



Integrated palaeoecological and historical data in the service of fine-resolution land use and ecological change assessment during the last 1000 years in Rõuge, southern Estonia

Siim Veski^{1*}, Kalev Koppel² and Anneli Poska¹

¹Institute of Geology, Tallinn University of Technology, Tallinn, Estonia and ²Department of History, Tartu University, Tartu, Estonia

ABSTRACT

Aims Our aim is to reconstruct decadal scale development of historical landscapes during the last 1000 years by means of fossil pollen analysis of annually laminated lake sediments, and detailed historical maps and documents.

Location Lake Rõuge Tõugjärv (Estonia), a small lake with annually laminated lake sediments situated in a dense prehistoric setting.

Methods The chronology of the palaeodata is based on the annual laminations supported by AMS ¹⁴C and ²¹⁰Pb dating and ¹³⁷Cs, ²⁴¹Am, and spheroidal carbonaceous particle marker horizons. The time-scale and resolution allows fine sampling (the pollen samples generally comprise 3.5 years) and vegetation change reconstruction. Relevant source area of pollen (RSAP) of the lake was estimated, and the statistical zonation, rate of change, palynological richness, and DCA and PCA ordinations were generated on the basis of the pollen data. The historical calibration data set (maps, numerical information on population, domestic stock, farmland division, etc.) is based on archival material preserved in the Estonian Historical Archives.

Results The topmost part (0–180 cm) of the sediment column of Lake Rõuge Tõugjärv, covering the last 1000 years, is visibly laminated carbonaceous gyttja. The varve chronology extends from AD 2000 to AD 1339, with a cumulative \pm 9-year error estimate. Beyond this the chronology is extrapolated using the ¹⁴C date and varve age–depth estimations. The simulation of the RSAP of Lake Tõugjärv shows that the major portion of the pollen loading originating from local vegetation is derived from plants growing within 2000 m of the sampling site. The pollen record divides into five statistically significant subgroups, which fall on the PCA plot into three clusters reflecting the general openness–closedness of the landscape. During the period between AD 1000 and 1200 (RT 1) the Rõuge area was generally wooded with birch, spruce and pine forests. The advancement of extensive farming gradually opened up the landscape between AD 1200 and 1650 (RT 2 and RT 3). The maximum openness of the landscape was reached between AD 1650 and 1875 (RT 4), with the most open period in the late eighteenth century. Historical maps from 1684 and 1870–99 and available quantitative data on population, domestic stock, farmland division, etc. show the same trend. The pollen data covering the last 125 years, and maps from 1935 and 1995, show the reduction of arable land in RSAP of the lake under investigation and the reduction of open land to an extent comparable with the end of the seventeenth century.

Main conclusions The formation and development of the cultural landscape at Rõuge over the last 1000 years is characterized by rapid changes in floristic richness and rates of vegetation change attributed to certain historic processes in

*Correspondence: Siim Veski, Institute of Geology, Tallinn University of Technology, Estonia pst. 7, 10143 Tallinn, Estonia.
E-mail: veski@gi.ee

the RSAP. Five phases of landscape and social development are clearly distinguished during the last 1000 years. The decadal scale vegetation response to human-induced forcing agrees with historical maps and documents and could be used for past landscapes prior to the period with solid historical data.

Keywords

Annually laminated sediments, development of agriculture, Estonia, historical documents, historical maps, numerical analysis, pollen, vegetation history.

Abbreviations

EAA, Eesti Ajalooarhiiv [Estonian Historical Archives]; MF, EAA microfilm collection; RA ÖJ, Riksarkivet [The National Archives of Sweden, Stockholm] Östersjöprovinsernas jordrevisionshandlingar 1589–1682, Vol. 36. Livland, Revisions jordebok 1690, L607–L613.

INTRODUCTION

One of the difficult aspects of palaeoecology, when tracking vegetation history from fossil pollen data, is the lack of control over past changes in land cover and landscape diversity. Vegetation history studies are generally based on the assumption that fossil pollen records reflect changes related to past natural vegetation dynamics and land-use patterns. A classic approach, where fossil pollen data are compared with known written sources and historical maps often stumbles on the problem of 'too accurate historical data' and the weak chronological control of the palaeo proxy. The controversy lies in the fact that in this way one may correlate events registered in the sediment and dated by extrapolation between dates with considerable error margins with those historically pinpointed to a certain datum. Annually laminated lake sediments with annual to seasonal time-resolution provide a solution for the latter. Another major problem of comparing archival and pollen data has been the lack of a concept of scale for the palaeoecological data. This has changed with the definition of the 'relevant source area of pollen (RSAP)' (*sensu* Sugita, 1994).

The formation and development of a cultural landscape is a complex process. Changes in spatial structure of a landscape result from natural processes such as climate variability or soil development combined with human activity driven by socio-economical and political factors. Historical rural land use and settlement structure has large regional and temporal variations and the reconstruction of a specific historical landscape can only be done by a high-resolution local case study (e.g. Sarmaja-Korjonen, 1992; Goslar *et al.*, 1999). The critical assumption for such reconstructions is the availability of relevant and reliable historical documents. As historical sources are chronologically and regionally unevenly preserved, the combined usage of different records is inevitable (Joosten, 1985; Petit & Lambin, 2002a,b; Nielsen & Odgaard, 2004). Large-scale cadastral maps, historical census data, taxpayers lists, plough-land revisions, etc. contain valuable information about historical land use, settlement structure, demographic

and economic parameters (Foster *et al.*, 1998, 2002; Fuller *et al.*, 1998; Goslar *et al.*, 1999; Cousins, 2001).

Lake sediments are natural archives, which store information on limnological, biological and geochemical, as well as anthropogenic processes in lakes and in their catchment areas. The sedimentary processes in the temperate zone have a cyclic character and in certain conditions they are reflected in sediment sequences as varves or annual laminations (O'Sullivan, 1983). A varve typically consists of two visible layers, a clastic inorganic spring/summer layer and a darker organic humic layer. In terms of vegetation history, annually laminated lake sediments have proven to be extremely useful, as the resultant precise chronology gives the possibility of calculating pollen accumulation rates (PARs) for different taxa and of estimating the vegetational rate of change to reveal periods of stability and disturbance in the landscape (Birks *et al.*, 1988; Lotter *et al.*, 1992, 2002; Birks, 1998; Lotter, 1998).

Currently, the development of reliable and robust methods to infer past quantitative changes in land cover (Broström *et al.*, 1998) and landscape/floristic diversity from fossil pollen data is in progress within the POLLANDCAL community (<http://www.geog.ucl.ac.uk/ecrc/pollandcal>), involving the prediction of the spatial scales of the landscapes represented by pollen for different sampling sites (Sugita, 1994; Broström, 2002), and the use of modern and historical analogues to generate predictive models of quantitative pollen/vegetation relationship (Gaillard *et al.*, 1992; Sugita *et al.*, 1999; Odgaard & Rasmussen, 2000).

This study aims at the reconstruction of decadal scale vegetation change, the formation and development of the cultural landscape at Rõuge during the last 1000 years (Fig. 1). Rapid changes in richness and rates of vegetation change are attributed to certain historic processes in the lake catchment and the RSAP. The decadal scale vegetation response is evaluated against human-induced forcing, compared with historical maps and documents and used to reconstruct past landscapes prior to the time for which solid historical data are available using fossil pollen analysis of annually laminated lake sediments and detailed historical maps and documents. The



Figure 1 Location of the study site. The rectangle marks the 60 × 60 km area used when determining the RSAP.

selected 1000-year time-frame covers the prehistoric local Estonian society before AD 1200, tens of Russian depredations in the eleventh to twelfth century, the German conquest and the Christianization of the Estonian area (AD 1208–1227), the supremacy of foreign powers and the wider spread and development of a manor-based economy. Cataclysms such as wars, famine and diseases, together with certain changes in society, have interrupted the general increase in population, the number of domesticated animals, and the need for food production through extensive agricultural practices, which have had a powerful effect on the landscape.

MATERIALS AND METHODS

Materials

In a detailed interdisciplinary study of past human–vegetation interactions two prerequisites, the existence of relevant and reliable historical documents and a sediment basin in the area, must be fulfilled. The Rõuge area meets both these requirements and the varved sediments are an advantage. Rõuge village is a centre of the historic Rõuge parish in south-east Estonia. The study area embraces two medieval manors – Rõuge manor, first mentioned in records in 1544, and Rõuge pastorate – with a total area 30 km². The area is part of the densely inhabited prehistoric Ugandi county with a village and major stronghold dating back to somewhere within the eighth to eleventh centuries.

Lake Rõuge Tõugjärv (114 m a.s.l.) is a small, 4.2 ha and 17 m deep lake with 8.32 m of sediment, mostly annually laminated, in a thermokarst depression in the ancient Rõuge valley (up to 75 m deep). Lake Tõugjärv is the lowest of a chain of lakes connected by a stream in the valley that cuts the

western slope of the Haanja Uplands, the highest area in Estonia, with a characteristic hilly hummocky landscape. The steepest slopes around the lake are covered with mixed forest and the more gentle slopes with fields and grassland.

The vegetation cover of the present-day patchy cultural landscape consists of an intricate mixture of forest, crop fields and grasslands with a slight prevalence of woodland (Fig. 2a). As the investigation area is situated at the southern limit of the boreo-nemoral forest zone two deciduous tree taxa (*Alnus* spp. and *Betula* spp.) and two coniferous species (*Picea abies* and *Pinus sylvestris*) are the major constituents in these woodlands. Different cereals are main crops grown on the fields and grass (*Poaceae*) species prevail on grasslands.

Methods

Palaeoecological methods

Six parallel overlapping sets of 1-m-long Russian cores of the 832-cm-long lake sediment sequence were recovered by coring at the deepest point of the 17-m-deep lake from the ice-covered surface in March 2000. Additionally a frozen-core from the topmost unconsolidated sediment, yielding four 1-m-long and 10-cm-wide frozen sediment slabs, was taken in 2001. The frozen sediment was cleaned, polished and photographed. Varves were repeatedly and independently counted by several analysts and measured directly from all four frozen slabs, both from photographs and from the cleaned fresh surface of the sediment cores (Lotter & Lemcke, 1999). Varve thickness was measured along a line from digital images.

