Environmental Pollution 179 (2013) 201–209

Contents lists available at SciVerse ScienceDirect

Environmental Pollution

journal homepage: www.elsevier.com/locate/envpol

Tracing decadal environmental change in ombrotrophic bogs using diatoms from herbarium collections and transfer functions

Aloisie Poulíčková [a,*], Petra Hájková [b,c], Kateřina Kintrová [b], Romana Bat'ková [a], Markéta Czudková [a], Michal Hájek [b,c]

[a] Department of Botany, Faculty of Science, Palacký University in Olomouc, Šlechtitelů 11, CZ-78371 Olomouc, Czech Republic
[b] Department of Botany and Zoology, Masaryk University, Kotlářská 2, 61137 Brno, Czech Republic
[c] Department of Vegetation Ecology, Institute of Botany, Academy of Sciences of the Czech Republic, Lidická 25/27, 65720 Brno, Czech Republic

ARTICLE INFO

Article history:
Received 23 January 2013
Received in revised form
5 April 2013
Accepted 6 April 2013

Keywords:
Epibryon
Diatoms
Bogs
Sampling
Transfer functions

ABSTRACT

Central European mountain bogs, among the most valuable and threatened of habitats, were exposed to intensive human impact during the 20th century. We reconstructed the subrecent water chemistry and water-table depths using diatom based transfer functions calibrated from modern sampling. Herbarium *Sphagnum* specimens collected during the period 1918–1998 were used as a source of historic diatom samples. We classified samples into hummocks and hollows according to the identity of dominant *Sphagnum* species, to reduce bias caused by uneven sampling of particular microhabitats. Our results provide clear evidence for bog pollution by grazing during the period 1918–1947 and by undocumented aerial liming in the early 90-ies. We advocate use of herbarized epibryon as a source of information on subrecent conditions in recently polluted mires.

1. Introduction

Mires represent specific semi-terrestrial ecosystems where organic matter tends to accumulate because of waterlogged and often poorly aerated conditions (Rydin and Jeglum, 2006). Mires with a surface isolated from groundwater and nourished solely by precipitation are known as ombrotrophic bogs (Vitt, 2006). These ecosystems can be characterized by low pH, oligotrophy and relatively high sensitivity to human impact. As ecosystems with a relict and island character, mountain bogs belong to the most valuable and threatened of habitats across Europe (Bezděk et al., 2006; Charman, 2002). Besides their importance in biodiversity protection, mires have recently been identified as environments that deserve high research priority because of their function as a sink for atmospheric carbon, which can be easily altered by ongoing environmental pollution (Bragazza et al., 2012; Dise, 2009).

The ombrotrophic bogs situated in Central Europe were exposed to intensive human impacts during the 20th century: pasture, draining, eutrophication, acidification or, in some regions during the 9th decade of the 20th century, contamination by lime used in forestry management (Štěpánková et al., 2008, 2012). Direct monitoring of environmental conditions largely started during the last decade of the 20th century (Hájková et al., 2011). Owing to the paucity of detailed historical studies on water chemistry and/or complete species compositions of bioindicators, there are no exact data for subrecent and/or reference environmental conditions in most of these mires.

Recent studies from the Jeseníky Mts, the mountain region in the NE part of the Czech Republic, revealed an unexpectedly low N:P ratio in *Sphagnum* capitula, which did not correspond to the nitrogen deposition level and ombrotrophic conditions (Jiroušek et al., 2011). In addition, data from the same region showed a strong response of microorganisms but weak response of macroorganisms to the pH/calcium gradient (Jiroušek, 2012; Štěpánková et al., 2012). These surprising results have been interpreted as a result of a rather recently formed pH/calcium gradient because of imprecise aerial liming of the surrounding forests (Jiroušek et al., 2011). Direct evidence is however missing as these events were illegal and hence not documented. The next challenging recent ecological results are enhanced phosphorus concentration in some bogs of the Jeseníky Mts of unknown origin and history (Jiroušek et al., 2011) and gradual disappearance of some hollow, water-demanding plants which may, or may not, be associated with a

* Corresponding author.
E-mail addresses: aloisie.poulickova@upol.cz (A. Poulíčková), buriana@sci.muni.cz (P. Hájková), kintrova@sci.muni.cz (K. Kintrová), hajek@sci.muni.cz (M. Hájek).

