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Towards quantitative reconstruction of peatland nutrient status from fens

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Abstract

In rich fens, unlike bogs, the key drivers structuring testate amoeba communities are related to nutrient status, suggesting the potential for transfer functions to quantitatively reconstruct changing nutrient status from palaeoecological records. Such records could be useful tools to investigate the long-term impacts of pollution and landscape change. Here we derive and test transfer functions for pH, water table depth, conductivity, Ca and Mg concentrations using a dataset from Polish fens. Results show that transfer functions for Ca and conductivity have apparent predictive power for surface samples; these models will require further validation and testing with palaeoecological data. Testate amoeba transfer functions for fen nutrient status may be a useful additional to the peatland palaeoecologist's tool-kit although further work will be required to demonstrate their usefulness in practise.

Key words: testate amoebae, trophic change, transfer function; Poland; brown moss; *Sphagnum*

Introduction

In the last two decades most peatland palaeoenvironment studies have focused on reconstructing Holocene climate change (Gałka et al., 2013; Swindles et al., 2009), however, reconstructing the trophic state of wetlands is also an important aim (Hájkova et al., 2012). Shifts in peatland nutrient status may be anthropogenic through pollution (Payne et al., 2012) or catchment land-use change (e.g. deforestation), autogenic (Zobel, 1988) for instance through ombrotrophication, or related to climatic change (Ammann, 1986). However methods for quantitative reconstruction are currently undeveloped.

Testate amoebae are protists that are widely used in palaeoecological research (Mitchell et al., 2008) because they form shells that are routinely preserved in peats (Charman, 2001). In bogs a key control on testate amoeba communities is depth to the water table (DWT) and testate amoebae have been widely used in climate reconstruction (Charman et al., 2002; Warner, 1990). However, compared to bogs, rich fen testate amoeba ecology has been much less intensively investigated. Recent studies in the Czech Republic (Opravilova and Hajek, 2006), the eastern Mediterranean (Payne, 2011) and Poland (Lamentowicz et al., 2011) have described species/environment relationships. Studies in Poland show that, unlike bogs, conductivity, calcium and pH are the most important environmental controls on testate amoeba communities. This suggests the potential for nutrient-status-related transfer functions but the only study to previously attempt this used a very small local training set (Dudova et al., 2012). Transfer functions for phosphorous have been applied in lakes (Patterson et al., 2012; Roe et al., 2010) and demonstrate the potential applications of similar models in fens. In this study we aim to: i) produce transfer functions for nutrient status-related factors based on a previously-derived dataset, ii) test transfer functions by cross-validation and iii) apply transfer functions to an existing high-resolution peat profile from N Poland (Lamentowicz et al., 2013).

Materials and Methods

Eight fens in western Poland (Wielkopolska region) (Fig. 1) were sampled in 8-22 locations per site (n=147). Vascular vegetation of the studied fens was composed mainly of sedges and rushes with *Schoenoplectus tabernaemontani*, *Cladium mariscus and Carex rostrata* dominant. Brown mosses were also common including *Calliergonella cuspidata* and *Calliergon giganteum* and the relict species

Tomenthypnum nitens and *Paludella squarrosa; Sphagnum fallax* and *S. angustifolium* were recorded in some acidic habitats. The data set we analyse here adds four further sites to the data previously discussed by Lamentowicz et al. (2011). Full details of sampling and analytical methods, and discussion of the autecology of species are contained in this paper.

The upper 5cm of mosses were removed and agitated in water with the fraction >20µm and <300 µm retained for analysis (Booth et al. (2010). 150 tests were identified per sample (Payne and Mitchell (2009) based on the established taxonomic literature (Clarke, 2003; Decloitre, 1978, 1979; Grospietsh, 1958; Mazei and Tsyganov, 2006; Ogden and Hedley, 1980; Ogden, 1980; Ogden and Fairman, 1979). Three replicate ground water subsamples were collected in the field and analysed as described in Lamentowicz et al. (2011).

