

# History of agriculture in Mikkeli Orijärvi, eastern Finland as reflected by palynological and archaeological data

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Received: 21 April 2006 / Accepted: 13 November 2006 / Published online: 8 March 2007  
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**Abstract** The introduction and development of cultivation in eastern Finland was studied by pollen and charcoal analysis of a palaeomagnetically dated sediment profile from Lake Orijärvi, in the vicinity of permanent prehistoric fields. The earliest changes of possibly anthropogenic origin are visible in the pollen data from 1630 B.C. onwards and indications of human impact become more evident from 500 B.C. onwards. According to finds of cereal pollen and AMS-dating of charred cereal grains from the oldest field layer, the onset of cultivation can be dated to the Merovingian period around A.D. 600. To a significant extent the pollen data reflect only the cultivation of *Secale* during the first 600 years. The marked intensification of agricultural activities including cultivation in permanent fields only becomes evident in the pollen data from about A.D. 1050 to 1080 onwards and the most intensive land use phase dates to A.D. 1300–1965. Archaeological and palaeoecological material indicate that swidden cultivation and permanent field cultivation were in use simultaneously during the late Iron Age. The combination of these techniques together with animal husbandry and hunting formed a subsistence strategy in the climatic border-zone outside the centres of the agricultural core areas.

**Keywords** Pollen · Palaeomagnetic dating · Iron Age · Prehistoric fields · Swidden cultivation · Permanent field cultivation

## Introduction

Lake Orijärvi (27°14'E, 61°40'N) is located in eastern Finland in the province of South Savo, ca. 4 km from the centre of the city of Mikkeli. An Iron Age dwelling site, which was later named Orijärvi Kihlinpelto, was found by local amateur archaeologists on the northern side of the lake in 1998. Initially, an Ottonian silver coin minted in Cologne (Mikkola and Talvio 2000) was found in the vicinity of the Kihli farmhouse, ca. 300 m from the lake, on a terrace-like platform that lies ca. 12 m above the present water level of the lake (Fig. 1). The landscape of the area, which has changed dramatically in recent years due to local development events, consisted of the farm, surrounded by a relatively large and open field sloping slightly (<5%) towards the south and west, with hilly woodland areas in the east and north.

In 1999 a trial excavation was carried out at the site. Further excavations were subsequently carried out by the National Board of Antiquities in 2000, 2002, 2003 and 2005. In these rescue excavations over 260 features and structures including five ancient fields have been found. The fields (Fig. 2) form two separate larger units, the Karilantie field complex and the Peltorannantie field complex. The former, which has been fully excavated, consists of three adjacent fields dating to the middle and late Iron Age and early Middle Ages (ca. A.D. 600–1200). The fields formed a single unit during the early Middle Ages. The latter complex consists of two adjacent fields that have been only partially excavated. Peltorannantie

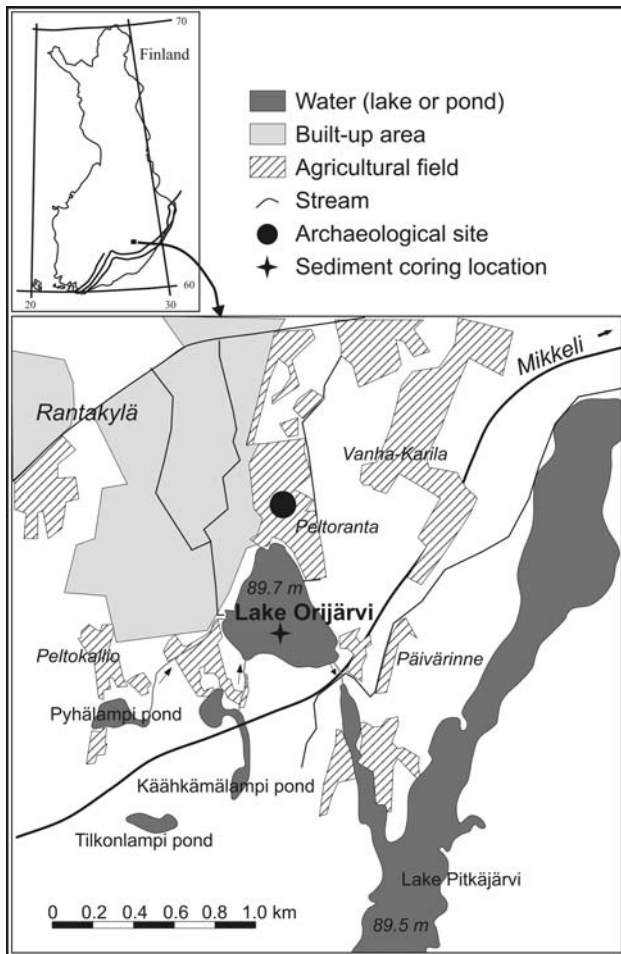
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Communicated by B. Aaby.

