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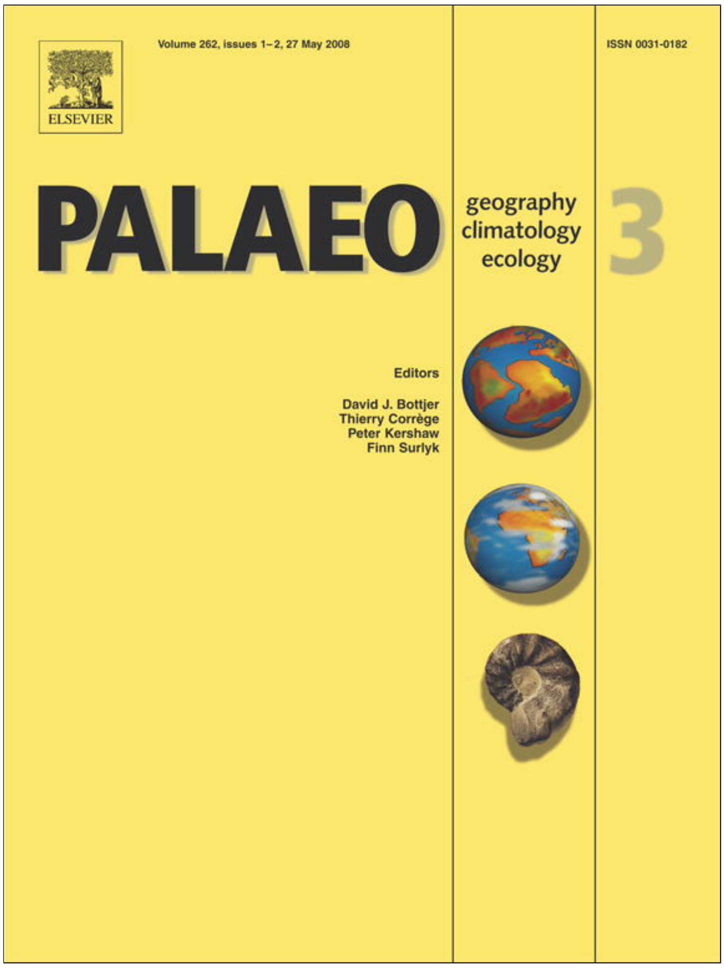

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Effects of human impact and climate change during the last 350 years recorded in a Swedish raised bog deposit

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

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Abstract

A peat core from an ombrotrophic mire in central Sweden was analysed for multi-proxy indicators (plant macrofossils, pollen/non-pollen microfossils, testate amoebae, colorimetric humification, carbon/nitrogen ratios, bulk densities, loss on ignition), to evaluate the relative contributions of climate change and human impact on vegetation and peat accumulation during the last c. 350 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. Changes in mire surface wetness were mainly caused by climate change (precipitation and evaporation), but the internal dynamics of the local bog vegetation may also have played a role in the recorded water table changes. The human impact signal in the pollen data was compared with Swedish population and land-use data. A link between climate change, human impact (openness of the vegetation) and demographic change was found. Cold and wet periods show a decrease in human impact and open land indicators in the pollen data, followed by an increase in death rate and/or an increase in emigration.

Keywords: ^{14}C AMS wiggle-match dating; Atmospheric bomb pulse; Ombrotrophic mire; Little Ice Age; Human impact; Pollen; Macrofossils; Testate amoebae; Sweden

1. Introduction

A key question in palaeoenvironmental research is the extent to which past changes in landscape and ecology were driven by climate, and to what extent they are a function of human impact. Multi-proxy and sometimes multi-archive studies are required to address this issue. For ombrotrophic bogs, data on changing hydrological conditions can be derived from remains in the peat such as plant macrofossils and testate amoebae. Because ombrotrophic bogs receive their water only from precipitation, changes in hydrological status are thought to be primarily a reflection of climate. Pollen analysis of the peat provides a record of local and regional landscape changes in the area, which can be directly correlated with the palaeoclimate records from other remains.

In order to assess the relationships between climate change, landscape and human impact, we have undertaken a series of multi-proxy studies on peatland sites in Sweden and northern Germany (van der Linden and van Geel, 2006; van der Linden et al., 2008). A key element in this work has been high precision dating using wiggle-matched ^{14}C analyses, including over the 'bomb-spike' period after AD 1950. Most Swedish raised bogs have a relatively undisturbed peat growth history in comparison to other Northwest European bog ecosystems. Swedish bogs are therefore suitable research sites to study changes in vegetation history and the relationship with climate change and human impact over the last 3–400 years. Proxy data derived from these studies can be used to test models that simulate and predict past and future peat accumulation and related processes such as carbon sequestration (Heijmans et al., in press). This is a valuable information in the discussion about causes and effects of climate change, global warming and the role of greenhouse gases.

The aim of the study reported in this paper was to reconstruct late Holocene landscape and climate change from a peatland in central east Sweden and to explore the linkages between climate, landscape and human impact. This is a particularly suitable region for a study of this kind because of the availability of suitable peat deposits, a long meteorological record and a well-known population,

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* Corresponding author. Tel.: +31 20 5257666; fax: +31 20 5257832.
E-mail address: vanderlinden@biax.nl (M. van der Linden).

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agricultural and industrial history. We aimed to distinguish between direct effects of climate changes (temperature and precipitation) and effects by changing human activities, on the regional and local vegetation development. We analysed the plant species composition of 1 m of peat, cored in a raised bog in central Sweden. Testate amoebae analysis was used to infer changes in water table depths. To obtain a high-resolution reconstruction, terrestrial plant remains were dated by ^{14}C wiggle-matching (van Geel and Mook, 1989; van der Plicht, 1993; Kilian et al., 1995, 2000; Speranza et al., 2000; Blaauw et al., 2004; van der Linden and van Geel, 2006). This dating strategy was used to investigate the possible link between the changing species composition of the bog vegetation and climate change. Potential causes of climate change such as solar variations were also explored as the ^{14}C record also acts as a proxy for solar activity (Mauquoy et al., 2002b). The human impact signal in the regional pollen data was compared with the demographic and land-use data of Sweden in order to search for links between human population growth, land-use types and landscape development.

2. Materials and methods

2.1. Research site

Peat cores were taken with a Wardenaar corer (Wardenaar, 1987) from the ombrotrophic mire Åkerlänna Römosse (ARM), c. 30 km north–west of Uppsala, Sweden (60° 01′ 11.74″N, 17° 21′ 33.52″ E, Fig. 1). Åkerlänna Römosse has an oval shape; it is c. 1000–1300 m long and 600–800 m wide. It is the mire area of what was once a large fen and bog area called Bälinge Stormossen (Eriksson, 1912; Lennartsson et al., 1996). Nowadays, the surrounding area is mainly farmland. Two long ditches enclose the mire. These ditches were probably dug between AD 1716 and 1862 because they are visible on maps dating from AD 1862 but not on maps from AD 1716. Smaller ditches for peat cutting activities were dug east of the eastern ditch. Exploitation took place mainly during the period AD 1910–1920 but lasted until 1953 (Soro et al., 1999). During the Second World War peat cutting activity increased temporarily. After the peat cutting activities stopped in 1953 the ditches were not maintained. Around the mire a vegetation belt with *Pinus sylvestris* and *Picea abies* is present (margin forest zone), which gradually changes to *Ledum palustre* (syn. *Rhododendron tomentosum*) dominated shrubby vegetation. Small pine trees grow on the mire surface. The centre of the bog is open and appears unaffected by drainage. Small hollows and hummocks are present and *Sphagnum fuscum, S. balticum, S. cuspidatum, S. majus, S. magellanicum, S. lindbergii, S. rubellum, S. angustifolium* and *S. capillifolium* were observed in the field. Both cores were taken in the centre of the mire, at a transition between hummock and hollow vegetation. Each core was packed in two metal boxes of 50 cm and transported to the laboratory. Contiguous 1 cm thick sub-samples were taken from peat core ARM-I, which had a length of 96 cm. The second peat core was stored for possible future research.

2.2. Microfossil analyses

A cylindrical sampler was used to take microfossil samples of c. 0.8 cm^3, each from 1 cm thick horizontal slices from the peat core. A known amount of *Lycopodium* grains (c. 10,679 in one tablet) was added to the samples before being treated with KOH and acetolysed (Fægri and Iversen, 1989). The *Lycopodium* grains were used to calculate pollen concentrations (Stockmarr, 1971) and pollen accumulation rates (PAR ≈ pollen influx in grains cm^{-2} yr^{-1} (Middeldorp, 1982; Autio and Hicks, 2004). 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 et al., 2003; van Geel and Aptroot, 2006) 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, shrubs and herbs. Herbs

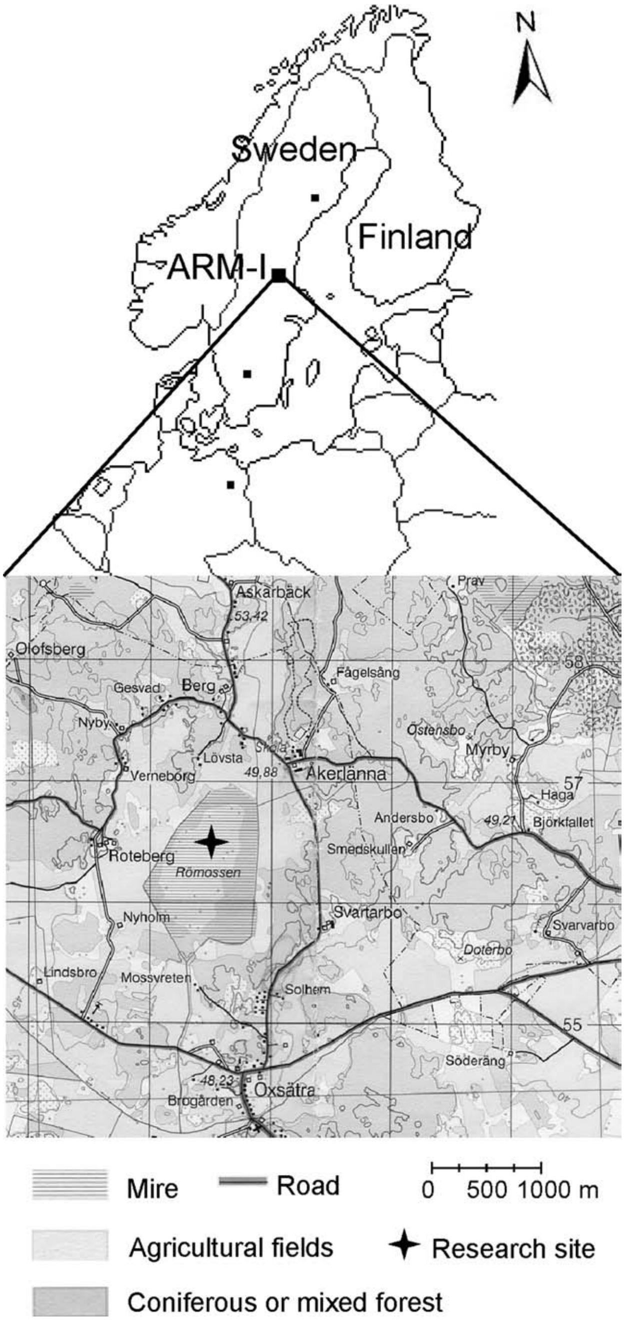


Fig. 1. Location map of Åkerlänna Römosse.

and shrubs 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. Pollen type *Humulus*/*Cannabis* is characterized as anthropochorous because *Humulus* (hop) and *Cannabis* (hemp) were grown on farms since AD 1442 and the 16th century respectively (Engelmark et al., 1976). Diagrams were prepared using the TILIAGRAPH and CONISS programs (Grimm, 1990).

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), the key of macrolichens of Denmark, Finland, Norway and Sweden (Dahl and Krog, 1973), 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

Thirty six levels of the peat core were ^{14}C AMS dated. Only above-ground plant remains of *S. fuscum* were selected from the macrofossil samples (Kilian et al., 1995; Nilsson et al., 2001). Samples were cleaned to remove root material and fossil 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 the samples were radiocarbon dated.

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

Type of indicator	Land-use category	Taxa
Anthropochores	Cultivated land	*Centaurea cyanus*
		Cerealia (non-*Secale*)
		Humulus/Cannabis
		Secale
		Symphytum officinale
Apophytes	Ruderals (minor[a])	Brassicaceae
		Plantago lanceolata
		Plantago major/media
		Rumex acetosa type
		Urtica
	Ruderals (major[b])	*Artemisia*
		Chenopodiaceae
	Meadow	Fabaceae
		Galium type
		Helianthemum spec.
		Ranunculaceae
	Open land	Apiaceae
		Asteraceae liguliflorae
		Asteraceae tubuliflorae
		Caryophyllaceae
		Poaceae
		Rosaceae undif.
	Dry meadow	*Juniperus*

[a] Differentiation on the basis of pollen production.

