Regional, national and trans-boundary pollutants in remote Scottish lochs as exemplified by Lochnagar.

N.L. Rose[1], D.T. Monteith[1], H. Yang[1], J. Nicholson[2], S. Metcalfe[2], L. Tarrasón[3] & A. Benedictow[3]

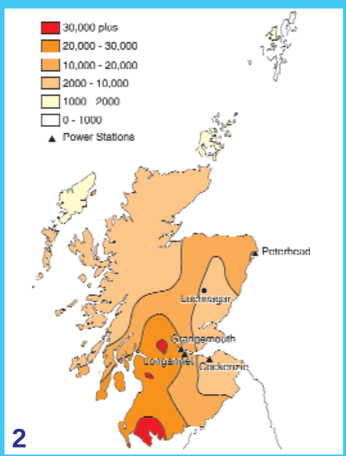
1. Environmental Change Research Centre, University College London, 26 Bedford Way, London, WC1H 0AP, UK.
2. Department of Geography, University of Edinburgh, Edinburgh, EH8 9XP, UK.
3. Norwegian Meteorological Institute, P.O. Box 43, Blindern, 0313 Oslo, Norway.

Introduction

Remote mountain lakes provide an excellent means by which to monitor the impacts of atmospherically deposited pollutants. Sensitive geologies, sparse soils and extreme meteorology combine to produce fragile ecosystems isolated from direct inputs of contamination. The additional stress of atmospheric pollutant inputs to these systems often results in detectable physico-chemical or biological change thus providing an 'early warning' indicator for impacts at less sensitive sites. Further, the lake sediment record provides a natural archive of ecosystem and depositional changes such that these can be studied retrospectively. In remote mountain areas where monitoring is recent or absent sediments provide one of the few practical ways to monitor changes over significant periods of time. Here, we describe how modelling, monitoring and sediment studies at Lochnagar (Figure 1), a remote loch in the Grampian mountains, have been used to indicate the impacts of environmental change at a range of spatial scales.


1

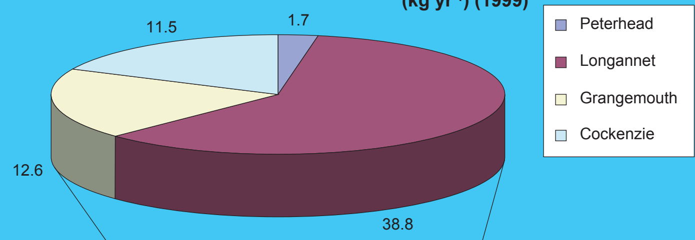
Mike Hughes



2

Regional

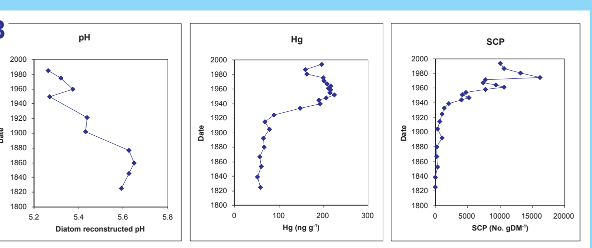
Spheroidal carbonaceous particles (SCPs) are produced only from high temperature combustion of fossil-fuels and provide an unambiguous indicator of pollutant deposition from these sources. Figure 2 shows the surface sediment concentrations of SCPs for a number of Scottish lochs showing that deposition of these pollutants, whilst wide-spread, are mainly focussed close to power station and refinery sources in the Firth of Forth and on the east coast. SCPs deposited at Lochnagar are derived from a combination of these local sources and from those further afield. The Hull Acid Rain Model (HARM) shows that for Scottish sources of total sulphur deposition at Lochnagar, 60.1%, 19.5%, 17.8% and 2.7% are derived from Longannet, Grangemouth, Cockenzie and Peterhead respectively. This translates into 64.7 kg of sulphur deposited onto the Lochnagar catchment from these sources in 1999 (Pie A).



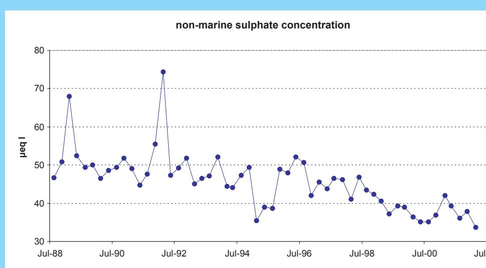
National

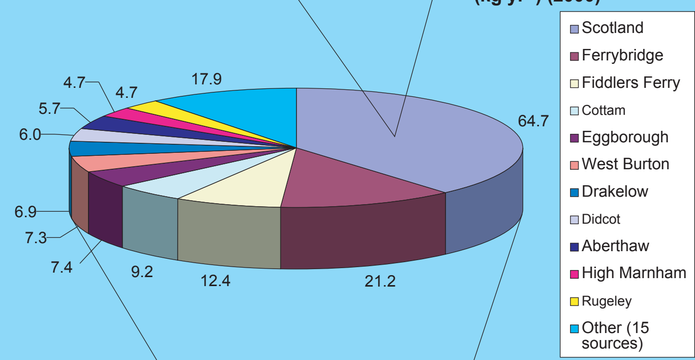
Sediment cores taken from Lochnagar show the historical trends in acidification as a result of acid deposition since the middle of the 19th century (Figure 3). Diatom reconstructed pH trends show similar patterns to the historical profiles of trace metals and SCPs, confirming the depositional source of acidifying substances. This Figure also illustrates that the algae in Lochnagar have undergone major species change as a result of acidification which has probably resulted in deleterious change at most levels of the food chain. More recently, monitoring as part of the UK Acid Waters Monitoring Network has shown a reduction in loch sulphate concentration (Figure 4). This improvement is, in part, due to the dramatic decline in sulphur emissions from UK power stations, in particular as a result of flue-gas desulphurisation (FGD) fitted to the major power stations of Drax and Ratcliffe in the English Midlands in the mid-1990s. HARM confirms this by showing that sulphur emissions from power stations and refineries in England and Wales are responsible for c. 61.5% of the sulphur deposition from UK sources (103 kg in 2000) at Lochnagar. In 1994, HARM showed that Drax was the single most important UK source of sulphur deposition at Lochnagar whereas now, as a result of FGD it is 12th (Pie B).

