H. obscurus Sturm
H. palustris L.
H. planus (Fab.)
H. pubescens (Gyllenhal)
H. tristis (Paykull)
Potamonectes assimilis (Paykull)
P. depressus elegans (Panzer)
P. griseostriatus (DeGeer)
Strictotarsus duodecimpustulatus (Fab.)
Oreodytes sanmarkii (Sahlberg)
Agabus arcticus (Paykull)
A. bipustulatus L.
A. guttatus (Paykull)
Rhantus exsoletus (Forster)
Dytiscus marginalis L.

Gyrinidae
Gyrinus minutus Fab.
G. substriatus Stephens

Hydrophilidae
Helophorus aequalis Thomson
H. brevipalpis Bedel
H. flavipes Fab.
Cercyon impressus (Sturm)
Laccobius atratus (Rottenburg)
Anacaena globulus (Paykull)

Hydraenidae
Limnebius truncatellus (Thunberg)

Elmidae
Elmis aenea (Müller)
Oulimnius tuberculatus (Müller)

CHAPTER 15

Terrestrial Biology in Limed Catchments

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15.1 INTRODUCTION

Although the focus of many restoration/liming studies lies with the improvement of surface water quality and its associated fauna and flora, a variety of studies on the associated terrestrial ecosystems have been undertaken at Loch Fleet, as well as at other restoration sites. The objectives are partly to deduce soil and hydrological conditions as revealed by vegetation, and to assess the contribution of terrestrial components, for example for fish diets, and furthermore to provide a basis for assessing any changes in the associated terrestrial environment as a consequence of liming or other restoration techniques.

The concern that catchment liming would alter soil and vegetation characteristics of upland terrain, as well as possible direct effects on components of the terrestrial fauna, has led to speculation that adverse effects might ensue. At Loch Fleet, several investigations have been undertaken during the post-liming period to identify and quantify any unwelcome responses. These studies include surveillance of wetland, moorland and forest vegetation, some terrestrial invertebrate communities, small mammals, and birds. Few studies were made prior to liming in 1986, but observations have been assessed by reference to "control" areas within the catchment, or to the current state of knowledge of terrestrial fauna and flora of the Galloway uplands.

In addition, as explained in Chapter 11, lime applications are expected to result in soil changes (pH rise, increase in cation exchange capacity, and percentage base saturation) which might have some longer-term consequences on the upland vegetation.

15.2 VEGETATION SURVEY AT LOCH FLEET

15.2.1 Conditions Prior to Liming

The vegetation of the Loch Fleet catchment prior to liming was recorded in October 1984 and May 1985 at marked points on a regular 50-m grid. A small subsample of these points was resurveyed in October 1987 after treatments had been applied. The whole catchment will be resurveyed in 1992.

At the start of the project, the moorland vegetation was dominated by flying bent (*Molinia caerulea*) and heather (*Calluna vulgaris*) (Fig. 15.1). A total of more than 70 species was recorded (see Appendix 15.1). A number of other upland plants and communities characterise the environmental conditions at each site, i.e. soil type, degree of flushing, base status, landform, and exposure. The planted forest (1963) on the south-west of the catchment occupies only about 10% of the total area. It comprises a mixture of Sitka spruce (*Picea sitchensis*) and lodgepole pine (*Pinus

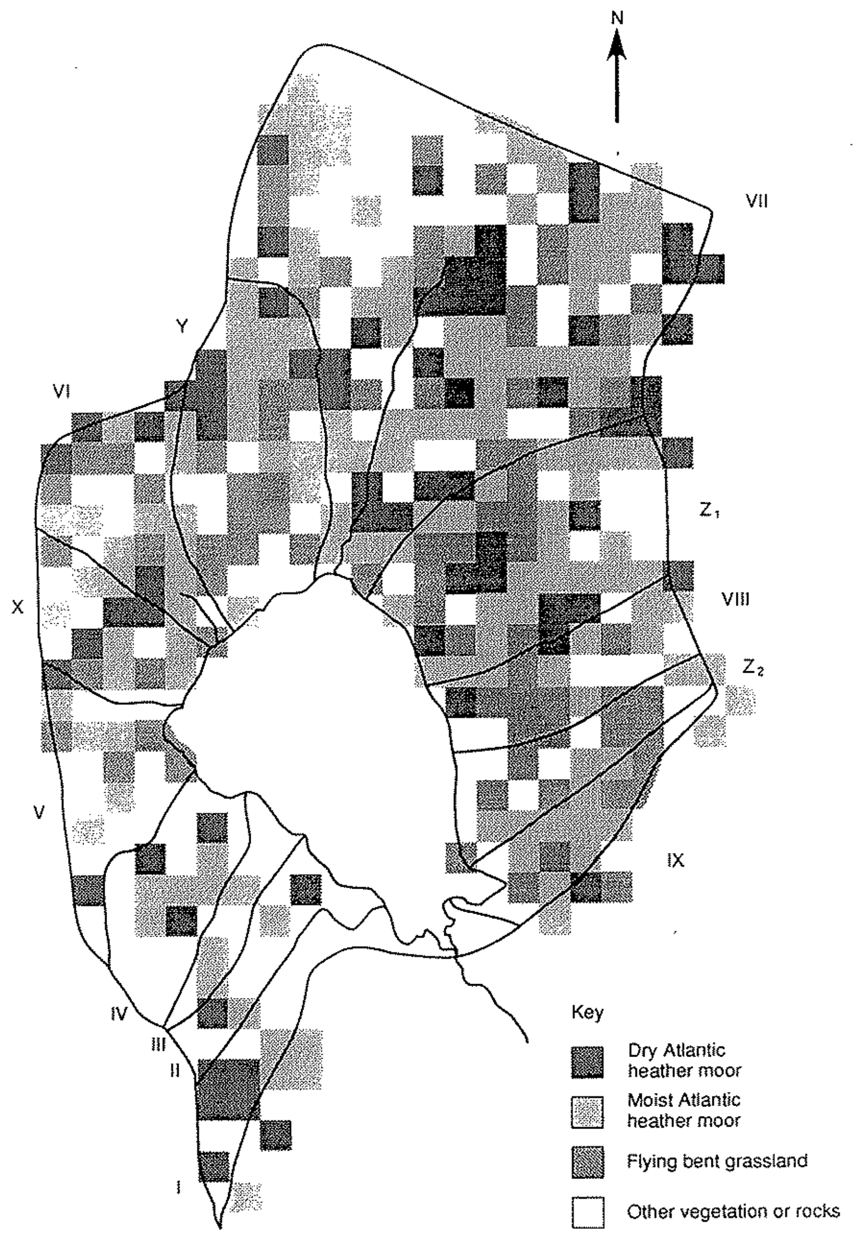

FIG. 15.1 Loch Fleet and its catchment: distribution of major plant communities.

TABLE 15.1
Plant communities and their frequency of occurrence

Code	Plant community	Number of occurrences	Hectares	% of total
CU1B	Dry Atlantic heather moor	66	16·5	14·6
CU1C	Moist Atlantic heather moor	152	38·0	33·6
SC1A	Common bog heather moor	11	2·75	2·4
SC1B	Northern bog heather moor	1	0·25	0·2
ES1A	Lowland blanket bog	68	17·0	15·0
ES1B	Northern blanket bog	1	0·25	0·2
ES1C	Blanket bog – terminal phase	1	0·25	0·2
ES1D	Flying bent bog	34	8·5	7·5
ES1E	Cotton-grass bog	1	0·25	0·2
ES1F	Common cotton-grass mire	2	0·5	0·4
ES1G	Upland blanket bog	12	3·0	2·7
N4C	Flying bent grassland	82	20·5	18·1
M1A	Species-poor sharp-flowered rush pasture	1	0·25	0·2
CN1B	Star sedge mire with sharp-flowered rush	2	0·5	0·4
CN9	Bog asphodel – bog moss water track	7	1·75	1·5
SP2	Common cotton-grass pool	1	0·25	0·2
R	Rock outcrops and boulders	9	2·25	2·0
W	Open water	1	0·25	0·2
	Total	452		99·6

contorta), with a few stands of larch (*Larix* × *eurolepis*) along the edge of the loch.