Continuous 1-cm samples were taken for loss-on-ignition (LOI) and radionuclide analyses. LOI was applied to estimate the content of organic matter and carbonates (Heiri *et al.*, 2001) by igniting at 500 and 900 °C, respectively.

Sediment samples from Lake Rõuge Tõugjärv were analysed for ²¹⁰Pb, ²²⁶Ra, ¹³⁷Cs and ²⁴¹Am by direct gamma assay in the Laboratory of the Center for Environmental Monitoring and Technology in Kiev, Ukraine, using an EG&G Ortec (Perkin-Elmer, Wellesley, MA, USA) HPGe GWL series well-type coaxial low background intrinsic germanium detector (Appleby *et al.*, 1986). Samples for spheroidal carbonaceous particle (SCP) analysis (fly ash) were taken continuously from 0 to 38 cm (AD 2000–1900) as 0.5-cm slices of sediment. SCP samples were prepared according to the modified method of Renberg & Wik (1985) and Rose (1990). *Lycopodium* marker spores were added to calculate SCP concentration and accumulation rates in the sediment. Bulk sediment from 169 cm and a piece of wood from 358 cm were radiocarbon dated by AMS method in Uppsala University.

Pollen samples of known volume, thickness and comprising a known number of annual laminations were taken every 10 varves from 0 to 124 cm (AD 2000–1620) and every 20 varves below that point. The thickness of pollen samples varied in accordance with varve thickness but was never < 0.4 cm. Between AD 1300 and 2000, the mean pollen sample contains 3.4 annual laminations, and for earlier periods 7.2 annual

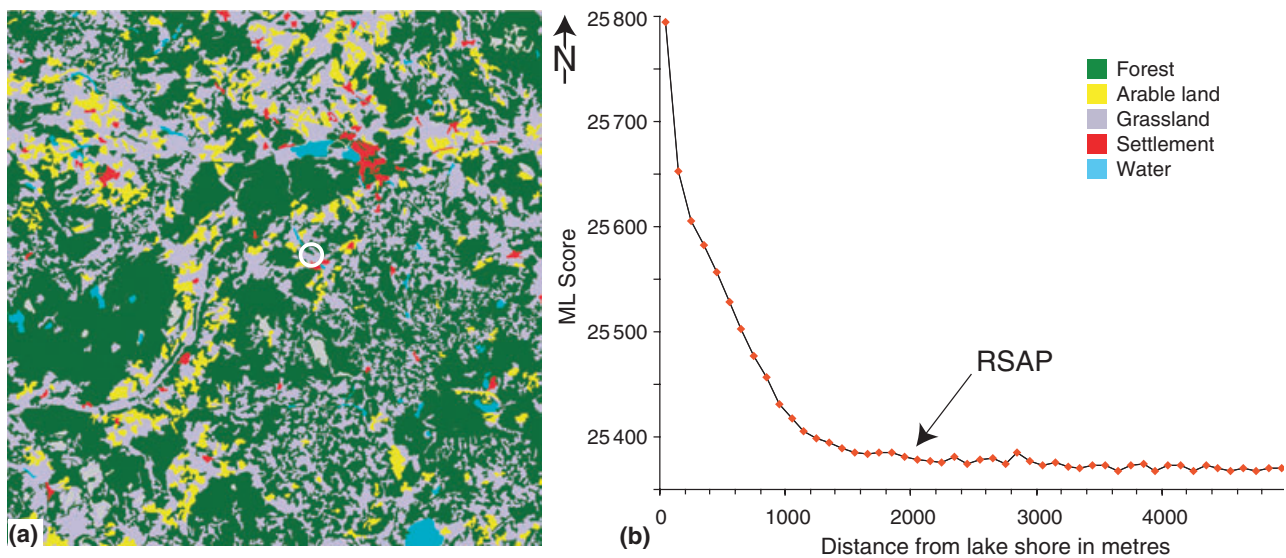


Figure 2 (a) A 60×60 km Corine five-class vegetation cover map showing the intricate patchy South Estonian landscape. The Corine biotope inventory aims at identifying sites of major importance for nature conservation on the European level and was created at the scale of 1 : 100,000. The white circle in the middle refers to the 2 km radius relevant source area of pollen (RSAP). (b) RSAP (≥ 2000 m) of Lake Rõuge Tõugjärv ($r = 50$ m) was modelled following methods described by Sugita (1994) and Sugita *et al.* (1999) with a grid of 36 simulated lakes, with radius similar to that of the basin being investigated, placed on the five class Corine vegetation map.

laminations. Mean pollen sample resolution (≥ 3.4 varves) was chosen to represent changes in vegetation. Annually laminated lake sediments allow finer, even annual sampling, but pollen deposition at annual temporal resolution reflects weather of the preceding year, primarily the temperature of the growing season of the year before pollen emission rather than vegetation (Hicks, 2001; Autio & Hicks, 2004). In lake sediments also, sedimentary processes, such as resuspension (depending on a variety of mechanisms) may cause large inter-annual variations in pollen sedimentation. Pollen sample preparation followed a standard acetolysis method (Berglund & Ralska-Jasiewiczowa, 1986) combined with cold concentrated HF treatment to remove inorganic matter. *Lycopodium* spores were added to calculate pollen concentration and through that PARs (Stockmarr, 1971). At least 1000 arboreal pollen grains were counted at each sample level. Charcoal particles were counted from pollen slides and measured along the longest axis. Pollen data are expressed as percentages of the total terrestrial pollen sum and PARs (pollen grains $\text{cm}^{-2} \text{year}^{-1}$). Counts of spores, algae, charcoal and other microfossils were calculated as percentages of the total terrestrial pollen sum.

Numerical methods

In order to determine the *relevant source area* of pollen (Sugita, 1994) of Lake Tõugjärv, a grid of 36 simulated lakes, with radii similar to that of the basin being investigated, was placed on the Corine vegetation map (Corine Land Cover Estonia, 1996; Corine Land Cover Latvia, 1998) of Southern Estonia (Fig. 2) using the GIS program ArcView. The determination of RSAP was carried out using the computer software programs

PolGrid, PolFlow, and PolLog (written by J. Bunting and R. Middleton, University of Hull, UK) and program ERV-v6 (written by S. Sugita, University of Minnesota, USA) provided by NorFA POLLANDCAL workgroup (<http://www.geog.ucl.ac.uk/ecrc/pollandcal/software.htm>) and following methods described by Sugita (1994), Sugita *et al.* (1999) and M.-J. Gaillard & POLLANDCAL Members (unpublished data).

The *zonation* of the pollen diagram produced from the pollen data is based on the binary splitting by sum-of-squares method using the PSIMPOLL 4.10 program (earlier version published in Bennett, 1994). The significance of statistically determined zones was estimated by comparison with the broken-stick model described by Bennett (1996).

Palyinological rate of change (ROC) was used to measure the rates of vegetation change. ROC is not *per se* a measure of vegetational change but may be seen as a proxy of such. Samples were taken out to achieve an even sampling interval of 20 years (pollen samples were analysed every 10 varves/years in the upper part of the core and every 20 varves/years further down the core). To determine ROC, chord distances were calculated as a dissimilarity measure using the PSIMPOLL 4.10 program. To avoid the high sample-to-sample variability that commonly occurs in fine-resolution data from laminated sediments (e.g. Lotter *et al.*, 1992; Birks, 1998), the data were smoothed with a three-point moving average.

Palyinological richness was estimated with rarefaction analysis (Birks & Line, 1992) using the PSIMPOLL 4.10 program. All identified terrestrial pollen taxa were included and the basic pollen sum for calculations was set to $E(T_{1000})$.

Ordination by detrended correspondence analysis (DCA) using Canoco for Windows 4.5 (ter Braak & Šmilauer, 1998) gave a compositional gradient length of the data set of < 2

(1.385 SD) standard deviation units, showing that the data set has mainly a linear structure, suggesting that principal components analysis (PCA) may be the appropriate ordination method to summarize the pollen data. Ordination by PCA was undertaken using Canoco and CanoDraw 3.10 (Šmilauer, 1994). PCA was applied after deleting minor taxa not reaching a value of 0.5%. The analysis was performed on a covariance matrix (centred by species) using square-root transformed data. Scaling in correlation biplots was focused on inter-sample distances.

Historical maps

Historical maps were digitized and the areal coverage of land-use categories within the radius of 2 km (the RSAP) at each existing time point was determined using a geographical information system (Ocad, Baar, Switzerland; MapInfo, Troy, NY, USA). Different land-use categories were reclassified and unified into five categories: settlement, arable field, grassland, woodland and water (non-pollen producing). Changes in land-cover proportions were calculated. Due to the lack of accurate cartographic materials we could not reconstruct the entire vegetation cover within the RSAP in the second half of the nineteenth century.

RESULTS

Lithology

The topmost part of the 832-cm sediment column of Lake Rõuge Tõugjärv, covering the last 1000 years, which is

discussed here, comprises visibly laminated carbonaceous gyttja between 0 and 162 cm. From 162 to 180 cm the sediment is darker, more organic rich and less visibly laminated. Chemical and microscope examinations showed that the varves consist of light beige coloured clastic inorganic and calcitic spring/summer layers separated by darker organic humic layers. The topmost 13-cm of the sediment (AD 2000–1986) is loose unconsolidated dark gyttja, while 13–162 cm (AD 1985–1339) is laminated gyttja with well-developed varves.

Chronology

The first priority in studies of laminated sediments is to establish the seasonal/annual nature of the layering (Lotter *et al.*, 2002). The annual nature of the laminations at the top of the core is independently verified by ^{210}Pb dating and by detecting ^{137}Cs , ^{241}Am and SCP marker layers (Fig. 3). The ^{210}Pb chronology based on 15 samples fits well with the varve counts within its uncertainty range (Fig. 3a). The levels of the 1986 Chernobyl fall-out event and the 1963 atmospheric nuclear bomb tests determined from the ^{137}Cs and ^{241}Am stratigraphy fall into the varve count within ± 1 year (Fig. 3b). Characteristic SCP marker layers show an increase of spheroidal fly-ash particle accumulation after 1945 (Alliksaar *et al.*, 2005) and maximum accumulation rates during the end of the 'Soviet period' in the late 1980s and early 1990s (Fig. 3a) (Alliksaar *et al.*, 1998; Lotter *et al.*, 2002; Alliksaar & Veski, 2003).