Five variables explaining most variance in the species data are considered here: depth to water table, pH, and conductivity measured in the field, and Ca and Mg concentrations by Atomic Absorption Spectrometry (AAS) in the laboratory (Hermanowicz et al., 1999). A one-metre core was extracted from the northern part of the main Stążka basin using a Wardenaar sampler (Wardenaar, 1987) and sub-sampled every centimetre. Detailed description of the core and multi-proxy results are provided in Lamentowicz et al. (2013).

Transfer functions were developed using two established methods which are known to perform well with testate amoeba data (Mitchell et al., 2013; Payne et al., 2011): Weighted averaging (WA) (Ter Braak and Barendregt, 1986) and weighted average partial least squares (WA-PLS) (Birks, 1998). Recently Juggins and Birks (2012) have introduced a new method which is tested here for the first time with testate amoeba data. Locally weighted weighted-averaging selects a local training-set of size k using the distance criterion of the modern analogue technique (MAT) and then applies weighted averaging to this sub-set. In this case we selected k=30 after initial trials and use squared chord distance. Transfer function performance was assessed using leave-one-out (LOO, also termed jack-knifing), boot-strap and leave-one-site-out (LOSO) cross validation, recently suggested as a more robust approach to account for within-site clustering of samples (Payne et al. 2012). To account for the possible impact of unevenly sampled gradients we also applied the segment-wise RMSEP approach advocated by Telford and Birks (2011a). Transfer functions were applied to the palaeo data set and significance testing carried out using randomTF (Telford and Birks, 2011b). All analyses were carried out in R 12.2.1 with the packages rioja (Juggins, 2012) and palaeoSig (Juggins and Birks, 2012)

Results and Discussion

Results show that transfer functions for water table depth and Mg have very little predictive power (Table 1): with LOO cross-validation R^2 values are <0.3, while when the more conservative LOSO cross-validation is applied R^2 is <0.15 and RMSEP is greater than standard deviation. This result for water table contrasts with many studies in bogs and reinforces the fundamental differences in testate amoeba ecology between bogs and fens (Payne 2011).

Results were more promising in the cases of Ca, pH and conductivity (Table 1). In all these cases multiple WA-PLS components did not improve on WA (inverse deshrinking). LWWA showed initial promise with standard cross-validation methods, however, when LOSO was used to cross-validate the models lost all predictive power (R^2<0.1 and RMSEP>sd). This is almost certainly due to the clustering problem discussed by Payne et al. (2012): in LOO and boot-strapping it is likely that the majority of the 30 preferentially-selected analogues will be from the same site as the test sample(s) and therefore model performance over-estimated. This is likely to be a general problem for LWWA in peatland transfer function studies. Due to these problems we selected WA (inverse deshrinking) as the preferred model for pH, Ca and conductivity. $R^2_{(LOO)}$ ranged from 0.35 to 0.44, lower than is typical for bog WTD transfer functions. In the case of both Ca and conductivity, model performance was weaker at the upper end of the gradient (Fig. 2). The gradients are unevenly sampled, particularly in the case of pH which is likely to have biased performance statistics, segment-wise RMSEPs $_{(LOO)}$ (Telford and Birks, 2011a) were larger than standard RMSEPs: 0.76 for pH, 55.4 for Ca and 276.6 for conductivity. In the case of pH this implies that the transfer function may not have predictive power when accounting for uneven sampling.

Reconstructions of pH, Ca and conductivity show very similar down-core trends (Fig. 2). This is unsurprising as all represent the nutrient status/base-richness gradient and there are strong correlations in the training set. Reconstructions support our previous qualitative interpretations (Lamentowicz et al., 2013) particularly in relation to deforestation and subsequent conifer afforestation in 1850-1900 (Giętkowski, 2011). However, when reconstruction significance is tested using the randomTF approach non-significant results are returned for all variables (Fig.3). While such a non-significant result does not mean that our interpretation of the record is incorrect it does call into question the usefulness of the transfer function output; this appears to be a general issue with testate amoeba transfer functions and will be discussed more elsewhere.

Overall, our results show that transfer functions for conductivity and Ca concentration appear to have predictive power for surface samples in fens, while addressing the usefulness of such transfer functions in palaeo reconstruction will require further research. We believe that testate amoeba transfer functions for fen nutrient status may be a useful additional to the peatland palaeoecologist's tool-kit.

