

This is a repository copy of *Towards quantitative reconstruction of peatland nutrient status from fens*.

White Rose Research Online URL for this paper:
<http://eprints.whiterose.ac.uk/88157/>

Version: Submitted Version

Article:

Lamentowicz, Mariusz, Lamentowicz, Lukasz and Payne, Richard J. (2013) Towards quantitative reconstruction of peatland nutrient status from fens. *The Holocene*. pp. 1661-1665. ISSN 0959-6836

<https://doi.org/10.1177/0959683613508162>

Reuse

Items deposited in White Rose Research Online are protected by copyright, with all rights reserved unless indicated otherwise. They may be downloaded and/or printed for private study, or other acts as permitted by national copyright laws. The publisher or other rights holders may allow further reproduction and re-use of the full text version. This is indicated by the licence information on the White Rose Research Online record for the item.

Takedown

If you consider content in White Rose Research Online to be in breach of UK law, please notify us by emailing eprints@whiterose.ac.uk including the URL of the record and the reason for the withdrawal request.

Towards quantitative reconstruction of peatland nutrient status from fens

Lamentowicz M.¹, Lamentowicz Ł.², Payne R.J.³

¹ Department of Biogeography and Palaeoecology & Laboratory of Wetland Ecology and Monitoring, Faculty of Geographical and Geological Sciences, Adam Mickiewicz University, Dziegielowa 27, 61-680 Poznań, Poland

² Department of Hydrobiology, Faculty of Biology, Adam Mickiewicz University, Umultowska 89, 61-614 Poznań, Poland

³ Biological and Environmental Sciences, School of Natural Sciences, University of Stirling, Stirling FK9 4LA, Scotland UK

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 addition to the peatland palaeoecologist's tool-kit although further work will be required to demonstrate their usefulness in practice.

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 (Gařka 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 (Oprailova 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 $>20\mu\text{m}$ and $<300\mu\text{m}$ 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). LWVA 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 LWVA 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.

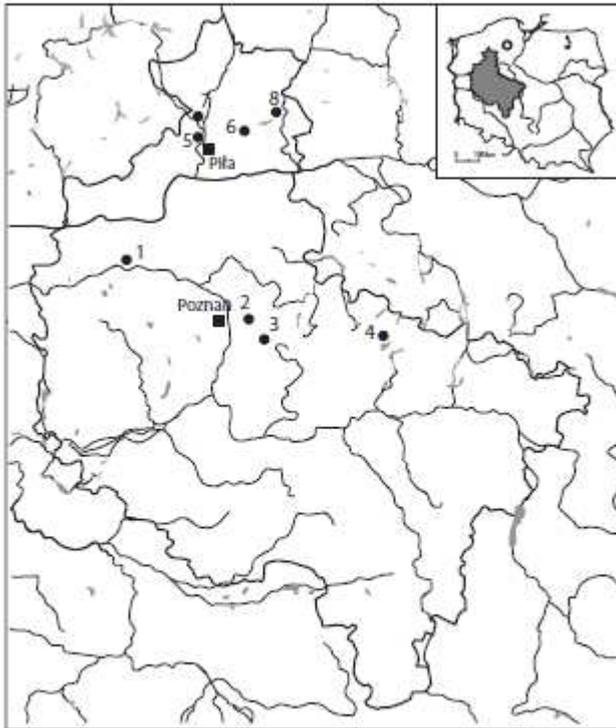
Acknowledgements

This study was financed by a scientific grant from the Polish National Science Centre (NCN) (No. 305077936, Principal Investigator – Łukasz Lamentowicz). We are grateful to Ralf Meisterfeld for the help in identification of the difficult testate amoeba taxa. We also acknowledge the support from the grant PSPB-013/2010 from Switzerland through the Swiss Contribution to the enlarged European Union. We thank to Maciej Gąbka for the fruitful discussion and cooperation.