The 3-cm bulk sample from 169 cm yielded an AMS radiocarbon date of 1400 ± 50 ^{14}C yr BP (Ua-19790). The 1σ

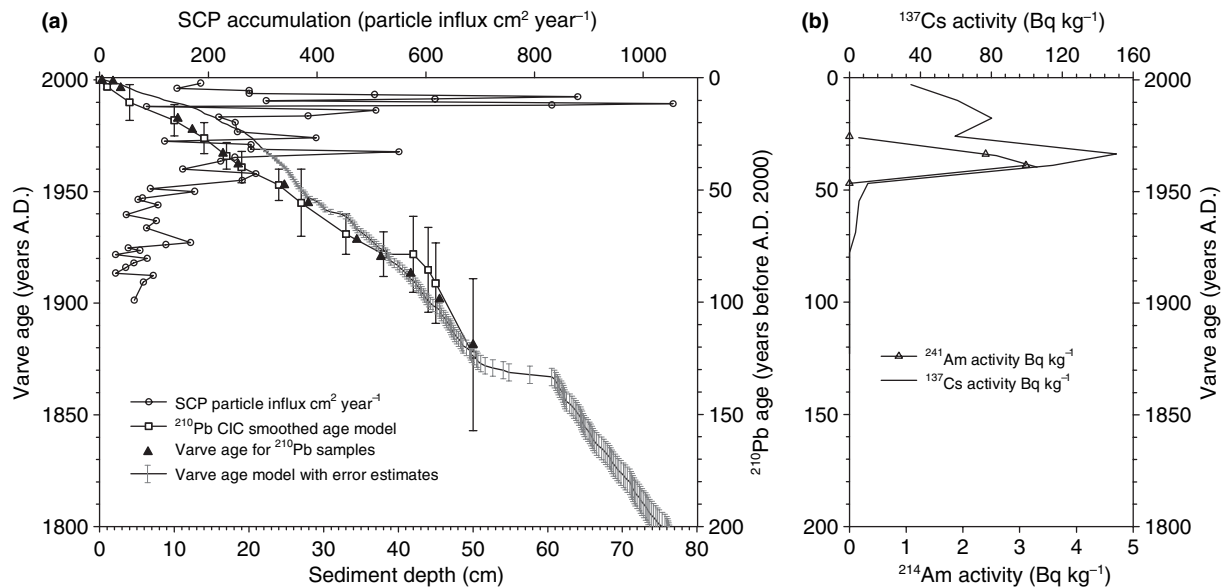


Figure 3 Chronology of the topmost annually laminated lake sediments of Lake Rõuge Tõugjärv. (a) Varve, radiometric and SCP chronology of Lake Rõuge Tõugjärv core showing SCP accumulation, varve age/sediment depth, cumulative varve counting errors, ^{210}Pb dates (CIC model) and corresponding varve ages. Please note that the long varve/age model differs slightly from the ^{210}Pb age model as the two models were constructed from different slabs of frozen sediment: the filled triangles mark the original varve ages for the ^{210}Pb chronology. (b) The 1963 and 1986 dates determined from the ^{137}Cs and ^{241}Am stratigraphy.

calibrated age of the level is thus AD 675–600. The piece of wood from 358 cm was dated at 3230 ± 60 ^{14}C yr BP (Ua-19532), corresponding to 1420–1600 BC.

The varve chronology extends from AD 2000 to 1339, with a cumulative ± 9 -year error estimate for the 661 years. Beyond this the chronology is extrapolated using the ^{14}C date and varve age–depth estimations as terrestrial macrofossils from annually laminated lake sediments have provided dates close to the true age of the sediments (Oldfield *et al.*, 1997; Zillén *et al.*, 2003). The bulk ^{14}C date is clearly 700–600 years older, probably due to old carbon in the sediment, as the dated sediment was taken 7 cm below the counted varves. A similar range of difference between bulk and terrestrial macrofossil dates from the same horizon in Estonian carbonaceous lake sediments has been observed before (Veski, 1998; Poska & Saarse, 2002).

Pollen data

The simulation of the RSAP for Lake Tõugjärv, based on modern conditions, shows that the major portion of the pollen originating in the local vegetation is derived from plants growing within 2000 m of the sampling site (Fig. 2b). However, there is a large background pollen signal reflecting the general regional vegetation of the area. Nielsen (2003) shows that the extent of RSAP may change due to considerable changes in landscape openness and patchiness, vegetation type and taxonomic richness. The sensitivity of RSAP to changes of landscape openness in the current investigation area was tested with a series of simulations using 100%, 75%, 50% (modern

value) and 25% forested landscape. The change of landscape openness did not considerably change the extent of the estimated RSAP. The current study is relatively concentrated in time (1000 years), bringing no major changes in general vegetation type and the areal patchiness of the landscape is highly determined by local topography. The extent of the modern RSAP was used as a constant through the investigated period. The pollen record of Lake Rõuge Tõugjärv is presented with pollen percentage data and summarized PARs plotted against time, in calendar years AD (Fig. 4). Numerical zonation by means of binary splitting by the sum-of-squares method indicated five local pollen assemblage zones with some statistical significance (Table 1).

Palynological ROC analysis provides time-series data about pollen-compositional change per time unit and, with an accurate annual time resolution, can be interpreted as a proxy of the rate of change of the vegetation. In the case of the current study, the ROC shows changes in land use. ROC for the pollen record of Rõuge Tõugjärv indicates relatively stable conditions between AD 1000 and 1500 (Fig. 5c). Rapid changes occur after AD 1500, culminating c. AD 1700, followed by a period of stability and, since AD 1800, a new rapid change phase that continues up to the present day.

Changes in palynological richness are generally interpreted as reflecting predominantly the changing floristic richness of the vegetation types in the pollen source area of a lake and the changing mosaic structure of the landscape through time (Birks & Line, 1992). However, factors such as local site characteristics and differences in pollen production and

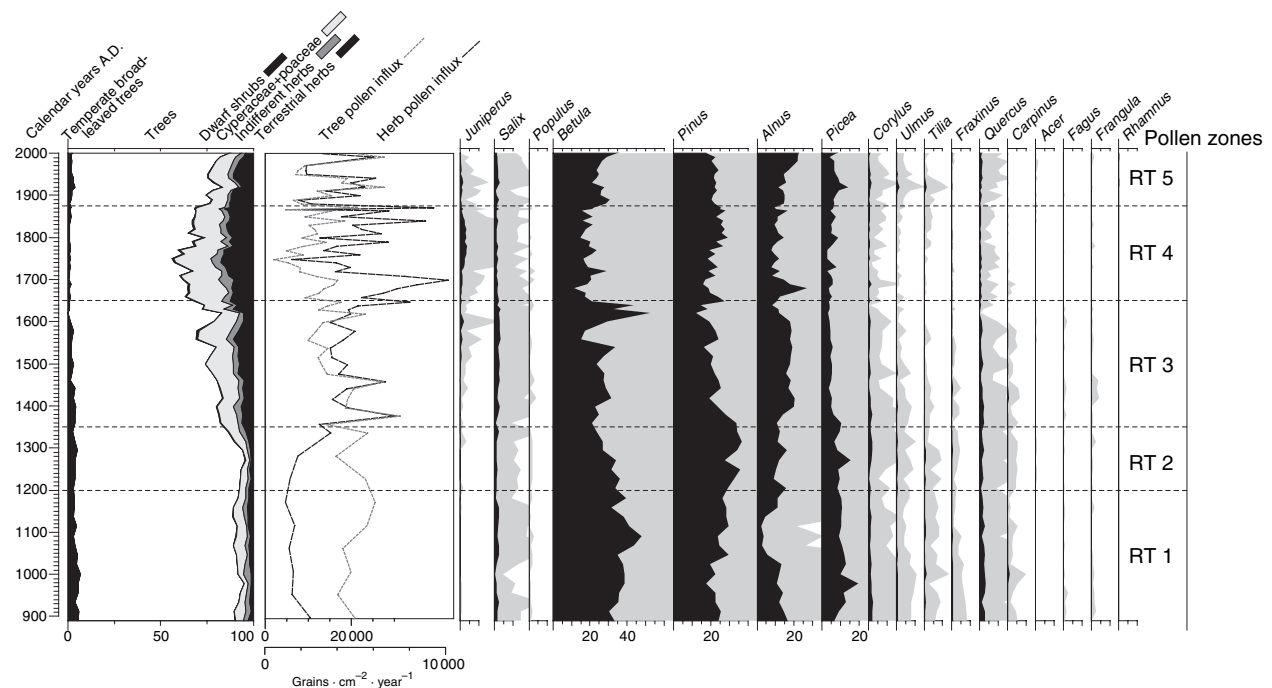


Figure 4 Pollen diagram of selected tree pollen percentages and PARs of tree and herb pollen (grains $\text{cm}^{-2} \text{ year}^{-1}$). Lower scale for herb PARs. Pollen zones correspond to Table 1.

Table 1 Description of pollen zones. The zonation was carried out by means of binary splitting by the sum-of-squares method

| Zone | Age (years AD) | Pollen zone description |
|------|----------------|--|
| RT1 | 1000–1200 | Relatively closed vegetation dominated by birch, spruce and pine. Cultivation of <i>Triticum</i> (wheat) and <i>Hordeum</i> (barley), less <i>Secale</i> (rye). High tree PARs |
| RT2 | 1200–1350 | A change first to closed and then to more open vegetation. Start of extensive rye cultivation close to the end of the period. A drop in tree pollen accumulation and increase in herb pollen accumulation |
| RT3 | 1350–1650 | Gradual opening of the landscape with rye and <i>Cannabis</i> (hemp) cultivation and abundant ruderals. Rise in the charcoal curve |
| RT4 | 1650–1875 | Maximum openness. Herb pollen constitutes nearly 50% of the total pollen. Minimum of temperate broad-leaved trees, in both percentages and PAR. Peak of rye and hemp cultivation, with <i>Centaurea cyanus</i> and <i>Convolvulus arvensis</i> as weeds. <i>Juniperus</i> , <i>Trifolium</i> and others indicate grazing |
| RT5 | 1875–2000 | General closing of the landscape due to reforestation. Increase in tree pollen accumulation |

dispersal of taxa and lack of taxonomic precision must be kept in mind using palynological richness as a measure of floristic diversity (Birks & Line, 1992; Odgaard, 1999). Palynological richness is relatively low around AD 1000, but there is a steady rise from AD 1000 to 1300 and the values then remain around 35 taxa between AD 1300 and 1550 (Fig. 5c). A sudden decrease occurs around AD 1600, followed by a rise to maximum values in the early nineteenth century, after which the palynological richness decreases.

