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Vegetation history and human impact during the last 300 years recorded in a German peat deposit

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ABSTRACT

A peat core from the Barschpfuhl kettlehole mire in north-east Germany was analysed for multiproxy indicators (plant macrofossils, pollen/non-pollen microfossils, testate amoebae, colorimetric humification, carbon/nitrogen ratios, bulk density, loss on ignition), to investigate the effects of climate change and human impact on vegetation and peat accumulation during the last c. 300 years. 14C wiggle-match dating was applied for high-precision dating. Testate amoebae assemblages were used to reconstruct past water table depths and compared with other proxies and instrumental climate data from the mid–18th century onwards. The mire hydrology of this relatively small bog was heavily influenced by forestry changes in the area. The climate signal was therefore obscured. Afforestation with fast-growing conifers and drainage for agricultural purposes resulted in a lowering of the water level, changes in trophic status, changes in mire surface vegetation and increased decomposition of the peat. Variations in the openness and cultivated land indicators in the pollen data of Barschpfuhl reflect regional population density and land use changes.

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1. Introduction

Most mires in north-west Europe are affected by human activities. Many Dutch and German peat bogs have been exploited for peat extraction or have been affected by land use changes. This has resulted in the total destruction of bog ecosystems or at least stagnation in peat accumulation or the loss of the surface peat layers. Only 1% of former mire area remains in Germany and the Netherlands, compared to 65% and 70% in Sweden and Norway respectively (Joosten and Couwenberg, 2001). The loss of mires is unfortunate because peatlands are carbon sinks and useful water reservoirs. Also, peat deposits are valuable archives to study past vegetation and climate changes. Proxy data derived from these studies can be used to test models which simulate and predict past and future peat accumulation and related processes such as carbon sequestration (Heijmans et al., 2008). This is valuable information for evaluating causes and effects of climate change and the role of greenhouse gases.

Over longer timescales and under undisturbed conditions, climate change is the primary factor influencing ombrotrophic peatland development. Numerous studies now demonstrate that peatlands have experienced significant hydrological changes due to climate change, for example during the Maunder and Dalton minima of solar activity (Mauquoy et al., 2002b; Speranza et al., 2003; van Geel et al., 1999). These changes are most often indicated by mire plant remains, testate amoebae and humification of peat deposits, but dry land pollen deposition may also reflect climate changes. For example, decreases of thermophilous trees in pollen records have been linked to climatic deterioration associated with reduced solar activity (van der Linden and van Geel, 2006). However, over shorter timescales and particularly during recent centuries when human impact on peatlands has increased, climate change may have been less important than anthropogenic impacts such as drainage, forestry and peat cutting.

The German landscape has been strongly influenced by humans. German population doubled from 1800 until 1870 and this had a major impact on the landscape (Lutze, 2003). Forests were heavily exploited and trees, especially conifers, were planted for forest renewal. Also agricultural activities and the associated water demand increased with population growth. Since the 18th century the federal state of Brandenburg has lost at least 85% of its natural or semi natural wetland areas as a consequence of drainage for agricultural purposes, extraction of water and stimulation of river runoff. Also monocultures of Pinus sylvestris promote water loss from the system (MLUW, 2004; UNESCO-Biosphärenreservat, 2007). These historical changes in vegetation and hydrology can be studied palaeoecologically.

The aim of this study is to reconstruct the late Holocene vegetation composition in and around a mire in north-east Germany over the last few hundred years, and to distinguish between the effects of climate changes (temperature and precipitation) and the effects of changing human activities on regional and local vegetation development. To achieve this, we analyzed the upper peat from the Barschpfuhl kettlehole mire. The studied peat section covers the period of available instrumental meteorological data. High resolution pollen and macrofossil records were used to reconstruct plant species composition and
testate amoebae analysis was applied to infer the past water table changes. To obtain a chronology of sufficient precision for comparison with documentary and instrumental records of climate and human history, terrestrial plant remains were dated by 14C wiggle-matching (Blaauw et al., 2004; Kilian et al., 1995, 2000; Speranza et al., 2000; van der Linden and van Geel, 2006; van der Plicht, 1993; van Geel and Mook, 1989).

2. Material and methods

2.1. Research site

A peat core was taken in May 2003 from Barschpfuhl (BPF), a small mire situated c. 10 km north-west of Angermünde, Germany (53° 03’ 21.11” N, 13° 50’ 58.39” E, Fig. 1). The region is relatively dry with an annual precipitation of c. 531.7 mm and average annual temperature of 8.4 °C over the period 1951–2000 (Werner et al., 2005). The Berlin–Dahlem temperature record is the longest available record which was measured relatively nearby. Because summer conditions are the main driver of peatland condition in temperate regions (Charman, 2007), here we focus on the summer record of temperature and precipitation (Fig. 2). The summer temperature record does not show major changes over the last 300 years (Fig. 2A). At the beginning of the measurements relatively cold summers were recorded (AD 1720–1755), while the period between 1756 and 1770 was relatively warm. Gaps are present in the dataset and it is known to be quite unreliable until 1876 (G. Müller–Westermeier, personal communication). Relatively cold intervals were recorded from c. AD 1800–1820, 1900–1920, and 1950–1985. Precipitation measurements are available from 1876 onwards (Fig. 2B). Two intervals with relatively wet summers were recorded from 1926–1935 and from 1953–1966. Since 1970 it has been relatively dry in the summer. The last c. 8 years in the Berlin–Dahlem records have been both dry and warm.

