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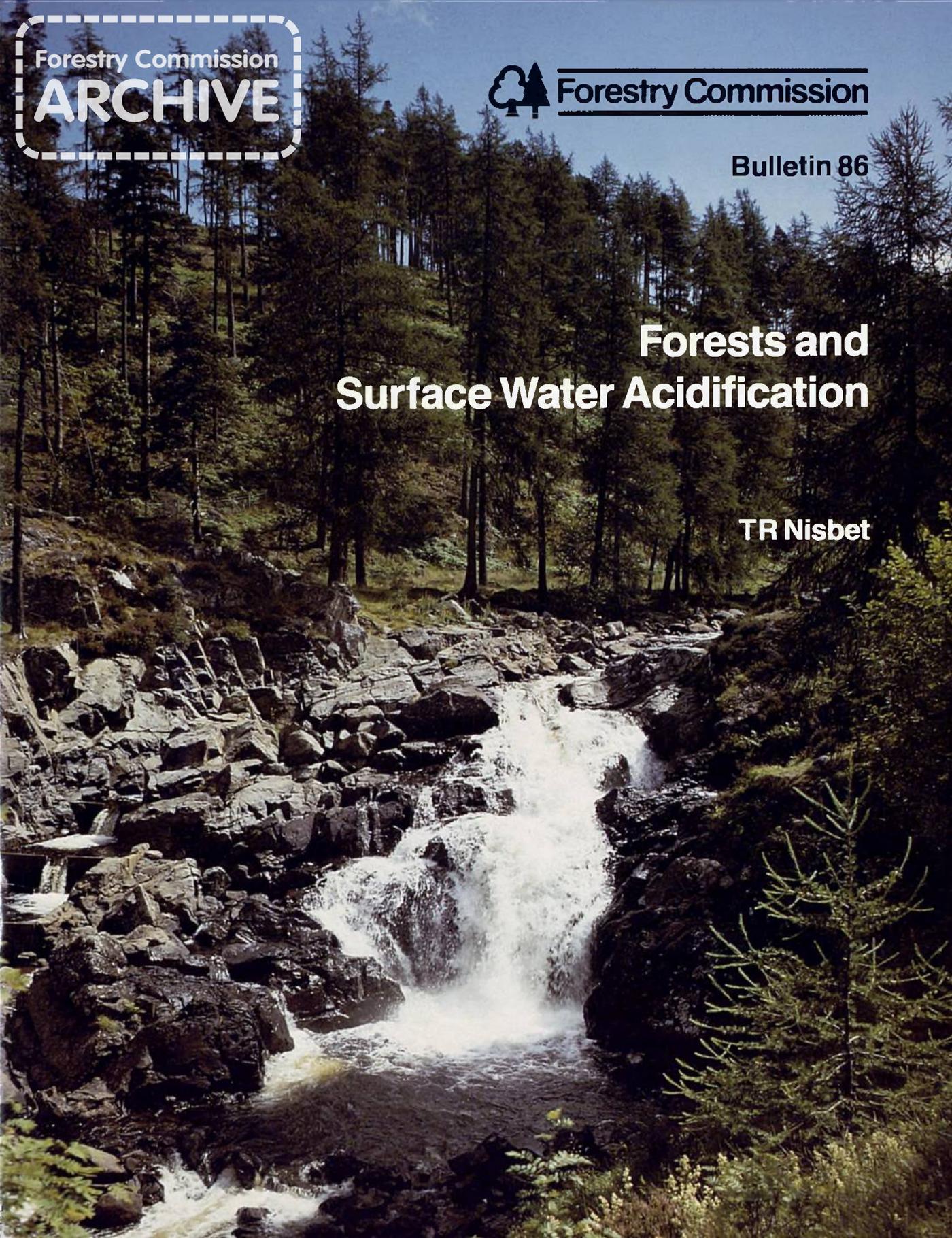


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Forests and Surface Water Acidification

TR Nisbet



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Forests and Surface Water Acidification

T. R. Nisbet

Hydrologist, Forestry Commission

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Enquiries relating to this publication
should be addressed to
the Technical Publications Officer,
Forestry Commission, Forest Research Station,
Alice Holt Lodge, Wrecclesham,
Farnham, Surrey GU10 4LH.

