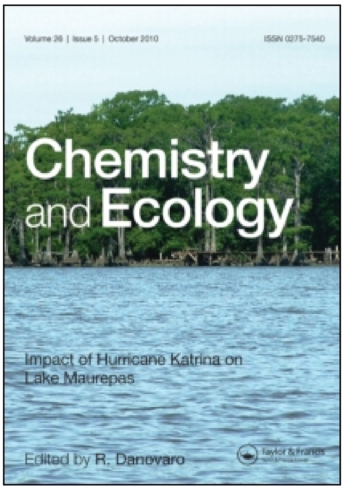

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G. N. Foster[a]; M. D. Eyre[b]; M. L. Luff[c]; S. P. Rushton[c]
[a] Environmental Sciences Department, SAC Auchincruive, Scotland, UK [b] Entomological Monitoring Services, England, UK [c] Department of Agricultural and Environmental Science, University of Newcastle upon Tyne, England, UK

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RESPONSES OF SOME TERRESTRIAL INVERTEBRATES TO CATCHMENT TREATMENTS APPLIED AT LOCH FLEET

G. N.FOSTER[1], M. D. EYRE[2], M. L. LUFF[3] and S. P. RUSHTON[3]

[1]*SAC Auchincruive, Environmental Sciences Department, Ayr KA6 5HW, Scotland, UK*
[2]*Entomological Monitoring Services, 69 Mayfair Road, Newcastle upon Tyne, NE2 3DN, England, UK*
[3]*University of Newcastle upon Tyne, Department of Agricultural and Environmental Science, Newcastle upon Tyne, NE1 7RU, England, UK*

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The impact of liming and heather-burning on the beetle and spider faunas of open and afforested moorland was studied by use of pitfall traps. Of the 168 species identified, the catch of only one species, the ground beetle *Trechus obtusus* Erichson, increased in a way that could be related to intervention treatments. No species obviously declined as a result of the intervention treatments.

KEY WORDS: Acidification, liming, moorland, burning, afforestation, Carabidae, Araneae, pitfall traps, multivariate analysis

INTRODUCTION

Loch Fleet (National Grid Reference NX 559699) is a small loch on the granite massif of the Fell of Fleet. It is in an area of high acid deposition (United Kingdom Acid Waters Review Group, 1988). The loch lost its trout fishery in the early 1970s and the aim of the Loch Fleet project was to demonstrate that the water chemistry of a loch could be returned to a range suitable for trout to breed by treating the catchment rather than the loch waters direct, thus reversing the effects of acidification (Howells and Dalziel, 1992). The treatments largely involved the use of lime ($CaCO_3$) (Howells, Dalziel and Turnpenny, 1992).

This paper describes the effects of catchment interventions on two major groups of predators active on the soil surface and in low vegetation – ground beetles (Coleoptera, Carabidae) and spiders (Araneae).

METHODS

The catchment of Loch Fleet was distinguished as 13 sectors, of which eight were investigated, six of them in all three years of the study of invertebrates. These comprised a limed area (Sector IV) planted in 1963 with lodgepole pine (*Pinus contorta* Douglas *ex* Loudon) on peaty gley soils, three limed areas of open moorland (Sectors VI, VII and

IX), an area (Sector VIII) subject to heather burn, and an untreated area of moorland (Sector X). An untreated area of deeper peat planted in 1963 with a mixture of lodgepole pine and Sitka spruce (*Picea sitchensis* (Bong.) Carr.), lying immediately below the loch catchment, served as a control for the limed and afforested area. Another limed sector of moorland (Z_1) was investigated in 1988 and 1991 only. The treatments are summarised in Table 1.

In total, 445 tonnes of lime were applied to the catchment, 106 tonnes of which were applied in April 1986 in and around wet areas of a bog (NX 561706) in Sector VII. This bog supplies most of the catchment's water in the main feeder stream, the Altiwhat Burn. *Sphagnum* moss, in particular *S. papillosum* Lindb., was killed where directly exposed to limed water, but most of the vegetation, including the *Sphagnum* above the usual level of standing water, had survived three years after liming (Clymo *et al.*, 1992). Natural erosion of peat was high in untreated parts of the sector, up to 19 cm from 1987 to 1993, and mean peat loss in the limed area over the same period was estimated at 2 cm, with a few deposition gains (O. M. Bragg and R. S. Clymo, pers.comm.). It has been estimated (Howells and Dalziel, 1994) that 62 percent of the lime remained in Sector VII in February 1994.

Pitfall traps were operated from late April or early May until late September in the years indicated in Table 1. Traps, which were transparent plastic tumblers, 105 mm deep with an internal diameter at the mouth of 74 mm, were supplied with about 50 ml of proprietary anti-freeze solution (ethylene glycol) as a killing agent and preservative. The traps were covered with 2 cm chicken wire to prevent access by mammals and birds. Catches were collected once a month, the material being bulked for two lines each with nine traps at two metre intervals to give two replicates per sector. Adult Carabidae and spiders were identified in all three years, beetles other than Carabidae also being identified in 1991. Nomenclature follows Pope (1977) for ground beetles, except for the more recently recognised *Pterostichus rhaeticus* Heer (Luff, 1990), and follows Merrett, Locket and Millidge (1985) for spiders.