The Barschpfuhl mire (BPF) is situated in the UNESCO nature reserve Biosphärenreservat Schorfheide–Chorin, within the districts of Uckermark and Barnim in the north-east of the state Brandenburg. The area is characterised by a hilly landscape formed by push moraines of the Weichselian glacial (Schlaak, 1999). The mire is a Kesselmoor (kettlehole mire) type (Timmermann and Succow, 2001), located in a depression in the hilly landscape and is c. 160–190 m long and 130–150 m wide (mire surface approximately 2.5 ha). The hills are covered with coniferous, mixed and broadleaved forest and at present,
48% of the land area of the nature reserve is occupied by forest. Prior to human disturbance of the area, forest cover was around 90%, and only the mire surfaces were treeless. *Fagus* and *Quercus* would have been dominant species. Nowadays, only one third of the forest area is covered by broad-leaved and mixed forest; the rest is planted coniferous forest. This is the result of extensive forest exploitation during the 17th and 18th centuries. Since the start of the 19th century attempts have been made to restore the old forest area which had become a wide open, shrub-like forest (Ebert et al., 2001). Reforestation with *Pinus sylvestris* was favoured, resulting in coniferous monocultures (UNESCO-Biosphärenreservat, 2007). The Autobahn was constructed in the late 1930s and 1940s in the bog catchment, which may have influenced the bog hydrology. Schorfheide has had a protected status since 1936 and was a national nature reserve with an area of c. 60,000 ha in 1945. However during the Second World War the terrain was heavily damaged by military activity and airfields (Ebert et al., 2001). After the Second World War, Russian demand for timber increased logging and *Pinus* and other fast growing conifers were replanted (personal communication R. Michels, LUA Brandenburg). The Schorfheide Foundation was dissolved in 1952 by the Soviets and the area became state property. After the political change in 1990 Schorfheide became a nature reserve with several levels of protection. Barschpfuhl is located within the restricted area of the nature reserve (Fig. 1).

The local mire surface vegetation consists of *Sphagnum magellanicum*, *S. fallax*, *Polytrichum* spp., *Drosera rotundifolia*, *Eriophorum vaginatum*, *E. angustifolium*, *Oxycoccus palustris*, *Carex pulicaris*, *C. rostrata*, *Rhyynchospora alba*, *R. fusca* and *Pinus sylvestris*. The surface peats are very fibrous as a result of thick *Eriophorum* fibres which prevented conventional coring using a Wardenaar corer (Wardenaar, 1987). Therefore a small pit was dug in the centre of the mire and two boxes were pushed into the cut peat face to collect the peat down to 60 cm depth. Contiguous 1 cm thick sub-samples were taken from peat core BPF-I in the laboratory.

### 2.2. Microfossil analyses

A cylindrical sampler was used to take microfossil samples of c. 0.8 cm³, from the 1 cm thick horizontal slices of peat core. A known amount of *Lycopodium* spores (c. 10^679 in one tablet) was added to the samples before being treated with KOH and acetolysed (Fægri and Iversen, 1989). The *Lycopodium* spores were used to calculate pollen concentrations (Stockmarr, 1971) and pollen accumulation...
Apophytes Ruderals (minor*) followed Berglund (1986) and Behre (1986). Non-pollen palynomorphs (2004) and a reference collection. Interpretation of the pollen record was also relatively small. The estimated RSAP for smaller patches has been estimated to be between 500 and 700 m (Broström et al., 2005).

2.3. Macrofossil analyses

A cylindrical sampler of 25.2 mm diameter was used to take macrofossil samples of c. 5 cm³. Samples were heated for c. 30 min in a 5% KOH solution and sieved (mesh 160 μm). Macrofossils were scanned in water in a petri dish under a binocular microscope and identified using Grosse-Brauckmann (1972, 1974, 1986), the moss flora of Britain and Ireland (Smith, 1978), the Nordic Sphagnum flora (Johansson, 1995), the seed atlas of Katz et al. (1965), and a reference collection (Mauquoy and van Geel, 2007). Volume percentages were estimated for the mosses, roots and epidermis material. Other remains such as seeds and twigs were counted.

2.4. Sample preparation for accelerator mass spectrometry (AMS) 14C dating

Age estimates were obtained on 32 samples using 14C AMS. Remains of Sphagnum were selected from the macrofossil samples (Kilian et al., 1995; Nilsson et al., 2001). At some sample depths it was necessary to use other material than Sphagnum, e.g. Polytrichum spp. moss and Oxycoccus palustris leaves. Samples were cleaned to remove root material and fungal remains. The samples were stored for one night in HCl (4%) and afterwards cleaned with millipore water until pH-neutral. The samples were checked again for contamination and oven-dried in tin cups at 80 °C for 48 h. The tin cups filled with the dry samples were weighed and sent to the Centre for Isotope Research, University of Groningen, The Netherlands, where they were radiocarbon dated.

