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Testate amoebae reflect present environmental conditions in restored cut-over bogs

A new tool for evaluation and monitoring?

Introduction

In Central Europe, bogs have strongly decreased in both extension and quality. This loss is particularly drastic in North-Western Germany due to extensive use for centuries for agricultural purposes or peat extraction. Thirty years ago, the German federal state of Lower Saxony pushed rewetting activities with a peatland protection programme. Since then, restoration measures on more than 11,000 ha have been initiated. Nevertheless, reliable and practicable methods for the evaluation of large-scale bog restoration are still lacking.

Here, we tested if testate amoebae (TA) may provide information on the present state of restored bog ecosystems and can thus be used as feasible monitoring tools as proclaimed by recent studies. The aims of this study are (a) to identify which taxa are widespread in restored sites of Lower Saxony to provide a baseline for further surveys, (b) to investigate how the distribution of TA communities is related to water regime and water chemistry and (c) to evaluate whether and to what extent TA have potential to serve as indicators for restoration success by revealing underlying causes.

Methods

In 16 bogs throughout Lower Saxony living *Sphagnum* samples were collected on 46 rewetted sites differing in vegetation cover either dominated by *Eriophorum vaginatum*, *E. angustifolium*, *Juncus effusus* or *Molinia caerulea.* Additionally, sites differed in restoration age and agricultural land-use before the peat extraction. Water table as well as pH and conductivity of pore water were measured between April 2011 and January 2012. In April, June/July and September pore water was sampled and analysed for NH_4^+, NO_3^-, PO_4^{3-}, K^+, Na^+, Ca^{2+} and Mg^{2+}. TA communities were extracted from mosses and for each sample species were identified and counted until a number of 60 living shells were reached. Detrended correspondence analysis (DCA) was performed with total numbers of living TAs per gram of dried *Sphagnum*. Data of water table fluctuations and biogeochemical characteristics of the pore water were correlated with the ordination axes. Additionally, we calculated bootstrap optima and tolerances in relation to the mean water table depths by distinguishing between the dry and wet season of the year.

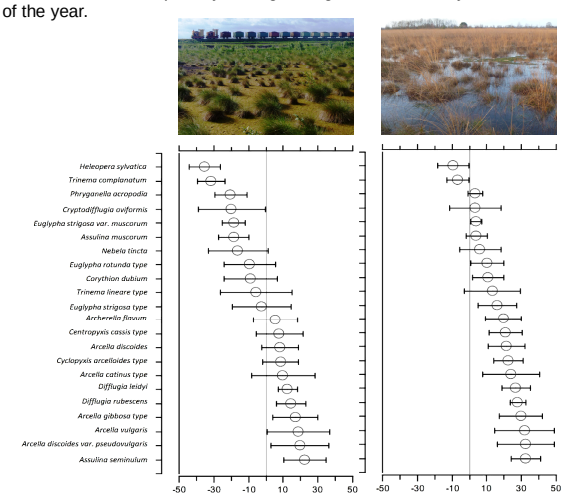

Figure 1. Bootstrap optima and tolerances of testate amoebae inhabiting restored sites in North-Western Germany for mean depth of water table [cm] in dry/summer (left) and wet/winter seasonal conditions (right). Line indicates terrain surface.

Table 1. Median and range of measured water chemistry parameters for restored sites (n=46) in bogs of North-Western Germany (conductivity in µS; nutrients in mg l^{-1}; * = below limit of detection).

	mpH	mCond.	Ca^{2+}	Mg^{2+}	Na^+	K^+	PO_4^{3-}	mNO_3^-	mNH_4^+
Sampling	Apr-Sep	Apr-Sep	Jun/Jul	Jun/Jul	Sep	Sep	Jun/Jul	Apr-Sep	Apr-Sep
Median	4.22	96.76	1.25	1.05	6.24	1.28	0.07	0.12	0.40
Range	3.6–4.8	65–230	0.3–8.7	0.3–6.7	2.5–16.6	0.1–4.9	0.0*–1.3	0.0*–1.6	0.0*–8.5

Results

- In total, we found 31 testate amoebae taxa of which 25 occurred commonly.
- Restoration sites differed strongly in measured hydrological and biogeochemical parameters, among themselves as well as on each plot during the observed season (table 1).
- Indirect ordination of the TA community data (figure 2) revealed strong correlations between species composition patterns and hydrological characteristics along the first gradient.
- We found distinct responses to mean depth of water table during the dry and wet season of TA species (figure 1).
- Correlations along the second DCA gradient revealed strong relationships between TA communities and pH as well as restoration age in opposing directions. In addition, the percentage of dead shells increases slightly with time since restoration.
- On the wet side of the hydrological gradient sites were more variable in TA species composition compared to the dry side of the gradient. Such differences also seemed to be reflected by vegetation, in the main either characterized by dominance of *J. effusus* or *Eriophorum* species.
- Further correlations with environmental data revealed weak relationships between TA and conductivity, potassium, sodium, calcium as well as magnesium.

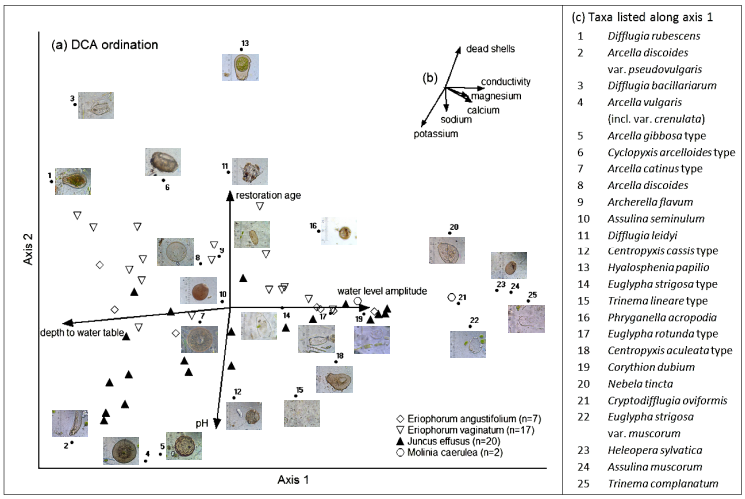

Figure 2. (a) DCA biplot of testate amoebae communities inhabiting restored bogs in North-Western Germany. Symbols represent dominating vegetation on sampling sites. Axis 1 and 2 represent 30 % of the total variance (eigenvalues 0.736 and 0.267, respectively total inertia = 3.388). Taxa are numbered according to their position along axis 1. Direction and strength of environmental correlations are indicated by the direction and length of arrows. (b) Significant correlations lower than 0.5 but greater than 0.3 are shown separately. (c) List of taxa arranged along axis 1 from wet to dry.

Conclusions

- Indirect ordination indicates that TA assemblages strongly reflect present hydrological conditions in terms of both mean water levels and seasonal fluctuations.
- TA occurring in hollows and pools are more strongly affected by acidity. This implies that species to be found there can also be used to indicate pH, which was mostly negatively related with restoration age.
- The potential of TA to serve as indicators for water nutrient concentrations on restored sites is estimated to be comparatively low.
- The significant potential of TA to be applied as bio-indicators lies in the capacity of integrating hydrological conditions in terms of mean water tables, but also seasonal fluctuations.
- TA communities can serve as a powerful monitoring tool which can contribute valuable information which may help to identify obstacles and development potentials of restoration sites.
- Thus, TA might have the potential to replace labour- and cost-intensive hydrological and partly biogeochemical measurements in the restoration monitoring process.

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