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Forests and Surface Water Acidification

Summary

This Bulletin reviews the evidence for a suggested forest effect in the acidification of surface waters in Great Britain. Acid deposition from the atmosphere within susceptible areas of Britain has affected fresh water flora and fauna, causing the decline and in some instances the complete loss of fish populations. Currently there is a debate about whether the presence of forests has increased the acidity of surface waters and contributed to the observed decline. The evidence for the significance and scale of such a forest effect is by no means clear and only limited conclusions can be drawn from studies undertaken so far. Long-term monitoring of streamwater chemistry within individual catchments is being undertaken. In due course the results of these studies will allow researchers to come to firm conclusions regarding the extent of any forest acidification effect.

Les Forêts et L'Acidification des Eaux Superficielles

Sommaire

Ce Bulletin analyse les connaissances de la recherche sur l'effet suggéré des forêts dans l'acidification des eaux superficielles dans La Grande-Bretagne. La deposition acide de l'atmosphère dans les régions susceptibles a affecté la flore et la faune d'eau douce, et a causé le déclin et quelquefois la perte entière des populations des poissons. Au moment on discute si les forêts ont augmenté l'acidité des eaux superficielles, et s'ils ont contribué au déclin observé. L'évidence pour l'importance et l'échelle d'un tel effet par les forêts n'est pas du tout sûre, et seulement des conclusions limitées sont possibles des études faites jusqu'ici. On poursuit le monitoring chimique à long terme des eaux fluviales dans des bassins individuels. En temps voulu les résultats de ces études permettront les chercheurs de faire des conclusions solides sur l'importance d'un tel effet acidifiant par les forêts.

Wald und Gewässerversäuerung

Zusammenfassung

Dieses Bulletin bespricht die Beweisgründe für eine mögliche Waldwirkung bei der Versäuerung von oberflächlichen Gewässern in Grossbritannien. Die Säure-Deposition aus der Atmosphäre innerhalb empfindlicher Gebiete in Britannien hat sowohl die Süsswasserflora als -fauna beeinflusst, und hat den Rückgang und gegebenenfalls den ganzen Verlust von Fischbeständen verursacht. Gegenwärtig steht zur Debatte, ob das Wald die Azidität von oberflächlichen Gewässern vergrössert hat, und daher zum beobachteten Rückgang beigetragen hat. Der Nachweis für die Bedeutung und das Ausmass solcher Waldwirkung ist keineswegs klar, und gestattet nur beschränkte Schlussfolgerungen von den Untersuchungen, die bis jetzt gemacht worden sind. Das langfristige Monitoring der Chemie des Flusswassers innerhalb einzelner Einzugsgebiete wird durchgesetzt. Die Ergebnisse dieser Studien werden zu gehöriger Zeit den Forschern erlauben, feste Schlussfolgerungen über das Ausmass irgendeiner Waldversäuerungswirkung zu machen.

Forests and Surface Water Acidification

T. R. Nisbet, Hydrologist, Forestry Commission

Introduction

Acidification of surface waters caused by pollutant deposition is a particular problem in a number of areas of Britain (UK Acid Waters Review Group, 1989). Increased acidity of water has been implicated in the decline and in some instances the complete loss of fish populations and certain riverine species of birds. However, the Acid Waters Review Group report also placed strong emphasis on the role of conifer afforestation as a direct cause of surface water acidification. The evidence for the significance and scale of a forest effect is by no means as clear and conclusive as the report suggests. This Bulletin examines the arguments concerning the existence of a forest effect.

The studies of Battarbee *et al.* (1988) have shown that acid deposition, partly via acid rain, is the principal cause of the acidification of streams, rivers and lakes in certain acid susceptible areas of Britain. The susceptibility of a given area is governed by the nature of its underlying soils and rocks; if poor in base elements such as calcium and magnesium, which are able to neutralise rainfall acidity, this acidity is more readily transferred to drainage waters (Edmunds and Kinniburgh, 1986).

