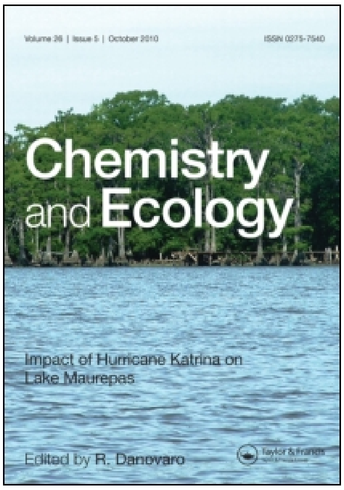

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SEVEN YEARS OF CHANGE FOLLOWING LIMING OF *SPHAGNUM* COMMUNITIES IN SECTOR VII OF THE LOCH FLEET CATCHMENT

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In 1986, application of lime within the upper wetland area of sector VII of the Loch Fleet catchment initiated numerous unscheduled small-scale experiments on the vegetation of this heterogeneous terrain. Vegetation changes and erosion were monitored in permanent or relocated plots established in 1987 and 1989 and re-surveyed in 1993, seven years after liming.

The most striking early effect, possibly occurring within a few weeks of lime application, was the death of *Sphagnum papillosum* carpet in soakways within the 2.5 ha area. Some patches of dead material were washed away, but bare surfaces were generally colonised by vascular plants, notably *Juncus bulbosus*. Effects in moorland and bog communities with dwarf shurbs were more subtle, involving reduction in *Sphagnum* cover and expansion of *Erica teralix, Molinia caerulea*, sedges and *Narthecium ossifragum*, but little change in the frequency of occurrence of *Calluna vulgaris*.

KEY WORDS: bog vegetation, catchment liming, peat erosion, plant nutrients, vegetation change

INTRODUCTION

Liming in sectors IV, VI and VII of the Loch Fleet catchment in April 1986 caused rapid changes in runoff water chemistry. This was designed to improve conditions for trout, but an informal inspection of the limed wet land source area of sector VII in November 1986 showed large areas of apparently dead *Sphagnum* (bog-moss).

Sphagnum grows in wet places. Its leaves, which are one cell thick, are directly exposed to the surrounding water, so it responds rapidly to changes in water chemistry. Rooted plants such as *Calluna vulgaris* (common ling), *Eriophorum vaginatum* (cotton grass) and *Molinia caerulea* (purple moor grass), all of which are abundant in the Loch Fleet catchment, have complex stems and roots with outer layers of cells which insulate the plants from the direct effects of changes in runoff water chemistry. If these changes were to penetrate the soil, the roots of such plants might respond (if at all) only after a lag of months or years.

Sphagnum is also more susceptible than rooted vascular plants to erosion by moving water. However, the water table seldom rises above the surface of a living *Sphagnum* carpet, since the structure of the stand allows water to be dispersed by lateral runoff before this stage is reached (Ingram and Bragg, 1984). Once the *Sphagnum* is dead, it may compact, reducing sub-surface porosity so that the water table rises more frequently above the surface; or it may decay to expose bare peat. In either case, the possibility of erosion is enhanced.

The work reported here is the result of three surveys within sector VII of the catchment. The first (1987), just over one year after liming, provided information on the extent of short-term damage to *Sphagnum* and established a baseline for assessment of further vegetation change; the second (1989) established a baseline against which subsequent erosion could be assessed; and the third (1993) recorded the changes which had occurred. All three surveys were conducted at the same time of year, between 11th and 20th May, and were reported to the Loch Fleet Project Committee (Bragg and Clymo, undated (a); Bragg and Clymo, undated (b); Bragg, 1993).

THE STUDY AREA

The study area (~2.5ha) lay on the right bank of the Altiwhat Burn at altitude 410–430 m OD (Figure 1). Its position in relation to National Grid markers NX

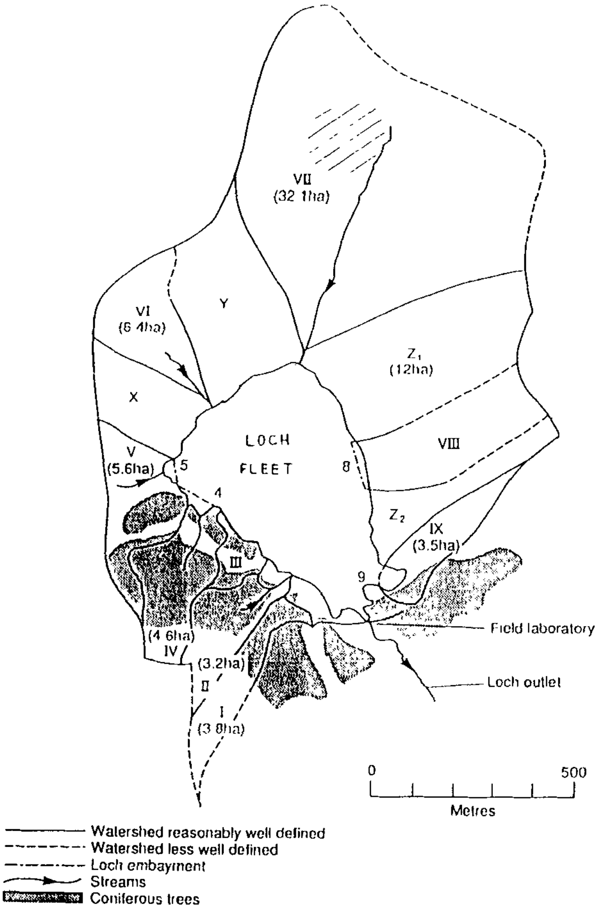

Figure 1 Map of the Loch Fleet catchment, showing the approximate location of the limed area within Sector VII (shaded). (From Howells and Dalziel, 1992).