Ordination by PCA shows the local patterns of vegetation change in the Rõuge area for the last 1000 years. Ordination results show relatively high explanatory power of the first two axes ($\lambda_1 = 0.494$ and $\lambda_2 = 0.104$). The first PCA axis, explaining 49.4% of the variance, follows the openness–closedness trend of the landscape with positive values associated with woodland and negative values with open areas (Fig. 6). The pollen samples divide into five statistically significant subgroups corresponding to the local pollen assemblage zones (Table 1), which fall into three general clusters (RT 1 and RT 2; RT 3 and RT 5; RT 4).

During the period between AD 1000 and 1200 (RT 1) the landscape at Rõuge was relatively closed, with birch, spruce and pine dominating the forests. Then, from AD 1200 to 1350 (RT 2) the landscape slowly starts to open up, but is still rather closed. The third subgroup of samples in the centre of the plot shows the gradual opening up of the landscape AD 1350–1650 (RT 3). Subgroup 4 represents the maximum openness of the landscape

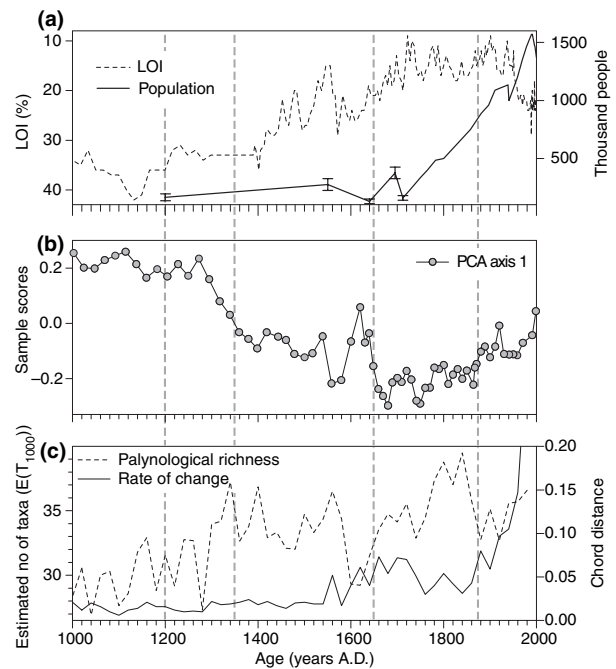


Figure 5 (a) The content of organic matter in the sediments of Lake Rõuge Tõugjärv estimated by loss-on-ignition. The second curve shows the population of Estonia (Palli, 1998). (b) Stratigraphical plot of sample scores on the first PCA axes. (c) Rates of palynological change (ROC), as measured by chord distances and palynological richness as measured by estimated number of taxa [$E(T_{1000})$], plotted against time in calendar years AD. Grey vertical grid lines denote the boundaries of the pollen assemblage zones.

between AD 1650–1875 (RT 4) with the most open period in the late eighteenth century. The last subgroup shifts back towards more closed landscape conditions in 1875–2000 (RT 5).

Historical maps and land cover

Archival records of Estonian history until 1917 have been preserved in the Estonian Historical Archives (EAA). The most valuable materials for landscape reconstruction are detailed historical maps. The first systematic cadastral mapping over Estonian territory took place in the 1680s: manor maps on a scale of c. 1 : 10,400, parish maps on a scale of 1 : 52,000 and map description books were compiled. The two earliest maps covering the surroundings of Lake Tõugjärv originate from that period, both from the year 1684 (EAA, 308-2-178). The next large-scale maps of Rõuge originate from the second half of the nineteenth century: a draft copy of the map of the manor from 1899 (EAA, 3724-5-2867), the map of the church manor from 1870 (EAA, 3724-4-1917) and eight plans of real estates from the year 1867 (1 : 4200) (EAA, 2486-3-272). To extend the time series and the number of reference points, the cadastral maps (1 : 10,000) from 1935 and 1995 were included. Different land use categories were classified into five categories (Table 2) and generalized into land-cover maps (Fig. 7).

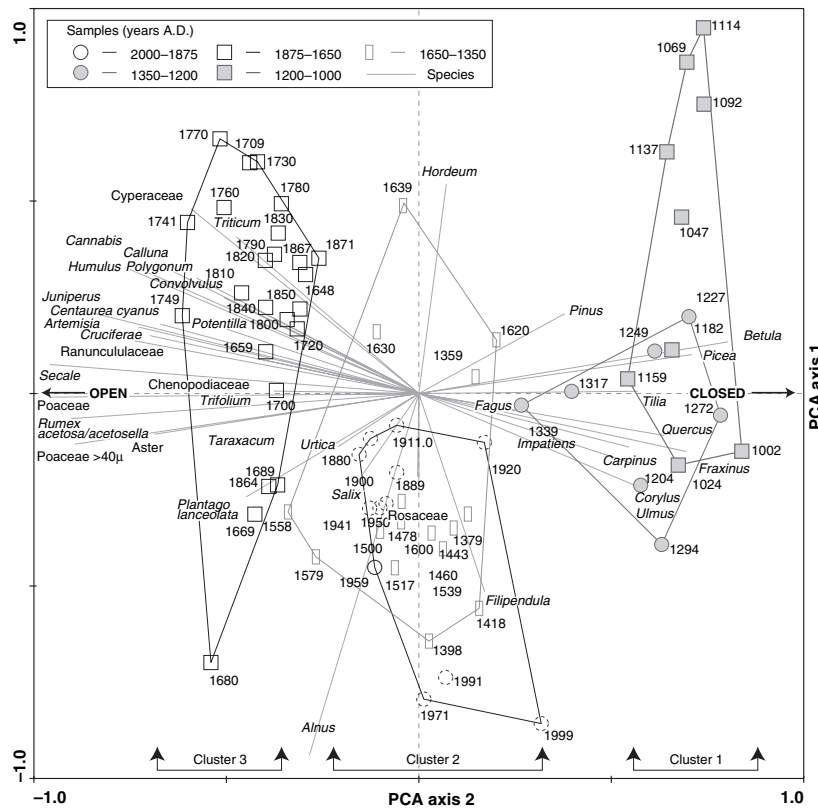


Figure 6 Principal components analysis (PCA) biplot of pollen data for taxa > 0.5% combined by levels. The loadings of the pollen taxa (arrows) and the position of samples (plotted as different symbols assigned to each pollen zone*) are plotted as scores on the first two principal components axes. *Clusters of samples comprising pollen zones have been independently delimited on the basis of numerical zonation (PSIMPOLL 4.10; Bennett, 1996). The first PCA axis explains 49.4% and the second PCA axis a further 10.4% of the variation in the data set.

Table 2 Changes in the proportions of land cover (%) within a radius of 2 km from the lake centre (RSAP) on the maps and pollen percentages for the corresponding years (three sample average) (for maps see Fig. 7). Land-use categories within the RSAP at each existing time point were determined using GIS. Different categories were reclassified and unified into five categories: settlement, arable field, grassland, woodland and water (non-pollen producing surface)

| Land use category | 1684 | | 1870–99 | | 1935 | | 1995 | |
|-------------------|------|--------|---------|--------|------|--------|------|--------|
| | Map | Pollen | Map | Pollen | Map | Pollen | Map | Pollen |
| Settlement | 0.2 | | 1.0 | | 2.2 | | 7.0 | |
| Arable land | 24.1 | 2 | 64.8 | 2 | 54.8 | 1 | 33.2 | 1 |
| Grassland | 3.6 | 11 | 12.3 | 9 | 15.7 | 6 | 9.7 | 4 |
| Water | 3.4 | | 2.7 | | 2.5 | | 2.8 | |
| Forest/brush-wood | 68.6 | 59 | 11.7 | 64 | 24.8 | 71 | 47.4 | 79 |
| Data are missing | – | | 7.5 | | – | | – | |

During the period being studied, the three-field system predominated – crop fields were divided into three parts – fields of summer and winter crops and a field of fallow. A gradual transition from the triennial rotation system to the four- or five-field systems took place in the second half of the nineteenth century (EAA, 1400-1-184). Extensive agricultural techniques, such as the slash and burn type of cultivation, were very common in south-east Estonia until the second half of the nineteenth century. The period of fallow in that case was up to 20 years but became shorter over time due to the intensification of agriculture and population pressure. This land-use category is marked on maps as *Buschland* and often no further information is available about the circumstance, whether these

areas were covered by young forest or were in use as crop fields.

In the nineteenth century the term *Buschland* appears to be under the meaning of newly broken land.