By dating the changes in fossil diatom (microscopic algae) populations contained within stratified lake sediments, R. Battarbee and colleagues have been able to reconstruct the historical changes in lake water acidity (pH) in response to increasing acid deposition. The diatom population is a good indicator of water acidity, different species preferring different degrees of acidity. This work has shown that a rapid increase in acidification has occurred during the past 100 to 150 years, with lake water pH declining by between 0.5 and 1.5 units (Figure 1). Two of the worst affected areas where

the combination of base-poor soils and rocks and large volumes of acid rain have resulted in widespread surface water acidification, are the Galloway area of south-west Scotland (granite geology) and the uplands of mid and north Wales (Ordovician and Silurian sediments). Many lakes within these areas, *regardless of whether their catchments are under moorland or forest*, have been acidified to below pH 5.0 and are now virtually fishless (Battarbee *et al.*, 1988; Maitland *et al.*, 1987).

Comparative studies

Despite the fact that an acidity problem exists irrespective of land use, since the late 1970s there has been increasing concern that conifer afforestation may increase the rate or magnitude of surface water acidification within susceptible areas receiving high levels of pollutant deposition. A major line of argument in support of a forest effect is based on studies which have compared streamwater chemistry between forested and unforested catchments (Table 1). Evidence is available from a number of such studies, although by no means all, showing that streams draining conifer forested catchments (aged 15 to 25 years) are significantly more acidic. Streams draining younger forested catchments (aged up to 10 years) were often found not to be significantly different from moorland streams. Forest streams also had lower fish numbers and a generally less diverse freshwater life.

Surface water acidification does not appear to be a problem in forested catchments within susceptible areas when there are only low levels of pollutant deposition. Initial results from studies being carried out in north-west Scotland led Battarbee (1989) to conclude that forestry

