The last hundred years of land-use history in Estonia as inferred from pollen records

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The pollen composition of the uppermost part of sediments formed during the last hundred years in four lakes located in different landscapes (open agricultural land, forested area, ombrotrophic bog) in Estonia was studied. The pollen of land-use indicator taxa are arranged into three groups: indicators of cultivated land, ruderal communities, and meadow and pasture land. We established clear differences in the pollen proportions of cultivated, ruderal and meadow plants, depending on the intensity of human impact around studied site. The temporal changes of the share of different human impact pollen indicators show especially good correlation with the history of land-use when the changes took place in the immediate vicinity of the lake (Ruusmäe). In those areas close to the actively used arable land the proportion of Cerealia pollen may reach 6%–8% of the total pollen sum. Values of Cerealia pollen of 1%–2% reflect the background values for the region.

Introduction

As shown by many palaeoecological studies, the magnitude of human impact on local and regional vegetation and landscape history has varied greatly in space and time throughout the Holocene, just as it has in the recent past. The causes for these variations include changes in human settlement and land-use patterns, population density, climate, vegetation composition and structure, local or regional hydrology, and soil fertility, as well as socio-economic, demo-graphic, and cultural factors, and the complex but poorly understood interactions between these components (Berglund 1985, 1991).

Much attention has been paid to finding and tracing the first signs of human impact and its increasing intensity by using pollen analysis in different landscapes. Less attention has been paid to checking such reconstruction against historical data. Good results have been obtained in Finland (Vasari & Väänänen 1986, Hicks 1992, 1997), Sweden (Gaillard *et al.* 1992, 1994), Denmark (Odgaard & Rasmussen 1998) and
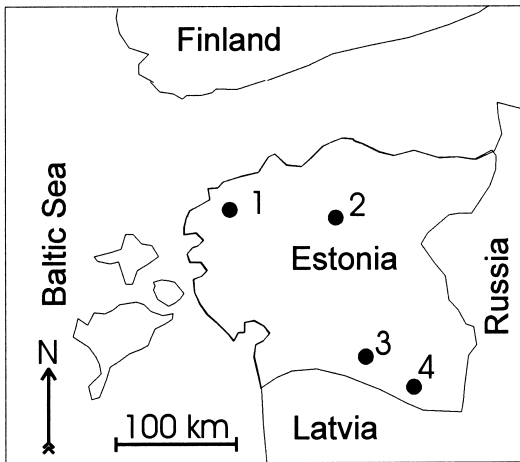
Fig. 1. Location of the study lakes. 1: Mustjärv, 2: Matsimäe, 3: Õdre and 4: Ruusmäe.

Ireland (Huang & O'Connell 2000). Estonia, which has a large number of continuous lake and bog sediment sequences and dramatic changes in land-use over the last hundred years caused by drastic changes in the social and economic system, offers a good opportunity to study the correspondence between the pollen-based reconstructions and historical data. In recent years, there has been increased emphasis on understanding the role of human activity in influencing the Holocene environment in Estonia (Koff 1995, Poska & Saarse 1999, Poska *et al.* 1999). Though the role of human activity in effecting changes over the last hundred years is well documented in historical maps and/or archives, correlation with changes in the composition of pollen spectra and pollen influx in sediments is poorly studied. This type of correlation is needed to reconstruct the processes of land-use history, including recovery after intensive use. An understanding of the relationship between changes in pollen data and the established history of land-use would enable these correlations to be extended to other areas.

An earlier paper (Koff *et al.* 2000) focused on the study of the relationship between arboreal pollen (AP) influx and the character and intensity of disturbances in the pollen catchment area. It was estimated that in the case of small lakes (area 3–6 ha) in a forested landscape, past disturbances can be reliably detected when the dis-

turbance occurred in the immediate vicinity of the lake and at least ca. 25% of the local pollen source area was involved. This paper focuses on the influx of herbaceous pollen (NAP), an indicator of human activity in the immediate surroundings of the lakes. The percentage of NAP in the total pollen assemblage has been considered as an indicator of landscape openness, but assessment data from Europe (Frenzel 1992) and new data from Sweden (Gaillard *et al.* 1998) demonstrate that the relationship between landscape openness and NAP percentages from lake surface sediments is not straightforward. Recent studies have also raised questions about the real limitations of pollen analysis — to what extent are land-use changes traceable in pollen profiles and what is the realistic time resolution of the samples in order to distinguish short-term changes from real trends?

This work focuses on pollen diagrams from lake sediments formed during the last hundred years in different landscape areas of Estonia. The aim is to correlate pollen data with known changes in land use.

Study sites

The uppermost sediments of four lakes (Ruusmäe, Matsimäe, Õdre, and Mustjärv) in four different landscape areas were studied (Fig. 1). Details of these lakes are given in Table 1. The selection of the sites followed the main criteria established by Gaillard *et al.* (1998) for a pilot study in South Sweden.

The selected lakes have approximately the same size (3–5 ha). This is the optimal area for the study of local history in relation to pollen distribution models (Janssen 1973, Jacobson & Bradshaw 1981, Sugita 1994). The lakes are situated in varied landscapes (mixed or coniferous forest, ombrotrophic raised bog, pastures, meadows, and crop fields). The distance to the nearest fields is variable (0.1–8 km). For all sites good historical records of local land-use are available.