At first sight the vegetation of the catchment appears to be a mosaic of heather (*Calluna vulgaris*) and flying bent (*Molinia caerulea*) in various proportions, and this impression appears to be borne out by the high occurrence of these species at the sample points, 87% and 75%, respectively. Closer examination, however, revealed that the vegetation is made up of a number of discrete units or communities that reflect the differing combinations of environmental conditions, such as soil type, moisture status, degree of flushing, base status, landform, and exposure within the catchment (Table 15.1).

The most abundant of the dwarf shrub communities, moist Atlantic heather moor, forms the dominant vegetation of the lower slopes. Deer-grass (*Trichophorum cespitosum*), a component species, occurs in a distinct zone across the upper, eastern margin of the catchment where there is a marked break in slope. This species is found also on the exposed, rocky

ridges on either side of the deep gully of the Altiwhat in sector VII. Dry Atlantic heather moor is confined to the steep slopes of mounds and gullies and is most extensive north of the loch on the steep upper slopes where it is grazed by red deer. Lowland blanket bog occurs mainly on lower slopes. On the high ground west of the forestry and on the high peat plateau of sector VII it is replaced by its upland counterpart. Two flush communities are widespread, each dominated by dense tussocks of flying bent (*Molinia caerulea*). Flying bent bog is differentiated by the presence of cotton-grass (*Eriophorum vaginatum*) and is most common on the northern and eastern flanks. Flying bent grassland, extensive in the northern part of the catchment, is also heavily grazed by deer in the more sheltered sites.

There are clear, definable relationships between vegetation and the environment, with various environmental properties being reflected in the presence of specific communities or species (Table 15.2). The dominant environmental influence is that of flushing, which to some degree affects virtually every site in the catchment. Areas least flushed are the steep slopes at the highest point of the northern watershed and the peat "flats" under the coniferous plantations in the south-west. The middle and lower slopes of the northern and eastern sectors are the most flushed. The percentage cover abundance of flying bent grass (*Molinia caerulea*) provides a crude estimate of the degree of flushing.

The link between vegetation and soil within the catchment is primarily one associated with the structure of the organic soil horizons and soil wetness. There is a gradient from dry heather moor on well-structured, peaty soils which are occasionally or frequently waterlogged, to bog heather moor on soils subject to prolonged waterlogging, then to blanket bog on unstructured peat where the waterlogging is prolonged or very prolonged.

15.2.2 Conditions Following Liming

The vegetation resurvey 2 years after liming (but comprising only 12 limed sites) revealed only slight changes following liming, with a few additional species which were thought unlikely to be new colonisers, but rather to have been undetected during the initial survey. There was some indication from one resurveyed site on peat in sector VI, however, that there was a slight trend to greater dominance of the grass *Molinia caerulea* over *Calluna* which had died at that sample site. In sector VIII, *Calluna* is regenerating after 1987 muirburn. With the exception of *Calluna* damage at the single site, the changes in the short term appear to be slight or

TABLE 15.2
Diagnostic plant species and their frequency of occurrence

Plant species	Diagnostic for	Occurrence Sites	%
Calluna vulgaris	moorland	394	87·2
Empetrum nigrum	exposure	16	3·5
Erica cinerea	dry heath	203	44·9
E. tetralix	moist and wet heath	259	57·3
Vaccinium myrtillus	dry heath; exposure	56	12·4
Molinia caerulea	acid flushing	341	75·4
Nardus stricta	acid peaty soils	64	14·2
Carex echinata	flushing	1	0·2
C. panicea	flushing	43	9·5
Juncus acutiflorus	better base status flushes	9	2·0
Eriophorum vaginatum	blanket bog	90	19·9
Trichophorum cespitosum	moist and wet heath, exposure	180	39·8
Anemone nemorosa	better base status	1	0·2
Narthecium ossifragum	wet heath and bog: flush channels	28	6·2
Potentilla erecta	in wet communities, flushing	112	24·8
Viola palustris	better base status flushes	2	0·4
Hypnum jutlandicum	acid moorland	338	74·8
Racomitrium lanuginosum	exposure	25	5·5
Rhytidiadelphus loreus	exposure	29	6·4
Sphagnum auriculatum	flush channels	7	1·5
S. capillifolium	moorland	61	13·5
S. papillosum	blanket bog	45	10·0
Thuidium tamariscinum	better base status	1	0·2
Larix × eurolepis	coniferous plantations	8	1·8
Pinus contorta	coniferous plantations	47	10·4
Picea sitchensis	coniferous plantations	37	8·2

insignificant. Four years after liming the catchment presents the same picture overall, only two sites indicating changed communities.

Although the soil conditions at limed sites are changing, the indications were that aerial shoots of *Sphagnum* were killed (3 sites, sectors VI and VII) and *Calluna* cover was reduced by liming (1 site, sector VI). The dominance of *Molinia* is favoured, in the short term, by both muirburn and liming of the moist Atlantic heather moor community.

15.3 WETLAND/MOSS STUDIES

15.3.1 Introduction

Mosses have no roots. Their leaves are, in most cases, only one cell thick with no waxy cuticle (or no more than a very thin one). Most mosses take in water and solutes directly through their leaves. Some species, including the bog moss *Sphagnum*, move solutes around internally. Mosses are therefore particularly susceptible to chemicals in the environment. *Sphagnum* has disappeared from large parts of the southern Pennines, probably as a consequence of high concentrations of sulphur dioxide and bisulphite aerosol in the atmosphere there (Ferguson *et al.*, 1978).

Sphagnum is, quantitatively, much the most important moss at Loch Fleet. It is a component of the heather moorland and of the *Molinia* moorland that covers much of the catchment; it is co-dominant in some of the upper catchment blanket bog (particularly in sector VII); and submerged species were prominent in the loch itself prior to liming, at 2–5 m deep (extending to greater depths than any other macrophyte) (see Chapter 14). Although the large-scale vegetation survey undertaken at Loch Fleet (Section 15.2) categorises only a limited area of the catchment (3.1% of 110 ha) as blanket bog, in many areas *Sphagnum* species are commonly found, although not dominant. Over the catchment as a whole, the biomass of *Sphagnum* is clearly less than that of *Molinia* or *Calluna* on the moorland terrain, or of the planted forest. Methods of lime application concentrated effects within limited areas; in sector IV, runoff from the forest is routed through deep ploughed furrows, and in sector VII about 2.7 ha of the treated area (in total about 10 ha) is upland blanket bog dominated by *Sphagnum* species.

Sphagnum produces up to 30% of its dry mass as polymeric uronic acids. These are formed in the –COOH form, but the acid can dissociate, so the H^+ can be exchanged by other cations in rain or in groundwater seeping among the plants (Clymo, 1963). As a consequence the surrounding water is made more acid. A second important property of *Sphagnum* is that it is sensitive to the *combination* of high pH and high calcium concentration produced by liming (Clymo, 1973). The species differ in their susceptibility. *Sphagnum papillosum* is among the more sensitive species, and on sector VII is exposed to permanent or intermittent limed flows, while *S. capillifolium* growing at slightly higher levels above the standing water can avoid direct exposure to the limed water. Two other species, *S. inundatum* and *S. recurvum*, are less sensitive. A further species, *S. subnitens*, found in the forested sector IV, is another more resistant species.