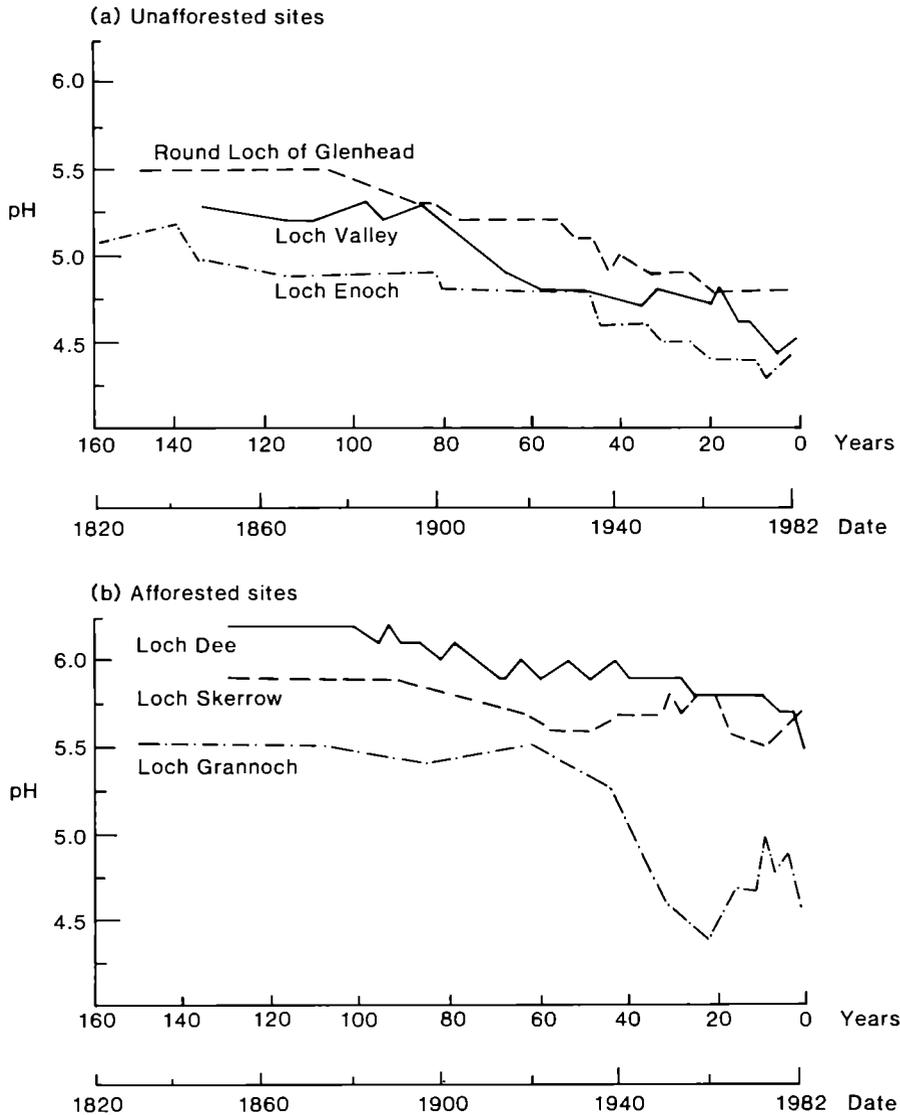


Figure 1. The recent history of lake water acidity changes, (a) in three unafforested Scottish sites, and (b) at three afforested sites planted in 1973-75 (Loch Dee), 1957-59 (Loch Skerrow) and 1962 (Loch Grannoch), reconstructed from sediment core diatom analysis. After Flower *et al.* (1987), reproduced by kind permission of R. W. Battarbee (co-author) and the editor of the *Journal of Ecology*.

north-west of the Great Glen was unlikely to cause surface water acidification.

A number of mechanisms have been advanced to explain the markedly higher acidity found in certain streams draining 15 to 25-year-old conifer forested catchments within susceptible areas receiving high pollutant deposition. These possible mechanisms are described in Table 2. There are considerable doubts about the import-

ance of the last two mechanisms since the afforestation of 90 per cent of the peaty Cwm catchment in mid Wales had no discernible effect on streamwater acidity (Roberts *et al.*, 1989). Of the remaining three mechanisms, the principal one is believed to be the ability of tree canopies to filter out more pollutants from the atmosphere than shorter vegetation (Fowler *et al.*, 1989). This ability is likely to apply to both broadleaved and

Table 1. Comparative studies.

<i>Study</i>	<i>Comparison</i>	<i>Findings</i>
Galloway, SW Scotland Wright and Henriksen (1980)	70 moorland and forest lochs and 11 streams	Neither the degree of acidification nor water pH correlated with the percentage of forest cover within a given catchment. Catchments not ranked according to calcium concentration. Concluded, 'Effects of forestry are small relative to variation in other factors, such as geology'.
Loch Ard, central Scotland Harriman and Morrison (1982)	5 moorland and 7 forest streams	Mature forest (aged 24 years) streams always more acidic although having slightly lower calcium concentrations.
Galloway, SW Scotland Harriman <i>et al.</i> (1987)	22 lochs and 27 forest and moorland streams	Stream acidity significantly higher in semi-mature (15-25 years old) forested catchments draining one particular area, despite similar non-marine calcium plus magnesium concentrations. No difference between moorland and young forest (up to 12 years old) catchment streams.
Tywi, mid Wales Stoner <i>et al.</i> (1984)	6 moorland and 7 forest streams	Certain forest (aged 23 years) streams more acidic despite similar hardness concentrations.
Tywi, mid Wales Stoner and Gee (1985)	1 moorland and 1 forest river; 3 moorland and 3 forest lakes	Forest river and lakes (forests aged 23 years and between 13 and 42 years, respectively) more acidic despite having similar hardness concentrations.
Plynlimon, mid Wales Ormerod and Edwards (1985)	2 moorland and 4 forest streams	Forest (aged up to 48 years) streams more acidic although having slightly lower hardness concentrations.
Plynlimon, mid Wales Reynolds <i>et al.</i> (1986)	3 grassland and 2 forest streams	No difference in pH between forest (aged between 20 and 46 years) and grassland streams draining areas with similar soils and geology, but aluminium concentrations greater in forest streams.
Dartmoor, SW England Williams <i>et al.</i> (1987)	Stream above and below forest	No significant increase in acidity as stream passed through forest (aged 55 years).
Cumbria, N England Bull and Hall (1986)	2 forest and a number of moorland streams	Although forest (aged between 30 and 47 years) streams were very acid, conditions were similar in an adjacent moorland stream.

coniferous trees because increased interception is the result of the aerodynamic properties of a forest stand. The increased capture of atmospheric pollutants, as the tree canopy develops from seedling to full canopy closure at around 15 to 20 years, is thought to be the main driving

force responsible for the higher level of acidity.