Table I Treatments of Sectors of the Loch Fleet Catchment where invertebrates were studied.

Sector	*Land cover*	*Treatment*	*Years of study*
"FC"	afforested	no treatment	all
IV	afforested	1986 limestone slurry at 23.9 t ha^{-1} below forest canopy	all
VI	moorland	1986 limestone dust at 21.3 t ha^{-1} spread uniformly	all
VII	moorland and wetland	1986 limestone dust at 10.6 t ha^{-1} in/around wet areas	all
VIII	moorland	1987 muirburn	all
IX	moorland	1987 limestone pellets at 7.0 t ha^{-1} scattered uniformly	1988
X	moorland	no treatment	all
Z_1	moorland	1987 limestone dust at 5 t ha^{-1} spread uniformly	1988 and 1993

In addition to statistical analysis for some of the commoner species on an individual basis, data were also subject to multivariate analysis. Ground beetle and spider data were analysed as two data-sets by Detrended Correspondence Analysis (DECORANA – Hill, 1979), without downweighting rare species. Values for species were calculated as the percentage contribution to the total annual catch per replicate set of nine traps. This provided 42 data-points (six observations for each of six sectors, plus four observations from Sector Z_1 in 1988 and 1993, and two observations from Sector IX in 1988).

RESULTS

Ground beetles

Twenty eight species were identified from the 1,757 individuals caught in the sectors trapped in all three years of study (Table II). The α index of diversity (Williams, 1964) was generally higher in Sectors VII and VIII than in other sectors (Table III), but the only clear trend was for the index to increase in the control sector of moorland. The fauna was dominated by nine species (Table IV), the most numerous beetle overall being *Trechus obtusus* Erichson (543 individuals comprising 31 percent of the total catch), followed by two species of *Pterostichus*, *P. diligens* (Sturm) and *P. niger* (Schaller)). *T. obtusus* was among the commonest beetles in all sectors except in the untreated control. With that exception, the dominant species of the afforested area

Table II Summary of ground beetle and spider counts in the Loch Fleet catchment for areas surveyed in all three years of the study.

Sector	*Number of species caught*							
	Carabidae				*Araneae*			
	1988	*1991*	*1993*	*Total*	*1988*	*1991*	*1993*	*Total*
FC	7	8	6	9	25	11	15	31
IV	9	10	8	12	27	12	12	32
VI	10	10	14	14	34	23	22	45
VII	14	11	9	22	32	22	25	44
VIII	13	8	13	15	31	10	12	35
X	7	8	12	15	34	18	17	43
Sector	*Number of individuals caught*							
	Carabidae				*Araneae*			
	1988	*1991*	*1993*	*Total*	*1988*	*1991*	*1993*	*Total*
FC	52	59	35	146	267	58	95	420
IV	66	195	62	323	158	51	49	258
VI	62	191	104	357	224	104	152	480
VII	139	146	176	461	209	134	193	536
VIII	107	47	84	238	168	69	78	315
X	71	46	115	232	266	74	170	510

Table III Williams's index of diversity (α) for yearly catches of ground beetles and spiders in the Loch Fleet catchment for areas surveyed in all three years of the study, and counts of species unique to sectors for all three years combined.

Sector	*Index of diversity (Williams's α)*						*Number of species unique to sector*
	Carabidae			*Araneae*			*Both groups*
	1988	1991	1993	1988	1991	1993	
FC	2.17	2.49	2.08	6.75	4.02	5.01	2
IV	2.81	2.23	2.44	9.36	4.94	5.07	9
VI	2.02	2.24	2.72	11.15	9.14	7.06	3
VII	3.88	2.75	5.40	10.53	7.48	7.65	8
VIII	3.87	2.76	4.30	11.17	3.21	3.96	1
X	1.92	2.79	3.37	10.35	7.57	4.70	4

Table IV First five rankings for the total numbers of ground beetles caught in three years.

Species	*Moorland*				*Afforested*	
	limed VI	*limed VII*	*burnt VIII*	*control X*	*limed IV*	*control FC*
	Ranking for sector					
Carabus glabratus Paykull	4	–	5	5	4	–
Leistus rufescens (Fab.)	5	4	–	4	–	3
Notiophilus biguttatus (Fab.)	–	–	–	–	3	4
Loricera pilicornis (Fab.)	–	5	–	–	–	–
Patrobus assimilis Chaudoir	–	–	–	–	2	2
Trechus obtusus Erichson	1	2	3	–	1	1
Pterostichus diligens (Sturm)	3	3	1	1	–	–
P. niger (Schaller)	2	1	2	2	5	5
P. rhaeticus Heer	–	–	4	3	–	–

differed from those of the open moorland. No species was markedly more common or more rare in the burnt area than on limed or unlimed moorland.