Lime was added to the Loch Fleet catchment in different ways in the different sectors (see Chapter 9). In the upper wetland area of sector VII, where most of the upland blanket bog of the catchment is found, limestone was distributed in the standing water and wetter areas to provide a source of limed water to the Altiwhat, specifically to counter acid pulses in this spawning tributary during periods of heavy rainfall. It was thus intentionally focused in these areas and inevitably has produced a mosaic of concentrations of calcium and of H^+ in the standing water of the bog. As a consequence in sector VII, the pattern of addition and the consequent pattern of exposure concentrations is highly heterogeneous. In effect, a large number of undesigned and uncontrolled small-scale exposures has resulted from the original large-scale designed experiment. In these circumstances much may be learned from observation, but it is difficult to produce numerical results.

15.3.2 Observations

In Loch Fleet itself, *Sphagnum auriculatum* (one of the Subsecunda) was abundant prior to liming in the depth zone from 2 to 5 m. The responses of this species to the changed water quality within the lake itself are reported in Chapter 14 (Section 14.5.3); there is reduced growth and a substantial reduction in biomass. The closely related species, *S. inundatum*, found in the upland bog of sector VII, is surviving in the intermittently submerged areas, but not spreading much.

In sector IV mosses are particularly abundant in the ploughed furrows within the forest. Lime was applied below the canopy as a slurry, and runoff concentrated effects into the furrows. It may be noted that the conditions within the forest reflect the land use and management of that area over the past three decades and shading has restricted the understory. Six months after treatment some mosses were thriving; these included *Hypnum jutlandicum*, *Dicranum scoparium*, and *Polytrichum commune*. Two species of *Sphagnum* – *S. subnitens* = *S. plumulosum* and *S. recurvum* – both survive and are apparently healthy. But two other species – *S. capillifolium* and *S. papillosum* – were completely dead. The different response of these two pairs is consistent with their general ecology. The pair that died are species characteristic of ombrotrophic (rain-water-dependent) bog, but the two that survived are often found in flushed situations, subject to a greater supply of solutes. These responses do, of course, depend on *local* dose effects.

In preliminary trials of limestone and chalk applications at 10 and 20 t ha^{-1} on a series of small plots on open moorland just outside the catchment near sector IX, vegetation survey at 12 months after treatment showed rather equivocal results, with *Sphagnum* (no species given) present in some plots only, and the moss *Hypnum jutlandicum* reduced in some, but increased in others. There was no consistent difference related to the dose applied.

In the upper part of sector VII (Fig. 15.2), in the source area of the Altiwhat Burn, where lime was spread at an average rate of 10 t ha^{-1} over about a third of the sector, more conspicuous effects are seen. In this difficult terrain, distribution was uneven and in the wetter areas there are still (3 years later) in numerous places patches of limestone congealed to a semi-solid mass of several centimetres (even up to 100 cm) across. The hydrology of the area is complex and varies with flow, with at least six sub-catchments (Fig. 15.2), one much larger than the rest and with four distinct parts. The complex pattern of water flow has interacted on the original distribution of lime to give a bewildering pattern of doses in the water seeping past the plants.

The results of differential survival to this varied exposure are similar to those seen in sector IV. Wherever lime is still visible, *Sphagnum papillosum* is dead, and *S. capillifolium* is often dead but survives on low hummocks above the reach of limed water. In contrast, both *S. auriculatum* and *S. recurvum* have survived in places immediately adjacent to, or intermixed with, the remains of these two, more sensitive, species. The effects are clearly related to water flow patterns: in some cases *S. papillosum* has been killed at least 30 m down-slope from the nearest visible lime deposit. In other places patches of *S. papillosum* survive in backwaters, presumably growing aside from the flow of limed water. The plants are able to reacidify small flows of water by the cation exchange process already described. In the 3 ha of this limed sub-catchment to the north-west of the Altiwhat, about 35% of the area was dominated by *Sphagnum*. Twelve months after liming, in 3% of the area, *Sphagnum* was still alive but in 32% (almost all *S. papillosum*) was dead. Probably most plants died within a few weeks of liming.

Three years later the sheets of dead *Sphagnum* remain a whitish grey colour. The apices of the plants have disintegrated, but much of the rest remains, although it is compacting. There is a possibility that erosion may occur. If it were to do so, it might be rapid, but there is as yet no obvious sign, although there is evidence of past erosion (prior to liming) outside the limed areas of sector VII. Nor is there any sign of recovery of these two

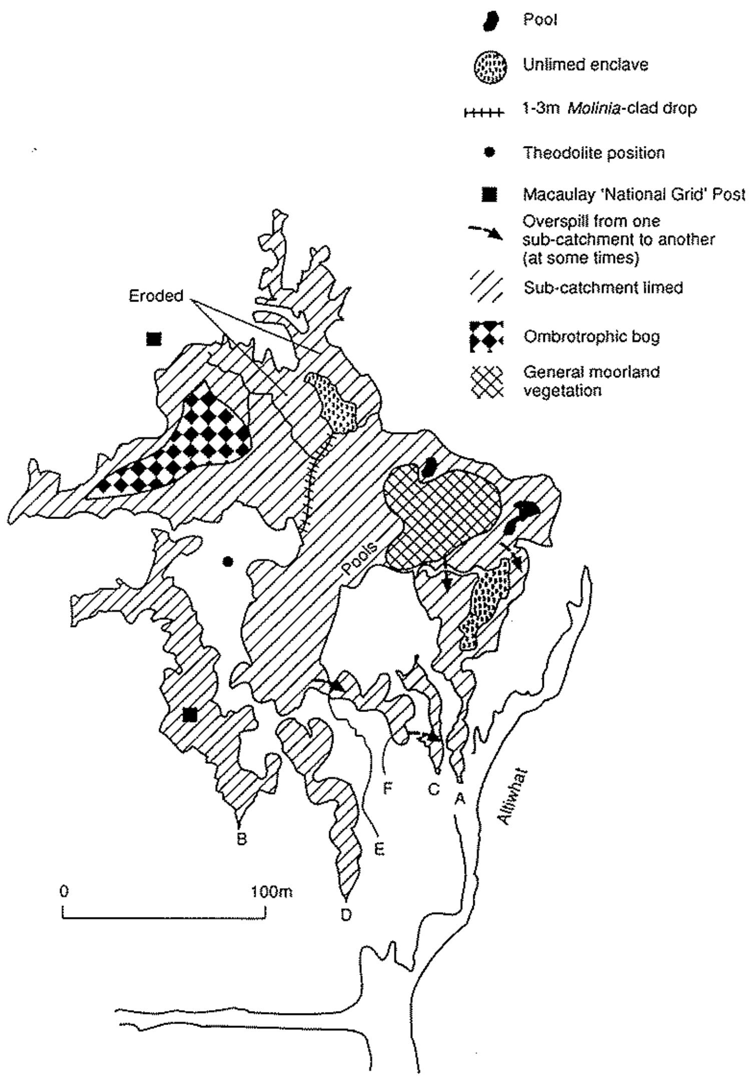

FIG. 15.2 Loch Fleet limited wetland study area in sector VII. Subcatchments (A to F) as in text.

species of *Sphagnum*, although the less sensitive species (*S. inundatum* and *S. recurvum*) were growing actively 4 years after liming.

15.3.3 Conclusions

At 6 months and 12 months after liming, the two most sensitive *Sphagnum* species were affected where they were directly exposed to limed water in sectors IV and VII. Other species are less damaged, even *S. capillifolium*, where they may grow above the usual level of standing water. While *Sphagnum* damage is still evident 3 years after liming in the upland area of sector VII, many other plants characteristic of bogs (the moss *Racomitrium lanuginosum*, bog heather, *Erica tetralix*, bog cotton, *Eriophorum vaginatum*, sundew *Drosera* sp., bog asphodel, *Narthecium ossifragum* are evidently healthy.

The possibility of increased erosion post-liming has also been considered, and permanent plots established to assess it. So far there is no evidence of erosion. It may be noted that there are indeed areas of long-standing and substantial erosion in sector VII and elsewhere in the upper parts of the catchment where liming did not occur.