Captions to figures

Figure 1. Location of the study sites – (A) transfer function and (B) peat sampling. (1 – Makąty; 2 – Kazanie; 3 – Wagowo; 4 – Czarne; 5 – Kuźnik Olsowy i Kuźnik Bagienny; 6 – Czarci Staw; 7 – Rurzyca; 8 – Wierzchołek)

Figure 2. Performance of the transfer function of the particular variables: A – Ca, B – COND, C – pH.

Figure 3. Quantitative reconstruction of Ca, pH and COND from *Bagna nad Stążką* peat core published by Lamentowicz et al. (2013)

Tables

Table 1. Performance of transfer functions for the different variables using various cross-validation methods: LOO – Leave One Out, LOSO – Leave One Site Out, boot- boot-strapping. Best performing variables shown in bold and best results in terms of predictive power have grey background.

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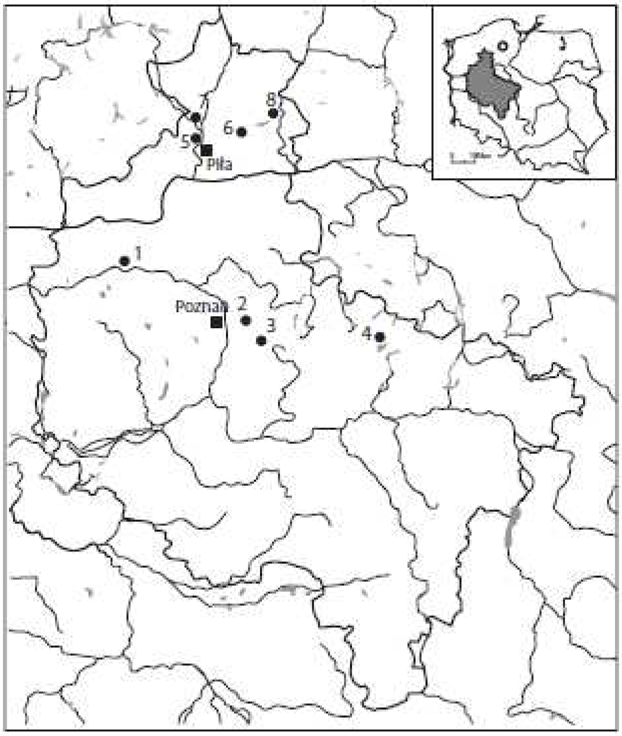