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 opposed to glycerol 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 in Fig. 8. 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

This technique is believed to represent a semi-quantitative measure of average summer effective rainfall (Blackford and Chambers, 1993, 1995), since the decomposition state is dependent on the time the plant remains take to pass from the biologically active acrotelm into the almost inert catotelm. 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 an 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). Therefore high transmission values (low absorption) indicate a fast passage of peat through the acrotelm and the reverse for peat samples that possess low transmission values (Mauquoy et al., 2002a,b). High transmission values should indicate a high average summer effective rainfall causing a relatively high water table in a raised bog. However, local species composition affects decomposition processes and decay products, the species effect (Chambers et al., 1997). This can be likely driven by internal dynamics or responses to external forcing (Mauquoy et al., 2002a,b). Recent studies combining humification with other proxies of mire surface wetness have identified inconsistencies between the records, and therefore this proxy should be interpreted with caution, especially where there are major changes in peat composition (Yeloff and Mauquoy, 2006). However, other multi-proxy studies show agreement between the humification data and other surface-moisture proxies (Sillasoo et al., 2007).

3. Results

3.1. Geochemical analyses

Results of the bulk density measurements (g cm^{-3}), degree of humification (transmission%), carbon and nitrogen concentration and ratio, and the organic matter content (LOI %) are presented in Fig. 2. Because the upper samples are still within the acrotelm, and are still undergoing rapid decay, the characteristics of the upper samples are not directly comparable with those lower in the profile. For example, the decrease in bulk density and increased transmission are mainly a function of this factor. The deepest part

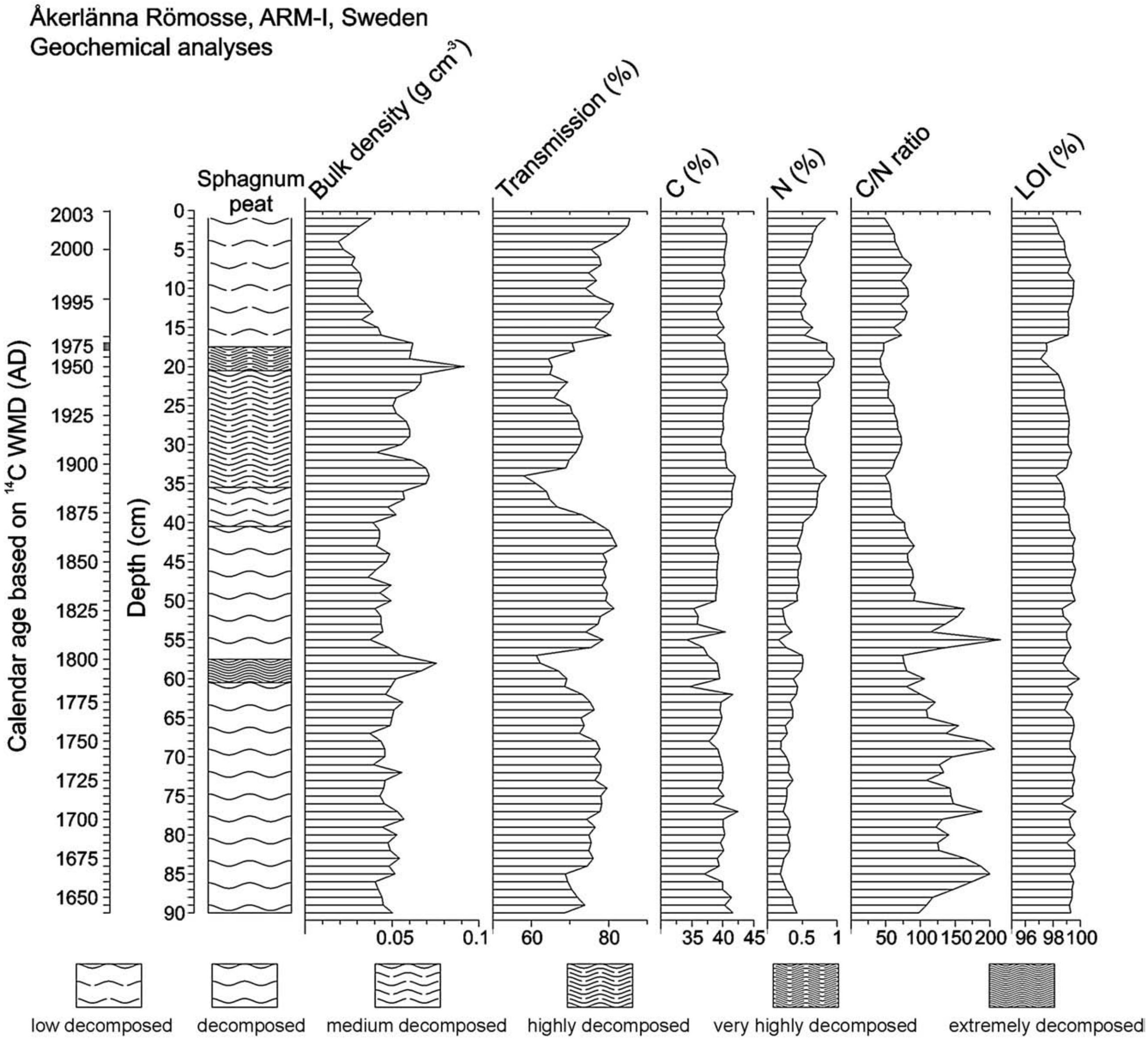


Fig. 2. Åkerlänna Römosse chemical analyses. Results of bulk density (g cm^{-3}), degree of humification (% transmission), C/N ratio and Loss on Ignition (LOI, % organic material) analyses. Note the differences in *x*-axis scales.

of the peat core between 90 and 60 cm depth has rather stable bulk densities, between 0.04 and 0.06 g cm^{-3}. High C/N ratios are observed when N percentages are low; C percentages are not necessarily high. At 59 and 58 cm depth a dark layer is visible in the peat stratigraphy and high bulk densities are present. Transmission percentages show a minimum. Both C and N percentages are relatively high and a small decrease in LOI is visible. From 55 to 40 cm depth bulk density and transmission values are relatively stable. C/N ratio starts high and decreases afterwards. At 40 cm depth the peat colour changes to a darker shade. Bulk densities and C and N percentages steadily increase. Transmission percentages decrease. At 35 cm depth a transition to darker coloured peat is visible in the stratigraphy. Bulk densities increase and transmission percentages decrease. Hardly any decrease is visible in the LOI percentages. The interval from 30 to 20 cm depth shows no major changes. From 20 to 17 cm the colour of the peat is very dark. A peak in bulk density is present at 20 cm depth. Low transmission and LOI percentages together with high N percentages are visible between 20 and 17 cm depth. In the top part of the peat core, which is the acrotelm in which decomposition process is still going on, bulk densities decrease and transmission percentages increase.

3.2. Chronology

The results of ^{14}C AMS dating are presented in Table 2. The dates were not calibrated in the conventional way, but wiggle-matched (van Geel and Mook, 1989; Kilian et al., 2000) using the INTCAL 98 calibration curve (Stuiver et al., 1998). The atmospheric bomb pulse ('bomb peak') was used to wiggle-match the post-1950 ^{14}C dates (Levin et al., 1994; Goodsite et al., 2001; Goslar et al., 2005). Therefore the Excel-approach (Mauquoy et al., 2002b; Blaauw et al., 2003, 2004; van der Linden and van Geel, 2006) updated with modern 'negative' radiocarbon years (Cain and Suess, 1976; Levin et al., 1994; Levin and Hesshaimer, 2000; van der Linden and van Geel, 2006) was used. 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.

The dataset was split up into 4 sub-sets, each one with its own linear peat accumulation rate. The subdivision in sub-sets was based on shifts in the pollen concentration, *Sphagnum* species composition, degree of humification and bulk density results (Kilian et al.,

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

Sample depth	GrA- number	δ^{13}C	Carbon content	^{14}C		^{14}C age		Wiggle-match date			Sample composition
cm		%	%	%	+/−	BP	+/−	AD	+/−	sub-set	
4	26623	−27.25	45.4	109.76	0.46	−750	35	2001	0.4	I	*Sphagnum fuscum*
7	26624	−27.28	42.7	110.79	0.44	−825	30	1998	0.4	I	*Sphagnum fuscum*
10	25968	−27.09	43.7	111.16	0.62	−850	40	1996	0.4	I	*Sphagnum fuscum*
14	26626	−26.97	41.0	113.52	0.45	−1020	30	1993	0.4	I	*Sphagnum fuscum*
15	29024	−27.87	46.7	112.89	0.48	−970	35	1992	0.4	I	*Sphagnum fuscum*
16	29010	−27.05	47.0	114.05	0.50	−1060	35	1991	0.4	I	*Sphagnum fuscum*
17	26627	−24.59	41.2	119.64	0.46	−1440	30	1985	7	II	*Sphagnum fuscum*
18	31252	−28.86	44.8	116.97	0.36	−1260	25	1958	2	III	*Sphagnum fuscum*
19	29013	−28.42	45.8	100.27	0.44	−20	35	1954	2	III	*Sphagnum fuscum*
20	25970	−27.42	48.4	98.67	0.49	110	40	1950	2	III	*Sphagnum fuscum*
24	26628	−28.02	39.8	98.89	0.40	90	35	1934	2	III	*Sphagnum fuscum*
27	26631	−27.57	41.0	98.64	0.41	110	35	1922	2	III	*Sphagnum fuscum*
30	25997	−27.62	44.1	99.61	0.75	30	40	1910	2	III	*Sphagnum fuscum*
34	26682	−26.40	39.7	99.05	0.52	80	40	1894	2	III	*Sphagnum fuscum*
37	26632	−25.55	40.9	98.09	0.41	155	35	1882	2	III	*Sphagnum fuscum*
40	25998	−25.08	43.9	98.64	0.51	110	40	1870	2	III	*Sphagnum fuscum*
44	26633	−25.34	42.9	99.08	0.41	75	35	1854	2	III	*Sphagnum fuscum*
47	26634	−24.40	42.1	99.46	0.40	45	35	1842	2	III	*Sphagnum fuscum*
50	26000	−24.82	43.9	98.34	0.51	135	40	1830	2	III	*Sphagnum fuscum*
53	29014	−25.67	46.5	98.28	0.44	140	35	1818	2	III	*Sphagnum fuscum*
54	26636	−24.82	47.0	98.41	0.40	130	35	1814	2	III	*Sphagnum fuscum*
55	29026	−24.75	45.6	98.85	0.42	95	35	1810	2	III	*Sphagnum fuscum*
57	26637	−25.49	45.6	98.01	0.39	160	35	1802	2	III	*Sphagnum fuscum*
60	26001	−26.24	43.9	97.46	0.56	205	45	1790	2.5	IV	*Sphagnum fuscum*
64	26638	−25.90	43.6	97.82	0.41	180	35	1770	2.5	IV	*Sphagnum fuscum*
67	26641	−26.13	43.5	98.21	0.42	145	35	1755	2.5	IV	*Sphagnum fuscum*
70	26003	−25.60	44.4	98.68	0.51	105	40	1740	2.5	IV	*Sphagnum fuscum*
74	26642	−26.13	43.7	98.63	0.41	110	35	1720	2.5	IV	*Sphagnum fuscum*
77	26644	−25.10	43.4	97.29	0.40	220	35	1705	2.5	IV	*Sphagnum fuscum*
80	26004	−25.38	43.4	98.26	0.54	140	40	1690	2.5	IV	*Sphagnum fuscum*
83	26646	−25.23	42.3	97.91	0.41	170	35	1675	2.5	IV	*Sphagnum fuscum*
85	26647	−26.54	42.0	97.17	0.39	230	35	1665	2.5	IV	*Sphagnum fuscum*
87	29028	−26.26	44.7	97.30	0.44	220	35	1655	2.5	IV	*Sphagnum fuscum*
88	26648	−26.26	42.3	96.92	0.40	250	35	1650	2.5	IV	*Sphagnum fuscum*
89	29030	−26.67	45.0	96.22	0.43	310	35	1645	2.5	IV	*Sphagnum fuscum*
90	26005	−26.92	44.1	96.10	0.48	320	40	1640	2.5	IV	*Sphagnum fuscum*

2000; Speranza et al., 2000; Blaauw et al., 2003, 2004). For each sub-set the best fit with the ^{14}C calibration curve was found by applying several accumulation rates to the data. The year of sampling was used as a starting point for the top sample and then the samples were wiggle-matched from young to old using the oldest year of the previous (younger) sub-set as anchoring point. The results are plotted on the ^{14}C calibration curve in Fig. 3. The ages of the samples between the wiggle-matched levels were estimated by linear interpolation (Appendix A). The maximum of the atmospheric bomb pulse signal in the ARM data is not registered, although data in Appendix A suggest it should be at c. 17 cm depth. However, the same data indicate that the sample at that depth comprised some 27 years, and so will represent the average ^{14}C accumulation over that period. This resulted in a 'flattening' of the bomb peak (see also Goslar et al. (2005). Indeed, the results from contiguous samples between 14 and 20 cm suggest that there was a period of very slow or no peat accumulation in the late 20th century.