15.4 TREE STUDIES

15.4.1 Introduction

Although afforestation in the Loch Fleet catchment covers only 10% of the area, some studies of tree response to liming were undertaken because of greater interest in more densely forested sites elsewhere.

Calcium is known to affect plant growth directly through its action on hormone transport. It also has an indirect action on plant productivity through its interaction with soil ions, reducing or increasing their availability to the plant. Of significant importance is likely to be the increased availability of bicarbonate ions, which may affect cytokinin transport (Marschner, 1986). These indirect effects may not be immediately obvious but are likely to be evident in long, multiple rotations (Gessll, 1987). At excessive rates of application, lime-induced chlorosis may occur and this may either be a direct effect of calcium or an indirect effect due to iron deficiency or that of some other element such as phosphorus or potassium (Rafahi, 1982; Marschner, 1986).

The effects of nutrients on tree productivity are most easily assessed through the measurement of morphological characters. The most commonly used characters, and those that are most straightforward to assess, are overall tree height and diameter at breast height (dbh). However, these characters are unlikely to show significant responses within the short term. Needle length has also been used widely to monitor the vigour of conifers (e.g. Binns *et al.*, 1980).

Conifers are outbreeding trees and are, therefore, genetically and morphologically heterogeneous. When planted in close stands they are also subject to substantial site differences between trees and even between branches within a tree owing to differential light penetration of the canopy. It is therefore necessary to sample a large number of sites and trees to obtain a reliable assessment of mean tree performance.

15.4.2 Observations on Limed and Unlimed Areas

Lodgepole pine and spruce, 25 years old, were present at Loch Fleet in mixed stands, of which one area had been limed (see Chapter 9, Table 9.4) in 1986. Observations made after the cessation of growth in 1988, when 15 trees of each species were sampled from the limed sector IV and from the adjacent, unlimed sector III. Growth cycles, one of which is produced in each year on each lateral branch, were identified from the pre-liming year 1985 and from the post-liming years 1986, 1987, and 1988. Appropriate growth cycles were sampled from two branches from each of an unshaded, upper whorl and a shaded, lower whorl. Characteristics of the growth cycles, i.e. length, needle density, and needle length, which are considered to be indicative of tree vigour, were measured.

Soil pH below the trees showed considerable heterogeneity, with unexpectedly high pH values occurring even within the unlimed subcatchment. This heterogeneity, together with the inter-tree variability noted in the assessments of all the characters, made the analysis and interpretation of results subject to confounding effects. These preliminary results suggest the possibility of a slight growth depressant effect on the vigour of lodgepole pine but, in contrast, a beneficial effect on Sitka spruce. These results must be considered as short-term effects giving no indication of the effects of calcium on long-term rotations.

Assessment of the effect of liming on coniferous trees has also been made by foliar analyses (Wilson *et al.*, 1988). Needle samples collected from pine and spruce in 1986, 1987, and 1988 showed an increase in foliar nitrogen and phosphorus concentrations, possibly as a result of a flush of soil microbial activity after liming increased the mineralisation of organic matter. Thus, for upland sites such as Loch Fleet, characteristically nitrogen and phosphorus deficient, liming appears to have had a beneficial effect on tree mineral nutrition, at least in the short term. Longer-term effects

during the expected 50-yr rotation of forest plantations would require longer-term monitoring.

15.5 GROUND BEETLE AND SPIDER COMMUNITIES

15.5.1 Introduction

Recent studies of small limed ombrogenous bog plots (e.g. Mackenzie, 1989) have shown some differences in invertebrate communities between limed and control plots, specifically in mites, Collembola, and ants, 18 months after liming. In the same trials, predatory species such as beetles increased non-significantly, but spiders were 30% fewer. It was considered valuable to discover if this change had occurred with the larger scale trials at Loch Fleet and work was undertaken in 1988 to detect if any effects had occurred. Terrestrial invertebrates selected for study were ground beetles (*Carabidae*) and spiders (*Aranea*), predatory species common on moorland; 26 beetle species and 68 spider species were recorded. The view was taken that such predators would be better indicators of any change than lower trophic groups. The ecology of these two groups is well known and each includes species that are sensitive to environmental changes as well as opportunist species that colonise disturbed habitats.

Traps were set out in all sectors (limed and unlimed) and each supplied with about 50 ml of proprietary antifreeze solution (ethylene glycol), a killing agent and preservative that is neither attractive nor repellent to invertebrates. The traps were covered with 2 cm chicken wire to prevent access by mammals and birds. Trap catches were collected monthly, the material being bulked into catches for each line of traps, giving two replicates per sectoral treatment. Catches were identified to species level. Data were subject to multivariate analysis.

15.5.2 Findings (Appendices 15.2 and 15.3)

Of all the species of spiders identified (Merrett *et al.*, 1985) most catches were dominated by *Pardosa pullata*. The groupings identified by TWINSPAN were differentiated by reference to the abundance of the commonest species, *P. pullata*, or to the presence of some less common species.

The soils of the "wetter" moorland of sectors VII and IX were characterised paradoxically by the lowest percentage of water and organic matter and the highest dry bulk densities. This was because these areas are flat and received inorganic material from beneath the blanket bog up-slope. Thus the soil of the sloping moorland comprises almost pure peat, whereas more inorganic material is incorporated into the peat of the flat moorland. Despite the apparent paradox of low soil moisture values, the flatter parts of catchment were the only ones with open pools of water and thus able to support moisture-loving species.

The DECORANA ordination (Fig. 15.3) confirmed the division into flat moorland with standing water (sectors VII and IX), afforested areas (FC and IV), and the rest of the samples on sloping, unafforested moorland. The moorland treated by muirburn formed an outlying group. There was no tendency for limed sectors (IV, VI, VII, IX, and Z_1) to be associated in ways that could not be explained by other features.

Diversity (Williams, 1964) was generally lowest in the afforested area (FC), most variable in the watershed mire with spot applications of lime (VII), and highest on the fringe of an afforested area (IX).

Of all the species of carabid identified (Pope, 1977), the species most often caught was *Pterostichus diligens*, an upland wetland species. *Carabus* species were common in many catches. TWINSPAN of abundance classes split the samples into two distinct groups: from afforested areas and from moorland (Fig. 15.4). The moorland group could not be subdivided in a meaningful way.

The lowest values for diversity were associated with open moorland receiving the highest rate of lime treatment (sector VI, site 1) and with untreated moorland (sector X, site 1). The second highest diversity value for ground beetles was for the same trap transect (sector VII, site 2) which had the highest diversity of spiders. The diversities of the ground beetle fauna were generally low.

15.5.3 Conclusions

The principal predator assemblages of moorland invertebrates, ground beetles and spiders, could thus be divided into those of open moorland and those of afforested areas. It was not possible to detect any effects on assemblages associated with liming.

More spider species were found than ground beetle species and it was possible to subdivide the spider assemblages of moorland into those of the sloping area and the flat area with open pools, and that associated with muirburn. The two flat areas of moorland, on sectors VII and IX, were both subject to low rates of lime, but on the basis of lack of discernible effect on the other moorland sectors, it is reasonable to conclude that liming had no effect in these sectors.

