UNIVERSITY OF AMSTERDAM

UvA-DARE (Digital Academic Repository)

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

van der Linden, M.; Vickery, E.; Charman, D.J.; Broekens, P.; van Geel, B.

DOI
10.1016/j.revpalbo.2008.05.001

Publication date
2008

Published in
Review of Palaeobotany and Palynology

Link to publication

Citation for published version (APA):
van der Linden, M., Vickery, E., Charman, D. J., Broekens, P., & van Geel, B. (2008). Vegetation history and human impact during the last 300 years recorded in a German peat deposit. *Review of Palaeobotany and Palynology*, *152*(3-4), 158-175. https://doi.org/10.1016/j.revpalbo.2008.05.001

General rights
It is not permitted to download or to forward/distribute the text or part of it without the consent of the author(s) and/or copyright holder(s), other than for strictly personal, individual use, unless the work is under an open content license (like Creative Commons).

Disclaimer/Complaints regulations
If you believe that digital publication of certain material infringes any of your rights or (privacy) interests, please let the Library know, stating your reasons. In case of a legitimate complaint, the Library will make the material inaccessible and/or remove it from the website. Please Ask the Library: https://uba.uva.nl/en/contact, or a letter to: Library of the University of Amsterdam, Secretariat, P.O. Box 19185, 1000 GD Amsterdam, The Netherlands. You will be contacted as soon as possible.

UvA-DARE is a service provided by the library of the University of Amsterdam (https://dare.uva.nl)

Download date:14 Oct 2026

Provided for non-commercial research and education use.
Not for reproduction, distribution or commercial use.

This article appeared in a journal published by Elsevier. The attached copy is furnished to the author for internal non-commercial research and education use, including for instruction at the authors institution and sharing with colleagues.

Other uses, including reproduction and distribution, or selling or licensing copies, or posting to personal, institutional or third party websites are prohibited.

In most cases authors are permitted to post their version of the article (e.g. in Word or Tex form) to their personal website or institutional repository. Authors requiring further information regarding Elsevier's archiving and manuscript policies are encouraged to visit:

http://www.elsevier.com/copyright

Author's personal copy

Review of Palaeobotany and Palynology 152 (2008) 158–175

Contents lists available at ScienceDirect

Review of Palaeobotany and Palynology

journal homepage: www.elsevier.com/locate/revpalbo

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

Marjolein van der Linden [a,*], Emma Vickery [b], Dan J. Charman [b], Peter Broekens [a], Bas van Geel [a]

[a] Institute for Biodiversity and Ecosystem Dynamics, Universiteit van Amsterdam, Kruislaan 318, 1098 SM Amsterdam, The Netherlands
[b] School of Geography, University of Plymouth, Plymouth, Devon, PL4 8AA United Kingdom

ARTICLE INFO

Article history:
Received 18 September 2007
Received in revised form 28 March 2008
Accepted 7 May 2008
Available online 20 May 2008

Keywords:
^{14}C AMS wiggle-match dating
atmospheric bomb pulse
kettlehole mire
human impact
multi-proxy

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. ^{14}C 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.

© 2008 Elsevier B.V. All rights reserved.

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 (MLUV, 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 Barschpful 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

* Corresponding author. Tel.: +31 20 3652831; fax: +31 20 5257832.
E-mail address: vanderlinden@biax.nl (M. van der Linden).

0034-6667/$ – see front matter © 2008 Elsevier B.V. All rights reserved.
doi:10.1016/j.revpalbo.2008.05.001

Author's personal copy

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 ^{14}C 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,

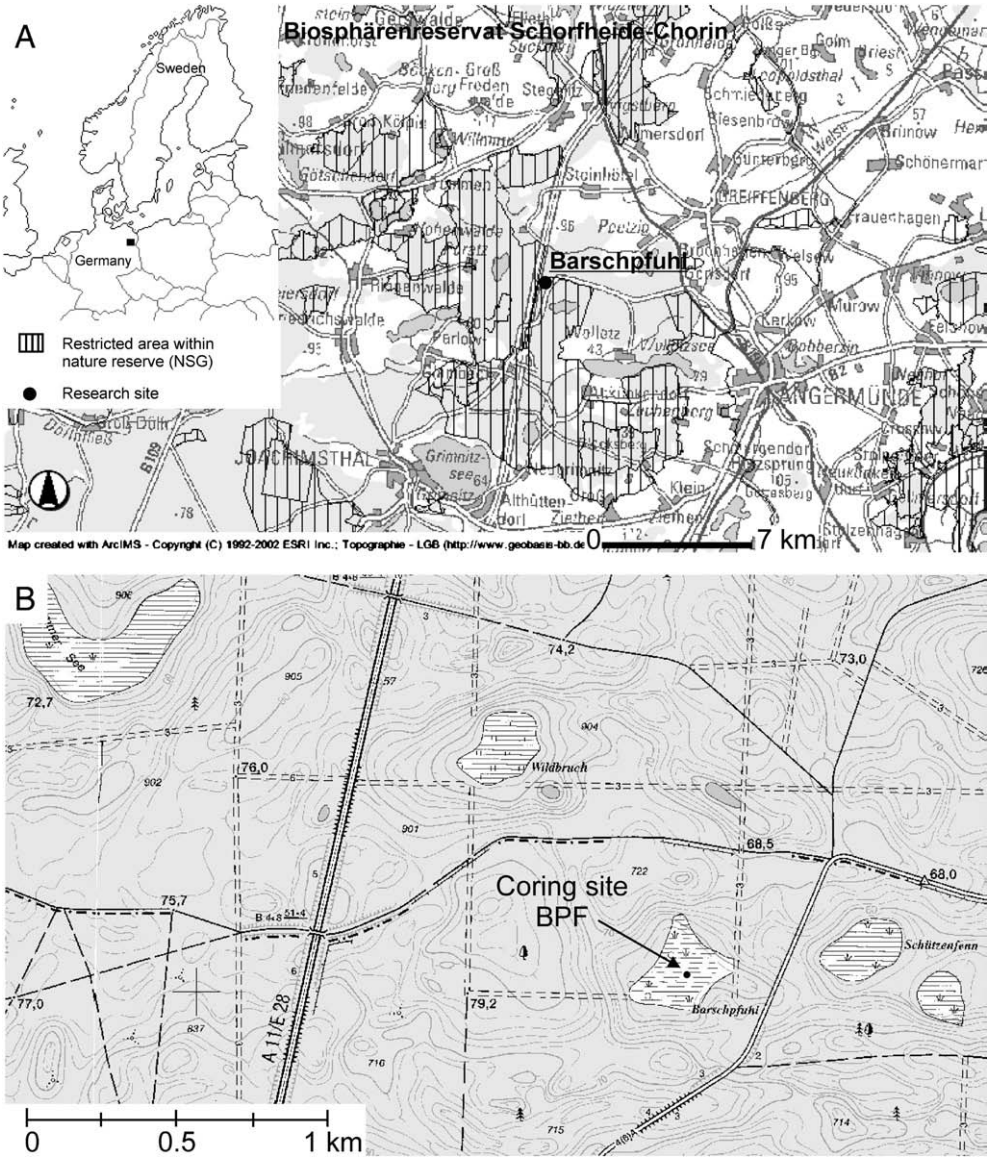

Fig. 1. (A) Map of UNESCO nature reserve Biospärenreservat Schorfheide-Chorin with location of Barschpfuhl, (B) location of coring site in Barschpfuhl.