Demographic data, domesticated animals and crop yields

The fragmentary time series of maps is supported by additional information about the demographic and economic situation in the area. We assume that during the period the number of people and domesticated animals reflect the landscape in terms of openness and closedness. Plough-land revisions and

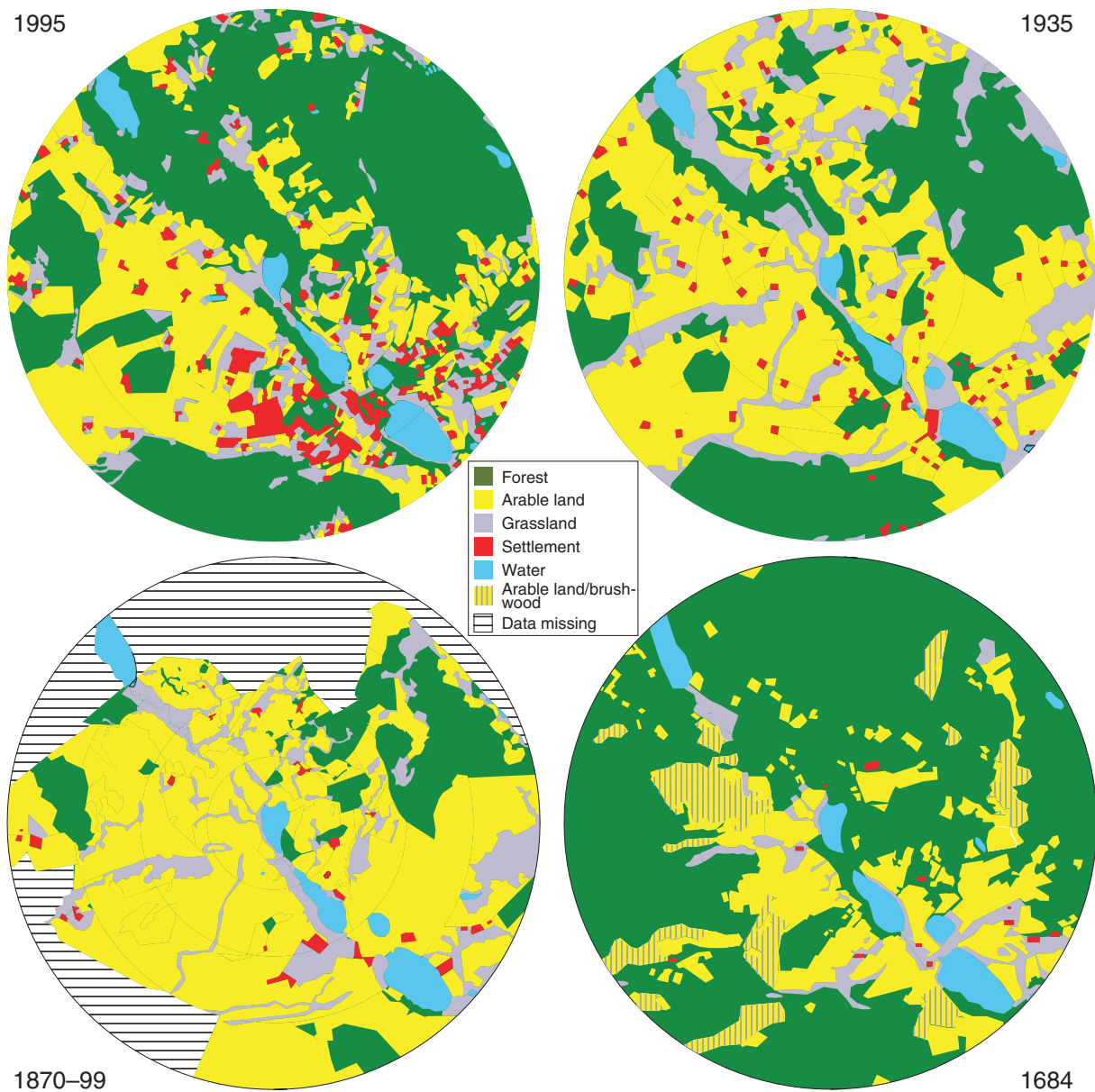


Figure 7 Land cover inside a 2-km radius around Lake Rõuge Tõugjärv in the late seventeenth and late nineteenth century and in 1935 and 1995. Digitized from manor, parish and cadastral maps. Proportions of land cover correspond to Table 2.

registers of *Wackenbücher* [books drawn up to *Wacka*, the annual inspection of peasants, which attempted to establish the number of plough-lands (*unci*) held by each peasant] are the earliest documents that describe the historical situation in detail. Regularly conducted plough-land revisions fixed the number of households, the number of people (children, people capable of working, retired people, both sexes distinguished), the number of draught animals (horses and oxen), cattle and heifer, quantity of sowing, etc. Land revisions and *Wackenbücher* allow us to construct the following time series: 1627, 1638, 1688, 1721, 1744, 1750, 1758, 1805 and 1814 (Rebane, 1941; Roslavlev, 1965; RA ÕJ, 1589–1682; EAA, MF 37-1-17, 85; EAA, MF 2-1-35; EAA, 567-1-275; EAA, 567-1-801) (Fig. 8).

Detailed demographic information derives from population registers (inventories of taxable population) since 1782. The number of men, women and children in 1782, 1795, 1826 and 1858 (EAA, 1865-1-81/10, 81/21, 84/4, 84/5) were added to the previous list (Fig. 8b). A broader picture of land-use efficiency and gradual intensification is drawn using the detailed annual data on the average yield of rye (yield/sowing) in Estonia from 1629 to 1996 (Tarand & Kallaste, 1998) (Fig. 8c).

DISCUSSION

The pollen evidence, relatively low NAP and high tree PAR (Fig. 9) and sample scores in the positive end of the first PCA

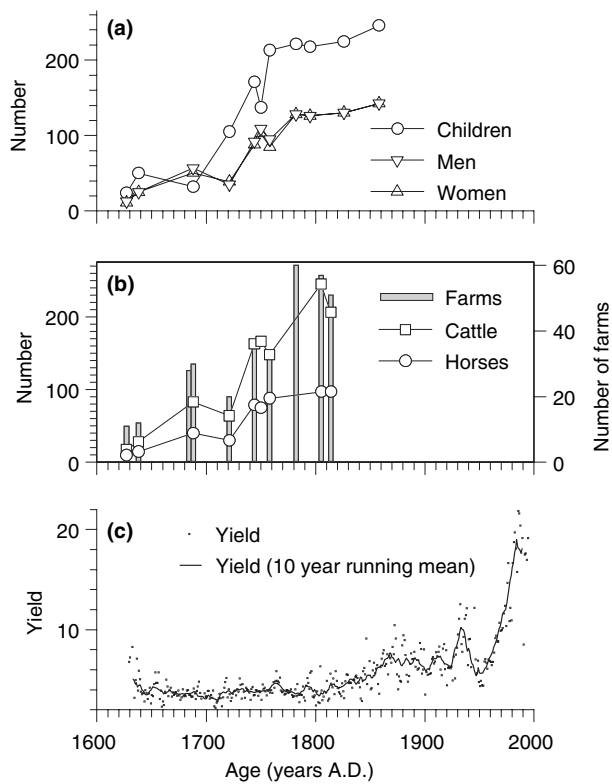


Figure 8 (a) The number of men and women (capable of working) and the number of children in Rõuge manor between 1627 and 1858. (b) The number of farms and livestock in Rõuge manor between 1627 and 1814. (c) Annual data on the average yield of rye (ratio between grains sown and grains harvested) in Estonia from 1629 to 1996 (Tarand & Kallaste, 1998).

axis around AD 1000, indicate a comparatively undisturbed and mostly forested landscape near Rõuge Tõugjärv (Figs 5b & 6). The low palynological richness and palynological rate of change values in combination with high LOI [pointing to little erosion in the catchment (Fig. 5a)] further support this conclusion. Pollen evidence suggests some crop cultivation since pollen grains of *Hordeum*, *Triticum* and, to a lesser extent *Secale* and *Cannabis*, are present throughout this period (Fig. 9). All this points to a relatively low and stable human occupation involving small-scale arable farming in the area around AD 1000–1200. The real extent of land use is probably underestimated as a major stronghold by Lake Liinjärv (c. 2 km SE of the centre of Lake Tõugjärv at the edge of the RSAP) dating back to between the eighth and eleventh centuries and a village dating from the sixth to eleventh century (Jaanits *et al.*, 1982) are known from this period. A pollen signal, which originates from small arable plots scattered in a generally wooded landscape, is hard to detect (Hicks, 1988; Sugita, 1994; Davis, 2000). It is also possible that the fields situated at the edge of the RSAP of the lake, and the appearance of forest grazing indicators (*Melampyrum* and *Pteridium*) point to somewhat more cattle rearing activity in the area AD 1000–1200. The occurrence of fields outside the RSAP are further supported by rather low cereal PARs, < 1000 pollen grains $\text{cm}^{-2} \text{year}^{-1}$ (Fig. 9). Although the accumulation rate of cereal pollen at a sediment surface depends on a variety of factors (such as distance to the fields, the area of the fields, degree of sediment (pollen) focusing in the lake), Koff & Punning (2002) estimated the relationship between nearby arable field distances and cereal pollen influx into certain Estonian lakes by Tauber and sediment traps and found that

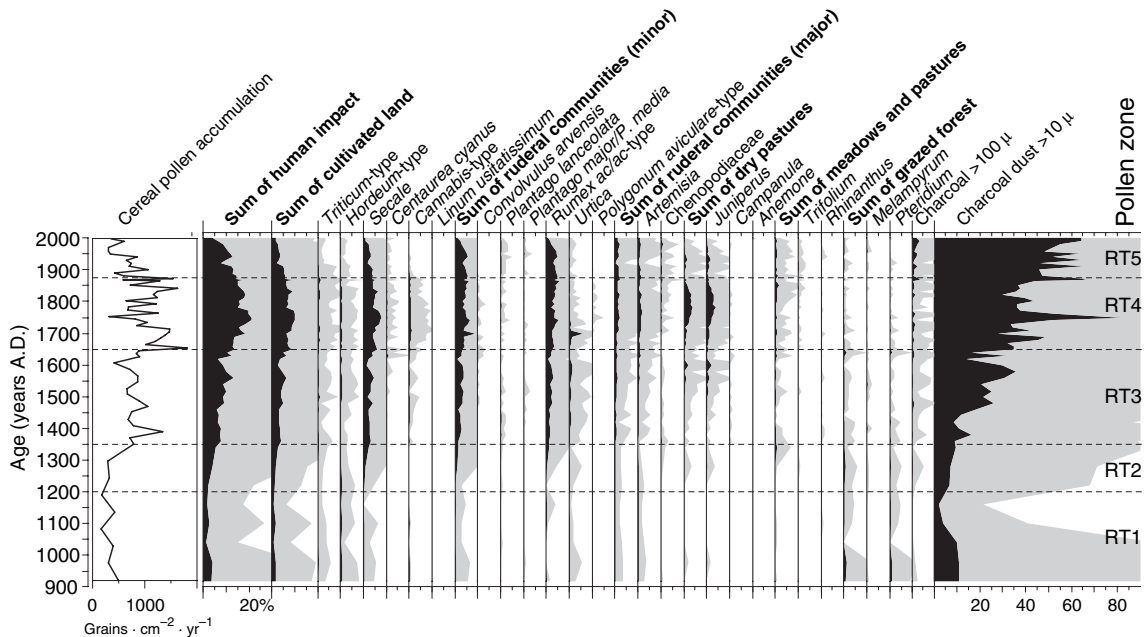


Figure 9 Pollen diagram of selected herb pollen percentages together with the PAR of cereals ($\text{grains cm}^{-2} \text{year}^{-1}$). Pollen zones correspond to Table 1. Grouping of pollen types into different land-use categories after Poska *et al.* (2004).

influx values under 1000 cereal pollen grains $\text{cm}^{-2} \text{ year}^{-1}$ record the nearest fields *c.* 2 km away from the lake.