The drainage basin of Lake Ruusmäe lies in the Haanja Heights in south-eastern Estonia (Fig. 1 and Table 1) in an area which has been actively used for agricultural purposes for centuries. Geomorphologically the drainage area repre-

sents a moraine plain where podzolic soils dominate. The vegetation around the lake includes mixed forest, arable land mainly used for grassland cultivation, meadows and paludified pasture communities. Near the north-western shore there is a manor house and an old park.

Õdre (Fig. 1 and Table 1) is a lake situated in southern Estonia, in the northern part of the Karula National Park. It is a typical woodland lake, shaped by the mosaic hills (105–110 m a.s.l.) of the Karula Upland. The main vegetation type around the lake is pine forest; birch is growing only on the south-eastern and north-western swampy shores. The nearest agriculturally used area is situated 2 km to the south of the lake.

Matsimäe (Fig. 1 and Table 1) is a typical dystrophic lake situated in central Estonia, which feeds mainly from precipitation and water from a surrounding bog. The lake, almost circular in shape, is surrounded by an open stretch of ombrotrophic raised pine bog. Along the western shore is an esker covered with birch, alder and spruce mixed forest. Within a distance of ca. 10 km from the lake large bogs and swamps unsuitable for agricultural activities predominate and only in the south-western direction are there fields, at a distance of ca. 2 km.

Mustjärv (Fig. 1 and Table 1), a typical dystrophic lake, is situated in the northern part of the West-Estonian lowland in an area of sandy soils and large ombrotrophic raised bogs. Mustjärv has swampy shores, surrounded with pine trees

and birches towards the north and west and with an open mire landscape towards the east. There is historical evidence of forest fires close to the next lake, Tänavjärv, ca. 2.5 km to the north-west. The nearest fields are in a south-eastern direction, at a distance of approximately 8 km.

Methods

Sampling

Sediment samples were obtained through the ice in the winters of 1996 and 1997 using a modified Livingstone–Vallentyne piston corer equipped with an extension rod. The lithology of the sediments was recorded in the field. The sampling was continuous, at 1-cm intervals up to 40 cm and 2-cm intervals at greater depths. Samples were put into plastic bags and kept in a refrigerator until the analyses were made.

Pollen analysis

A measured volume of samples was dried at 105 °C and the water content and density estimated. For pollen analysis 50 mg of dried sample was boiled in 10% KOH and treated with standard acetolysis (Moore & Webb 1978). Three tablets with known content of *Lycopodium* spores (Stockmarr 1971) were added to each sample at the beginning of the laboratory treatment to cal-

Table 1. Characteristics of the study lakes.

Characteristic	Ruusmäe	Õdre	Matsimäe	Mustjärv
Latitude	57°38′N	57°45′ N	59°04′ N	59°10′ N
Longitude	27°05′ E	26°27′ E	25°31′E	23°48′E
Width (m)	150	140	230	270
Area (ha)	4.7	3.0	5.5	4.8
Max depth (m)	11.6	9.1	8.1	2.7
Average sediment accumulation (mm yr^{-1})	0.96	0.21	0.17	0.27
Elevation (m a.s.l.)	223	95	77	19
Length (m)	370	260	340	300
Catchment area (km^2)	0.22	0.92	1.53	
Catchment characteristic	Farms, agricultural land	Pine forest	Ombrotrophic raised bog, reforested quarry	Ombrotrophic raised bog
Distance to the nearest field (km)	0.1	2	2	8

culate pollen concentration. In general, at least 500 AP grains were determined and counted under the microscope. The pollen diagrams were made using the TILIA program (Grimm 1990). Percentage pollen diagrams are based on total terrestrial pollen, i.e. the sum of AP and NAP. The pollen influx values (grains cm^2 yr^{-1}) were calculated using the concentration data transferred from the dried matter to the volume of the sample and the reconstructed timescale. The land-use indicator taxa were grouped into three main categories following Behre (1981), Berglund (1991), Berglund and Ralska-Jasiewiczowa (1986), and Koff (1995):

I. Pollen indicating arable land, consisting of pollen of cultivated plants such as *Cerealia*, *Secale cereale* and *Zea mays* and the weed *Centaurea cyanus*.
II. Ruderal communities including Chenopodiaceae, *Artemisia*, *Plantago major/media*, *Urtica* and *Rumex acetosa/acetosella* type pollen.
III. Pasture land and meadow indicators containing Cyperaceae, Gramineae, Caryophyl-

laceae, Compositae (Asteraceae + Cichoriaceae), Apiaceae, Ranunculaceae, Fabaceae, *Trifolium*, Rosaceae, *Melampyrum*, *Galium* type and *Saxifraga* pollen.