Author's personal copy

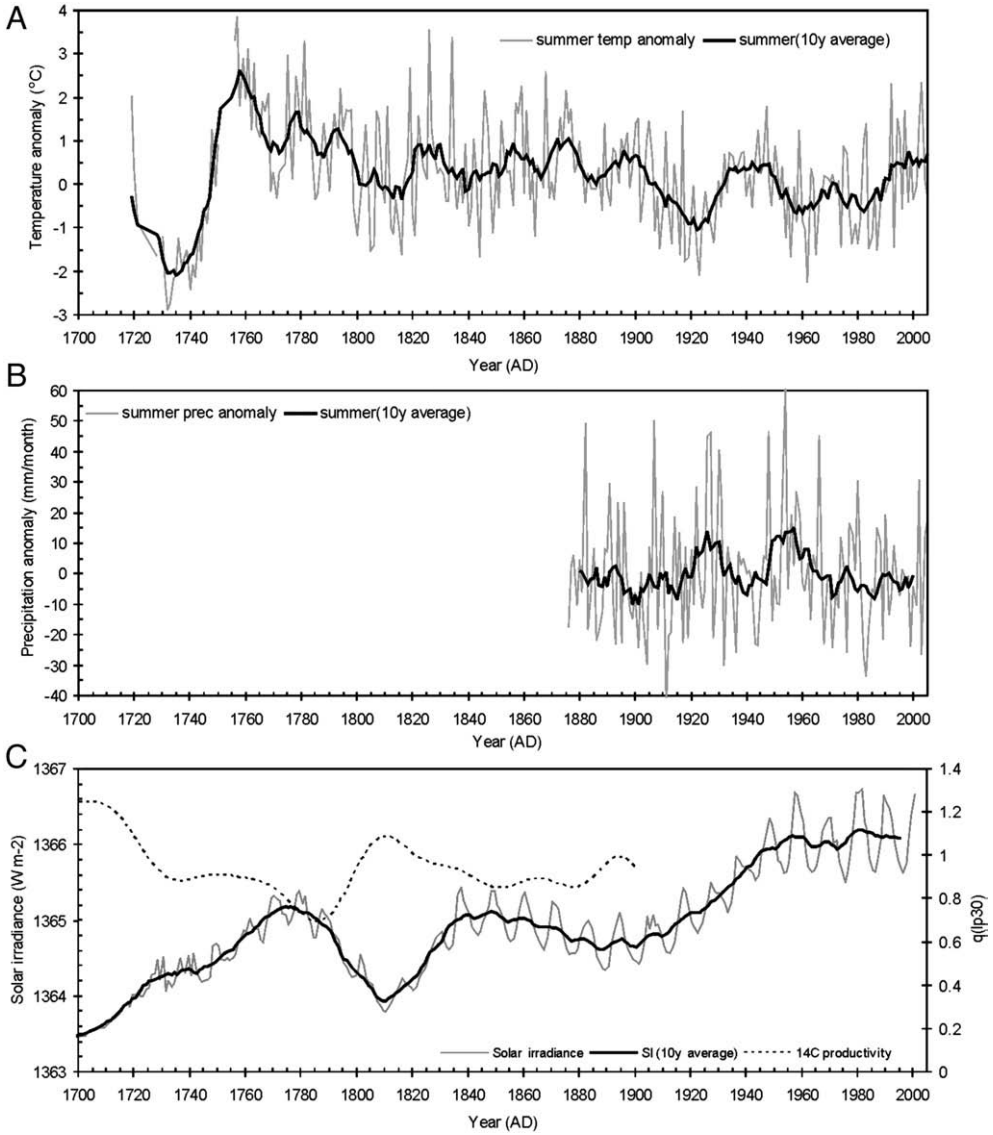

Fig. 2. (A) Instrumental data of Berlin–Dahlem summer temperature anomaly of AD 1876–2003 mean (source Deutsche Wetterdienst), oldest part of record from AD 1719–1875 is less reliable, (B) instrumental data of Berlin-Dahlem summer precipitation anomaly of AD 1876–2001 mean (source Deutsche Wetterdienst), (C) ^{14}C productivity, q(lp30), (Masarik and Beer, 1999; Muscheler et al., 2007) and solar irradiance (Lean, 2000, 2004).

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*, *Rhynchospora 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 cm^3, from the 1 cm thick horizontal slices of peat core. A known amount of *Lycopodium* spores (c. 10679 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

Author's personal copy

Table 1
List of herb pollen included in the human impact indicators (Behre, 1986; Berglund, 1986; Poska et al., 2004)

Type of indicator	Land-use category	Taxa
Anthropochores	Cultivated land	*Centaurea cyanus*
		Cerealia (non *Secale*)
		Helianthus annuus
		Humulus/Cannabis
		Secale
		Symphytum officinale
Apophytes	Ruderals (minor*)	*Ambrosia* type
		Brassicaceae
		Plantago lanceolata
		Echium
		Mercurialis annua type
		Plantago major/media
		Polygonum aviculare type
		Rumex acetosa type
		cf. *Sanguisorba officinalis* type
		Urtica
		cf. *Verbascum* spec.
	Ruderals (major*)	*Artemisia*
		Chenopodiaceae
	Meadow	Fabaceae
		Galium type
		Hypericum perforatum type
		Ranunculaceae
		Rhinanthus group
	Open land	Apiaceae
		Asteraceae liguliflorae
		Asteraceae tubuliflorae
		Caryophyllaceae
		Poaceae
		Rosaceae undif.
	Dry meadow	*Jasione montana* type
		Juniperus

*Differentiation on the basis of pollen production.

rates = PAR ≈ pollen influx in grains cm^{-2} yr^{-1} (Autio and Hicks, 2004; Middeldorp, 1982). Pollen was identified using Moore et al. (1991), Beug (2004) and a reference collection. Interpretation of the pollen record followed Berglund (1986) and Behre (1986). Non-pollen palynomorphs (van Geel, 1978; van Geel and Aptroot, 2006; van Geel et al., 2003) and pollen types not included in the pollen sum were recorded and expressed as percentages of the pollen sum. The pollen sum (minimum of 400 grains) included pollen of regional trees and shrubs (AP: arboreal pollen) and herbaceous dry land taxa (NAP: non-arboreal pollen). Herbs were separated into two groups, apophytes and anthropochores (Berglund, 1986; Poska et al., 2004), and were sorted into land-use categories (Table 1). Apophytes are native plants that invade abandoned fields. Anthropochores are a group of plants of which the seeds are dispersed as a result of human activity. The shrub *Juniperus* was also included in the apophytes. Cyperaceae were excluded from the pollen sum as many species in this taxon grow on the mire surface. Diagrams were prepared using the Tilia program (Grimm, 1990) and assemblage zones were based on the Coniss program output (Grimm, 1987). Since the mire is not very large, the relevant source area of pollen (RSAP) will also be 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 cm^3. 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) ^{14}C dating

Age estimates were obtained on 32 samples using ^{14}C 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 cm^3 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

Plate I. Microscopic photos of the newly described microfossils Type 268 and Type 269.

1. Type 268: Globose microfossil of c. 21–24 μm diameter, bacculate or sometimes eroded psilate surface.
2. Type 269: Globose microfossil of c. 14–21 μm diameter, "wrinkled" surface.

Author's personal copy

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

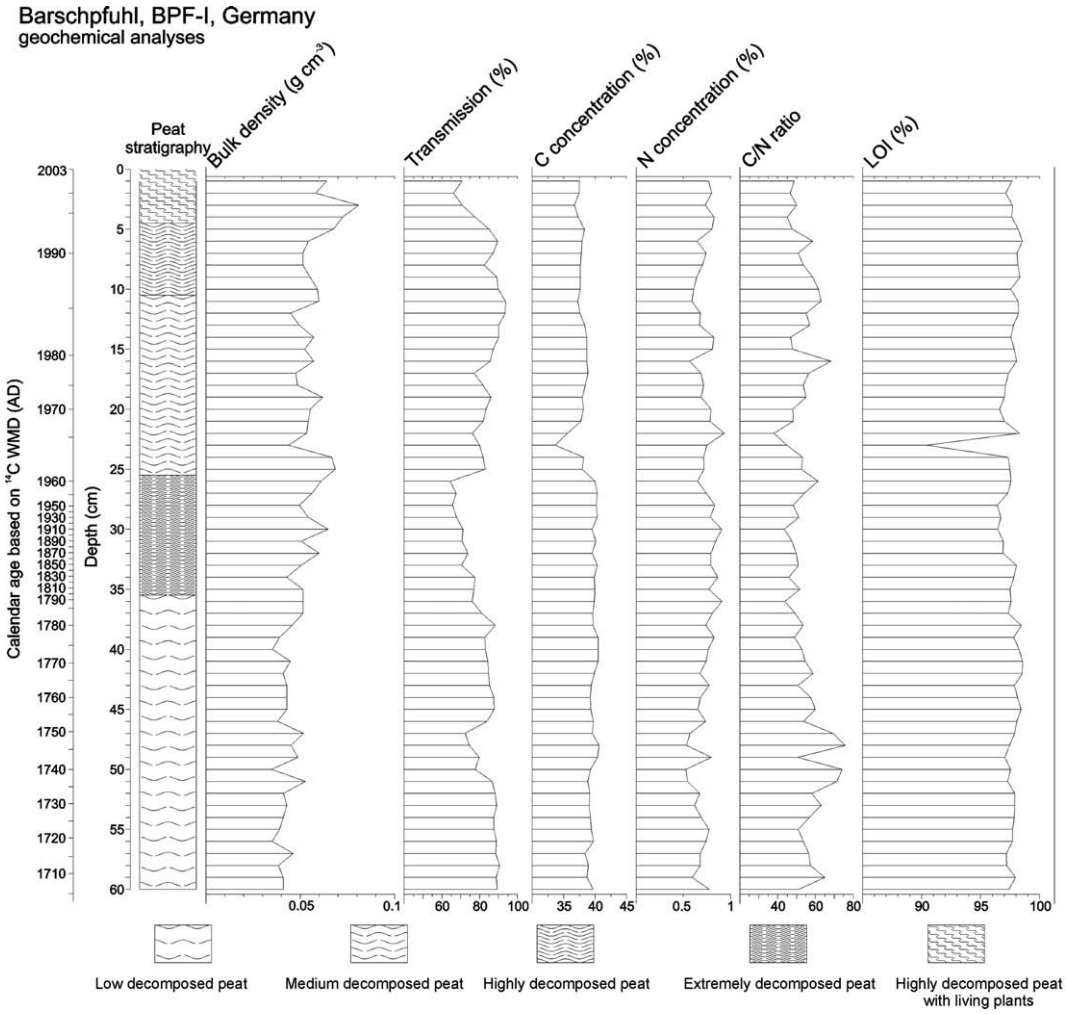

Fig. 3. Barschpfuhl geochemical analyses. Results of bulk density (g cm^{-3}), degree of humification (% transmission), carbon concentration, nitrogen concentration, C/N ratio and Loss on Ignition (LOI, % organic material) analyses. Note the differences in *x*-axis scales.

Author's personal copy

depths 1–25 cm from the upper box and sample depths 26–60 of the lower box.

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 from 51 to 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 are rather stable. Bulk density and C/N ratio show small peaks at 16 and 11 cm depth. From 11 to 7 cm bulk densities and C/N ratio decease. Both transmission percentages and C/N ratios show a peak at 6 cm depth. The top 5 cm of the core show high bulk densities with a peak at 3 cm depth. Transmission values decrease towards the top and N concentration is relatively high.