3.3. Micro- and macrofossil analyses

3.3.1. Regional vegetation development (dry land taxa)

The results of the pollen analysis of regional taxa are presented in Fig. 4 (percentages) and Fig. 5A (concentrations) and B (pollen accumulation rates, PAR). A zonation was made with CONISS

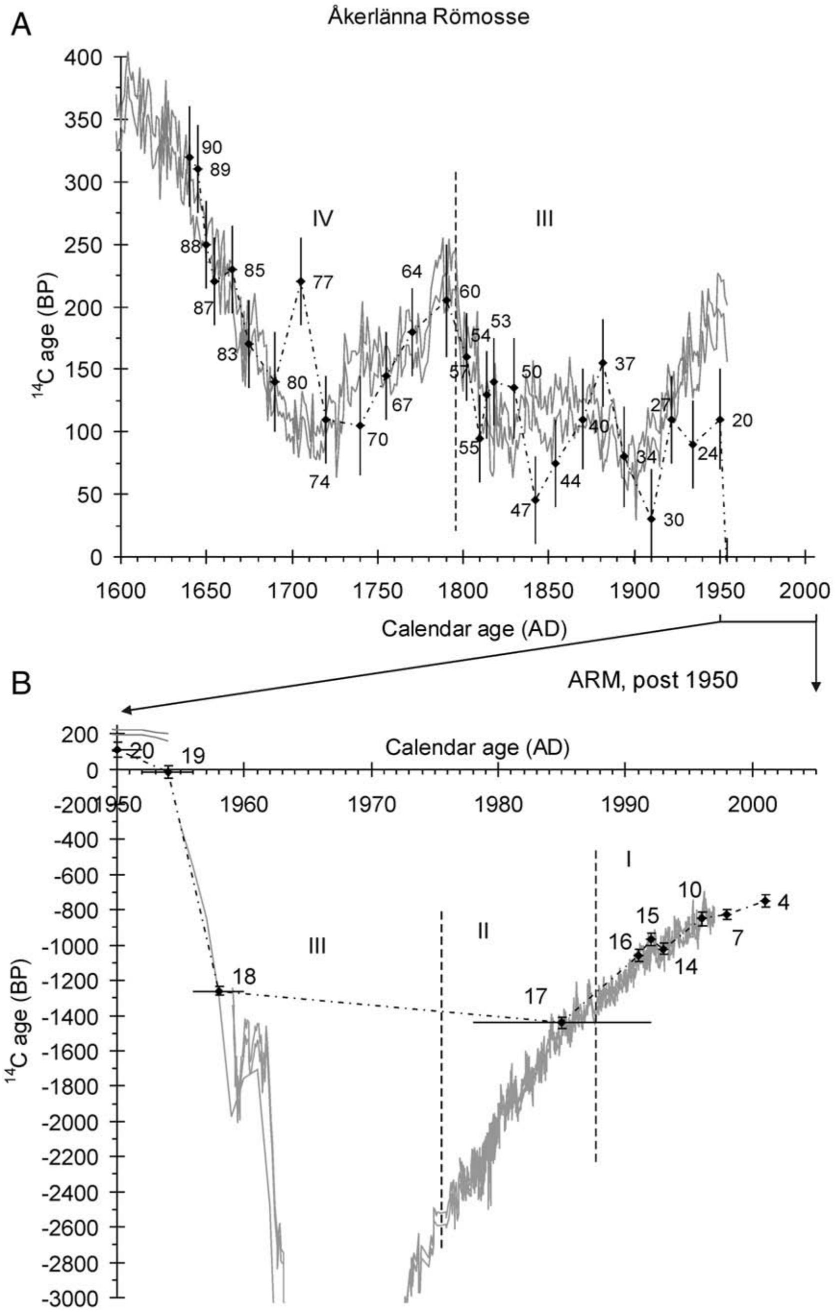


Fig. 3. ^{14}C AMS wiggle-match dating of the Åkerlänna Römosse (ARM) peat deposit using the INTCAL 98 calibration curve (Stuiver et al., 1998) updated with the modern ^{14}C record reflecting the atmospheric bomb pulse (Levin et al., 1994; Levin and Hesshaimer, 2000; Goodsite et al., 2001). The radiocarbon dates are marked with their sample depths in cm. A) ^{14}C dates before AD 1950 and B) ^{14}C dates after AD 1950.

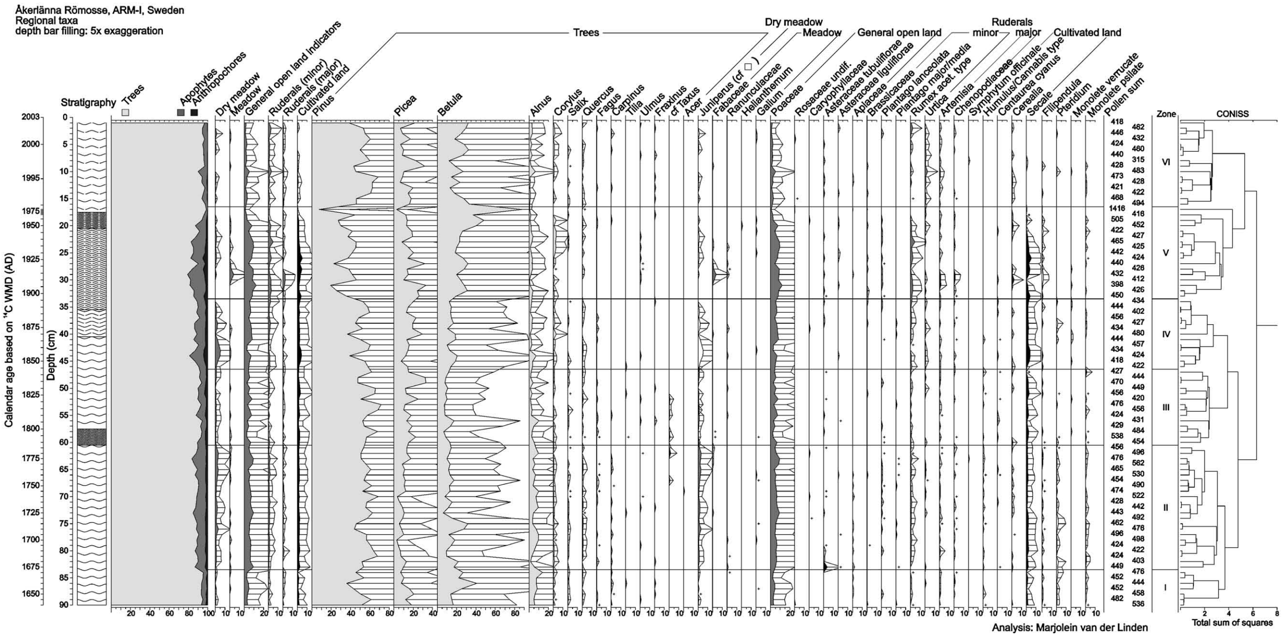


Fig. 4. Pollen percentage diagram of regional vegetation (dry land taxa) of Åkerlänna Römosse. Omitted taxa are named in Appendix B. The black silhouettes show the percentage curves of all taxa; the depth bar filled silhouettes show the five times exaggeration curves. The legend is described in Fig. 2.

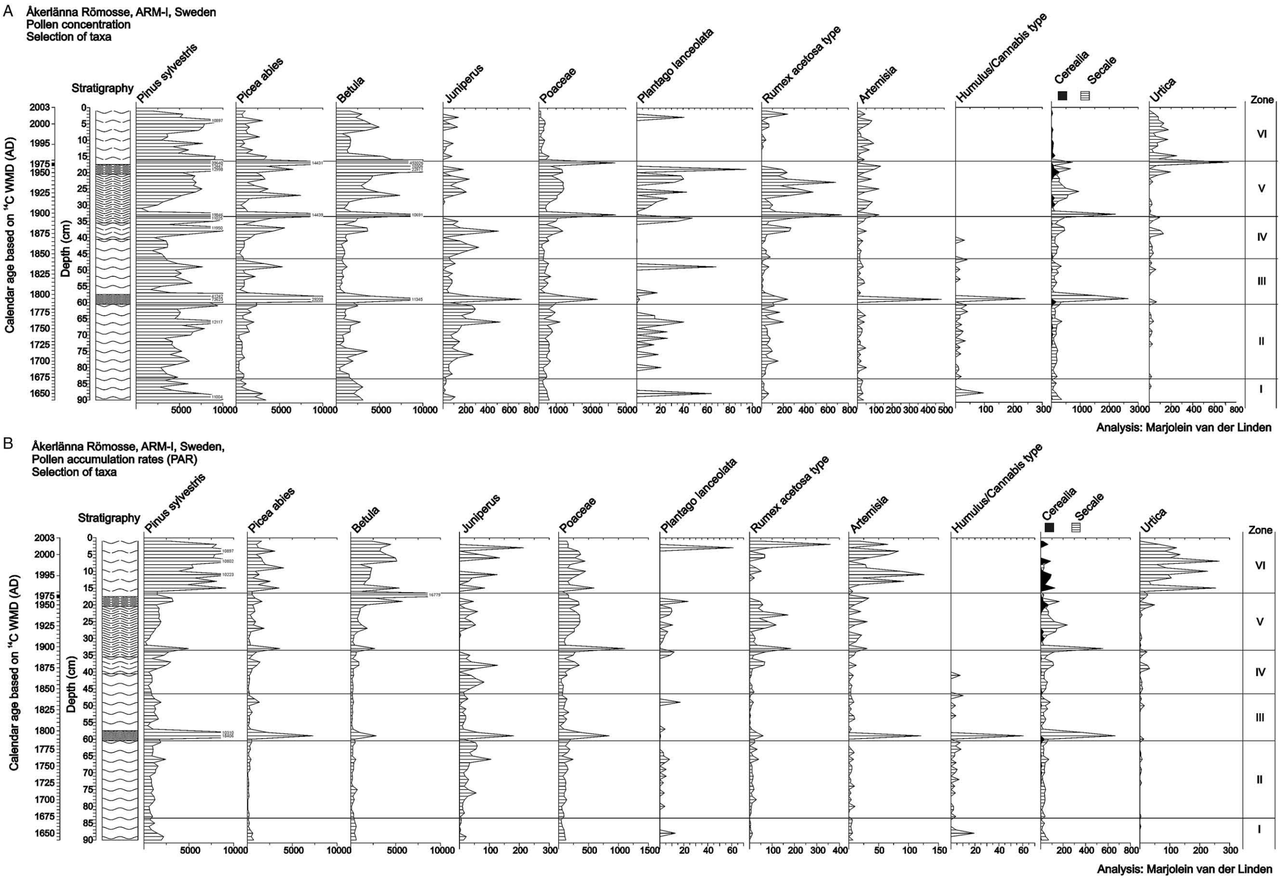


Fig. 5. A) Pollen concentrations and B) pollen accumulation rates (PAR) of regional vegetation (dry land taxa) of Åkerlänna Römosse. The legend is described in Fig. 2.

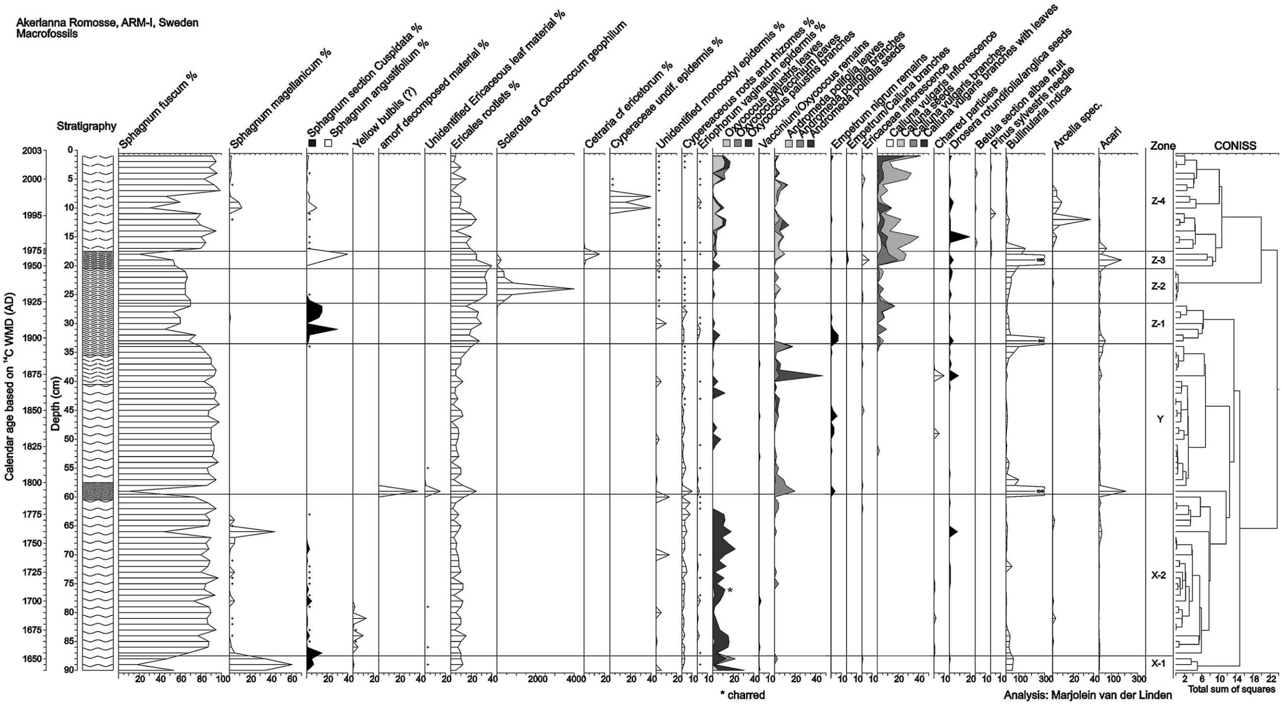


Fig. 6. Macrofossil diagram (local vegetation) of Åkerlänna Römosse. Omitted taxa are named in Appendix B. The legend is described in Fig. 2.

