

Late Holocene climate change and human impact recorded in a south Swedish ombrotrophic peat bog

Marjolein van der Linden*, Bas van Geel

Institute for Biodiversity and Ecosystem Dynamics, Universiteit van Amsterdam, Kruislaan 318, 1098 SM Amsterdam, The Netherlands

Received 7 September 2005; received in revised form 2 February 2006; accepted 16 March 2006

Abstract

A peat core from a raised bog in southern Sweden was examined (plant macrofossils, pollen/non-pollen microfossils, colorimetric humification, carbon/nitrogen ratios, bulk densities, loss on ignition) to investigate the effects of climate change and human impact on the plant species composition and carbon accumulation of the peat forming vegetation. ^{14}C wiggle-match dating was applied for fine-resolution dating. Cooling at the start of the Little Ice Age was reflected by a decline of thermophilous trees from the pollen record between ca. cal AD 1275–1590, coinciding with increases in atmospheric $\Delta^{14}\text{C}$ pointing to decreases of solar activity (Wolf and Spörer minimum). Human impact also decreased. Later, the effect of human impact was clearly visible in the form of a black brown, decomposed peat layer, the top of which marks a gap of more than 300 years. Artificial drainage probably caused secondary decomposition and oxidation of the peat. From ca. cal AD 1960 the water table of the peat bog was restored following construction of a road and raised bog vegetation regenerated.

© 2006 Elsevier B.V. All rights reserved.

Keywords: ^{14}C AMS wiggle-match dating; Atmospheric bomb pulse; Raised bog; Little Ice Age; Human impact; Solar forcing

1. Introduction

Studies of peat monoliths provide proxy data giving information on the changing plant species composition, climate and human activities in the past. These data help to unravel the development of vegetation and carbon accumulation in peat bogs. Reconstructions of vegetation and climate can also provide key information about the future. Palaeo proxy data are used to validate models explaining present-day climate and predicting future climate. Policy makers influenced by the output of these

models and palaeo records, establish policies on emission of greenhouse gasses and nature conservation.

Peat growth and carbon accumulation in raised bogs form a complex system and are affected by many external and internal factors. The amount of precipitation, temperature and CO_2 concentration influence the species composition of the peat-forming vegetation. Under wet and cold conditions other plant species will grow in and around the peat bog than under dry and warm conditions. Climate can also influence the amount of human activities in an area. Dry conditions in a raised bog, either climate or human-induced, can cause more decay. Decomposing peat releases CO_2 into the atmosphere, which might affect climate because of the enhanced greenhouse effect.

* Corresponding author. Tel.: +31 20 5257666; fax: +31 20 5257832.

E-mail address: M.vanderlinden@uva.nl (M. van der Linden).

Compared to other bog ecosystems, *Sphagnum*-raised bogs have the greatest peat accumulation potential and therefore the highest carbon accumulation potential (Thormann et al., 1999). Water availability is crucial for *Sphagnum* growth (Clymo and Hayward, 1982), and *Sphagnum* mosses lack the efficient water conducting system of vascular plants and are therefore more sensitive to extended periods of drought (Malmer et al., 1994; Heijmans et al., 2001). The decomposition rate varies between *Sphagnum* species. Very wet growing species such as *Sphagnum cuspidatum* tend to decompose faster when exposed to air than relatively dry growing species such as *Sphagnum rubellum*. The species composition and carbon accumulation of bog ecosystems is therefore sensitive to climate change and to changes in water availability owing to human impact (Johnsson and Damman, 1991; Malmer et al., 1994).

Sphagnum bogs are also excellent deposits for investigating the relationship between changing solar activity and past climate (Mauquoy et al., 2002a,b). Ombrotrophic *Sphagnum* bogs are closely coupled to the atmosphere, since they receive all their water through precipitation alone. van Geel et al. (1996), Mauquoy et al. (2002a,b), and Speranza et al. (2003) linked wet-shifts during the Subboreal/Subatlantic transition and the Little Ice Age (indicated by changing *Sphagnum* composition) to periods of low solar activity and high ^{14}C production in the atmosphere.

Fluctuations in Holocene atmospheric radiocarbon concentrations have been shown to be due to variations in the solar magnetic field. Solar wind is a proton–electron gas pushed into space by the sun. The intensity of the galactic cosmic rays reaching the Earth's atmosphere is modulated by the solar wind. During periods of reduced solar activity more cosmic rays reach the atmosphere and thus the production of the cosmogenic isotopes increases. The records of cosmogenic isotopes, ^{14}C in tree rings, and ^{10}Be in Greenland ice, reflect changing solar activity in the past (Beer et al., 1988; Hoyt and Schatten, 1997; van Geel et al., 1999). Periods of increasing production of ^{14}C and ^{10}Be highlight changes from relatively high to low solar activity. Past atmospheric ^{14}C fluctuations can be recorded in the peat deposits which are also studied paleoecologically.

The aim of our study is to reconstruct changes in climate, based on the record of changing plant species composition of raised bog vegetation during the late Holocene. In addition we study carbon accumulation at the sampling site. Furthermore, we aim to distinguish between direct effects of climate changes and the effects

on raised bog growth caused by changing human activities. We analyzed the plant species composition and carbon accumulation of the upper half meter of an ombrotrophic raised peat bog in Southern Sweden. To obtain a high-resolution reconstruction, the results of pollen and macrofossil analyses 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). This dating strategy was used to investigate the possible link between bog vegetation, climate change and solar activity. To evaluate the carbon accumulation capacity of a raised bog in South Sweden, we compared the changing plant

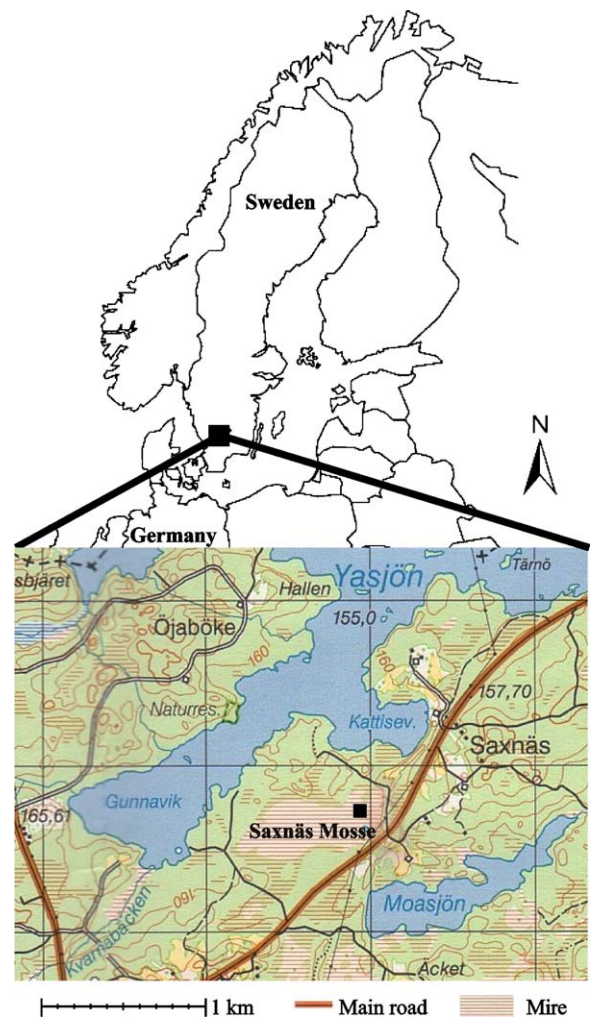


Fig. 1. Research site Saxnäs Mosse in southern Sweden, a raised bog situated in between two lakes (Yäsjön and Moasjön) and several roads (black and orange lines). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

species composition with bulk densities, C/N ratios, loss on ignition and degree of humification.

2. Material and methods

2.1. Research site

We took several cores with a Wardenaar corer (Wardenaar, 1987) in the raised bog Saxnäs Mosse (SNM) near Lidhult, Sweden (56°51'20.78"N, 13°27'39.62"E, Fig. 1) and selected the longest ones that were not affected by the coring process. Peat core SNM-I did not show any visible compression and the complete Wardenaar monolith of 94 cm depth was transported to the laboratory in two metal boxes of 50 cm each. A second monolith (SNM-II, 56°51'20.28"N, 13°27'39.92"E), was collected for extra analyses if necessary. The upper 50 cm of the first monolith (SNM-I) was studied. Contiguous 1 cm thick sub-samples were taken from the peat monolith for all analyses.

2.2. Microfossil analyses

A cylindrical sampler of 10 mm diameter was used to select microfossil samples of ca. 0.79 cm³ each. A known amount of *Lycopodium* grains (ca. 10 679 in one tablet) was added to the samples before being treated with KOH and acetolysed (Faegri and Iversen, 1989). The *Lycopodium* grains were used to calculate pollen concentrations (Stockmarr, 1971) and pollen accumulation rates (PAR) (Middeldorp, 1982). Pollen grains were

identified using Moore et al. (1991), Beug (2004) and a reference collection of pollen type slides. Interpretation of the pollen record followed Berglund (1986) and Behre (1986). Non-pollen palynomorphs (van Geel, 1978) were recorded and expressed as percentages of the pollen sum. Two 'new' fungal spore types were distinguished (Type 264, Plate I: 1–3 and Type 265, Plate I: 4 and 5). The pollen sum (minimum of 400 grains) included pollen of trees and shrubs, grasses, human impact indicators and other herbs. The herb pollen types are listed in Appendix 1. Percentages of microfossil taxa not included in the pollen sum were expressed as percentages of the pollen sum.

2.3. Macrofossil analyses

A cylindrical sampler of 25.2 mm diameter was used to select the macrofossil samples of ca. 4.99 cm³. Macrofossil samples were boiled for ca. 30 min with 5% KOH and sieved (mesh 160 µm). Macrofossils were scanned 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. Volume percentages were estimated for the mosses, roots and epidermis material. Leaves, branches and seeds of flowering plants were counted. Acari, testate amoebae and fungal remains were estimated in classes of abundance expressed on a five-point scale, one plus meaning low numbers, five plusses pointing to high numbers.