2.5. Testate amoebae

Peat samples measuring 1 cm³ were prepared using standard techniques for testate amoebae analyses (Hendon and Charman, 1997). Minor deviations from the described process include the use of deionised water as both storage and counting medium for improved optical clarity, and Safranin dye was not used. Counts were continued until at least 150 tests had been identified. All tests were identified using the taxonomic key in Charman et al. (2000) and are displayed as percentages of the total count. Reconstructed water tables (RWTs) have been calculated using a transfer function that employs modern testate assemblage data and environmental variables across 7 European mire sites (Charman et al., 2007). A complex weighted average partial least squares (WAPLS) model performed slightly better in cross validation of the modern samples (RMSEP=5.63 cm), but a
weighted average tolerance downweighted (WA-Tol) model was adopted for this site because of its similar performance in cross validation (RMSEP=5.97 cm) and its relative simplicity. Zones used in the macrofossil diagram have been transferred to the testate diagram as this facilitates comparison between the two figures allowing consistent changes to be identified. Changes in water table are described in terms of the reconstructed water table (RWT). A fall in RWT indicates drier conditions (deep water tables) and a rise indicates wetter conditions (shallower water table depths).

2.6. Bulk density, loss on ignition and C and N contents

Bulk density was measured for all samples. Sub-samples of 10.5 cm$^3$ were used. The dry weight of the samples was determined after placing the samples in the oven at 105 °C until constant weight. Organic matter content was determined as loss on ignition by incinerating sub-samples of c. 35 cm$^3$ for 3 h at 550 °C. Carbon and nitrogen contents were determined with a Fisons EA1108 CHN-O element analyser.

2.7. Colorimetric determination of peat humification

Peat humification was measured to assess changes in the degree of decay of the peat, as an indicator of changing hydrological conditions (Blackford and Chambers, 1993, 1995). Sub-samples of c. 5 cm$^3$ were taken from the peat core and analysed with a modified version of the Bahnson colorimetric method (Blackford and Chambers, 1993). The results are presented as percentage light transmission values (measured after 3 h at 550 nm). Absorption of light from the alkaline extract of peat is proportional to the amount of humic matter dissolved, with greater transmission of light through less humified material (Aaby and Tauber, 1975).

High transmission values (low absorption) indicate low decay and high water tables, presumably related to low temperatures and high precipitation during summer months. However, humification measures are affected by non-hydrological processes, especially local species composition which may alter decomposition rates and decay products (e.g. Caseldine et al., 2000; Yeloff and Mauquoy, 2006). The technique may be effective. Despite these potential problems, the technique is often effective in practice, particularly where there is good agreement between the humification data and other surface-moisture proxies (e.g. Sillasoo et al., 2007).

3. Results and interpretation

3.1. Matching of the boxes

The peat core was taken in two adjacent boxes with an overlap of c. 35 cm. The best match between the two cores was based on pollen records, radiocarbon dates and geochemical analyses. The results presented below comprise a continuous record consisting of sample

Fig. 3. Barschpfuhl geochemical analyses. Results of bulk density (g cm$^{-3}$), degree of humification (% transmission), carbon concentration, nitrogen concentration, C/N ratio and Loss on Ignition (LOI, % organic material) analyses. Note the differences in x-axis scales.
3.2. Geochemical analyses

Results of the geochemical analyses of the Barschpfuhl peat deposit are presented in Fig. 3. The deepest part of the peat core from 60 to 38 cm depth shows relatively stable bulk densities, transmissions, and LOI percentages apart from the interval between 51 and 47 cm depth in which bulk densities and C/N ratio are high and transmission, nitrogen and LOI percentages are relatively low. From 38 to 26 cm depth bulk densities increase and transmission percentages decrease. LOI percentages show a small decrease. At 23 cm depth a sharp decrease in C concentration and LOI percentages is visible. However, also bulk density is low. N concentration increases and the C/N ratio decreases to 22 cm depth. From 21 cm depth to the top C concentration and LOI percentages is visible. Both transmission percentages and C/N ratios show a peak at 6 cm depth. From 11 to 7 cm bulk densities and C/N ratio decrease. Both transmission percentages and C/N ratios show a peak at 6 cm depth. From 11 to 7 cm bulk densities and C/N ratio decrease. Both transmission percentages and C/N ratios show a peak at 6 cm depth. From 11 to 7 cm bulk densities and C/N ratio decrease.
3.4.1.1. Zone 1 (60–49.5 cm depth; c. AD 1705–1740). Zone 1 is characterised by a relatively high degree of openness of the surrounding vegetation up to 30% non-arboreal pollen (NAP). Between 58 and 54 cm depth (c. AD 1712–1726) a less open phase with increased Pinus and Fagus percentages is present (Fig. 5). Poaceae, Rumex acetosa type and Secale have lower percentages during this phase. By the end of zone 1 Pinus shows a sharp decrease. Picea is present after 53 cm depth (c. AD 1730). Ranunculaceae (meadow indicators) are regularly found and general open land indicators, ruderals and cultivated land species represent a large part of the landscape. PARs of trees decrease towards the end of zone 1 (Fig. 6). This trend is also visible in the NAP. By using the threshold limits for pollen accumulation rates in deposits from openings of c. 200 m diameter (Hicks and Sunnari, 2005), the density of Pinus, Picea and Betula forest could be derived (see Table 3 and Fig. 6; bearing in mind that these threshold limits are based upon northern-Fennoscandian pollen data). Although Pinus sylvestris PARs indicate fluctuations between an open and a dense forest in zone 1, the high percentage of apophytes and anthropochores indicates a relatively open landscape and significant human impact in the region.