The catch of the commonest ground beetle, *T. obtusus*, appeared to increase in response to liming and possibly also in response to heather burn. Analysis of variance of the replicates for the six sectors surveyed in all three years was undertaken using the data transformed $\log_{10}(n + 1)$. Variation between sectors was highly significant (F with 5 and 18 degrees of freedom = 14.3, $P < 0.001$), as was variation between years (F with 2 and 18 degrees of freedom = 4.2, $P < 0.01$). Totalled over the three years of study, there were 3.7 times as many *T. obtusus* caught per trap in the limed, afforested area as in the control afforested area and 2.9 times as many on the burnt moorland as on the untreated moorland sector. Taking data for all four limed moorland sectors compared with the appropriate yearly values from the untreated moorland Sector X, it was possible to detect a significant positive response to rate of liming (by linear regression, adjusted $r^2 = 0.76$; $P < 0.05$). The response appeared to be sigmoid, with an exponential response between 5 and 10 t ha^{-1} (Figure 1).

None of the other ground beetle species appeared to respond, either positively or negatively, to the presence of lime. In 1991, sixty four species of non-carabid beetle were identified from 1,023 trapped individuals. None of these responded in a way consistent with population increase or reduction associated with liming and/or burning, but some were more numerous on open moorland than on the forest floor.

A plot of axis 1 × axis 2 of the DECORANA site scores for ground beetles (Figure 2a) indicated more variation in some control replicates than in treated sectors. It was possible to recognise a cluster based on the afforested areas, which showed less variation than the cluster associated with open moorland (Figure 2b). It was also possible to recognise clustering based on years within each of the two main clusters (Figure 2c). It was not possible to recognise clusters based either on individual sectors, or on limed sectors as opposed to untreated sectors, though much of the variation in axis 3 (which accounted for 10.5 percent of the variation of the first three axes) was associated with the 1993 catches from Sector IV being dominated by *T. obtusus*.

Spiders

Seventy six species were identified from the 2,519 individuals caught in the sectors trapped in all three years of study (Table II). Yearly variations in spider catches were greater than those of ground beetles, with higher α indices of diversity in 1988 than in

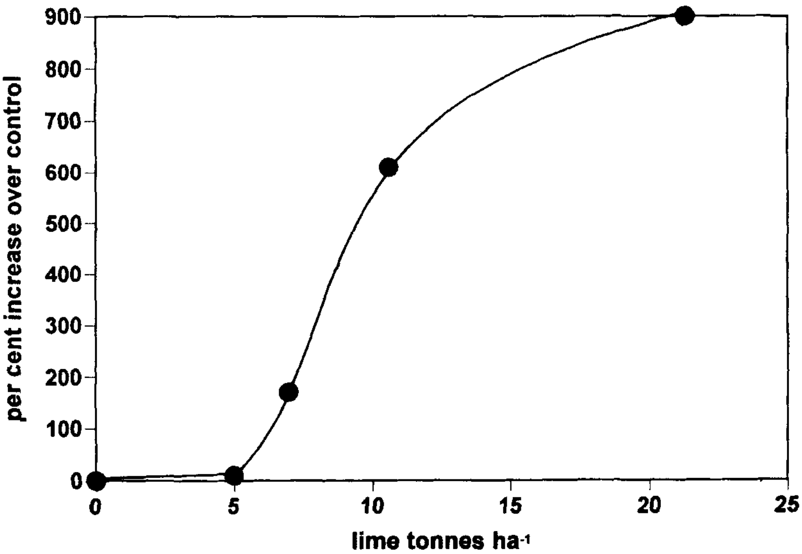

Figure 1 Changes in the numbers of adult *Trechus obtusus* Erichson caught in pitfall traps in limed moorland sectors of the Loch Fleet catchment, expressed as percentage increases over an untreated sector.

the following years (Table III). The commonest species was a sheet web spider, *Lepthyphantes zimmermanni* Bertkau (450 individuals), but it represented only 18 percent of the catch and was rare in 1993. The moorland fauna was dominated in all years by the wolf spiders *Pardosa pullata* (Clerck), *P. nigriceps* (Thorell) and *Trochosa terricola* Thorell (Table V). Wolf spiders were almost entirely absent from the forest