56000/70600 and NX 56000/70800 (established by the Macaulay Institute) is shown in Figure 2.

The main slope was from northeast to southwest, increasing towards Loch Fleet. Rock outcrops formed a series of irregular steps approximately parallel to the Altiwhat, intercepting water draining downslope and channelling this into a system of *Sphagnum*-dominated soaks. Higher ground between the soaks consisted of a combination of bare rock, moorland and bog. Lime had been spread on some of the surrounding moorland, but was placed preferentially in the soaks. The northern part of the area lay within eroding gullies in deep blanket peat. Six streams emerged from its southern end, each originating from a more or less distinct part of the soak system. On this basis, the area was divided into six sub-catchments, A to F, some of which were connected (Figure 2).

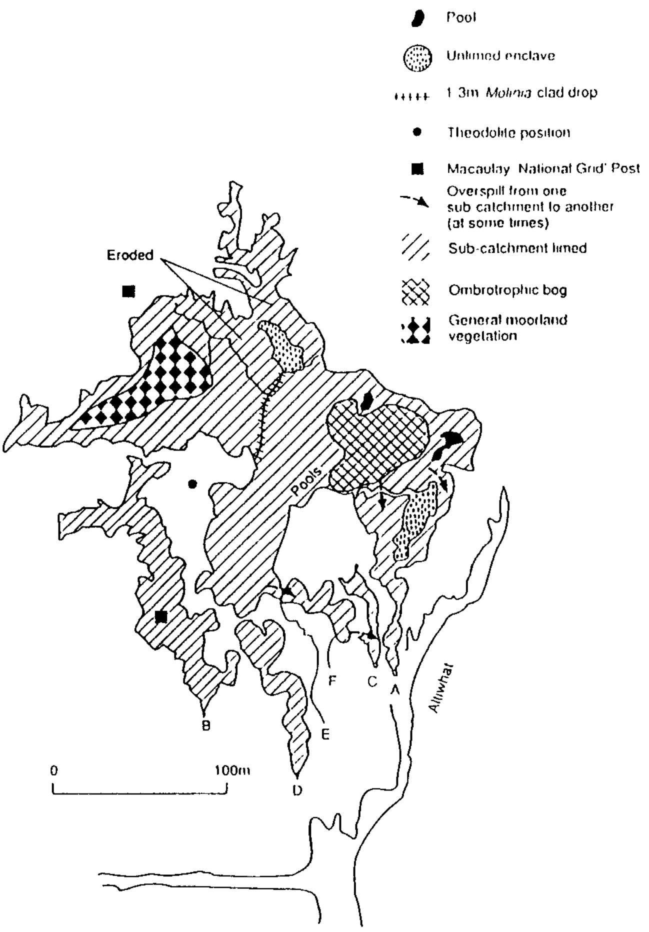

Figure 2 Sketch map of the study area. Upper case letters (A-F) indicate the outflows from the six sub-catchments. (From Clymo *et al.*, 1992).

METHODS

In 1987, the extent of obvious damage to *Sphagnum* was assessed. Working systematically upwards from the lowest point of each sub-catchment, sketches were made to show the shapes and approximate sizes of limed areas, the dominant vegetation, the proportion of *Sphagnum* cover and how much of this was white and apparently dead. The sketches were later interpreted with reference to a 1:10,000 air photograph (Mason Land Surveys, Dunfermline; sortie Clyde 8119; prints 1706–1707; August 1981) to yield Figure 2, together with estimates of the total area limed and the areas of live and dead *Sphagnum*.

The heterogeneity of the study area was striking, the nature of its surface changing from bare rock to *Sphagnum* hummocks and pools, *Molinia* swards and eroded blanket peat within short distances. Correspondingly, the vegetation displayed heterogeneity on scales ranging from a few centimetres to tens of metres. The way in which the lime had been spread introduced yet another source of areal variation. For these reasons, the approach adopted to monitoring changes involved establishment and re-survey of permanent plots.

In 1987, 128 numbered bamboo (vegetation) markers were placed in the area. Approximately half ("unbiassed") were placed at intervals of 10–20 m along the main axis of each sub-catchment, and the remainder ("biassed") were chosen to sample particular features, such as side branches of soakways, junctions between live and dead *Sphagnum*, or moorland vegetation. At each marker, a 25 × 25 cm quadrat frame was temporarily placed on the ground, plant species present within the frame recorded, and the plot photographed. The positions and relative altitudes of all the markers were recorded by theodolite/EDM survey.