0269-7491/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.envpol.2013.04.007

drier climate (Hájková et al., 2011). Either drought or nutrient enrichment by grazing have been hypothesised to be responsible for the hiatus in the peat sedimentation at some point between 1320 and 1954, found in palaeoecological records from one summit bog and ending following grazing cessation after the World War 2 (Dudová et al., 2013).

Diatoms are one of the most important indicators of recent and past water quality, climate warming, eutrophication, acidification and water chemistry recovery (Smol and Stoermer, 2010). Diatoms exhibit a variety of life strategies, have specific ecological preferences and their short life spans enable them to respond rapidly to environmental changes (Rühland et al., 2003). Although the recent diatom flora is quite well known in Central European mires (Buczkó and Wojtal, 2005; Cantonati et al., 2011; Poulíčková et al., 2013), the reference historical data are mostly missing. While stratigraphic diatom analyses allow for the reconstruction of former lake conditions (Smol and Stoermer, 2010), similar reconstruction in bogs is problematic. Silica-organic-acid complexes may be the cause of the poor preservation of diatoms in decomposed peat (Bennet and Siegel, 1987). Historic herbarium macrophyte specimens, preserved in museums over the world, often retain the epiphytic diatom communities which have the potential to be used to interpret the former water quality (Cocquyt and De Wever, 2002; Van Dam and Mertens, 1993). Denys (2009) reconstructed 153 years of lake history using herbarium specimens of macrophytes, and called this approach "paleolimnology without a core". For this reason, dried specimens of bryophytes (*Sphagnum*) herbarized and deposited in museums could likewise be used for comparison of recent and sub-recent diatom flora and may be used for tracing historical changes in the bog areas as well (Poulíčková et al., 2013). However, these data cannot be usually processed using conventional statistical testing (e.g., regressing mean indicator values with time), because historical samples are usually temporally clustered, with some periods missing and others oversampled. Various diatom inference models have been applied by limnologists (Denys, 2006; Ter Braak and van Dam, 1989). In this study we decided to use the transfer function, a numerical technique conventionally applied in the millennial- and century-scale palaeoecology in order to reconstruct past environmental conditions (Denys, 2007). This approach, however, requires directly measured recent environmental conditions and complete recent species lists from the same or similar areas.

The bogs in the Jeseníky Mts represent a suitable model system to conduct such a reconstruction of past environments. First, there is a network of permanent monitoring plots with known long-term water chemistry and water level measurements (Dudová et al., 2013; Hájková et al., 2011) and species composition of diatoms (Poulíčková et al., 2013). Second, there are available herbarium specimens of bryophytes as well as museum collections of diatoms that may be used in retrospective monitoring. Third, there are interesting research hypotheses around, for example: the pH/calcium gradient appeared rather recently after aerial liming applied by foresters, nutrient enrichment caused by grazing before World War 2 and only recently decreasing water levels and increasing phosphorus concentrations.

In this study, we thus aimed to test the predictions that (1) calcium plus magnesium concentrations, pH and phosphate concentrations increased after massive aerial liming in the early 90-ties in some bogs (Trojmezí and Vozka bogs; Jiroušek et al., 2011); (2) the availability of these nutrients was enhanced before the end of World War 2 as a consequence of grazing (Dudová et al., 2013; Novák et al., 2010); (3) water level fluctuations correspond to changing precipitation regimes with recent tendencies to gradual mire desiccation.