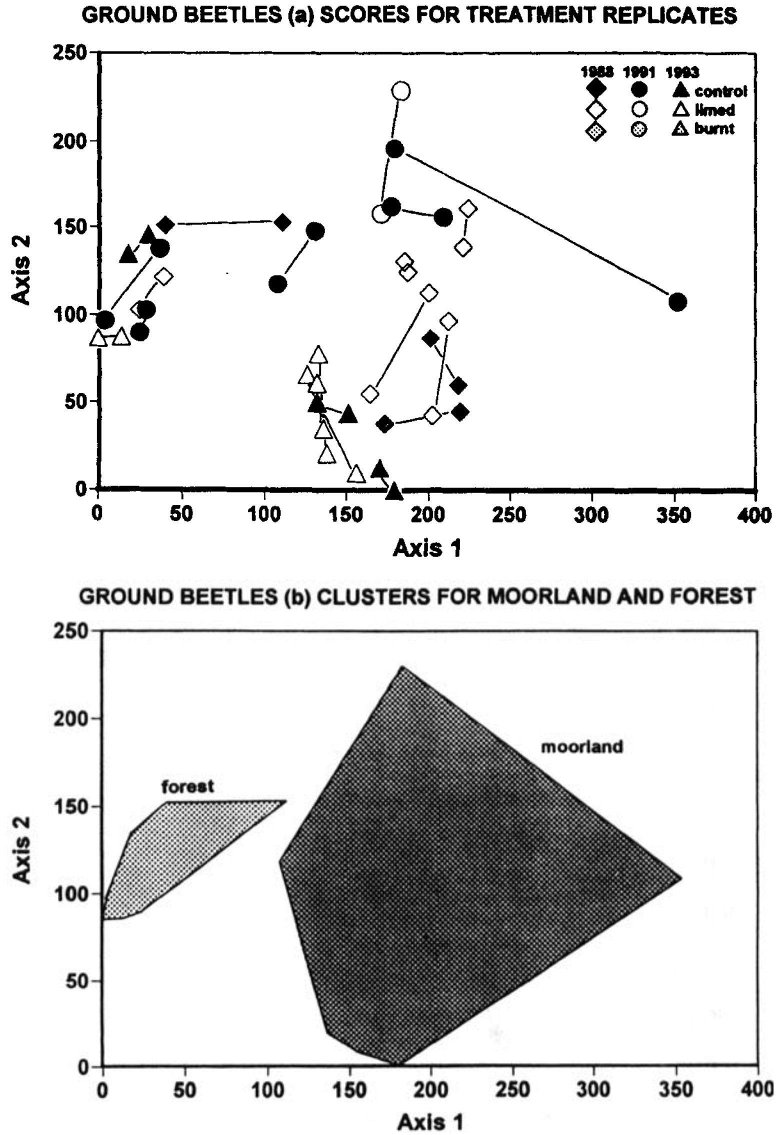

Figure 2 Axis 1 × axis 2 plot of DECORANA site scores (2a) for ground beetle assemblages of the Loch Fleet catchment. Symbols are also coded for year, and replicates within each year are linked by lines in Figure 2a. Figure 2b demonstrates the clusters associated with afforested and open moorland. The polygons in Figure 2c indicate yearly clusters for afforested and open moorland.

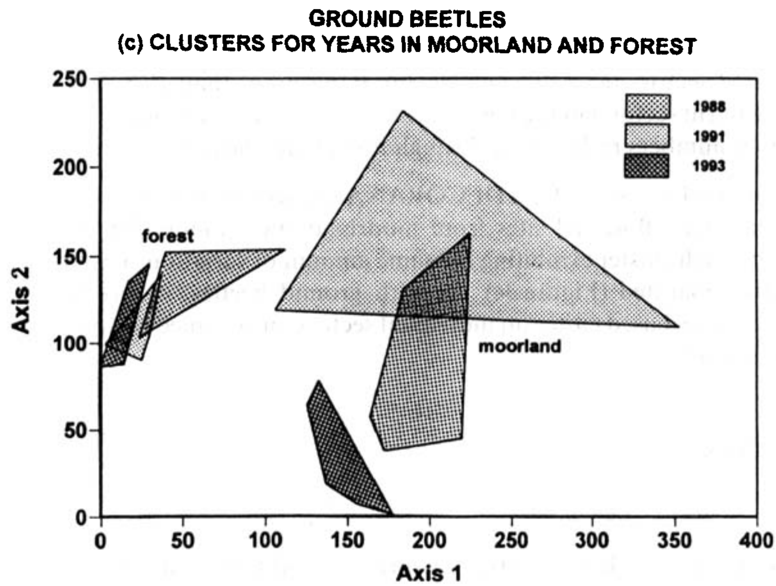

Figure 2 *(Continued)*

Table V First five rankings for the total numbers of spiders caught in three years.

Species	*Moorland*				*Afforested*	
	limed VI	*limed VII*	*burnt VIII*	*control X*	*limed IV*	*control FC*
	Ranking for sector					
Agroeca proxima (Pickard-Cambridge)	–	3	3	–	–	–
Pardosa nigriceps (Thorell)	5	4	1	4	–	–
P. pullata (Clerck)	3	1	4	2	–	–
Trochosa terricola Thorell	2	–	–	1	–	–
Robertus lividus (Blackwall)	–	–	–	–	2	3
Walckenaeria acuminata Blackwall	–	5	–	–	–	4
W. cuspidata (Blackwall)	4	–	2	–	–	–
Dicymbium tibiale (Blackwall)	–	–	–	5	–	–
Monocephalus fuscipes (Blackwall)	–	–	–	–	3	2
Hilaira excisa (Pickard-Cambridge)	–	–	–	–	4	5
Saaristoa abnormis (Blackwall)	–	–	–	–	5	–
Lepthyphantes zimmermanni Bertkau	1	2	5	3	1	1

floor, the catch of which, apart from *L. zimmermanni*, was dominated by a comb-toothed spider, *Robertus lividus* (Blackwall), and by a sheet web spider, *Monocephalus fuscipes* (Blackwall). *T. terricola* was specially abundant in 1993; it occurred in all sectors and was commonest on the areas of sloping moorland.

