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Testing peatland water-table depth transfer functions using high-resolution hydrological monitoring data

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ABSTRACT

Transfer functions are now commonly used to reconstruct past environmental variability from palaeoecological data. However, such approaches need to be critically appraised. Testate amoeba-based transfer functions are an established method for the quantitative reconstruction of past water-table variations in peatlands, and have been applied to research questions in palaeoclimatology, peatland ecohydrology and archaeology. We analysed automatically-logged peatland water-table data from dipwells located in England, Wales and Finland and a suite of three year, one year and summer water-table statistics were calculated from each location. Surface moss samples were extracted from beside each dipwell and the testate amoebae community composition was determined. Two published transfer functions were applied to the testate-amoeba data for prediction of water-table depth (England and Europe). Our results show that estimated water-table depths based on the testate amoeba community reflect directional changes, but that they are poor representations of the real mean or median water-table magnitudes for the study sites. We suggest that although testate amoeba-based reconstructions can be used to identify past shifts in peat hydrology, they cannot currently be used to establish precise hydrological baselines such as those needed to inform management and restoration of peatlands. One approach to avoid confusion with contemporary water-table determinations is to use residuals or standardised values for peatland water-table reconstructions. We contend that our test of transfer functions against independent instrumental data sets may be more powerful than relying on statistical testing alone.

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1. Introduction

Quantitative reconstruction of past environmental variability from fossil data has become increasingly common in palaeoecology since Imbrie and Kipp (1971) first produced a reconstruction of past sea-surface temperature using fossil foraminiferal assemblages. Models for predicting past environmental conditions (so-called ‘transfer functions’) are firmly based in uniformitarian principles. The relationships between contemporary taxa and environmental variables are modelled and the resultant function is used to transform fossil data from a biostratigraphic sequence into quantitative estimates of an environmental variable in the past. Transfer functions have been developed for several groups of microfossils to reconstruct a variety of climatic, chemical and hydrological variables (e.g. Imbrie and Kipp, 1971; Fritz et al., 1991; Gasse et al., 1995; Brooks and Birks, 2000; Charman et al., 2007). It has been suggested that the development of such quantitative reconstructions from biological proxies have revolutionised palaeoecology (e.g. Juggins, 2013); however, there have been several recent criticisms of transfer function approaches including the use of niche-based models (Belyea, 2007), spatial autocorrelation (Telford and Birks, 2005; Payne et al., 2012), and the confounding influence of non-causal/secondary variables (Juggins, 2013). It is now imperative that transfer functions are thoroughly and critically tested.

Peatlands accumulated 473–621 Gt of carbon during the Holocene (Yu et al., 2010), and store approximately the same amount of

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carbon as the atmosphere. Although it is established that global peatlands had a net cooling effect on climate through the Holocene (Frolking et al., 2006), there are still major questions over how they will respond to future climate change. This has led to a recent proliferation of studies examining the dynamics of peatlands in terms of carbon-accumulation, hydrology and ecology during the Holocene (e.g. Loisel and Garneau, 2010; van Bellen et al., 2011; Charman et al., 2013; Turner et al., 2014). Testate amoebae (TA) are a group of single-celled organisms that form a shell (their key identification feature – Charman et al., 2000). They are found in abundance on the surface of peatlands and can be well-preserved in Holocene peats (Charman and Warner, 1992; Tolonen et al., 1992, 1994; Charman et al., 2000). TA are sensitive to microenvironmental conditions on peatlands, especially moisture and to a lesser extent pH and water chemistry, and respond rapidly to environmental changes (Woodland et al., 1998; Marcisz et al., 2014). TA-based transfer functions have been key in the reconstruction of hydrological changes (primarily water-table depth) in peatlands across several regions of the world (e.g. Woodland et al., 1998; Booth, 2002; Charman et al., 2007; Lamentowicz et al., 2008a; Swindles et al., 2009; Amesbury et al., 2013; Lamarre et al., 2013; Turner et al., 2013; Swindles et al., 2014). These reconstructions have been used widely as proxy records of Holocene climate change (e.g. Mauquoy et al., 2008; Charman et al., 2009; Swindles et al., 2013).

