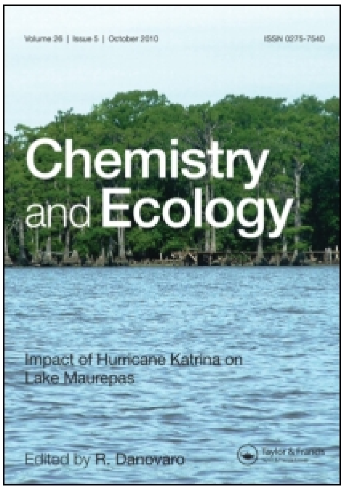

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THE LOCH FLEET PROJECT: OVERVIEW

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INTRODUCTION

The Loch Fleet Project was initiated early in 1984 as a pragmatic approach to reversing acidification, with support and funding from the national coal and electricity industries. While the chemical restoration of many acidified waters in Sweden had been achieved by direct addition of neutralising materials to lakes and streams, this was inappropriate in conditions found in United Kingdom where acidified waters were usually found in regions of heavy rainfall and rapid runoff. In these conditions, catchment liming would provide a longer lasting neutralising reserve within the soils, improving runoff chemistry. Catchment liming seemed a logical approach to counter the progressive acidification of base-poor soils in the area that had resulted from 150 years or more of acid deposition. However, few attempts to lime catchments of any field scale had been made when the Loch Fleet Project was initiated.

To develop an effective and acceptable catchment liming practice it was necessary to approach the task in a scientific and objective way. The original objectives of the Project were to demonstrate that the water chemistry of the lake could be brought into a range suitable for trout by the addition of basic minerals to catchment soils, and once suitable chemical conditions were achieved, to demonstrate that conditions were suitable for a self-sustaining trout population. These objectives were reached during the first five years, 1984 to 1989, and a second phase, 1989 to 1994, was designed to continue the monitoring of rain, stream and loch water chemistry, and fishery status, as well as to explore any perceived adverse effects of catchment liming.

The decade of investigation, now completed, of this small acid upland catchment in southwest scotland has provided detailed insight into the integral characteristics of its terrestrial and aquatic components and its response to several independent field interventions. Along with meeting the original aims, possible responses in non-target components of the ecosystem have also been followed over time. As lime effectiveness must inevitably decline, reacidification will occur and provides an opportunity to observe the ecosystem reaction. This unique and complex endeavour will continue to improve our understanding of both acidification and its remediation.

RECENT STUDIES

Recent and continuing studies undertaken at Loch Fleet, and not previously published, are included in this special issue of **Chemistry and Ecology**. They cover:

—estimation of the effectiveness of liming;
—soil changes since liming in treated areas of the catchment
—modelling of acidification in both past and future scenarios of S emission;
—further analysis of aquatic invertebrate communities of the loch, tributaries and in trout diets;
—macroinvertebrates of peat pools in limed and unlimed areas;
—current status of the fishery of the loch and tributary streams.

Two studies relating to possible adverse effects in the terrestrial environment are also reported here:

—beetle and spider assemblages of limed and unlimed forest and moorland areas;
—changes in vegetation in a small limed wetland source area.

In addition, some other terrestrial studies were undertaken, including resurvey of the vegetation of the whole catchment and a study of small mammals sampled by pitfall trapping. These studies are summarised below. In parallel, monitoring of rain and water quality of runoff from both "control" and treated sectors was continued. Rain analysis from 1985 to 1994 demonstrates no significant change in S loading (2.05 gm^{-2}) or sulphate concentration [SO_4] in bulk rainfall (mean 57 ueq l^{-1}), although there is a recent higher influx of nitrate, [NO_3], so that the ratio of S to N (including both nitrate and ammonia) has fallen over the decade. Acidity in rain is undiminished with pH $\sim$ 4.7, a mean H^+ loading of 0.05 gm^{-2}. Chloride remains (on an equivalent basis) the major anion component. While runoff from the 1986 lime-treated sectors maintains target water quality, that from sectors treated at lower "dose" has also been sustained; in runoff from sector Z1 and IX (limed at $\sim$ 5 t ha^{-1}), pH in 1994 is 5.68 and 5.91 and alkalinity is maintained at >60 and >100 ueq l^{-1}. This level of lime application is similar to that used in upland farm practice, and even in Loch Fleet conditions might be sufficient to maintain runoff of reasonably stable water quality and in the loch if used over sufficient area. In contrast, the runoff from sector V ("control") is still pH < 4.0 and alkalinity is zero. The effectiveness (longevity) of these lower treatments cannot be judged, however, since flows were not measured. Other treatments trialled at Fleet in 1987 included fertilizer application to a forest area and burning ("muirburn") of moorland vegetation . Neither of these treatments improved runoff water quality significantly (i.e. pH, calcium or aluminium), and effects were short-lived, although after fertilization treatments, nitrate and potassium increased.

Terrestrial vegetation throughout the Fleet catchment was recorded by the Macaulay Institute before liming in 1984/85 in 452 marked quadrats located from National Grid points (MLURI, 1986), and again in 1992 (MLURI, 1992). The vegetation in 1992 was characterized as 15 species-poor plant communities, of which 5 represent 80% of the catchment; one community had been shaded out by forest growth since 1984/85. Dominant species are the moss (*Hypnum jutlandicum*), heather (*Calluna vulgaris*) and moor grass (*Molinia caerulea*). Total plant species identified in 1992 were 78, of which

56 were common to the preliming survey. Six species found in 1984/85 were not found in 1992 (although found outside the marked quadrats) while 13 new species were found at the later date. Little significance can be attached to the apparent loss or gain of species from quadrat sampling and overall little change was seen as a consequence of liming.