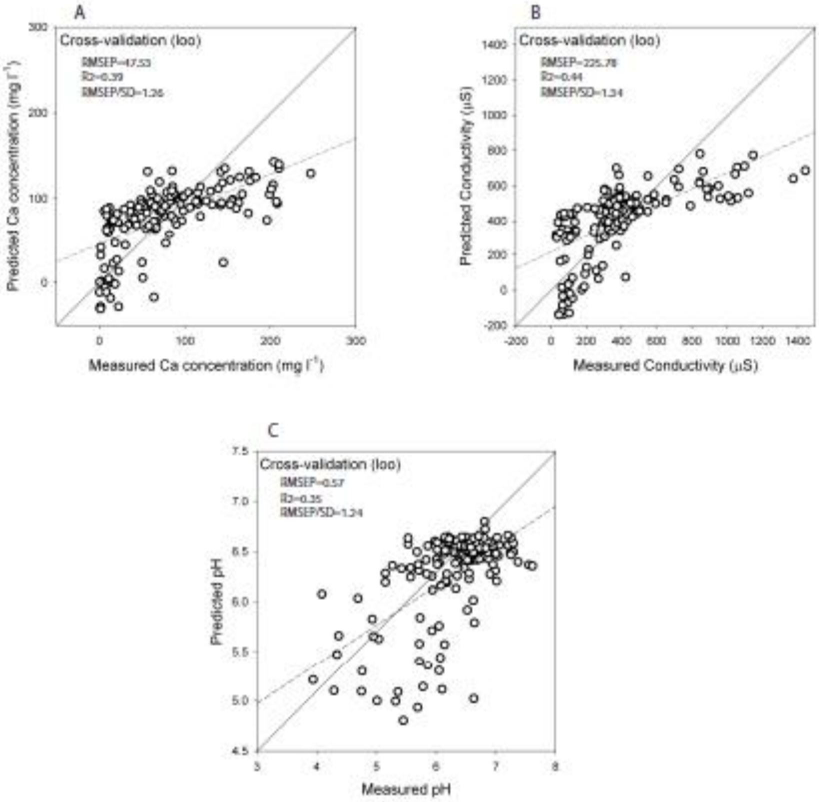
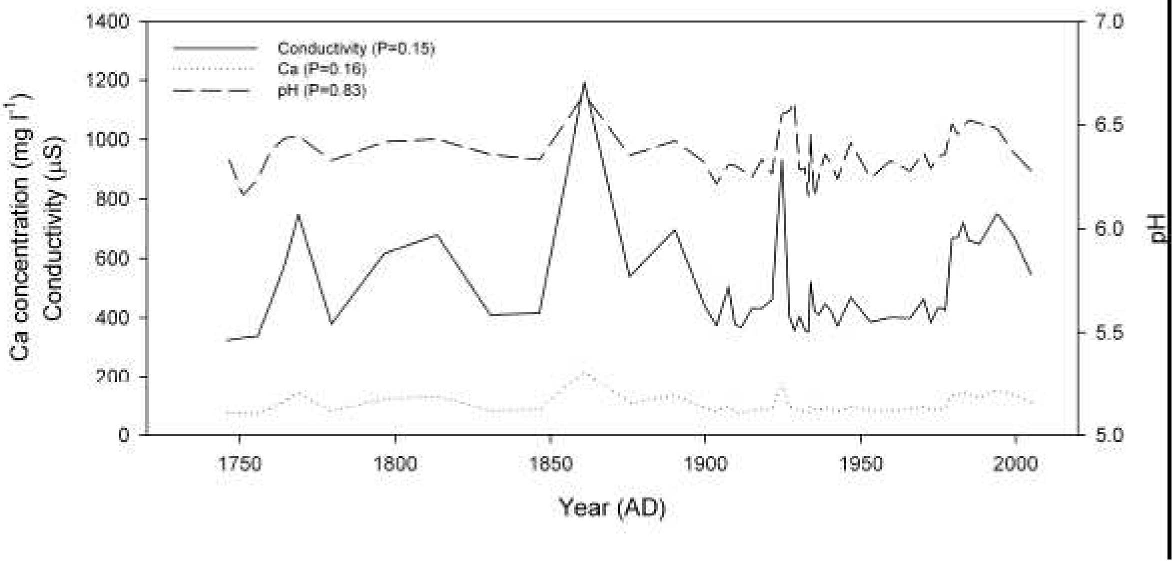

8
6
5
Piła
1
Poznań
2
3
4
● A
○ B

Fig. 1.


A
Cross-validation (loo)
RMSEP=47.53
R2=0.39
RMSEP/SD=1.26
Predicted Ca concentration (mg l-1)
Measured Ca concentration (mg l-1)
300
200
100
0
0
100
200
300
B
Cross-validation (loo)
RMSEP=225.78
R2=0.44
RMSEP/SD=1.34
Predicted Conductivity (µS)
Measured Conductivity (µS)
1400
1200
1000
800
600
400
200
0
-200
-200
0
200
400
600
800
1000
1200
1400
C
Cross-validation (loo)
RMSEP=0.57
R2=0.35
RMSEP/SD=1.24
Predicted pH
Measured pH
7.5
7.0
6.5
6.0
5.5
5.0
4.5
3
4
5
6
7
8


Conductivity (P=0.15)
Ca (P=0.16)
pH (P=0.83)
Ca concentration (mg l-1)
Conductivity (μS)
pH
Year (AD)
0
200
400
600
800
1000
1200
1400
5.0
5.5
6.0
6.5
7.0
1750
1800
1850
1900
1950
2000