The period AD 1200–1350, independently defined in the pollen data, is also apparent in the historical records as a major political disturbance. Namely, the German Order extended its crusade to prehistoric Ugandi and, Estonia, as a whole, was in the range of interest of the German Order, Russians, Lithuanians, Danes and Swedes. The war, with large casualties, lasted from 1208 to 1227 and the area of present-day Estonia was divided among the Order of the Brothers of the Sword, Denmark and bishops – the Middle Ages had begun in Estonia. Several attempts to push out the foreign feudal power were made up until 1343. This turbulent period is easily recognized in the pollen data, with very low NAP values and a decrease in human impact indicators. The famine in AD 1315 and the Black Death in the 1350s have no signal in the pollen record. However, the slight increase in indications of land use towards 1350 is seen and the PCA sample scores for those years seem to move towards more open conditions, probably due to wood consumption for military purposes and an increase in agrarian activities, as the PAR of tree pollen shows a decrease after AD 1200 and NAP accumulation rises drastically. There is a close correlation between population density and technological levels (including land use) before the agricultural revolution (Boserup, 1981). The decrease in population brings about stagnation or even temporary regeneration of technological development – agriculture may change to more extensive practices. The reason is simple: extensive cultivation requires less human labour than intensive, which is a result of limited natural resources under population pressure (Boserup, 1972). Changes in ratio between annual cropping and more extensive systems such as forest- or bush-fallow cultivation, have certain effects on landscape. So the decrease in tree pollen (especially birch) accumulation can be explained principally as a change in cultivation in favour of more extensive practices such as slash and burn agriculture. It is hard to believe that anthropogenic impact and clear-cutting of forests are fully responsible for that change, as pollen percentages show low NAP and the amount of human impact indicators and PAR of indicators of cultivated land only rise slightly. The decrease in tree pollen accumulation is most probably attributable to a combined human–climatic effect. The latter may show up as hampered production of tree pollen due to the end of the Medieval Warm Period and the start of Little Ice Age cooling.

Since AD 1350, the gradual opening of the landscape starts, with extensive rye and hemp cultivation, accompanied by abundant ruderals. *Cannabis* pollen may, however, reflect local retting in the lake, as retting, which may be the source of hemp pollen, gives a bias to the pollen record, but confirms the cultivation of hemp in any case. The rise in the charcoal curve (both, in smaller charcoal particles 10–100 μm and larger ones $> 100 \mu\text{m}$) indicates opening of new fields by fire and the practising of traditional slash-and-burn agriculture on overgrown fields. The latter is well-documented on maps from 1684, where large proportions of land surrounding the lake were categorized as ‘land overgrown with young birch bushes

suitable for slash-and-burn cultivation’ and ‘exhausted bush-land’. The palynological richness rises, pointing to more open conditions, with higher landscape diversity, as do the PCA sample scores. Verheyen *et al.* (1999) show that the period under discussion was the one with maximal land-use diversity in Belgium, due to transitional forms between forest and pasture. However, the change in landscape openness in Rõuge must have been rather gradual as the ROC still shows low values. The culmination in the increase of human impact around AD 1550, as derived from the pollen record, may be connected with the beginning of commercial rye production for the West-European market. The general trend to a more open landscape and extensive field cultivation is interrupted by a period of turbulence in the late sixteenth to the early seventeenth century when The Livonian War (1558–1583), the first Polish-Swedish war (1600–1629) and widespread famine caused by climate induced crop failures in 1601–02 in Northern Europe, and reduced the population of Estonia by half, resulting in the abandonment of *c.* 75% of farmsteads. These drastic changes are clearly recognizable in the pollen evidence from Lake Rõuge Tõugjärv as reduced NAP values and a fall in nearly all human impact indicator pollen types. There is a short increase in tree pollen accumulation and a decrease in the PAR of cereal pollen, supporting a good correlation with the above-mentioned historical data. The palynological richness drops to initial values around AD 1000–1200 and the rise of ROC indicates rapid changes in vegetation. The abandonment of farms resulted in less agricultural activity, leading to overgrowing of fields by birch woodland, indicated by high *Betula* percentages. The decrease in the extent of arable land is also marked by the start of relatively organic rich sedimentation, indicated by increased LOI.

The near-zero numbers of people and domestic animals in 1627 is in keeping with the above-mentioned early seventeenth century human casualties and corresponding economic drawback, seen in the palaeodata as a reduction in the portion of arable land and total landscape openness. The number of farms in Rõuge is not indicative in that respect since recorded farms could still be unpopulated at that time (Fig. 8b). According to the Truce of Altmark (1629) the entire Estonian territory came under Swedish rule in 1629 and manors began to flourish. By 1688, the number of farms had doubled and there is a noticeable increase in cattle, pointing indirectly to an increasing population. The whole population of Estonia tripled from 1630 to 1680 (Fig. 5a) (Palli, 1998). The post-1630s economic growth is visible in both pollen and LOI data as high NAP percentages and high minerogenic material input into the lake, as a result of the increasing area of arable and grassland. The same is suggested by the PCA sample scores, which cluster into the ‘open landscape’ end of the first axis. The map from 1684 illustrates the contemporaneous landscape within the 2000 m radius from the coring point in the centre of lake Rõuge Tõugjärv (Fig. 7). Much of the open area is described as impoverished fields or areas suitable for slash-and-burn practices, showing the ongoing rotation. The forest/open land ratio is 69/28% (Table 2) and arable land is by far the

dominant category within the open area. A similar analysis of seventeenth and eighteenth century land-cover transitions in Nynäs, Sweden show 28% of arable land and a 60/32% ratio of grassland and arable fields among the open land (Cousins, 2001; Cousins *et al.*, 2002). Estonia was under Swedish rule at that time and both Rõuge and the area studied by Cousins (2001) had so-called 'infields – the enclosed land around villages and manors', so that the land-use patterns could have been similar in the two areas even though the land structure, especially the grassland/arable field ratio, differed a great deal. The difference in land use could be explained by differences in soils, topography and other factors, such as that the Nynäs area had an exceptionally high degree of semi-natural grasslands compared with other parts of the region. In Rõuge, the low percentage of grasslands may be explained by forest grazing traditions (the map from 1684 shows hay meadows but not pastures) and by the fact that cattle rearing was on a rather limited basis in Estonian manors before 1700 (Kahk, 1992). Also Cousins (2001) mentions that some of the wet deciduous forest was mapped as grassland in the eighteenth century, suggesting forest grazing.

After the period of restoration and relatively stable increase in population, new disasters such as the Great Famine (1695–97), battles of the Great Northern War, depredations of the Russian army (1701–04) and the plague (1710–11), devastated south-east Estonia. The total population of Estonia in 1712 dropped to the level of the early seventeenth century (Fig. 5a). It is understandable that detailed records about this obscure period are not available. Data of the number of people and the economic situation are available from 1721, when plough land revision was carried out, showing that the loss in local population was great. Despite this, the population grew very quickly after the war. These drastic events were focused in time and the current pollen analytical resolution of 10 years is not fully able to recognize the event. More detailed analysis is needed to reveal disturbances in vegetation. Interestingly, a single high peak of *Urtica* appears at 1700 and may pinpoint the abundance of nettle around abandoned farm buildings (Fig. 9). Since 1700 the population in Rõuge (Figs 5a & 8a) and Estonia has constantly increased. Taavitsainen *et al.* (1998) found a direct exponential relationship between the population size and cereal grain PAR in SE Finland. In Rõuge, the cereal PAR trend is not exponential and precedes the human population graph by at least 400 years, but is consistent with the Finnish data in respect of the trend in cereal PAR being the converse of the accumulation of tree (spruce) pollen (Simola, 1995). In latitudinally similar areas of southern Sweden, the reversed graphs of temperate broad-leaved trees and cereals show the same trend (Lindbladh *et al.*, 2000). In colonial environments, human population growth directly affected the forest area (Foster *et al.*, 1998; Bellemare *et al.*, 2002). In areas of permanent habitation, these processes are more gradual. The manorial economy of eighteenth century Estonia was orientated towards the Russian market and, in addition to grain, spirit became a very important export commodity. Manors

focused on rye cultivation and, because spirit distillation from rye demanded fuel (wood), this led to intensive deforestation, reflected in the pollen rain as the lowest tree pollen accumulation within the last 1000 years. The restrained forest regeneration in combination with the rise in the proportion of pollen types indicating dry meadows (mainly *Juniperus*) is probably a consequence of well-established cattle rearing. The short-term decrease in human impact indicators reflected in the pollen records in the middle of the eighteenth century may be explained by a recession in cattle breeding caused by anthrax in the late 1740s and early 1750s and a cattle epidemic in the 1770s. During the nineteenth century, even the steepest slopes along the chain of lakes running from SE to NW were clear-cut and used as meadows and pastures. Maps from the late nineteenth century show an almost entirely open landscape with just a larger patch of woodland (the church forest) to the east of Lake Tõugjärvi (Fig. 7). The forest/open land ratio is reduced to 12/77% (Table 2). This type of open landscape and the openness of steep slopes lead to the accumulation of highly minerogenic sediments in lakes. Pollen percentages clearly underestimate the real extent of landscape openness depicted on the maps. Accumulation of tree pollen on the other hand shows the opening of the landscape since the thirteenth century as the decrease in AP accumulation rates, and exceptionally high NAP accumulation at the end of seventeenth and nineteenth century (Fig. 9). The cereal PAR in those periods is also the highest but does not exceed 1500 pollen grains $\text{cm}^{-2} \text{year}^{-1}$. Comparable cereal PARs in South Estonia indicate sites directly affected by agricultural activities (Koff & Punning, 2002).