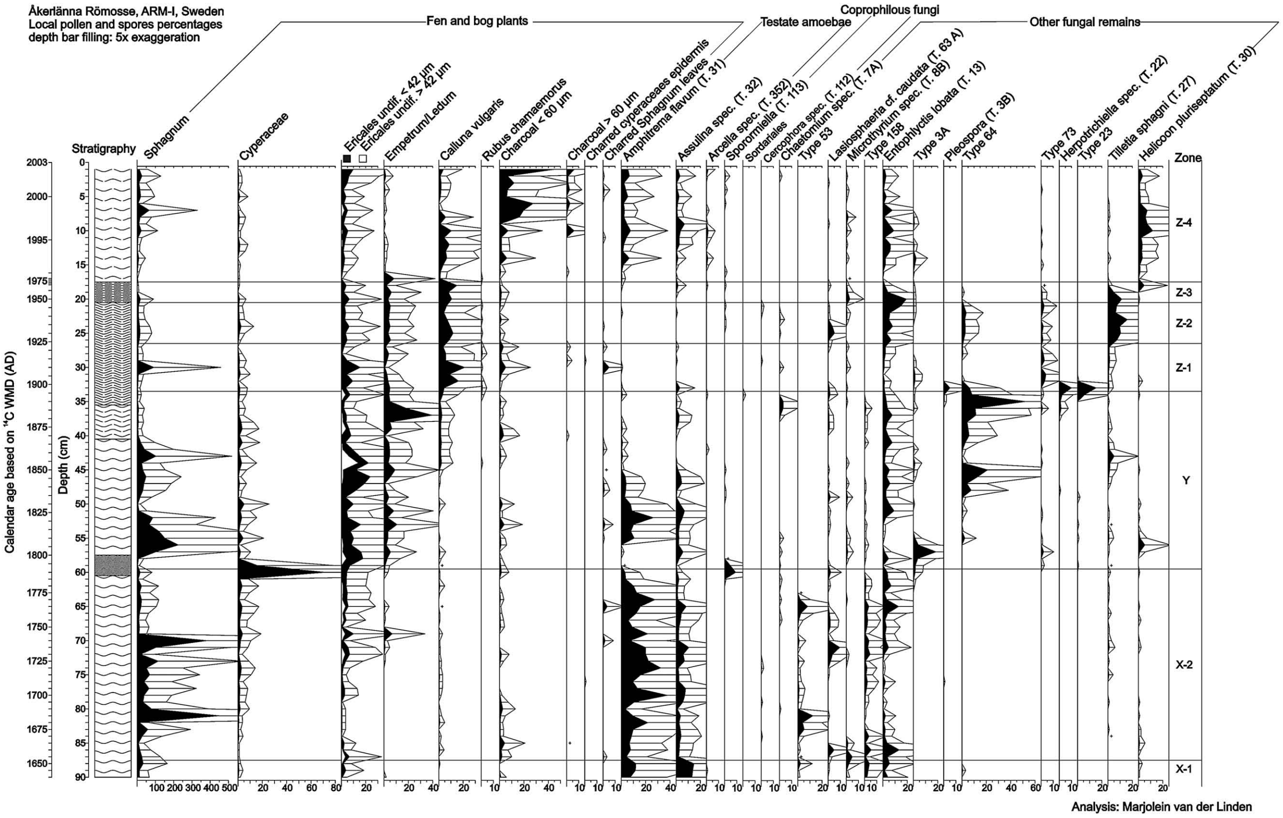


Fig. 7. Diagram of local taxa (pollen and non-pollen palynomorphs) of Åkerlänna Römosse. Some testate amoebae were counted in the pollen slides. See Fig. 8 for complete testate amoebae analysis. Omitted taxa are named in Appendix B. The legend in described in Fig. 2.

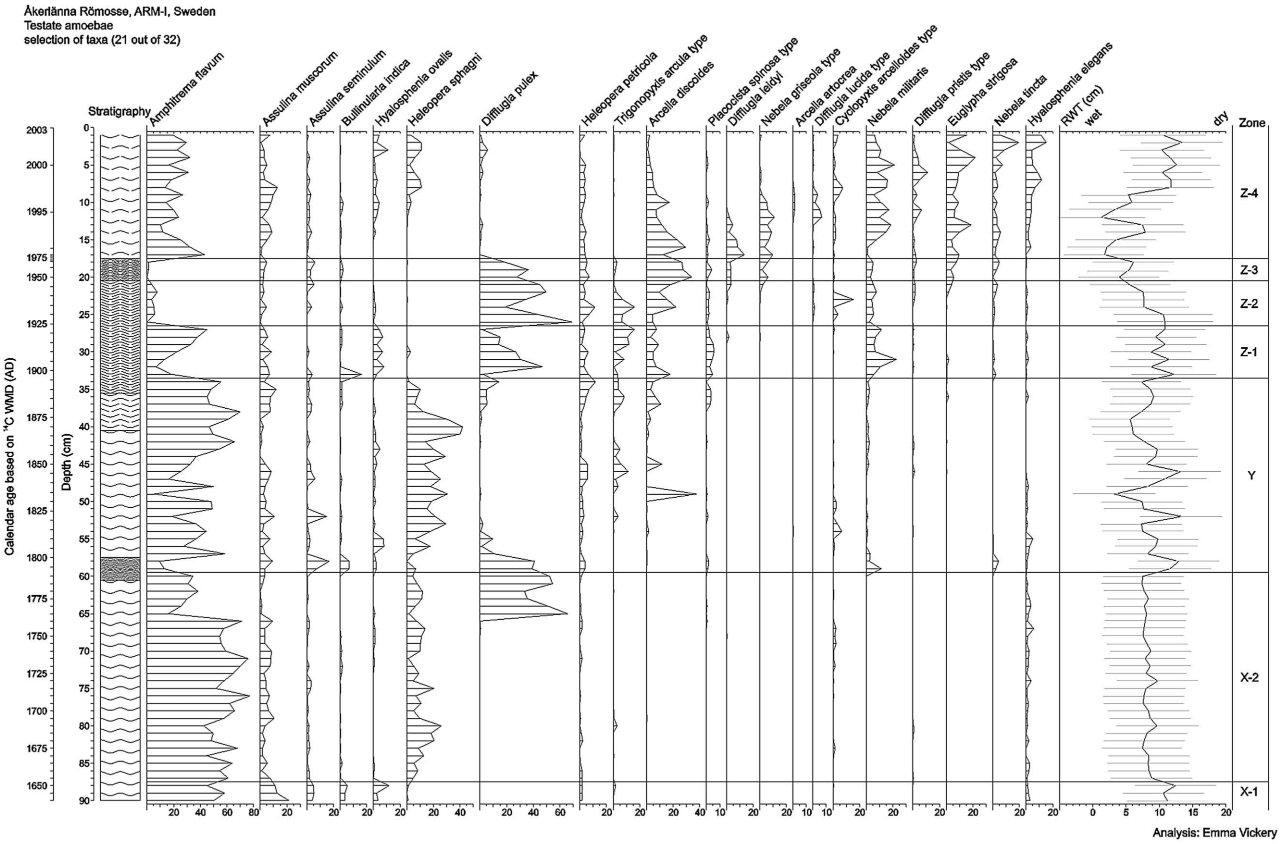


Fig. 8. Testate amoebae (main taxa) and reconstructed water table of Åkerlänna Römosse. The legend is described in Fig. 2.

(square root transformation) using the pollen percentages of pollen sum taxa as species data. Tree pollen dominates the entire pollen record. *P. sylvestris* shows the highest percentages followed by *Betula spp*. and *P. abies*. *Pinus* and *Betula* are in the pollen sum and counted as regional taxa. However, these species can also grow on the bog surface and might therefore occasionally represent a local signal. The macrofossil data may indicate local presence of these species. Dates in the text will be given in calendar years AD without the error. The chronology with the corresponding errors is presented in Table 2.

3.3.1.1. Zone ARM-I (90–83.5 cm depth; AD 1640–1673). Apophytes and anthropochores show low percentages. *P. sylvestris* decreases from 89 to 86 cm depth. *Betula* and Poaceae increase at the same time. *Rumex acetosa* type decreases. The decline of *Pinus* and the peak in *Betula* are also present in the PAR data.

3.3.1.2. Zone ARM-II (83.5–60.5 cm depth; AD 1673–1787). Apophytes show higher percentages than in the previous zone. At 76–75 cm depth a peak in *Betula* and *Juniperus* is visible. *P. sylvestris* percentages decrease. At 57–56 cm depth another peak in *Betula* and *Juniperus* and a decrease in *Pinus* is visible. Poaceae and *Pteridium* increase. Grains of *Plantago lanceolata* and *P. major/media* are found on a regular basis. *R. acetosa* type shows relatively high percentages in the entire zone, but slightly decreases when *Betula* peaks.

3.3.1.3. Zone ARM-III (60.5–46.5 cm depth; AD 1787–1844). Tree percentages increase and apophytes decrease caused by the decline in *Juniperus*, Poaceae and *R. acetosa* type. Between 60 and 57 cm depth peaks in PAR are visible in all taxa.

3.3.1.4. Zone ARM-IV (46.5–33.5 cm depth; AD 1844–1896). Increasing percentages of *Juniperus*, Poaceae and *R. acetosa* type and a related slight decrease in tree percentages characterize this interval. Between 38 and 37 cm depth peaks in PAR are visible in all taxa.

3.3.1.5. Zone ARM-V (33.5–16.5 cm depth; AD 1896–1987). This zone is characterized by high *Betula* percentages. *P. sylvestris* shows lower percentages than in previous zones. At the start of the zone, increases in Poaceae, Fabaceae and Ruderals are recorded. Apophytes percentages remain relatively high but decrease towards the top of the zone. Also Ranunculaceae, Brassicaceae and *P. lanceolata* are found regularly. At 33 cm depth most taxa peak in pollen accumulation rates, afterward they show low values which slowly increase. The same pattern is visible in the pollen concentration data. The peak in *P. sylvestris* percentages is not visible in PAR. At the end of the zone Poaceae and *Secale* decrease, while *R. acetosa* type almost disappears. At the top of the zone at 17 cm depth a huge peak of 70% *Betula* and very low *P. sylvestris* percentages are recorded.

3.3.1.6. Zone ARM-VI (16.5–0 cm depth; AD 1988–2003). Apophytes have low percentages and cultivated land taxa are hardly present. *P. sylvestris* is dominant. Poaceae show lower percentages than in previous zones. Ruderals are still present but *Urtica* is now dominant over *R. acetosa* type.

3.3.2. Local vegetation development (mire surface)

The macrofossil results are presented in Fig. 6. A zonation was made with CONISS (square root transformation) using the plant remains data. The macrofossil zonation was also used in the local pollen and spores diagram (Fig. 7) and the testate amoebae diagram (Fig. 8). Testate amoebae were well preserved throughout the profile. Concentrations were low in some samples with <1000 tests cm^3; however, count levels in excess of between 150 and 200 were obtained on all samples. The testate amoebae assemblages show major changes in both the presence and the relative abundance of different taxa and both of these factors drive the reconstructed water level (RWT) changes in the transfer function. Testate amoebae were also counted in the pollen slides. These do not give a complete view of the species composition or ratio because some tests probably dissolved during the pollen treatment.

3.3.2.1. Zone X (90–59.5 cm depth; AD 1640–1792). Zone X is mainly characterized by the presence of *S. fuscum*, *Sphagnum magellanicum*, *Sphagnum* section *Cuspidata* and *Oxycoccus palustris* (syn. *Vaccinium oxycoccus*).

3.3.2.2. Subzone X-1 (90–87.5 cm depth; AD 1640–1653). This subzone is characterized by high percentages of *S. magellanicum* and Sphagnum section *Cuspidata*. *S. fuscum* percentages are low. Some *O. palustris* branches were found. *Amphitrema flavum* is dominant within the testate amoebae community. *Assulina muscorum* shows relatively high percentages but is decreasing. *Assulina seminulum, Bullinularia indica* and *Hyalosphenia ovalis* are present. RWT is relatively low with a minimum of 12.4 cm at 88 cm depth.