TWINSPAN indicated the possibility of using the abundance of *Pardosa pullata* as an indicator of assemblage type. This could lead to false conclu-

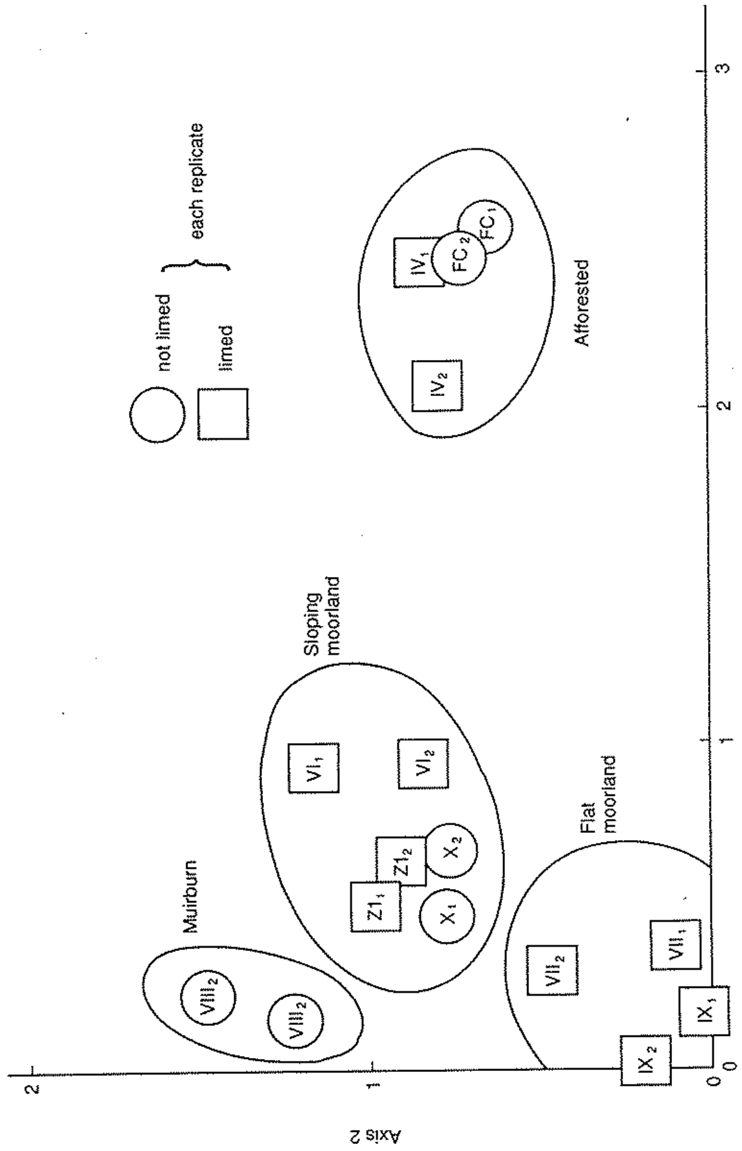

FIG. 15.3 DECORANA ordination of spider assemblages for limed as unlimed sectors of Loch Fleet catchment. FC is a forest control site, outside the Fleet catchment.)

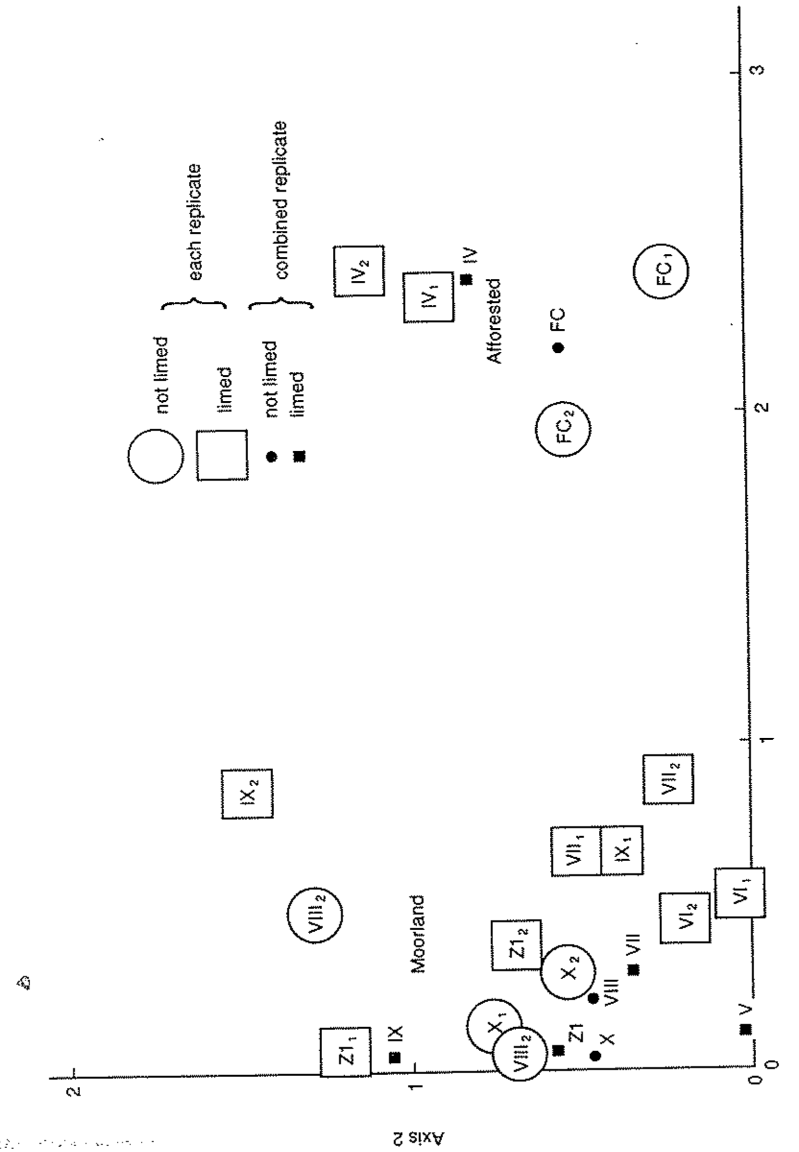

FIG. 15.4 DECORANA ordination of ground beetle assemblages for limed and unlimed sectors of Loch Fleet catchment (FC is a forest control site outside the Loch Fleet catchment.)

sions owing to trapping efficiency varying with the terrain. The presence or absence of less abundant species would be more appropriate even though TWINSPAN of presence/absence data was less effective than TWINSPAN of abundance classes.

The presence and abundance of *Carabus* species did not appear to be affected by liming. Most species of this genus are particularly sensitive to habitat disturbance in lowland grassland (Tietze, 1985) and upland grassland (Luff and Rushton, 1988).

Diversity was higher for spiders than for ground beetles. Diversity did not appear to be affected by liming.

15.6. OTHER TERRESTRIAL FAUNA

15.6.1 Small Mammals (Shore, 1990)

The small mammal fauna of upland moors is dominated by common shrews, *Sorex araneus*, and pygmy shrews, *S. minutus* (Butterfield *et al.*, 1981; Yalden, 1981), both of which are protected under the Wildlife and Countryside Act (1981). Moorland and upland sheepwalk is also marginal habitat for field voles, *Microtus agrestis* (Corbett and Southern, 1977), which are a major prey of protected birds of prey on moorland (Davis and Davis, 1981; Newton *et al.*, 1982). Mackenzie (1989) found that the number of shrews incidentally captured in her pitfall traps (set to catch invertebrates) was greater in control plots than in small (less than 25 m^2), experimentally limed plots (4·05 vs 2·9 shrews per trap, respectively; $\chi^2_{(1)} = 4{\cdot}7$; $p = 0{\cdot}02$). There was no significant effect of liming on vole captures. These results suggested that shrew activity was lower on limed plots than on controls, possibly reflecting differences in the abundances of prey organisms.

It was judged useful to study whether catchment liming at Loch Fleet has affected small mammal populations. Small mammal numbers on sectors VI and Z_1 (limed in 1986 and 1987, respectively) and sectors X and Y (non-limed controls) at Loch Fleet were estimated by pitfall trapping in August 1989. Results from Loch Fleet indicate that, at least 2 years after application, there are no significant differences between limed and control areas in the numbers of common shrews and field voles captured (Table 15.3). However, significantly fewer female pygmy shrews were captured on limed than on control sites overall (16 vs 31; $\chi^2_{(1)} = 4{\cdot}79$; $p < 0{\cdot}05$), although there was no difference in the number of male pygmy shrews captured in limed and control areas.