In 1804 the peasants of Livonia were granted the right of private property and inheritance; a bill abolishing serfdom was passed in 1816 in Estonia and 1819 in Livonia. In Rõuge most of the farmsteads were bought for demesne in the beginning of the 1880s. The first farm in Rõuge manor was bought in 1870 and the last four farms in 1886 (Rumma *et al.*, 1926). Land division in the 1860–70s had no larger effect upon the southern Estonian hilly landscape with its traditionally relatively scattered settlement pattern. These characteristics hindered landscape changes when compared with the scale of change in the flat landscapes of North Estonia (Veski, 1998; Poska *et al.*, 2004). There these changes had a great influence on landscape as re-arrangements in ownership relations and in the structure of the settlement enabled more effective land use. A gradual transition from the three-field system to the four- or five-field system took place in the second half of the nineteenth century. Works of soil amelioration and drainage and the introduction of artificial fertilizers created more advantageous conditions for intensive agricultural production.

These important transformations in agricultural patterns towards modern land use – the start of mechanized cultivation, fertilization, ditching, plant breeding and more effective private farms – led to a new landscape pattern seen on the map from 1935 (Fig. 7). Farms are scattered in the area and the steepest slopes, difficult to cultivate with developing machin-

ery, are left under woodland again, resulting in a pollen signal that points to a more forested environment than before (Figs 7 & 9). Since the mid-nineteenth century crop cultivation has gained new levels and shifted from extensive farming, where the growth in population was compensated for by more and more arable land, to intensive farming where the same aims were reached by the more effective use of the existing land. This is seen in the graph of rye cultivation in Estonia from 1629 to 1994 (Tarand & Kallaste, 1998) where the yield of rye in seed units (yield/seed) increased in the nineteenth century as a result of more effective farming (Fig. 8c). The change from a subsistence farming system to an open economy around 1890 in Belgium resulted in a reduction of land-use area (Petit & Lambin, 2002a). Palynological richness was greatest in the nineteenth century, most probably due to the open patchy landscape and under-representation of trees at a regional scale, which allows more herb taxa to be seen in the pollen record, but certainly leads to the stability of the landscape as seen in the rate of change graph. In that sense the periods with the highest change were in the seventeenth century, when the open landscape was created, and during the last 150 years when, for a variety of reasons, more closed landscape developed as indicated by the falling NAP percentages and decreasing palynological richness. Similar processes have been described in other parts of Estonia (Palang *et al.*, 1998; Pärtel *et al.*, 1999) and elsewhere (Andreasen *et al.*, 1996).

People have lost interest in some of the crops widely grown 200 years ago, such as *Cannabis sativa*, because of the introduction of artificial fibres (Joosten, 1985). *Linum usitatissimum*, being a moderate pollen producer, shows up in just one sample around 1870, although it was widely cultivated in southern Estonia and, in fact, played an important role as the source of finance for buying farmsteads for demesne at that time, as world linen prices were high due to the American Civil War. Following the disappearance of hemp and linen cultivation, for instance, ruderals associated with these fields have also vanished.

In the early twentieth century the landscape was still relatively open (Fig. 7), with 70% covered by fields and grasslands, but the immediate surroundings of the lake were more forested. The number of farms has increased rapidly compared with the previous map. The Second World War and the subsequent Soviet period devastated the farming landscape by loss in population, collectivization, etc. For a variety of reasons the rate of change is highest in the last century not only in Rõuge but probably in many areas (e.g. Cole, 1995; Goslar *et al.*, 1999; Lindbladh *et al.*, 2000; Cousins, 2001; Petit & Lambin, 2002b). Even if agricultural production rose in the late twentieth century the undulating patchy landscapes of southern Estonia were not suitable for large-scale industrial type agricultural production and Rõuge remained out of focus in that respect leading to forest regeneration as seen in the rising tree PAR. Today the landscape looks much like that illustrated in Fig. 7 and the area is more and more utilized for recreational aspects than for farming (Peterson & Aunap, 1998), resulting in even

more reforestation, which is currently the main direction in which the landscape is developing.

CONCLUDING REMARKS

The formation and development of the cultural landscape at Rõuge during the last 1000 years is characterized by rapid changes in richness and rates of vegetation change attributed to certain historic processes in the lake catchment and the RSAP. Five phases of landscape and societal development are clearly distinguished during the last 1000 years. The decadal scale vegetation response to human-induced forcing agrees with historical maps and documents and can be used to reconstruct past landscapes prior to the time for which solid historical data are available.

ACKNOWLEDGEMENTS

We would like to thank the POLLANDCAL group for educating discussions. We are grateful to S. Hicks for her valuable comments on an earlier version of the manuscript. Two anonymous referees are thanked for their constructive and useful reviews.

Financial support was provided by Estonian target funding projects 0331758s01 and 0332626s03 and Estonian Science Foundation (grants 4963 and 5923). This is a contribution to the NordForsk funded network POLLANDCAL (<http://www.geog.ucl.ac.uk/ecrc/pollandcal/>). We thank the Estonian and Latvian Ministries of the Environment for the Corine land-cover data.

REFERENCES

- Alliksaar, T. & Veski, S. (2003) Comparison of different dating methods in a lake with annually laminated sediments. *Geochimica et Cosmochimica Acta*, **67**(Suppl. 1), 13.
- Alliksaar, T., Hörstedt, P. & Renberg, I. (1998) Characteristic fly-ash particles from oil shale combustion found in lake sediments. *Water, Air and Soil Pollution*, **104**, 149–160.
- Alliksaar, T., Heinsalu, A., Saarse, L., Salujõe, J. & Veski, S. (2005) A 700-year decadal scale record of lake response to catchment land use from annually laminated lake sediments in southern Estonia. *Verhandlungen des Internationalen Vereins für Theoretische und Angewandte Limnologie*, **29** (in press).
- Andreasen, C., Stryhn, H. & Streibig, J.C. (1996) Decline of the flora in Danish arable fields. *Journal of Applied Ecology*, **33**, 619–626.
- Appleby, P.G., Nolan, P.J., Gifford, D.W., Godfrey, M.J., Oldfield, F., Anderson, N.J. & Battarbee, R.W. (1986) ^{210}Pb dating by low background gamma counting. *Hydrobiologia*, **141**, 21–27.
- 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.

- Bellemare, J., Motzkin, G. & Foster, D.R. (2002) Legacies of the agricultural past in the forested present: an assessment of historical land-use effects on rich mesic forests. *Journal of Biogeography*, **29**, 1401–1420.
- Bennett, K.D. (1994) *Psimpoll version 2.23: A C program for analysing pollen data and plotting pollen diagrams*, INQUA Working Group on Data-Handling Methods Newsletter, **11**, 4–6.
- Bennett, K.D. (1996) Determination of the number of zones in a biostratigraphical sequence. *New Phytologist*, **132**, 155–170.
- Berglund, B.E. & Ralska-Jasiewiczowa, M. (1986) Pollen-analysis and pollendiagrams. *Handbook of Holocene palaeoecology and palaeohydrology* (ed. by B.E. Berglund), pp. 455–484. Wiley, Chichester.
- Birks, H.J.B. (1998) Numerical tools in palaeolimnology – progress, potentialities, and problems. *Journal of Paleolimnology*, **20**, 307–332.
- Birks, H.J.B. & Line, J.M. (1992) The use of rarefaction analysis for estimating palynological richness from Quaternary pollen-analytical data. *The Holocene*, **2**, 1–10.
- Birks, H.J.B., Line, J.M. & Persson, T. (1988) Quantitative estimation of human impact on cultural landscape development. *The cultural landscape past, present and future* (ed. by H.H. Birks, H.J.B. Birks, P.E. Kaland and D. Moe), pp. 229–240. Cambridge University Press, Cambridge.
- Boserup, E. (1972) *The conditions of agricultural growth: the economics of agrarian change under population pressure*. George Allen & Unwin Ltd, London.
- Boserup, E. (1981) *Population and technology*. Blackwell, Oxford.
- ter Braak, C.J.F. & Šmilauer, P. (1998) *CANOCO reference manual and users guide to Canoco for Windows. Software for canonical community ordination (version 4)*. Microcomputer Power, Ithaca.
- Broström, A. (2002) Estimating source area of pollen and pollen productivity in cultural landscapes of southern Sweden – developing a palynological tool for quantifying past plant cover. *LUNDQUA Thesis*, **46**, 1–116.
- Broström, A., Gaillard, M.J., Ihse, M. & Odgaard, B. (1998) Pollen-landscape relationships in modern analogues of ancient cultural landscapes in southern Sweden – a first step towards quantification of vegetation openness in the past. *Vegetation History and Archaeobotany*, **7**, 189–201.
- Cole, K.L. (1995) Vegetation change in national parks. *Our living resources* (ed. by E.T. LaRoe), pp. 224–227. US Department of the Interior, Washington, DC.
- Corine Land Cover Estonia (1996) *CD CLCEE0036 European Commission*. Estonian Map Centre, Tallinn, Estonia.
- Corine Land Cover Latvia (1998) *CD CLCLV0030 European Commission*. Latvian Environmental Agency, Riga, Latvia.
- Cousins, S.A.O. (2001) Analysis of land-cover transitions based on 17th and 18th century cadastral maps and aerial photographs. *Landscape Ecology*, **16**, 41–54.
- Cousins, S.A.O., Eriksson, Å. & Franzén, D. (2002) Reconstructing past land use and vegetation patterns using palaeogeographical and archaeological data: a focus on grasslands in Nynäs by the Baltic Sea in south-eastern Sweden. *Landscape and Urban Planning*, **61**, 1–18.
- Davis, M.B. (2000) Palynology after Y2K – understanding the source area of pollen in sediments. *Annual Review of Earth and Planetary Sciences*, **28**, 1–18.
- Foster, D.R., Motzkin, G. & Slater, B. (1998) Land-use history as long-term broad-scale disturbance: regional forest dynamics in central New England. *Ecosystems*, **1**, 96–119.
- Foster, D.R., Hall, B., Barry, S., Clayden, S. & Parshall, T. (2002) Cultural, environmental and historical controls of vegetation patterns and the modern conservation setting on the island of Martha's Vineyard, USA. *Journal of Biogeography*, **29**, 1381–1400.
- Fuller, J.L., Foster, D.R., McLachlan, J.S. & Drake, N. (1998) Impact of human activity on regional forest composition and dynamics in central New England. *Ecosystems*, **1**, 76–95.
- Gaillard, M.-J., Birks, H.J.B., Emanuelsson, U. & Berglund, B.E. (1992) Modern pollen/land-use relationships as an aid in reconstruction of past land-uses and cultural landscapes: example from south Sweden. *Vegetation History and Archaeobotany*, **1**, 3–17.
- Goslar, T., Ralska-Jasiewiczowa, M., van Geel, B., Łacka, B., Szeroczyńska, K., Chróst, L. & Walanus, A. (1999) Anthropogenic changes in the sediment composition of Lake Gościąg (central Poland), during the last 330 yrs. *Journal of Paleolimnology*, **22**, 171–185.
- Heiri, O., Lotter, A.F. & Lemcke, G. (2001) Loss on ignition as a method for estimating organic and carbonate content in sediments: reproducibility and comparability of results. *Journal of Paleolimnology*, **25**, 101–110.
- Hicks, S. (1988) The representation of different farming practices in pollen diagrams from northern Finland. *The cultural landscape past, present and future* (ed. by H.H. Birks, H.J.B. Birks, P.E. Kaland and D. Moe), pp. 188–207. Cambridge University Press, Cambridge.
- Hicks, S. (2001) The use of annual arboreal pollen deposition values for delimiting tree-lines in the landscape and exploring models of pollen dispersal. *Review of Palaeobotany and Palynology*, **117**, 1–29.
- Jaanits, L., Laul, S., Lõugas, V. & Tõnisson, E. (1982) *Eesti esiajalugu [Estonian Prehistory]*. Eesti Raamat, Tallinn.
- Joosten, J.H.J. (1985) A 130 year micro- and macrofossil record from regeneration peat in the Peel, the Netherlands: a palaeoecological study with agricultural and climatological implications. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **49**, 277–312.
- Kahk, J. (1992) *Eesti talurahva ajalugu [Estonian peasants]*. Olion, Tallinn.
- Koff, T. & Punning, J.-M. (2002) The last hundred years of land-use history in Estonia as inferred from pollen records. *Annales Botanici Fennici*, **39**, 213–224.
- Lindbladh, M., Bradshaw, R. & Holmqvist, B.H. (2000) Pattern and process in south Swedish forests during the last 3000 years, sensed at stand and regional scales. *Journal of Ecology*, **88**, 113–128.

