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A test of the land-use hypothesis for recent lake acidification by using hill-top lakes in southwest Norway: an extended summary

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Introduction

Three hypotheses have been proposed to explain recent lake acidification in northwest Europe; the acid-deposition, the land-use and the long-term hypotheses. The hypothesis of natural, long-term soil acidification is not relevant for explaining recent, rapid lake acidification. A critical requirement in testing the first two hypotheses is to distinguish unambiguously between lake acidification due to atmospheric deposition and lake acidification following land-use and associated soil changes, such as the accumulation of raw humus.

Hill-top lakes are small, deep basins perched on tops of cliffs and hills. They have very small catchments, often consisting of bare rock. The chemistry of these lakes is primarily influenced by the chemical composition of precipitation and by the underlying bedrock. Because of their very small catchments, their chemistry cannot be influenced by changes in catchment land-use. Hill-top lakes are thus ideal situations in which to test the two hypotheses, because any acidification in these lakes cannot be a result of changes in land-use, but only of acid precipitation. Thus if hill-top lakes have acidified recently, the land-use hypothesis would be falsified for these sites. On the other hand, the acid-deposition hypothesis would clearly be supported.

The sites

Two small hill-top lakes (Holetjørn, Ljosvatn) in the Moi-Flekkefjord-Kvinesdal area of Vest-Agder, southwest Norway were selected for palaeoecological studies, involving diatoms, pollen, microscopic charcoal, geochemistry, and carbonaceous particles (produced by industrial fossil fuel burning). Standard SWAP procedures were followed. Chronology was provided by ^{210}Pb dating at one site, and by statistical correlation with the carbonaceous particle stratigraphy at the other site. Both lakes lie on acid granitic migmatite at elevations of 485 and 385 m. They are small (0.016–0.11 km^2), deep (17–25 m), clear and oligotrophic, with pH values of 4.4–4.6 at present. They are in the area with a weighted yearly precipitation mean pH of 4.4 and an annual deposition of excess SO_4^{2-} of 3.5 g m^{-2}. They have catchment:lake ratios of 2–3.

Conclusions

The following conclusions can be drawn from the results of our palaeoecological studies.

1. Both lakes were naturally acid prior to *ca.* 1880. The reconstructed pH values were 4.8 and 5.1, as inferred from weighted averaging calibration of the diatom assemblages preserved in the sediments.
2. Both acidified to pH 4.5–4.6 beginning at *ca.* 1930–1940.

3. Vegetational change (as shown by pollen analysis) in the last century has been almost non-existent. What vegetational change has occurred is the opposite of predictions from the land-use hypothesis, namely Ericaceae have decreased as the lakes became more acid.

4. The reconstructed drop in pH, of *ca.* 0.5 units, is similar in magnitude to estimates from other palaeolimnological studies in southern Norway.

5. Increased concentrations of trace metals (Cu, Zn, Cr, Pb) occur in the last 100 years. Carbonaceous particles appear about 1880. All peak in the 1930s or later, the same time as lake pH began to drop. These increases reflect atmospheric input into the lake following emission into the atmosphere by fossil fuel combustion.

6. The first major Pb increase, representing the earliest record of atmospheric contamination, pre-dates the onset of lake acidification by 50–100 years. At no site in Norway or Britain is there any convincing evidence for recent lake acidification before the first increase in trace-metal concentrations or the first occurrence of carbonaceous particles.

7. The demonstration of recent lake acidification in these hill-top lakes falsifies the land-use hypothesis.

8. The temporal relations in the hill-top lakes between lake acidification, carbonaceous particles, and trace-metal concentrations support the acid-deposition hypothesis. We conclude that acid deposition is the most likely cause of recent acidification in these two hill-top lakes.

9. In the absence of any critical palaeoecological evidence to support the land-use hypothesis as a mechanism causing recent lake acidification in northwest Europe, and in the face of several independent refutations, we propose that it is perhaps time to put the land-use hypothesis to rest.

This is an extended summary of a paper entitled 'A palaeoecological test of the land-use hypothesis for recent lake acidification in southwest Norway by using hill-top lakes' submitted to the *Journal of Paleolimnology*.

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