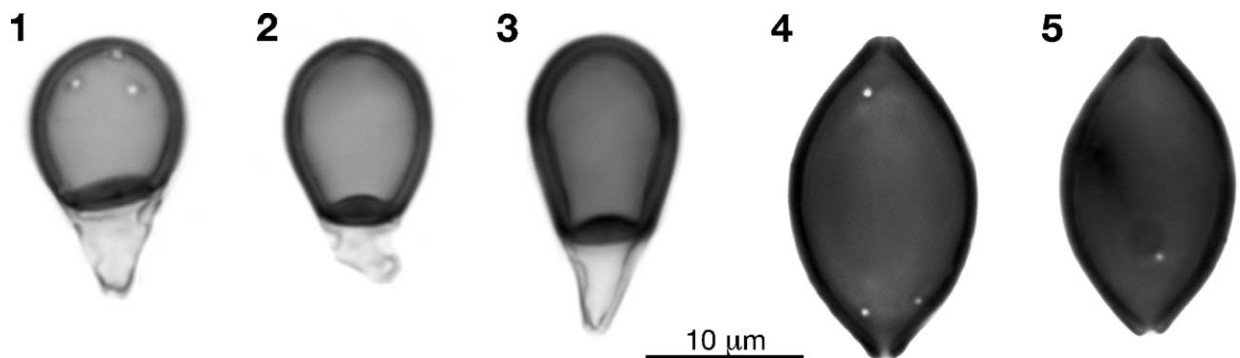


Plate I. Microscopic photos of new fungal types found in Saxnäs Mosse. Scale bars are 10 µm long.

- 1–3. Type 264 (sample SNM50, ×1000): Chlamydo-spores (?), transversally one-septate, (16–) 18–20 (–21) × 10–13 µm. Top cells brown, 10–13 µm long, and 10–13 µm wide, narrow towards septum. At the septum, the spores are 5–6 µm wide. The basal cells are hyaline and have a triangular shape. Type 264 spores occur in the *Sphagnum papillosum* peat section of Saxnäs Mosse.
- 4,5. Type 265 (sample SNM28, ×1000): Ascospores ellipsoidal, non-septate, wall dark brown with smooth surface, 18–20 × 10–13 µm with two protruding apical pores, about 1 µm wide. Type 265 spores are present together with *Sphagnum* Section *Cuspidata* and *Rhynchospora alba* in Saxnäs Mosse. Type 265 spores may indicate local wet conditions.

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

In total 31 levels of the peat core were ^{14}C AMS dated. In order to obtain a better perspective for the age–depth modeling the level of 60 cm depth was also radiocarbon dated. Only aboveground plant remains were selected from the macrofossil samples (Kilian et al., 1995). Preferably *Sphagnum* remains (branches or stems with leaves) were used. Some samples of very decomposed peat did not contain sufficient *Sphagnum* remains, and therefore other plant remains were selected for dating. 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 then dried in tin cups in a stove 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.

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

The bulk density (dry weight/fresh volume) was measured for the top 50 cm of the core. Sub-samples of 10.5 cm³ 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 drying sub-samples of ca. 35 cm³ for 3 h at 550 °C. C and N contents were determined with a Fisons EA1108 CHN–O element analyser. These analyses provided information on the decomposition state of the sampled material. A high state of decomposition points to relatively dry local conditions, while a low state of decomposition indicates wet local conditions.

2.6. Colorimetric determination of peat humification

This technique is believed to represent a semiquantitative measure of average summer effective rainfall (Blackford and Chambers, 1993), 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. One should keep in mind that local vegetation change due to internal dynamics of the bog vegetation can also affect the decomposition process (Mauquoy et al., 2002a,b). Sub-samples of ca. 5 cm³ 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 matrices that possess low transmission values (Mauquoy et al., 2002a,b). Therefore high transmission values should indicate a high average summer effective rainfall causing a high water table in a raised bog.

3. Results

3.1. Bulk density, C/N ratio, LOI and degree of humification

In Fig. 2 the results of bulk density measurements, degree of humification (transmission), C/N ratio and loss on ignition (LOI) are shown. The layer from 50 to 30 cm depth shows high bulk densities and high degree of humification by low transmission values. In the darker-coloured peat layer between 40 and 30 cm depth, very high bulk density and low C/N ratios with higher N percentages and low LOI values are visible. At 30 cm depth a change occurs. Bulk densities show a decline and transmission percentages, C/N ratio and LOI percentages show a steep rise. At 24 cm depth bulk densities decrease and transmission values, C/N ratios and LOI percentages increase.

3.2. Chronology

The results of ^{14}C AMS dating are presented in Table 1. The dates were wiggle-matched (van Geel and Mook, 1989; Kilian et al., 2000) using the INTCAL 98 calibration curve (Stuiver et al., 1998) within the Groningen computer program Cal25 (van der Plicht, 1993). The atmospheric bomb ‘peak’ was used to wiggle-match the post-1950 ^{14}C dates (Levin and Hesshaimer, 2000; Levin et al., 1994; Goodsite et al., 2001; Donders et al., 2004; Goslar et al., 2005). Therefore the Excel-approach (modified windows version of Cal25) (Mauquoy et al., 2002a,b; Blaauw et al., 2003, 2004) was updated with modern ‘negative’ radiocarbon years. 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.

Saxnäs Mosse analyses

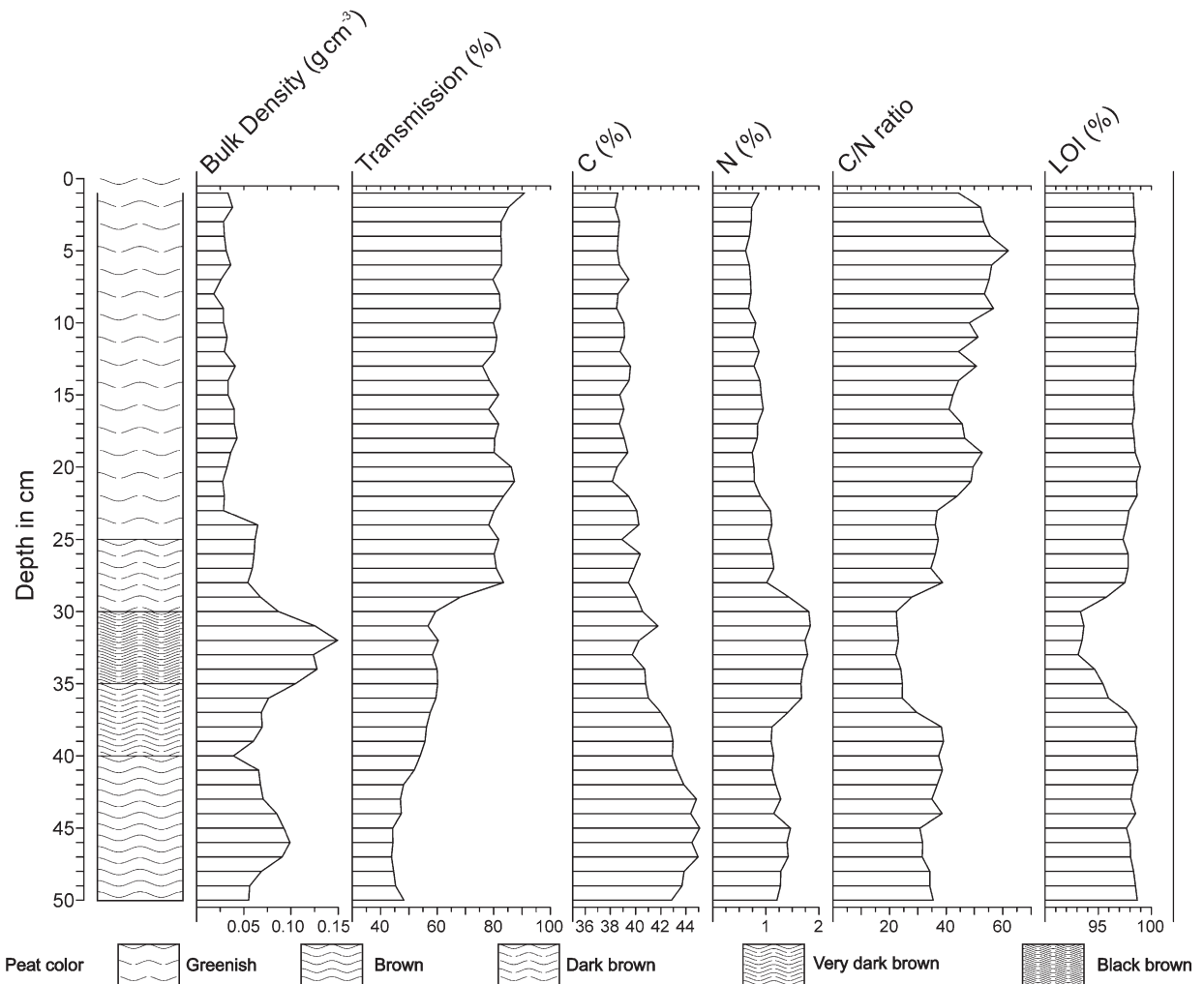


Fig. 2. Results of bulk density (g cm^{-3}), degree of humification (% transmission), C/N ratio and Loss on Ignition (LOI, % organic material) analyses. Note the differences in scale.

The data set was split up into five stratigraphic sub-sets. This subdivision was based on shifts in the pollen concentration, *Sphagnum* composition, degree of humification and bulk density results (Speranza et al., 2000; Kilian et al., 2000; Blaauw et al., 2003, 2004). One linear accumulation rate seemed highly unlikely given the changes in *Sphagnum* species composition and an uncompacted fresh acrotelm with an underlying compressed catotelm. Initially the dates were wiggle matched using four sub-sets. Fig. 3a shows the radiocarbon dates before 1950 from 50–30 cm depth, divided in two sub-sets (50–42 cm and 41–30 cm). In this way the dates from 39 to 30 cm depth did not fit very well with the calibration curve. Most of the dates seemed to be too old. However, we had no reason to

doubt these dates. Guided by the relatively high degree of decomposition of the peat we assumed that there was a hiatus present between 30 and 29 cm depth. Based on this assumption, the samples below the hiatus were older than shown in Fig. 3a. We divided the data set into five sub-sets: 50–42 cm, 41–36 cm, 35–30 cm, 29–25 cm and 24–0 cm depth. Fig. 3b and c show the wiggle-match results with a supposed hiatus between 30 and 29 cm depth. The hiatus level is also the boundary between pre- and post-atomic bomb ^{14}C dates (atmospheric ^{14}C levels steeply rose after ca. AD 1955). The wiggle-match records are presented in separate Fig. 3b and c because of scaling problems. The ages of samples between the wiggle-match dated levels were estimated by linear interpolation (Appendix 2).