- Lotter, A.F. (1998) The recent eutrophication of Baldeggersee (Switzerland) as assessed by fossil diatom assemblages. *The Holocene*, **8**, 395–405.
- Lotter, A.F. & Lemcke, G. (1999) Methods for preparing and counting biochemical varves. *Boreas*, **28**, 243–252.
- Lotter, A.F., Ammann, B. & Sturm, M. (1992) Rates of change and chronological problems during the late-glacial period. *Climate Dynamics*, **6**, 233–239.
- Lotter, A.F., Appleby, P.G., Bindler, R., Dearing, J.A., Grytnes, J.A., Hofmann, W., Kamenik, C., Lami, A., Livingstone, D.M., Ohlendorf, C., Rose, N. & Sturm, M. (2002) The sediment record of the past 200 years in a Swiss high-alpine lake: Hagelseewli (2339 m a.s.l.). *Journal of Paleolimnology*, **28**, 111–127.
- Nielsen, A.B. (2003) *Pollen based quantitative estimation of land cover – relationships between pollen sedimentation in lakes and land cover as seen on historical maps in Denmark AD 1800*. PhD Thesis, University of Copenhagen and Geological Survey of Denmark and Greenland, rapport 2003/57.
- Nielsen, A.B. & Odgaard, B.V. (2004) The use of historical analogues for interpreting fossil pollen records. *Vegetation History and Archaeobotany*, **13**, 33–43.
- O'Sullivan, P.E. (1983) Annually-laminated lake sediments and the study of Quaternary environmental change – a review. *Quaternary Science Reviews*, **1**, 245–313.
- Odgaard, B.V. (1999) Fossil pollen as a record of past biodiversity. *Journal of Biogeography*, **26**, 7–17.
- Odgaard, B.V. & Rasmussen, P. (2000) Origin and temporal development of macro-scale vegetation patterns in the cultural landscape of Denmark. *Journal of Ecology*, **88**, 733–748.
- Oldfield, F., Crooks, P.R.J., Harkness, D.D. & Petterson, G. (1997) AMS radiocarbon dating of organic fractions from varved lake sediments: an empirical test of reliability. *Journal of Paleolimnology*, **18**, 87–91.
- Palang, H., Mander, Ü. & Luud, A. (1998) Landscape diversity changes in Estonia. *Landscape and Urban Planning*, **41**, 163–169.
- Palli, H. (1998) *Eesti rahvastiku ajaloo lühiülevaade. [Estonian Population]*. Sisekaitseakadeemia, Tallinn.
- Pärtel, M., Mändla, R. & Zobel, M. (1999) Landscape history of a calcareous (alvar) grassland in Hanila, western Estonia, during the last three hundred years. *Landscape Ecology*, **14**, 187–196.
- Peterson, U. & Aunap, R. (1998) Changes in agricultural land use in Estonia in the 1990s detected with multitemporal Landsat imagery. *Landscape and Urban Planning*, **41**, 193–201.
- Petit, C.C. & Lambin, E.F. (2002a) Long-term land-cover changes in the Belgian Ardennes (1775–1929): model-based reconstruction vs. historical maps. *Global Change Biology*, **8**, 616–630.
- Petit, C.C. & Lambin, E.F. (2002b) Impact of data integration technique on historical land-use/land-cover change: comparing historical maps with remote sensing data in the Belgian Ardennes. *Landscape Ecology*, **17**, 117–132.
- Poska, A. & Saarse, L. (2002) Biostratigraphy and ¹⁴C dating of a lake sediment sequence on the north-west Estonian carbonaceous plateau, interpreted in terms of human impact in the surroundings. *Vegetation History and Archaeobotany*, **11**, 191–200.
- Poska, A., Saarse, L. & Veski, S. (2004) Reflections of pre- and early-agrarian human impact in the pollen diagrams of Estonia. *Palaeogeography Palaeoclimatology Palaeoecology*, **209**, 37–50.
- Rebane, H. (1941) Liivimaa 1638. a. maarevisjon. Eesti asustusala I. Kaguosa [Land revision of Livland in 1638]. *ENSV Riigi Keskarhiivi Tartu osakonna toimetused*, **1**, 195–200.
- Renberg, I. & Wik, M. (1985) Soot particle counting in recent lake sediments: an indirect counting method. *Ecological Bulletins*, **37**, 53–57.
- Rose, N.L. (1990) A method for the extraction of carbonaceous particles from lake sediment. *Journal of Paleolimnology*, **3**, 45–53.
- Roslavlev, O. (1965) *Das Dorpater Land 1624/27. Hefte zur Landeskunde Estlands*. Wolfratshausen-Waldram, München.
- Rumma, J., Tammekann, A. & Veski, J.V. (1926) *Võrumaa. Maateaduslik, tulunduslik ja ajalooline kirjeldus, Eesti*, Vol. 2. Eesti Kirjanduse Selts, Tartu.
- Sarmaja-Korjonen, K. (1992) Fine-interval pollen and charcoal analyses as tracers of early clearance periods in S Finland. *Acta Botanica Fennica*, **146**, 1–75.
- Simola, H. (1995) Sedimentary records of human occupation in the eastern Finnish Lake District. *PACT*, **41**, 117–123.
- Šmilauer, P. (1994) Exploratory analysis of paleoecological data using the program CanoDraw. *Journal of Paleolimnology*, **12**, 163–196.
- Stockmarr, J. (1971) Tablets with spores used in absolute pollen analysis. *Pollen et Spores*, **13**, 615–621.
- Sugita, S. (1994) Pollen representation of vegetation in Quaternary sediments: theory and method in patchy vegetation. *Journal of Ecology*, **82**, 881–897.
- Sugita, S., Gaillard, M.-J. & Broström, A. (1999) Landscape openness and pollen records: a simulation approach. *The Holocene*, **9**, 409–421.
- Taavitsainen, J.-P., Simola, H. & Grönlund, E. (1998) Cultivation history beyond the periphery: early agriculture in the North European boreal forest. *Journal of World Prehistory*, **12**, 199–253.
- Tarand, A. & Kallaste, T. (eds) (1998) *Country case study on climate change impacts and adaptation assessments in the Republic of Estonia*. SEI, UNEP, Tallinn.
- Verheyen, K., Bossuyt, B., Hermy, M. & Tack, G. (1999) The land use history (1278–1990) of a mixed hardwood forest in western Belgium and its relationship with chemical soil characteristics. *Journal of Biogeography*, **26**, 1115–1128.
- Veski, S. (1998) Vegetation history, human impact and palaeogeography of West Estonia. Pollen analytical studies of lake and bog sediments. *Striae*, **38**, 1–119.
- Zillén, L., Snowball, I., Sandgren, P. & Stanton, T. (2003) Occurrence of varved lake sediment sequences in Värmland, west central Sweden: lake characteristics, varve chronology and AMS radiocarbon dating. *Boreas*, **32**, 612–626.

BIOSKETCHES

Siim Veski and **Anneli Poska** are palaeoecologists at the Tallinn University of Technology, Estonia, with research interests in Quaternary geology, post-glacial vegetation history and prehistoric human impact on landscapes.

Kalev Koppel is an archivist at the Estonian Historical Archives and an MSc student at the Tartu University, Estonia, with special interest in historical maps, documents and agrarian history.

Editor: Robert Whittaker