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

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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. 14C wiggle-match dating was applied for high precision dating. Testate amoebae assemblages were used to reconstruct past water table depths and compared with other proxies and instrumental climate data from the mid-18th century onwards. 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.

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Keywords: 14C 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 14C 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,
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
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 cm³. Samples were heated for 2.3. Macrofossil analyses

**Table 1**

<table>
<thead>
<tr>
<th>Type of indicator</th>
<th>Land-use category</th>
<th>Taxa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anthropochores</td>
<td>Cultivated land</td>
<td><em>Centarea cyanus</em></td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>Cerealia</em> (non-Secale)</td>
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<tr>
<td></td>
<td></td>
<td><em>Humulus/Cannabis</em></td>
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<tr>
<td></td>
<td></td>
<td><em>Secale</em></td>
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<tr>
<td></td>
<td></td>
<td><em>Symphytum officinale</em></td>
</tr>
<tr>
<td>Apophytes</td>
<td>Ruderals (minor*)</td>
<td><em>Brassicaeae</em></td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>Plantago lanceolata</em></td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>Plantago major/media</em></td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>Rubus acetosus type</em></td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>Urtica</em></td>
</tr>
<tr>
<td></td>
<td>Ruderals (major*)</td>
<td><em>Artemisia</em></td>
</tr>
<tr>
<td>Meadow</td>
<td>Fabaceae</td>
<td><em>Chenopodiaceae</em></td>
</tr>
<tr>
<td></td>
<td>Galium type</td>
<td><em>Galium</em></td>
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<tr>
<td></td>
<td><em>Helianthemum spec.</em></td>
<td></td>
</tr>
<tr>
<td></td>
<td><em>Ramunculaceae</em></td>
<td></td>
</tr>
<tr>
<td>Open land</td>
<td>Apiaceae</td>
<td><em>Asteraceae liguliflorae</em></td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>Asteraceae tubuliflorae</em></td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>Caryophyllaceae</em></td>
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<tr>
<td></td>
<td></td>
<td><em>Poaceae</em></td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>Rosaceae undif.</em></td>
</tr>
<tr>
<td>Dry meadow</td>
<td></td>
<td><em>Juniperus</em></td>
</tr>
</tbody>
</table>

* Differentiation on the basis of pollen production.

2.5. Testate amoebae

Peat samples measuring 1 cm³ were prepared using standard techniques for testate amoebae analyses (Hendon and Charman, 1997). Minor deviations from the described process include the use of deionised water as 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 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 incinerating sub-samples of c. 35 cm³ 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 cm³ were taken from the peat core and analysed with a modified version of the Bahnsen 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.](image-url)
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; Goosdite 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, \textit{Sphagnum} species composition, degree of humification and bulk densities (Kilian et al., 2000).
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. 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 is described in Fig. 2.
Fig. 8. Testate amoebae (main taxa) and reconstructed water table of Åkerlänna Römosse. The legend is described in Fig. 2.
P. sylvestris and P. lanceolata

3.3.1.6. Zone ARM-VI (16.5 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 (59.5 cm depth; AD 1640–1792).
Zone X is mainly characterized by the presence of *S. fuscum*, *Sphagnum magellanicum*, *Sphagnum section Caspidata* 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 Caspidata*. *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 Caspidata* 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 *Diffugia 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* are found. *A. flavum* and *Helcopea sphagni* are the dominant testate amoebae species. *Helopea 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 *Emetrum* 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. *Entophylyctis 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 *Emetrum, 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. *Trigonopyxis 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 *Diffflugia 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, Diffflugia 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 Åkerlännä Römmes 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.
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 if 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 contemporaneous 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 epidermids.

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

<table>
<thead>
<tr>
<th>Zone</th>
<th>NP-10</th>
<th>NP-1</th>
<th>P-sparsely</th>
<th>Open forest</th>
<th>Dense forest</th>
</tr>
</thead>
<tbody>
<tr>
<td>ARM-I</td>
<td><em>Pinus</em></td>
<td>VI</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td></td>
<td>V</td>
<td>X</td>
<td>X</td>
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<td>IV</td>
<td>X</td>
<td>X</td>
<td>X</td>
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<td></td>
<td></td>
<td>III</td>
<td>X</td>
<td>X</td>
<td>X</td>
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<td>II</td>
<td>X</td>
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<td></td>
<td></td>
<td>I</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>ARM-I</td>
<td><em>Picea</em></td>
<td>VI</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td></td>
<td>V</td>
<td>X</td>
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<td>IV</td>
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<td></td>
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<td>I</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

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).
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. Filix pendula 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. geophillum implies local dry conditions, also implied by the disappearance of Sphagnum section Cuspidata and high Ericales rootlet 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),
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.
Åkerlåna Römosse is about 100 km northeast of Stockholm.
This region was probably affected by the disease too. As a con-
sequence 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 aban-
donment of arable land. The pollen record shows a decrease in
Pinus pollen, which may be explained by logging of Pine trees

and may have lowered the demand for water. Between AD 1958

and 1980 was relatively dry and

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 ¹³C and ¹³C

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 pre-

cipitation 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 ¹³C

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, evapotran-
spiration 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 Harman evapotranspiration anomaly of AD 1723–2001 mean, D) Reconstructed water table based on testate amoebae composition, E) ¹³C 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.

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 Äkerlänna 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.

Äkerlänna 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 14C 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.

Acknowledgements

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Appendix A

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

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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%

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