Table 1
Radiocarbon and ^{14}C AMS wiggle-match date results for Saxnäs Mosse

Sample depth (cm)	GrA-number	$\delta^{13}\text{C}$ (‰)	Carbon content (%)	^{14}C age (BP)	Laboratory standard deviation (BP)	Wiggle-match date		Sample composition
						(AD)	+/-	
4	26501	-28.2	42.7	-710	40	2000	0.4	<i>Sph mag</i> St+Le
7	26395	-27.1	43.7	-785	30	1998	0.4	<i>Sph mag</i> St+Le
10	24430	-25.9	43.4	-980	40	1995	0.4	<i>Sph mag</i> St+Le
14	27752	-25.5	40	-1185	35	1992	0.4	<i>Sph mag</i> St+Le
17	26397	-27.2	39.2	-1195	30	1990	0.4	<i>Sph mag</i> St+Le
20	24431	-26.1	43	-1475	40	1987	0.4	<i>Sph mag</i> St+Le
24	26399	-26.5	40.7	-1350	30	1984	0.4	<i>Sph mag</i> St+Le
26	26400	-26.3	39.9	-1970	30	1977	3	<i>Sph sp.</i> St
27	27754	-25.8	41.5	-2805	35	1971	3	<i>Sph mag</i> St+Le
28	26621	-26.4	43.2	-3290	30	1965	3	<i>Sph sp.</i> St+O
29	27683	-26.4	47.5	-1025	50	1959	3	<i>Sph sp.</i> Br, <i>Eric tet</i> Br
30	24419	-24.5	49.4	300	50	1648	10.8	<i>Rhy alb</i> Se, <i>Eric tet</i> Se, <i>Dro rot</i> Se, <i>Dro int</i> Se
31	27684	-22.8	45.2	380	60	1626	10.8	<i>Sph mag</i> St+Le
32	26679	-26.5	43.2	260	50	1605	10.8	<i>Sph sp.</i> St, <i>Rh alb</i> Fr, <i>Cal vul</i> Br
33	27686	-27.4	51.2	340	60	1583	10.8	<i>Erio vag</i> Sk sp, <i>Sph mag</i> , St+Le, <i>Eric tet</i> Br, <i>And pol</i> Se and <i>Rhy alb</i> Fr
34	26680	-27.7	49	110	45	1562	10.8	Ericaceous inflorescences, <i>Sph sp.</i> St, <i>And pol</i> Le
35	27687	-26.5	49.7	440	50	1540	10.8	<i>Sph mag</i> St+Le, <i>And pol</i> Le
36	26643	-25.8	42.2	100	35	1518	11	<i>Sph sp.</i> St
37	27688	-25.1	48.3	500	50	1496	11	<i>Sph mag</i> St+Le
38	26622	-26.4	45.2	420	35	1474	11	<i>Sph sp.</i> St
39	27690	-28.3	65.5	490	50	1452	11	<i>Cal vul</i> Br
40	24432	-26.0	46	470	40	1430	11	<i>Sph mag</i> St+Le, <i>And pol</i> Se, <i>Bet sp.</i> Fr
41	27692	-23.9	48.7	570	50	1408	11	<i>Sph mag</i> St+Le, <i>Rhy alb</i> Fr
42	27693	-25.0	48.4	650	60	1382	13.3	<i>Sph mag</i> Le, <i>Rhy alb</i> Fr
43	27694	-26.7	55.4	620	50	1355	13.3	<i>Sph mag</i> Le, <i>Cal vul</i> Br
44	27696	-25.1	55.2	770	70	1329	13.3	<i>And pol</i> Br, <i>Sph mag</i> St+L
45	27697	-27.6	56.2	690	50	1302	13.3	<i>Sph mag</i> Le+Op, <i>Rhy alb</i> Fr, <i>Cal vul</i> Br, <i>And pol</i> Br
46	26681	-25.1	43.6	850	45	1276	13.3	<i>Sph sp.</i> St, <i>Rhy alb</i> Fr
48	27698	-24.7	50.3	710	50	1223	13.3	<i>And pol</i> Le, <i>Sph mag</i> St+Le, <i>Rhy alb</i> Fr
50	24429	-22.5	44	880	40	1170	13.3	<i>Sph pap</i> St+Le
60	24426	-19.4	41.2	1035	40	905	13.3	<i>Sph pap</i> St+Le

The dates were wiggle-matched using the INTCAL 98 calibration curve (Stuiver et al., 1998) within the Groningen program Cal25 (van der Plicht, 1993). The atmospheric bomb pulse was used to calibrate the modern ^{14}C dates (Goodsite et al., 2001; Levin et al., 1994). Sample composition: *Sph sp.*=*Sphagnum sp.*, *Sph mag*=*Sphagnum magellanicum*, *Sph pap*=*Sphagnum papillosum*, *Eric tet*=*Erica tetralix*, *Rhy alb*=*Rhynchospora alba*, *Dro rot*=*Drosera rotundifolia/anglica*, *Dro int*=*Drosera intermedia*, *Cal vul*=*Calluna vulgaris*, *Erio vag*=*Eriophorum vaginatum*, *And pol*=*Andromeda polifolia*, *Bet sp.*=*Betula sp.*, St=stems, Le=leaflets, Se=seeds, Op=opercula, Br=branches, Sk sp=sklerenchym spindles, Fr=fruit.

3.3. Macrofossils and microfossil analyses

3.3.1. Regional vegetation development (dry land taxa)

The zonation of the pollen percentage diagram (Fig. 4) is based on the pollen record of the regional vegetation. Fig. 5a shows the pollen concentrations (grains cm^{-3}) of trees and shrubs and human impact indicators. These curves reflect the trends in concentration changes of all species (not shown). Fig. 5b shows the pollen accumulation rate (PAR, grains $\text{cm}^{-2} \text{year}^{-1}$) of a selection of taxa. Zones in Fig. 5a and b are derived from Fig. 4.

Zone I (50–41.5 cm depth; ca. AD 1170–1395):

This zone is based on the relatively high abundances of thermophilous trees. The pollen curves of these trees decrease to the top of the zone.

Sub-zone I-1 (50–46.5 cm depth; ca. AD 1170–1265): The pollen spectrum is dominated by arboreal pollen (more than 95%). *Fagus*, *Corylus*, *Carpinus* and *Tilia* show relatively high percentages and pollen accumulation rates. Human impact indicators show low percentages and pollen accumulation rates. Relatively high pollen concentrations are recorded.

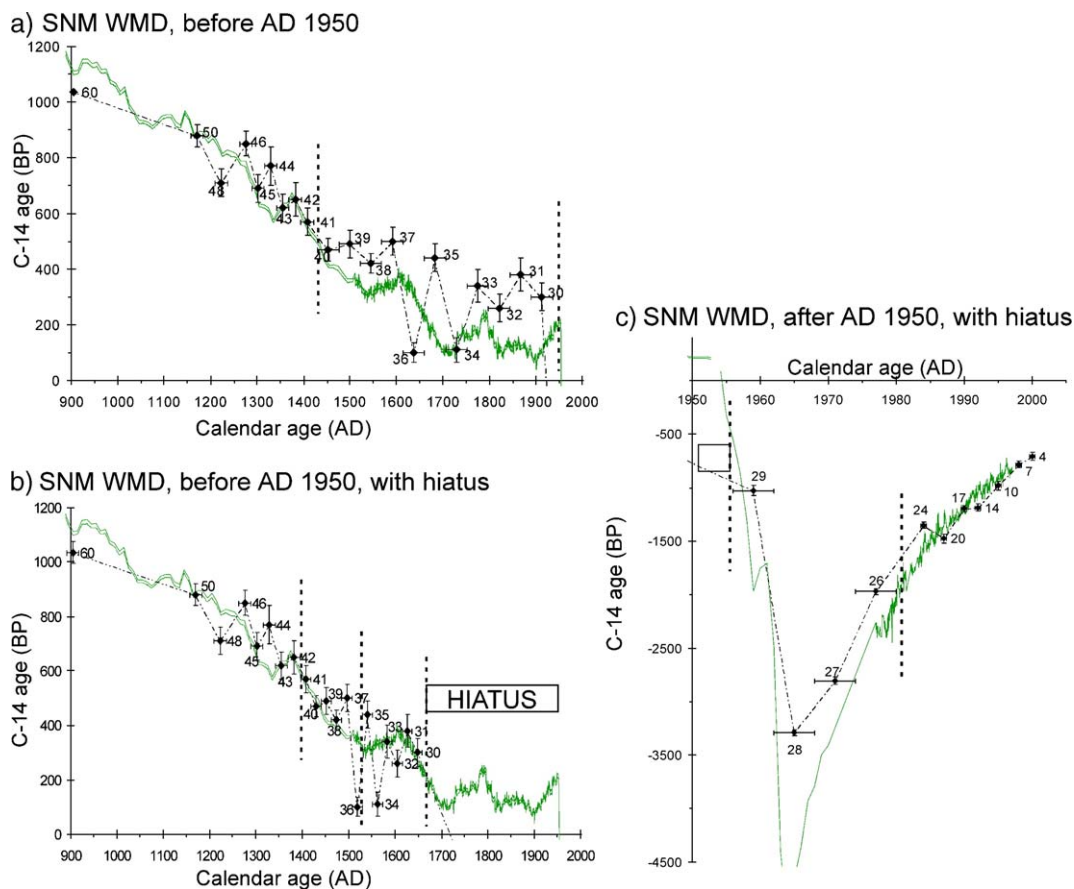


Fig. 3. ^{14}C AMS wiggle-match dating Saxnäs Mosse (SNM) using the INTCAL 98 calibration curve (Stuiver et al., 1998) updated with the modern ^{14}C record reflecting the atmospheric bomb pulse (Goodsite et al., 2001; Levin and Hesshaimer, 2000; Levin et al., 1994). The radiocarbon dates are marked with their sample depths. (a) Wiggle-matched radiocarbon dates before 1950. Sample depth in cm indicated. Two subsets: 60–41 cm and 40–30 cm. (b) Wiggle-matched radiocarbon dates before 1950 with a supposed hiatus between 30 and 29 cm depth. Three subsets: 60–42 cm, 41–36 cm and 35–30 cm. (c) Wiggle-matched radiocarbon dates after 1950 with a supposed hiatus between sample depths 30 and 29. Two subsets: 29–25 cm and 24–0 cm.