3.4.1.2. Zone 2 (49.5–37.5 cm depth; c. AD 1740–1780). The boundary between zone 1 and 2 is marked by a sharp increase in Pinus percentages and a decrease in NAP (Fig. 5). Some variation is present in tree composition. Dominance of Pinus is replaced by a more broad-leaved tree composition i.e. Betula, Fagus and Quercus at 45 and 41 cm depth. The apophyte and anthropochores species composition remains
Fig. 5. Pollen percentage diagram of regional vegetation (dry land taxa) of Barschpfuhl. Omitted taxa are named in Appendix B. The black silhouettes show the percentage curves of all taxa, the depth bar filled silhouettes show the five times exaggeration curves. The legend is described in Fig. 3.
stable. Relatively high counts of Apiaceae pollen occur. At the end of the zone NAP increases. All taxa show the same trends in pollen accumulation rates with a minimum at 46–45 cm depth and an increase towards the top of the zone. *Betula* PARs decrease towards the top of the zone (Fig. 6). PARs indicate a slightly denser *Pinus* forest with some *Picea* and *Betula* (Table 3).

### 3.4.1.3. Zone 3 (37.5–29.5 cm depth; c. AD 1780–1920).

Zone 3 comprises a long time period in a relatively short peat interval. NAP is relatively high, c. 25%, at the start of zone 3, indicating a relatively open forest. *Pinus* percentages are relatively low but increase as apophytes and anthropochores decrease. At 32 cm very low *Pinus* percentages are recorded. At the same time Poaceae and *Rumex acetosa* type and *Secale* and *Humulus/Cannabis* type show relatively high percentages, but also a variety of broad-leaved trees in which *Betula* and *Quercus* are dominant is recorded. PARs decrease to low numbers in zone 3. The increase in *Pinus* percentages afterwards may represent the forest renewal activity at the end of the 19th and start of the 20th century. PARs indicate an open pine forest. However, PARs of all species are very low. Very low

### Table 3

Forest density with threshold limits after Hicks and Sunnari (2005) for Barschpfuhl pollen accumulation rates

<table>
<thead>
<tr>
<th>Barschpfuhl regional microfossil zones</th>
<th>PAR</th>
<th><em>Pinus sylvestris</em></th>
<th><em>Picea abies</em></th>
<th><em>Betula</em></th>
</tr>
</thead>
<tbody>
<tr>
<td>6 (1982–2003)</td>
<td>DF</td>
<td>(Pbs-)DF</td>
<td>DF</td>
<td></td>
</tr>
<tr>
<td>5 (1964–1982)</td>
<td>DF</td>
<td>DF-OF-Pbs</td>
<td>DF</td>
<td></td>
</tr>
<tr>
<td>4 (1920–1964)</td>
<td>OF-DF</td>
<td>NP1-Pbs-DF</td>
<td>NP1-DF</td>
<td></td>
</tr>
<tr>
<td>3 (1780–1920)</td>
<td>NP1-OF</td>
<td>NP10</td>
<td>NP1-Pbs</td>
<td></td>
</tr>
<tr>
<td>2 (1740–1780)</td>
<td>OF-DF</td>
<td>NP1-Pbs</td>
<td>NP1-Pbs</td>
<td></td>
</tr>
<tr>
<td>1 (1705–1740)</td>
<td>OF-DF</td>
<td>NP1</td>
<td>NP1-Pbs</td>
<td></td>
</tr>
</tbody>
</table>
Fig. 7. Macrofossil diagram (local wetland vegetation) of Barschpfuhl. Omitted taxa are named in Appendix B. The legend is described in Fig. 3.
Fig. 8. Diagram of local wetland taxa (pollen and non-pollen palynomorphs) of Barschpfuhl. Some testate amoebae were counted in the pollen slides. See Fig. 9 for complete testate amoebae analysis. Omitted taxa are named in Appendix B. The legend is described in Fig. 3.
Fig. 9. Testate amoebae (main taxa) and reconstructed water table of Barschpfuhl. The legend is described in Fig. 3.
pollen accumulation rates might point to a hiatus between 33 and 32 cm depth. If so, the wiggle-matched chronology and PARs would be different. The calendar age of 34 cm would become c. AD 1810 and that of 32 cm c. AD 1935. PARs would increase because less time is present within the samples. Unfortunately sample depth 33 was not radiocarbon dated, so it remains uncertain if a hiatus is present. We do know that thepeat in the interval from 35 to 26 cm depth is extremely decomposed and shows low transmission data (Fig. 3). We assume that no hiatus is present and that this peat section is very compacted and therefore has a slow peat accumulation rate. This may have been caused by a change in the water balance of the bog as an effect of the construction of Autobahn A11 in the 1930s. This matter will be further discussed in Section 5.

3.4.1.4. Zone 4 (29.5–22.5 cm depth; c. AD 1920–1964). Zone 4 is characterised by high AP and low NAP values (Fig. 5). Pinus shows high percentages up to 80%. Quercus shows relatively low percentages. Picea increases in the deepest part of zone 4. This is probably caused by the forest renewal. Ranunculaceae, Rumex acetosa type, Plantago lanceolata, Secale and Humulus/Cannabis type decrease. At 26 cm Fougurus is recorded. PARs are very low at the start of zone 4 and show a sharp increase towards the end of the zone at c. AD 1961–1963 (Fig. 6). These wiggle-matched dates and thus also the PARs can be trusted because they represent 14C-values which can only originate from the bomb peak period. The PARs indicate a dense Pinus and Picea forest with Betula.