TABLE 15.3
Small mammal catches at Loch Fleet, 1989

Sites	*Common shrew*		*Pygmy shrew*		*Field vole*	
	Male	*Female*	*Male*	*Female*	*Male*	*Female*
Y (control)	12	15	28	23	1	1
VI (lime)	17	16	24	11	4	0
X (control)	8	10	12	8	0	1
Z_1 (lime)	17	10	15	5	2	1
Total:						
Control	20	25	40	31	1	2
Lime	34	26	39	16	6	1

Interpretation of these findings at Loch Fleet calls for analysis of the results obtained from other sites. Catchment liming may potentially have both short- and long-term effects on shrews. At Llyn Conwy, N. Wales, fewer common and pygmy shrews were pitfall trapped on the small (5 × 5 m) limed plots than on control areas up to 2 months and 5 months after application, respectively, and live-trapping suggested that the number of pygmy shrews on limed sites was reduced up to 4–5 months after application (Shore, 1990). Liming may initially reduce shrew activity by decreasing prey availability; fewer small invertebrates were captured in pitfall traps on limed than on control plots (Mackenzie, 1989). However, the reduction in shrew activity appears to be short lived. At Llyn Conwy, common and pygmy shrews were live-trapped in equal numbers on limed and control areas 2 months and 5 months after application, and 1 year after liming, pitfall trap capture success was not significantly different for limed and control areas at both Llyn Conwy and at Llyn Brianne, mid-Wales.

Longer-term effects of liming on shrews were indicated by results from Loch Fleet and Llyn Brianne where pitfall trap captures of common shrews were always slightly greater on limed than on control areas (Table 15.3; Shore, 1990). These data suggest that, at least 1 year after application, there is an increase in common shrew activity on limed sites. Although results from Loch Fleet also suggest that capture success of female pygmy shrews is lower on limed than on control areas, this may not have been due to liming because the number of female pygmy shrews captured was not greater on control than on limed areas at any other site.

Live-trapping studies suggest that there may be an initial decrease in field vole numbers following liming (Shore, 1990). However, there is no evidence from pitfall trap studies that liming has any consistent, long-term effect on field vole activity.

Overall it is clear from pitfall trap studies that shrews and voles do occur on limed areas. However, the possible effects of liming on small mammal populations are still uncertain because pitfall traps monitor activity, not abundance. Differences in animal activity between sites may not reflect differences in population numbers; for example, animals may be more active if prey is scarce. Liming may also alter forage quantity and quality without significantly altering population numbers; areas with poor food availability may support the same number of individuals as better areas but contain fewer adult, dominant animals and many individuals in poor condition. Live-trapping studies are currently being carried out to determine if liming affects population dynamics. Age, body size, and condition of shrews captured at Loch Fleet and Llyn Brianne will be examined to study any effects of liming on nutrition and population structure.

15.6.2 Other Observations (MacKay, 1989; Appendix 15.4)

The bleak upland moorland surrounding Loch Fleet imposes severe limitations on the range of wildlife to be found there. The only British mammal that is exclusively montane is the mountain hare (*Lepus timidus*). Other mammals, such as the red deer (*Cervus elaphus*), spend the summer on the upland moors but migrate to lower ground in winter, especially into the conifer plantations. Plantations also provide shelter for roe deer (*Capreolus capreolus*), foxes (*Vulpes vulpes*), stoats (*Mustela erminea*), rabbits (*Oryctolagus cuniculus*), and wood mice (*Apodemus sylvaticus*). The dense rough upland grassland is the habitat for small mammals, especially the short-tailed vole (*Microtus agrestis*), common shrews (*Sorex araneus*), and pigmy shrews (*S. minutus*).

Adders (*Vipera berus*) are fairly common around Loch Fleet, feeding on the small mammals. They also eat lizards (*Lacerta vivipara*), toads (*Bufo bufo*), and frogs (*Rana temporaria*), which are all common and were so even prior to liming around the loch. The palmate newt (*Triturus helveticus*) is also found.

Several species of birds found at Loch Fleet are characteristic of upland and moorland areas. These include the red grouse (*Lagopus lagopus*), black grouse (*Lyrurus tetrix*), ravens (*Corvus corax*), meadow pipits (*Anthus pratensis*), stonechats (*Saxicola torquata*), and wheatears (*Oenanthe oenanthe*). The meadow pipits occur in large numbers during the summer, although they are dependent on insect populations. In turn, they are the main food for the hen harriers (*Circus cyaneus*) and the peregrine falcon (*Falco peregrinus*), which can often be seen to the north and east of the loch. The short-eared owl (*Asio flammeus*) feeds mostly on small mammals. Buzzards (*Buteo buteo*) occasionally soar over the loch, and very rarely a golden eagle (*Aquila chrysaetos*) can be seen.

Many of the birds that visit Loch Fleet are typical of freshwater habitats, such as the ducks, mallard (*Anas platyrhynchos*), and teal (*A. crecca*), which visit the loch in spring and early summer, often making several unsuccessful nesting attempts. Tufted duck (*Aythya fuligula*), pochard (*A. ferina*), and goldeneye (*Bucephala clangula*) are all regular winter visitors. The common sandpiper (*Actitis hypoleucos*) breeds at Loch Fleet in early summer. Grey wagtails (*Montacilla cinerea*), pied wagtails (*M. alba yarrellii*), and dippers (*Cinclus cinclus*) are also fairly common, the latter present in the Altiwhat even before liming. Almost all species present probably occurred before liming, except possibly the fish eaters.

Since fish were reintroduced to the loch in 1987, several fish eaters have found the loch. In 1989 a single cormorant (*Phalacrocorax carbo*) was seen almost daily throughout the summer. Mink (*Mustela vison*) and otters (*Lutra lutra*) have also been recorded. The first sighting of a heron (*Ardea cinerea*) was in September 1989 near the outlet. Gulls are often seen in flight overhead but seldom land on the loch.

The forested area also gives shelter to a number of species, including the carrion crow (*Corvus corone corone*), which is mainly a scavenger, but also preys on frogs and toads in spring when they are spawning. The crow has learnt how to remove the toad's distasteful skin. Other birds, found mainly in the woodland, include chaffinches (*Fringilla coelebs*), robins (*Erithacus rubecula*), willow warblers (*Phylloscopus trochilus*), siskins (*Carduelis spinus*), wrens (*Troglodytes troglodytes*), and blackbirds (*Turdus merula*), although the latter two can also be found elsewhere around the loch, especially in the Altiwhat gully.

Other birds seen or heard in the forest, especially along the forest roads approaching Loch Fleet, include the cuckoo (*Cuculus canorus*), wood pigeons (*Columba palumbus*), jays (*Garrulus glandarius*), crossbills (*Loxia curvirostra*), bullfinches (*Pyrrhula pyrrhula*), and woodcocks (*Scolopax rusticola*).

15.7 CONCLUSIONS

Although it has sometimes been claimed (eg. Persson, 1982) that catchment liming will change terrestrial communities, this has seldom been documented, perhaps not surprising in view of the relatively few projects followed through for sufficient time. The opportunity to record and measure such effects has been provided at Loch Fleet with studies extending through four post-liming years. While direct contact with applied lime or high pH/high calcium drainage water has damaged two *Sphagnum* species in a limed upland wetland, other vegetational changes of significance are not evident, nor are invertebrate or vertebrate communities apparently affected. Thus concern relates only to possibly adverse changes to ombrotrophic *Sphagnum* wetlands (MacKenzie, 1989). Reference to historic changes in the Cairnsmore-of-Fleet area (NCC, 1983) suggests that major husbandry changes (the introduction of rabbits in 1830, sheep monoculture early in the nineteenth century, the reintroduction of red deer in 1900) and changing land-use practices (forestry since 1945) have had evident and extensive effects on the area. The limited area and extent of *Sphagnum* effects at Loch Fleet is notable and should be set in the context of benefits to the fishery and other aquatic components.