2. Methods

2.1. Species data

A network of 29 permanent plots, situated at 8 bogs (F–M, Fig. 1, Table 1), with vegetation and water chemistry monitoring were established in the Jeseníky Mts in 1993 (Hájková et al., 2011; Rybníček, 1997). All plots can be characterised as purely ombrotrophic habitats (Hájková et al., 2011; Poulíčková et al., 2013; Štěpánková et al., 2008, 2012), representing either hollows (i.e., rather aquatic habitat with long-term stagnating water and dominance of submerged bryophytes) or hummocks (i.e., semi-terrestrial habitat slightly elevated above the water level, dominated by peatmoss with apical parts phytosynthetising above the water level). Samples for recent diatom species composition were taken at permanent plots in August 2008 and 2010 by squeezing of bryophytes into plastic bottles. The samples were concentrated by sedimentation, oxidized with a mixture of acids and mounted in Naphrax (Poulíčková et al., 2013). Historical samples (1918–1998; $n = 46$; Table 1) were obtained as herbarized bryophytes from museums in Olomouc, Opava, Prague, Brno and the private collection of K. Rybníček. We also obtained a few samples (year 1955) from the desmid sample collection of Jiří Růžička deposited in the Moravian Museum in Brno. Entire dried herbarium bryophyte specimens (cca. 9 cm^3) were mineralized and diatoms were mounted in Naphrax (Poulíčková et al., 2013). The diatoms were identified according to Krammer and Lange-Bertalot (1986–1991), Lange-Bertalot et al. (2011) and the nomenclature was updated according to Algaebase (January 2013). The relative abundance of individual diatom species was estimated by counting 400 valves from each Naphrax slide.

2.2. Environmental data

Environmental conditions were obtained from the results of the long-term monitoring (Hájková et al., 2011; Jiroušek, 2012). The pore water for chemical analyses was taken annually from the permanent holes. At least one sample per year was taken in each plot, but three seasonal samples (May, July, and September) were collected in most years. The water was collected from the permanent holes, filtered in order to remove mechanical particles and transported in plastic bottles to the laboratory. The water level with respect to the bog surface was measured directly in the field.

Water pH and electrical conductivity (both standardised at 20 °C) were measured using a multimeter (Hach Lange HQ 40D multi) with the IntelliCal electrodes (3 M KCl PHC301-01 for pH; CDC401-01 for conductivity). Conductivity caused by H^+ ions was subtracted according to the formula of Sjörs (1952). We used only corrected conductivity in this study. Concentrations of calcium (Ca) and magnesium (Mg) were measured using atomic absorption spectrometry directly in the concentrated sample. Phosphates (PO_4^{3-}) were detected spectrophotometrically as phosphomolybdenum blue. Because the values of phosphate concentrations were under the detection limit (0.05 mg l^{-1}) in many cases, the original concentration data were transformed into an ordinal scale. Exponential categories were used, with the value below the detection limit equal to 1, values between 0.05 and 0.1 mg l^{-1} equal to 2, values between 0.1 and 0.2 mg l^{-1} equal to 3, values between 0.2 and 0.4 mg l^{-1} equal to 4, values between 0.4 and 0.8 mg l^{-1} equal to 5 etc.

Climatic data were obtained from the Czech Hydrometeorological Institute. As there is no single climate station measuring parameters over the whole period, we used data from the four stations of the same altitude and similar macroclimate: Vidly (780 m a.s.l.; period 1903–1937), Ramzová (759 m a.s.l.; period 1947–1955), Karlova Studánka (780 m a.s.l.; period 1958–1971) and Rejvíz (780 m a.s.l.; period 1988–2010). Data from 1946 to 1947 are not available. We always used the means from the bryophyte sampling year and from the preceding year. We excerpted mean annual precipitation and mean summer temperature (the period May–October).

2.3. Data analysis

We divided the data set into hummock and hollow subsets according to the identity of dominant *Sphagnum* species in the sample, with samples formed by *Sphagnum cuspidatum* and *Warnstorfia fluitans* being always classified as hollows and samples formed by *S. magellanicum*, *S. rubellum* and *S. russowii* being always classified as hummocks. Samples formed by *S. recurvum* agg. (*S. fallax*, *S. angustifolium*, *S. balticum*) and samples lacking information about dominant bryophytes (a part of the Jiří Růžička collection, 1955) were classified according to the measured or reconstructed water table level; habitats with water levels more than 10 cm below the surface were classified as hummocks, other samples as hollows. This threshold corresponds to recent diversification of hummocks and hollows in the study area (K. Rybníček, M. Jiroušek, P. Hájková & M. Hájek, unpublished data). For some analyses we further divided the data set into three periods corresponding to historical events. The first period spans up to 1947, the threshold of the end of grazing activities on mountain summits (Jeník and Hampel, 1992; Kočí, 2007). The second period spans from 1948 to 1989, the period of communism with decrease in agricultural and forestry management of summit areas, except for afforestation of summits by spruce plantations. The third period spans from 1990 up to the present and it is characterised by aerial liming of some summit regions applied in order to improve the spruce plantations damaged by acid rains. Although the impact of