3.3. Radiocarbon chronology

The results of the AMS radiocarbon dating are presented in Table 2. A detailed chronology was created by wiggle-matching the dates to the INTCAL 98 calibration curve (Stuiver et al., 1998). The post-1950 samples were wiggle-matched against the 'negative' radiocarbon ages of the atmospheric bomb pulse (Goodsite et al., 2001; Goslar et al., 2005; Levin and Hesshaimer, 2000; van der Linden et al., 2008a; van der Linden and van Geel, 2006; van der Linden et al., 2008b). In this approach linear peat accumulation over limited stratigraphic intervals is preferred over a more complex accumulation model. Blaauw et al. (2003, 2004) showed that this approach produced satisfactory and reliable results. First, the dataset was split up into four subsets. This subdivision was based on shifts in pollen concentration, macrofossil composition, degree of humification and bulk density results (Kilian et al., 2000; Speranza et al., 2000). During the wiggle-matching process the radiocarbon dates at 26 and 24 cm depth did not seem to fit within one of the subsets. Therefore these sample depths were given their own subset. Finally, six subsets have been used. Results are presented in Table 2 and Fig. 4. The record is not older than c. AD 1700, because no dates which fit on the steep part of the calibration curve between AD 1650 and 1700 are present. Between 1800 and 1950 only 8 cm of peat deposit is present. This will be discussed in Section 5. The peak of the atmospheric bomb pulse is captured within sample depths 23 and 22. The decrease of ^{14}C in the atmosphere since the cessation of nuclear testing in AD 1963 is clearly recorded within the peat deposit. The age of samples between wiggle-match dated levels were estimated by linear interpolation (Appendix A). Sample ages in the text will be printed without the errors; these are presented in Table 2.

3.4. Microfossil and macrofossil analyses

3.4.1. Regional vegetation development (dry land taxa)

The dry land vegetation development was divided into six pollen assemblage zones (1–6) based on the major divisions in the CONISS dendrogram (square root transformation; Fig. 5). This zonation was also used in the pollen concentration and pollen accumulation rate diagrams (Fig. 6).

Table 2
Radiocarbon and ^{14}C AMS wiggle-match date results for Barschpfuhl

Sample depth	GrA-number	$\delta^{13}C$	Carbon content	^{14}C		^{14}C age		Wiggle-match date			Sample composition
cm		‰	%	%	+/−	BP	+/−	AD	+/−	sub-set	
4	30497	−28.07	45.8	114.31	0.45	−1075	35	1994	0.6	I	*S. angustifolium*
7	30498	−27.80	45.9	115.98	0.46	−1191	30	1990	0.6	I	*S. angustifolium*
10	26007	−27.27	41.9	116.71	0.60	−1240	40	1987	0.6	I	*Polytrichum* stems
14	30500	−27.35	45.8	126.80	0.48	−1910	30	1982	0.6	I	*S. angustifolium*
17	30501	−27.45	47.1	133.41	0.51	−2315	30	1978	0.6	I	*S. angustifolium*
18	30502	−26.62	46.3	150.02	0.56	−3260	30	1975	1.2	II	*S. ang* and Cc
19	30504	−27.66	46.7	144.74	0.54	−2970	30	1973	1.2	II	*S. angustifolium*
20	26008	−26.47	41.9	156.65	0.71	−3605	35	1970	1.2	II	*S. angustifolium*, O b, Ra
21	30506	−28.63	46.4	165.04	0.59	−4025	30	1968	1.2	II	*S. angustifolium*
22	30507	−26.16	44.9	179.05	0.65	−4680	30	1966	1.2	II	*S. angustifolium*
23	30508	−27.43	47.3	177.02	0.64	−4590	30	1963	1.2	II	*S. angustifolium*
24	30510	−26.81	46.4	143.66	0.55	−2910	30	1963	0.6	III	*S. angustifolium*
26	25990	−28.45	49.1	124.05	0.64	−1730	40	1960	2.25	IV	*Oxycoccus* leaves
28	30517	−28.39	42.5	97.02	0.41	245	35	1951	10.25	V	*Sphagnum* and Cc
30	30520	−28.77	51.7	97.79	0.39	180	35	1910	10.25	V	*Sphagnum* and Cc
32	30522	−27.89	52.1	97.45	0.40	210	35	1869	10.25	V	*Sphagnum* and Ra
34	30612	−28.65	45.3	98.25	0.38	140	30	1828	10.25	V	*Sphagnum* stems
36	25991	−22.94	41.6	97.24	0.54	225	45	1787	10.25	V	Cc, Df and O l
38	30614	−26.23	44.3	98.03	0.38	160	30	1780	1.7	VI	*Sphagnum* stems
40	30602	−26.46	47.1	98.26	0.39	140	30	1774	1.7	VI	*Sphagnum* stems
42	30604	−27.50	46.4	97.72	0.37	185	30	1767	1.7	VI	*Sphagnum* stems
44	30605	−26.07	47.3	97.98	0.38	165	30	1760	1.7	VI	*Sphagnum* stems
46	25993	−27.01	41.8	97.90	0.58	170	45	1753	1.7	VI	Cc, Df and O l
48	30606	−27.99	46.6	98.14	0.39	150	35	1746	1.7	VI	*Sphagnum* stems, S op and Df
50	30609	−27.50	48.4	98.19	0.38	145	30	1740	1.7	VI	*Sphagnum* stems
52	30610	−25.06	47.5	97.87	0.38	175	30	1733	1.7	VI	*Sphagnum* stems
54	30611	−26.53	48.2	99.06	0.38	75	30	1726	1.7	VI	*Sphagnum* stems
56	26009	−26.55	45.9	98.25	0.51	140	40	1719	1.7	VI	Ra, Ca c, D rot, 5 S op
57	30624	−25.94	47.8	98.59	0.37	115	30	1716	1.7	VI	*Sphagnum* stems
58	30625	−26.55	48.9	98.18	0.39	150	30	1712	1.7	VI	*Sphagnum* stems
59	30626	−25.68	48.1	98.72	0.38	105	30	1709	1.7	VI	*Sphagnum* stems
60	30627	−26.58	48.0	98.83	0.38	95	45	1706	1.7	VI	*Sphagnum* stems

Cc: *Calliergon cordifolium* stems+leaves; O bf: Oxycoccus branch; O l: *Oxycoccus* leaves; D rot: *Drosera rotundifolia/anglica* seed; Ra*: Rhynchospora alba* fruit; Df: *Drepanocladus fluitans* stems+leaves; Ca c: *Carex curta* fruits; S op: *Sphagnum* opercula.

Author's personal copy

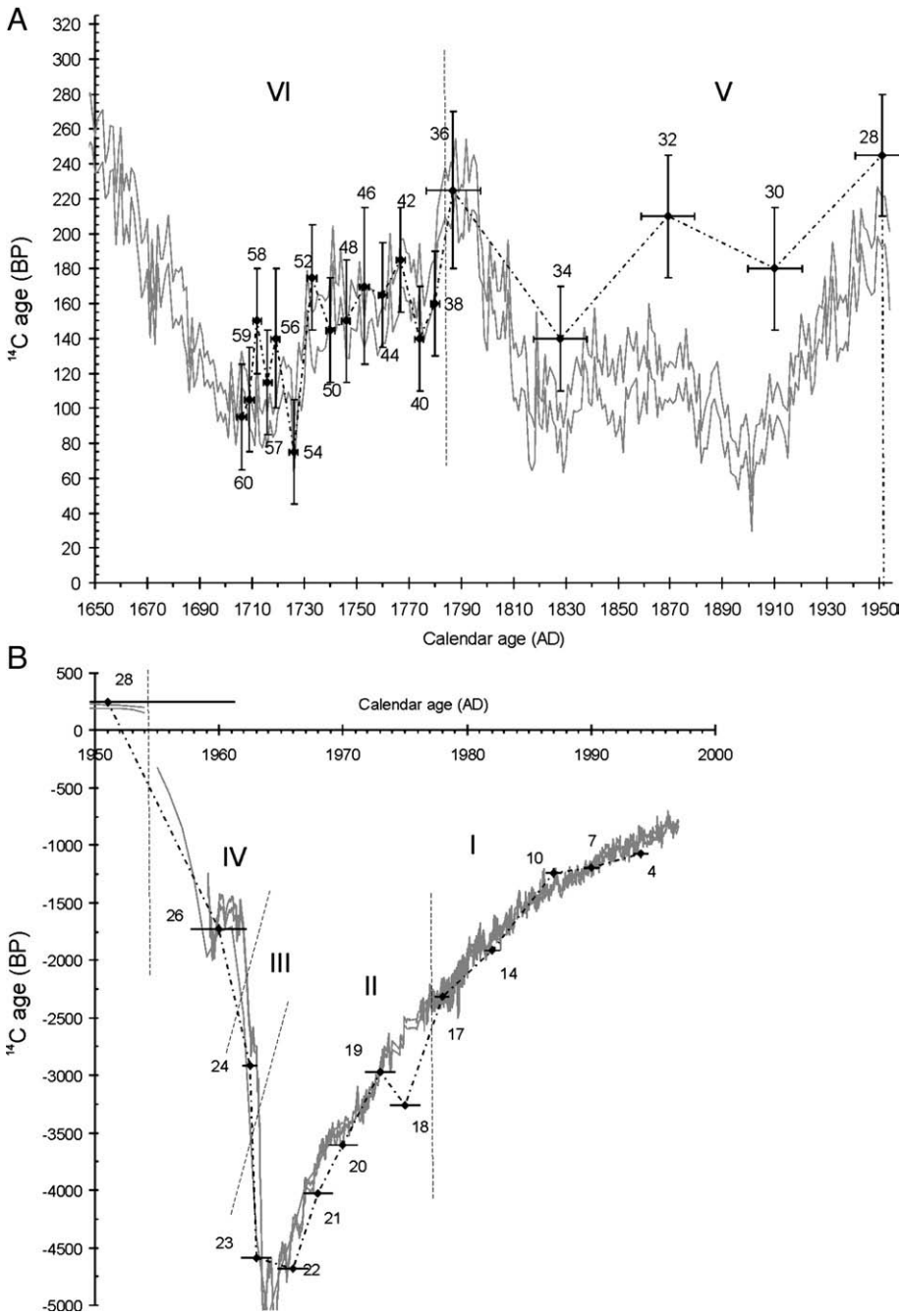

Fig. 4. ^{14}C AMS wiggle-match dating of the Barschpfuhl (BPF) peat deposit using the INTCAL 98 calibration curve (Stuiver et al., 1998) updated with the modern ^{14}C record reflecting the atmospheric bomb pulse (Goodsite et al., 2001; Levin and Hesshaimer, 2000; Levin et al., 1994). The radiocarbon dates are marked with their sample depths in cm. A) Chronology before AD 1950 and B) chronology after AD 1950.