The relative abundance of the two *Pardosa* species varied between sectors. In the wettest area, Sector VII, the numbers of *P. pullata* were significantly higher than those of *P. nigriceps* ($t = 4.8$ with 10 degrees of freedom, $P < 0.001$). Numbers caught were not significantly different in other moorland sectors, being almost equal in all three years in the untreated sector, and rather higher for *P. nigriceps* than *P. pullata* in the burnt sector. The burnt sector had the lowest catches of all sectors; this was based on a general reduction in numbers rather than through loss of any particular species.

A plot of axis 1 × axis 2 of the DECORANA site scores for spiders (Figure 3a) more clearly separated afforested sites from moorland sites (Figure 3b) than for ground beetles, with each cluster exhibiting the same amount of variation. Yearly clusters were also clearly separated (Figure 3c). As with ground beetles, it was not possible to recognise clusters based either on individual sectors, or on limed sectors as opposed to untreated sectors.

DISCUSSION

Diversity

Many ecological models predict that disturbance and temporary increases in productivity will result in higher diversity (e.g. Hildrew and Townsend, 1987). The variations in diversity observed in the Loch Fleet catchment were, however, more likely to be associated with seasonal variation than with the disturbance associated with the catchment intervention treatments. The diversity of ground beetles increased from 1988 to 1993 in the untreated moorland sector (X). A similar but weaker trend in one of the limed sectors (VI) was coupled with an apparent decline in spider diversity. If there were changes in diversity associated with treatments, these were masked by yearly variations in abundance and diversity, which were more marked in the spider assemblages than in the ground beetle assemblages.

Response to liming by resident species

Of the ground beetles and spiders surveyed, only *Trechus obtusus* appeared to respond positively to the intervention treatments. No species declined significantly as a response to intervention. *T. obtusus* was the commonest species of beetle caught largely because of its strong response to the high rates of liming in Sectors IV, VI and VII. It is one of the smaller beetles in the area; its biology appears to be unremarkable. Lindroth (1945) stated that it lives in moderately moist soil, with meadow-type vegetation. He also stated that it is an autumn breeder (in Scandinavia), overwintering as larvae as well as adults, and that, in the northern part of its range, it is brachypterous. Den Boer and den Boer-Daanje (1990) identified *T. obtusus* as a winter developer in the Netherlands. In a study of ground beetles on the Lüneberg Heath, Germany (Mossakowski *et al.*, 1990), *T. obtusus* was intermediate between species indicative of undisturbed habitats and those of habitats created by the manoeuvres of military tanks. Bauer (1989) identified *T. obtusus* as one of the species associated with limestone 'habitat islands' in Pennine blanket peat. Coulson *et al.* (1990), in a study of the effects of moorland drainage ditches, singled out *T. obtusus*, the populations of which were twice as high above drainage ditches as in the drier peat below them, supporting many claims that the species is hygrophilous. Eyre and Luff (1990a), in classifying British grassland types, identified *T. obtusus* as frequent in well-drained heaths and in two unmanaged grassland types with long vegetation. In a survey of European grassland types, Eyre and Luff (1990b) associated *T. obtusus*