In 1989, 207 additional (erosion) markers were placed in sub-catchments B and E. These were arranged in transects, and each was pushed into 30 cm depth and had a PVC tape marker at ground level. Approximately half of the sites were in the soak system, and the other half in the natural erosion gullies to the north. Peat depth was measured at each marker in the soak system where this did not exceed 0.95 m, and plant species in the immediate vicinity of every marker were listed. The markers were again located by theodolite/EDM survey.

In 1993, a thorough search of the area resulted in re-discovery of 71 of the 128 original vegetation markers. The positions of nine more were accurately gauged, either by theodolite measurement or by reference to the 1987 photographs. Each of these 80 plots was photographed and recorded as in 1987. The remaining plots were re-located as accurately as possible using large-scale maps of the monitoring network and clues (for example, rocks and patches of heavy lime) visible in the 1987 photographs, and plant species were listed.

A similar proportion of the erosion markers had disappeared. However, their arrangement in transects meant that re-location by measurement from adjacent markers was usually straightforward. The change in surface level at each of the markers was estimated by one of three methods, depending on the way in which data had been recorded in 1989. For markers on shallow peat in the soakways, peat depth was re-measured. For those on deep peat in soakways, surface altitude was measured relative to the 1987/89 datum using the same theodolite equipment. In the erosion gullies, the length of bamboo exposed below the tape marker, or the depth to which the marker was buried, was measured with a flexible rule.

RESULTS

Short-term damage to Sphagnum

Estimates of the limed area assigned to each sub-catchment, and the areas of live and dead *Sphagnum* within each, are shown in Table I. The total extent of liming was a little less than 2.7 ha, approximately 35% of this area was *Sphagnum*-dominated, and just over 90% (0.84 ha) of the *Sphagnum* carpet appeared to have been killed by lime.

Erosion

Area eroding prior to liming. The arrangement of the 104 erosion markers placed in the gully system at the northern end of the limed area is shown in Figure 3. The markers were grouped in transects. Groups u, v and w were on branches at the head of the main gully, where mean slopes ranged from 10% to 40%; there were four short transects (t1, t2, r2, r3) on peat faces (slopes 52–79%) at the sides of the main gully; and two long tansects, r1 and s, crossed its entire width. Patterns of erosion within some of these transects between 1989 and 1993 are shown in Figure 3ii–3v.

In head gullies, most of the markers survived until 1993, and where erosion had occurred these showed bands of different shades attributed to three separate erosion episodes (Figure 3iii, 3iv). In general, progressive loss of peat had occurred, with some tendency for existing channels to deepen. Mean lowering of the surface, calculated for all (34) surviving markers, amounted to 19.3 cm over four years.

Although few markers had survived on peat faces, the fact that the lower canes had disappeared, together with the shapes of the profiles surveyed in 1989, suggested some attrition of peat from the walls and substantial deposition at their bases (Figure 3ii).

On the floor of the gully large areas were colonised only by *Eriophorum angustifolium*. Up to 12 cm of peat had been deposited amongst this vegetation (Figure 3v).

Table I Areas of liming, and live and dead *Sphagnum* carpet, within the study area in May 1987.

Sub-catchment	*Limed area (m^2)*	*Area of Sphagnum carpet (m^2)* Live	Dead
A	1900	< 10	740
B	3300	< 20	1550
C	350	20	< 5
D	1000	130	50
E	19600	680	5950
F	440	30	130
Totals	26590	880	8420