The use of the 'Magic' mathematical model to simulate the effect of afforesting a moorland catchment is based on the assumption that canopy closure will result in an arbitrary increase in acid deposition (Whitehead *et al.*,

Table 2. Proposed mechanisms to explain a forest enhanced acidification effect.

-
- 1 The efficient scavenging of acid pollutants from the atmosphere by tree crowns.
 - 2 Increased solute concentration as a result of canopy evapotranspiration.
 - 3 Soil acidification due to base cation uptake by trees.
 - 4 Modification of soil drainage pathways due to forest drainage and soil drying.
 - 5 Increased soil oxidation as a result of soil drying.
-

1988). Obviously, this type of modelling exercise cannot provide confirmatory evidence of the existence of a forest effect since the results simply reflect the assumptions built into the model.

The basic assumption in the above studies of paired catchments is that the susceptibility of the underlying soils and geology to acidification is similar in the catchments compared, so that any difference in water quality can be ascribed solely to the effects of land use. In reality it is often not possible to find such comparability because of the variability of soils, geology and topography and the possibility of associations between the presence or absence of forestry and particular site conditions which influence land use. Consequently, the basic assumption of comparability between paired catchments is questionable. In some of the studies in Table 1, catchments were ranked in order of hardness concentrations (as calcium carbonate) in order to try to quantify any such site differences. However, there is some uncertainty over the extent to which calcium concentrations in streamwater alone can account for the range of factors which determine catchment sensitivity to acidification. Furthermore, in most cases total concentrations are used instead of non-marine concentrations. The latter would more closely reflect the soil and geological characteristics of the site. There is also the problem of variability in the quantity of pollutant inputs received by individual catchments. Pollutant inputs are known to be strongly influenced by factors such as aspect and altitude.

In 1984, in an attempt to overcome the

problem of variability by increasing the number and range of sites, the Welsh Water Authority (WWA) carried out an extensive survey of 140 streams within the acid susceptible region of upland Wales. An analysis based on 96 of these streams found a significant positive correlation between the proportion of forest cover within a given catchment and the winter period streamwater acidity (Ormerod *et al.*, 1989). Despite this, forest cover was not significantly correlated with fish numbers (Gee and Stoner, 1988). Nevertheless, the results of this study were considered by the WWA to be strong evidence for the existence of a significant forest acidification effect and have been used to form the basis of a set of interim guidelines aimed at restricting any further planting of conifers in susceptible areas (as outlined in Gee and Stoner, 1989). The full information from the 1984 survey is currently being evaluated in a joint exercise by the WWA and the Forestry Commission.

A working group consisting of members drawn from the forest and water industries has prepared national *Forests and water guidelines* (Forestry Commission, 1988) which give recommendations covering a number of water quality issues. These guidelines provide advice to forest managers on working methods and measures which should be taken to minimise the effects of forestry on water quality. However, in view of the uncertainties surrounding both the existence of a significant forest acidification effect and the effectiveness of remedial measures which are still at the experimental stage, no firm guidelines could be given on the acidification issue. The essential recommendation is for forest managers to consult with local water authorities regarding proposals for afforestation within susceptible areas.