3.4.1.5. Zone 5 (22.5–13.5 cm depth; c. AD 1964–1982). Zone 5 is dominated by coniferous forest (Fig. 5). Pinus percentages vary but are relatively high and Picea percentages are also high. PARs indicate that a dense pine, spruce and birch forest was present on the hills surrounding the mire. When Pinus percentages are low, Quercus and Fagus percentages are relatively high. The PARs of other broad-leaved trees, e.g. Fagus and Quercus, are also relatively high, which means that these trees were also nearby. Nowadays, patches of coniferous and of mixed forest are present on the hills nearby. These trees appeared to be older than 20 years and it is most likely that these trees were already present in the period from AD 1964–1982. Secale percentages are high and Urtica increases towards the top of zone 5. Pollen concentrations and PARs are high at 18–17 cm depth (c. AD 1975–1978; Fig. 6).

3.4.1.6. Zone 6 (13.5–0 cm depth; c. AD 1982–2003). The topmost zone is characterised by coniferous forest vegetation and low anthropocene percentages (Fig. 5), and represents vegetation similar to that observed during sampling. Some small Pinus trees are present on the bog surface, but not at the coring location. Pinus shows a sharp decrease at 11 cm (c. AD 1988), where broad-leaved trees and Picea increase. Pinus slowly increases from 9 cm depth towards the top of zone 6. Urtica shows high percentages and Secale decreases. Very few Plantago lanceolata grains are recorded. In the surface samples pollen of Rhamnus catharticus type was found. Years in which PARs peak are: c. AD 1888, 1989, 1990, 1994 (Fig. 6). These are consistent with the years of high annual pollen deposition published by Hicks (2001). Relatively high PARs in recent years were also observed in other peat records of Sweden (van der Linden et al., 2008a; van der Linden and van Geel, 2006; van der Linden et al., 2008b). Bennett and Hicks (2005) showed that when pollen profiles are sampled with high (near-annual) temporal resolution, analyses of pollen accumulation rates reflect temperature-related pollen abundance rather than vegetation abundance (Barnekow et al., 2007). High summer temperatures result in an increased pollen production during the following flowering season (Auto and Hicks, 2004).

3.4.2. Local wetland vegetation development

The wetland vegetation development was divided into six zones (U–Z) based on the major divisions in macrofossil composition in the CONISS dendrogram (Fig. 7). This zonation was also used in the local microfossil diagram and testate amoeba analysis (Figs. 8 and 9).

Changes in trophic status and water regime type are shown in a schematic way in Table 4 for each macrofossil zone following the standards for nutrient-chemical (Succow and Stegmann, 2001) and ecological characteristics of mires in Table 5 (Koska et al., 2001). By expressing the nitrogen concentration (shown in Fig. 3) as percentages of the carbon content, Nc, can be calculated (Table 4). Together with the C/N ratio, the trophic status and water regime of the bog can be established. According to the nutrient-chemical characteristics there is not much variation in trophic conditions. All but one Barschpfuhl samples are characterised in this way as oligotrophic acid with very poor nutrient levels. The exception is at 22 cm depth (ASD 1964) where the Nc and C/N ratio indicates acid poor (and not very poor) conditions. The trophy level based on vegetation (Table 5) differs from the nutrient-chemical based reconstruction, suggesting slightly higher trophic status in general. The testate amoebae assemblages support the interpretation of predominantly oligotrophic status throughout the period sampled, with no taxa unequivocally diagnostic of more enriched conditions present (Charman et al., 2000).

3.4.2.1. Zone U (60–49.5 cm depth; c. AD 1705–1740). Zone U is dominated by Sphagnum angustifolium. Sphagnum magellanicum and S. cf. cuspidatum are present in low percentages but decrease towards the end of the zone, while the brown mosses Drepanocladus fluitans and Calliergon cordifolium increase (Fig. 7). Perichaenia and achenes of Carex curta are present which indicate mesotrophic acid conditions. Also the oligotrophic taxa Carex limosa, Scheuchzeria palustris and Rhyhchospora alba were recorded. Amphitrema wrightianum and A. flavum dominate the testate amoeba composition. Both species show a decrease towards the top of the zone while Cyclopaxis arcelloides type and Nebela grisea type increase (Fig. 9). In samples 53, 52 and 51 many charcoal particles have been recorded with at 51 cm depth charred Sphagnum and cyperaceous remains. In the top of zone V some ericales rootlets were found. The water regime was probably topogenic. Average RWT is 4.4 cm below surface and shows little variation in this zone. Conditions become drier at c. AD 1735.

3.4.2.2. Zone V (49.5–37.5 cm depth; c. AD 1740–1780). Zone V remains relatively dry with an average water table of 4.9 cm below the surface. Sphagnum angustifolium is present in relatively low percentages at the start of zone W. Drepanocladus fluitans and Calliergon cordifolium peak (Fig. 7). Carex curta and Scheuchzeria palustris show relatively high numbers but disappear at 47 cm depth and are replaced by Carex limosa remains. This indicates a change to more oligotrophic conditions. Oxycoccus palustris remains are present in low percentages.