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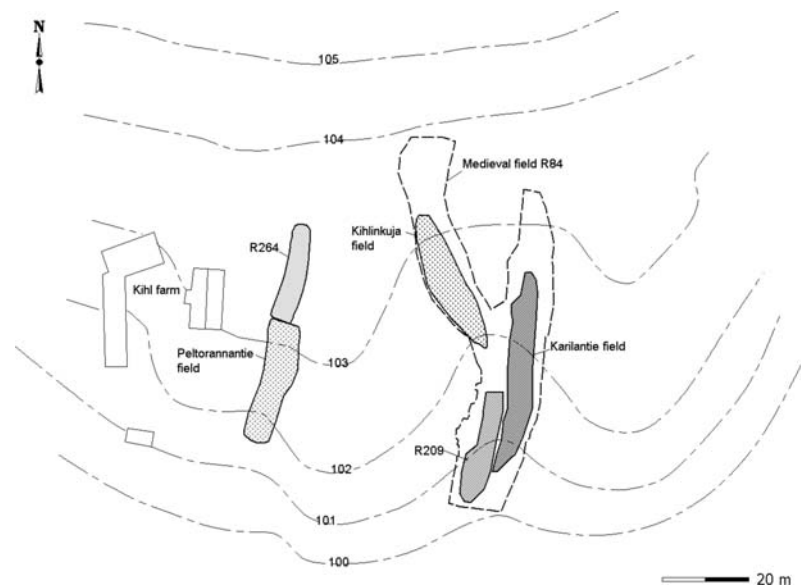
**Fig. 1** Location of Lake Orijärvi in Mikkelä, south-eastern Finland. The coring site is marked with a cross

fields formed a single unit from the Viking Age (ca. A.D. 1000) onwards. All the fields are morphologically similar, despite the differences in size; they are narrow and contain long patches of discoloured fine sand beneath the modern plough layer. The stratigraphy of the fields is quite distinct, which may well be the result of some form of crop rotation with periods of fallow and pasture, together with soil erosion. The sizes of these layers, which are approximately 5–20 cm thick, vary from 110 to 1,340 m<sup>2</sup>. The cultivated area in the 13th century was ca. 1,600 m<sup>2</sup>. During the ninth century the fields covered an area of ca. 1,000 m<sup>2</sup>. The oldest field was only ca. 200 m<sup>2</sup>.

Evidence of prehistoric arable cultivation in the form of fields has previously been found in the western and southern parts of Finland (e.g. from Yläne Kappelniitty, Turku Käsämäki, Kaarina Kirkkomäki, Malax Kalaschabrännan, Hartola Joenrantapelto) and at various locations on the Åland Islands. Only parts of these fields have been excavated and their dating is essentially based on stratigraphical and typological observations. However, in the late 1980s a field similar to the Kihlinpelto fields dating to the middle and late Iron Age was fully excavated on the slopes of the hillfort of Rapola in Sääksmäki (Vikkula et al. 1994). A diagnostic feature of this field type is a pattern of crossing ard marks, which is usually most discernible at the interface of the sterile subsoil and the darker ancient cultivation layer. Separate ard marks have been documented in various places in connection with excavations (cf. Roeck Hansen and Nissinaho 1995; Palo 2001).

On the basis of archaeological material alone it is impossible to determine the exact date for the introduction of cultivation at the Orijärvi Kihlinpelto site. In order to

**Fig. 2** The permanent fields and the Kihli farm at the Orijärvi Kihlinpelto site



shed light on the early stages of cultivation in the Orijärvi area, a detailed and high resolution pollen and charcoal diagram providing a continuum of vegetation dynamics over the past 9,000 years was constructed from the sediment sequence from Lake Orijärvi, situated about 700 m from the ancient fields of Kihlinpelto.

Therefore the main goal of this paper is to present an analysis of the vegetation history in the Orijärvi area and thereby investigate the introduction and development of cultivation at the Kihlinpelto site, where the temporal emphasis is on the middle Iron Age and the Early Middle Ages (ca. A.D. 600–1300). Another important study question concerns the relationship between swidden cultivation and permanent field cultivation. The finding of the Kihlinpelto site has already challenged former views on the predominance of swidden cultivation in the eastern parts of Scandinavia. According to historical records, slash-and-burn cultivation remained the major method of cereal crop cultivation in eastern Finland until the late 19th century (Heikinheimo 1915; Soininen 1974).

## Material and methods

### Geology of the area

Salpauselkä I and Salpauselkä II, stretching more than 600 km across southern parts of Finland, characterise its Quaternary geology. These ice-marginal formations exist because of the re-advance of the continental ice sheet during the Younger Dryas between 12,250 and 11,590 years ago (Saarnisto and Saarinen 2001). The continental ice sheet started to retreat north-westward from Salpauselkä II at around 11,590 years ago, more or less coincidentally with the drainage of the Baltic Ice Lake to the level of the Atlantic Ocean through the opening of the Billingen gate in southern Sweden. According to Sauramo's (1923, 1929) varved clay chronology, the deglaciation of the Mikkeli area took place ca. 100 varve years after the drainage of the Baltic Ice Lake, during the Yoldia Sea phase of the Baltic basin (Sauramo 1923; Björck 1995). At that time, the highest shore of the Yoldia Sea in the Mikkeli area was about 110 m above the present day sea level (a.s.l.) (Saarnisto 1970). The emergence of the deglaciated terrain proceeded rapidly and the Yoldia Sea and the succeeding Ancylus Lake stages were regressive in eastern Finland. As a result, Lake Orijärvi (89.7 m a.s.l.) became isolated from the Baltic basin at around 8600 B.C. Lake Orijärvi remained isolated during the following thousands of years, until transgressive waters of the Lake Saimaa complex (Suursaimaa) reached it at around 4500 B.C. (Saarnisto 1970). Lake Orijärvi was then a part of the Lake Saimaa complex for a few centuries and

was isolated again just before the waters of Suursaimaa broke through Vuoksenniska, forming the River Vuoksi (Saarnisto 1970). The Kihlinpelto site emerged from the Baltic basin some centuries before Lake Orijärvi (28.8 ha) took shape, and the site was not reached later by the transgression of Lake Suursaimaa.