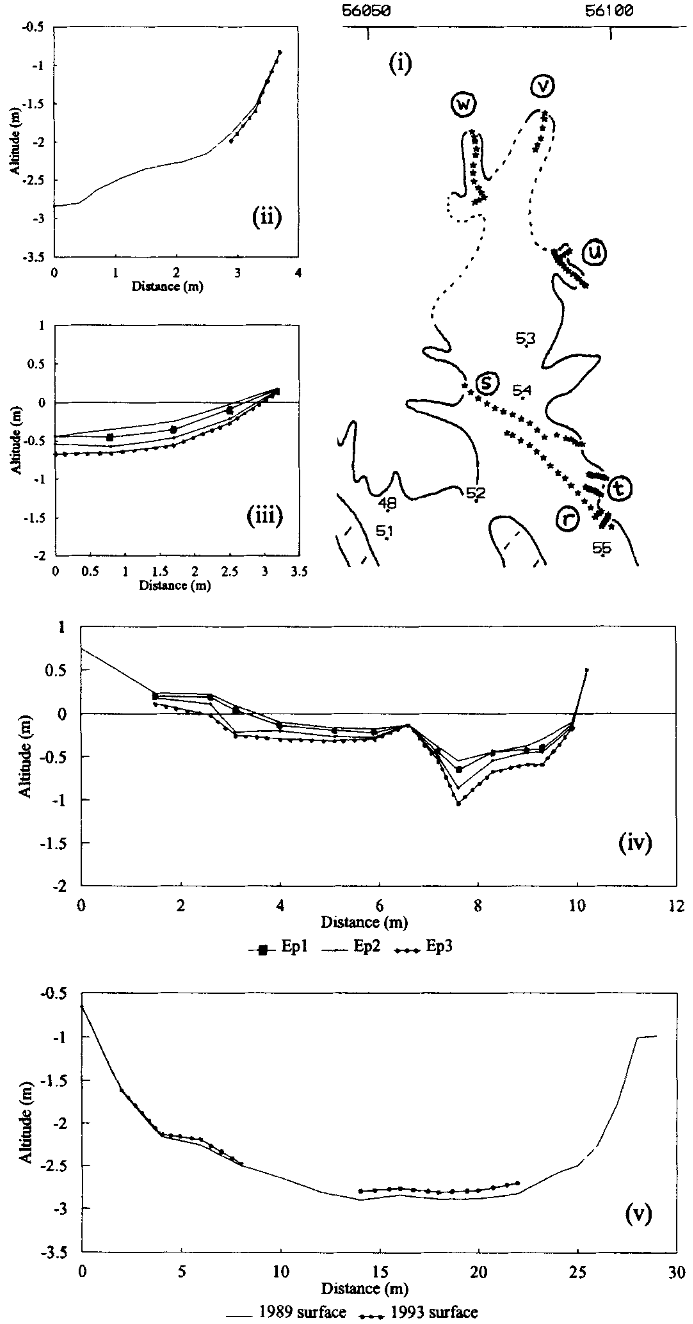

Figure 3 (i) Locations of erosion markers (bold asterisks) in the gully system at the northern end of the study area. The various transects/groups of markers are labelled with lower-case letters. Small numbered points indicate the positions of vegetation plots. Six-figure National Grid eastings are shown at the upper edge of the map. (ii)-(v) Profiles for four transects sampled in 1989 and 1993. Altitudes are in metres above the theodolite position (Figure 2). (ii) transect t2; (iii) transect u2; (iv) transect u1; (v) transect s. (iii) and (iv) also show profiles after intervening erosion episodes, Ep1, Ep2 and Ep3, apparent from bands of different shades on the newly-exposed parts of the markers.

Thus, erosion within this area appeared to consist of steady removal of peat, at mean rates up to 5 cm per year, from head gullies and side walls, with net deposition on the floor of the main gully.

Sphagnum carpets affected by lime. The positions of 91 of the 103 erosion markers placed in the southern part of the study area are shown in Fig. 4i. These were arranged in transects within or across soakways carpeted by dead *Sphagnum*. Examples of patterns of change in surface altitude (due to a combination of compaction, erosion and new growth) appear in Figures 4ii–4iv.

Between 1989 and 1993 a variety of fates befell different parts of the *Sphagnum* carpet. In places, the dead plants remained virtually unchanged except that their colour darkened, and some were beginning to produce new green shoots (innovations) in 1993. Some areas of healthy *S. papillosum* lawn remained, or had become re-established. In other places, the capitula had been lost from dead plants, and in others the surface had compacted to form a hard crust. Particularly on transect a, only small islands of the crust persisted, and upstream it appeared that all *Sphagnum* and peat had been stripped from an area of approximately 100 m^2, exposing the rocky substratum. Wholesale removal of the surface had also occurred in some places on deeper peat around group b, leaving bare areas where it was impossible to walk.

The combination of these processes had produced a rather uneven surface, particularly on transect a (Figure 4iv). Here, changes in surface altitude at individual markers ranged from 19 cm loss to 16 cm growth, with mean lowering of 2.1 cm, or 5.3% of total depth. For sites on deeper peat (group b), mean lowering was similar, at 1 to 3 cm.

Changes in vegetation

Changes in representation of species within the full sample of 128 vegetation plots are summarised in Table II. In 1987, 18 vascular and moss species were recorded. In 1993, five of these were not found, but 15 new ones were discovered. Young specimens and those which lacked some diagnostic features at this time of year (e.g. *Carex* spp. and a lone fern) were identified as far as possible. The presence of green algae and a number of leafy liverworts was also noted.

Decomposition and erosion of dead *Sphagnum papillosum* meant that it was still recognisable in only 21 of the 91 plots occupied in 1987. Numbers of plots with *Sphagnum capillifolium* and *Sphagnum recurvum* had halved, but all other species, including live *S. papillosum,* had spread. Detailed responses varied between species. While *Calluna vulgaris* disappeared from 12 plots and appeared in 15, *Erica tetralix* was lost from only 4 and spread to 36, so that by 1993 its frequency within the plots approached that of *Calluna*. *Eriophorum vaginatum* and *Trichophorum*