3.3.2.3. Subzone X-2 (87.5–59.5 cm depth; AD 1653–1792). Subzone X-2 is dominated by *S. fuscum*. Few remains of *S. magellanicum* and *Sphagnum* section *Cuspidata* are present. *O. palustris* branches were found regularly. RWT is relatively stable at, on average, 8.2 cm below the surface, principally due to the loss or decline of dryness indicators *A. muscorum* and *B. indica*. At 66 cm depth *S. magellanicum* peaks and replaces *S. fuscum* for a short period. *A. flavum* is dominant but is replaced by *Difflugia pulex* at 65 cm depth. Also at 65 cm depth 16 charred *Sphagnum* leaves were found. Fungal Type 53 shows two peaks and disappears from the record at 65 cm depth. Spores of cellulose-decomposing fungus *Chaetomium spec*. were found in the top of the subzone. At 60 cm depth there is a huge peak in Cyperaceae pollen representation and a peak of the coprophilous fungus *Sporormiella spec*.

3.3.2.4. Zone Y (59.5–33.5 cm depth; AD 1792–1896). Sample depth of 59 cm (AD 1794) deserves special attention. The species composition differs much from the other sample depths. The total *Sphagnum* percentage is only 10%. High percentages (38%) of amorphous organic material are found together with high amounts of Ericales roots and ericaceous leaf material. Also *Andromeda polifolia* and *Empetrum nigrum* branches have been recorded. Many *Sporormiella* spores are present. *A. flavum* decreases to minimal percentages and remains low at 58 cm depth (AD 1798*). D. pulex, A. seminulum, B. indica, Nebela militaris* and *Nebela tincta* peak at 59–58 cm depth. RWT is low at 11.6–13 cm below the surface.

The rest of the zone is dominated by *S. fuscum*, *A. polifolia* and *E. nigrum*. Ericales pollen grains larger than 42 µm are found when macrofossils of *A. polifolia* peak. These grains are probably from *Andromeda*. At 39 cm depth many *A. polifolia* and *Drosera rotundifolia/anglica* seeds are found. *A. flavum* and *Heleopera sphagni* are the dominant testate amoebae species. *Heleopera petricola, Trigonopyxis arcula* type and *Arcella discoides* show high values between 53–43 and 37–34 cm depth. At these depths, Type 64 is present in large quantities. It also seems to peak when *E. nigrum* pollen peaks. In between, *Tilletia sphagni* peaks at 43 cm depth. *Chaetomium spec*. peaks between 37 and 35 cm depth. RWT shows great variability with an amplitude of 10 cm in zone Y. From 49 to 43 cm depth a decrease in RWT from 3–13 cm below surface is recorded, in contrast to the rather stable macrofossil composition.

3.3.2.5. Zone Z (33.5–0 cm depth; AD 1896–2003). Zone Z is characterized by the presence of *Sphagnum* section *Cuspidata*, *S. magellanicum*, *Calluna vulgaris* and lower *S. fuscum* percentages.

3.3.2.6. Subzone Z-1 (33.5–26.5 cm depth; AD 1896–1924). Percentages of *S. fuscum* decrease while *Sphagnum* section *Cuspidata* and Ericales rootlets are increasing. From 33 cm depth *C. vulgaris* branches are present. At the start of subzone Z-1 some *Empetrum* remains were found. *A. flavum* and *H. sphagni* decline and are replaced by *D. pulex*. Dry-indicators *T. arcula* and *N. militaris* show relatively high percentages. RWT stays below 8.7 cm with a minimum of 12.3 cm below the surface. *C. vulgaris* pollen percentages increase. Pollen of (extralocal fen species) *Filipendula* and *Rubus chamaemorus* is present. A peak in *Sphagnum* spores coincides with a peak in charcoal (<60 µm) and charred *Sphagnum* leaves at 30 cm depth. Relatively few fungal remains were found. *Pleospora spec.* (T. 3B), *Herpotrichiella spec*. (T. 22) and Type 23 were found at the transition of zone Y to Z, but disappear afterward. *Entophlyctis lobata* shows low percentages. Type 73 increases.

3.3.2.7. Subzone Z-2 (26.5–20.5 cm depth; AD 1924–1948). This interval is characterized by the presence of sclerotia of *Cenococcum geophilum* and the temporary absence of *Sphagnum* section *Cuspidata*. Fewer remains of *C. vulgaris* are present than in the previous subzone. High percentages of Ericales rootlets were found. Pollen of *Empetrum, Calluna* and *R. chamaemorus* has been recorded. Fungal spores of *Lasiosphaeria cf. caudata* (T. 63A), *E. lobata*, Type 64, dryness indicator Type 73 and *T. sphagni* are present. *D. pulex* shows high percentages. *Cyclopyxis arcelloides* type peaks at 23 cm depth. *A. discoides* increases and *T. arcula* type decreases. RWT rises from 10.8 to 5.5 cm below the surface.

3.3.2.8. Subzone Z-3 (20.5–17.5 cm depth; AD 1948–c. 1970). This subzone is characterized by the presence of *Sphagnum angustifolium* and well preserved remains of the lichen *Cetraria* cf. *ericetorum*. *S. fuscum* shows relatively low values. *C. vulgaris* remains show higher percentages. *A. discoides* is present in high percentages together with other wet-indicators *Difflugia leidyi* and *Nebela griseola*. *D. pulex* is rapidly decreasing. *A. flavum* has the lowest percentages of the entire peat section. RWT falls from 4 to 6 cm below the surface. *Microthyrium spec*. peaks at 19–18 cm depth. *T. sphagni* and *E. lobata* fungal spores decrease and are hardly present at the top of this subzone. *Helicoon pluriseptatum* appears and increases from 18 cm depth.

3.3.2.9. Subzone Z-4 (17.5–0 cm depth; AD c. 1970–2003). The topmost subzone of this peat core is characterized by the presence of *S. angustifolium* and *S. magellanicum* (from 12 cm depth to the top). Branches with leaves attached and many seeds of *C. vulgaris* were found. Between 10 and 8 cm depth large amounts of Cyperaceae epidermis are present. *A. polifolia* and *O. palustris* are also present. A rapid increase in *A. flavum* was recorded at the start of subzone Z-4. *N. militaris*, *Diffluglia pristis* type, *Euglypha strigosa*, *N. tincta* and *Hyalosphenia elegans* are increasing. *A. discoides* decreases toward the surface and *D. pulex* is hardly present. RWT is variable; the highest and lowest stands of the water table of the entire core are present within this subzone. At 16 cm depth RWT is 1.8 cm below the surface. It decreases to 7.9 cm at 14 cm depth and rises sharply to 1.3 cm depth below surface at 12 cm sample depth. From that point RWT decreases to 11.7 cm at sample depth 8 and remains relatively stable until the surface. Large numbers of microscopic charcoal particles and some charred *Sphagnum* leaves were found. Type 3A fungal spores are present at the start of subzone Z-4. *E. lobata* and *H. pluriseptatum* start with low percentages and increase toward the surface with maxima between 12 and 8 cm depth.

4. Interpretation

4.1. Possible effects of climate change and human impact on regional vegetation development

4.1.1. AD 1640–1673 (Zone ARM-I; 90–83.5 cm depth)

The area around Åkerlänna Römosse is dominated by forest, which mostly comprises *P. abies* indicated by the high PARs. Few human impact indicators are recorded. At c. AD 1655 the forest composition changes to more *Betula* dominated forest types. At the same time small decreases in *R. acetosa* type and *Secale* are visible. The expansion of *Betula* may have been facilitated by the logging of pine forest and/or by abandonment of arable land. See Table 3 for interpretation of pollen accumulation rates in terms of forest openness after Hicks and Sunnari (2005).

4.1.2. AD 1673–1787 (Zone ARM-II; 83.5–60.5 cm depth)

Agricultural activities suddenly expanded in the area starting at c. AD 1673. A synchronous peak at c. AD 1710–1715 in *Betula* and *Juniperus* and decrease in *P. sylvestris* and *R. acetosa* type may have been induced by logging of Pine forest or abandonment of arable land.

Table 3
Forest density based on pollen accumulation rates threshold limits for openings of c. 200 m diameter, after Hicks and Sunnari (2005)

Zone	NP-10	NP-1	P-sparsely	Open forest	Dense forest
ARM-I	*Pinus*				
VI					X
V	X	X	X	X	X
IV		X	X	X	X
III		X	X	X	X
II			X	X	
I			X	X	
ARM-I	*Picea*				
VI					X
V			X	X	X
IV				X	X
III				X	X
II			X	X	X
I				X	X
ARM-I	*Betula*				
VI				X	X
V		X	X	X	X
IV		X	X		
III		X	X	X	X
II		X	X		
I		X	X		

NP-10: Not present within 10 km; NP-1: not present within 1 km; P-sparsely: Present, but only sparsely.
After Hicks and Sunnari (2005).

4.1.3. AD 1787–1844 (Zone ARM-III; 60.5–46.5 cm depth)

Low *Juniperus* and *P. lanceolata* percentages are present during the entire period indicating a decrease in pasture land. Between c. 1790 and 1800 a peak in the pollen accumulation rate of all taxa is present. Comparable intervals with high PARs were observed in other research sites of this project: raised mire Saxnäs Mosse in Southern Sweden (van der Linden and van Geel, 2006) and in a poor fen Lappmyran in Northern Sweden (van der Linden et al., 2008). Hicks (2001) suggested that the annual amount of pollen production is related to climate conditions and that, at this temporal scale, the climate signal overrides the vegetation signal. After warm summers pollen production is higher than normal (Autio and Hicks, 2004), which may lead to even higher pollen concentration and therefore PAR remains high. These intervals are composed of more humified peat, which may also suggest warm and dry conditions. Another theory is that in periods of dryness, more pollen remains airborne because it is not washed out of the air by rainfall (people with hay fever will recognise this). Therefore more pollen can reach the bog surface because it was not deposited elsewhere closer to the source. Barnekow et al. (2007) found a strong correlation between summer temperature and *P. abies*, *P. sylvestris* and *Betula* spp. pollen accumulation rates in Kiruna, Northern Sweden.

4.1.4. AD 1844–1896 (Zone ARM-IV; 46.5–33.5 cm depth)

Agricultural activities expand at c. AD 1850 indicated by the increase in *Secale*, *Juniperus* and *Betula*. From c. AD 1870 to 1896 high PARs are calculated for most taxa, which may indicate a warmer/drier period.

4.1.5. AD 1896–1988 (Zone ARM-V; 33.5–16.5 cm depth)

Pine forest declined at the end of the 19th century. *Betula* increases but total tree pollen decreases. Human impact was high, indicated by the wide variety of land-use indicators. Meadows are indicated by Fabaceae and Ranunculaceae and ruderal areas by *Artemisia* and Chenopodiaceae. The decrease in *R. acetosa* type suggests a decrease in arable land during the first half of the 20th century. At c. 1950 *Secale* cultivation disappeared and other human impact indicators decreased. The extreme peak in *Betula* at c. 1985 is probably not a regional signal. A pollen sum of 1415 grains was counted of which 1240 were *Betula* pollen. Some birch trees on the bog may have produced a lot of pollen. The macrofossil analysis showed that this interval had dry conditions (see Section 4.2 macro zone Z-2). Thus birch may have been present at the bog surface near the coring site. However, measured annual pollen deposition values (Hicks, 2001) show relatively high *Betula* pollen accumulation rates at 1985–1986 and extremely high values in 1989. These contemporous findings of high PARs in different regions imply temporary warm conditions resulting in a high pollen production and a dry environment.

4.1.6. AD 1988–2003 (Zone ARM-VI; 16.5–0 cm depth)

The last decades are dominated by *P. abies* and *P. sylvestris*. This is consistent with the current vegetation around the bog. Human impact indicators have been reduced to Poaceae, *Artemisia* and *Urtica*. The last-named is regularly present, indicating eutrophication in the area caused by increased nitrogen deposition. PARs are high and variable in this zone. The warming of the climate at the end of the 20th century may have increased pollen production. Bennett and Hicks (2005) concluded that when peat profiles are sampled at high (near-annual) temporal resolution, analyses of pollen accumulation rate do not reflect vegetation abundance, but temperature related pollen abundance. Peaks in PARs of Åkerlänna Römosse are consistent with high PARs measured in Kiruna, Northern Sweden (Barnekow et al., 2007) and Northern Finland (Hicks, 2001).

4.2. Possible effects of climate change and human impact on local vegetation development

4.2.1. AD 1640–1792 (Zone X; 90–59.5 cm depth)

This period is characterized by a wet mire surface vegetation indicated by the low presence of *Empetrum/Ledum* and *C. vulgaris*. According to the reconstructed water table, the period between AD 1640 and 1653 (subzone X-1) was slightly drier than the succeeding period from AD 1653 and 1792 (subzone X-2). After AD 1765 some changes occurred on the bog surface which caused a shift in testate amoebae and the mycoflora. The presence of charred *Sphagnum* leaves indicates a bog fire. The appearance of coprophilous fungi suggests increased animal presence on the mire, implying relatively dry conditions. Dung may have enriched the nutrient-poor bog environment and initiated a shift in testate amoebae and fungal composition. The peak of Cyperaceae pollen at AD 1790 may indicate dry and enriched conditions too. This is also suggested by the macrofossil remains of *Eriophorum vaginatum* and unidentified monocot epidermis.