Pollen and spore nomenclature follows that of Moore *et al*. (1991).
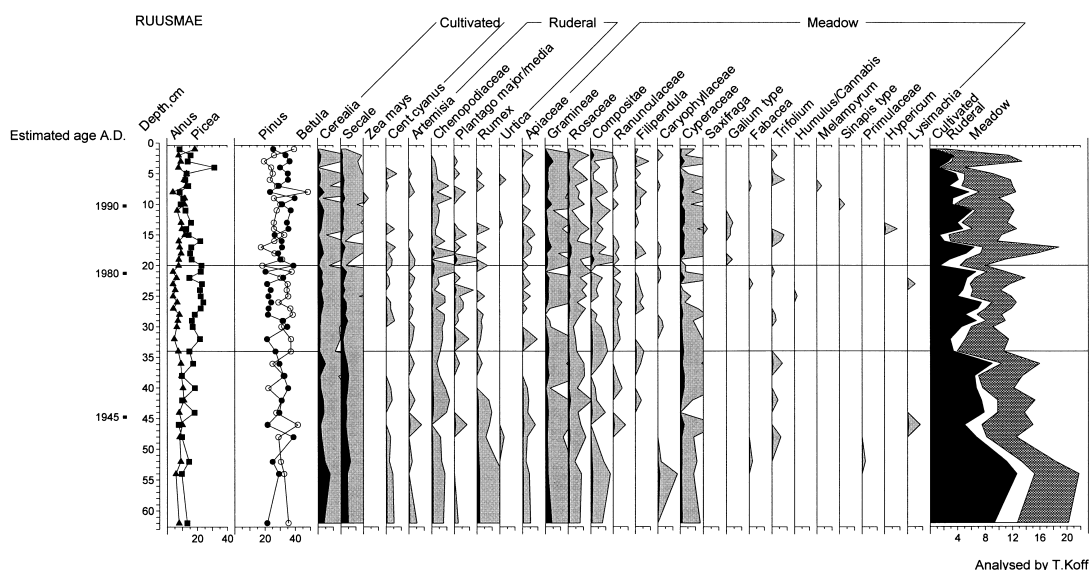
Results

Sediment stratigraphy

The upper part (up to 60 cm) of the sediments in Ruusmäe is blackish-grey homogeneous gyttja with a water content of 95%–97% in the surface sediment, decreasing downwards to 86% at a depth of 64 cm. In lakes Matsimäe, Õdre and Mustjärv the sediment sequence studied consists of dark brown homogeneous gyttja with a water content of 95%–98%.

The content of dry matter was the lowest in the core from Õdre where it varied from 0.01 g cm^{-3} at the surface up to 0.03 g cm^{-3} at a depth of 18 cm and then increased rapidly. The

Table 2. The main historically documented events of land-use changes in the surroundings of the investigated lakes.

Time, AD	Ruusmäe	Õdre	Matsimäe	Mustjärv[1]
2000	Small-scale farming in		The esker was excavated	
1995	the catchment.		as a gravel quarry and	1997
1990		National Park was	pine was planted. A	1992
1985	———————	established and clear-	swimming pool was built	
1980	Extensive cattle	cutting ceased.	in the lake, at the end of	1980
1975	breeding since 1970s,		the 1950s.	
1970	centre of the collective			
1965	farm 1948–1990.	———————		
1960		Young pine forest		
1955		indicating that just prior to		1952
1950		this large areas of the	Fields of size ca. 20 ha on	
1945	———————	forest have been cut down.	esker at a distance of 0.2	
1940	Small-scale farming in	Mature pine forest around	km from the western	
1935	the catchment.	the lake.	shore were cultivated	
1930			since World War II.	
1925				
1920				
1915				
1910				
1905		Probably field around the		
1900		lake.		

[1] Years of forest fires at a distance of more than 2.5 km from lake.

Fig. 2. Pollen percentages diagram for Ruusmäe divided into three zones. The estimated age on the left show the documented events what evidences in the lithological and geochemical records (Punning *et al.* 1999).

dry matter content records from lakes Matsimäe and Mustjärv are quite similar: 0.02–0.04 g cm^{-3} in the uppermost 5 cm and fluctuations between 0.05 and 0.06 in the lowermost part. The top 5 cm of the lake deposits in all lakes is a loose flocculent layer.

Chronology

Various methods were used for age estimation. The core from Matsimäe was dated in the most detailed way. Here we applied the ^{210}Pb method with the layers with maximum ^{137}Cs (ref. yr. 1986) (Punning *et al.* 2000) as a reference level. Considering the history of high temperature combustion of fossil fuels in Europe, the sediment layers with a significant increase in the concentration of spherical fly-ash particles must have accumulated at the end of the 1940s. The age of individual layers and the deposition rate were calculated on the basis of the mean annual sedimentation rate between the reference layer and the sediment surface, using the measured dry matter content in individual layers (Punning & Alliksaar 2000). For the lakes Õdre and Mustjärv we used the same approach together with other reference level, such as changes in lithology and their correlation with historical data (Koff

et al. 2000). For Ruusmäe the age-depth scale was compiled using historical data and reference levels obtained through ^{137}Cs analyses and the intensive load of nutrients which is seen in the C/N and P records (Punning *et al.* 1999). According to these combined data the mean accumulation rate in the different lakes varies from 0.17 mm yr^{-1} in Matsimäe to 0.96 mm yr^{-1} in Ruusmäe (Table 1).