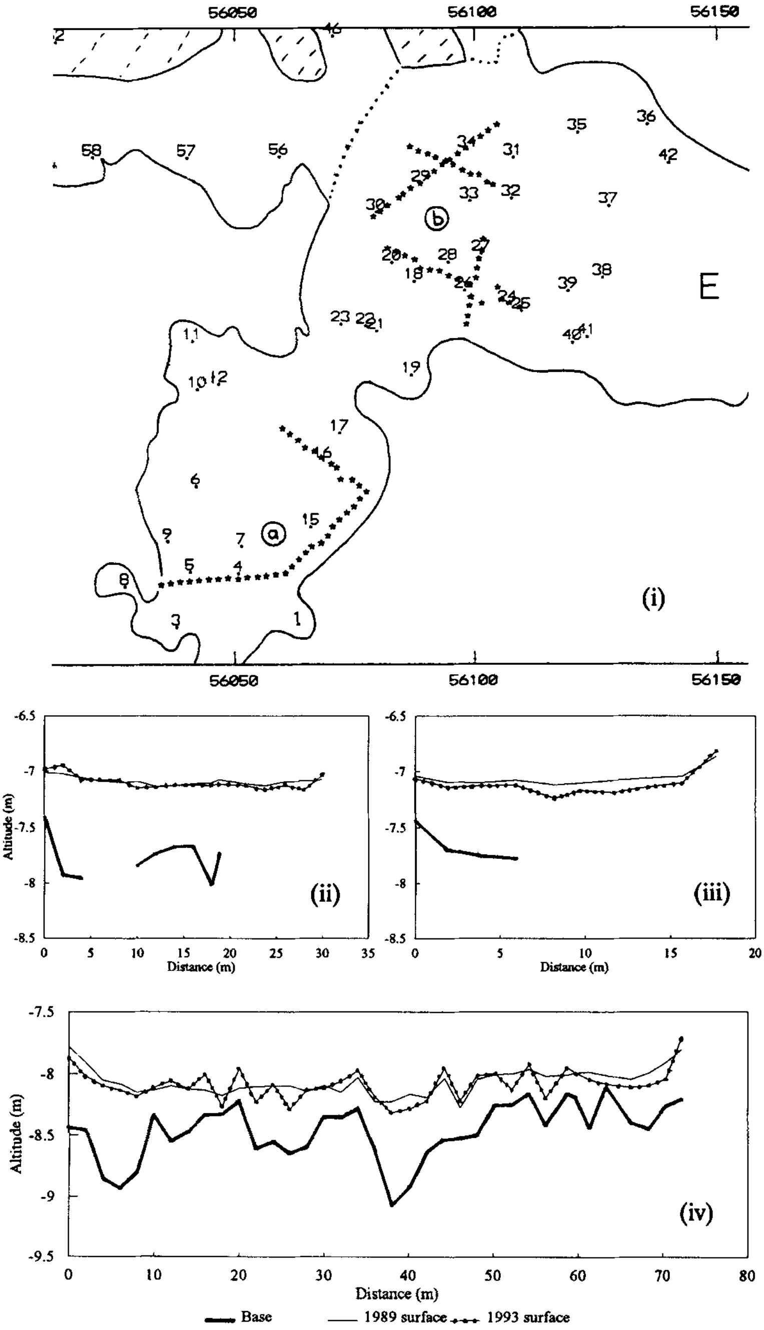

Figure 4 (i) Locations of erosion markers (bold asterisks) within sub-catchment E of the study area (groups a and b). National Grid eastings and positions of vegetation plots shown as in Figure 3, 4ii, 4iii: Profiles for two transects within group b, 1989 and 1993. 4iv: Profiles for the full length of transect a, 1989 and 1993. Altitudes (ordinates) are in metres above the theodolite position (Figure 2). The position of the underlying rock surface is shown where this was within the range of a 0.95 m probe.

cespitosum also spread significantly, whilst *Molinia caerulea* persisted in all of the 19 plots for which it was recorded in 1987 and had spread to a further 23 by 1993. *Eriophorum angustifolium*, already present in 70% of the plots in 1987, was represented in almost 80% by 1993. *Narthecium ossifragum* (whose shoots disappear in winter) was recorded in 36 new plots (lost from 3), but may have been more obvious after the mild spring of 1993 than during the 1987 survey. Whether or not *Narthecium* had spread, there were places where its dense rhizome system had been washed clean of *Sphagnum* and peat, and appeared to be stabilising the surface against further erosion. The most widespread new species were *Juncus bulbosus* and the moss *Pohlia nutans*.

Objective assessment of changes in species combinations within the plots was attempted using TWINSPAN (two-way indicator species analysis; Hill, 1979). This analysis performs successive two-way divisions of the whole sample of plot records on

Table II Changes in representation of species in the 128 vegetation plots between 1987 and 1993.