Table 4

<table>
<thead>
<tr>
<th>Macrofossil zone</th>
<th>Nc</th>
<th>C/N ratio</th>
<th>Trophy status</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average 1.94</td>
<td>52.15</td>
<td>Acid</td>
</tr>
<tr>
<td></td>
<td>Min 1.62</td>
<td>45.07</td>
<td>Very poor</td>
</tr>
<tr>
<td>Y (1977–1986)</td>
<td>Max 2.13</td>
<td>68.29</td>
<td>Oligotrophic</td>
</tr>
<tr>
<td></td>
<td>Average 1.80</td>
<td>56.38</td>
<td>Acid</td>
</tr>
<tr>
<td></td>
<td>Min 1.46</td>
<td>46.87</td>
<td>Very poor</td>
</tr>
<tr>
<td>X (1964–1977)</td>
<td>Max 2.62</td>
<td>55.03</td>
<td>Oligotrophic</td>
</tr>
<tr>
<td></td>
<td>Average 2.09</td>
<td>48.60</td>
<td>Acid</td>
</tr>
<tr>
<td></td>
<td>Min 1.82</td>
<td>38.10</td>
<td>Poor*–very poor</td>
</tr>
<tr>
<td>W (1780–1764)</td>
<td>Max 2.30</td>
<td>61.41</td>
<td>Oligotrophic</td>
</tr>
<tr>
<td></td>
<td>Average 2.02</td>
<td>49.89</td>
<td>Acid</td>
</tr>
<tr>
<td></td>
<td>Min 1.63</td>
<td>43.51</td>
<td>Very poor</td>
</tr>
<tr>
<td>V (1740–1780)</td>
<td>Max 2.04</td>
<td>75.85</td>
<td>Oligotrophic</td>
</tr>
<tr>
<td></td>
<td>Average 1.78</td>
<td>57.22</td>
<td>Acid</td>
</tr>
<tr>
<td></td>
<td>Min 1.32</td>
<td>48.91</td>
<td>Very poor</td>
</tr>
<tr>
<td>U (1705–1740)</td>
<td>Max 1.96</td>
<td>74.16</td>
<td>Oligotrophic</td>
</tr>
<tr>
<td></td>
<td>Average 1.70</td>
<td>59.81</td>
<td>Acid</td>
</tr>
<tr>
<td></td>
<td>Min 1.35</td>
<td>50.92</td>
<td>Very poor</td>
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</tbody>
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Also fungal types Entophytis lobata (T. 13) and Helicoon pluriseptatum (T. 30) are recorded (Fig. 8). Drosera rotundifolia/anglica remains have been found throughout zone V. In the top of the zone between c. AD 1775 and 1780 a phase with wet-growing Sphagnum cf. cuspidatum is present and a decrease in RWT (increased wetness). In this phase also the plant remains of Drosera rotundifolia/anglica are preserved. Amphithema flavum, Arcella discoides type and Cyclopyxis arcelloides type are dominant testate amoebae (Fig. 9).

3.4.2.3. Zone W (37.5–22.5 cm depth; c. AD 1780–1964). Zone W begins with oligotrophic conditions but becomes more mesotrophic as Carex limosa disappears at c. AD 1830 and is replaced by Rhynchospora alba (Fig. 7). Ericales rootlets and unidentified cyperaceous epidermis and rhizomes show relatively high numbers while Sphagnum angustifolium percentages decrease at 31–30 cm. Calliergon cordifolium and Oxycoccus palustris remains increase towards the top of the zone. RWT is relatively low, but fluctuates through the zone. Also Pinus sylvestris mycorrhizal roots (T. 387) and needles are present in the top of zone W which imply local Pinus growth. Contemporaneously fungal Type 158 is present (Fig. 8). At the transition from zone W to X, at 23 cm, a short eutrophic phase is recorded at c. AD 1963 in which Juncus bufonius seeds are recorded. Detailed data of fungal types Entophlyctis lobata (T. 13) and Helicoon pluriseptatum (T. 30) are recorded (Fig. 8). Drosera rotundifolia/anglica remains have been found throughout zone V. In the top of the zone between c. AD 1775 and 1780 a phase with wet-growing Sphagnum cf. cuspidatum is present and a decrease in RWT (increased wetness). In this phase also the plant remains of Drosera rotundifolia/anglica are preserved. Amphithema flavum, Arcella discoides type and Cyclopyxis arcelloides type are dominant testate amoebae (Fig. 9).

3.4.2.4. Zone X (22.5–17.5 cm depth; c. AD 1964–1977). Zone X shows mesotrophic conditions and is dominated by Calliergon cordifolium. There are only two testate amoebae samples I this zone, but they suggest that the water table starts low but increases (Fig. 9). Diffugia pulex shows a single peak at 31 cm (c. AD 1890). Arcella discoides type, Cyclopyxis arcelloides type, Assulina muscorum and Nebela griseola represent the testate amoebae composition in the top of zone W (Fig. 9).

3.4.2.5. Zone Y (17.5–10.5 cm depth; c. AD 1977–1986). Between 18 and 17 cm depth C. cordifolium is replaced by Oxycoccus remains (Fig. 7). At 16 cm Oxycoccus and Pinus sylvestris needles disappear and are replaced by high Sphagnum angustifolium percentages. Loricae of Callidina angusticollis (T. 37) are present above 21 cm depth (Fig. 8). A wide variety of testate amoebae is recorded at the start of zone Y, e.g. Nebela miliaris, Corythion-Trinema type, Hyalosphenia ovalis and Eriophorum vaginatum. Dryest conditions are at c. AD 1978–1980 with many ericaceous remains and an increase of Eriophorum vaginatum. At the end of zone Y the testate amoebae composition is dominated by Cyclopyxis arcelloides type, Assulina muscorum and Arcella discoides type.