Historical data

Using old maps, archived documents and interviews with local people, the main events that have happened in the catchment area of the lakes which might have an impact on pollen sources were constructed (Table 2).

Pollen data

In Ruusmäe (Fig. 2) the percentage values of *Pinus* and *Betula* pollen vary between 20% and 40% throughout the whole of the sediment sequence. The *Picea* pollen content is rather stable around 10%, and the values for *Alnus* fluctuate. NAP forms a maximum of 20% of the total terrestrial pollen. On the basis of the pollen
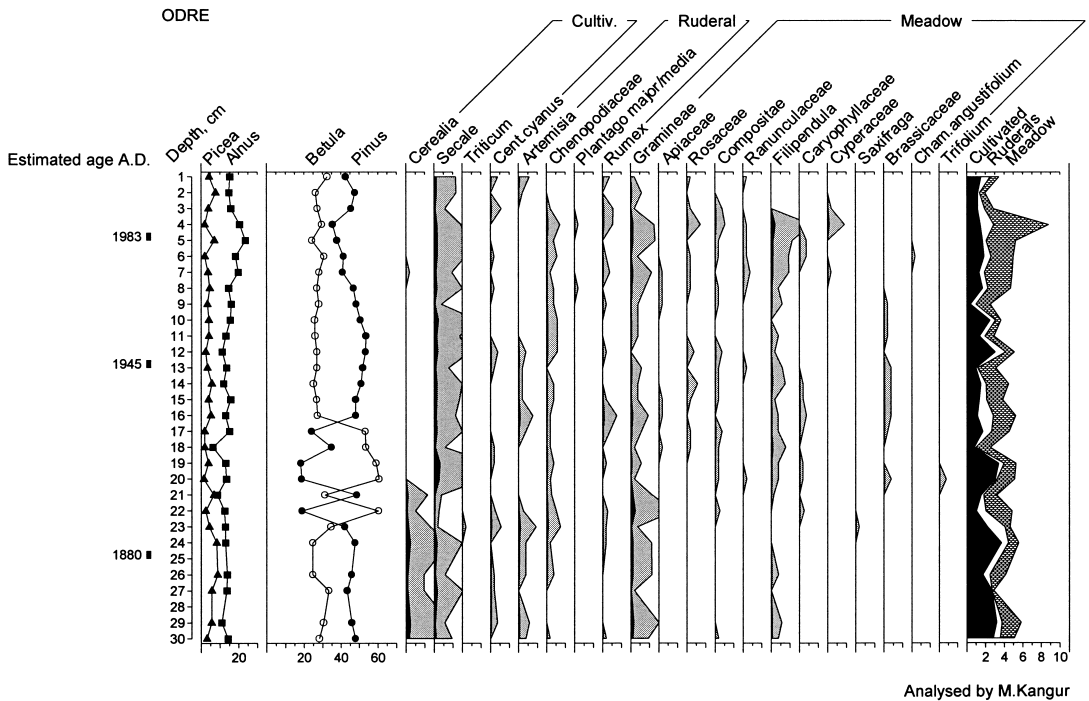
Fig. 3. Pollen percentages diagram for Õdre. The years on the left have been obtained by use of SFAP (Koff *et al.* 2000).

assemblages the sediment sequence can be separated into three zones: 62–34 cm, 34–20 cm and the upper 20 cm. In the lower zone the sum of pollen of cultivated plants has its highest value. Here Cerealia (in most cases *Hordeum* type) and *Secale cereale* pollen are represented by the highest values (up to 6%). Also pollen of meadow plants have high values, especially Gramineae, Compositae, and Caryophyllaceae. The zone between 34 and 20 cm is characterized by lower and fluctuating values of the pollen indicating cultivated land. Remarkable is a decrease in Cerealia and *Secale*. Pollen from the meadow group was found at low values and rather uniformly in this zone. The ruderals such as Chenopodiaceae and *Plantago major/media* became more abundant from 34 cm upwards, too. The curve of the meadow group decreased to low values at 28–30 cm, mainly due to a decrease in Cyperaceae and Gramineae. In the upper zone, from 20 cm upwards, Cerelia and *Secale* pollen values fluctuate between 2% and 4%. The single pollen grain of *Zea mays* at a depth of 9 cm is noteworthy because it is most probably the first such found in Estonian lake

sediments. From the meadow group Cyperaceae, Gramineae and Compositae are present continuously and the pollen sum of the whole meadow group tends to increase. Between 20 and 15 cm ruderals such as Chenopodiaceae, *Plantago* and *Rumex* have high values.

The pollen diagram for Õdre (Fig. 3) demonstrates rather stable values for *Picea* (around 10%) and *Alnus* (around 20%). For *Pinus* and *Betula* marked changes occur between 23 and 16 cm indicating essential changes in the forest composition around the lake. The percentage of NAP is very stable at around 5% without noticeable changes, with the exception of the depth of 5 cm where NAP increases up to 9%. Pollen of *Secale* is present through at rather low percentages (1%–2%). Cerealia pollen is present only in the lower part up to 21 cm. Meadow communities increase from a depth of 9 cm reaching maximum values at a depth of 4 cm.

