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Environmental Pollution 137 (2005) 119–133
ENVIRONMENTAL POLLUTION
www.elsevier.com/locate/envpol

Defining reference conditions for acidified waters using a modern analogue approach

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Received 31 October 2004; accepted 17 December 2004

The use of a palaeolimnological technique to identify modern ecological reference analogues for acidified lakes is demonstrated.

Abstract

Analogue matching is a palaeolimnological technique that aims to find matches for fossil sediment samples from a set of modern surface sediment samples. Modern analogues were identified that closely matched the pre-disturbance conditions of eight of the UK Acid Waters Monitoring Network (AWMN) lakes using diatom- and cladoceran-based analogue matching. These analogue sites were assessed in terms of hydrochemistry, aquatic macrophytes and macro-invertebrates as to their suitability for defining wider hydrochemical and biological reference conditions for acidified sites within the AWMN. The analogues identified for individual AWMN sites show a close degree of similarity in terms of their hydrochemical characteristics, aquatic macrophytes and, to a lesser extent, macro-invertebrate fauna. The reference conditions of acidified AWMN sites are inferred to be less acidic than today and to support a wider range of acid-sensitive aquatic macrophyte and macro-invertebrate taxa than that recorded in the AWMN lakes over the period of monitoring since 1988.

Keywords: Reference conditions; Analogue matching; Diatoms; Cladocera; Aquatic macrophytes; Macro-invertebrates; Palaeolimnology

1. Introduction

The acidification of sensitive surface waters through the deposition of strong acids has had serious impacts on the biological communities they support (e.g. Battarbee and Charles, 1986; Charles and Whitehead, 1986; Muniz, 1991; Henriksen et al., 1992). Using palaeolimnological techniques the cause of this acidification has been shown to be the emissions of oxides of sulphur and nitrogen from industrial and other sources (e.g. Flower and Battarbee, 1983; Battarbee et al., 1985; Battarbee and Charles, 1986; Battarbee, 1990). As a result of these and other findings, emission reduction protocols have been adopted across Europe and North America to control the emissions of these compounds, such as the Oslo and Gothenburg protocols. These have led to the dramatic reduction in the levels of sulphur deposition throughout Europe and beyond (NEGTAP, 2001).

As a result much of the focus of the work within the study of lake acidification has shifted towards monitoring acidified systems for signs of recovery from acidification (e.g. Monteith and Evans, 2000). Evaluating progress towards pre-disturbance conditions is an important

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doi:10.1016/j.envpol.2004.12.025

component of any monitoring programme designed to detect recovery in that system. To evaluate recovery a target community or state is required with which to compare present conditions (Bradshaw, 1984; Battarbee, 1997, 1999). Ideally, this target should reflect the community composition of the lake prior to the onset of acidification, which in the UK would be the community composition of the lake in ca. 1850 AD or before. However, the majority of acidified lakes are found in remote locations and few, if any, have records of their biological communities for this period.

In addition to the progress made in reducing the levels of acid deposition, the European Council Water Framework Directive (WFD; European Union, 2000) and the US Clean Water Act (Barbour et al., 2000) require that reference conditions be defined for different lake types based on biological, hydromorphological and physico-chemical elements of the water so that the current status of fresh waters can be assessed relative to a baseline state (Moss et al., 1997; Battarbee, 1999). The historical record of past environments, as recorded in lake sediments, is perhaps the only record of past community composition available for use in setting biologically-based targets for recovery from acidification (Battarbee, 1999). Yet, here the record is limited to those organisms that leave identifiable remains in the sediments of lakes (e.g. Smol et al., 2001a,b). These include diatoms Battarbee et al., 2001), single-celled siliceous algae, Cladocera (Korhola and Rautio, 2001), a group of microscopic crustacea, and chironomids (Walker, 2001), non-biting midges.

The use of palaeolimnology is stated in the WFD as one method by which reference conditions may be defined (European Union, 2000). One palaeolimnological approach is that of Bennion et al. (2004), who used TWINSPAN (Hill, 1979) to classify the pre-disturbance floras of 26 Scottish lochs. This allowed characterisation of the reference condition diatom floras for different lake types, while diatom-total phosphorus (TP) transfer functions applied to sediment cores from the 26 lochs were used to determine reference condition TP concentrations. An alternative approach is the use of a technique called analogue matching.

Analogue matching makes use of the historical record of community composition recorded in lake sediments. This is compared with the contemporary record found in the surface sediments of a range of modern reference lakes (Overpeck et al., 1985; Flower et al., 1997). By using a number of slices from different levels of a sediment core, corresponding to different periods in the history of the lake, it is possible to identify a series of ecological states ranging from the most highly impacted to reference conditions. These states may be used as restoration targets where total restoration is not achievable or prohibitively costly. It is assumed that those samples selected from the modern lakes as being the most similar to the fossil sample will also have a similar community composition in those species that do not leave reliable or interpretable records in lake sediments—a shortcoming of the more direct approach of Bennion et al. (2004).

The analogue approach has mainly been used by pollen analysts where fossil pollen spectra retrieved from lake or bog archives were compared to modern pollen spectra taken from a range of habitat types (e.g. Guiot et al., 1989; Fauquette et al., 1998; Peyron et al., 1998). By identifying that modern assemblage which is most similar to each of the fossil assemblages it is possible to infer the environmental conditions in the past from those of the lakes today where the modern assemblage was sampled. As such, analogue matching is also a well established technique used in palaeoenvironmental reconstruction (e.g. Overpeck et al., 1985).

Flower et al. (1997) extended the use of analogue matching, using the technique to identify restoration targets for two acidified lakes, Loch Dee (DEE) and the Round Loch of Glenhead (RLGH). Sub-fossil remains of diatoms were used to match fossil samples from these two lakes with surface samples taken from 194 sites from across Northern Europe. Their work demonstrated that close modern analogues could be identified for the reference conditions of the two study sites using diatom assemblages (Flower et al., 1997).

Some of the close modern analogues identified by Flower et al. (1997), however, had excessive lake water calcium concentrations when compared to the present day hydrochemistry of DEE and RLGH, placing their true value as reference sites in some doubt, especially if comparisons with the wider fauna and flora of the analogues were made (Flower et al., 1997).

An alternative approach has been developed by Simpson (2004, and in preparation) that builds on the work of Flower et al. (1997), but which uses a matching process based on diatom and cladoceran remains. In this paper we use this new approach to identify modern analogues that can be used as reference conditions for the lakes in the Acid Waters Monitoring Network (AWMN). We then compare a range of selected acid-sensitive aquatic macrophyte and macro-invertebrate taxa to define reference conditions for the AWMN lake sites and to assess how well the analogue matching approach performs in defining these conditions.

2. Methods

2.1. Modern training set and study sites

Analogue matching using sub-fossil remains of diatoms and cladocerans from lake sediment samples is described in detail in Simpson (2004), and was used to identify close modern analogues for 10 of the lake sites