All curves show a concentration maximum around 44 cm depth.

Sub-zone I-2 (46.5–41.5 cm depth; ca. AD 1265–1395): The pollen sum contains 85% of arboreal pollen, whilst non-arboreal pollen comprises up to 15% of the pollen sum. *Cerealia*, *Secale*, *Artemisia*, *Plantago lanceolata* and *Rumex acetosella* type show increasing percentages and pollen accumulation rates. Pollen of Poaceae increases to 5%. *Fagus* decreases to ca. 10% of the pollen sum. *Carpinus* and *Corylus* also decrease and *Tilia* disappears at the end of sub-zone I-2.

Zone II (41.5–29.5 cm depth; ca. AD 1395–1650): Zone II is characterized by high percentages of *Pinus* and Poaceae.

Sub-zone II-1 (41.5–34.5 cm depth; ca. AD 1395–1550): Non arboreal pollen slightly decreases

to 10%. There is a strong increase in *Pinus* pollen from 25% to 47%. Grasses and other human impact indicators slightly decrease.

Sub-zone II-2 (34.5–29.5 cm depth; ca. AD 1550–1650): Non-arboreal pollen increases and forms up to ca. 14% of the pollen sum. *Pinus* pollen percentages show a maximum. *Picea* shows increasing percentages and pollen accumulation rates. *Betula*, *Alnus* and *Quercus* show a decrease. *Carpinus* disappears. All curves show extremely high concentrations and relatively high pollen accumulation rates.

Zone III (29.5–0 cm depth; ca. AD 1960–2003): This zone is characterised by high percentages in *Picea* and *Pinus*.

Sub-zone III-1 (29.5–7.5 cm depth; ca. AD 1960–1997): The pollen sum comprises mostly arboreal

Regional vegetation of Saxnäs Mosse, Sweden

Pollen percentages, selection of taxa

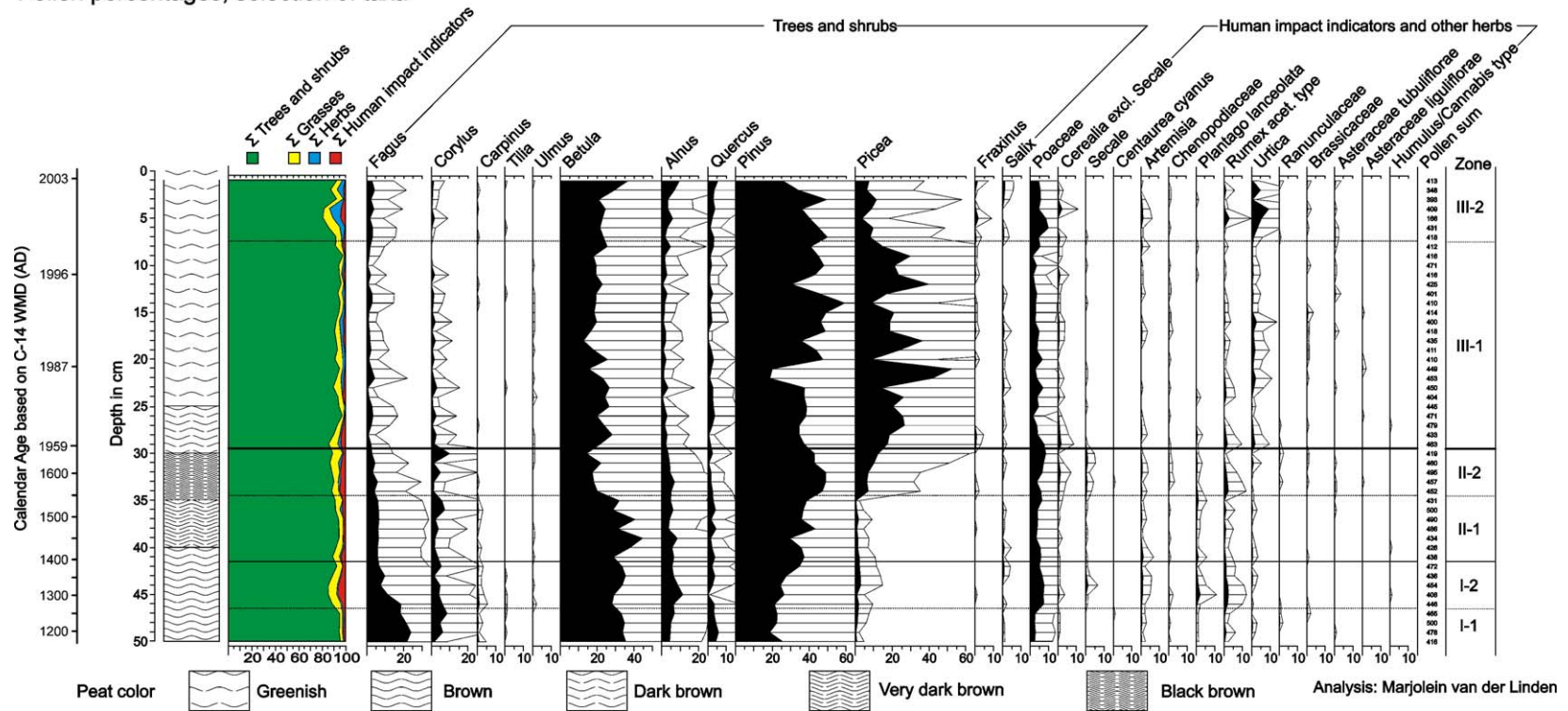


Fig. 4. Regional vegetation (dry land taxa) of Saxnäs Mosse. Pollen percentage diagram. Omitted taxa are named in Appendix 3. The black silhouettes show the percentage curves of all taxa, the depth bar filled silhouettes show the 5 \times exaggeration curves.

Regional vegetation of Saxnäs Mosse, Sweden

a) Pollen concentration

b) Pollen Accumulation Rate

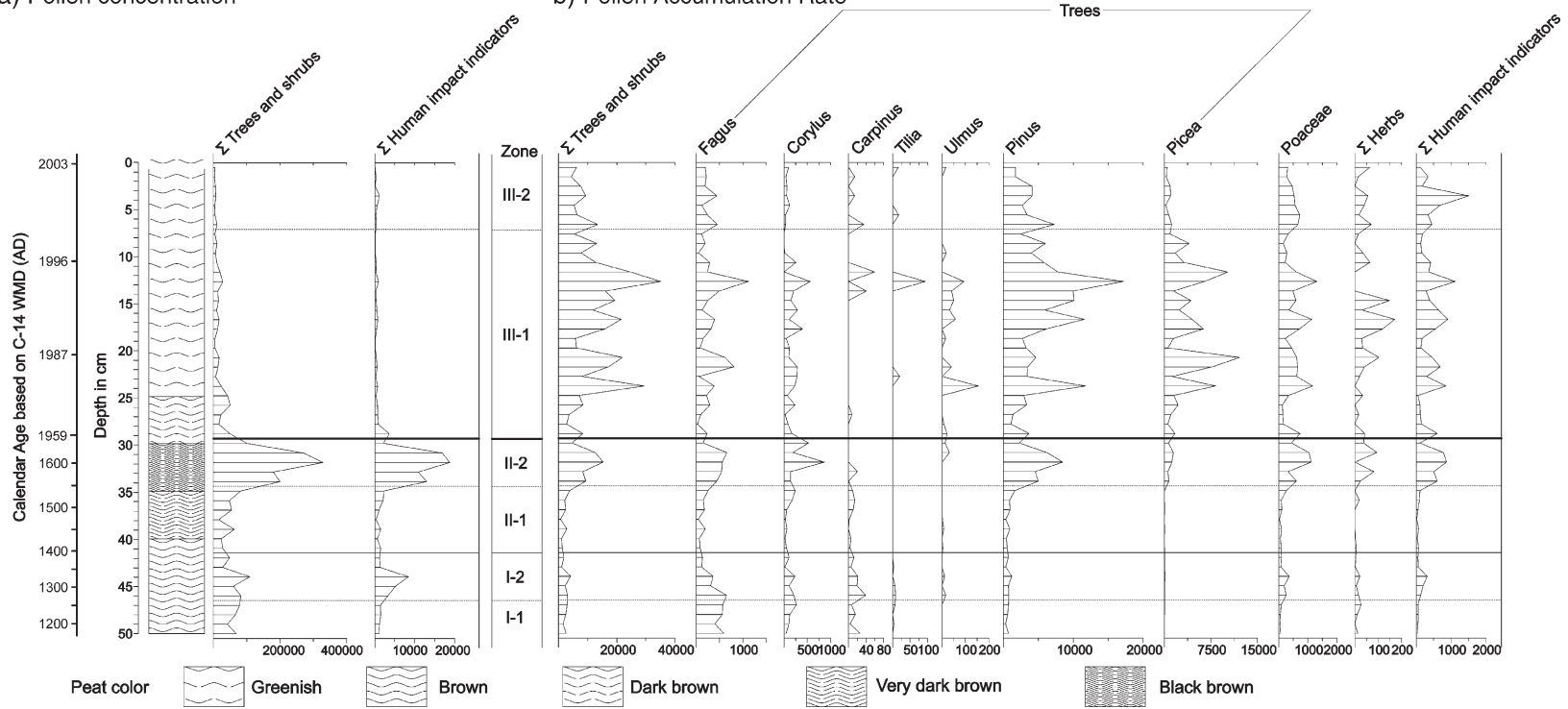


Fig. 5. Regional vegetation (dry land taxa) of Saxnäs Mosse, note the differences in scale: (a) pollen concentration; (b) pollen accumulation rate (PAR).

pollen (up to 97%). There is a strong increase in *Picea* pollen up to 52% but at the end of the zone *Picea* decreases to less than 20%. Poaceae and *R. acetosella* type pollen decrease to relatively low percentages. *Secale*, *Artemisia* and *P. lanceolata* are present in low numbers. *Urtica* shows higher values than before. Pollen concentrations decrease throughout sub-zone III-1 to low values. All curves show high pollen accumulation rates with strong fluctuations.

Sub-zone III-2 (7.5–0 cm depth; ca. AD 1997–2003): Arboreal pollen decreases to ca. 80%. *Picea* and *Pinus* decrease while *Betula*, *Alnus*, *Quercus*, *Fraxinus* and *Salix* show an increase. Grasses and other human impact indicators form a relatively large part of the pollen sum. Zone III-2 is especially characterised by high values of *Urtica*. Pollen concentrations are low. Pollen accumulation rates of human impact indicators show a maximum and decreases to the top.