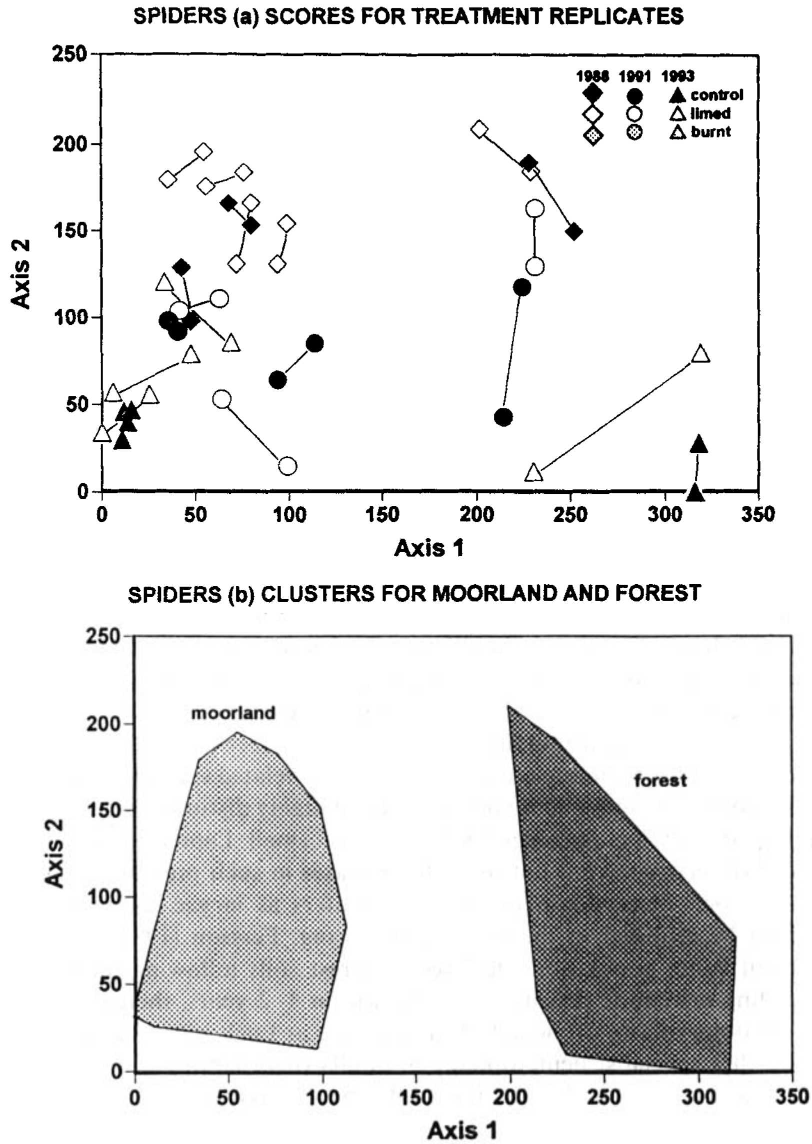

Figure 3 Axis 1 × axis 2 plot of DECORANA site scores (3a) for spider assemblages of the Loch Fleet catchment. Symbols are also coded for year, and replicates within each year are linked by lines in Figure 3a. Figure 3b demonstrates the clusters associated with afforested and open moorland. The polygons in Figure 3c indicate yearly clusters for afforested and open moorland.

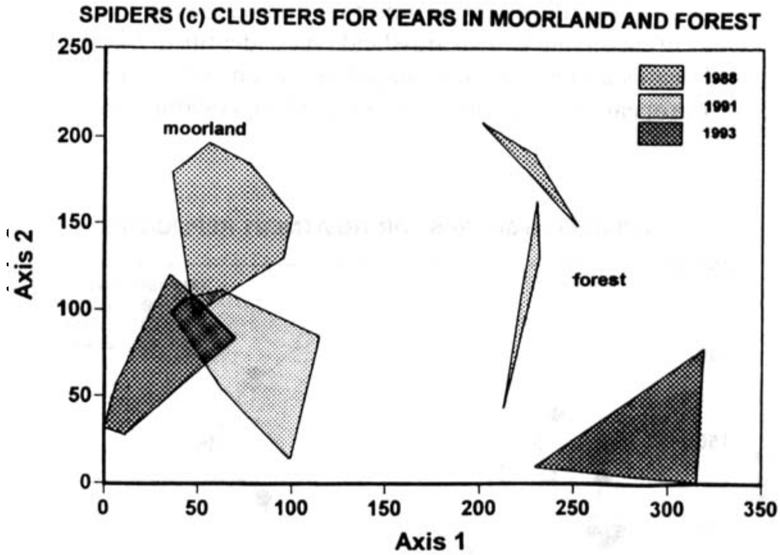

Figure 3 (*Continued*)

mainly with Norwegian upland heaths and with unmanaged lowland sites with a damp substratum. Eyre (1994), in attempting to explain the distribution of ground beetles in northern England, noted that *T. obtusus* had been recorded from sites with a wide range of disturbance; he classified its strategy as 'Any disturbance: low-mid productivity'.

Collectively, these references indicate that *T. obtusus* is associated with moisture, lime, rank grass and the potential to respond to attempted drainage. Despite the lack of data acquired before liming, the present observations show that *T. obtusus* can be regarded as an indicator of the effects of liming. The reasons why this particular species should respond to liming are unclear. A closely related species, *T. quadristriatus* (Shrank), is capable of flight and is characteristic of highly disturbed sites (Eyre, 1994). It is known to prey on the eggs and larvae of small Diptera, and on aphids. Unpublished observations did not indicate increases in such prey items in response to liming at Loch Fleet. As *T. obtusus* overwinters as larvae, an increased food source would be required in the winter and spring. Persson (1987) demonstrated that most soil fauna populations declined in forest soils following liming but that bacteria-feeding nematode density increased within 1–2 years, thereafter declining. There are no observations on nematode abundance at Loch Fleet, but it is tempting to speculate that specialist nematophagy in adults or in larvae of *T. obtusus* could provide the explanation for the observed differences in populations, as indicated by pitfall catches.