3.4.2.6. Zone Z (10.5–0 cm depth; c. AD 1986–2003). Zone Z is characterised by the presence of Polytrichum strictum and few Sphagnum magellanicum and Calliergon cordifolium remains (Fig. 7). Sphagnum angustifolium percentages decrease. The moss composition indicates mesotrophic conditions with inflow of minerogenic groundwater. The sharp increase of Polytrichum strictum implies a fast increase in nutrients and increasing dryness. A peak in Sphagnum spores is present at 10 cm depth. A new microfossil type (Type 269; see Plate I) has been recorded solely in the top samples of Barschpfuhl. Testate amoebae composition is dominated by Cyclopyxis arcelloides type, Assulina muscorum, Nebela griseola type. Also dry indicators Bullinularia indica, Eulophyta rotundata type, Trigonopyx arcula type and Trinema lineare are present (Fig. 9). The RWT is high at c. AD 1990–1994 but shows a sharp decrease in the topmost sample of the peat core. At 3 cm depth a peak in coprophilous fungi (Sporormiella, Cerophora type and other Sordariales) is present (Fig. 8). During macrofossil analysis a fruitbody with spores of Sporormiella was recorded at sample depth 1 (not shown in diagram). The fungal spores were probably produced in fruit bodies on boar dung. Wild boar enter the bog when conditions are dry enough, a situation which has occurred during the last years as indicated by testate amoebae and by the instrumental weather data (Fig. 2). The top part of the core might be trampled and more compacted by wild boar disturbing the bog surface.

4. Discussion

4.1. Vegetation history and population growth

Pollen percentages suggest that human impact was high from c. 1705 to the start of the 20th century and then decreased. During the 16th and 17th century foreign farmers (Dutch amongst others) migrated to the Uckermark region, bringing knowledge of water management and new crops such as potatoes and hop (Lutzke, 2003). In the beginning (c. AD 1716–1770) potatoes were only used as animal fodder. This had the advantage that livestock could be held in the barn all year. The forest vegetation (Waldweide in German) had been damaged by the foraging of pigs and other animals. The openness created is visible in the Barschpfuhl pollen record by the high
percentages of Poaceae, *Plantago lanceolata* and the presence of *Juni-
perus*. The park-like landscape served as a supply for fuel and other
goods and could hardly be called a forest, with woodland borders
merging into fields. Agricultural fields were wide and had few “green-
land-isles” and mires. Forest in this landscape was restricted to the
sand islands and fen and mire borders (Lutze, 2003). Such a landscape
is shown in pollen zone 1 of the Barschpfuhl pollen diagram (Fig. 5)
represented in the Barschpfuhl pollen record as an increase in Cerealia,
angus species explains many of the changes in vegetation.

different types and major transitions, though based on completely
different datasets. Apparently the transitions in development of local
and regional vegetation are influenced by the same factor(s). One factor
may be climate change. However, since Barschpfuhl is a relatively
small bog, it seems more likely that local factors have more influence.
One species that is both present in the local and regional vegetation
is *Pinus sylvestris*, and it seems that this species explains many of the
changes in vegetation.

The findings of *Pinus sylvestris* scale leaves (T. 387) throughout
the core suggest that *Pinus* trees have always grown close to the
sample site. Indeed, small pines are now found on some parts of the
bog and large pine trees grow on the hill slopes surrounding the bog.
From 26 cm (c. 1960) to 16 cm (c. 1979) pine needles were found and at
26 cm mycorrhizal roots. These findings point to growth of pine at the
core location. *P. sylvestris* has a high transpiration rate and takes up a
vast quantity of water from the environment. Local pine growth may
have desiccated the underlying peat and thus increased the decom-
position rate. This may be the reason for the dark and humified peat
layer with a slow peat accumulation rate between 35.5 and 25.5 cm. At
23 cm, there is a peak in *P. sylvestris* needles and *Juncus bufonius*
seeds are also found. At that point LOI percentages drop to 90% organic
matter and also C concentration is minimal. Both in the local and
regional vegetation developments this depth is a boundary between
assemblage zones. The mesotrophic status of the bog, indicated by
presence of *J. bufonius*, might also be a reason for the humified peat
layer because decay rates increase with trophy status (Johnson et al.,
1990). There remains a question about why pine settled on the bog
surface at this particular time. A period of warm and dry summers
may have caused a desiccation of the bog surface. However, climatic
conditions were not extreme around 1960. Actually, summers were
relatively cold and wet (Fig. 2). Another possibility may be that the bog
area suffered from drainage. Increased decomposition of the bog
surface may have started during the construction of the motorway in
the late 1930s. The poor chronological control for the record, during
this period of decay may be explained by the presence of a hiatus in
the peat record between c. AD 1810 and 1930, which would fit the 14C
calibration curve. The macrofossil record, however, does not show
abrupt changes between sample depths 35.5 and 25.5. Therefore we
assume a period of slow peat accumulation rather than a hiatus.

In addition to construction of the motorway, the forest regeneration
in the region probably caused a dehydration of the bog. After the Second
World War increased logging took place in order to meet the Russian
demand for timber. *Pinus sylvestris* and other fast-growing conifers
with a high transpiration rate were planted as replacement trees. This caused
a change in hydrology of the bog and pines could also grow on the bog
surface, thereby causing further desiccation of the surface.