References

- Ammann, B. 1986. Litho- and palynostratigraphy at Lobsigensee: Evidences for trophic changes during the Holocene - Studies in the Late-Quaternary of Lobsigensee No 13. *Hydrobiologia* 143, 301-307.
- Birks, H. J. B. 1998. Numerical tools in palaeolimnology - Progress, potentialities, and problems. *Journal of Paleolimnology* 20, 307-332.
- Booth, R. K., Lamentowicz, M. and Charman, D. J. 2010. Preparation and analysis of testate amoebae in peatland paleoenvironmental studies. *Mires and Peat* 7 (2010/11), 1-7.
- Charman, D. J. 2001. Biostratigraphic and palaeoenvironmental applications of testate amoebae. *Quaternary Science Reviews* 20, 1753-1764.
- Charman, D. J., Roe, H. M. and Gehrels, W. R. 2002. Modern distribution of saltmarsh testate amoebae: regional variability of zonation and response to environmental variables. *Journal of Quaternary Science* 17, 387-409.
- Clarke, K. J. 2003: *Guide to identification of soil Protozoa - Testate amoebae*. Ambleside: Freshwater Biological Association.
- Decloitre, L. 1978. Le genre *Centropyxis* I. Compléments à jour au 31.12.1974 de la monographie du genre parue en 1929. *Archiv für Protistenkunde* 120, 63-85.
- Decloitre, L. 1979. Le genre *Centropyxis* II. Compléments à jour au 31. Décembre 1974 de la monographie du genre parue en 1929. *Archiv für Protistenkunde* 121, 162-192.
- Dudova, L., Hajkova, P., Buchtova, H. and Opravilova, V. 2012. Formation, succession and landscape history of Central-European summit raised bogs: A multiproxy study from the Hruby Jeseník Mountains. *The Holocene*.
- Gałka, M., Miotk-Szpiganowicz, G., Goslar, T., Jęško, M., van der Knaap, W. O. and Lamentowicz, M. 2013. Palaeohydrology, fires and vegetation succession in the southern Baltic during the last 7500 years reconstructed from a raised bog based on multi-proxy data. *Palaeogeography, Palaeoclimatology, Palaeoecology* 370, 209 - 221.
- Giętkowski, T. 2011. Zmiany lesistości Borów Tucholskich w latach 1938 – 2000. *Promotio Geographica Bydgosiensia* IV, 1-12.
- Grospietsh, T. 1958: *Wechseltierchen (Rhisopoden)*. Stuttgart: Kosmos.
- Hájkova, P., Grootjans, A., Rybničková, E., Madaras, M., Opravilová, V., M., L., Wolejko, L., Hájek, M., H., J. and Michaelis, D. 2012. How a *Sphagnum fuscum* dominated bog changed into a calcareous fen: the unique Holocene history of a Slovak spring fed mire. *Journal of Quaternary Science* 27, 233-243.
- Hermanowicz, W., Dożańska, W., Dojlido, J. and Koziowski, B. 1999: *Fizyczno-chemiczne badania wody i ścieków*. Warszawa: Arkady.
- Juggins, S. 2012: *rioja: Analysis of Quaternary Science Data, R package version (0.8-4)*.
- Juggins, S. and Birks, J. 2012: Quantitative Environmental Reconstructions from Biological Data. In Birks, H. J. B., Lotter, A. F., Juggins, S. and Smol, J. P., editors, *Tracking Environmental Change Using Lake Sediments. Developments In Paleoenvironmental Research*: Springer, 431-494.
- Lamentowicz, Ł., Gabka, M., Rusińska, A., Sobczyński, T., Owsiany, P. M. and Lamentowicz, M. 2011. Testate amoeba (Arcellinida, Euglyphida) ecology along a poor-rich gradient in fens of western Poland. *International Review of Hydrobiology* 96, 356-380.
- Lamentowicz, M., Gałka, M., Milecka, K., Tobolski, K., Lamentowicz, Ł., Fiałkiewicz-Kozieł, B. and Blaauw, M. 2013. A 1300 years multi-proxy, high-resolution record from a rich fen in northern Poland: reconstructing hydrology, land-use and climate change. *Journal of Quaternary Science* in press.
- Mazei, Y. and Tsyganov, A. N. 2006: *Freshwater testate amoebae*. Moscow: KMK.
- Mitchell, E., Charman, D. and Warner, B. 2008. Testate amoebae analysis in ecological and paleoecological studies of wetlands: past, present and future. *Biodiversity and Conservation* 17, 2115-2137.
- Mitchell, E. A. D., Payne, R. J., van der Knaap, W. O., Lamentowicz, T., Gabka, M. and Lamentowicz, M. 2013. The performance of single- and multi-proxy transfer functions (testate amoebae, bryophytes, vascular plants) for reconstructing mire surface wetness and pH. *Quaternary Research (United States)* 79, 6-13.