Plate I. Microscopic photos of the *Cetraria* cf. *ericetorum* macrofossil remains. Jan van Arkel made the photo.

4.2.2. AD 1792–1896 (Zone Y; 59.5–33.5 cm depth)

This interval starts with an extreme event at c. AD 1794 (59 cm depth) which causes high decomposition rates resulting in amorphous and unidentifiable macrofossils. This was probably caused by the dry conditions at the end of zone X-2. However, the bog vegetation recovered quickly and surface wetness increased from c. AD 1798. Spores of coprophilous fungi disappeared, indicating a return to nutrient-poor conditions. *A. flavum* regained dominance with wet conditions, though generally not as wet as in zone X as *A. polifolia* is more dominant than *O. palustris*. A short wet interval is indicated by a rise in RWT and dominance of *O. palustris* between c. AD 1830 and 1834. The RWT falls after c. AD 1834 to 13.2 cm below surface at c. AD 1846. During this increasingly dry period, remains of *E. nigrum* and charred *Sphagnum* leaves were found which imply dry conditions with bog fires.

4.2.3. AD 1896–2003 (Zone Z; 33.5–0 cm depth)

Dry hummock vegetation is present at the coring site between AD 1896 and 1924 (subzone Z-1) with *E. nigrum, C. vulgaris* and *R. chamaemorus*. However, wet growing *Sphagnum* section *Cuspidata* is also present, which may suggest that the coring spot developed from hollow to hummock vegetation. The reconstructed water table is on average low, 10.4 cm below surface, but shows variability which may be another indication for a transition stage. A bog fire may have occurred at c. AD 1910, indicated by the findings of many charcoal particles and charred *Sphagnum* leaves in sample depth 30. *Filipendula* pollen is found in relatively large quantities which suggest the presence of fen conditions in the area. This is supported by evidence from a field survey in 1912 (Eriksson, 1912), showing Bälinger mosser still had extensive fen and marsh areas south west of the mire.

4.2.4. AD 1924–1948 (Subzone Z-2; 26.5–20.5 cm depth)

The presence of sclerotia of *C. geophilum* implies local dry conditions, also implied by the disappearance of *Sphagnum* section *Cuspidata* and high Ericales rootlets percentages. Another possibility is that the remains of the weak *Sphagnum* section *Cuspidata* were less resistant to decomposition and therefore totally degraded (Clymo, 1984; Johnson and Damman, 1991).

4.2.5. AD 1948 to c. AD 1970 (Subzone Z-3; 20.5–17.5 cm depth)

During this period a mix of dry and wet growing vegetation was present. Well preserved remains of *Cetraria* cf *ericetorum* (see Plate I) were found which is quite unusual because normally lichens do not form any identifiable macrofossils in peat. Hummocks can have patches of lichens at the driest spots, the *E. vaginatum-Cladonia rangiferina* association. When lichens are present, the peat accumulation process stagnates and the peat can become highly decomposed. This results in a more humified deposit towards the surface, which may make drainage more difficult. In such conditions even a small increase in humidity may have caused accumulation of water in depressions, favouring the formation of hollow communities (Svensson, 1988). In Åkerlänna Römosse, the wet growing *S. angustifolium* has overgrown the lichen vegetation, thereby encapsulating and preserving the remains of *Cetraria*. This process is also supported by the dating evidence which suggests a hiatus between 18 and 17 cm depth (Fig. 3) and the RWT, which rises significantly over this transition.

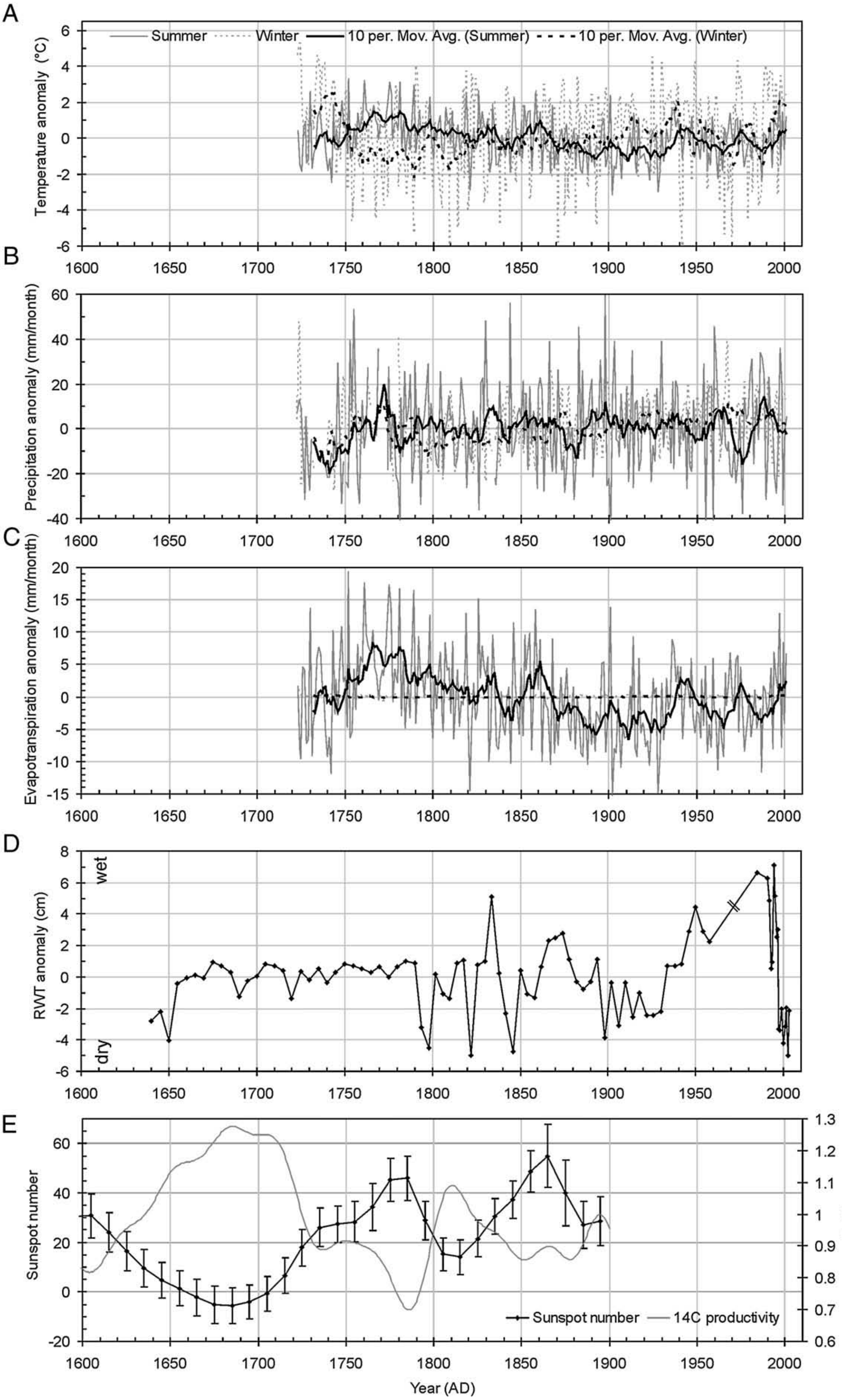
4.2.6. c. AD 1970 to 2003 (Subzone Z-4; 17.5–0 cm depth)

The vegetation during the last interval indicates slightly wetter conditions. *E. nigrum* and *R. chamaemorus* pollen show low frequencies and from 12 cm depth *S. magellanicum* and many Cyperaceae remains, probably *E. vaginatum,* occur. These plants form the hollow forming *Magellanicum* peat type (*E. vaginatum-S. magellanicum* association) (Svensson, 1988). The RWT also shows wet conditions from 12 cm, although there is a return to drier conditions above 8 cm peat depth, concurrent with the reversion to *S. fuscum*. Charcoal particles are recorded pointing to local fires which indicate dry conditions. The last 5 years show a relatively stable environment dominated by *S. fuscum*, *O. palustris, C. vulgaris* and a relatively stable RWT. However, the testate amoebae assemblages in this phase (top 5 cm of the core) are probably within the living assemblage zone and should be interpreted with caution.

5. Discussion

5.1. Mire surface wetness, climate change and human impact

Average water table depth in ombrotrophic mires is related to the amount of precipitation and evaporation during the warm season, and especially to the length and magnitude of the period of moisture deficit (Charman, 2007). Precipitation will be relatively high and evaporation will be low during periods with increased low-level clouds. According to Svensmark (2007) low-level cloud formation is enhanced by condensation nuclei, created by cosmic rays reaching the atmosphere. Cosmic ray intensity, on centennial timescales, is affected by the strength of the solar wind. With low solar activity, more cosmic rays will reach the atmosphere and more low-level clouds will be formed (Svensmark, 2007). Cosmic ray intensity also influences ^{14}C production. Therefore the atmospheric ^{14}C concentration can be used as a proxy for solar activity and maybe also for low-level cloud production. In between the Spörer and Maunder minima of solar activity, c. AD 1340 until c. AD 1600, the solar activity was high. According to the theory above, this must have been a relatively dry and warm period. Solar activity decreased during the 17th century and from AD 1645 the Maunder minimum starts which lasted until c. AD 1715 (Eddy, 1976; Hoyt and Schatten, 1997). Thus, low-level cloud cover and precipitation may have increased. This is consistent with the reconstructed water table of Åkerlänna Römosse (Fig. 9) but does not match the ecology of the *Sphagnum* species. In mire surface ecology described by Svensson (1988) *S. magellanicum* is part of the hollow communities and more wet growing than *S. fuscum*, but drier-growing than *Sphagnum cuspidatum*. The RWT based on testate amoebae composition of Åkerlänna Römosse shows the opposite: low water tables when *S. magellanicum* plays a role and high when there is a dominance of *S. fuscum*. Other mechanisms than water table depth may play a role in *Sphagnum* species turnover. According to van Geel and Middeldorp (1988),


A
Temperature anomaly (°C)
Summer
Winter
10 per. Mov. Avg. (Summer)
10 per. Mov. Avg. (Winter)
6
4
2
0
-2
-4
-6
B
Precipitation anomaly (mm/month)
60
40
20
0
-20
-40
C
Evapotranspiration anomaly (mm/month)
20
15
10
5
0
-5
-10
-15
D
RWT anomaly (cm)
wet
dry
8
6
4
2
0
-2
-4
-6
E
Sunspot number
q (lp30)
60
40
20
0
-20
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
Sunspot number
14C productivity
1600
1650
1700
1750
1800
1850
1900
1950
2000
Year (AD)

soil dust eutrophication may be of importance. It seems that *S. magellanicum* is favoured by the more nutrient-rich soil dust coming from agricultural fields and deposited on the mire surface by wind (McClymont et al., in press). The regional pollen diagram (Fig. 4) shows a decrease in human impact from c. AD 1650 when the climate became colder. This coincides with the decrease in *S. magellanicum* and supports the soil dust eutrophication theory.

During the period AD 1649–1653 big floods, bad harvests and famines occurred in Sweden. Grain was imported from the Baltic States. The year 1653 was extremely cold (Holmgren, 2005). The plague epidemic which reached Stockholm in AD 1654 may be another cause for the relatively low level of human impact indicators and the increase of the pollen curve of *Betula*. Åkerlänna Römosse is about 100 km northeast of Stockholm. This region was probably affected by the disease too. As a consequence some arable land may have been abandoned owing to lack of farmers and facilitated expansion of *Betula* trees.

Additionally, Sweden was at war with Poland from AD 1655 until 1660 (Stiles, 1992; Lagerqvist, 2001). Recruitment for the army may also have caused a decline in population and abandonment of arable land. The pollen record shows a decrease in *Pinus* pollen, which may be explained by logging of Pine trees for ship building (masts) and possibly tar production (Hjulström et al., 2006). Open places created by clearing of forest are a suitable habitat for *Betula*. From AD 1675 the human impact indicators increase suggesting a more open landscape. This is caused by the expansion of *Juniperus* which grows in a dynamic landscape or grazed dry meadow. This can represent a change to less intensive agricultural activities like livestock breeding. This can be a result of a change in land use caused by colder and wetter climate.

Also, both disease and warfare affected the population size and thus had an impact on the landscape. A comparable event is recorded in the ARM core about 50 years later when the Great Northern war was being fought between AD 1700 and AD 1721 (Lagerqvist, 2001; Nordstrom, 2002). Crop failures and famine due to harsh weather conditions were reported in the years AD 1709–1710 and 1716–1718 and another plague epidemic (probably smallpox) struck Stockholm in AD 1710/12 (Holmgren, 2005). The synchronous peak in *Betula* and *Juniperus* and fall in *P. sylvestris* and *R. acetosa* type at AD 1710 may be caused by the same reasons stated above. The increase of *Juniperus* and regular findings of *P. lanceolata* imply a shift to pasture land which is a less labour-intensive way of farming. Similar events are recognised in pollen diagrams of Swedish, Estonian, and Danish sites (van der Linden et al., 2008; Veski et al., 2005; Yeloff and van Geel, 2007).