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 anthropochore species composition remains

Author's personal copy

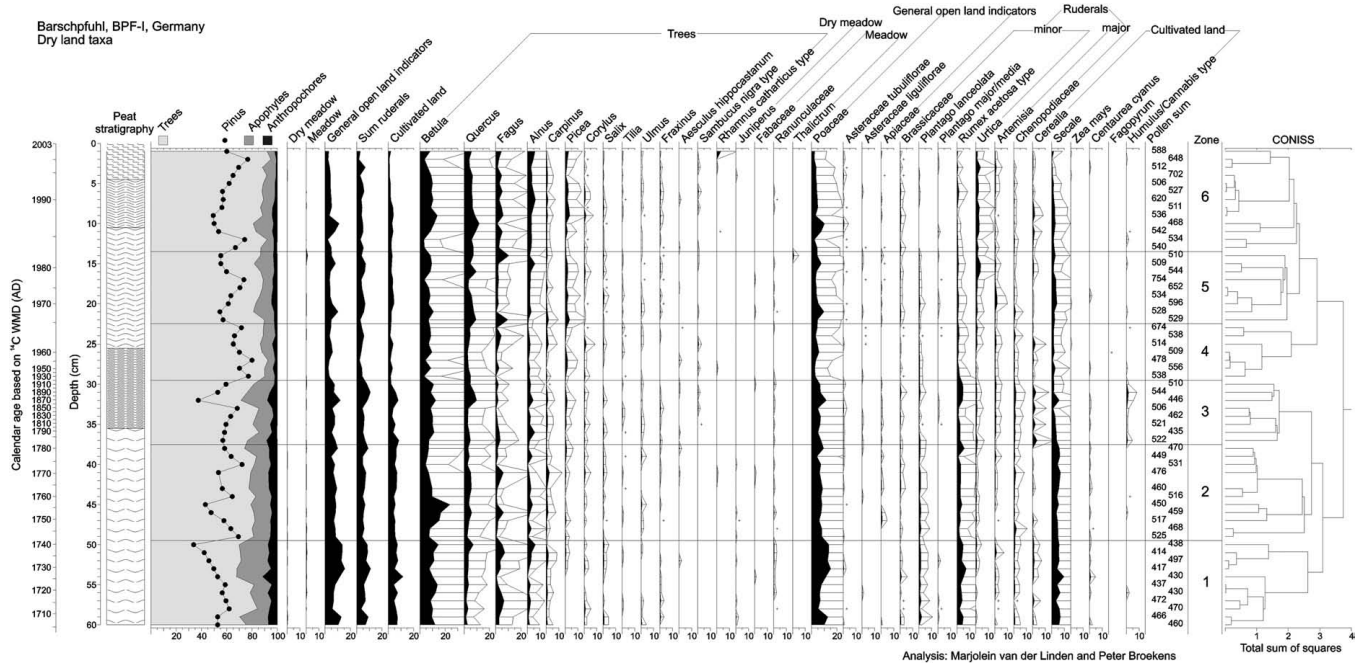

Fig. 5. Pollen percentage diagram of regional vegetation (dry land taxa) of Barschpfuhl. Omitted taxa are named in Appendix B. The black silhouettes show the percentage curves of all taxa, the depth bar filled silhouettes show the five times exaggeration curves. The legend is described in Fig. 3.

Author's personal copy

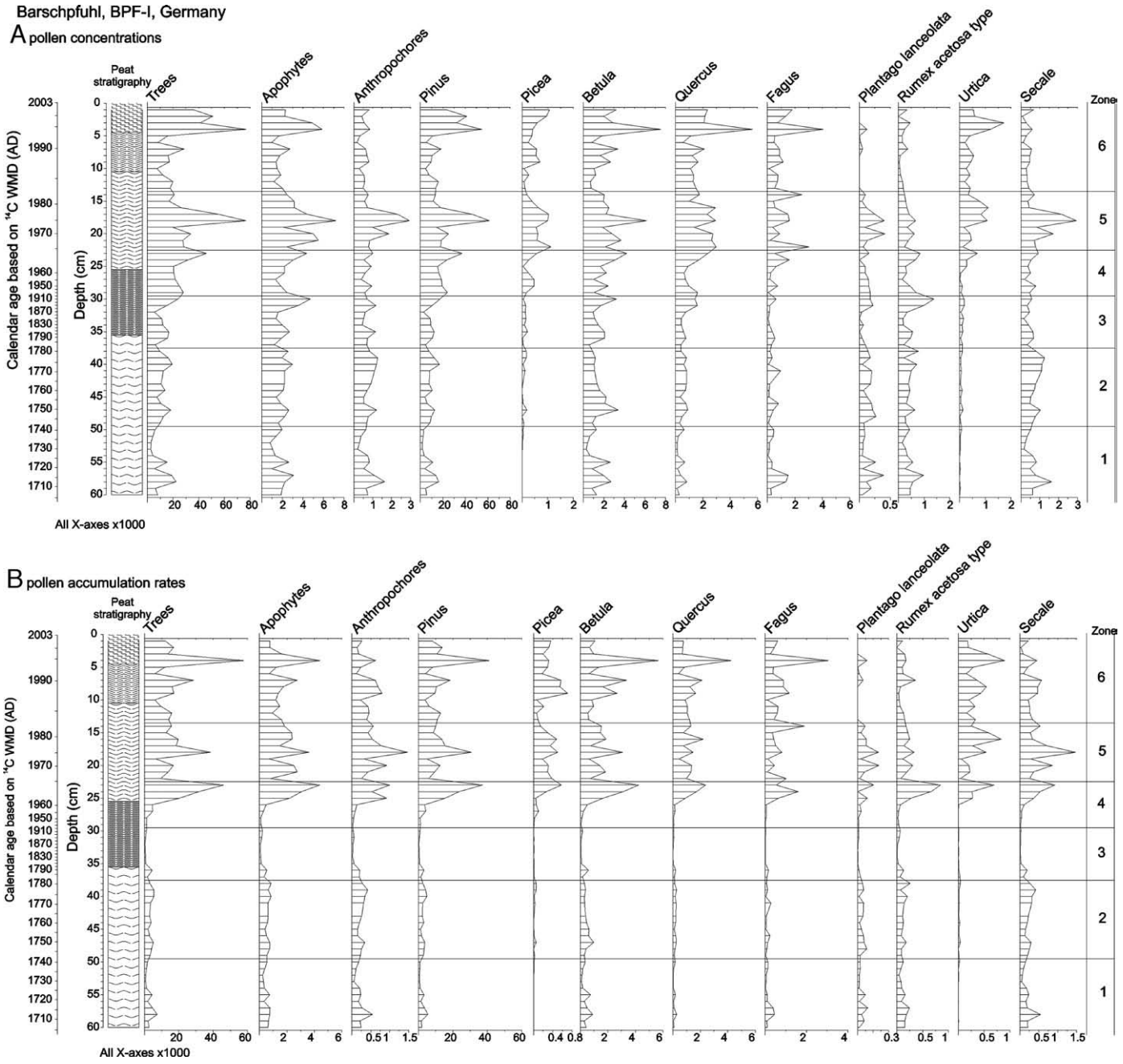

Fig. 6. (A) Pollen concentrations and (B) pollen accumulation rates (PAR) of regional vegetation (dry land taxa) of Barschpfuhl. The legend described in Fig. 3.