With reference to the percentage values of the main tree pollen types the pollen diagram for Matsimäe (Fig. 4) shows low values for *Picea* (up to 10%) and a little higher for *Alnus* (10%–20%). *Pinus* pollen is dominant (up to 60%),
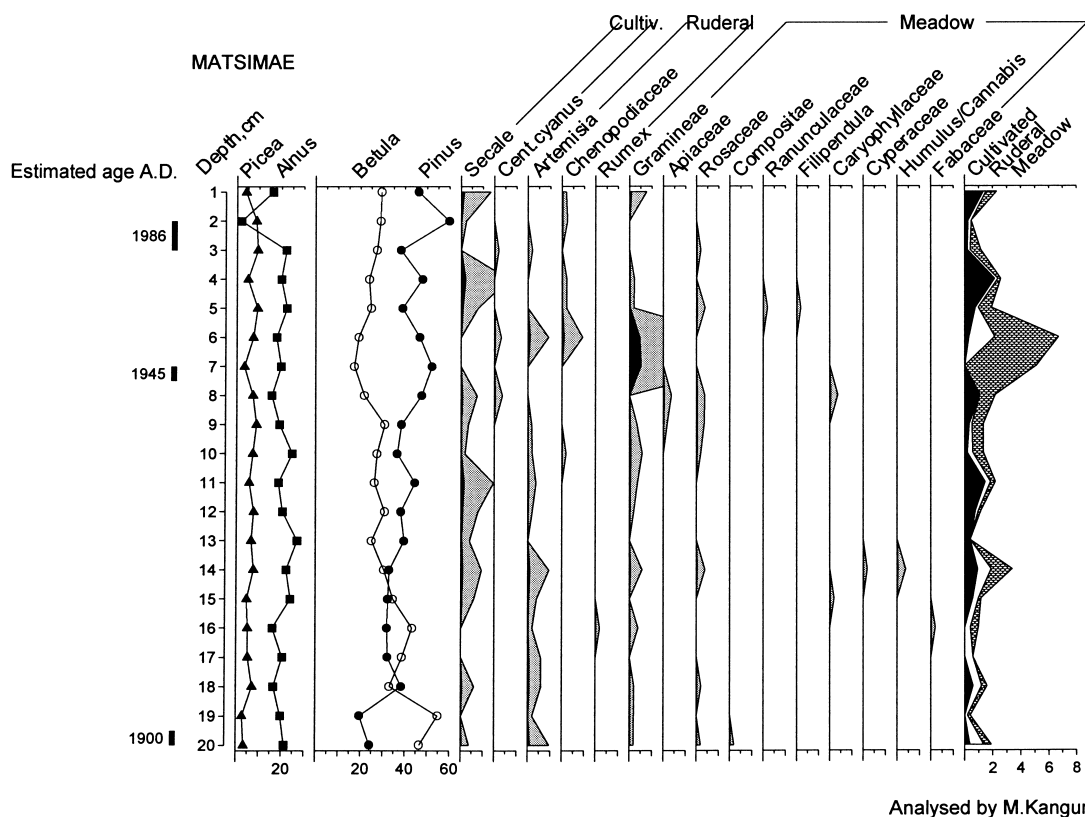
Fig. 4. Pollen percentages diagram for Matsimäe. The years on the left are estimated by use of ^{210}Pb, ^{137}Cs and SFAP methods (Punning *et al.* 2000).

being followed by that of *Betula* with higher percentages in the lower part of the core and a tendency to decrease in the upper part. Through the whole sequence NAP is smaller than 5%, with the exception of the interval from 7 to 5 cm where there is an increase up to 10%, primarily due to an increase in the Gramineae pollen and the presence of *Artemisia*, Chenopodiaceae and *Calluna* type pollen. This increase in NAP is at the same level as the decrease in *Betula* pollen.

The same proportions of the main pollen types can also be seen in the sediments of Must-järv (Fig. 5). The dominating pollen type is *Pinus*, which increases significantly in the upper 6 cm, where it comprises up to 60%, while that of *Betula* decreases by an equivalent amount. *Picea* is very stable with low values: smaller than 10%, and *Alnus* smaller than 20%. The percentage of NAP is around 5% without marked fluctuations, throughout the whole sequence. The main pollen types are Ericaceae and *Calluna*, which are

typical of bog vegetation, and also Gramineae. At the same time some pollen types character-istic of agricultural activities, such as Cerealia, Chenopodiaceae, *Rumex*, *Centaurea cyanus* and *Plantago* are present in low values.

As seen from the pollen diagrams the sequence with the richest NAP diversity is Ruus-mäe where 27 different pollen taxa were found. In Matsimäe this number is 15, Mustjärv 17 and in Õdre 20. Also the percentages of total NAP and the different indicator taxa are highest in the Ruusmäe diagram.

