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The significance of land-use and land-management change in the acidification of lakes in Scotland and Norway: an assessment utilizing documentary sources and pollen analysis

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Documentary sources reveal that various land-use and management changes in the catchments of six Scottish lakes during the past 200 years cannot be related to the acidification of specific lakes nor can acidification be related to any general 'land-use' hypothesis. At five of the sites these conclusions are supported by pollen-derived reconstruction of catchment vegetation. In Norway, documentary evidence fails to support a 'land-use' hypothesis of acidification as grazing intensity has actually increased in the area where waters are most strongly acidified. It is considered that the failure to attribute acidification to catchment processes provides further evidence for an explanation in terms of acid precipitation.

Introduction

The recent acidification of surface waters is frequently ascribed to the impact of acidic precipitation in areas of sensitive geology. However, other explanations have been put forward that centre upon changes in land-use and management within lake catchments. To assess the role of changing land-use or management practice, or both, documentary sources and pollen analysis of lake sediment cores, have been utilized to examine the significance of such change in relation to the recent acidification of lakes in Scotland and Norway.

Land-use hypotheses

Rosenqvist (1977, 1978, 1981) proposed that ion exchange reactions in raw humus layers and the uptake of cations by plant growth are the most important factors in determining the acidity of surface waters. The acidification of lakes in southern Norway was attributed to the increase in accumulation of acid humus resulting from the enhanced biomass of acidic heathland (particularly *Calluna*) and forest species, consequent upon a decline in the intensity of pastoral activity in the region. Particular importance was attributed to the decline in burning (Rosenqvist 1981). This hypothesis has found some support as an explanation of contemporary acidification (see, for example, Krug & Frink (1983)).

Study sites

Documentary research was instigated in relation to six specific lake catchments in Scotland and two broad areas in southern and western Norway (figure 1). Palynological analysis was

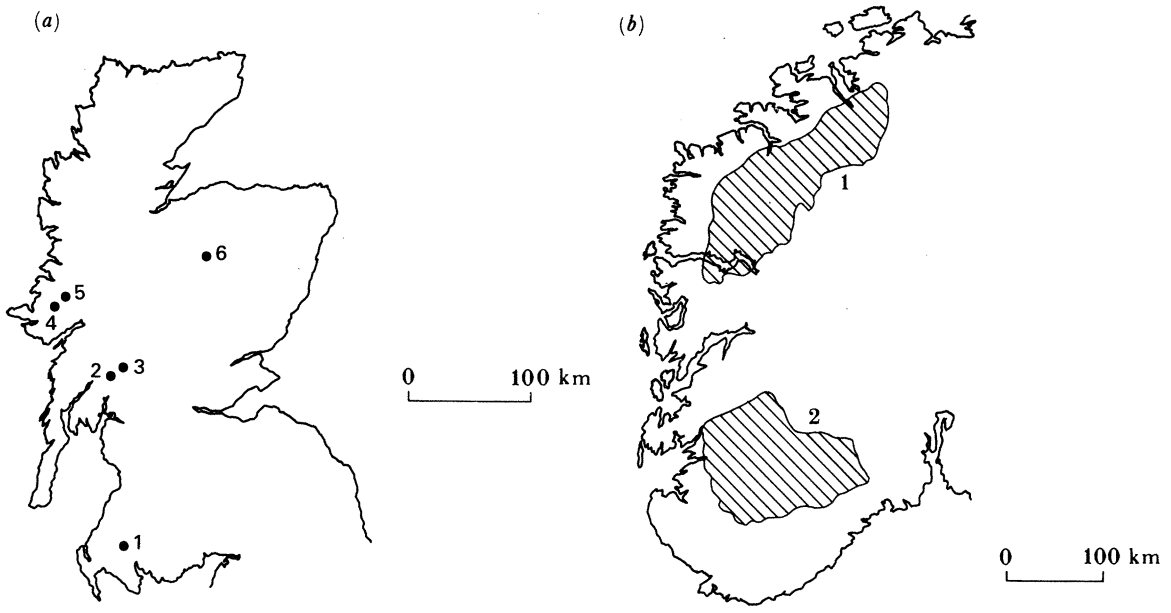

FIGURE 1. Areas of study in (*a*) Scotland; (1), Round Loch of Glenhead; (2), Loch Chon; (3), Loch Tinker; (4), Loch Doilet; (5), Lochan Dubh' (6), Lochan Uaine. (*b*) Norway; (1) area 'west'; (2) area 'south'.

carried out on lake sediment cores from the six Scottish sites. Although the sites vary in size and catchment land-use they share the common attribute of experiencing surface water acidification (to a varying degree) within the past 150 years. Of the two Norwegian areas (figure 1), that in the south has been widely influenced by acidification (particularly the higher areas), whereas that in the west has been little affected.