- Ogden, C. D. and Hedley, R. H. 1980: *An atlas of freshwater testate amoebae*. London and Oxford: British Museum (Natural History) and Oxford University Press.
- Ogden, C. G. 1980. Shell structure in some pyriform species of *Diffugia* (Rhizopodea). *Archiv für Protistenkunde* 123, 455-470.
- Ogden, C. G. and Fairman, S. 1979. Further observations on pyriform species of *Diffugia* (Rhizopodea). *Archiv für Protistenkunde* 122, 372-381.
- Opravilova, V. and Hajek, M. 2006. The variation of testacean assemblages (Rhizopoda) along the complete base-richness gradient in fens: A case study from the Western Carpathians. *Acta Protozoologica* 45, 191-204.
- Patterson, R. T., Roe, H. M. and Swindles, G. T. 2012. Development of an Arcellacea (testate lobose amoebae) based transfer function for sedimentary phosphorus in lakes. *Palaeogeography, Palaeoclimatology, Palaeoecology* 348-349, 32-44.
- Payne, R. J. 2011. Can testate amoeba-based palaeohydrology be extended to fens? *Journal of Quaternary Science* 26, 15-27.
- Payne, R. J. and Mitchell, E. A. D. 2009. How many is enough? Determining optimal count totals for ecological and palaeoecological studies of testate amoebae. *Journal of Paleolimnology* in press.
- Payne, R. J., Mitchell, E. A. D., Nguyen-Viet, H. and Gilbert, D. 2012. Can pollution bias peatland paleoclimate reconstruction? *Quaternary Research* 78, 170-173.
- Payne, R. J., Telford, R. J., Blackford, J. J., Blundell, A., Booth, R. K., Charman, D. J., Lamentowicz, L., Lamentowicz, M., Mitchell, E. A., Potts, G., Swindles, G. T., Warner, B. G. and Woodland, W. 2011. Testing peatland testate amoeba transfer functions: Appropriate methods for clustered training-sets. *The Holocene* 22, 819-825.
- Roe, H. M., Patterson, R. T. and Swindles, G. T. 2010. Controls on the contemporary distribution of lake thecamoebians (testate amoebae) within the Greater Toronto Area and their potential as water quality indicators. *Journal Of Paleolimnology* 43, 955-975.
- Swindles, G. T., Charman, D. J., Roe, H. M. and Sansum, P. A. 2009. Environmental controls on peatland testate amoebae (Protozoa: Rhizopoda) in the North of Ireland: Implications for Holocene palaeoclimate studies. *Journal of Paleolimnology* 42, 123-140.
- Telford, R. J. and Birks, H. J. B. 2011a. Effect of uneven sampling along an environmental gradient on transfer-function performance. *Journal Of Paleolimnology* 46, 99-106.
- Telford, R. J. and Birks, H. J. B. 2011b. A novel method for assessing the statistical significance of quantitative reconstructions inferred from biotic assemblages. *Quaternary Science Reviews*.
- Ter Braak, C. J. F. and Barendregt, L. G. 1986. Weighted averaging of species indicator values: Its efficiency in environmental calibration. *Mathematical Biosciences* 78, 57-72.
- Wardenaar, E. C. P. 1987. A new hand tool for cutting peat profiles. *Canadian Journal of Botany* 65, 1772-1773.
- Warner, B. G. 1990: Testate Amoebae (Protozoa). *Methods in Quaternary Ecology: Geoscience Canada*, 65-74.
- Zobel, M. 1988. Autogenic succession in boreal mires – a review. *Folia Geobotanica et Phytotaxonomic* 23, 417-445.



- A
- B

Fig. 1.