Discussion

On the basis of the present day situation and the historical data about land use around the lakes under investigation during the last century we can distinguish three different intensities of human impact:
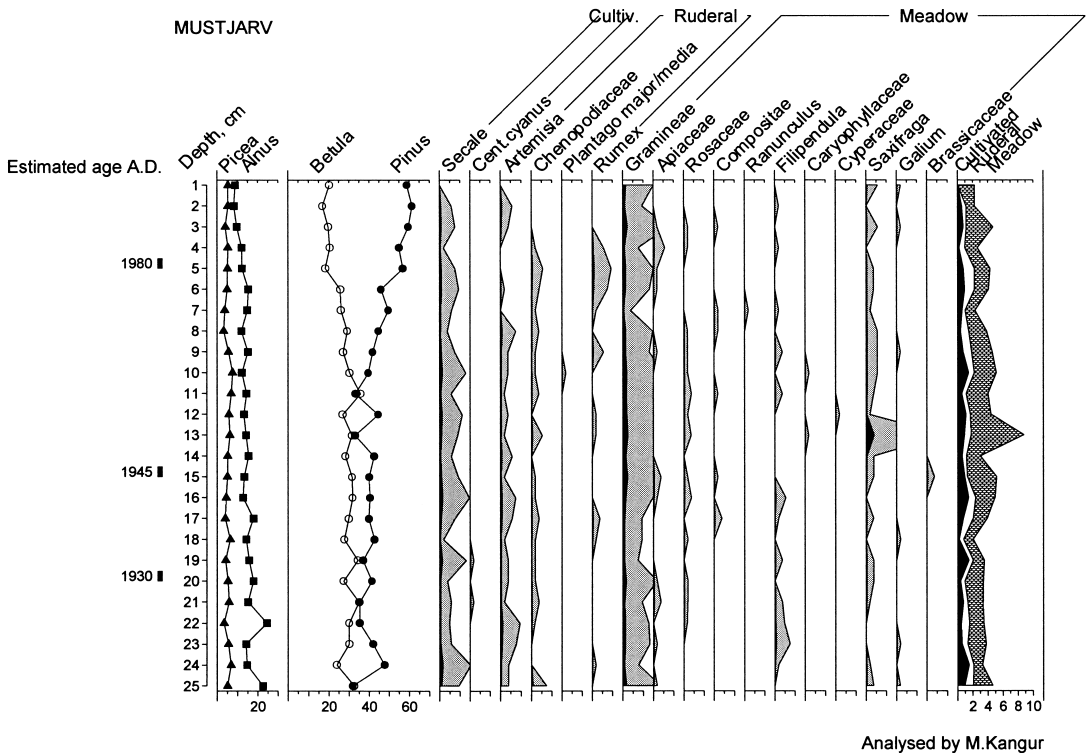
Fig. 5. Pollen percentages diagram for Mustjärv. The years on the left have been obtained by use of SFAP (Koff *et al.* 2000).

I.   Intensive human impact (agriculturally used, partly open area in the immediate vicinity of the lake, a settlement, cattle breeding and cattle sheds in the catchment): Ruusmäe.

II. Low human impact (forest lakes, a small farm or fields within around 2 km): Matsimäe, Õdre.

III. No direct human impact (lakes in an open raised bog, the distance to the nearest settlement about 7–8 km): Mustjärv.

As has already been established by Broström *et al.* (1998), despite the large variation in landscape composition between sites, the variation in the composition of pollen assemblages is rather small. The authors explained these low variations and particularly the low NAP percentages by more substantial input of regional AP due to the dominance of high pollen producing taxa such as *Betula* and *Pinus* in the regional pollen source area. Our data confirm that conclusion. In the case of Ruusmäe where the forested area in the catchment of the lake is only 20% at present

the AP percentage is 78% of the total pollen sum.

The relevant source area, is defined by Sugita (1994, 1998) as the area beyond which the correlation between pollen loading and distance-weighted plant abundance does not improve. In the boreal forests of Canada Sugita showed by means of a simulation model that, for a medium sized lake (250-m radius), the relevant pollen source area is 600–800 m from the shore. Broström *et al.* (1998) estimated for the open agricultural region of southern Sweden (defined as landscape unit *Open* i.e. open grassland other than cultivated fields with a tree cover not exceeding 20%) that a 1000-m radius area is close to the relevant source area pollen reconstruction and prediction of the area of open grassland. The main changes during the last fifty years in the catchment of Ruusmäe — similar to open agricultural area in sense of Broström *et al.* (1998) — were the increase in land area under various buildings such as dwelling houses, store houses, cowhouses etc. (Fig. 6). The dif-