3.3.2. Local vegetation development (mire surface taxa)

The macrofossil diagram (Fig. 6) shows the changes in local vegetation. The zone boundaries are mainly based on the changes in the dominance of *Sphagnum* species. The zonation of the pollen and non-pollen palynomorphs diagram (Fig. 7) is derived from Fig. 6.

Zone W (50–45.5 cm depth; ca. AD 1170–1290): Zone W is dominated by decreases in *Sphagnum papillosum*. *Sphagnum magellanicum* appears at 46 cm depth. Fungal spores of Type 264 (Plate I: 1–3) co-occur with *S. papillosum*. Ericaceous rootlets and pollen are found in relatively high percentages. *Andromeda polifolia* and *Oxycoccus palustris* Pers. (synonym *Vaccinium oxycoccus* L.) macrofossils are found in low numbers. Pollen of *Calluna vulgaris* is present. Fungal spores of Type 10, Type 12, *Entophlyctis lobata* and Type 18 show low percentages at the bottom but increase towards the top of the zone. Fruits and pollen of *Rhynchospora alba* are found. *Eriophorum vaginatum* shows maxima. *Acari*, *Bullinularia indica* and *Trigonopyxis arcuata* are present in high numbers.

Zone X (45.5–29.5 cm depth; ca. AD 1290–1650): This zone is characterised by the dominance of *S. magellanicum* and presence of *C. vulgaris* and *Drosera rotundifolia/anglica*.

Sub-zone X-1 (45.5–41.5 cm depth; ca. AD 1290–1395): This sub-zone is dominated by *S.*

magellanicum. At 43 cm depth *S. papillosum* and *Sphagnum* Section *Cuspidata* occur. Ericaceous rootlets are found in high percentages. Branches of *A. polifolia* and *C. vulgaris* are found in high numbers. Fungal Types 10, 12, 18, 90 and *E. lobata* show very high percentages. Fruits and epidermis of *R. alba*, epidermis and sclerenchyma of *E. vaginatum* and seeds of *D. rotundifolia/anglica* are present.

Sub-zone X-2 (41.5–35.5 cm depth; ca. AD 1395–1530): The total volume percentage of *Sphagnum* macrofossils is high. At 42–41 and at 37 cm depth *S. magellanicum* co-occurs with *S. papillosum*. The percentages of ericaceous rootlets decrease. *A. polifolia* and *C. vulgaris* are present. Types 10 and 12 show very low percentages, *E. lobata* and Type 18 show high percentages. Relatively high percentages of monocotyledonous epidermis are recorded. For the first time *Trichophorum cespitosum* is present. *R. alba* epidermis and fruits are found in low percentages and numbers, while *R. alba* pollen disappears. The number of *D. rotundifolia/anglica* seeds increases.

Sub-zone X-3 (35.5–29.5 cm depth; ca. AD 1530–1650): The total percentage of *Sphagnum* remains decreases from 75% to about 45%. *S. magellanicum* shows a dramatic decrease whereas *S. papillosum* shows a slight increase to 15%. Ericaceous rootlets show a strong increase to 25%. Monocotyledonous epidermis, roots and rhizomes are present in high quantities. *Erica tetralix* enters the site and becomes the dominant heath species while *A. polifolia* and *C. vulgaris* decrease. Spores of Types 10 and 12 are present in low percentages. Sporangia of *E. lobata* decrease. Fungal Types 18 and Type 264 decrease and disappear. Spores of Type 92 are found for the first time and increase towards the top of the zone. Fruits and epidermis of *R. alba* are found in increasing numbers. Vegetative remains of *E. vaginatum* are abundant. The number of *D. rotundifolia/anglica* seeds decreases. Few seeds of *Drosera intermedia* are found. Charred particles are found in low numbers in the macrofossil samples but in high numbers in the microfossil slides. *Acari*, *B. indica*, *T. arcuata* are found in high numbers. Sklerotia of the fungus *Cenococcum geophilum* are found throughout this sub-zone. The highest percentages of ascospores of coprophilous fungi are found in this sub-zone.

Zone Y (29.5–24.5 cm depth; ca. AD 1960–1984): This zone is characterised by a dominance of *Sphagnum* Section *Cuspidata*. The total percentage

Local vegetation of Saxnas Mosse, Sweden Macrofossils, selection of taxa

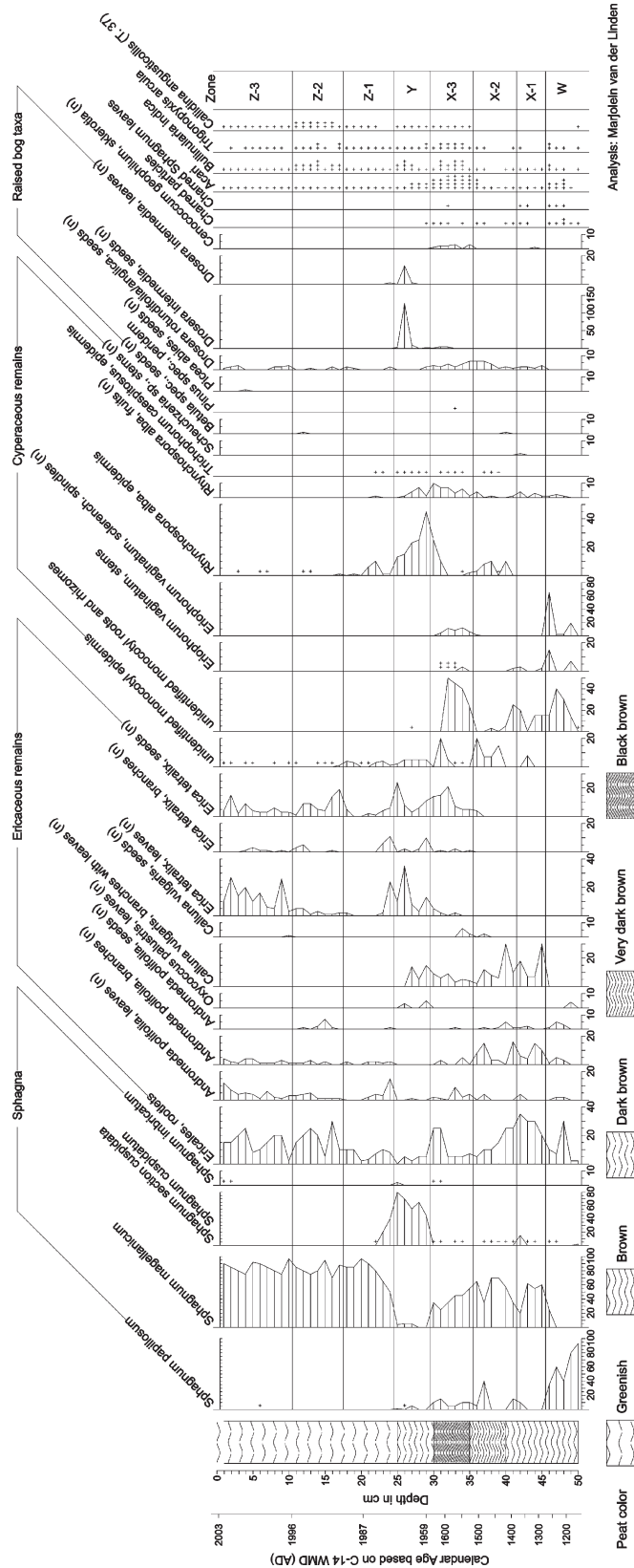


Fig. 6. Local vegetation (mire surface) of Saxnas Mosse, macrofossils. Note the differences in scale.

Local vegetation of Saxonäs Mosse, Sweden
Pollen and non-pollen palynomorphs, selection of taxa

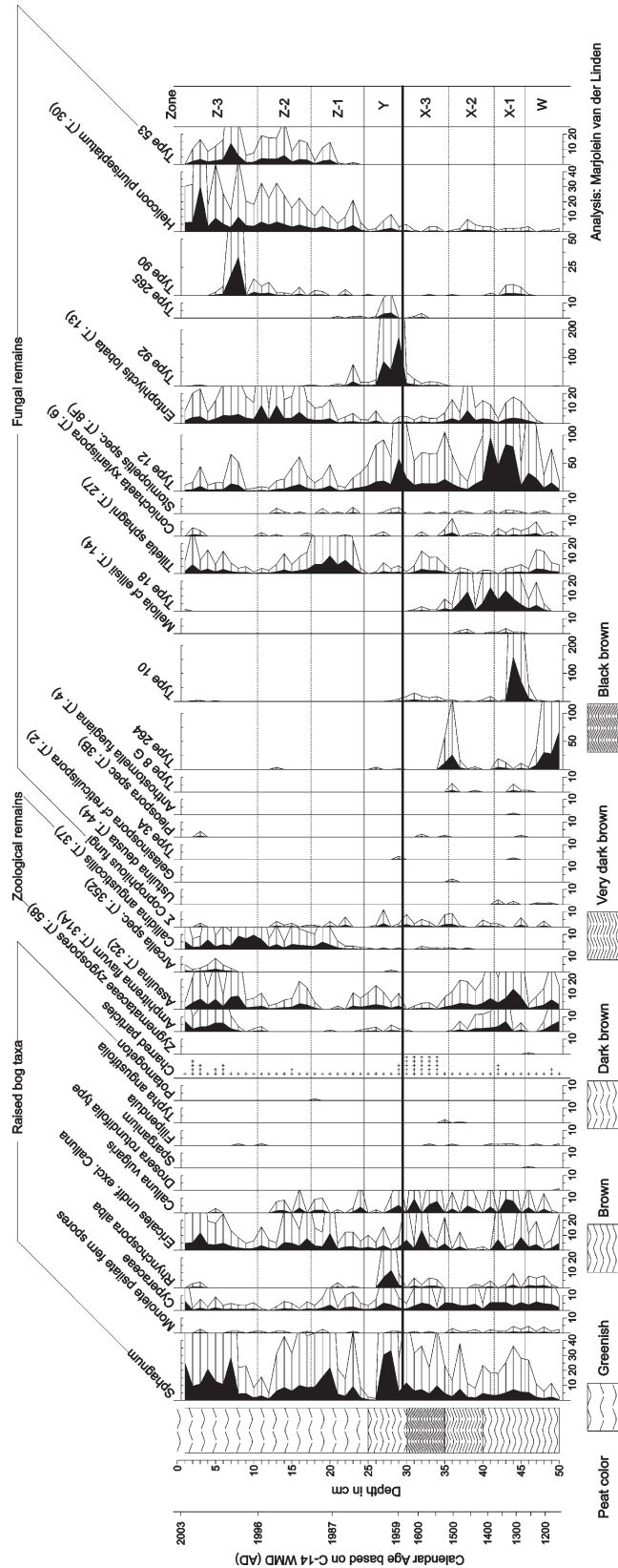


Fig. 7. Local vegetation (mire surface) of Saxonäs Mosse, local pollen and non-pollen palynomorphs.

of *Sphagnum* increases to 90%. Relatively low percentages of Ericaceous rootlets are found. Remains of *A. polifolia* appear at the end of the zone. *C. vulgaris* and Type 10 disappear from the record. Remains of *E. tetralix* are present in high numbers but low pollen percentages of Ericales and fungal microfossils were found. Both pollen and macrofossils of *R. alba* are present. *D. intermedia* seeds and leaf remains are characteristic for zone Y. Type 92 and Type 265 (Plate 1: 4 and 5) show very high percentages. *Acari* and *B. indica* macrofossils and *Assulina* microfossils are present in relatively high percentages which decrease towards the top of the zone.