The Quaternary geology of the study area is dominated by the Mikkeli esker formation running through Mikkeli in a north–south direction ca. 3 km east of Lake Orijärvi. It is a typical glaciofluvial esker in Finland, being composed of water-sorted gravel and sand, which was deposited during the retreat of the continental ice sheet. The area around Lake Orijärvi consists of jagged bedrock outcrops, composed mainly of mica gneiss and veined gneiss (Simonen and Niemelä 1980), sometimes overlain by a thin till layer (Haavisto-Hyvärinen and Rainio 1991). The highest points of the bedrock reach over 140 m a.s.l. There is a well-pronounced flat area of littoral sands 3 km north of Lake Orijärvi, which was formed at the level of the Baltic basin prior to the isolation of the lake. The Kihlinpelto site actually lies on the southern extension of this littoral formation. The lowest-lying south-western corner of Lake Orijärvi consists of fine-grained silt deposits. This mineral material has been gradually eroded and transported into Lake Orijärvi by small streams running from the ponds Pyhälampi and Käähkämälampi during the last ca. 10,000 years.

### Archaeological data, macrofossil analysis and the $^{14}\text{C}$ dates

The remarkable archaeological material found at the Kihlinpelto site includes 140 silver coins or coin fragments dating to the tenth and early 11th century A.D. (Mikkola and Talvio 2000), bronze ornaments, iron artifacts, glass-paste beads, two mill stone fragments and ceramics. Of the artifact material that can be typologically dated, nearly all dates to the Viking age and the Crusade period (A.D. 800–1200). Interestingly, the majority of the finds have been from the ancient cultivation layers. Pottery, daub and fragments of clay disks used as loom weights are among the most common find categories. The amount of dwelling-site material in the fields may well be the result of manuring of the fields with household waste. However, another plausible explanation may be found in the practice of taking the location of a destroyed dwelling into cultivation by integrating it into an adjacent field. There are especially high concentrations of daub on the fringes of the fields, which could indicate that such a practice did exist.

It is worth noting that no typologically datable artifacts or ornaments have been found in the oldest layers. The extreme rarity of metal artifacts, combined with problems

related to the dating of settlement sites on the basis of pottery typology alone, may well explain the apparent sparseness of settlement in eastern Finland between the fifth and seventh centuries A.D. Therefore the dating of the beginning of the settlement and permanent cultivation at the site, which has great socio-economical significance, must be approached by other methods. Thus, an extensive macrofossil sampling programme has been carried out at the site. Even though the samples taken in 2003 and 2005 remain unanalysed, as many as 87 specimens of *Cerealia* grains have been found. Of these, 57 are of *Hordeum vulgare*, 3 of *Secale cereale* and 3 of *Avena sativa* (or *Festuca pratensis*). Only one charred grain of *Triticum compactum* has been identified. Radiocarbon dates have been obtained from five charred grains (Table 1). Hela-592 dates a grain of barley that was found in the lowermost layer of the Karilantie field. Three grains of barley and one of *T. compactum*, the subject of dates Hela-593, Hela-594, Hela-595 and Hela-596, were found in the Peltorannantie field. Notably, the oldest date was derived from a grain of *Hordeum* from the Karilantie field. Interestingly, in the same context there were also two grains of *Secale*. The conversion from radiocarbon ages to calendar years shown in Table 1 was performed using the radiocarbon calibration program CALIB version 5.0 (Stuiver and Reimer 1993) with the IntCal04 calibration dataset (Reimer et al. 2004). Calibrated age ranges are rounded to the nearest 10 years.

#### Coring, sediment stratigraphy and dating

Sedimentological methods used in this work include detailed sediment description, measurements of loss on ignition (LOI) and magnetic susceptibility, and palaeomagnetic dating. Sediment coring was performed in April 2003, when the lake was ice-covered. The deepest point of the lake (8.4 m), situated on the southern side of the basin,

was selected for a coring position for several reasons (Fig. 1). It was considered the most likely area to have maintained a high rate of continuous sedimentation, free of sediment slumping from the littoral zone and deep enough for calm sedimentary conditions. We retrieved two parallel sets of cores from this location using a lightweight model of piston corer (Putkinen and Saarelainen 1998) operated with a series of 2-m long rigid aluminium rods. Both sets of cores consist of three overlapping ca. 2-m long sediment sequences (approximately 0–200, 150–350, 300–500 cm), which were stored in a cold room at +4°C before being opened in the sediment laboratory of the Geological Survey of Finland (GTK).

Sediments were described and LOI determined at 1 cm resolution by burning previously dried (105°C, overnight) sediment samples in a furnace for 2 h at 550°C. LOI is a measure of sediment organic content (Håkanson and Jansson 1983). Volume magnetic susceptibility ( $\kappa$ ) was determined at 5 mm intervals using a Bartington MS2E1 surface-scanning sensor. Susceptibility is a measure of the concentration and grain size of magnetic minerals and potentially indicates fluctuations in different erosion-related processes within the lake catchment, such as lake isolation and human activities (Snowball and Sandgren 2001).

The Lake Orijärvi sediment sequence was dated by a palaeomagnetic dating method (e.g. Thompson and Oldfield 1986; King and Peck 2001). The method is based on the orientation of small magnetic grains parallel to the earth's prevailing magnetic field during the sedimentation process. This orientation remains unchanged in undisturbed conditions and the sediment deposits contain records of natural remanent magnetization (NRM) of the secular variations of the earth's palaeomagnetic field. NRM elements—declination, inclination and intensity—can be used as a relative dating method in lacustrine and marine environments on condition that the deposits reflect true sedi-

