Can pollution bias peatland paleoclimate reconstruction?

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A B S T R A C T

Peatland testate amoebae are widely used to reconstruct paleohydrological/climatic changes, but many species are also known to respond to pollutants. Peatlands around the world have been exposed to anthropogenic and intermittent natural pollution through the late Holocene. This raises the question: can pollution lead to changes in the testate amoeba paleoecological record that could be erroneously interpreted as a climatic change? To address this issue we applied testate amoeba transfer functions to the results of experiments adding pollutants (N, P, S, Pb, O3) to peatlands and similar ecosystems. We found a significant effect in only one case, an experiment in which N and P were added, suggesting that pollution-induced biases are limited. However, we caution researchers to be aware of this possibility when interpreting paleoecological records. Studies characterising the palaeoecological response to pollution allow pollution impacts to be tracked and distinguished from climate change.

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Transfer function
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Introduction

Peatlands are an increasingly utilized source of data on Holocene paleoclimate (Blackford, 2000; Chambers and Charman, 2004). Ombrotrophic peatlands receive all their moisture from the atmosphere so changes in their surface wetness largely reflect the balance between precipitation and evapotranspiration. Many proxies have been developed to reconstruct surface wetness variability from peats (Chambers et al., 2012), including the widely used analysis of testate amoebae (Mitchell et al., 2008). Several transfer functions have been established to enable quantitative reconstruction of water table depths from amoeba assemblages (Mitchell et al., 1999; Payne et al., 2006; Charman et al., 2007), the results of which are increasingly important to our understanding of Holocene climate change (Charman, 2001).

The direct link between the peat surface and the atmosphere makes ombrotrophic peatlands sensitive to climate but also makes them extremely sensitive to atmospheric pollution. In many industrialised regions of the world there are few, if any, peatlands unaffected by anthropogenic pollution. For instance, output from the European Monitoring and Evaluation Programme deposition model (Jonson et al., 1998) shows that almost all of Europe (99.6%) receives nitrogen (N) deposition above the natural background (~0.5 kg N ha−1 yr−1; Dentener et al., 2006) and a majority (68.6%) receives sufficient for impacts on peatland plants to occur (>5 kg N ha−1 yr−1 critical load lower limit; UNECE, 2010). Some palaeoecologically well-studied peatlands receive considerable pollution; for instance, N deposition at Walton Moss in northern England (Barber and Langdon, 2007) is around 18 kg N ha−1 yr−1, almost four times the lower limit of the critical load. Pollution has been widespread over the last 150 yr and has had major impacts on some peatlands. Large areas of blanket bog in the southern Pennines of northern England have been extensively degraded by sulphur (S) and metal pollution since the mid-19th century (Lee, 1998). Impacts may also extend deeper in time. Geochemical records show anthropogenic input of heavy metals to peatlands spanning several thousand years (e.g., Shotyk et al., 1998; Martínez-Cortizas et al., 1999) and eutrophication by anthropogenic dust has been proposed as a mechanism for the late-Holocene decline of Sphagnum austinii in many European peatlands (Hughes et al., 2007). Throughout the Holocene peatlands have been exposed to intermittent, but potentially significant, natural pollution by volcanogenic sulphur and animal urine, faeces and cadavers (Augustine and Frank, 2001; Carter et al., 2007). Most palaeoecologically

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studied peatlands will have been exposed to pollutants for at least some of their history.

Experimental studies have shown changes in abundance and community composition of peatland testate amoebae in response to a wide range of pollutants. The mechanisms behind these changes are poorly understood but may include direct toxic effects through absorption or ingestion of pollutants, indirect effects through interactions with predators, prey, symbionts and parasites and indirect effects through changes to the amoeba’s physical and chemical environment. Species with relative abundance changes demonstrated in response to pollution in peatland experiments include many that are also considered good indicators of hydrological conditions such as *Nebela carinata* and *Heleopera sphagni* (wet indicators negatively affected by lead (Pb); Nguyen-Viet et al., 2008), *Assulina muscorum* (a dry indicator negatively affected by N and P; Mitchell, 2004) and *Bullimularia indica* (a dry indicator positively affected by N: Mitchell and Gilbert, 2004). These findings raise an important possibility: that pollution could force changes in the peatland ecologic record that could be mis-interpreted as a climatic change. Pollution impacts are most likely in the last 150 yr but cannot be excluded through most of the Holocene.

**Methods**

Here we address this issue by applying testate amoeba transfer functions to the results of several pollution experiments to see whether pollution is capable of leading to changes in the peatland paleoclimate record independent of real climatic changes. Such changes may be due to either a real pollution-induced change in local wetness (for instance through impacts on vegetation) or other direct or indirect impacts of pollution on testate amoebae.

We consider all experiments that address the impact of anthropogenic pollutants on peatland testate amoebae. These experiments include most of the major pollutants that are known to drive ecological change in peatlands, including sulphur (Payne, 2010; Payne et al., 2010), ozone, lead (Nguyen-Viet et al., 2008) and nitrogen alone (Gilbert et al., 1998; Mitchell and Gilbert, 2004; Payne et al., 2012), and in combination with other macronutrients (Mitchell, 2004). All experiments have suggested some evidence for impacts on testate amoebae, although the scale of these impacts and the approach to data analysis varied among the studies. We paired the experiments with testate amoeba transfer functions from the same region or the closest available region (Table 1) with taxonomic harmonisation carried out as required (full details are given in Supplementary Table 1: note particularly the broad groupings required for the experiment of Gilbert et al., 1998). The published transfer functions were applied with bootstrap error estimation (1000 cycles: Line et al., 1994) using C2 (Juggins, 2003). Both the inferred water table depths and their associated errors were analysed to identify any significant differences between treated and control samples. Analyses used t-tests for the simplest experimental designs, one-way analysis of variance (ANOVA) where there were multiple treatment levels, nested-ANOVA where there was pseudo-replication, repeated measures ANOVA (RM-ANOVA) for experiments over multiple time-periods or depths, and Pearson’s r for a gradient experiment. Appropriate tests for normality, sphericity and heteroscedasticity were applied and some data were ln(x+1) transformed.

**Results**

For most experiments we found no statistically significant difference in inferred water-table depth or boot-strapped errors (Table 1). The sole exception was the experiment of Mitchell (2004) in which N and P were applied to an Arctic Alaskan fen (Boelman et al., 2003). This dataset is relatively small (7 samples), but the effect of treatment is large, with a mean difference in inferred water-table depth of 18 cm.
The possible confounding influence of pollution has been addressed in other areas of paleoecology (Holtgrieve et al., 2011) but has received little consideration in the peatland archive despite the large quantity of modern ecological research addressing pollution impacts in peatlands. For instance, in dendro climatic research it is known that pollution can cause changes in ring width independent of climate, which can compromise climate calibration and reconstruction for the recent past (e.g., Thompson, 1981; Wilson and Elling, 2004). Crutzen (2002) has coined the term Anthropocene to encapsulate the idea that different forcings may operate in the recent era in which human activity has been a dominant driver of environmental change compared to the more distant past. Our results provide little evidence that pollution compromises climate reconstruction, but it would be unwise to ignore pollution as a possible agent of paleoecological change in the peatland record. Further experimental studies characterising the paleoecological response to pollution would be helpful to allow pollution and climate impacts to be differentiated.

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Appendix A. Supplementary data

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References

signature of anthropogenic nitrogen deposition to remote watersheds of the northern hemisphere. Science 334, 1545–1548.


Thompson, M.A., 1981. Tree rings and air pollution: a case study of Pinus monophylla growing in east-central Nevada. Environmental Pollution A 26, 251–266.