Studies of sediment cores

While a number of between catchment comparisons point to an association between forested *catchments* and increased streamwater acidity, it cannot, for the reasons discussed above, prove that trees are the causative agent. In order to determine the extent of any forest effect over and above acidification which is the result of in-

creased emissions of acidifying pollutants since the start of the industrial revolution, it is necessary to turn to the evidence from longer term studies. One source of evidence is the lake diatom studies carried out by Battarbee *et al.* (1988) within forested catchments. Unfortunately, these studies also provide inconclusive evidence of a forest effect. Reconstruction of the period of acidification in the susceptible, now seriously acidified waters of Loch Grannoch, south-west Scotland (70 per cent afforested), revealed that the main period of acidification occurred prior to forest planting in 1962 (Figure 1b). In contrast, the rapid acidification (pH 5.6 to 4.6) of nearby Loch Fleet was estimated to have occurred around 1975, 13 years after forest planting. However, it is unlikely that a forest effect was responsible for this sudden acidification since only 10 per cent of the catchment was forested. Similarly, of those studies which have been carried out in less susceptible areas, in one case at Loch Chon, central Scotland (40 per cent afforested), the main period of acidification (pH 6.0 to 5.5) occurred 15 to 20 years after afforestation. This was in contrast to two other cases, Loch Skerrow, south-west Scotland (Figure 1b) and Llyn Cwm Mynach, mid Wales, where there has to date been no significant acidification following afforestation (54 per cent and 51 per cent respectively).

Clear felling studies

Evidence is also available from studies which have monitored the effect of clear felling parts of a forested catchment on streamwater chemistry. Although clear felling severely disturbs a number of site processes, if trees were responsible for causing a significant surface water acidification effect then removing them might be expected to result in a decrease in stream acidity once the site disturbance effects had subsided. Published results from studies at Kershope, northern England (Adamson *et al.*, 1987) and Beddgelert, north Wales (Stevens and Hughes, 1989) show no significant decrease in stream pH during the first four years following clear felling, but there is evidence of a decline in aluminium concentrations in the third and fourth years. Although the

latter suggests some forest effect, this might also be a delayed effect of site disturbance. Clearly, a longer run of data and a more detailed analysis of results collected to date are required before any definite conclusions can be drawn from these and other clear felling studies.

Long-term studies

A more reliable approach to establishing the cause and scale of any effect is to carry out long-term monitoring of streamwater chemistry within individual afforested and moorland control catchments. Fortunately, a number of such studies (Table 3) are already in place within acid susceptible areas of Britain. Although these studies are as yet incomplete, in some cases there has been a provisional analysis of the results collected to date (unpublished). At both Loch Dee and Llyn Brianne, the results do not support the thesis of increasing streamwater acidity; either (a) with increasing tree growth up to canopy closure, or (b) with continued tree growth during the initial post canopy closure phase. These results do not support the conclusions being drawn from the between catchment comparisons, or the predictions of the 'Magic' model. Clearly, a more thorough analysis of the results from all of the long-term studies is required.

Table 3. Long-term monitoring studies.

Site	Study details
Loch Dee, SW Scotland	Streamwater chemistry monitored in three catchments since 1980, two planted between 1973 and 1975 and one remaining as moorland.
Loch Ard, central Scotland	Streamwater chemistry monitored in twelve catchments since late 1970s, some of which were planted in 1955, 1975, 1978 and 1982. Others remaining as moorland.
Llyn Brianne mid Wales	Streamwater chemistry monitored in four catchments since 1981, three of which were planted in 1957-59, 1961-63 and 1971-77 respectively.

Conclusions

Acid deposition from the atmosphere has caused the acidification of a number of streams, rivers and lakes in both moorland and forested catchments within those susceptible areas of Britain. This increased acidification has affected freshwater flora and fauna, causing the decline, and in some instances the complete loss, of fish populations. The current debate centres upon whether the presence of forests has made the situation significantly worse than it otherwise would have been. While there is evidence of an association between forested catchments within acid susceptible areas receiving high levels of pollutant deposition and streamwaters with

higher acidity, this cannot be taken as proof of a significant forest effect *per se*. Only limited conclusions can be drawn from studies which simply compare paired catchments. This is because there may be an association between the presence or absence of forest and site conditions such as geology, soils and topography, which influence land use, and also because exact quantification of the pollutant inputs to catchments with different vegetation is not possible. Firm conclusions regarding the extent of any forest acidification effect can only be based on the analysis of results from the various long-term studies which are currently being carried out.

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