However, one of the potential problems is that the water-table depths used in such studies typically come from a 'one-off' water-table measurement from the TA sample extraction point. The use of one-off water-table depth measurements in TA studies has been debated previously (Bobrov et al., 1999; Booth, 2008); however, it has been suggested that such measurements are adequate to drive a hydrological gradient for TA transfer-function development (Woodland, 1996; Charman et al., 2007; Booth, 2008). Several authors have argued that one-off measurements are adequate as long as times of extreme weather conditions (e.g. prolonged rain or drought) are avoided (Charman et al., 2007; Booth et al., 2008; Swindles et al., 2009; Turner et al., 2013).

One value of water-table depth is produced by the transfer function (i.e. *n* cm below the peat surface), with sample-specific errors generated through a statistical resampling approach (bootstrapping). However, we know that water tables fluctuate in peatlands and are dynamic (Price, 1992; Evans et al., 1999; Holden et al., 2011). Traditional TA transfer function-generated water-table data may not adequately capture a mean value from a site, and do not account for water-table dynamics (e.g. seasonal or annual variability) which could influence the TA community composition. Here we test the robustness of TA-based transfer functions for water-table reconstruction in peatlands. Previously, model performance and robustness have been tested using advanced statistical tools (cf. Telford and Birks, 2011; Telford, 2013). Here we take an alternative approach: we use real-world data from independent test sites with high-resolution monitored water-table data to determine the predictive power of two published transfer functions.

2. Materials and methods

We tested two established TA transfer functions – 1. The pan-European transfer function from the ACCROTELM project based on eight raised bogs across Europe (Charman et al., 2007) and 2. A regional transfer function from Northern England based on three blanket peatlands and three raised bogs (Turner et al., 2013). These transfer functions have been used for palaeohydrological reconstruction from fossil data and have provided very similar results (Turner et al., 2013). They were deemed to be appropriate models for our test data in terms of community composition and site characteristics. The models chosen were constructed using weighted averaging-tolerance-downweighted regression with inverse deshrinking as this was found to have very good performance in both cases.

Three independent test datasets were used – 1. Blanket peatlands in the Pennine region of Northern England; 2. An oceanic raised bog in Wales and 3. High-latitude peatlands in Finland (Table 1). These sites were chosen as they have dipwells equipped with pressure transducers providing high-resolution (logged at least once every two hours, but mainly 15-min) peatland water-table data. These data were checked for quality control and a suite of water-table statistics for each point was determined including means, medians, ranges and temporally-constrained measures including water-table depth residence times (Supplementary file 1). These values were calculated as 3-year, 1-year, and summer values (1 year and 3 years) prior to the TA sampling time for each dipwell. Only summer data are available for the sites in Finland as they are frozen during the rest of the year (Supplementary file 1).

Immediately adjacent (<0.5 m) to each dipwell (but away from any areas of trampling or disturbance), a surface sample of *Sphagnum* or other moss was extracted and the TA community composition determined in the laboratory. We analysed the green fraction of the moss (the living plant) and a 1-cm thick section of the brown section to ensure that a sample representing only the very recent period was obtained. TA were extracted using a modified version of Booth et al. (2010). Moss samples were placed in boiling water for 15 min and shaken. Extracts were passed through a 300 μm sieve, back-sieved at 15 μm and allowed to settle before sub-samples were used to make slides for microscopy. Many testate

Table 1
Site and sample details. The samples with codes in brackets were removed from the analysis as they had very deep water tables (see Fig. 2).

Site	Number of automated dipwells	Codes	Type	Location (decimal degrees)
Keighley Moor (England)	2	B1-2	Blanket peatland	53.850°, −2.034°
Wessenden Moor (England)	1	B3	Blanket peatland	53.569°, −1.919°
Bradfield Moor (England)	6	B4-7 (B20-21)	Blanket peatland	53.420°, −1.678°
Moor House (England)	4	B8-11	Blanket peatland	54.679°, −2.430°
Oakner (England)	8	B12-17 (B22-23)	Blanket peatland	53.599°, −1.972°
Oxenhope (England)	2	B18-19	Blanket peatland	53.791°, −1.970°
Cors Fochno (Wales)	11	R1-11	Raised bog	52.501°, −4.011°
Röyvänsuo (Finland)	1	F1	Sedge fen	65.820°, 27.804°
Marjasuo (Finland)	1	F2	Sedge fen	65.805°, 27.812°
Helvetinjärvi V (Finland)	1	F3	Sedge fen	61.996°, 23.942°
Helvetinjärvi II (Finland)	1	F4	Sedge bog	61.998°, 23.880°
Susimäki (Finland)	1	F5	*Vaccinium* bog	61.857°, 24.237°

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