**Table 1**  $^{14}\text{C}$  data from the ancient fields at Orijärvi

Lab.no.	Explanation	Material	$^{14}\text{C}$ age year B.P.	Cal age— $2\sigma$ -range; (relative area under probability distribution)	Cal age— $1\sigma$ -range; (relative area under probability distribution)
Hela-592	Karilantie field, the oldest field phase?	<i>Hordeum vulgare</i>	1335 ± 60	A.D. 600–780 (0.945)	A.D. 650–720 (0.754)
Hela-593	Peltorannantie field, the youngest preserved layer	<i>Hordeum vulgare</i>	1195 ± 55	A.D. 690–900 (0.870)	A.D. 770–890 (0.911)
Hela-594	As above	<i>Hordeum vulgare</i>	1200 ± 60	A.D. 680–900 (0.873)	A.D. 770–890 (0.864)
Hela-596	As above	<i>Triticum compactum</i>	1270 ± 80	A.D. 640–900 (0.954)	A.D. 660–780 (0.783)
Hela-595	Peltorannantie, a sample taken near a medieval hearth	<i>Hordeum vulgare</i>	665 ± 50	A.D. 1270–1400 (1)	A.D. 1280–1320 (0.518)

Conversion from radiocarbon ages to calendar years is performed with the radiocarbon calibration program CALIB version 5.0 (Stuiver and Reimer 1993) using the IntCal04 calibration dataset (Reimer et al. 2004). Calibrated age ranges are rounded to the nearest 10 years

mentary NRM and there is a well-dated local reference curve (i.e. master curve) available for comparison. The stability of NRM can be tested by AF demagnetisation (e.g. Thompson and Oldfield 1986). Here, sediment sampling for palaeomagnetic measurements and testing of the stability of NRM followed Ojala and Tiljander (2003) and the palaeomagnetic results from Lake Orijärvi were compared with the Lake Nautajärvi varve-dated reference curves from Ojala and Tiljander (2003). These reference curves are based on carefully documented varve chronology with an estimated error of less than  $\pm 1\%$ . NRM was measured at GTK with a 2G-Enterprises SRM-755R tri-axial SQUID magnetometer and the inclination/declination curves were visually matched with the Nautajärvi reference curves to construct an age-depth transformation for the Lake Orijärvi sediment sequence.

#### Pollen and charcoal analysis

Sediment sub-samples of  $1\text{ cm}^3$  were taken at 1 cm resolution for pollen and charcoal particle analysis (e.g. Bennett and Willis 2001; Whitlock and Larsen 2001). Pollen slides were prepared following standard procedures using glycerine as a mounting medium (e.g. Berglund and Ralska-Jasiewiczowa 1986). For the determination of the pollen and charcoal particle concentration ( $\text{grains}/\text{cm}^3$ ), *Lycopodium* spores (Stockmarr 1971) were added. Altogether 197 samples were counted. The samples were counted at every cm in the uppermost metre, every second sample was counted between 100 and 200 cm and every fourth sample was counted in the lowest part of the sediment, between 200 and 467 cm. At least 700 arboreal pollen grains (AP) were counted from each sample. Identification of pollen and spores was based on keys by Erdtman et al. (1961), Fægri and Iversen (1989), Moore et al. (1991) and Reille (1992, 1995), and on the pollen and spore reference collection kept at the Geological Survey of Finland. Grains between 40 and 60  $\mu\text{m}$  with an annulus diameter  $>10\ \mu\text{m}$  and a distinct outer margin, were identified as cereals separate from the wild grass group. *Secale* was distinguished from other cereal pollen by its oblong grain outline, scabrate surface and the undulating outer margin of its annulus. *Hordeum* has an annulus diameter between 10 and 12  $\mu\text{m}$  in contrast to the *Avena-Triticum* group that has an annulus diameter larger than 12  $\mu\text{m}$ . *Cannabis* was distinguished from *Humulus* type by size and by thickness of the exine. Grains greater than 20  $\mu\text{m}$  (according to older literature by Faegri and Iversen 1989) and with an exine about 0.5  $\mu\text{m}$  thick away from the vicinity of the pori, were identified as *Cannabis*. Grains less than 20  $\mu\text{m}$  and about 0.8  $\mu\text{m}$  thick away from the vicinity of the pori, were identified as *Humulus*.

Charcoal particles were counted between 8 and 423 cm and expressed as a count per 30% of the *Lycopodium* spores recorded in the pollen analysis. They were measured along the longest axis and divided into two size classes: 10–25 and  $>25\ \mu\text{m}$  (Tolonen 1983, 1986). The pollen percentages of arboreal (AP) and non-arboreal pollen (NAP) were calculated from the basic sum of terrestrial pollen grains,  $P = AP + NAP$ . The percentages of aquatic pollen and spores were calculated from the sums  $P + AqP$  and  $P + \text{spores}$ . Pollen and charcoal accumulation rates ( $\text{grains}/\text{cm}^2/\text{year}$ ) were calculated between 8 and 423 cm from the pollen concentrations and the age-depth transformation obtained from palaeomagnetic dating. The pollen and spore nomenclature is according to Moore et al. (1991).

For the comparison of species richness between samples a rarefaction analysis (Birks and Line 1992) was carried out using the POLPAL program (Walanus and Nalepka 1999). This enables a comparison of species richness between samples, as the pollen count is standardised to a single sum ( $n = 544$ ). The pollen sequence was numerically divided into pollen assemblage zones using Constrained Incremental Sums of Squares cluster analysis with the CONISS program (Grimm 1991). Aquatics, spores and pollen types less than 1% of the sum were excluded from the calculation.

## Results

#### Sediment dating

Downcore variations in the Lake Orijärvi NRM are compared with the Nautajärvi reference curves in Fig. 3. Oscillations of declination and inclination records basically reveal all the characteristic features that are typically seen around northern Europe, and in particular, in the Lake Nautajärvi NRM record. This correspondence is an excellent basis for palaeomagnetic comparison between records and importantly for assigning palaeomagnetic ages for different depth levels of the Lake Orijärvi sediment sequence for the last ca. 10,000 years. In addition, the AF demagnetisation behaviour of the Lake Orijärvi palaeomagnetic test samples from depths of 87 and 196 cm indicates that the NRM results from a stable primary component of the declination and inclination, and also that fine-grained (SD and PSD) magnetite is a dominant carrier of the remanence in the Lake Orijärvi sediment deposits. The results are comparable with the AF demagnetisation behaviour of the Lake Nautajärvi reference curve samples (Ojala and Saarinen 2002).

