* 81B, 65-77.

Biggin, P. (1982) Forestry and bracken. *Proceedings of the Royal Society of Edinburgh.* 81B, 19-27.

Brown, R.W. (1986) Bracken in the North York Moors: its ecological and amenity implications in National Parks. *Bracken: Ecology, land-use and control technology.* pp 77-86. Eds. *Smith & Taylor.* Parthenon.

Burge, M.N. and **Kirkwood, R.C.** (1992) The Control of Bracken. *Critical Reviews in Biotechnology.* 12(4), 299-333.

Cook, G.T., Stephen, N.H. and **Duncan, H.J.** (1982) Fundamental studies in bracken control - the use of additives to enhance herbicide uptake and translocation. *Proceedings of the Royal Society of Edinburgh.* 81B, 97-109.

Fenwick, G.R. (1988) Bracken (*Pteridium aquilinum*) - Toxic effects and toxic constituents. *Journal of Science, Food and Agriculture.* 46, 147-173.

Galpin, O.P., Whitaker,C.J., Whitaker, Rh. and **Kassab, J.Y.** (1990) Gastric cancer in Gwynedd. Possible links with bracken. *British Journal of Cancer.* 61, 737-740.

Heywood, B.J. (1982) Bracken control by asulam. *Proceedings of the Royal Society of Edinburgh.* 81B, 111-116.

Hopkins, A. (1990) Bracken (*Pteridium aquilinum*): its distribution and animal health implications. *British Veterinary Journal.* 146, 316-324.

Hudson, P.J.(1986) Bracken and ticks on grouse moors in the North of England. *Bracken: Ecology, land-use and control technology* pp 161-170. Eds. *Smith & Taylor.* Parthenon.

Jarrett, W.F.H. (1982) Bracken and cancer. *Proceedings of the Royal Society of Edinburgh.* 81B, 79-83.

Kirkwood, R.C. and **Hinshalwood, A.** (1985) Recent studies on the biology of bracken and the mode of action of herbicides used in its control. *Proceedings of the Royal Society of Edinburgh.* 86B, 179-185.

Kirkwood, R.C., Veerasekaran, P. and **Fletcher, W.W.** (1982) Studies on the mode of action of asulam in bracken. *Proceedings of the Royal Society of Edinburgh.* 81B, 85-96.

Lawton, J.H., Rashbrook, V.K. and **Compton, S.G.** (1988) Biocontrol of British bracken: the potential of two moths from Southern Africa. *Annals of Applied Biology.* 112, 479-490.

Lee, H.C. and **Cooke, J.A.** (1989) Effects of bracken litter and frond canopy on emergence and survival of ryegrass and white clover seedlings. *Journal of Agricultural Science, Cambridge.* 113, 397-400.

Lowday, J.E. (1985) Asulam applied by rope wick applicator for controlling scattered bracken on a grassland nature reserve. *Annals of Applied Biology.* 106S, 90-1

Lowday, J.E. (1987) The effects of cutting and asulam on numbers of frond buds and biomass of fronds and rhizomes of bracken *Pteridium aquilinum. Annals of Applied Biology.* 110, 175-184.

Lowday, J.E., and **Lakhani, K.H.** (1987) The effects of cutting pre-treatments on the performance of asulam on bracken (*Pteridium aquilinum*). *Annals of Applied Biology,* 111, 607-616.

Lowday, J.E. and **Marrs, R.H.** (1992) [i] Control of bracken and the restoration of heathland. I. Control of bracken. *Journal of Applied Ecology.* 29, 195-203.

Lowday, J.E. and **Marrs, R.H.** (1992) [ii] Control of bracken and the restoration of heathland. III. Bracken litter disturbance and heathland restoration. *Journal of Applied Ecology*. 29, 212-217.

MacLeod, A. (1982) The bracken problem in the Highlands and Islands. *Proceedings of the Royal Society of Edinburgh*. 81B, 11-18.

McCreath, John B. (1982) Some reflections and projections on bracken control. *Proceedings of the Royal Society of Edinburgh*. 81B, 135-143.

Marrs, R.H. (1985) The Effects of Potential Bracken and Scrub Control Herbicides on Lowland *Calluna* and Grass Heath Communities in East Anglia, UK. *Biological Conservation*. 32, 13-32.

Marrs, R.H. (1987) Studies on the conservation of lowland *Calluna* heaths. II Regeneration of *Calluna*, and its relation to bracken infestation. *Journal of Applied Ecology*. 24, 177-189.

Marrs, R.H. and **Lowday, J.E.** (1992) Control of bracken and the restoration of heathland. II. Regeneration of the heathland community. *Journal of Applied Ecology*. 29, 204-211.

Marrs, R.H., Lowday, J.E., Jarvis, L., Gough, M.W. and **Rowland, A.P.** (1992) Control of bracken and the restoration of heathland. IV. Effects of bracken control and heathland restoration treatments on nutrient distribution and soil chemistry. *Journal of Applied Ecology*. 29, 218-225.

Marrs, R.H., Pakeman, R.J. and **Lowday, J.E.** (1993) Control of bracken and the restoration of heathland. V. Effects of bracken control treatments on the rhizome and its relationship with frond performance. *Journal of Applied Ecology*. 30, 107-118.

Martin, D.J. and **Sparke, C.J.** (1982) Field trials in south-west Scotland. *Proceedings of the Royal Society of Edinburgh*. 81B, 117-123.

Page, C.N. (1982) The history and spread of bracken in Britain. *Proceedings of the Royal Society of Edinburgh*. 81B, 3-10.

Pakeman, R.J. and **Marrs, R.H.** (1992) The conservation value of bracken *Pteridium aquilinum* (L.) Kuhn-dominated communities in the UK, and an assessment of the ecological impact of bracken expansion or its removal. *Biological Conservation.* 62, 101-114.

Piggott, C.D. (1955) The vegetation of Upper Teesdale. *Journal of Ecology.* 44, 546-586.

Scragg, E.B. (1982) The bracken problem and its control in northern Scotland. *Proceedings of the Royal Society of Edinburgh.* 81B, 125-134.

Sheffield, E., Wolf, P.G. and **Haufler, C.H.** (1989) How big is a bracken plant? *Weed Research.* 29, 455-460.

Taylor, J.A. (1986) [i] The bracken problem: a local hazard and a global issue. *Bracken: Ecology, land-use and control technology* pp21-42 Eds. *Smith & Taylor.* Parthenon.

Taylor, J.A. (1986) [ii] Bracken: an increasing problem and a threat to health. *Outlook on Agriculture.* 10 (6), 298-304.

Trotter, W.R. (1990) Is bracken a health hazard? *The Lancet.* 336, 1563-1565.

Varvarigos, P. and **Lawton, J.H.** (1991) Farmers' perceptions of the scale of the bracken problem on farms in Less Favoured Areas in England and Wales. *Journal of Applied Ecology.* 28, 988-1003.

Veerasekaran, P., Kirkwood, R.C. and **Fletcher, W.W.** (1976) The mode of action of asulam [methyl (4-aminobenzenesulphonyl) carbamate] in bracken. *Botanical Journal of the Linneaen Society.* 73, 247-268.