SOURCES AND METHODS

For Scottish sites, documentary information relating to land-use–management was derived from estate plans and records, large scale Ordnance Survey maps, manuscript maps of the 1930s Land Utilization Survey, aerial photographs, Annual Parish Agricultural Returns, the parish-based Statistical Surveys (1790–1798, 1845, 1960s), Forestry Commission records and historical guides and topographies. Similarly, Norwegian histories were compiled by using the agricultural census, land registrations and reports from farming organizations (Timberlid 1989). In both countries a range of miscellaneous site-specific documents were traced and much use was made of personal recollections from farmers, anglers and gamekeepers.

Pollen analysis of lake sediment cores followed standard procedures (Stevenson *et al.* 1987). The results presented here utilize the *Calluna*:Gramineae pollen ratio as an indication of the changing type and proportions of moorland vegetation.

RESULTS

(*a*) *Scotland*

The three moorland sites of Round Loch of Glenhead, Loch Tinker and Lochan Dubh (figure 1) have a long history of low-intensity grazing. Until the late-eighteenth century, native

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sheep and cattle characterized the pastoral economy and the rough grazing of these elevated catchments was exploited primarily in summer. The introduction of hardier breeds of sheep facilitated longer grazing periods and by the early-nineteenth century sheep dominated grazing regimes in such areas. Subsequently sheep numbers have fluctuated, but there is no evidence to suggest a decline in grazing intensity in these catchments. Indeed, as adjacent moorland has been lost to afforestation in the twentieth century they have retained their importance for pastoralism. At Round Loch of Glenhead and Lochan Dubh the prevalence of burning as a management practice has declined, but the Loch Tinker catchment is still regularly burnt. The pollen evidence from Round Loch and Lochan Dubh indicates a trend away from *Calluna* since the mid-nineteenth century, presumably because of increased grazing pressure. At Loch Tinker, for as yet unexplained reasons, this trend is reversed in the 1940s (figure 2).

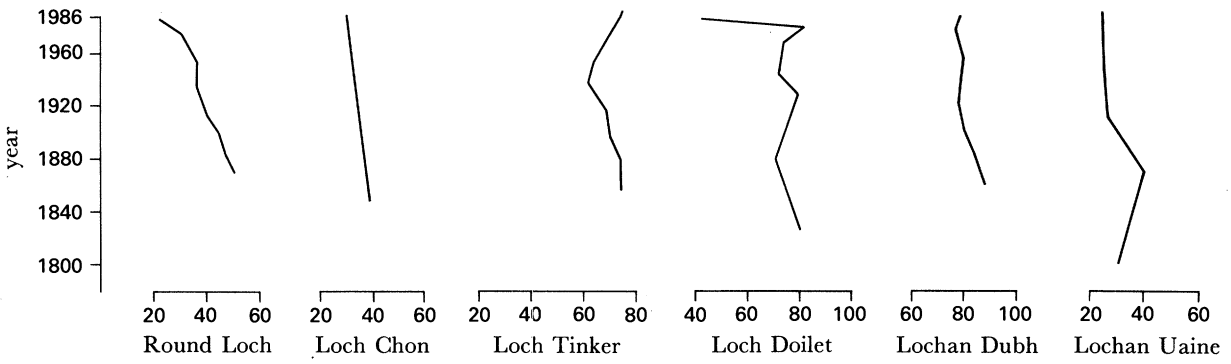

FIGURE 2. ^{210}Pb-dated *Calluna*:Gramineae ratio profiles from lake sediment cores at Scottish sites.

The large, lower-lying and now partly afforested sites, of Loch Chon and Loch Doilet (figure 1) have a history of improvement and management, primarily for animal husbandry. At the peak of agricultural activity in the early–mid-nineteenth century, both catchments contained one or two active farms with plots of arable and meadow land maintained by enclosure, liming and drainage. In addition, the Loch Chon catchment supported a system of deciduous woodland management for charcoal production. Agricultural and silvicultural activity and associated management practices declined from the late-nineteenth century. Conifers were introduced in the Loch Doilet catchment from the 1920s and in the Loch Chon catchment from the 1950s. In the latter catchment there is a suggestion that afforestation may have affected surface water pH, as acidification accelerated in the 1960s (Kreiser *et al.*, this symposium). Since those dates, active land management has been largely confined to practices associated with forestry. Despite the decline in agricultural activity since the mid-nineteenth century, neither the Loch Chon or Loch Doilet *Calluna*:Gramineae ratios exhibit evidence of a more mature heathland vegetation (figure 2).

At 900 m the rocky, sparsely vegetated and exposed catchment of Lochan Uaine lies above the limit of summer sheep grazing in the region. At this altitude there is no evidence for, nor rational expectation of, any land-use change or active land management within the catchment. The catchment may thus be considered a control site in terms of land-use–management effects. Interestingly, since the mid-nineteenth century the *Calluna*:Gramineae ratio has decreased

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(figure 2), probably reflecting a regional trend rather than a catchment-specific record of vegetation change at this small sparsely vegetated site.