Dating of the Lake Orijärvi core is based on matching nine declination features (a, b, d, e, f, g, g', h, i) and ten

inclination features ( $\gamma, \delta, \epsilon', \epsilon, \eta, \theta, \iota, \lambda, \mu, \nu$ ) to the reference curve maximum/minimum features and turning points. These were found from sediment depths of 28.8 to 423.8 cm in the Lake Orijärvi core. They allowed us to anchor a total of 19 depths to true calendar years (A.D./B.C.), and subsequently to construct an age-depth transformation for the Lake Orijärvi sediment core between the present and 7660 B.C. (Fig. 4). The age-depth transformation illustrates that the rate of sedimentation (i.e. the amount of material deposited on the lake floor during 1 year) has remained fairly stable at around 0.45 mm/year since 7660 B.C., which is the lowest (i.e. oldest) anchored palaeomagnetic feature. Only the last few centuries indicate an increased rate of sedimentation. The age-depth transformation can then be used to assign ages to sediment depths between anchored features. Importantly, such a well-secured sediment chronology, as well as stable and continuous sedimentation, clearly enhances the usability of the Lake Orijärvi sediment sequence in cultural-related pollen studies.

#### Lithostratigraphy and physical parameters

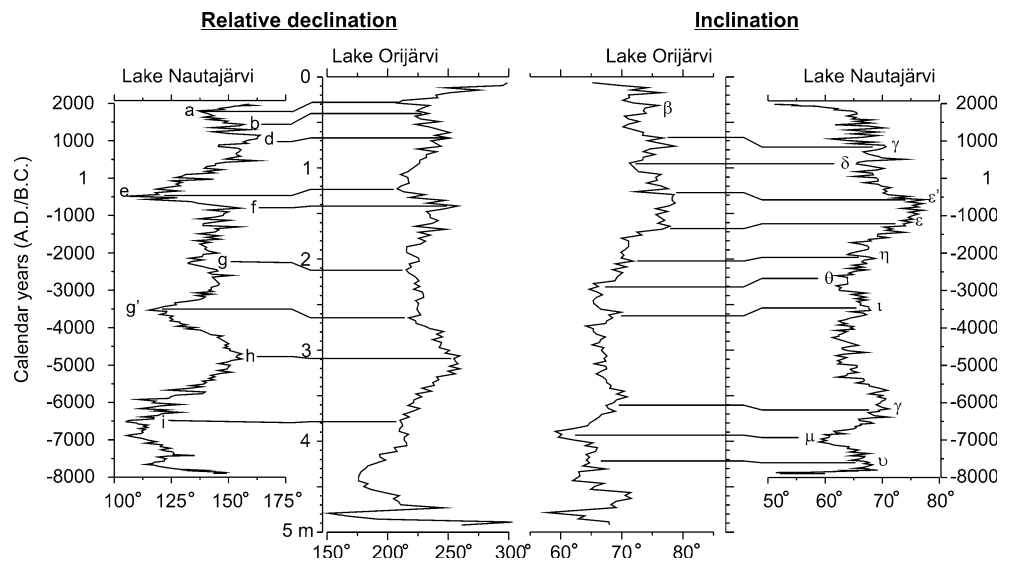
The 528 cm sediment profile from Lake Orijärvi can be divided into two lithostratigraphical units based on sediment structure, LOI and magnetic susceptibility (Fig. 5). The boundary between clay (470–514 cm) and gyttja/clay gyttja (0–470 cm) units is gradual. The lower unit is composed of massive clay that was deposited during the Baltic basin stage in the history of Lake Orijärvi, and has a considerably higher susceptibility ( $>15 \text{ SI} \times 10^{-5}$ ) and lower LOI ( $<3\%$ ) than in the upper unit. Above the isolation stage, LOI increases steadily and susceptibility declines from 15 to 7 in the lower part of the gyttja/clay gyttja

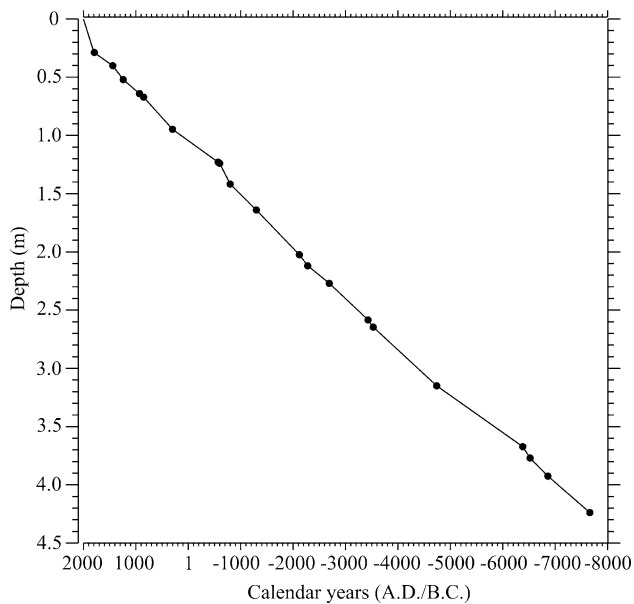
unit. Such a decreasing trend in the allochthonous mineral matter yield from the catchment and increased autochthonous primary productivity is very typical of Finnish lakes that have undergone a transition from the Baltic basin into smaller isolated basins (e.g. Ojala and Saarnisto 1999; Saarnisto 2000). It typically takes one to two thousand years, as is also apparent in the Lake Orijärvi case.