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

Barschpfuhl regional microfossil zones	PAR		
	Pinus sylvestris	*Picea abies*	*Betula*
6 (1982–2003)	DF	(Pbs-)DF	DF
5 (1964–1982)	DF	DF-OF-Pbs	DF
4 (1920–1964)	OF-DF	NP1-Pbs-DF	NP1-DF
3 (1780–1920)	NP1-OF	NP10	NP1-Pbs
2 (1740–1780)	OF-DF	NP1-Pbs	NP1-Pbs
1 (1705–1740)	OF-DF	NP1	NP1-Pbs

Author's personal copy

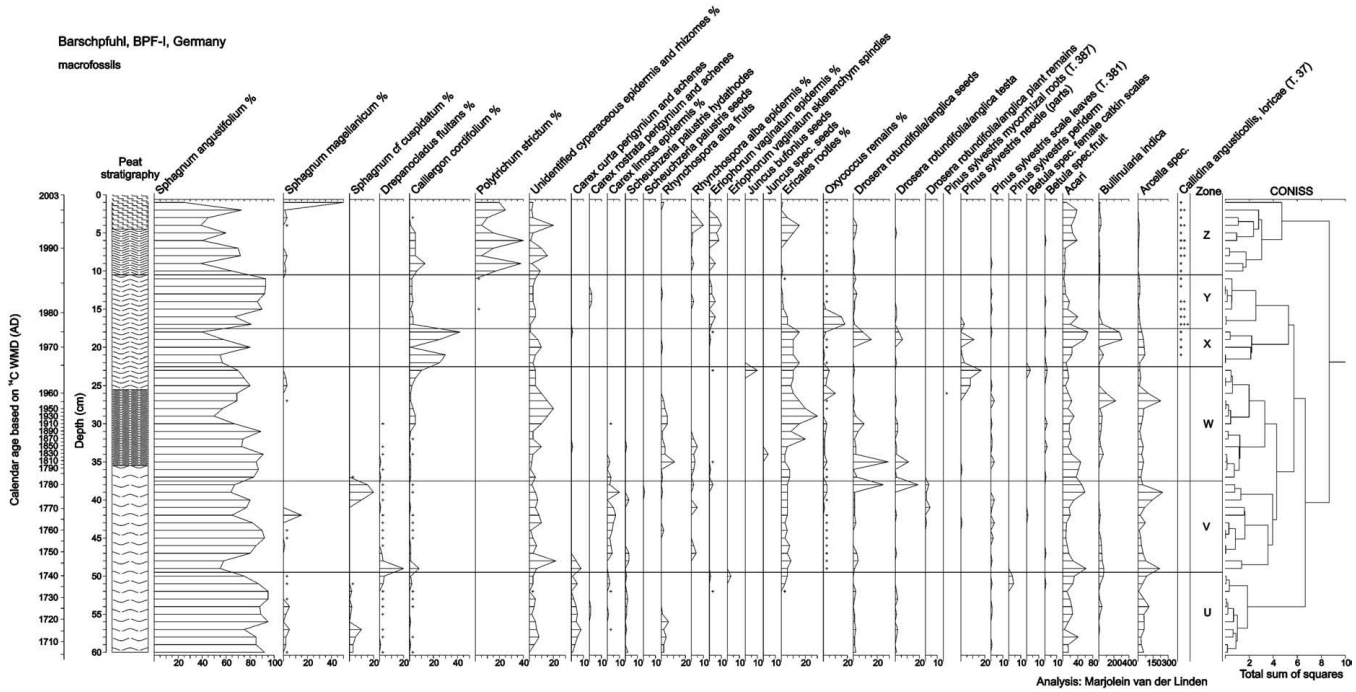

Fig. 7. Macrofossil diagram (local wetland vegetation) of Barschpfuhl. Omitted taxa are named in Appendix B. The legend is described in Fig. 3.

Author's personal copy

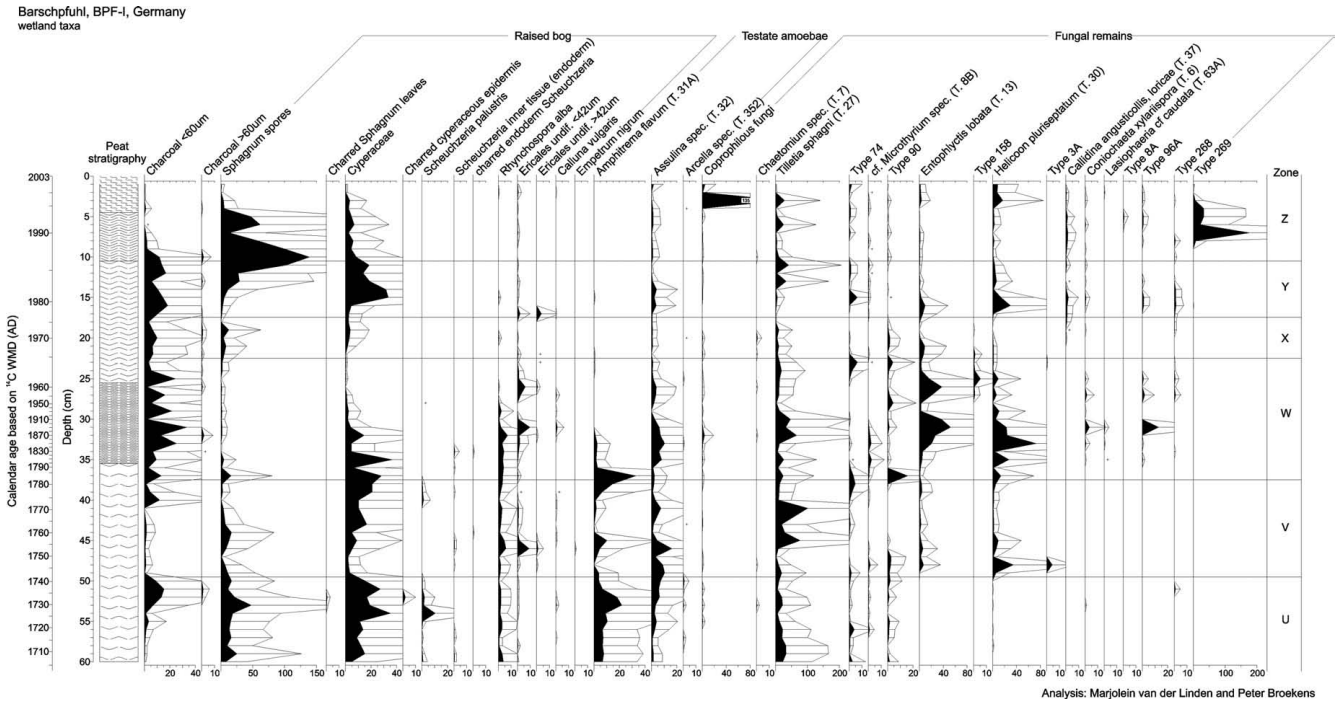

Fig. 8. Diagram of local wetland taxa (pollen and non-pollen palynomorphs) of Barschpfuhl. Some testate amoebae were counted in the pollen slides. See Fig. 9 for complete testate amoebae analysis. Omitted taxa are named in Appendix B. The legend is described in Fig. 3.

Author's personal copy

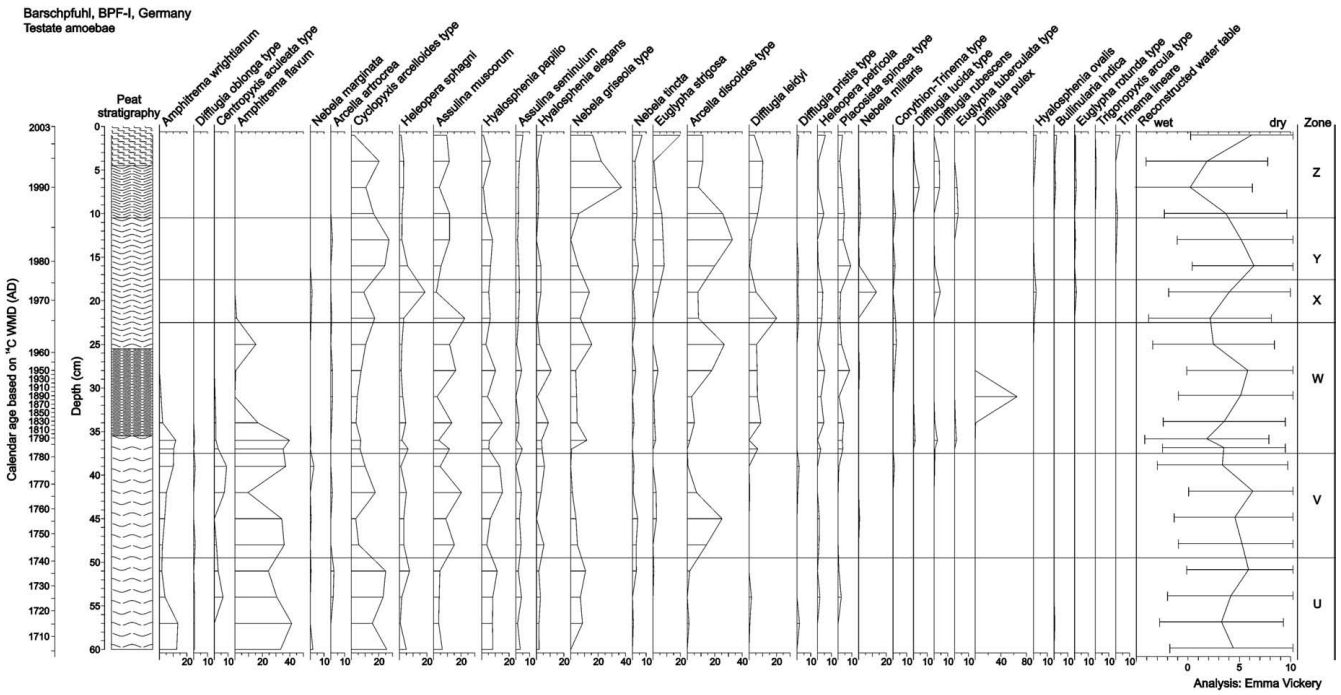

Fig. 9. Testate amoebae (main taxa) and reconstructed water table of Barschpfuhl. The legend is described in Fig. 3.