The moorland spider fauna was dominated by the same two species of wolf spider in the limed sectors as in the unlimed area. There was an apparent shift towards *P. nigriceps* dominating the area of burnt moorland. This species, as juveniles, shows more aeronautic activity than *P. pullata* (Richter, 1970).

Evidence of recent colonisation

In the absence of data acquired before liming, it is difficult to identify the extent to which the area has been invaded by new species, but its extent can be inferred. Rather than examining the data-set in its entirety, it should be possible to identify new colonists by considering the habitat ranges described for species confined to particular sectors. Colonisation might be claimed on the basis of accretion of species considered atypical of the untreated habitats. This was done using habitat descriptions largely derived from Lindroth (1945) for ground beetles and Locket and Millidge (1951, 1953) and Roberts (1985) for spiders.

Twenty seven species of ground beetle and spider were found only in one sector of the six fully surveyed (Table III). The sector with the greatest number of unique species was the limed and afforested Sector IV. The species here were *Leistus ferrugineus* (L.) (xerophilous, also often in afforested areas), *Trechus rubens* (Fab.) (wet litter, often in forest), *Pardosa amentata* (Clerck) (one of the commonest and most abundant spiders in Britain, a wolf spider associated with exposed conditions with some moisture), *Gongyllidiellum vivum* (Pickard-Cambridge) (damp litter and moss), *Erigonella hiemalis* (woodland litter and moss), *Diplocephalus latifrons* (Pickard-Cambridge) (common in moss, grass and leaf litter), *Erigone dentipalpis* (Wider) (a very common aeronaut and a highly invasive species, e.g. Meijer, 1977), *Agyneta olivacea* (Emerton) (damp moss and litter) and *Lepthyphantes cristatus* (Menge) (common in moss, grass, leaf litter and undergrowth). *E. dentipalpis* would be expected to occur infrequently in uplands as a vagrant, and the other species appear to be occupying habitats typical of the forest floor. With the exception of the *Erigone*, none of these species could be regarded as invasive.

The next sector in order of abundance of unique species was the spot-limed peat bog (VII) with *Carabus arvensis* Herbst (flightless, heathland species). *Notiophilus aquaticus* (L.) (also a heathland species, sometimes capable of flight)), *Agonum muelleri* (Herbst) (moist loam soils, often in the open in disturbed land – a species taking readily to flight), *Zelotes latreillei* (Simon) (under stones in open habitats), *Hypselistes jacksoni* (Pickard-Cambridge) (rare in moss in marshes), *Cnephalocotes obscurus* (detritus and moss), *Erigone atra* (Blackwall) (common aeronautic vagrant) and *Agyneta decora* (Pickard-Cambridge) (undergrowth, moss and grass). Two of these species, the *Agonum* and the *Erigone*, could be either new colonists or vagrants whilst the others, so far as their habitats are known, could occupy undisturbed open moorland and bogs. *Zelotes* species are often associated with sand dunes.

Of the remaining ten species unique to a particular sector, two were highly mobile colonists of new habitats (*Trechus quadristriatus* and *Bembidion lampros* (Herbst)) and both occurred only in the untreated moorland of Sector X in 1993. The burnt moorland of Sector VIII, which was visually the most affected of any of the intervention treatments, had only one species not found elsewhere, the heathland lycosid, *Pardosa palustris* (L.).

The range of habitats described in the literature for each species is either too vague or too wide to allow prediction as to whether the species should occur in the area as a whole. The only clear relationship is with shade, some species avoiding it and others being confined to the forest floor. The few highly mobile vagrant species occurred, not only on limed areas, but also in "control" sectors. This approach, though largely inconclusive, at least indicated that invasion of the treated areas by new species has not occurred to any extent.

Insensitivity to lime

The paucity of clear responses to the presence of lime, either by loss of 'acidophilous' species, or by incursions of opportunistic species, appears to be at variance with the generally held view that calcifuge and calcicolous species exist, but is echoed in the conclusions of surveys of the terrestrial vegetation of the Loch Fleet catchment. The general lack of response cannot be claimed to be associated with early loss of lime from the catchment. Much of the lime had persisted until 1992. Nor were the amounts used insubstantial, the lowest rate (5 t ha^{-1}), for example, being the same as that employed in agriculture. It should, however, be pointed out that the application rate calculated for the catchment as a whole would be 3.5 t ha^{-1}.

The effects of liming a catchment are clearly less than those associated with natural, annual variations in assemblage composition, and far less than those associated with afforestation of a catchment. This insensitivity accords with experimental observations by Lindroth (1949) that 'calcicole' species respond to soil microclimate rather than to lime concentration or pH *per se*; species at the opposite extreme must be dependent more on the availability of a moist, organic substratum than on soil chemistry.