Species		*Changes in representation in 128 plots, 1987–1993*			*Change in occurrence 1987–1993*
	Species code	*lost from*	*retained by*	*gained by*	
Calluna vulgaris	Cv	12	45	15	+3
Erica tetralix	Et	4	16	36	+32
Vaccinium sp.				1	+1
unidentified fern				1	+1
Agrostis sp.		1			−1
Molinia caerulea	Mc	0	19	23	+23
Carex sp.	Cx	1	1	9	+8
Eriophorum angustifolium	Ea	8	82	21	+13
Eriophorum vaginatum	Ev	1	9	17	+16
Trichophorum cespitosum	Tc	6	10	18	+12
Juncus articulatus/squarrosus		15			−15
Juncus bulbosus	Jb			28	+28
Narthecium ossifragum	No	3	6	36	+43
Drosera rotundifolia				3	+3
Montia fontana				3	+3
Polygala serpyllifolia				5	+5
Sphagnum auriculatum	Sa	1	4	4	+3
Sphagnum capillifolium	Sc	6	4	1	−5
(*Sphagnum papillosum*): dead		71	20	1	−70
Sphagnum papillosum: live	Sp	4	15	10	+6
Sphagnum recurvum	Sr	1	1	0	−1
Sphagnum subnitens				1	+1
Sphagnum tenellum				1	+1
Hypnum jutlandicum		2	4	4	+2
Pholia nutans				21	+21
Racomitrium lanuginosum				3	+3
other mosses		3	0	5	+2
liverworts				11	+11
green algae	ga			4	+4
Cladonia portentosa				1	+1
bare peat	bp	1	0	14	+13

the basis of differences in their species complements. The end groups of each division are labelled in binary format. Thus, the first division yields groups 0 and 1; group 0 is then divided into groups 00 and 01 and group 1 into groups 10 and 11, the process continuing in a standard run until a maximum of 32 end groups are distinguished. Species are ordered by similar means. The end product is a table in which species and plot records are ordered with the most similar together.

It was assumed that if the dead condition of much of the *Sphagnum papillosum* recorded in 1987 was ignored, the data collected at this stage would represent the vegetation before liming. Dead *Sphagnum* still present in 1993 was not included in the analysis. Data collected from all 128 plots in 1987 and 1993 were included initially in two separate analyses. In each case, one plot (a different one in the two analyses) proved to be so different from the remainder of the sample that it was singled out at the first division. The analyses were therefore repeated excluding these plots; they were, however, included in the final tables. In each case, a standard TWINSPAN run was conducted, then the resulting end groups recombined until groups with 1 to 3 constant species were obtained.

Constancy of each species within each end group was classified according to the scheme summarised in Table III.

The classification derived for the 1987 data is shown in Table IV. Seven groups were distinguished. One plot lay on completely bare (eroded) peat. Two plots, apparently outside the influence of lime and both containing *Sphagnum recurvum*, were placed in group 00. Group 010 included 45 plots in the wetter parts of soakways, characterised by the presence of *Sphagnum papillosum* and *Eriophorum angustifolium* (constancy V). The 58 plots in group 011 had *S. papillosum* (V), *E. angustifolium* (IV) and *Calluna vulgaris* (IV); these were situated in drier parts of soakways and on elevated areas. Ten plots on *Molinia*-dominated slopes within the soak systems were placed in group 101 and eight on moorland areas in group 100. Four plots with *Sphagnum capillifolium* were assigned to group 11.

The classification of the 1993 data is shown in Table V. Ten groups were distinguished. In general, *Molinia*-dominated plots appear at the extreme left of the table (group 000) and plots with dwarf shrubs are placed to this side of the centre, while

Table III Definition of constancy classes used in Tables IV and V. After Dierssen (1992).

Constancy class	*proportion (%) of all quardrats*
r	$\leqslant 5$
+	$>5 \leqslant 10$
I	$>10 \leqslant 20$
II	$>20 \leqslant 40$
III	$>40 \leqslant 60$
IV	$>60 \leqslant 80$
V	$>80 \leqslant 100$

Table IV TWINSPAN classification of 128 vegetation plots sampled in 1987. Constancy of species within each group as defined in Table III.

Group *Number of plots*	*bare* *1*	*00* *2*	*010* *45*	*011* *58*	*100* *8*	*101* *10*	*11* *4*
Carex panicea			III				
Juncus articulatus			II	r			
Sphagnum recurvum		V					
Agrostis sp.				r			
Drepanocladus sp.				r			
Juncus squarrosus				r			
Polytrichum commune				r			
Eriophorum angustifolium		III	V	IV	I	+	
Narthecium ossifragum			+	+			
Eriophorum vaginatum				+		+	
Sphagnum papillosum		III	V	V	IV	+	
Calluna vulgaris			r	IV	V	IV	V
Hypnum jutlandicum				+	I	+	
Sphagnum capillifolium				I			V
Sphagnum auriculatum		III	r				III
Molinia caerulea			+	r	III	V	II
Trichophorum cespitosum				I	IV	I	II
Erica tetralix				II		III	
bare peat	V						

Eriophorum angustifolium is more characteristic of plots towards the right. On the basis of most characteristic species, three of these groups broadly resemble groups distinguished in 1987; these are the two with significant occurrence of *S. papillosum*, 010 (like 1987/011) and 0110 (like 1987/100), and the *Molinia*-dominated group 000 (like 1987/101)