Human impact is relatively high in the Åkerlänna Römosse record during the 18th century. By the end of the 18th century, the presence of *E. nigrum* and coprophilous fungal spores and the disappearance of *O. palustris* remains suggest that Åkerlänna Römosse became relatively dry and accessible for animals. The large amount of highly decomposed amorphous material at AD 1794 (sample depth 59) is most likely caused by local dry conditions. This is confirmed by the occurrence of dry indicators within the testate amoebae composition and the fall in RWT to 13 cm depth. Fig. 9 shows an increase in both summer and winter temperatures at the end of the 18th century. A sharp drop in winter precipitation is also visible, together with a smaller drop in summer precipitation. The years AD 1792–94 were drier than others according to mean annual precipitation measurements of Uppsala (not shown). This fits very well with the wiggle-matched date. Solar activity is high but decreasing during this period. Afterwards, solar activity is low during the Dalton minimum (until c. AD 1820) which has high Δ ^{14}C and ^{14}C productivity (Masarik and Beer, 1999; McCracken et al., 2004; Reimer et al., 2004; Muscheler et al., 2007) and low number of sunspots (Solanki et al., 2004). During this period winter precipitation increases and summer temperatures drop. We want to draw attention to the short period with wet growing *Sphagnum* section *Cuspidata* remains and the temporary increase in ^{14}C productivity and minimum in sun spot number between AD 1889 and 1902. During this interval 3 years with an extremely high mean precipitation during the growing season have been observed. RWT shows a small peak at AD 1894. A series of dry years with low precipitation between AD 1898 and 1900 is visible in the RWT at AD 1898 (sample depth 33). These changes in bog surface wetness may be related to changes in solar activity.

During the 20th century, the water tables in the bog were affected both by climate change and human activities. From AD 1900 until 1934 RWT is relatively low. However, evapotranspiration during this period is also relatively low, which would have caused an increase of the water table. During this period peat cutting activities took place in the eastern part of the bog (Lennartsson et al., 1996; Soro et al., 1999) which provides explanation for the lowering in water table. The peat cutting area was nearest to the coring site during the Second World War (AD 1940–45) until the end of the peat cutting activities in AD 1953. However, the reconstructed water depth is not particularly deep in this interval, and it actually rises from AD 1934. This is concurrent with increasing summer temperatures and decreasing precipitation, resulting in increased moisture availability, suggesting the RWT is responding more to climate change than to the effects of peat cutting at the margin of the mire. Also agricultural activities decreased since the 1930s (see Section 5.2) and may have lowered the demand for water. Between AD 1958 and 1985 no high-resolution data could be inferred from the peat core because this interval consists of only 1 cm of peat. This decomposed layer of peat may be the result of the drainage for peat cutting. However, this period of slow peat accumulation falls after the last peat cutting date. Although the residual effects of peat cutting would be felt after abandonment of the cuttings, it seems likely that some hydrological recovery would have taken place. The period from AD 1960–1980 was relatively dry and warm, especially with dry summer conditions and a very dry summer at 1976. As a consequence it is possible that the mire

Fig. 9. A) Instrumental data of Uppsala summer and winter temperature anomaly of AD 1723–2001 mean, B) Instrumental data of Uppsala summer and winter precipitation anomaly of AD 1723–2001 mean, C) summer and winter Hammon evapotranspiration anomaly of AD 1723–2001 mean, D) Reconstructed water table based on testate amoebae composition, E) ^{14}C productivity (Masarik and Beer, 1999; Muscheler et al., 2007) and sunspot number (Solanki et al., 2004).

surface desiccated and peat accumulation slowed down or ceased. There may even have been some loss of surface material through oxidation of recent peat. The RWT registers only the initial change to drier conditions in the 1950s but there is a gap in the record until 1985. During the dry phase, lichens could grow on the dry surface and most probably *Betula* and *P. sylvestris* trees too. Tree growth may have further exacerbated the water table lowering by increasing transpiration. The pollen accumulation rates (Fig. 5) show that *Betula* increased since AD c. 1900. Whereas *P. sylvestris* does not show very different values than the previous years. Between AD 1900 and 1958 no *Betula* or *P. sylvestris* macrofossils have been found. However, in sample depths 18, 17 and 16 (AD 1958–1991) *P. sylvestris* needles were found and in sample depth 16 two *Betula* section *albae* fruits were present. These findings suggest that pine and birch trees were growing on or close to the coring spot. Therefore the peak in *Betula* at 17 cm depth (c. 1985) was a result of local birch growth, possibly caused by a warmer and drier climate (Hicks, 2001). From 1985 to 1995 high summer and winter precipitation ranges are reflected in high RWT levels. A drop in precipitation and increase in temperatures, and thus increased evapotranspiration, since AD 1997, may have been the cause for the lowering of the water table over the last few years of the record.

5.2. The Swedish Demographic Transition and the landscape

The demographic transition is a model that describes population changes over time (Fig. 10). The model is based on the observed changes in birth and death rates in industrialized societies (Chesnais and Kreager, 1992; Montgomery, 2007). In the first demographic stage, the pre-modern stage, a balance between birth and death rates is present, and both rates are relatively high. This results in a slow increase in population. In the second demographic stage, the urbanizing/industrializing stage, the balance between birth and death rates is broken. This results in a rise in population caused by a decline in death rate. Improved agricultural practices (the agricultural revolution), like crop rotation and selective breeding, results in higher yields. Also improvements in public health and hygiene reduced mortality (Chesnais and Kreager, 1992; Montgomery, 2007). Stage three, the mature industrial stage, is characterized by a decline in birth rate, leading to a stabilization of the population size. Several causes have been suggested, although some are speculative, like female employment, contraceptive technology, costs of children in urban society and decrease in childhood mortality. Stage four, the post-modern stage, is characterized by both low birth and death rates and stagnation in population size.

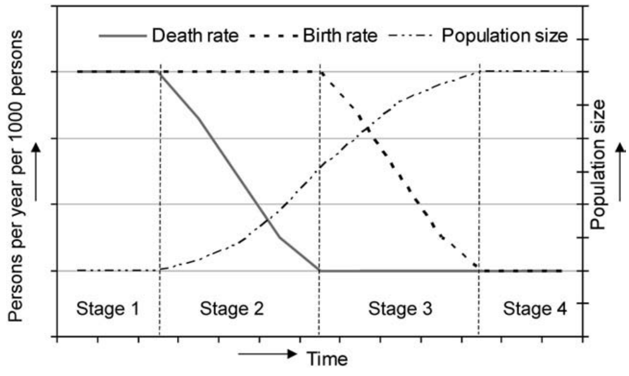


Fig. 10. Schematic view of the Demographic Transition model (after Chesnais and Kreager, 1992; Montgomery, 2007).

Swedish demographic data, available since AD 1749 on the website of the Swedish Statistics council (SCB), were used to calculate Swedish population growth and birth and death rates. The results were divided into four stages according to the Demographic Transition model. During the first demographic stage in Sweden, a higher death rate is observed in the years AD 1771/73, which are cold and wet years with crop failures and famines (Holmgren, 2005), resulting in a decrease in population size. The population recovers to positive numbers at AD 1774. However, a negative trend is visible during the periods AD 1774–1809. We have compared these figures with the non-arboreal pollen percentages of Åkerlänna Römosse (Fig. 11A) in order to find a relationship between population growth and openness of the landscape as a measure for human impact. We found that the demographic trends can also be observed in the pollen percentages of human impact indicators (Fig. 11A; full data in Fig. 4). Human impact pollen percentages (apophytes plus anthropochores) are relatively high between AD 1750 and 1778, but subsequently decrease until the start of the 19th century. This period is known as the Dalton minimum (c. AD 1790–1820) in solar activity, which is actually a series of very dry and warm years (around AD 1800), and cold and wet intervals (around AD 1810–1820) in the Uppsala region.

In the second demographic stage, the urbanizing/industrializing stage, the balance between birth and death rates was broken. Human impact pollen percentages slowly increase as population increases in stage 2.

The third stage, the mature industrial stage, starts at c. 1866 in Sweden (Montgomery, 2007). Population size increases during the interval AD 1866–1940, but growth decreases toward AD 1940. The human impact percentages do not show the same trend as the population growth during stage 3. This can be explained by many Swedes migrating (mostly to the United States of America) in the periods AD 1866–1914 (Runblom and Norman, 1976). This is shown by the discrepancy between the total population change and the natural population change in Fig. 11C. Natural population change only includes births and deaths; total population change also includes population change by immigration and emigration. Large emigration waves (total population change values lower than natural population change values) are visible in the periods AD 1867–68 and 1880–1893; in these periods human impact percentages in the pollen record are low. The period 1868–1890 is a generally cold period according to temperature measurements from Uppsala with some extremely dry summers and extremely wet summers which caused bad harvests and famine (Holmgren, 2005). Many people migrated from the countryside and therefore forest could expand.

Åkerlänna Römosse is located in the Uppsala municipality. Uppsala has been connected to the railway system since AD 1866, which promoted industrialization. In AD 1867 about 80 people worked in industry in Uppsala. In AD 1890 23 factories were established in Uppsala, and this number had even grown to 93 in AD 1910. By AD 1920 about 3000 people were working in

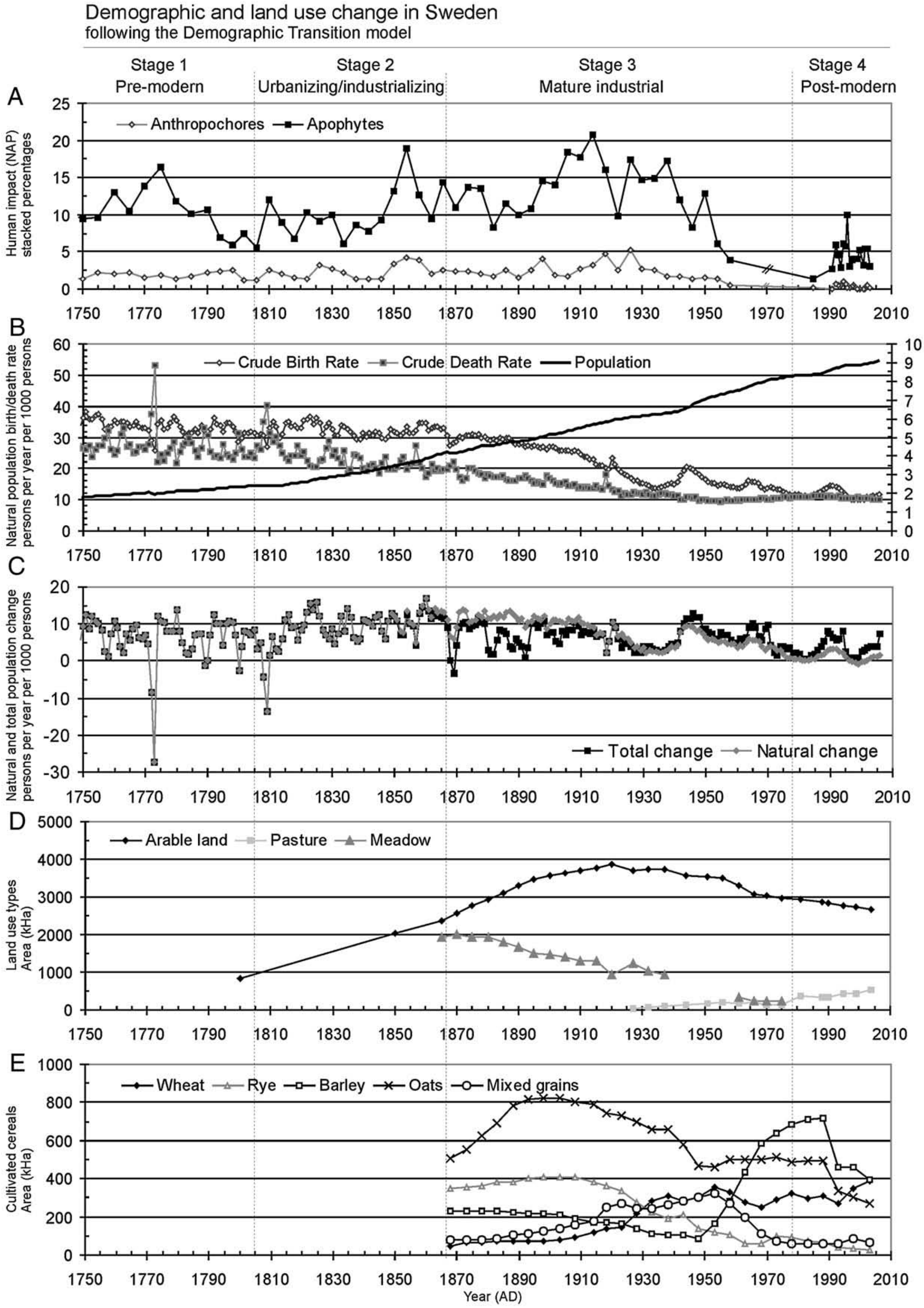


Fig. 11. Demographic and land-use change in Sweden. A) Human impact recorded in Åkerlänna Römosse (NAP = non-arboreal pollen) in stacked percentages, B) Natural population, birth and death rates (persons per year per 1000 persons), C) Natural and total population change (persons per year per 1000 persons), D) Area of Sweden occupied by land-use type (kHa), E) Area of Sweden used for cereal cultivation (kHa).