Fig. 6. Land-use around Ruusmäe (Lake R) for the periods up to 1948 (**A**) and 1979–1998 (**B**). The maps were compiled on the basis of topographic maps from 1948, 1979 and 1996 (Punning *et al.* 1999).
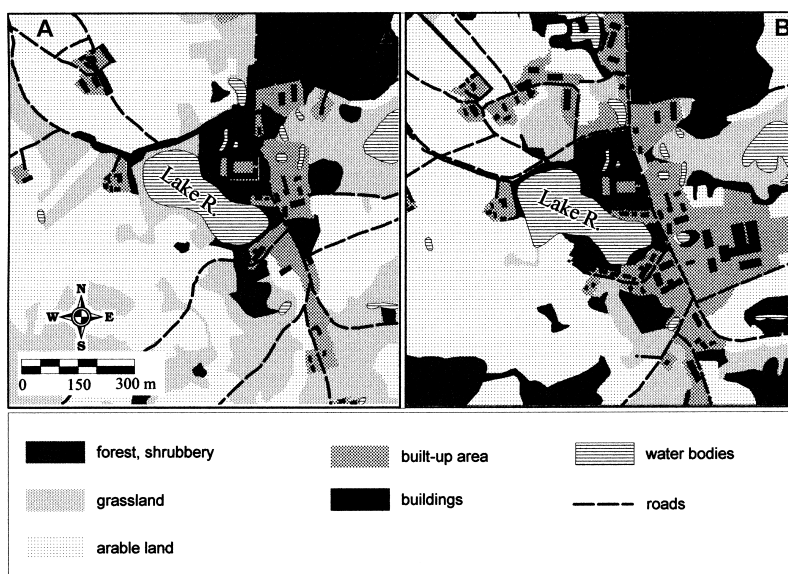
ference in the area covered by such buildings between the years 1948 and 1978 is more than double (Punning *et al.* 1999). The transition from private farming to extensive collective farms required many improvements and beside small-size fields a big area of cultivated land was created. The latter was mainly used for cultivated grassland (Fig. 6).

The pollen diagram of Ruusmäe differs greatly from the others presented in this paper. Here the proportion of NAP pollen is 5–10 times higher than in the other lakes studied where the shores are mainly paludified (Matsimäe and Mustjärv) or covered by mature forest (Õdre).

The sharp decrease in the pollen of cultivated plants (Fig. 2) from a depth of ca. 45 cm is in good temporal correlation with the period when private farms were destroyed and the farmers deported to Siberia. The subsequent intensive development of the economic and administrative centre of a collective farm on the lake shore started. The intensification of cattle breeding and related activities, which culminated in the 1980s (depth ca. 20 cm), is recorded in the pollen diagram as a period with a decrease in the proportion of pollen of cultivated plants and a slight increase the pollen of meadow species. Of the ruderals the pollen type connected with human influence is *Plantago media/major*. There is a certain increase and more regular representation

of this type of pollen beginning from 34 cm. The increase in Chenopodiaceae pollen could also be connected with the existence of big collective farms. The maximum of that pollen is between 21 and 18 cm.

A clear record of the changes in land-use can be seen in the pollen diagram for Matsimäe. Near this lake, surrounded by ombrotrophic raised mires, fields occurred only on top of an esker with an area of no more than 17 ha. The esker was excavated at the end of the 1950s and a swimming pool was established in the lake. The latter event is also recorded in the lithological composition of sediments at a depth of 6–9 cm as an increase in the content of mineral matter. In the pollen diagram (Fig. 4) a sharp increase in the pollen of meadow plants is clearly visible at this depth. The increase in Gramineae was a result of extensive gravel excavation and recreational activity on the western shore of the lake. The proportion of pollen of cultivated plants, mainly *Secale*, is variable. Since this pollen type did not decrease markedly following the end of agricultural activity, due to excavating the esker, it can be assumed that *Secale* pollen is transported to the lake from the fields outside the surrounding mire at a distance of over 2 km.

In the sediments of Õdre, surrounded by forest, the content of NAP is quite constant. In the lower part of the section studied, up to a depth

of 20 cm pollen of Cerealia is present. It is known that around 1870 the land from the forested areas was sold for peasants to make new fields. Today there are no traces of these fields and the distance to the nearest permanently used fields is about 2 km. The share of ruderal plant pollen is low, pollen of meadow plants reached its maximum at a depth of 4 cm. The cyclical changes in the proportion of pollen of meadow plants may be caused by changes in the littoral area of the lake, due to periodic water level fluctuations that is confirmed by different size of the lake on the maps from different periods. During the high lake-level periods the northern shore was flooded and the growth of the birches stopped there. The dead trees can still be seen at the present day. On the forest maps from 1950 to 1980 of clear-cut plots with an area ca. 3–5 ha are shown. As their area in comparison with the total pollen source area is relatively small we can not see any reflection of this in the pollen diagrams.

The lowest proportions of all the human indicator pollen types are in the diagram of the Mustjärv core. This lake is situated far from settlements and fields and the pollen of human indicators are mainly transported over long distances. Therefore the pollen distribution curves of the different species are smoothed without marked changes. The most remarkable events in this area are repeated forest fires in the pine forest at a distance of 2.5 km and more. Some of these fires covered areas of 2000 ha (Koff *et al.* 2000). The effect of them on the pollen content of AP or NAP is not clear.