(*b*) *Norway*

Throughout the western area, both grazing by domestic animals and the use of støl (summer-hill) land have decreased since the 1860s (Timberlid 1989). This development has resulted from a demand for better livestock nutrition and for a more rational system of production and has led to the increased use of cultivated pasture on inlying fields. In this western area there are no indications of surface water acidification (Henriksen *et al.* 1988).

In the southern area there has also been a decrease in grazing intensity on land below 600 m, but in the remoter areas above this altitude, sheep are still brought in from other regions for high-level summer grazing. As a result of this practice sheep numbers have changed little since 1896 (Timberlid 1989). Because modern sheep consume twice as much fodder as their nineteenth century counterparts, the grazing pressure in these upland areas has increased. It is, however, the area above *ca.* 600 m where surface water acidification is strongest.

Summary

With the exception of Lochan Uaine, all of the Scottish lake catchments in this study have experienced changes in land-use or land management, or both, in the past 200 years. However, these changes have occurred at different times and have been of differing nature and varying magnitude. With the possible exception of afforestation at Loch Chon, there is no evidence that lake acidification is related to land-use/management effects in any one catchment, far less that acidification can be attributed to any general 'land-use' hypothesis.

At five of the Scottish sites pollen data provide evidence that during the period of recent acidification catchment vegetation has changed little or has shifted towards Gramineae and away from *Calluna*, the antithesis of the 'land-use hypothesis'. Only at Loch Tinker does an increase (unexplained) in the *Calluna*:Gramineae ratio occur.

In Norway the 'land-use hypothesis' also breaks down. In the regions where grazing density has declined (western and southern areas below *ca.* 600 m) there is little evidence of acidification, but in the area where grazing intensity has increased (southern area above *ca.* 600 m) surface waters are strongly acidified.

To date, sources similar to those used in this study have shown no evidence for a land-use/management role in surface water acidification at other sites in the United Kingdom (see, for example, Battarbee *et al.* (1988); Patrick (1987); Patrick & Stevenson (1990)) and Norway (see, for example, Drabløs *et al.* (1980); Timberlid (1980)). Together with evidence of the atmospheric pollution record from lake sediments, the failure to attribute acidification to catchment processes argues strongly for an explanation in terms of acid precipitation.

References

Battarbee, R. W., Anderson, N. J., Appleby, P. G., Flower, R. J., Fritz, S. C., Haworth, E. Y., Higgitt, S., Jones, V. J., Kreiser, A., Munro, M. A. R., Natkanski, J., Oldfield, F., Patrick, S. T., Richardson, N. G., Rippey, B. & Stevenson, A. C. 1988 *Lake acidification in the United Kingdom 1800–1986 : evidence from analysis of lake sediments*. London: Ensis Publishing.

Drabløs, D., Sevaldrud, I. & Timberlid, J. A. 1980 Historical land-use changes related to fish status development in different areas in southern Norway. In *Ecological impact of acidic precipitation* (ed. D. Drabløs & A. Tollan), pp. 367–370. SNSF Project Report, Oslo.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

Henriksen, A., Lien, L., Traaen, T. S., Sevaldrud, I. S. & Brakke, D. F. 1988 Lake acidification in Norway – present and predicted chemical status. *Ambio* **17**, 259–266.

Krug, E. C. & Frink, C. R. 1983 Acid rain on acid soil in a new perspective. *Science, Wash.* **221**, 520–525.

Patrick, S. T. 1987 Palaeoecological evaluation of the recent acidification of Welsh lakes. V. The significance of land use and land management. Palaeoecology Research Unit, University College London, Research Paper no. 19.

Patrick, S. T. & Stevenson, A. C. 1990 Acidified Welsh lakes: the significance of land use and management change. In *Acid waters in Wales* (ed. R. Edwards *et al.*). (In the press.)

Rosenqvist, I. Th. 1977 *Acid soil–acid water*. Oslo: Ingeniørsforlaget.

Rosenqvist, I. Th. 1978 Alternative sources for acidification of river water in Norway. *Sci. tot. Environ.* **10**, 39–49.

Rosenqvist, I. Th. 1981 Importance of acid precipitation and acid soil in freshwater lake chemistry. *Vann.* **4**, 402–409.

Stevenson, A. C., Patrick, S. T., Kreiser, A. & Battarbee, R. W. 1987 Palaeoecological evaluation of the recent acidification of susceptible lakes: methods utilized under DoE contract PECD 7/7/139 and the Royal Society SWAP project. Palaeoecology Research Unit, University College London. Research Paper no. 26.

Timberlid, J. A. 1980 Have changes in use of land influenced the regional lake acidification? In *Ecological impact of acidic precipitation* (ed. D. Drabløs & A. Tollan), pp. 352–353. SNSF Project Report, Oslo.

Timberlid, J. A. 1990 Driftsendringar i jordbruket som årsak til forsuring av norske vassdrag? Ein samanliknande studie av utmarksbruket på Vest – og Sørlandet i perioden 1850–1980. *Økoforsk* no. 14.

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