The gyttja/clay gyttja unit consists of visibly distinguishable finely laminated sediments. It is possible that these laminae couplets, which have a thickness of about 0.3–0.4 mm, were formed due to the annual cycle of sedimentation and therefore represent varved-type sediment deposits (e.g. Ojala et al. 2000; Ojala 2001). However, the couplets were not distinctive and thick enough to allow identification and counting on a layer-by-layer basis throughout the entire sediment sequence. In other words, it was impossible to create an inherent varve chronology for the Lake Orijärvi sediment sequence. Nevertheless, the appearance of these laminae indicates that there is no temporal mixing of the sediment as is produced in many lakes by bottom-living animals or wave activity. In the Lake Orijärvi case, biological remains, such as pollen grains that accumulate on the bottom of the lake, have not undergone mixing with older or newer material. Records are therefore free of smoothing, improving the quality and resolution of the investigated proxies.

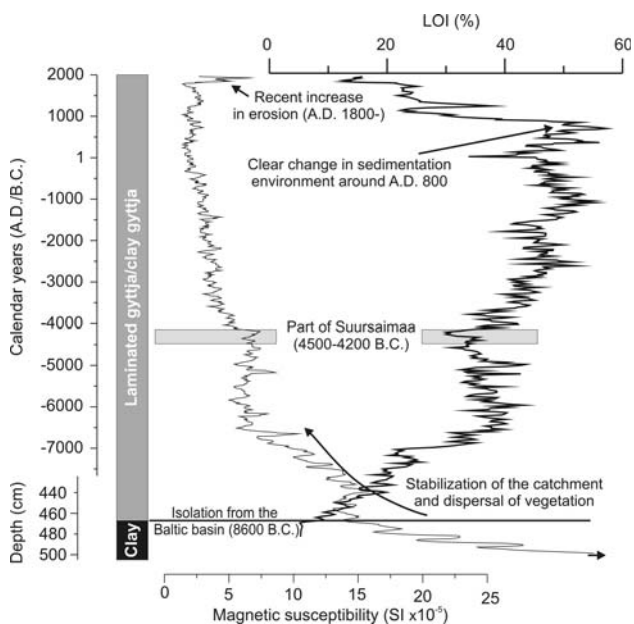
Even if Lake Orijärvi was once isolated from the Baltic Basin some 4,000 years earlier, it is likely that the Sursaimaa transgression maximum at 4300 B.C. reached Lake Orijärvi, as was earlier suggested by Saarnisto (1970) in shore-line displacement studies. The Saimaa transgression was caused by the emerging watershed and tilting of the area towards the north-west after deglaciation. Physical evidence, i.e. increased susceptibility and a minimum in

**Fig. 3** Records of NRM inclination and declination from Lake Orijärvi compared with the Lake Nautajärvi palaeomagnetic master curves in order to date the Orijärvi sediment sequence. Characteristic features of the NRM signal are connected with lines. Inclination feature  $\beta$  (dated A.D. 1340) is based on the Lake Korttajärvi PSV data (Ojala and Tiljander 2003)





**Fig. 4** Age-depth transformation for the Lake Orjærvi sediment sequence based on palaeomagnetic dating



**Fig. 5** Sediment stratigraphy and physical properties of the Orjærvi core plotted against sediment age between the present and 7660 B.C. and against sediment depth below 423.8 cm. Some of the events in the lake history are shown in the figure

LOI, in the Lake Orjærvi sediment sequence suggests that the lake was a part of Suursaimaa between 4500 and 4200 B.C. These dates agree well with Saarnisto's (1970) previous studies. Following the Suursaimaa maximum transgression (about 91 m a.s.l. in the Lake Orjærvi vicinity), the water level began to drop just before the waters of

Suursaimaa broke through Salpausselkä I at Vuoksenniska around 3900–3700 B.C., forming the River Vuoksi (Saarnisto 1970). Lake Orjærvi was isolated for a second time in its history prior to this event, which is seen in a drop in the level of susceptibility and an increase in LOI at around 4200 B.C.

There is a general declining trend in magnetic susceptibility between 4000 B.C. and A.D. 1800, but no clear short-term phases of increased mineral matter erosion. Interestingly, LOI increases between 4000 B.C. and A.D. 800, and has maximum values between A.D. 700 and 800. It then suddenly drops from more than 50% to approximately 20% within less than 300 years. In other words, there is a clear change in sedimentation environment that could very well be related to human presence in the lake vicinity. In addition, there are two short-term phases of higher LOI values between 219 and 187 cm (2530–1790 B.C.) and 156 and 105 cm (1000 B.C.–A.D. 20).

The last two centuries are characterised by increased susceptibility and a decrease in LOI, indicating an increased rate of mineral matter influx from the catchment due to erosion. This is seen in the sediment stratigraphy as mineral-containing layers in the sediment sequence and generally thicker laminae in the uppermost 40 cm of the sediment. In addition, there are visible thin mineral layers in the sediment stratigraphy at the sediment depth of 37–50 cm, which dates back to A.D. 1050–1500. It is possible that they also indicate human activities in the lake vicinity during this period.

#### Pollen and charcoal record

Based on the CONISS division, five pollen assemblage zones (ORI 1–5) were defined (Fig. 6). The lowermost pollen assemblage zone, Ori-1 (470–406 cm) covers the time period from the isolation of Lake at around 8600 B.C. until 7270 B.C.