Table VI shows how plots assigned to each of the 1987 vegetation groups were reclassified in 1993. Least change was apparent for the 10 *Molinia*-dominated plots (1987/101), 7 of which were reclassified together in the similar 1993 group 000. Conversely, the two large samples of plots originally dominated by *Sphagnum papillosum* were spread across the whole range of 1993 groups. Their distributions are shown graphically in Figure 5. Plots in group 1987/010 generally lacked dwarf shrubs. Their distribution amongst the 1993 groups shows bias to the right, the modal group (100) being characterised by *E. angustifolium* and *Juncus bulbosus*. Seven (less than 16%) of the plots are placed in groups with *S. papillosum*. By contrast, the distribution for plots in group 1987/011, which generally contained dwarf shrubs in 1987, shows bias to the left of the 1993 classification, with mode at group 001 (most constant species *E. angustifolium* and *Erica tetralix*). Sixteen plots (27.6%) are placed in the *S. papillosum* groups 010 and 0110.

The other four samples included in Table VI all contain less than 10 plots, and only tentative conclusions are based on the data. However, changes in classification of plots in the two 1987 moorland/bog groups 100 and 11 suggest increases in *E. angustifolium*, *E. tetralix*, *Narthecium ossifragum* and *S. papillosum* at the expense of *Calluna vulgaris* and *Sphagnum capillifolium*. It is also interesting to note that the single plot on bare peat sampled in 1987 had been colonised by *E. angustifolium* and *J. bulbosus* by 1993.

Table V TWINSPAN classification of 128 vegetation plots sampled in 1993. Constancy of species within each group as defined in Table III.

Group *Number of plots*	*000* *11*	*001* *25*	*010* *15*	*0110* *16*	*0111* *14*	*100* *16*	*101* *12*	*110* *8*	*111* *10*	*ga* *1*
Vaccinium sp.		r								
unidentified fern		r								
Philonotis sp.		r								
Polygala serpyllifolia	+	I								
Bryum pseudotriquetrum		r								
Eurhynchium strictum		+								
Hypnum jutlandicum	II	I		+	+					
Polytrichum commune		r								
Odontoschisma sphagni		r								
Riccardia sp.		I		+	+					
Scapania sp.				+						
Racomitrium lanuginosum					II					
Sphagnum subnitens					+					
Sphagnum tenellum				+						
Cladonia portentosa					+					
Sphagnum capillifolium			II		+					
Sphagnum papillosum		r	V	IV						
Calluna vulgaris	III	III	IV	V	IV	II				
Erica tetralix	+	IV	III	IV	IV			III	+	
Molinia caerulea	V	II	+	V	II	I	I			
Drosera rotundifolia			+		+				+	
Narthecium ossifragum		I	II	III	V			IV	III	
Trichophorum cespitosum		r	+	III	V	+		III	+	
Sphagnum auriculatum			I	I			II			
Leafy liverworts		+			+				+	
Eriophorum vaginatum	+	III	I		+	+			IV	
Montia fontana		+					+			
Pohlia nutans		II			I	II			II	
Eriophorum angustifolium	II	V	III	III	V	V	V	V	V	
Carex flacca/nigra					II		I	III	I	
green algae		r				I		I		V
Juncus bulbosus					+	V	I	V	I	
Sphagnum recurvum							+			

DISCUSSION

Observations across the Loch Fleet catchment as a whole indicated only slight moorland vegetation changes eight years after liming (MLURI, 1992, Howells, 1994). Differential survival of *Sphagnum* species exposed to lime-rich water in the wetland source area of sector VII appeared to be consistent with their general ecology; those (*S. capillifolium* and *S. papillosum*) characteristic of ombrotrophic (rain-water-dependent) bog were killed while those occurring naturally in flushed situations (*S. recurvum, S. auriculatum, S. subnitens*) survived. For vascular plants, cover of *Calluna vulgaris* was reduced while dominance of *Molinia caerulea* increased. Many other plants characteristic of bogs, including *Racomitrium lanuginosum, Erica tetralix, Eriophorum vaginatum, Drosera* sp. and *Narthecium ossifragum* were evidently healthy (Clymo *et al.*, 1992).

Within the area covered by the present study, the initial response of *Sphagnum* spp. to liming indicated wide variations in dosage rates associated with the way in