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References

Bauer, L. J. (1989) Moorland beetle communities on limestone 'habitat islands'. In. Isolation, invasion and local species diversity in carabids and staphylinids. *Journal of Animal Ecology*, **58**, 1077–1098.

den Boer, P. J. and den Boer-Daanje, W. (1990) On life history tactics in carabid beetles: are there only spring and autumn breeders? pp. 247–258. In *The Role of Ground Beetles in Ecological and Environmental Studies* (N. E. Stork, Ed.). Intercept, Andover.

Clymo, R. S., Foster, G. N., MacKay, J., Robertson, J., Shore, R. and Skidmore, D. I. (1992) Terrestrial biology in limed catchments. pp. 331–361. In *Restoring Acid Waters: Loch Fleet 1984–1990* (G. Howells and T. R. K. Dalziel, Eds.), Elsevier Applied Science, London.

Coulson, J. C., Butterfield, J. E. L. and Henderson, E. (1990) The effect of open drainage ditches on the plant and invertebrate communities of moorland and on the decomposition of peat. *Journal of Applied Ecology*, **27**. 549–561.

Eyre, M. D. (1994) Strategic explanations of carabid species distributions in northern England. pp. 267–275, in *Carabid Beetles: Ecology and Evolution* (K. Desender, M. Dufrere, M. Loreau, M. L. Luff, and J. P. Maelfait, Eds). Kluwer Academic Publishers, Dordrecht.

Eyre, M. D. and Luff, M. L. (1990a) The ground beetle (Coleoptera: Carabidae) assemblages of British grasslands. *Entomologist's Gazette*, **41**, 197–208.

Eyre, M. D. and Luff, M. L. (1990b) A preliminary classification of European grassland habitats using carabid beetles. pp, 227–236, in *The Role of Ground Beetles in Ecological and Environmental Studies* (N. E., Stork, Ed.), Intercept, Andover.

Hill, M. O. (1979) *DECORANA – a FORTRAN program for detrended correspondence analysis and reciprocal averaging.* Cornell University, New York, 52 pp.

Hildrew, A. G. and Townsend, C. R. (1987) Organization in freshwater benthic communities. pp. 347–371, in *Organization of Communities Past and Present* (J. H. R. Gee and P. S. Giller, Eds), Blackwell Scientific Publications, Oxford.

Howells, G. and Dalziel, T. R. K. (eds) 1992 *Restoring Acid Waters: Loch Fleet* 1984–1990. Elsevier Applied Science, London. 421 pp.

Howells, G., Dalziel, T. R. K. and Turnpenny, A. W. H. (1992) Loch Fleet; liming to restore a brown trout fishery. *Environmental Pollution*, **78**, 131–139.

Lindroth, C. H. (1945) *Die Fennoscandischen Carabidae: Eine Tiergeographische studie.* **1**. *Spezieller Teil.* Elanders Boktryckeri, Göteborg, 676 pp.

Lindroth, C. H. (1949) *Die Fennoscandischen Carabidae: Eine Tiergeographische Studie.* **3**. *Spezieller Teil.* Bröderna Lagerström Boktryckare, Stockholm, 911 pp.

Locket, G. H. and Millidge, A. F. (1951) *British Spiders.* Volume 1. Ray Society, London, 310 pp.

Locket, G. H. and Millidge, A. F. (1953) *British Spiders.* Volume 2. Ray Society, London, 314 pp.

Luff. M. L. (1990) *Pterostichus rhaeticus* Heer (Col., Carabidae), a British species previously confused with *P. nigrita* (Paykull). *Entomologist's Monthly Magazine*, **126**, 245–249.

Meijer, J. (1977) The immigration of spider (Araneida) into a new polder. *Ecological Entomology*, **2**, 81–90.

Merrett, P., Locket, G. H. and Millidge, A. F. (1985) A check list of British spiders. *Bulletin of the Arachnological Society*, **6**, 381–403.

Mossakowski, D., Främbs, H. and Baro, A. (1990) Carabid beetles as indicators of habitat destruction caused by military tanks. pp. 237–243, in *The Role of Ground Beetles in Ecological and Environmental Studies* (N. E. Stork, Ed.), Intercept, Andover.

Persson, T. (1987) *Effects of liming on soil fauna in forests – a literature review.* National Environmental Protection Board Report **3418**. National Environmental Protection Board, Solna, 72 pp.

Pope, R. D. (ed.) (1977) A check list of British Insects. Part 3: Coleoptera and Strepsiptera. *Handbooks for the Identification of British Insects* **11** (3). Royal Entomological Society of London.

Richter, C. J. J. (1970) Aerial dispersal in relation to habitat in eight wolf spider species (*Pardosa*, Araneae, Lycosidae). *Oecologia*, **5**, 200–214.

United Kingdom Acid Waters Review Group, (1988) *Acidity in United Kingdom Fresh Waters, Second Report.* Department of the Environment, HMSO, London, 61 pp.

Williams, C. B. (1964) *Patterns in the Balance of Nature and Related Problems in Quantitative Ecology*, Academic Press, London, 324 pp.