Zone Z (24.5–0 cm depth; ca. AD 1984–2003):

Zone Z is characterised by the dominance of *S. magellanicum*.

Sub-zone Z-1 (24.5–17.5 cm depth; ca. AD 1984–1989): *Sphagnum* Section *Cuspidata* disappears and *S. magellanicum* becomes the single dominant *Sphagnum* species. Ericales pollen and *Sphagnum* spores show high percentages. Ericaceous rootlets increase to about 15%. The number of ericaceous aboveground remains is extremely low. Type 12 decreases. *E. lobata* increases to relatively high percentages. *R. alba* disappears. *Acari*, *B. indica* and *T. arcuata* appear in low numbers. *Amphitrema flavum* and *Assulina* disappear and record a minimum respectively. *Callidina angusticollis* is increasing to relatively high percentages. Type 53 has entered the record and increases.

Sub-zone Z-2 (17.5–10.5 cm depth; ca. AD 1989–1995): Higher percentages of ericaceous rootlets are found in this sub-zone. *A. polifolia* and *E. tetralix* are found in slightly increasing numbers. *E. lobata* shows relatively high percentages. *Tilletia sphagni* decreases. *B. indica*, *T. arcuata* and *C. angusticollis* are present in relatively high numbers. *Assulina*, *Helicoon pluriseptatum*, Type 53 and Type 90 increase.

Sub-zone Z-3 (10.5–0 cm depth; ca. AD 1995–2003): In the top of the core some leaves of *S. papillosum* and *Sphagnum imbricatum* are found. Ericaceous rootlets have relatively high percentages. *A. polifolia* leaves show relatively high numbers. *E. tetralix* leaves and seeds are found in relatively high numbers. *A. flavum*, *Assulina*, *C. angusticollis*, *Arcella* sp., *H. pluriseptatum* and Type 53 show high percentages. Type 90 peaks and disappears. High numbers of charred particles are present in the upper samples.

4. Interpretation

4.1. Period from ca. AD 1170–1650

4.1.1. Regional vegetation development

In the basal part of the core *Fagus*, *Carpinus*, *Corylus*, *Ulmus* and *Tilia* show relatively high percentages (Fig. 4). At 46 cm depth *Fagus* and *Corylus* start to decrease, at 42 cm depth *Tilia* disappears and at 32 cm *Carpinus* disappears. The northern borders of the habitats of these thermophilous trees are situated in Southern Sweden (Hultén, 1950). The declines and disappearance of these trees from the pollen record suggests a change to a cooler climate between ca. AD 1275–1590. This cooling of the climate probably represents the start of Little Ice Age (LIA) and is linked to rises in $\Delta^{14}\text{C}$ (Wolf and Spörer minimum, Fig. 8) which reflect decreases of solar activity (Hoyt and Schatten, 1997). When *Fagus*, *Corylus* and *Tilia* start to decrease the pollen record shows rising percentages of open landscape indicators (*Artemisia* and Poaceae) and human impact indicators (*R. acetosella* type, *P. lanceolata* and Cerealia). Therefore logging of trees could be another possibility for the decreases in thermophilous trees. But at the end of sub-zone I-2 (ca. AD 1395) grasses and human impact indicators decreased. This may suggest that the climate also became unfavourable for agricultural activities. However, we cannot exclude the effect of the Black Death. Myrdal (1999) reconstructed the impact of the Black Death by establishing the construction date of wooden houses in Southern Sweden. Almost no wooden houses were built between AD 1350 and 1450, which suggests a decrease in human population probably caused by the Black Death.

4.1.2. Local vegetation development

In the basal part of the core a dominance of *S. papillosum* can be seen (Fig. 6). After 46 cm depth (ca. AD 1290) *S. papillosum* decreases and local water levels appear to go down. Ericaceous rootlets and *A. polifolia* remains increase and drier growing *C. vulgaris* with its fungal parasite *Meliola ellisii* appears in the local bog vegetation. The high abundances of Type 10 conidia (fungus on *Calluna* rootlets, van Geel, 1978) and the fungus Type 12 also indicate a lower local water level. The hummock-forming *S. magellanicum* starts to dominate. Lower local water levels, internal dynamics or human impact (soil dust; see discussion) could be reasons for this change in *Sphagnum* composition.

The peak in *S. papillosum* and *R. alba* remains indicate a rise of water level at AD 1450–1500 (38–37 cm depth). At the same time, a decrease in ericaceous

Saxnäs Mosse, Sweden

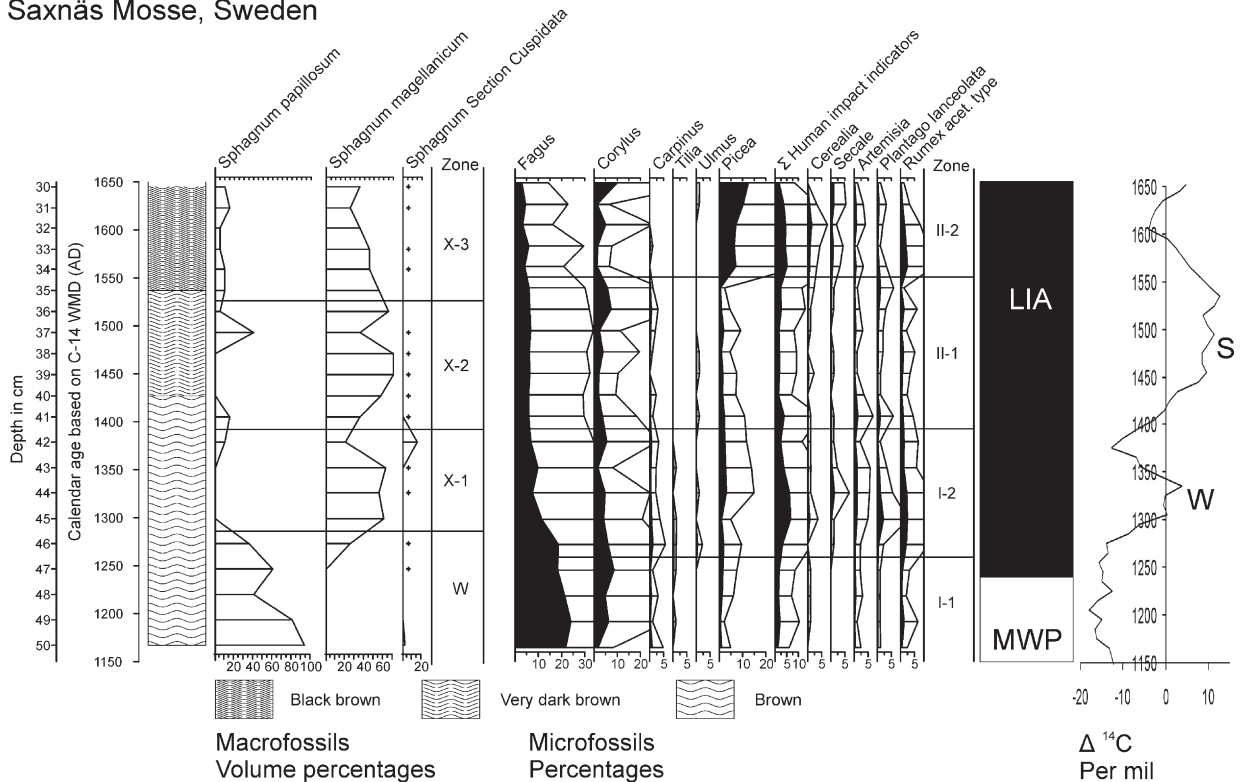


Fig. 8. Selection of macrofossils and microfossils from 50 to 30 cm depth. The relatively warm (MWP=Medieval Warm Period) and cold (LIA=Little Ice Age) periods are indicated together with the $\Delta^{14}\text{C}$ record. Periods of decreased solar activity are indicated with W (Wolf minimum) and S (Spörer minimum). $\Delta^{14}\text{C}$ record after [Stuiver et al. \(1998\)](#).

remains and absence of *E. vaginatum* is visible. The fungal spores of Type 264 are likely to be indicators of wet conditions since they appear in combination with *S. papillosum* and *R. alba*.

In the black brown layer (35–30 cm depth, sub-zone X-3) indicators of both wet (*R. alba*, *E. vaginatum* and *D. rotundifolia/anglica*) and dry local conditions (*C. geophilum*) are present. *S. magellanicum* is becoming less dominant and *S. papillosum* (wet conditions) is still present. Increased concentrations of pollen, and high numbers of Acari and testate amoebae indicate slow accumulation. The black brown layer reflects a period of intense decomposition and oxidation which probably occurred after the peat layer was formed. The occurrence of sklerotia of *C. geophilum* suggests secondary decomposition (renewed decay of already deposited peat; [Tipping, 1995](#); [Borgmark and Schoning, 2006](#)) because sklerotia are formed under the peat surface during dry conditions. The wiggle-matched radiocarbon dates ([Table 1](#)) show a calendar age of $\text{AD } 1648 \pm 11$ at 30 cm depth and $\text{AD } 1959 \pm 3$ at 29 cm depth. Thus, a hiatus is present in the record which could be the result of human impact (drainage for peat exploitation)

causing a drop in the water table of the peat bog (see Discussion).