Author's personal copy

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 the peat 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 *Fagopyrum* 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 ^{14}C-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 dominated by coniferous forest vegetation and low anthropochore 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 broadleaved 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 1988, 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 peat 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 (Autio 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 amoebae 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). Perichynia and achenes of *Carex curta* are present which indicate mesotrophic acid conditions. Also the oligotraphentous taxa *Carex limosa*, *Scheuchzeria palustris* and *Rhynchospora alba* were recorded. *Amphitrema wrightianum* and *A. flavum* dominate the testate amoebae composition. Both species show a decrease towards the top of the zone while *Cyclopyxis arcelloides* type and *Nebela griseola* 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
Barschpfuhl vegetation succession described following Succow and Stegmann (2001) with trophy status based on Nc and C/N ratio

Macrofossil zone		Nc	C/N ratio	Trophy status
Z (1986–2003)	Max	2.22	61.56	Oligotrophic
	Average	1.94	52.15	Acid
	Min	1.62	45.07	Very poor
Y (1977–1986)	Max	2.13	68.29	Oligotrophic
	Average	1.80	56.38	Acid
	Min	1.46	46.87	Very poor
X (1964–1977)	Max	2.62	55.03	Oligotrophic
	Average	2.09	48.60	Acid
	Min	1.82	38.10	Poor*–very poor
W (1780–1964)	Max	2.30	61.41	Oligotrophic
	Average	2.02	49.89	Acid
	Min	1.63	43.51	Very poor
V (1740–1780)	Max	2.04	75.85	Oligotrophic
	Average	1.78	57.22	Acid
	Min	1.32	48.91	Very poor
U (1705–1740)	Max	1.96	74.16	Oligotrophic
	Average	1.70	59.81	Acid
	Min	1.35	50.92	Very poor

*1963–1964.

Author's personal copy

Table 5
Barschpfuhl vegetation succession described following Succow and Stegmann (2001) with trophy level based on vegetation composition

Macrofossil zone	Moss species	Monocots	Oxyc.	Pine	Trophy status	Mire community type
Z (1986–2003)	*P. strictum* *S. magellanicum* *C. cordifolium*	*E. vaginatum* *R. alba*	+	−+	Oligo-meso acid	*E. vaginatum–S. recurvum*
Y (1977–1986)	*C. cordifolium*	*E. vaginatum* *C. rostrata* *R. alba*	++	++	Oligo-meso acid-baserich	*Pinus sylvestris–S. magellanicum* *E. vaginatum–S. recurvum*
X (1964–1977)	*C. cordifolium*	*C. curta* *R. alba*	+	−+	Oligo-meso acid-baserich	*Pinus sylvestris–S. magellanicum* *E. vaginatum–S. recurvum*
W (1780–1964)	*C. cordifolium* *S. magellanicum* *D. fluitans*	*R. alba* *C. limosa* *J. bufonius**	++	++	Oligo-meso acid-baserich (*Eutroph)	*P. sylvestris–S. magellanicum* **S. recurvum–J. effuses*
V (1740–1780)	*S. magellanicum* *S.* cf. *cuspidatum* *D. fluitans* *C. cordifolium*	*C. limosa* *S. palustris* *R. alba* *C. curta*	+	−+	Oligo acid	*S. magellanicum* *S. cuspidatum–C. limosa*
U (1705–1740)	*S. magellanicum* *S.* cf. *cuspidatum* *D. fluitans* *C. cordifolium*	*C. curta* *S. palustris* *R. alba* *C. rostrata* *C. limosa*	−	+	(Oligo) meso acid	*S. magellanicum* *S. cuspidatum–C. limosa*

Waterregime T: topogene; O: ombrogene;*1963–1964; −: not present; −+: hardly present; +: present; ++: many findings.

Also 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. *Amphitrema 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. Contemperaneously 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. *Amphitrema flavum* decreases and *A. wrightianum* disappears. *Difflugia 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).

3.4.2.4. 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). *Difflugia leidyi* and *Heleopora sphagni* show high numbers and the presence of *Hyalosphenia ovalis* may indicate input of minerogenic groundwater.

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 militaris, Corythion-Trinema* type, *Hyalosphenia ovalis* and *Euglypha rotunda* type. Driest 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*, *Euglypha rotunda* type, *Trigonopyxis 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*, *Cercophora* 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 (Lutze, 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

Author's personal copy

percentages of Poaceae, *Plantago lanceolata* and the presence of *Juniperus*. 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) indicated by the high percentages of non-arboreal taxa. This is in agreement with the fact that drawings and paintings of the Angermünde and Eberswalde area dating from the 17th and 18th century hardly show any trees and shrubs in the cultural landscape (Lutze, 2003).

By the end of the 18th century the Uckermark region had become the main grain source area for Berlin. To keep up with the demand, an expansion and improvement of agricultural fields was necessary. This was called the "große Melioration" in German. In total c. 230,000 ha of wetland in Brandenburg was made arable and c. 300,000 people immigrated there (Lutze, 2003). Many new villages arose, e.g. Neu-Barnim and Neureetz. Between 1800 and 1870 the German population doubled. The Angermünde–Eberswalde region shows an increase in population from 12,000 to 32,000 residents (see Fig. 10). This may be represented in the Barschpfuhl pollen record as an increase in Cerealia, Chenopodiaceae, Poaceae, *Humulus/Cannabis* and *Plantago major/media* (pollen zone 3), although total cultivated land percentages decrease, as a result of reforestation in the area. The decrease in NAP and openness in the Barschpfuhl pollen record at the start of pollen zone 4 may reflect the overall decrease in population which occurred between the late 1930 s and the early 1950s. After the Second World War many refugees came to the area. In name of the 'anti fascism-democratic revolution' (antifaschistisch-demokratischen Umgestaltung in German) all the farmland, which was in the hands of 112 landlords, was divided in small pieces and given to 4681 farmers. From 1950–1975 a sharp decrease in small villages and a population increase in cities occurred, with an overall increase of c. 20,000 residents. Openness slowly increases in the pollen record. After 1990 both the population in small villages slowly increased but overall the population decreased rapidly to c. 65,000 residents in 2002 (Lutze, 2003). The political change and unification of Germany at the end of 1989 had far-reaching social consequences. The number of persons employed in agriculture decreased to only one third of the number before 1990 (Lutze, 2003). Also a change in land use to a more multi-functional landscape with tourism and nature conservation commenced. This is reflected in the cultivated land pollen percentages of Barschpfuhl which have decreased since c. AD 1990 when land use changed and Schorfheide–Chorin became a UNESCO nature reserve (Lutze, 2003).

4.2. Impact of Pinus monocultures on the mire surface

Large kettlehole mires of 0.5–2 ha are usually oligotrophic with ombrotrophic parts (Timmermann and Succow, 2001). Barschpfuhl is c. 2 ha and shows oligotrophic acid to mesotrophic acid to occasionally base rich conditions. The vegetation is comparable with Grosse Mooskute and Kreuzfenn in Brandenburg (Timmermann and Succow, 2001) with *Polytrichum* at the borders and *Eriophorum vaginatum* and *Pinus sylvestris* in the central part of the mire. The vegetation development over the last 300 years shows a change from relatively oligotrophic (ombrogenic–topogenic) wet to more mesotrophic (topogenic) and drier conditions. Succession within mire vegetation communities can be classified starting as a *Sphagnum cuspidatum–Carex limosa*-community and *Sphagnum magellanicum*-community developing to a *Pinus sylvestris–Sphagnum magellanicum*-community (briefly *Sphagnum recurvum–Juncus effusus*-community at c. AD 1963–1964) to a *Eriophorum vaginatum–Sphagnum recurvum*-community in recent years (Koska et al., 2001).

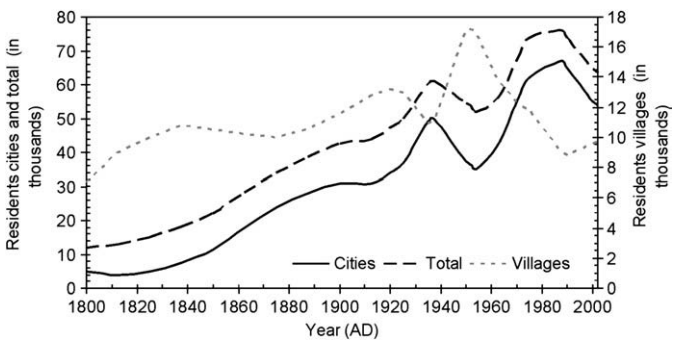

Fig. 10. Population history for cities and small villages in Angermünde–Eberswalde area, redrawn after Lutze, 2003.

The local wetland and regional dry land pollen and macrofossil assemblage zones created with the CONISS program show the same 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 decomposition 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 ^{14}C 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

Author's personal copy

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 ^{14}C 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 *Calliergon 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 be related to land use, e.g. open forest used for grazing (*Waldweide*). 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 ^{14}C 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, BvG) and European Union Framework V (ACCROTELM EVK2-CT-2002-00166, EV, DC).