The most abundant tree species are *Betula* and *Pinus*. *Betula* dominates in the lower part of the zone at around 70% and *Pinus* in the upper part of the zone at around 50%. *Populus*, *Ulmus*, *Corylus* and *Salix* occur in proportions of 1–4%. Herb pollen remains at about 20% of total land pollen with Poaceae as most abundant with a proportion of about 15%. Cyperaceae, *Polypodium*, *Filipendula*, *Artemisia*, Chenopodiaceae and also *Humulus* from the upper part of the zone occur with proportions of 1–2%. The average influx of charcoal particles in the lowermost analysed levels between 423 and 406 cm is 5.7 particles/cm<sup>2</sup>/year.

The pollen assemblage zone Ori-2 (406–272 cm) covers the time period between 7270 and 3790 B.C. The zone is characterised by high AP pollen values with *Pinus* (20%), *Betula* (50%) and *Alnus* (10%) as the major pollen types





with a mean accumulation rate of 3,370, 7,500 and 1,600 grains/cm<sup>2</sup>/year, respectively. The proportion of QM (Quercetum Mixtum) trees is increasing, constituting altogether about 10% of total land pollen by the end of the zone. *Populus* is present in proportions of 3–4%, *Corylus* in proportions of 1–2% and *Quercus* and *Fraxinus* make up less than 1% of the total pollen. The proportion of *Ulmus* pollen shows an increasing trend, reaching over 2% of total land pollen in the upper part of the zone, between 5750 and 4470 B.C. An increase in *Tilia* pollen is visible between 5490 and 5230 B.C. and the highest values are recorded between 4720 and 4070 B.C. Pollen of Cyperaceae, Poaceae, *Artemisia*, *Humulus* and spores of Polypodiaceae and *Sphagnum* are continuously present at around 1–2% as is *Juniperus* from 5750 B.C. onwards. A decreasing trend can be seen in charcoal particle accumulation. The mean total charcoal influx during the zone is 3 grains/cm<sup>2</sup>/year, and the mean total pollen accumulation rate is 14,000 grains/cm<sup>2</sup>/year. The Suursaimaa transgression ended around 4200 B.C., and a decreasing trend in total accumulation values around 4200 B.C. reflects the second isolation of Lake Orijärvi, which is also seen in a reduced level of susceptibility and increase in LOI.

From the beginning of pollen assemblage zone Ori-3 (272–180 cm), covering 3790–1630 B.C., the introduction of, and a steep rise in *Picea* pollen is recorded. Its values then remain between 10 and 20% throughout the zone with a mean of 1,100 grains/cm<sup>2</sup>/year. *Pinus* and *Alnus* pollen percentages remain around 25 and 15%, and the mean pollen accumulation rates are 2,400 and 880 grains/cm<sup>2</sup>/year, respectively. *Betula* pollen percentages fluctuate between 40 and 55%, with a mean of 4,500 grains/cm<sup>2</sup>/year. QM trees show a decreasing trend from 10 to 5%. No marked changes are visible in the herb and shrub pollen percentages. Cyperaceae, *Artemisia*, *Juniperus*, Poaceae, *Salix*, *Humulus*, *Filipendula* and Chenopodiaceae occur continuously at less than 2%. The mean total charcoal influx is 1.6 particles/cm<sup>2</sup>/year and the mean total pollen accumulation is 9,800 grains/cm<sup>2</sup>/year.

The pollen assemblage zone Ori 4 (180–44 cm) is divided into three subzones: 4A, 4B and 4C. Subzone Ori-4A (180–129 cm) covers the period from 1630 B.C. to 500 B.C., and during this subzone arboreal trees constitute about 95% of the land pollen. The mean total pollen accumulation during the subzone is 8,200 grains/cm<sup>2</sup>/year. *Picea* proportions fluctuate between 20 and 30% with a mean of 1,810 grains/cm<sup>2</sup>/year. The *Pinus* pollen percentage remains at around 30% with a mean of 2,500 grains/cm<sup>2</sup>/year. *Betula* values show a sudden decrease from about 50 to 30–40% and *Alnus* from 10 to 6–8%. A decrease in accumulation rates is also recorded, the mean pollen accumulation for *Betula* dropping from 4,500 to 2,700 grains/cm<sup>2</sup>/year,

and that for *Alnus* from 880 to 550 grains/cm<sup>2</sup>/year. QM values remain between 2 and 4%. A clear decrease is visible in *Populus* and *Ulmus* pollen percentages. New pollen species include sporadic occurrences of *Rumex*, *Plantago major/media*, *Plantago lanceolata* and *Potentilla*. The mean total charcoal accumulation remains low, at 1 particle/cm<sup>2</sup>/year.

In the subzone Ori-4B (129–67 cm), covering 500 B.C.–A.D. 830, no changes are visible in the relative proportions of arboreal pollen. However, the mean total pollen accumulation (7,200 grains/cm<sup>2</sup>/year) values and values for main tree species (*Picea* 1,500, *Pinus* 2,200, *Betula* 2,500, *Alnus* 450 grains/cm<sup>2</sup>/year) all decrease from the previous level, indicating a slight change in the sedimentation environment. A sudden decrease in *Corylus* and *Ulmus* pollen proportions is visible from the beginning of the subzone, simultaneously with the start of the continuous occurrence of *Calluna* and a more abundant occurrence of *Urtica* and *Rumex*. Single occurrences of *P. lanceolata*, *Melampyrum*, Caryophyllaceae and *Epilobium* are recorded. An increase in *Pteridium* and a decrease in *Alnus* is recorded from about 80 cm, A.D. 550, upwards. At the same time, *Urtica* becomes more abundant. The first pollen find of a cereal crop, *Secale*, was detected in the upper part of Ori-4B at the depth of 77 cm, A.D. 615. The mean total charcoal influx in the subzone still remains low, at 1.1 particles/cm<sup>2</sup>/year.