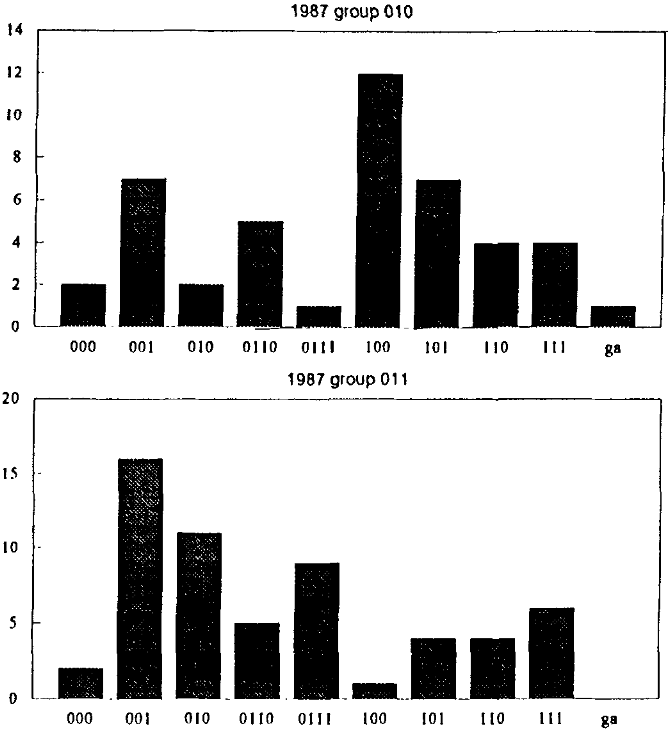

Figure 5 Classification of 1993 vegetation in plots assigned to TWINSPAN groups 010 and 011 in 1987. Ordinates: number of plots. Abscissae : 1993 vegetation groups ordered as in Table V.

which lime was spread, and patterns of water movement imposed by the nature of the terrain. On elevated bog and moorland areas, lime was broadcast unevenly. Since the water supply to these areas consists almost entirely of rainfall, which drains towards the soakways, subsequent events would tend to reduce lime concentrations progressively. Eight years later, even the thickest lime patches (with the notable exception of a full bag of material apparently overlooked during the spreading operation) had disappeared from these areas, although their local effects were still evident. Where *Sphagnum* had died, a variety of new vascular species, mosses and liverworts had appeared (e.g. Table V, groups 001, 0110 and 0111). In other places, presumably where the initial lime dosage rate was low or zero, *S. capillifolium* and *S. papillosum* remained healthy (Table V, group 010).

The soakways originally received heavier doses of lime than did the surrounding moorland. Large amounts remained seven years after application, indicating effective storage of lime for prolonged, slow release to the stream system. However, even with uniform application, we might expect dosages to soakway vegetation to be longer sustained and more evenly distributed than on moorland and bog, as lime from upstream parts of the sub-catchments dissolves progressively and moves through the full lengh of the soak system. The short-term result was striking, producing the sheets of dead *S. papillosum* whose subsequent fate was the main focus of this study. Over seven years, however, these suffered neither wholesale erosion nor re-colonisation by

Table VI Summary of classification of vegetation plots recorded in 1987 and 1993, showing numbers of plots placed in each 1993 group according to their classification in 1987. The most constant species for each group are indicated by species codes defined in Table II.

		1993 groups:	*000*	*001*	*010*	*0110*	*0111*	*100*	*101*	*110*	*111*	*ga*
	Constancy	*V*	*Mc*	*Ea*	*Sp*	*CvMc*	*EaNoTc*	*EaJb*	*Ea*	*EaJb*	*Ea*	*ga*
		IV		*Et*	*Cv*	*EtSp*	*CvEt*			*No*	*Ev*	
		III	*Cv*	*CvEv*	*EaEt*	*EaNoTc*				*CxEtTc*	*No*	
1987 groups	*Constancy*											
bare	V	bp										
	IV							1				
	III											
00	V	Sr										
	IV				1				1			
	III	EaSaSp										
010	V	EaSp										
	IV		2	7	2	5	1	12	7	4	4	1
	III	Cx										
011	V	Sp										
	IV	CvEa	2	16	11	5	9	1	4	4	6	
	III											
100	V	Cv										
	IV	SpTc		1		2	3	2				
	III	Mc										
101	V	Mc										
	IV	Cv	7	1		2						
	III	Et										
11	V	CvSc										
	IV				1	2	1					
	III	Sa										

S. papilillosum or any other *Sphagnum* species - although both effects occurred within limited areas. Within three years, significant areas were colonised by *Juncus bulbosus* while blooms of green algae appeared in pools (Bragg and Clymo undated (b)); these changes were still apparent in 1993. But this was only one of a number of ways in which soakway vegetation could develop (Figure 5).

Apparent responses of vascular plants to liming are consistent with the results reported by Clymo *et al.* (1992), but we may add *Erica tetralix, Eriophorum angustifolium, Eriophorum vaginatum, Narthecium ossifragum* and *Trichophorum cespitosum* to the list of bog species favoured by liming.

Overall, the patchiness of *Sphagnum* death and erosion increased the heterogeneity of the area. While some parts of the moorland remained substantially unchanged, elsewhere the variety of species and combinations increased as species performance adjusted, over different timescales, to new (and themselves possibly inconstant) plant nutrient levels.

There is no evidence that the situation has now stabilized. While levels of lime at moorland and mire surfaces may be declining, we do not know how long chemical enrichment of the soil, and thus potential further effects on vascular plants, may persist (see Wilson and Bache, this volume). In soakways, lime concentrations remain high, and considerable areas of bare peat are still susceptible to erosion and available for colonisation by new vegetation. However, the *Sphagnum* spp. which dominated before liming appear to be thriving in functional refugia, both on raised areas and adjacent to main drainage pathways, where appropriate nutrient levels are present. It remains to be seen whether the original character of the vegetation will eventually return or whether permanent changes have been initiated by liming.

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