Our data demonstrate that it is hard to find correlations between the AP assemblages and disturbances that occurred nearby (Koff *et al.* 2000). A better correlation is seen between the abundance of different land-use indicator pollen taxa and the geographical situation of the lake being investigated and its land-use history. Naturally the most reliable and direct indicators of human impact are the pollen of cultivated plants. So in all four pollen diagrams *Secale* pollen was found. Vuorela (1973) studied the variation in pollen rain in the vicinity of an agricultural area surrounded by forest and her principal conclusion was of the pollen filtering action of the forest. *Secale* as a wind pollinated crop has a higher pollen production and

better dispersal possibilities than other cereals. If the pollen of *Secale* is well dispersed and is found in peatbogs and lake sediments far away from cultivated areas, then its frequencies must represent regional background values. Thus in this investigation the *Secale* frequencies in the Mustjärv pollen diagram reflects the regional background, which has to be taken into account in interpreting the diagrams. This means that pollen of *Secale* can come from larger areas than the relevant pollen source area. It is important to keep in mind that every pollen type has its own relevant pollen source area. Pollen of other types of Cerealia, such as *Hordeum*, are distributed more close to their source.

The spatial–temporal analysis of the distribution of pollen indicating cultivated land shows, that in the case of the Estonian mosaic boreal landscape, the areas with intensive agriculture are characterised by the presence of Cerealia (both Cerealia and *Secale* in sum) pollen from 4% to 8%; areas with moderately intensive agriculture have from 2% to 3% Cerealia pollen. Less than 2% Cerealia pollen represents the regional background frequency. These data are of essential importance for the study of the history of land-use and settlement.

Pollen deposition data monitored for three years with Tauber traps (Koff 2001) in different areas throughout Estonia show that the distribution and influx values of Cerealia pollen correlate well with the distance from the nearest crop, thus making it possible to estimate the closeness of the nearest field. We can distinguish the following three groups:

I. Traps containing more than 1000 grains cm^2 yr^{-1} Cerealia pollen — sites directly affected by agricultural activities;
II. Traps where Cerealia influx is 200–1000 grains cm^2 yr^{-1} — sites where the nearest fields are situated at a distance of 1–2 km;
III. Influx of Cerealia pollen less than 200 grains cm^2 yr^{-1} — sites lying far away (> 10 km) from fields.

Figure 7 shows the Cerealia pollen influx values against the distance from the nearest field to the Tauber trap. It is quite obvious that in the case of very short distances (up to 0.5 km) the

correlation between the Cerealia influx and the distance from the nearest field is relatively good. From 6 km the correlation seems to reach an asymptote, i.e. the pollen composition reflects the regional background and is not informative for any specific area around the lake. In the case of distances of 1–3 km from the field to the pollen trap, the pollen influx values are very variable and are greatly determined by the wind direction and weather conditions during pollination. The figure also illustrates the average Cerealia pollen influx values for the period 1970–1990 obtained from the lake sediments under investigation. The highest values are for Ruusmäe (1000–4000 pollen grains cm^2 yr^{-1}) and the lowest (50–350 grains cm^2 yr^{-1}) for Mustjärv. In lakes Õdre and Matsimäe the influx values are between 100 and 350 grains cm^2 yr^{-1}. These data are in good accordance with the distribution of modern Cerealia pollen monitored by the Tauber traps.

Conclusions

The pollen diagrams from sites where human impact is intensive are characterised by a higher variability in pollen types than those from the sites where human impact is weak. The AP proportion in the total pollen sum did not vary significantly, being around 80% even when the percentage of the forested area around the lake within the radius of 1 km was only 20%–22%. The NAP proportion varies from 1%–8% in the sites from forested areas (lakes Matsimäe, Õdre, Mustjärv) but is up to 20% in the open agriculturally used areas (Ruusmäe). The latter is also characterised by a higher diversity of different NAP types than those from the sites where human impact is weak.

We observed clearly expressed differences in the pollen proportions of cultivated, ruderal and meadow plants, which depend on the intensity of human impact and geographical location. The variation in cultivated plants is especially sensitive. The temporal changes of the share of different human impact pollen indicators show especially good correlation with the history of land-use when the changes took place in the immediate vicinity of the lake (Ruusmäe).
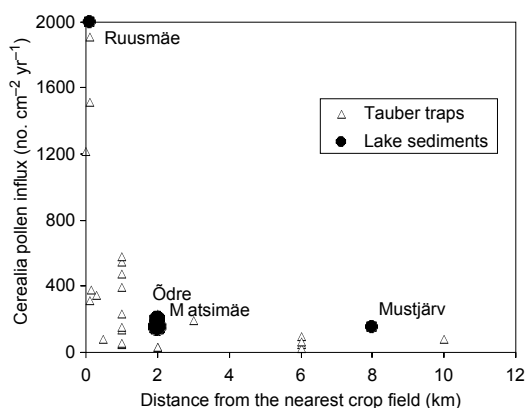
Fig. 7. Cerealia pollen influx into Tauber traps plotted against the distance from fields (triangles). The average values of Cerealia pollen influx to the sediments of lakes Mustjärv, Matsimäe, Õdre and Ruusmäe (filled circles) for the period 1970–1990 are also given.

Values of Cerealia pollen of 1%–2% reflect the background values for the region. In those areas close to the actively used arable land the proportion of Cerealia pollen may reach 6%–8% of the total pollen sum.

Data on Cerealia pollen influx obtained from the lake sediments investigated agree with data from traps monitoring modern pollen deposition. Influx values of more than 1000 grains cm^2 yr^{-1} of Cerealia pollen correlate well with agricultural activities in the vicinity of the pollen trap.

Acknowledgements

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