In the case of direct lake or stream liming, there is little justification for considering terrestrial effects, although changes in the aquatic invertebrate community will no doubt increase the population or density of riparian birds such as the dipper.

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APPENDIX 15.1: PLANT SPECIES RECORDED WITHIN THE CATCHMENT

Trees (planted)	
Larix × eurolepis	Larch
Picea sitchensis	Sitka spruce
Pinus contorta	Lodgepole pine
Other trees/shrubs	
Salix aurita	Eared willow
Betula pendula	Silver birch
Sorbus aucuparia	Mountain ash
Dwarf shrubs	
Calluna vulgaris	Common heather
Empetrum nigrum	Crowberry
Erica cinerea	Purple heather
E. tetralix	Cross-leaved heath
Myrica gale	Bog myrtle
Vaccinium myrtillus	Bilberry
Ferns	
Blechnum spicant	Hard fern
Dryopteris dilatata	Broad buckler fern
Oreopteris limbosperma	Lemon scented fern
Polypodium vulgare	Polypody
Grasses	
Agrostis canina montana	Velvet bent
A. capillaris	Brown bent
A. stolonifera	Creeping bent
Anthoxanthum odoratum	Scented vernal grass
Deschampsia flexuosa	Wavy hair grass
Festuca ovina	Sheep's fescue
F. vivipara	Sheep's fescue (variety)
Holcus mollis	Creeping soft grass
Molinia caerulea	Purple moor grass, flying bent
Nardus stricta	Mat grass
Sieglingia decumbens	Heath grass
Sedges and rushes	
Carex binervis	Green-ribbed sedge
C. echinata	Star sedge
C. nigra	Common sedge
C. panicea	Carnation grass

C. pilulifera	Pill sedge
Juncus acutiflorus	Sharp-flowered rush
J. articulatus	Jointed rush
J. bulbosus	Bulbous rush
J. conglomeratus	Conglomerate rush
J. effusus	Soft rush
J. squarrosus	Heath rush
Luzula multiflora	Many flowered wood rush
Eriophorum angustifolium	Common cotton grass
E. vaginatum	Hare's tail grass
Trichophorum cespitosum	Deer grass

Mosses

Andreaea alpina	
Aulacomnium palustre	
Campylopus atrovirens	
C. flexuosus	
Dicranella heteromalla	
Dicranum scoparium	
Hylocomium splendens	
Hypnum jutlandicum	
Leucobryum glaucum	
Plagiothecium undulatum	
Pleurozium schreberi	
Pholia nutans	
Polytrichum commune	Hair moss
Racomitrium lanuginosum	Woolly fringe moss
Phytidiadelphus loreus	Hooked moss
Sphagnum auriculatum	Bog moss
S. capillifolium	Bog moss
S. cuspidatum	Bog moss
S. papillosum	Bog moss
S. recurvum	Bog moss
Thuidium tamarischinum	

Liverworts

Calypogeia muellerana
Cephaloziella sp.
Diplophyllum albicans
Lophocolea bidentata

Odontoschisma sphagni
Pleurozia purpurea

Lichens

Cladonia coccifera
C. impexa
C. furcata
C. floerkeana
C. squamosa
C. uncialis
Cornicularia aculeata
Parmelia physodes

Forbs

Anemone nemorosa	Wood anemone
Cerastium fontanum	Common mouse ear
Cirsium arvense	Creeping thistle
C. palustre	Marsh thistle
C. vulgare	Spear thistle
Crepis paludosa	Marsh hawk's beard
Dactylorhiza ericetorum	Heath spotted orchid
Digitalis purpurea	Foxglove
Drosera rotundifolia	Sundew
Epilobium angustifolium	Rose bay willow herb
E. palustre	Bog willow herb
E. montanum	Broad-leaved willow herb
Euphrasia officinalis	Eyebright
Galium saxatile	Heath bedstraw
Listera ovata	Twayblade
Narthecium ossifragum	Bog asphodel
Pedicularis sylvatica	Lousewort
Pinguicula vulgaris	Common butterwort
Polygala serpyllifolia	Heath milkwort
Potentilla erecta	Common tormentil
Ranunculus flammula	Lesser spearwort
Rumex acetosa	Common sorrel
R. obtusifolius	Broad-leaved dock
Senecio jacobaea	Ragwort
Solidago virgaurea	Golden rod
Stellaria alsine	Bog stitchwort

Succisa pratensis	Devil's bit scabious
Trifolium repens	White clover
Veronica serpyllifolia	Thyme-leaved speedwell
Viola palustris	Bog violet/marsh violet
Aquatic/marginals	
Carex rostrata	Beaked sedge
Isoetes echinospora	Spring quillwort
I. lacustris	Quillwort
Littorella uniflora	Shore weed
Lobelia dortmanna	Water lobelia
Potamogeton polygonifolius	Bog pond weed
Utricularia intermedia	Bladderwort

APPENDIX 15.2: SPIDERS FROM PITFALL TRAPS AROUND LOCH FLEET IN 1988

Identified by Dr. S.P. Rushton.
Names follow Merrett, Locket & Millidge (1985).

Gnaphosidae	
Drassodes cupreus	(Blackwall)
Haplodrassus signifer	(C.L. Koch)
Micaria pulicaria	(Sundevall)
Clubionidae	
Clubiona diversa	Pickard-Cambridge
C. reclusa	Pickard-Cambridge
C. trivialis	C.L. Koch
Liocranidae	
Agroeca proxima	(Pickard-Cambridge)
Thomisidae	
Xysticus cristatus	(Clerck)
Oxyptila trux	(Blackwall)
Salticidae	
Neon reticulatus	(Blackwall)

Lycosidae	
Pardosa nigriceps	(Thorell)
P. palustris	(L.)
P. Pullata	(Clerck)
Alopecosa pulverulenta	(Clerck)
Trochosa terricola	Thorell
Pirata piraticus	(Clerck)
Theridiidae	
Robertus lividus	(Blackwall)
Pholcomma gibbum	(Westring)
Linyphiidae	
Ceratinella brevipes	(Westring)
Walckenaeria acuminata	Blackwall
W. antica	(Wider)
W. atrotibialis	(Pickard-Cambridge)
W. cuspidata	(Blackwall)
W. nudipalpis	(Westring)
Dicymbium tibiale	(Blackwall)
Dismodicus bifrons	(Blackwall)
Gonatium rubellum	(Blackwall)
G. rubens	(Blackwall)
Pepocranium ludicrum	(Pickard-Cambridge)
Pocadicnemis pumila	(Blackwall)
Oedothorax gibbosus	(Blackwall)
O. retusus	(Westring)
Pelecopsis mengei	(Simon)
Silometopus elegans	(Pickard-Cambridge)
Tapinocyba pallens	(Pickard-Cambridge)
Monocephalus fuscipes	(Blackwall)
Gongylidiellum vivum	(Pickard-Cambridge)
Micrargus herbigradus	(Blackwall)
Erigonella hiemalis	(Blackwall)
Savignya frontata	(Blackwall)
Diplocephalus cristatus	(Blackwall)
Erigone atra	(Blackwall)
E. dentipalpis	(Wider)
Hilaira excisa	(Pickard-Cambridge)
Aphileta misera	(Pickard-Cambridge)

Porrhoma pallidum	Jackson
Agyneta decora	(Pickard-Cambridge)
A. olivacea	(Emerton)
A. ramosa	Jackson
Meioneta saxatlis	(Blackwall)
Centromerus dilutus	(Pickard-Cambridge)
C. prudens	(Pickard-Cambridge)
C. sylvaticus	(Blackwall)
Centromerita concinna	(Thorell)
Saaristoa abnormis	(Blackwell)
S. firma	(Pickard-Cambridge)
Bathyphantes gracilis	(Blackwall)
B. parvulus	(Westring)
Tapinopa longidens	(Wider)
Stemonyphantes lineatus	(L.)
Bolyphantes luteolus	(Blackwall)
Lepthyphantes alacris	(Blackwall)
L. Ericaeus	(Blackwall)
L. mengei	Kulczynski
L. pallidus	(Pickard-Cambridge)
L. zimmermanni	Bertkau
Linyphia clathrata	Sundevall
Microlinyphia pusilla	(Pickard-Cambridge)

APPENDIX 15.3: GROUND BEETLES CAUGHT IN PITFALL TRAPS 1988.