Earlier work (reported in Howells and Dalziel, 1992) had shown little difference in the growth of Sitka spruce or lodgepole pine sampled in 1988 in limed and unlimed areas. The forest trees at Fleet were judged to be potassium and nitrogen deficient from foliar analysis, and some increase in these elements in needles was found in the three years after liming. However, it is possible that these early results may not be valid in the longer term; seven years after liming it may be noted that the 51 quadrats shaded out since the earlier survey, and implied that forest growth was maintained.

A further independent study was made of small mammals in the catchment (partially reported in Howells and Dalziel, 1992; Shore 1991; Shore and Mackezie, 1993). The study at Fleet was an adjunct to a larger study of small experimentally limed plots at Llyn Conwy, Wales and on larger plots at Llyn Brianne. There, it was found that liming had short-term effects on common shrews, but no long-term effects on activity, numbers, population dynamics or nutritional status. In contrast, the surface activity of pygmy shrews (*Sorex minutus*) was reduced by liming for at least 6 months. At Fleet, such an effect on pygmy shrews applied to the females only, and was attributed (Shore and Mackenzie, 1993) to a reduced abundance of invertebrate prey, even though nutritional state of the shrews was unaffected (Shore, 1991).

Invertebrate studies reported in this volume (Foster *et al.*, 1994) do not confirm this. There is no evidence that liming at Fleet affected the numbers of common shrews or voles.

INTEGRATION

The Fleet Project has provided a closely integrated study of catchment conditions before and after liming, monitoring wet deposition and water quality of inflow streams, loch and outflow waters on a continuous basis. Survey, and resurvey of terrestrial ecosystem components and soil conditions have been undertaken on several occasions within the decade of study. The status of the restored brown trout fishery has been followed through each year.

Inspite of this wealth of co-ordinated data, there are questions unresolved, possibly to be answered by revisiting the site on later occasions. A major uncertainty lies in the response of the soils to lime applications made in 1986 and their expected release of alkalinity to runoff in years to come. These predictions differ on the basis of soil analysis (Wilson and Bache, 1994, this volume) and measurement of calcium fluxes (Dalziel, 1994, this volume). The problems of sampling a heterogeneous terrain and the uneven lime distribution in the field are compounded by uncertainty (or variability) of hydrological flow as explained in Howells and Dalziel, 1992). For these reasons, the more integrated and continuous measurement of calcium fluxes is preferred for predicting the longevity of effective lime treatment. Even so, some discrepancy between predicted and currently measured stream calcium concentrations is noted, the latter being more optimistic than the former. Other questions also remain. MAGIC modelling for Fleet (Skeffington and Lines, 1994, this volume) suggests that the alkaline groundwater at Fleet (Cook *et al.*, 1991) delayed its acidification (cf. other Galloway lakes) and could be sufficient to return the lake water quality to a range suitable for fish within the next 20 years, assuming that planned S emissions are met. Yet, the budget derived from calcium fluxes prior to liming reasonably estimated lake calcium concentration, although the groundwater calcium flux was not included.

Furthermore, the benefit of a groundwater supply of alkalinity and calcium is unlikely to be seen in the nursery stream, essential for satisfactory fish reproduction (Turnpenny *et al.*, 1994, this volume). Nor will it counter acid, high aluminum, episodes in runoff associated with "sea salt" rains, where possibly the recharged exchangeable calcium in limed soils provides for retention of toxic monomeric aluminium.

The continuing surveillance of the health of the brown trout population will show in due course, their response to progressive re-acidification. Impaired hatching, reduced juvenile survival, growth and delayed maturity may follow. However, we do not know if this will be a response to an increasing frequency of acid episodes, or to the release of soil aluminium in toxic form, either during episodes or sustained, or to a progressive decline of calcium concentration and falling pH in the loch itself. It might be expected that a fading fish population will match that seen in the years prior to acidification, but since the genetic make-up of the current fish population differs from that prior to 1970, this may not be the case.

A search for possible adverse effects of catchment liming has been undertaken, with rather little evidence of change in the terrestrial environment. An exception is the small wetland area (2.5 ha) of sector VII where *Sphagnum* species were killed by contact with lime, or high lime concentrations in runoff. The significance of this effect is moderated by a greater diversity of species, and after seven years, some evidence of *Sphagnum* recovery. Of course, it is possible that further changes, yet unrecognized, may be identified over a longer term, although evidence that surface lime has been transferred to deeper soils where it is less accessible, and the wide experience and acceptance of upland agricultural liming, suggests that any such damage in the future will be small or undetectable. Nonetheless, there is an inference that such effects could be avoided by limiting the extent and frequency of treatment in areas considered to be inviolable.

SUMMARY AND CONCLUSIONS

Whether liming (direct or to catchments) is an answer to progressive acidification, from whatever cause, is debatable. Control of S and N emissions is desirable, but can only affect that component of acidification for which they are responsible. It may not be achieved in the short term, nor perhaps effective at specific sites. Further, current laboratory and field studies demonstrate that lower acidity in deposition will, in base-poor soils, reduce the supply of calcium and magnesium to runoff, worsening the conditions for the aquatic community. However, acidophil species such as *Sphagnum* may flourish and this may be welcomed. The choices made must be guided by policy but hopefully informed by science, to which the Loch Fleet Project has contributed with scientific rigour and objectivity.

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