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

Sample depth	Year AD	Sample depth	Year AD
1	2003.0	31	1889.5
2	2000.0	32	1869.0
3	1997.0	33	1848.5
4	1994.0	34	1828.0
5	1992.7	35	1807.5
6	1991.3	36	1787.0
7	1990.0	37	1783.5
8	1989.0	38	1780.0
9	1988.0	39	1777.0
10	1987.0	40	1774.0
11	1985.8	41	1770.5
12	1984.5	42	1767.0
13	1983.3	43	1763.5
14	1982.0	44	1760.0
15	1980.7	45	1756.5
16	1979.3	46	1753.0
17	1978.0	47	1749.5
18	1975.0	48	1746.0
19	1973.0	49	1743.0
20	1970.0	50	1740.0
21	1968.0	51	1736.5
22	1966.0	52	1733.0
23	1963.0	53	1729.5
24	1962.0	54	1726.0
25	1961.0	55	1722.5
26	1960.0	56	1719.0
27	1955.5	57	1716.0
28	1951.0	58	1712.0
29	1930.5	59	1709.0
30	1910.0	60	1706.0

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. Arboreal 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

Author's personal copy

Ambrosia type: 11 cm: 0.2%
Echium: 10 cm: 0.2; 15 cm: +
Polygonum aviculare type: 5 and 52 cm: 0.2%
Mercurialis annua type: 11 cm: +, 17 cm: 0.1%; 29, 34 and 39 cm: 0.2%
cf. *Sanguisorba officinalis*: 57 cm: 0.2%
cf. *Verbascum* spec. 12 and 13 cm: 0.2%
Cultivated land
Helianthus annuus: 5 cm: 0.2%
Symphytum officinale type: 30 cm: 0.2%
Exotics
Ephedra fragilis type: 36 cm: 0.2%
cf. *Ostrya carpinifolia*: 13 cm: 0.2%
Pteridophytes
Pteridium: 4 cm: +, 14 cm: 0.2%; 15 cm: 0.2%; 23 cm: 0.1%
Monolete psilate: 1, 5, 6, 8, 35, 41, 45 and 60 cm: 0.2%; 4 cm: 0.3%; 7, 9, 11 and 32 cm: +, 17 cm: 0.1%; 19 cm: 0.4%;
Monolete verrucate: 16 cm: 0.2%
Fen and *marsh*
Filipendula: 3, 7, 8, 9, 14, 16, 26, 31, 39, 43, 54 and 55 cm: 0.2%; 4, 15, 16, 23 and 25 cm: +; 10 and 44 cm: 0.6%, 36 and 49 cm: 0.4%; 51 cm: 0.5%; 53 cm: 0.3%
cf. *Hippuris vulgaris*: 27 cm: 0.2%
Hydrocotyle vulgaris: 32 cm: 0.2%
cf. *Lysimachia*: 43 cm: 1%
cf. *Nymphaea*: 14 cm: +
Potentilla type: 4 cm: +; 45 and 51 cm: 0.2%
Rumex hydrolapathum type: 2 cm: 0.2%
Sparganium: 53 cm: 0.2%
Typha angustifolia: 16, 25 and 33 cm: 0.2%
Typha latifolia: 3, 24, 31, 48 and 49: 0.2%; 7 cm: +
C. Macrofossils:
Sphagnum opercula: regularly present
Scheuchzeria palustris epidermis: 36, 47 and 54 cm: 1%; 39, 46, 50, 51, 52 and 53 cm: +; 40, 48 and 60 cm: 3%; 49 and 59 cm: 4%; 55 and 57 cm: 5%
Eriophorum vaginatum stems: 50 cm: 1
Eriophorum spec. fruits: 19 cm: 2; 53 cm: 1
Oxycoccus/*Andromeda* leaves: 14 cm: 13; 22 cm: 1; 43 cm: 10; 44 cm: 3; 45 cm: 4
Oxycoccus/*Andromeda* branches: 14 cm: 3; 20 cm: 1
Vaccinium/*Oxycoccus* seeds: 26 cm: 2
Vaccinium spec. berry: 11 cm: 1; 13 cm: 1; 24 cm: 1
Ericaceae inflorescence: 20 cm: 1; 26 cm: 5; 51 cm: 3
Ericaceae branches: 9 and 11 cm: 1; 15 cm: 2
Sporormiella fruitbody with ascospores: 1 cm: 1

References

Aaby, B., Tauber, H., 1975. Rates of peat formation in relation to degree of humification and local environment as shown by studies of a raised bog in Denmark. Boreas 4, 1–17.

Autio, J., Hicks, S., 2004. Annual variations in pollen deposition and meteorological conditions on the fell Aakenustunturi in northern Finland: potential for using fossil pollen as a climate proxy. Grana 43 (1), 31–47.

Barnekow, L., Loader, N.J., Hicks, S., Froyd, C.A., Goslar, T., 2007. Strong correlation between summer temperature and pollen accumulation rates for *Pinus sylvestris*, *Picea abies* and *Betula* spp. in a high-resolution record from northern Sweden. Journal of Quaternary Science 22 (7), 653–658.

Behre, K.-E. (Ed.), 1986. Anthropogenic indicators in pollen diagrams. A. A. Balkema, Rotterdam, Boston.

Bennett, K.D., Hicks, S., 2005. Numerical analysis of surface and fossil pollen spectra from northern Fennoscandia. Journal of Biogeography 32 (3), 407–423.

Berglund, B.E. (Ed.), 1986. Handbook of Palaeoecology and Palaeohydrology. John Wiley and sons, New York.

Beug, H.J., 2004. Leitfaden der Pollenbestimmung für Mitteleuropa und angrenzende Gebiete. Verlag Dr. Friedrich Pfeil, München.

Blaauw, M., Heuvelink, G.B.M., Mauquoy, D., van der Plicht, J., van Geel, B., 2003. A numerical approach to ^{14}C wiggle-match dating of organic deposits: best fits and confidence intervals. Quaternary Science Reviews 22, 1485–1500.

Blaauw, M., van Geel, B., Mauquoy, D., van der Plicht, J., 2004. Carbon-14 wiggle-match dating of peat deposits: advantages and limitations. Journal of Quaternary Science 19 (2), 177–181.

Blackford, J.J., Chambers, F.M., 1993. Determining the degree of decomposition for peat based palaeoclimatic studies. International Peat Journal 5, 7–24.

Blackford, J.J., Chambers, F.M., 1995. Proxy climate record for the last 1000 years from Irish blanket peat and a possible link to solar variability. Earth and Planetary Science Letters 133 (1–2), 145–150.

Broström, A., Sugita, S., Gaillard, M.-J., Pilesjö, P., 2005. Estimating spatial scale of pollen dispersal in the cultural landscape of Southern Sweden. The Holocene 15, 1–14.

Caseldine, C.J., Baker, A., Charman, D.J., Hendon, D., 2000. A comparative study of optical properties of NaOH peat extracts: implications for humification studies. The Holocene 10, 649–658.

Charman, D.J., 2007. Summer water deficit controls on peatland water table changes: implications for Holocene palaeoclimate reconstructions. The Holocene 17, 217–227.

Charman, D.J., Blundell, A., ACCROTELM-members, 2007. A pan-European testate amoebae transfer function for palaeohydrological reconstruction on ombrotrophic peatlands. Journal of Quaternary Science 22 (3), 209–221.

Charman, D.J., Hendon, D., Woodland, W.A., 2000. The identification of Testate Amoebae (Protozoa: Rhizopoda) in peats. QRA Technical Guide, vol. 9. Quaternary Research Association, London. 147 pp.

Ebert, W., Hofmann, G., Schlaak, N., Loose, R., Suter, H., 2001. Natur und Geschichte der Schorfheide. Entdeckungen entlang der Märkische Eiszeitstrasse, 6. Gesellschaft zur Erforschung und Förderung der Märkische Eiszeitstrasse e.V., Eberswalde. 84 pp.

Fægri, K., Iversen, J., 1989. Textbook of pollen analysis. John Wiley, Chichester.

Goodsite, M.E., Rom, W., Heinemeier, J., Lange, T., Ooi, S., Appleby, P.G., Shotyk, W., van der Knaap, W.O., Lohse, C., Hansen, T.S., 2001. High-resolution AMS ^{14}C dating of post-bomb peat archives of atmospheric pollutants. Radiocarbon 43 (2B), 495–515.

Goslar, T., van der Knaap, W.O., Hicks, S., Andric, M., Czernik, J., Goslar, E., Rasanen, S., Hyotyla, H., 2005. Radiocarbon dating of modern peat profiles: Pre- and post-bomb C-14 variations in the construction of age-depth models. Radiocarbon 47 (1), 115–134.

Grimm, E.C., 1987. CONISS: a fortran 77 program for stratigraphically constrained cluster analyses by the method of incremental sum of squares. Computers and Geosciences 13, 13–35.

Grimm, E.C., 1990. TILIA and TILIA GRAPH PC spreadsheet and graphics software for pollen data. INQUA commission for study of the Holocene. Sub-comission on data-handling methods. Newsletter 4, 5–7.

Grosse-Brauckmann, G., 1972. Über pflanzliche Makrofossilien mitteleuropäischer Torfe - I. Gewebereste krautiger Pflanzen und ihre Merkmale. Telma 2, 19–55.

Grosse-Brauckmann, G., 1974. Über pflanzliche Makrofossilien mitteleuropäischer Torfe - II. Weitere Reste (Früchte und Samen, Moose, U.A.) und ihre Bestimmungsmöglichkeiten. Telma 4, 51–177.

Grosse-Brauckmann, G., 1986. Analysis of vegetative plant macrofossils. In: Berglund, B.E. (Ed.), Handbook of Holocene Palaeoecology. John Wiley and sons, Chichester, pp. 591–618.

Heijmans, M.M.P.D., Mauquoy, D., van Geel, B., Berendse, F., 2008. Long-term effects of climate change on vegetation and carbon dynamics in peat bogs. Journal of Vegetation Science 19 (3), 307–320.

Hendon, D., Charman, D.J., 1997. The preparation of testate amoebae (Protozoa: Rhizopoda) samples from peat. Holocene 7 (2), 199–205.

Hicks, S., 2001. The use of annual arboreal pollen deposition values for delimiting tree-lines in the landscape and exploring models of pollen dispersal. Review of Palaeobotany and Palynology 117 (1–3), 1–29.

Hicks, S., Sunnari, A., 2005. Adding precision to the spatial factor of vegetation reconstructed from pollen assemblages. Plant Biosystems 139 (2), 127–134.

Johansson, P., 1995. Vitmossor i Norden. Vasastadens Bokbinderi AB, Göteborg.