Names follow Pope (1977) with exception of *Pterostichus rhaeticus*.

Cychrus caraboides	(L.)
Carabus glabratus	Paykull
C. granulatus	L.
C. problematicus	Herbst
C. violaceus	L.
Leistus rufescens	(Fab.)
Notiophilus biguttatus	(Fab.)
N. germinyi	Fauvel
Loricera pilicornis	(Fab.)
Dyschirius globosus	(Herbst)
Patrobus assimilis	Chaudoir
Trechus obtusus	Erichson
Pterostichus diligens	(Sturm)
P. niger	(Schaller)
P. rhaeticus (originally confused with *P. nigrita* (Paykull))	Heer
P. versicolor	(Sturm)
Olisthopus rotundatus	(Paykull)
Agonum fuliginosum	(Panzer)
Amara lunicollis	Schiödte
Harpalus latus	(L.)

APPENDIX 15.4: WILDLIFE OF LOCH FLEET

Mammals	
Cervus elaphus	Red deer
Capreolus capreolus	Roe deer
Lepus timidus	Blue hare
Oryctolagus cuniculus	Rabbit
Vulpes vulpes	Fox
Lutra lutra	Otter
Mustela vison	Mink
M. erminea	Stoat
Sorex araneus	Common shrew
S. minutus	Pigmy shrew
Microtus agrestis	Short-tailed vole
Apodemus sylvaticus	Wood mouse
Talpa europaea	Mole
Reptiles	
Lacerta vivipara	Common lizard
Vipera berus	Adder
Amphibians	
Triturus helveticus	Palmate newt
Bufo bufo	Common toad
Rana temporaria	Common frog

Birds

Anas platyrhynchos	Mallard
A. crecca	Teal
Aythya fuligula	Tufted duck
A. ferina	Pochard
Bucephala clangula	Goldeneye
Corvus corax	Raven
C. corone corone	Carrion crow
Larus argentatus	Herring gull
L. fuscus	Lesser black-backed gull
L. canus	Common gull
Phalacrocorax carbo	Cormorant
Lyagopus lagopus	Red grouse
Larurus tetrix	Black grouse
Numenius arquata	Curlew
Actitis hypoleucos	Common sandpiper
Haematopus ostralegus	Oyster catcher
Gallinago gallinago	Snipe
Aquila chrysaetos	Golden eagle
Buteo buteo	Buzzard
Circus cyaneus	Hen harrier
Falco peregrinus	Peregrine falcon
Asio flammeus	Short-eared owl
Ardea cinerea	Heron
Phylloscopus trochilus	Willow warbler
Anthus pratensis	Meadow pipit
Montacilla alba yarrellii	Pied wagtail
M. cinerea	Grey wagtail
Cinclus cinclus	Dipper
Troglodytes troglodytes	Wren
Saxicola torquata	Stonechat
Oenanthe oenanthe	Wheatear
Erithacus rubecula	Robin
Turdus merula	Blackbird
Fringilla coelebs	Chaffinch
Carduelis spinus	Siskin

Not seen at Loch Fleet but common in surrounding forestry:

Cuculus canorus	Cuckoo
Columba palumbus	Wood pigeon

Garrulus glandarius	Jay
Scolopax rusticola	Woodcock
Loxia curvirostra	Crossbill
Pyrrhula pyrrhula	Bullfinch

Butterflies

Pieris napi	Green-veined white – occasional in flight June/July
Vanessa atalanta	Red admiral– feeding on heather flowers, Sector V, Sept. 1987
Aglais urticae	Small tortoiseshell – near loch outlet, Sept. 1989
Clossiana selene	Small pearl-bordered fritillary – In flight esp. around May–July
Coenonympha pamphilus	Small heath – common at base of Altiwhat June/July

Moths

Lasiocampa quercus callunae	Northern eggar – males day flying, June/July
Ematurga atomaria	Common heath – common around loch, May–August
Ceramica pisi	Broom moth – green and yellow striped caterpillar often found on various foodplants around loch, July–September

Dragonflies

Pyrrhosoma nymphula	Large red damselfly – common around outlet and pools in July
Coenagrion pulchellum	Variable damselfly – common over loch and embayments, especially 4, June–August
Cordulegaster boltonii	Golden ringed dragonfly – Common especially around outlet, July/August
Aeshna juncea	Common hawker – pair in sector V, August 1989

RESTORING ACID WATERS: LOCH FLEET 1984–1990

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ELSEVIER APPLIED SCIENCE
LONDON and NEW YORK

ELSEVIER SCIENCE PUBLISHERS LTD
Crown House, Linton Road, Barking, Essex IG11 8JU, England

Sole distributor in the USA and Canada
ELSEVIER SCIENCE PUBLISHING CO., INC.
655 Avenue of the Americas, New York, NY 10010, USA

WITH 52 TABLES AND 101 ILLUSTRATIONS

British Library Cataloguing in Publication Data

Restoring acid waters: Loch Fleet 1984–1990.
I. Howells, Gwyneth, 1925– II. Dalziel, Thomas Ralph Kennedy, 1959–
T. R. K. (Thomas Ralph Kennedy)
363.7386

ISBN 1-85166-663-X

Library of Congress Cataloging-in-Publication Data

Restoring acid waters: Loch Fleet, 1984–1990/edited by G. Howells and T.R.K. Dalziel.
p. cm.
Includes bibliographical references and index.
ISBN 1-85166-663-X
1. Acid pollution of rivers, lakes, etc.—Scotland—Fleet, Loch (Dumfries and Galloway) 2. Water quality management—Scotland—Fleet, Loch (Dumfries and Galloway) 3. Lake renewal—Scotland—Fleet, Loch (Dumfries and Galloway) 4. Lake ecology—Scotland—Fleet, Loch (Dumfries and Galloway) 5. Neutralization (Chemistry) 6. Lime. I. Howells, Parry, Gwyneth II. Dalziel, Thomas Ralph Kennedy
TD427.A27R48 1991
628.1′68—dc20 91-4107
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The funding agencies of the Loch Fleet project have supported the presentation of the project findings in this book, for which permission to publish has been granted.

Foreword

Even today, after more than a decade of practical experience in Sweden and a number of trials in Scandinavia and in the UK, the restoration of acid waters by "liming" is still viewed with suspicion by environmental purists. Tolerated as a stopgap until agreement was reached on emission reductions, the addition of limestone to acidified soils and waters was, at one time, condemned as an unethical diversion of attention and resources from that supreme objective. More recently has come the realisation that the acidification accumulated in soil by 150 years of industrialisation will not respond overnight to emission reductions, however swingeing.

The Loch Fleet project was born of environmental pragmatism. To get fish back soon, you have to do something to restore the quality of the water or, for a longer-lasting effect, of the soil. What you do has to be scientifically based to ensure that it will be effective and without unacceptable side-effects. This volume marks the successful achievement of these objectives at Loch Fleet and will surely be a pathfinder for success elsewhere. Not least, it makes a fitting testimonial to the foresight and persistence of the scientific team led by Dr Howells and to the practical and financial assistance of the coal and electricity industries in a project well ahead of its time.

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December 1990