3



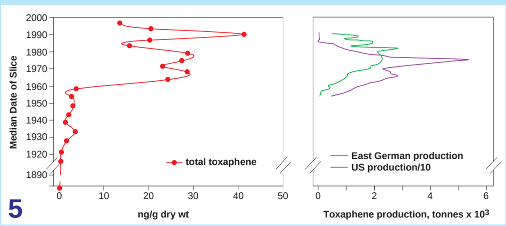
4





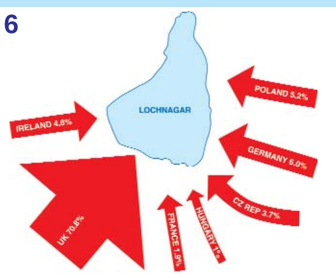
International

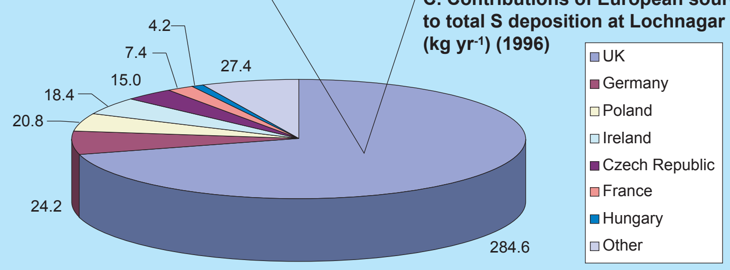
The historical profile of toxaphene, a highly toxic pesticide never used or produced in the UK, has recently been determined for a sediment core taken from Lochnagar (Figure 5; taken from Rose *et al*., 2001). The double-peaked profile suggests atmospheric inputs from two sources. First, southern and eastern Europe, confirming pollutant transport from this latter region identified from black snow episodes in the Cairngorms in the 1980s (Davis *et al*., 1984) and second, trans-oceanic transport from the United States of America. EMEP also predicts the transport of sulphur from European sources (Figure 6) principally Germany, Poland, Ireland and the Czech Republic (Pie C). However, the primary source of sulphur deposition for Lochnagar remains the UK.



5

6

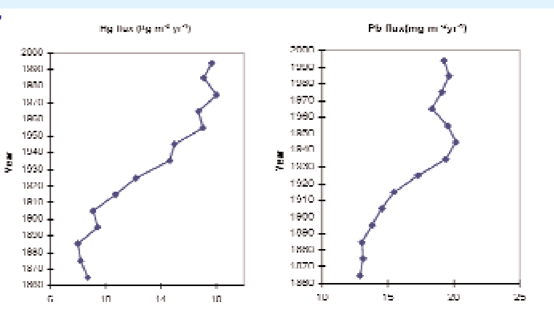




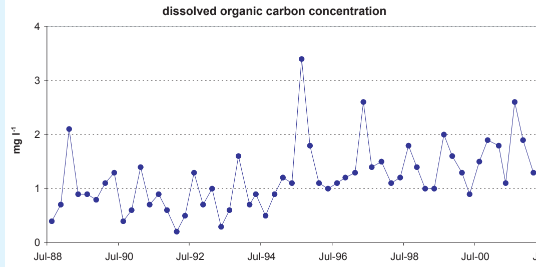
Global

Impacts which may relate to global climate change are also being observed at Lochnagar. Figure 7 shows the full lake basin sediment fluxes for mercury and lead since 1850 (Yang *et al*., 2002) revealing that expected declines resulting from dramatic reductions in metal emissions to the atmosphere are not being observed. This may be due to a combination of climatically driven factors. First, increased erosion of metals from contaminated catchment soils as a result of increased rainfall. Second, climate enhanced decomposition of soil organic matter in warmer summers leading to increased leaching of dissolved organic carbon (DOC) (Freeman *et al*., 2001) with adsorbed metals. Certainly, the DOC levels in Lochnagar waters have increased in recent years (Figure 8). Future climate change may further exacerbate these effects. Furthermore, climate warming may increase the transport and deposition of persistent organic pollutants at high latitude and altitude sites, such as Lochnagar, as a result of an increase in the global distillation effect.

7



8



Conclusions

Remote mountain lake ecosystems are sensitive to atmospherically deposited inputs from a wide variety of sources from a broad spatial scale. The protection of these fragile ecosystems therefore requires local and national legislation as well as international co-operation on emissions policies. However, despite major reductions in emissions over the last few decades, these sites remain threatened by the potentially massive store of previously deposited pollutants, stored in catchment soils, whose release may be accelerated as a result of current and future climate change.

References

Davis, T.D., Abrahams, P.W., Tranter M., Blackwood, I, Brimblecombe, P. & Vincent C.E. (1984) *Nature*. 312: 58 – 61.

Freeman, C., Evans, C.D., Monteith, D.T., Reynolds, B. & Fenner, N. (2001). *Nature* 412: 785.

Rose,N.L., Backus, S., Karlsson, H. & Muir, D.C.G. (2001). *Environmental Science & Technology*. 35: 1312 – 1319.

Yang, H., Rose, N.L., Battarbee, R.W. & Boyle J.F. (2002) *Environmental Science & Technology*. 36: 1383-1388.