Uppsala industry (Uppsala-municipality, 2007). The Åkerlänna Römosse area was probably not directly affected by the industry. However, the pollen diagram shows a decrease in tree pollen, mainly *P. sylvestris*, and increase in human impact until AD 1914. It is very likely that pine forests were logged for fuel and space for industry or arable land. Fig. 10D shows the Swedish land area in kHa that was in use as arable land, pasture or meadow. At c. AD 1870 meadows and arable land area were almost the same, resp. 2000 and 2500 kHa. At c. AD 1920 meadow area had decreased to c. 1000 kHa and arable land expanded to c. 3900 kHa. Since AD 1920 both meadows and arable land decrease and pastures increase. The human impact curve of Fig. 11A follows the same trend of the arable land curve in Fig. 11D.

The cultivation area in Sweden of different cereal species is presented in Fig. 11E. Initially, *Secale* (rye) and *Avena* (oats) had the highest proportion, and cultivation area increased during the period AD 1866/70–1906/10. From c. AD 1926/30 rye and oats decrease and cultivation of wheat and mixed grains increased. From AD 1956/60 the area with *Hordeum* (barley) cultivation increased rapidly and became the largest cereal crop. These changes in cereal cultivation are visible in the human impact pollen record of Åkerlänna Römosse. By the time of AD 1950 rye cultivation has disappeared. The curve of the anthropochores in Fig. 11A mainly consists of wind-pollinated rye pollen and shows the same shape as rye cultivation curve in Fig. 11E. Oats and barley are cleistogamic (with closed flowers and self-pollination) and are therefore hardly present in the pollen record. Potatoes and sugar beets increased after AD 1920. However, these crops are also not wind pollinated, and therefore hardly recorded in the pollen record. Grasses now dominate the apophytes group. Land use changed from arable land to pastures as shown in Fig. 11D.

Another effect recorded in the pollen record may be that people stopped farming and employment moved from the countryside to the cities. This phenomenon was related to a shift from intensive (small-scale) to extensive farming (large-scale). Statistics show that the number of cattle, pigs and sheep in Sweden increased during the 20th century; however, the number of animal farms decreased dramatically by 96%. From 1951 to 2003 the number of people employed in agriculture decreased from 869,000 to 168,000, i.e. by more than 80% (SJV, 2005).

According to Montgomery (2007) demographic stage 4, the post-modern stage, starts at AD 1977 in Sweden. The decades of the 20th century have been a series of periods with increased population growth caused by baby booms and immigration waves which are probably linked to periods of war and uncertainty elsewhere in the world. These increases in population are not reflected by the openness in the landscape around Åkerlänna Römosse because most of the population growth is in the cities. Additionally, forests could expand as a result of changes in nature conservation legislation.

6. Conclusions

A pollen and macrofossil reconstruction of the vegetation of the past c. 350 years in, and surrounding the raised bog Åkerlänna Römosse delivered detailed information about vegetation history, hydrological change and human impact. Testate amoebae composition has been used to reconstruct the past water tables. Generally, the testate amoebae record suggests similar hydrological changes to those suggested by local vegetation development. However, testate amoebae composition seems to be more sensitive to dry-shifts than to wet-shifts. It is shown that a high precision chronology can be derived for this time period using wiggle-matched ^{14}C dating. This allows secure correlation of proxy-climate and palynological records with historical meteorological and land use and population data. Changes in mire surface wetness are mainly caused by climate change (precipitation and evaporation), as shown by instrumental climate data since the mid-18th century. Occasionally, no evidence for climate change or human impact on the hydrology is present and natural succession or internal bog dynamics may have caused water table changes. The human impact signal of the pollen data was compared with Swedish population and land-use data. A link between changes in population growth and human impact (openness of the vegetation) is shown and related to a demographic transition model. Key historically known agricultural changes such as the variations in *Secale* cultivation are clearly recorded in the pollen data.

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Appendix A

Calendar age of all sampled levels based on 14C AMS wiggle-match dated chronology of Åkerlänna Römosse

Depth (cm)	Age (AD)	Depth (cm)	Age (AD)
1	2003	46	1846
2	2002.3	47	1842
3	2001.7	48	1838
4	2001	49	1834
5	2000	50	1830
6	1999	51	1826

(continued on next page)

Appendix A (*continued*)

Depth (cm)	Age (AD)	Depth (cm)	Age (AD)
7	1998	52	1822
8	1997.3	53	1818
9	1996.7	54	1814
10	1996	55	1810
11	1995.3	56	1806
12	1994.5	57	1802
13	1993.8	58	1798
14	1993	59	1794
15	1992	60	1790
16	1991	61	1785
17	1985	62	1780
18	1958	63	1775
19	1954	64	1770
20	1950	65	1765
21	1946	66	1760
22	1942	67	1755
23	1938	68	1750
24	1934	69	1745
25	1930	70	1740
26	1926	71	1735
27	1922	72	1730
28	1918	73	1725
29	1914	74	1720
30	1910	75	1715
31	1906	76	1710
32	1902	77	1705
33	1898	78	1700
34	1894	79	1695
35	1890	80	1690
36	1886	81	1685
37	1882	82	1680
38	1878	83	1675
39	1874	84	1670
40	1870	85	1665
41	1866	86	1660
42	1862	87	1655
43	1858	88	1650
44	1854	89	1645
45	1850	90	1640

Appendix B

Omitted taxa of (A) macrofossils (Fig. 6) and (B) fen and bog pollen and spores (Fig. 7).

Omitted taxa:

A. Macrofossils (n)

Eriophorum spec. fruit: 1 cm: 1, 15 cm: 1, 48 cm: 1, 59 cm: 1, 73 cm: 1

Eriophorum vaginatum sklerenchym spindles: 9 cm: 2, 62 cm: 2, 74 cm: 1, 77 cm: 4, 84 cm: 30

Cyperaceae spec. seed: 19 cm: 1, 32 cm: 1

cf. *Scheuchzeria palustris* epidermis: present (+) in samples 30-80 cm depth

B. Fen and bog pollen and spores

Fen

Potentilla type: 78 cm: 0.2%

Typha angustifolia: 25 cm: 0.2%, 69 cm: 0.2%, 71 cm: 0.2%

Raised bog

Drosera rotundifolia/anglica: 46 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, 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 14C 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.

Cain, W.F., Suess, H.E., 1976. Carbon-14 in tree rings. Journal of Geophysical Research-Atmospheres 81, 3688–3694.

Chambers, F.M., Barber, K.E., Maddy, D., Brew, J., 1997. A 5500-year proxy-climate and vegetation record from blanket mire at Talla Moss, borders, Scotland. The Holocene 7, 391–399.

Charman, D.J., 2007. Summer water deficit variability controls on peatland water-table changes: implications for Holocene palaeoclimate reconstructions. Holocene 17 (2), 217–227.

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

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.

Chesnais, J.-C., Kreager, E., 1992. The Demographic Transition: Stages, Patterns, and Economic Implications: A Longitudinal Study of Sixty-seven Countries Covering the Period 1720–1984. Clarendon Press, Oxford. 633 pp.

Clymo, R.S., 1984. The limits to peat bog growth. Philosophical Transactions of the Royal Society of London 303, 605–654.

Dahl, E., Krog, H., 1973. Macrolichens of Denmark, Finland, Norway and Sweden. Universitetsforlaget, Scandinavian University Books, Oslo, Bergen, Tromsø, 185 pp.

Eddy, J.A., 1976. The Maunder minimum. Science 192 (4245), 1189–1202.

Engelmark, R., Olsson, I.U., Renberg, I., Zackrisson, O., 1976. Palaeo-ecological Investigations in Coastal Västerbotten, Northern Sweden. Early Norrland, 9. SLU Umeå Sweden, Umeå.

Eriksson, J.V., 1912. Bälinge mossars utvecklingshistoria och vegetation. Svenk Botanisk Tidskrift, BD 6 H2: 8-190.

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 14C 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., 1990. TILIA and TILIA GRAPH PC spreadsheet and graphics software for pollen data. INQUA commission for study of the Holocene. Sub-commission 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., in press. Long-term effects of climate change on vegetation and carbon dynamics in peat bogs. Journal of Vegetation Science.

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.

Hjulström, B., Isaksson, S., Hennius, A., 2006. Organic geochemical evidence for pine tar production in middle Eastern Sweden during the Roman Iron Age. Journal of Archaeological Science 33, 283–294.

Holmgren, K., 2005. Klimatet, människan och samhället. In: Bunte, C., Berglund, B.E., Larsson, L. (Eds.), Arkeologi och naturvetenskap. Grahns tryckeri AB, Lund.

Hoyt, D.V., Schatten, K.H., 1997. The Role of The Sun in Climate Change. Oxford University Press, New York. 279 pp.

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

Johnson, L.C., Damman, A.W.H., 1991. Species-controlled *Sphagnum* decay on a South Swedish raised bog. Oikos 61 (2), 234–242.

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 Russian).

Kilian, M.R., van Geel, B., van der Plicht, J., 1995. Dating raised bogs: new aspects of AMS 14C 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. 14C AMS wiggle matching of raised bog deposits and models of peat accumulation. Quaternary Science Reviews 19, 1011–1033.

Lagerqvist, L.O., 2001. A History of Sweden. Värnamo, Fälth and Hässler AB.

Lennartsson, T., Sundberg, S., Persson, T., 1996. Landskapets förändringar. In: Frederiksson, R., Tjernberg, M. (Eds.), Upplands fåglar—fåglar, människor och landskap genom 300 år, Uppsala.

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

Levin, I., Kromer, B., Schoch-Fischer, H., Bruns, M., Münnich, M., Berdau, D., Vogel, J.C., Münnich, K.O., 1994. Delta 14CO2 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.

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

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., 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.

McClymont, E. et al., in press. Increased bog wetness, changing nutrient supplies, and the disappearance of *Sphagnum imbricatum* from Butterburn Flow, U.K. The Holocene.

McCracken, K.G., McDonald, F.B., Beer, J., Raisbeck, G., Yiou, F., 2004. A phenomenological study of the long-term cosmic ray modulation, 850–1958 AD. Journal of Geophysical Research-Space Physics 109 (A12).

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.

Montgomery, K., 2007. The Demographic Transition. Department of Geography and Geology, University of Wisconsin, Marathon County, US.

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.

Nordstrom, B.J., 2002. The History of Sweden. Greenwood Press, Westport, CT.

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.

Reimer, P.J., et al., 2004. IntCal04 terrestrial radiocarbon age calibration, 0–26 cal kyr BP. Radiocarbon 46 (3), 1029–1058.

Runblom, H., Norman, H., 1976. From Sweden to America, A History of Migration. University of Minnesota Press, Minneapolis. 391 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.

SJV, 2005. Swedish agriculture in figures 1800–2004 (Svenskt jordbruk i siffror 1800–2004). Jordbruksverket Statistikrapport 6 2005.

Smith, A.J.E., 1978. The Moss Flora of Britain and Ireland. Cambridge University Press, Cambridge.

Solanki, S.K., Usoskin, I.G., Kromer, B., Schüssler, M., Beer, J., 2004. An unusually active sun during recent decades compared to the previous 11,000 years. Nature 431, 1084–1087.

Soro, A., Sundberg, S., Hakan, R., 1999. Species diversity, niche metrics and species associations in harvested and undisturbed bogs. Journal of Vegetation Science 10 (4), 549–560.

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 14C wiggle-matching. Quaternary Science Reviews 19, 1589–1604.

Stiles, A., 1992. Sweden and the Baltic 1523–1721. Hodder and Stoughton, London. 137 pp.

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.

Svensmark, H., 2007. Cosmoclimatology: a new theory emerges. Astronomy and geophysics 48, 1.18–1.24.

Svensson, G., 1988. Fossil plant communities and regeneration patterns on a raised bog in South Sweden. Journal of Ecology 76, 41–59.

Uppsala-municipality 2007. http://www.uppsala.se/uppsala/templates/StandardPage____14877.aspx.

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., 2008. Late Holocene human impact and climate change recorded in a north Swedish peat deposit. Palaeogeography Palaeoclimatology Palaeoecology 258 (1–2), 1–27.

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., Middeldorp, A.A., 1988. Vegetational history of Carbury Bog (Co. Kildare, Ireland) during the last 850 years and a test of the temperature indicator value of 2H/1H measurements of peat samples in relation to historical sources and meteorological data. New Phytologist 109, 377–392.

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

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

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.

Veski, S., Koppel, K., Poska, A., 2005. Integrated palaeoecological and historical data in the service of fine-resolution land use and ecological change assessment during the last 1000 years in Rouge, southern Estonia. Journal of Biogeography 32 (8), 1473–1488.

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

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

Yeloff, D., van Geel, B., 2007. Abandonment of farmland and vegetation succession following the Eurasian plague pandemic of AD 1347–1352. Journal of Biogeography 34, 575–582.