Johnson, L.C., Damman, A.W.H., Malmer, N., 1990. *Sphagnum* macrostructure as an indicator of decay and compaction in peat cores from an ombrotrophic South Swedish peat-bog. Journal of Ecology 78 (3), 633–647.

Joosten, J.H.J., Couwenberg, J., 2001. Bilanzen zum Moorverlust. Das Beispiel Europa. In: Succow, M., Joosten, J.H.J. (Eds.), Landschaftsökologische Moorkunde. E. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart, p. 622 (section 8.2).

Katz, N.J., Katz, S.V., Kipiani, M.G., 1965. Atlas and keys of fruits and seeds occurring in the Quaternary deposits of the USSR. Publishing House Nauka, Moscow. (in Russion).

Kilian, M.R., van Geel, B., van der Plicht, J., 1995. Dating raised bogs: new aspects of AMS ^{14}C wiggle matching, a reservoir effect and climatic change. Quaternary Science Reviews 14, 959–966.

Kilian, M.R., van Geel, B., van der Plicht, J., 2000. ^{14}C AMS wiggle matching of raised bog deposits and models of peat accumulation. Quaternary Science Reviews 19, 1011–1033.

Koska, I., Succow, M., Timmermann, T., 2001. Vegetationsformen der offenen, naturnahen Moore und des aufgelassenen Feuchtgrünlandes. In: Succow, M., Joosten, J.H.J. (Eds.), Landschaftsökologische Moorkunde. E. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart, p. 622 (section 4.3.1).

Lean, J., 2000. Evolution of the sun's spectral irradiance since the Maunder Minimum. Geophysical Research Letters 27 (16), 2425–2428.

Lean, J., 2004. Solar irradiance reconstruction. IGBP PAGES/world data center for paleoclimatology, data contribution series # 2004-035. NOAA/NGDC Paleoclimatology Program, Boulder CO, USA.

Levin, I., Hesshaimer, V., 2000. Radiocarbon, the unique tracer of global carbon cycle dynamics. Radiocarbon 42, 69–80.

Author's personal copy

Levin, I., Kromer, B., Schoch-Fischer, H., Bruns, M., Münnich, M., Berdau, D., Vogel, J.C., Münnich, K.O., 1994. Delta $^{14}CO_2$ records from two sites in central Europe. In: Boden, T.A., Kaiser, D.P., Sepanski, R.J., Stoss, F.W. (Eds.), Trends 93 — A compendium of data on global change. Oak Ridge National Laboratory: Carbon Dioxide Information Analysis Centre, Oak Ridge, pp. 203–222.

Lutze, G., 2003. Landschaft um Wandel — der Nordosten Brandenburgs vom 17. Jahrhundert bis heute. Entdeckungen entlang der Märkischen Eiszeitstrasse, 8. Gesellschaft zur Erforschung und Förderung der Märkischen Eiszeitstrasse e.V., Eberswalde. 78 pp.

Masarik, J., Beer, J., 1999. Simulation of particle fluxes and cosmogenic nuclide production in the Earth's atmosphere. Journal of Geophysical Research-Atmospheres 104 (D10), 12099–12111.

Mauquoy, D., Engelkes, T., Groot, M.H.M., Markesteijn, F., Oudejans, M.G., van der Plicht, J., van Geel, B., 2002a. High resolution records of late-Holocene climate change and carbon accumulation in two north-west European ombrotrophic peat bogs. Palaeogeography, Palaeoclimatology, Palaeoecology 186, 275–310.

Mauquoy, D., van Geel, B., 2007. Mire and peat macros. In: Elias, S.A. (Ed.), Encyclopedia of Quaternary Science. Elsevier, Oxford, pp. 2315–2336.

Mauquoy, D., van Geel, B., Blaauw, M., van der Plicht, J., 2002b. Evidence from northwest European bogs shows 'Little Ice Age' climatic changes driven by variations in solar activity. The Holocene 12 (1), 1–6.

Middeldorp, A.A., 1982. Pollen concentration as a basis for indirect dating and quantifying net organic production in peat bog system. Review of Palaeobotany and Palynology 37, 225–282.

MLUV, 2004. Berichte aus der Arbeit 2000, http://www.mluv.brandenburg.de/cms/detail.php/183298.

Moore, P.D., Webb, J.A., Collinson, M.E., 1991. Pollen analysis. Blackwell, London.

Muscheler, R., Joos, F., Beer, J., Müller, S.A., Vonmoos, M., Snowball, I., 2007. Solar activity during the last 1000 yr inferred from radionuclide records. Quaternary Science Reviews 26 (1–2), 82–97.

Nilsson, M., Klarqvist, M., Bohlin, E., Possnert, G., 2001. Variation in C-14 age of macrofossils and different fractions of minute peat samples dated by AMS. Holocene 11 (5), 579–586.

Poska, A., Saarse, L., Veski, S., 2004. Reflections of pre- and early-agrarian human impact in the pollen diagrams of Estonia. Palaeogeography, Palaeoclimatology, Palaeoecology 209 (1–4), 37–50.

Schlaak, N., 1999. Nordostbrandenburg — Entstehungsgeschichte einer Landschaft. Entdeckungen entlang der Märkischen Eiszeitstrasse, 1. Gesellschaft zur Erforschung und Förderung der Märkischen Eiszeitstrasse e.V., Eberswalde. 48 pp.

Sillasoo, U., Mauquoy, D., Blundell, A., Charman, D., Blaauw, M., Daniell, J.R.G., Toms, P., Newberry, J., Chambers, F.M., Karofeld, E., 2007. Peat multi-proxy data from Mannikjärve bog as indicators of late Holocene climate changes in Estonia. Boreas 36 (1), 20–37.

Smith, A.J.E., 1978. The moss flora of Britain and Ireland. Cambridge University Press, Cambridge.

Speranza, A., van der Plicht, J., van Geel, B., 2000. Improving the time control of the Subboreal/subatlantic transition in a Czech peat sequence by ^{14}C wiggle-matching. Quaternary Science Reviews 19, 1589–1604.

Speranza, A., van der Plicht, J., van Geel, B., 2003. Evidence for solar forcing of climate change at ca. 850 cal BC from a Czech peat sequence. Global and Planetary Change 35, 51–65.

Stockmarr, J., 1971. Tablets with spores used in absolute pollen analysis. Pollen et Spores 13, 615–621.

Stuiver, M., Reimer, P.J., Braziunas, T.F., 1998. High-precision radiocarbon age calibration for terrestrial and marine samples. Radiocarbon 40, 1127–1151.

Succow, M., Stegmann, H., 2001. Nährstoffökologisch-chemische Kennzeichung. In: Succow, M., Joosten, J.H.J. (Eds.), Landschaftsökologische Moorkunde. E. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart, p. 622 (section 3.3).

Timmermann, T., Succow, M., 2001. Kesselmoore. In: Succow, M., Joosten, J.H.J. (Eds.), Landschaftsökologische Moorkunde. E. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart, p. 622 (section 7.7).

UNESCO-Biosphärenreservat, 2007. Natur und Landschaft, http://www.schorfheide-chorin.de/landschaft_index.htm.

van der Linden, M., van Geel, B., 2006. Late-Holocene climate change and human impact recorded in a south Swedish ombrotrophic peat bog. Palaeogeography, Palaeoclimatology, Palaeoecology 240, 649–667.

van der Linden, M., Barke, J., Vickery, E., Charman, D.J., van Geel, B., 2008a. Late Holocene human impact and climate change recorded in a North-Swedish peat deposit. Palaeogeography, Palaeoclimatology, Palaeoecology 258, 1–27.

van der Linden, M., Vickery, E., Charman, D.J., van Geel, B., 2008b. Effects of human impact and climate change during the last 350 years recorded in a Swedish raised bog deposit. Palaeogeography, Palaeoclimatology, Palaeoecology 262, 1–31.

van der Plicht, J., 1993. The Groningen radiocarbon calibration program. Radiocarbon 35, 231–237.

van Geel, B., 1978. A palaeoecological study of Holocene peat bog sections in Germany and The Netherlands. Review of Palaeobotany and Palynology 25, 1–120.

van Geel, B., Aptroot, A., 2006. Fossil ascomycetes in Quaternary deposits. Nova Hedwigia 82 (3–4), 313–329.

van Geel, B., Mook, W.G., 1989. High resolution ^{14}C dating of organic deposits using natural atmospheric ^{14}C variations. Radiocarbon 31, 151–155.

van Geel, B., Rasparov, O.M., Renssen, H., van der Plicht, J., Dergachev, V.A., Meijer, H.A.J., 1999. The role of solar forcing upon climate change. Quaternary Science Reviews 18, 331–338.

van Geel, B., Buurman, J., Brinkkemper, O., Schelvis, J., Aptroot, A., van Reenen, G., Hakbijl, T., 2003. Environmental reconstruction of a Roman period settlement site in Uitgeest (The Netherlands), with special reference to coprophilous fungi. Journal of Archaeological Science 30, 873–883.

Wardenaar, E.C.P., 1987. A new handtool for cutting soil monoliths. Canadian Journal for Soil Sciences 67, 405–407.

Werner, P.C., Gerstengarbe, F.-W., Lahmer, P., Suckow, F., Weschung, F., 2005. Klima, Klimaänderungen und deren Auswirkungen im Gebiet der Märkischen Eiszeitstrasse. Entdeckungen entlang der Märkischen Eiszeitstrasse, 10. Gesellschaft zur Erforschung und Förderung der Märkischen Eiszeitstrasse e.V. 53 pp.

Yeloff, D., Mauquoy, D., 2006. The influence of vegetation composition on peat humification: implications for palaeoclimatic studies. Boreas 35 (4), 662–673.