4.2. Period from ca. AD 1960–2003

4.2.1. Regional vegetation development

Pinus and *Picea* are present with high percentages and pollen accumulation rates. ([Figs. 4 and 5](#)). These high values are probably caused by pollen input from planted trees. From the end of the 19th century and the beginning of the 20th century very extensive plantations of *Picea* and *Pinus* were created in the region ([Björkman, 1996, 1997](#)). In the beginning of the 1950s the area south of Saxnäs Mosse along the main road eastward from Halmstad to Ljungby was still an open landscape with heathlands and small fens. This is today replaced by *Picea* forest, except for a couple of small nature reserves (Nils Malmer, 2003, personal communication). At 10 cm depth (ca. AD 1993) a decrease in total tree pollen is observed because less *Pinus* and *Picea* pollen was found. Poaceae, Cerealia, *R. acetosella* type and *Artemisia* are present in relatively high percentages and pollen accumulation rates, indicating openness of the

landscape in the area surrounding the raised bog. Samples of the upper part of the core represent few years. The pollen accumulation rates show large fluctuations in this part of the diagram. These fluctuations can be caused by the differences in pollen production per year. Pollen production is affected by thermal factors of the year previous to flowering (Auto and Hicks, 2004). Therefore considerable changes in pollen deposition per species per year can occur. The increase of *Urtica* indicates nitrogen eutrophication. *Urtica* is usually found in highly fertilised places, like road verges or beside ditches.

4.2.2. Local vegetation development

C. vulgaris is absent and *Sphagnum* Section *Cuspidata* is dominant in zone Y (Figs. 6 and 7). Together with high abundances of *D. intermedia* remains (pioneer vegetation) and *R. alba*, wet local conditions are indicated. Type 265 fungal spores may also reflect wet local conditions. At 25 cm depth the water level drops slightly when *Sphagnum* Section *Cuspidata* decreases and *S. magellanicum* becomes the single dominant species. Only 20 years are present in the top 24 cm of the peat core, demonstrating a fast peat growth (no compaction yet and incomplete decomposition).

4.3. Carbon accumulation

Carbon accumulation rates (Fig. 9) were calculated from the bulk density and C content data and plotted against time using the radiocarbon chronology. A relatively low carbon accumulation was found in the deeper and older part of the peat core. The peat may

have been affected by secondary decomposition below the hiatus. From 35 to 30 cm depth, bulk densities, N percentages and pollen concentrations are high, and C/N ratio and Loss on Ignition show low values (Fig. 2). Low C/N ratios in combination with high N percentages suggest an intensified decay of the peat (Belyea and Warner, 1996; Borgmark and Schoning, 2006). Carbon accumulation is somewhat higher than before. Unfortunately owing to the hiatus the data for the period from ca. AD 1650 to 1960 AD are missing. Above the hiatus the carbon accumulation shows a sharp rise to high values because there was fast growth and an incomplete decay process.

4.4. Peat humification

We found very low (less than 50%) transmission percentages between 50 and 42 cm depth, meaning very humified material. Between 41 and 30 cm depth transmission values were between 50% and 60%. The macrofossil record shows that secondary decomposition caused an 'extra' decay of peat. Fewer *Sphagnum* remains were found and these were in a decomposed state (separate leaves and hardly any stems). Other macrofossils also showed a high degree of decomposition. This affected the carbon sequestration in the deepest part of the core because during oxidation carbon was released into the atmosphere. At 29 cm depth, after the hiatus, transmission values go up to 85% and hardly change to the top (incomplete decomposition).

5. Discussion

During the late Holocene it is very difficult to identify and distinguish between natural and human-induced patterns of vegetation change. Climate change almost certainly occurred but the problem is to isolate unambiguously its effects on biotic patterns from other processes (Birks, 1986). Climate change may have affected the tree species composition in the region around Saxnäs Mosse in the past. Thermophilous trees declined and disappeared from the pollen record when the climate became cooler at the transition from the Medieval Warm Period (MWP) to the Little Ice Age (LIA, Fig. 8). This coincides with rises in $\Delta^{14}\text{C}$. These rises reflect minima in solar activity and suggest a link between decreases of solar activity, climate and change to cooler conditions and declines of thermophilous trees.

Around AD 1275 there was a shift in *Sphagnum* composition from *S. papillosum* to a dominance of *S. magellanicum*. Interpreting the local succession of peat-forming plants in a single core is speculative. Shifts in

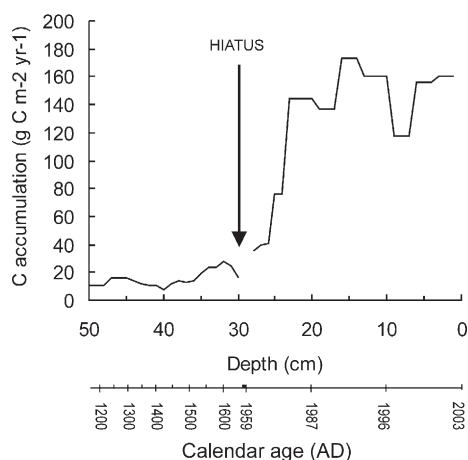


Fig. 9. Carbon accumulation over the last 800 years in Saxnäs Mosse (core SNM-I).

peat-forming vegetation could be a consequence of climate change, but based on the hydrological requirements of *S. papillosum* and *S. magellanicum* one would conclude a shift to a somewhat drier climate, while cooler periods are expected to be characterized by higher effective precipitation.

An alternative explanation for the above-mentioned change from *S. papillosum* to *S. magellanicum* is that it could be the effect of soil dust deposition on the raised bog caused by an increased exploitation of soils for agriculture in the surroundings of the bog. Increased human impact around AD 1275 is evident from the pollen record and this co-occurs with the change in *Sphagnum* to a dominance of *S. magellanicum*. An increased eutrophication of the bog surface may have favoured *S. magellanicum* (compare van Geel and Middeldorp, 1988). Mauquoy et al. (2002a,b) also recorded late Holocene changes to dominance of *S. magellanicum* at times of increased human impact in Walton Moss, UK, and Lille Vildmose, Denmark.

A hiatus in the peat sequence encompasses the period from ca. AD 1650 to ca. 1960. Climatic conditions cannot explain a gap in peat growth of more than 300 years. Human activities most probably caused oxidation of the peat surface. After recognition of the hiatus we went back to Saxnäs Mosse. The black brown strongly decomposed layer appeared to be present in all other cores between ca. 19 and 40 cm depth. This means that Saxnäs Mosse was affected by some drainage event which occurred after ca. AD 1650 and before ca. AD 1960. This drainage event probably caused the high pollen concentration in the black brown layer (sub-zone X-3). We tried several higher peat accumulation rates to lower the calculated pollen accumulation rate (PAR), but the PAR remained much higher than in the deeper sub-zones and the ^{14}C wiggle-match became worse and unrealistic. Therefore we assumed that the chronology as given in Fig. 3b and c is correct and that the accumulation rate is also correct. But, as a consequence, the pollen concentration is unusually high and we explain that as follows. When the vegetative plant remains decomposed, the strong-walled pollen grains remained. While the macrofossil record from the hiatus period is missing, many microfossils may have survived the secondary decomposition process and therefore the pollen concentration is extra high. The sharp increase of *Picea* pollen percentages and pollen accumulation rates (Fig. 4a and c) below the hiatus point to another phenomenon. *Picea* was present near Saxnäs Mosse in medieval times, but in very low numbers (Björkman, 1996, 1997). *Picea* only became more abundant in the

area by the beginning of the 20th century. This means that the high *Picea* pollen percentages below the hiatus (before ca. AD 1650) point to mixing of younger pollen with older peat, resulting in high pollen concentrations and also a high pollen accumulation rate. If our interpretation is right, then the pollen record of zone II-2 represents a mixture of pollen grains from different periods.

The owner of the peat bog provided some information about the history of the bog. There were no agricultural fields near the bog and some trees (species unknown) were planted northwest of the bog in 1912. Also, there has been cutting of peat as a source of fuel for domestic heating (in Swedish: husbehov).

The results in this paper suggest that drainage to facilitate peat cutting has been the cause of oxidation and the disappearance of a layer of peat in Saxnäs Mosse. It does not mean that the top layer of the bog was removed. In order to facilitate peat-cutting, the bog surface could be drained by digging ditches in and around the bog.

Construction of the main road adjacent to the bog may have reinitiated peat growth. The main road (Fig. 1) was already built in AD 1900 but was reinforced around AD 1960–1962. Sample depth 29 from which normal peat growth started again has a ^{14}C wiggle-match date of AD 1959 \pm 3. The building date of 1960–1962 falls within the range of the date. We suppose that when the roads were reinforced, the artificial drainage was ended. Nowadays the roads function as dikes partly surrounding the raised bog, and keeping the water in. The water table of the mire was restored and peat growth could start again. The present bog surface shows the typical raised bog vegetation and evidence for the recent dramatic drainage event became invisible.

Owing to artificial drainage, accelerated secondary decomposition and oxidation of the peat took place, and therefore the carbon accumulation rates below the hiatus do not show the natural original situation. As a consequence, we were not able to distinguish between the effects of climate-induced changes and the effects of human activities on the carbon accumulation of the bog vegetation during the period before the hiatus. The decomposition process of the peat above the hiatus has not ended yet and therefore the process of carbon accumulation and carbon release is still incomplete.

6. Conclusions

Human activities greatly affected the peat sequence at Saxnäs Mosse, which was formed during the last

eight centuries. Nevertheless, we were able to reconstruct the effects of climate change at the transition from the Medieval Warm Period to the start of the Little Ice Age. The declines of thermophilous trees correspond to increasing levels of $\Delta^{14}\text{C}$, most probably indicating a link between declines of solar activity, climate change and the response of thermophilous tree species. Although the bog area was not exploited for commercial value, we could show that its hydrology was substantially affected by artificial drainage. As a consequence, a large part of the archive including the greatest part of the Little Ice Age is missing. The record shows that the raised bog vegetation can regenerate from a strongly disturbed bog to a 'living' bog when the water table is restored, even after a drastic drainage event.