4.3. Human impact, climate change and solar activity

Many studies show a link between climate change and peatland
development including changes over historical time especially related
to the Little Ice Age which caused wet shifts in raised bog deposits during periods of low solar activity (e.g. Mauquoy et al., 2002b). However, the hydrology of kettlehole mires like Barschpfuhl is not only influenced by precipitation but also by groundwater. Furthermore, the surface of kettlehole mires is often partially ‘floating’ on a subsurface water lens, so that surface vegetation is buffered against fluctuations in water table. This is also suggested by the reconstructed water table (RWT) based on the testate amoebae composition, which shows very little variation. All fluctuations are in a range of 5 cm, and there are no long-term trends in the data. Owing to buffering, it may be difficult or even impossible to distil a clear climate signal from the Barschpfuhl macrofossil record. This is also the case for the microfossil record. Thermophilous tree species e.g. Fagus, Quercus, Tilia and Ulmus were growing near the research site, but would have been accessible and affected by logging activities. The planting of Pinus sylvestris and other conifers altered the natural forest composition and also influenced the pollen record. The Berlin–Dahlem temperature record does not show great changes over the last 300 years and may be unreliable in early measurements (Fig. 2A). The instrumental records show that the last c. 8 years have been dry and warm. This is consistent with the high pollen accumulation rates in the top of the peat deposit, but this may be a reflection of short-term weather variability rather than climate change.

In contrast to raised bog conditions (compare Mauquoy et al., 2002a,b) the peat moss composition may react to changes in hydrology and trophic conditions, independent from climatic factors. From 1705–1750 the macrofossil record indicates a wet period, which is also observed in the reconstructed water table based on testate amoebae. During this cold period the solar activity is low (Fig. 2C), indicated by low solar irradiance and high 14C productivity. However no other links are visible between the Berlin–Dahlem summer temperature, summer precipitation and solar irradiance record (Lean, 2000, 2004).

Mesotrophic conditions, indicated by Calligonon cordifolium (1910–1930 and 1960–1975) are present during two periods of increased summer (and winter) precipitation. The last period is also characterised by a high reconstructed water table. Increased inflow of runoff water from the hills into the mire as a result of increased precipitation is probably the cause of these mesotrophic conditions.

5. Conclusions

In attempting to distinguish between effects of climate change and human impact on the mire hydrology and ecology of the kettlehole mire Barschpfuhl, it is clear that the human activities around the mire have had a much greater influence on the plant communities and bog hydrology than climate change. We were able to reconstruct the regional and local changes in vegetation from c. 1705 until 2003 from the pollen and macrofossil record. We could also reconstruct changes in hydrology by analysing the macrofossils and the testate amoebae record. Most changes in ecology and hydrology were explained by changes in land use (mainly forestry). Logging of trees and planting of conifers in the region altered the natural forest composition. The planting of fast-growing Pinus sylvestris was a major influence on the mire hydrology and peat accumulation. The recorded tree species composition in the forest could have been related to land use, e.g. open forest used for grazing (Waldwiese). The pollen record of Cerealia and Secale could be linked to the cultivation history of cereals in the Uckermark region.

Acknowledgements

We want to thank Frank Berendse, Monique Heijmans, Angela Breeuwer, Jan van Walsem and Frans Möller from Wageningen University for helping with the fieldwork and for measuring the degree of humification, C/N ratio and Loss on Ignition. Beate Blahy, Heike Mauersberger and Rüdiger Michels from Landesumweltamt Brandenburg (LUA) and Biosphärenreservat Schorfheide-Chorin suggested Barschpfuhl as a research site and provided information about the vegetation history of the area. We thank Hans van der Plicht from CIO for his help with 14C dating and Gerhard Müller-Westermeier from DWD for providing the instrumental temperature and precipitation data of the Berlin station. This project was financially supported by NWO (Netherlands Organisation for Scientific Research; project number: 852.00.021, MvdL, BvC) and European Union Framework V (ACCROTELM EVK2-CT-2002-00166, EV, DC).

Appendix A. Calendar age of all sampled levels based on 14C AMS wiggle-match dated chronology of Barschpfuhl

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Appendix B. Omitted taxa of (A) regional pollen record (Fig. 5), (B) macrofossils (Fig. 7) and (C) fen and bog pollen and spores (Fig. 8)

A. Arboral pollen
Abies: 52 cm: 0.2%
Acer: 10 and 13 cm: 0.2%; 11 cm: +
cf. Cornus mas type: 18 cm: 0.2%
cf. Castanea sativa: 2, 10, 16, 19, 26, 33, 36, 40, 46, and 59 cm: 0.2%; 50 cm: +
Myrica: 9 and 13 cm: 0.2%
cf. Populus: 33 cm: 0.2%
Sorbus group cf. Sorbus aucuparia: 20 cm: 0.5%
Sorbus group cf. Prunus padus: 2 cm: 0.2%; 17 cm: +
B. Non-arboreal pollen
Dry meadow
Jasione montana type: 39 cm: 0.2%; 50 cm: 0.2%
Meadow
Fabaceae undif.: 17 cm: 0.1%; 41 and 54 cm: 0.2%
Fabaceae Genista-group: 21 cm: 0.2%
cf. Helleborus: 51 and 56 cm: 0.2%
Galium: 1, 14, 19, 24 and 48 cm: +; 38 cm: 0.4%; 49 cm: 0.2%
Hypericum perforatum type: 12 and 24 cm: 0.2%
Rhinanthus group: 48 cm: 0.2%
General open land indicators
Rosaceae undif.: 1, 4, 16, 29 and 45 cm: 0.2%; 13 cm: +
Caryophyllaceae: 5, 24, 30, 54, 55 and 58 cm: 0.2%; 35 and 40 cm: +
Ruderals
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