Acknowledgements

We thank Dr. Frank Berendse, Dr. 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. Bo Wallén suggested Saxnäs Mosse as a research site. We thank Dr. Nils Malmer for his comments on *Pinus* and *Picea* plantations and Erik Johnsson and Andreas Kullgren for information on the history of the raised bog. Dr. Dmitri Mauquoy kindly improved the English.

Appendix A

List of pollen types defined as human impact indicators or as other herbs.

Human impact indicators:	Other herbs:	
Cerealia	Chenopodiaceae	cf. <i>Ulex</i>
<i>Secale</i>	Asteraceae tubuliflorae	<i>Anthriscus</i> type
<i>Artemisia</i>	Asteraceae liguliflorae	<i>Potentilla</i> type
<i>Plantago lanceolata</i>	Caryophyllaceae	Apiaceae
<i>Plantago major/media</i>	Ranunculaceae	<i>Urtica</i>
<i>Plantago</i> sp.	cf. <i>Humulus</i>	Brassicaceae
<i>Rumex acetosella</i> type	<i>Humulus/Cannabis</i> type	<i>Galium</i> type
<i>Centaurea cyanus</i> type	<i>Polygonum aviculare</i> type	Rosaceae undif
<i>Trifolium</i> type	<i>Saxifraga hirsuta</i> type	<i>Hypericum</i> sp.
	<i>Saxifraga stellaris</i> type	<i>Mercurialis</i> type
	<i>Hypericum perforatum</i> type	

Appendix B

Age of subsequent cm levels of the core Saxnäs Mosse, based on ^{14}C AMS wiggle-match dating.

Sample depth (cm)	Age (AD)
1	2003
2	2002
3	2001
4	2001
5	2000
6	1999
7	1998
8	1997
9	1997
10	1996
11	1995
12	1994
13	1993
14	1993
15	1992
16	1991
17	1990
18	1989
19	1988
20	1987
21	1986
22	1985
23	1984
24	1984
25	1983
26	1977
27	1971
28	1965
29	1959
30	1648
31	1626
32	1605
33	1583
34	1562
35	1540
36	1518
37	1496
38	1474
39	1452
40	1430
41	1408
42	1382
43	1355
44	1329
45	1302
46	1276
47	1250
48	1223
49	1197
50	1170

Appendix C

Taxa omitted from Fig. 4 (regional vegetation).

Omitted taxa	Depths and percentages				
cf. <i>Humulus</i>	9 cm:	10 cm:	21 cm:	34 cm:	36 cm:
	0.6%	0.2%	0.2%	0.2%	0.4%
Apiaceae	40 cm:				
	0.2%				
Polygonum <i>aviculare</i> type	2 cm:	5 cm:	20 cm:	21 cm:	45 cm:
	0.3%	0.6%	0.2%	0.2%	0.2%
Rosaceae	19 cm:	21 cm:	25 cm:		
	0.2%	0.2%	0.2%		
<i>Juglans</i>	11 cm:	25 cm:	50 cm:		
	0.2%	0.2%	0.2%		
<i>Hypericum</i> sp.	3 cm:	21 cm:			
	0.3%	0.2%			
Caryophyllaceae	18 cm:	31 cm:			
	0.2%	0.2%			
<i>Galium</i> type	7 cm:	36 cm:			
	0.2%	0.2%			
<i>Plantago</i> <i>major/media</i>	29 cm:	40 cm:			
	0.2%	0.2%			
cf. <i>Taxus</i>	16 cm:	49 cm:			
	0.3%	0.2%			
<i>Saxifraga</i> <i>hirsuta</i> type	2 cm:				
	0.3%				
<i>Saxifraga</i> <i>stellaris</i> type	17 cm:				
	0.2%				
<i>Trifolium</i> type	17 cm:				
	0.2%				
<i>Aesculus</i>	18 cm:				
	0.2%				
<i>Hypericum</i> <i>perforatum</i> type	19 cm:				
	0.2%				
<i>Anthriscus</i> type	23 cm:				
	0.2%				
<i>Mercurialis</i> type	34 cm:				
	0.2%				
cf. <i>Ulex</i>	36 cm:				
	0.2%				
<i>Plantago</i> sp.	44 cm:				
	0.2%				
<i>Potentilla</i> type	44 cm:				
	0.2%				
cf. <i>Juniperus</i>	46 cm:				
	0.4%				

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, 31–47.
- Beer, J., Siegenthaler, U., Bonani, G., Finkel, R.C., Oeschger, H., Suter, M., Wölfli, W., 1988. Information on past solar activity and geomagnetism from ^{10}Be in the Camp Century ice core. *Nature* 331, 675–679.
- Behre, K.-E. (Ed.), 1986. *Anthropogenic Indicators in Pollen Diagrams*. A.A. Balkema, Rotterdam.
- Belyea, L.R., Warner, B.G., 1996. Temporal scale and the accumulation of peat in a *Sphagnum* bog. *Canadian Journal of Botany* 74, 366–377.
- 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.
- Birks, H.J.B., 1986. Late-Quaternary biotic changes in terrestrial and lacustrine environments, with particular reference to north-west Europe. In: Berglund, B.E. (Ed.), *Handbook of Holocene Palaeoecology*. John Wiley and Sons, Chichester, pp. 3–65.
- Björkman, L., 1996. The Late Holocene history of beech *Fagus sylvatica* and Norway spruce *Picea abies* at stand-scale in southern Sweden. *Lundqua Thesis* 39, 1–4.
- Björkman, L., 1997. The role of human disturbance in the local Late Holocene establishment of *Fagus* and *Picea* forests at Flahult, western Småland, southern Sweden. *Vegetation History and Archaeobotany* 6 (2), 79–90.
- 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., van der Plicht, J., 2004. Carbon-14 wiggle-match dating of peat deposits: advantages and limitation. *Journal of Quaternary Science* 19, 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.
- Borgmark, A., Schoning, K., 2006. A comparative study of peat proxies from two eastern central Swedish bogs and their relation to meteorological data. *Journal of Quaternary Science* 21, 109–114.
- Clymo, R.S., Hayward, P.M., 1982. The ecology of *Sphagnum*. In: Smith, A.J.E. (Ed.), *Bryophyte Ecology*. Chapman and Hall, London, pp. 229–289.
- Donders, T.H., Wagner, F., van der Borgh, K., de Jong, A.F.M., Visscher, H., 2004. A novel approach for developing high resolution sub-fossil peat chronologies with ^{14}C dating. *Radiocarbon* 46, 455–463.
- Faegri, 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, 495–515.
- Goslar, T., van der Knaap, W.O., Hicks, S., Andrić, M., Czernik, J., Goslar, E., Räsänen, S., Hyötylä, H., 2005. Radiocarbon dating of modern peat profiles: pre- and post-bomb ^{14}C variations in the construction of age–depth models. *Radiocarbon* 47, 115–134.
- 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., Arp, W.J., Berendse, F., 2001. Effects of elevated CO₂ and vascular plants on evapotranspiration in bog vegetation. *Global Change Biology* 7, 817–827.
- Hoyt, D.V., Schatten, K.H., 1997. *The Role of the Sun in Climate Change*. Oxford University Press, Oxford.
- Hultén, E., 1950. Atlas of the distribution of the vascular plants of Northwest Europe. Atlas över växternas utbredning i Norden. Generalstabens Litografiska Anstalts Förlag, Stockholm, pp. 1–512.
- Johansson, P., 1995. Vit Mossor i Norden. Vasastadens Bokbinderi AB, Göteborg (Mossornas Vännen).
- Johnsson, L.C., Damman, A.W.H., 1991. Species controlled *Sphagnum* decay on a south Swedish raised bog. *Oikos* 61, 234–242.
- Katz, N.Ja., 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.
- Kilian, M.R., van der Plicht, J., van Geel, B., 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.
- Levin, I., Heshshaimer, 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. $\Delta^{14}\text{CO}_2$ 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: 203–222 and Online Updates (Online Trends)*. Carbon Dioxide Information Analysis Centre. Oak Ridge National Laboratory, Oak Ridge.
- Malmer, N., Svensson, B.M., Wallén, B., 1994. Interactions between *Sphagnum* mosses and field layer vascular plants in the development of peat-forming systems. *Folia Geobotanica et Phytotaxonomica Praha* 29, 483–496.
- Mauquoy, D., van Geel, B., Blaauw, M., van der Plicht, J., 2002a. Evidence from northwest European bogs shows ‘Little Ice Age’ climatic changes driven by variations in solar activity. *The Holocene* 12, 1–6.
- Mauquoy, D., Engelkes, T., Groot, M.H.M., Markesteijn, F., Oudejans, M.G., van der Plicht, J., van Geel, B., 2002b. 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.
- Middeldorp, A.A., 1982. Pollen concentration as a basis for indirect dating and quantifying net organic and fungal production in a peat bog system. *Review of Palaeobotany and Palynology* 37, 225–282.
- Moore, P.D., Webb, J.A., Collinson, M.E., 1991. *Pollen Analysis*. Blackwell, London.
- Myrdal, J., 1999. *Jordbruket under feodalismen 1000–1700. Det Svenska jordbrukets historia*. Natur och Kultur/LTs förlag, I samarbete med Nordiska museets förlag och Stiftelsen Lagersberg.
- Smith, A.J.E., 1978. *The Moss Flora of Britain and Ireland*. Cambridge University Press, Cambridge.
- Speranza, A., van der Plicht, J., van Geel, 2000. Improving the time control of the Subboreal/Subatlantic transition in a Czech peat sequence by ¹⁴C wiggle-match dating. *Quaternary Science Reviews* 19, 1589–1604.
- Speranza, A., van Geel, B., van der Plicht, J., 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.
- Thormann, M.N., Szumigalski, A.R., Bayley, S.E., 1999. Above-ground peat and carbon accumulation potentials along a bog-fen-marsh wetland gradient in southern boreal Alberta, Canada. *Wetlands* 19, 305–317.
- Tipping, R., 1995. Holocene evolution of a lowland Scottish landscape: Part I. Peat and pollen-stratigraphic evidence for raised moss development and climate change. *The Holocene* 5, 69–81.
- 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 indicators value 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., Buurman, J., Waterbolk, H.T., 1996. Archeological and paleoecological indications for an abrupt climate change in The Netherlands and evidence for climatological teleconnections around 2650 BP. *Journal of Quaternary Science* 11, 451–461.
- van Geel, B., Raspopov, 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.
- Wardenaar, E.C.P., 1987. A new handtool for cutting soil monoliths. *Canadian Journal of Soil Science* 67, 405–407.