From the beginning of subzone Ori-4C (67–44 cm), A.D. 830–1300, the overall proportion of arboreal pollen starts to decrease and herb pollen gradually increases from 5 to 10%. QM trees now constitute less than 2% of land pollen. Poaceae and *Salix* increase from 0.5 to 2% and from 0.5 to 1%, respectively. Pollen of *Humulus/Cannabis* type, *Secale* and *Rumex* is recorded continuously in relative proportions of about 0.5%. Amongst aquatic pollen a sharp increase in *Nymphaea* percentages is clearly registered between A.D. 800 and 1000. The mean total charcoal influx through the subzone is 6.2 grains/cm<sup>2</sup>/year, the highest values being recorded from around A.D. 900 onwards. At the same time, *Pteridium* and *Cannabis* increase. The proportions of *Juniperus*, Poaceae, *Urtica*, *Humulus/Cannabis* type, Brassicaceae, *Rumex*, Ranunculaceae and *Potentilla* all show a clear increase from around 1090 B.C. onwards and spores of *Isoetes* start to occur continuously. *Hordeum* is recorded for the first time at 48 cm, A.D. 1220. The mean total pollen accumulation increases from the preceding subzone to 10,700 grains/cm<sup>2</sup>/year. Mean pollen accumulation for *Picea* decreases from 1500 to 1450 grains/cm<sup>2</sup>/year. A marked decrease in *Picea* is visible from A.D. 1180 onwards. Mean pollen accumulation rate for *Pinus* increases from 2,200 to 4,700 grains/cm<sup>2</sup>/year, for *Betula* from 2,500 to 3,000 grains/cm<sup>2</sup>/year and for *Alnus* from 450 to 530 grains/cm<sup>2</sup>/year.

In the uppermost pollen assemblage zone Ori-5 (44–6 cm), covering A.D. 1300–1960, the mean total pollen accumulation decreases to 9800 grains/cm<sup>2</sup>/year. Mean pollen accumulation rates for *Picea* (600), *Pinus* (3,200) and *Betula* (2,500) all decrease from the preceding subzone, while *Alnus* increases from 530 to 990 grains/cm<sup>2</sup>/year. The largest presence of pollen from crop plants is recorded during this zone. New cultivated species include *Avena/Triticum* and *Fagopyrum*. The number of apophytes and anthropochores such as *Centaurea*, *Melampyrum*, Caryophyllaceae, *Plantago*, *Potentilla*, *Urtica*, Asteraceae and Cichoriaceae is the highest in the entire sequence studied. *Juniperus* and Poaceae both show a rapid increase from 2 to 6% and the highest proportions of *Salix*, *Filipendula*, Cyperaceae, *Artemisia*, *Calluna*, *Pteridium* and *Isoetes* are recorded in the uppermost pollen assemblage zone. *Secale*, *Juniperus*, *Rumex* and Poaceae reach their highest proportions between A.D. 1770 and 1900. The proportion of *Secale* starts to decrease from A.D. 1900 and that of *Pteridium* from A.D. 1840 onwards. The mean total charcoal accumulation is 9.8 particles/cm<sup>2</sup>/year.

#### Rarefaction analysis

The rarefacted number of pollen types remains between 10 and 20 in Ori-1, Ori-2 and until the middle of Ori-3, about 2890 B.C. The number of pollen types then remains between 20 and 25 until the beginning of Ori-4A, ca. 1630 B.C. In Ori-4A, between ca. 1630 and 500 B.C., the rarefacted number of pollen types fluctuates between 19 and 21, dropping suddenly to below 20 at the beginning of Ori-4B and reaching over 25 in the middle of Ori-4B, around A.D. 140. A decreasing trend from 29 to 21 is then recorded from A.D. 140 until the beginning of Ori-4C, A.D. 830. In Ori-4C, A.D. 830–1300, the rarefacted number of pollen types remains between 25 and 30, and the highest values are reached in the uppermost zone between A.D. 1300 and 1960 (Fig. 6).

#### Discussion

Lake Orijärvi became isolated from the Baltic basin at around 8600 B.C. and the lowermost part of the pollen stratigraphy from 8600 to 7270 B.C. reflects the early stages of vegetation development around the lake after isolation with local lakeshore vegetation as a dominating element in the pollen diagram. The oldest information on Holocene forest history (Vasari et al. 1996) is visible from about 7270 B.C. onwards, when a mixed pine-deciduous forest with *Betula* and *Alnus* as major deciduous trees dominated the region. The general spread of *Tilia* in the area dates to

5500–5250 B.C. and the highest values are recorded between 4740 and 4100 B.C. *Picea* became a major component in the forests in this region around 3790 B.C.

The earliest somewhat questionable changes that might be anthropogenic in origin are already visible in the pollen record from the beginning of the Early Bronze Age around 1630 B.C. onwards. Small-scale changes are mainly changes in tree pollen proportions, with a decrease in broad-leaved trees *Betula*, *Alnus*, *Populus*, *Ulmus* and *Tilia*. However, indications of human impact become more evident by the end of the Bronze Age, from around 500 B.C. onwards, when a clear increase in *Calluna*, sporadic occurrences of *Rumex*, *Urtica*, *Epilobium* and a decrease in broad-leaved *Corylus* and *Ulmus* suggest human impact, probably grazing in a forested environment.

The onset of cultivation, reflected by the earliest cereal pollen (*Secale*), dates to the Merovingian period around A.D. 600. Preceding actual cultivation signs, however, the palynological richness increases sharply already from around A.D. 180 as a result of environmental heterogeneity created by human activities (Grönlund 1995). The anthropogenic impact then becomes clearly visible at about A.D. 550, when *Urtica*, associated with footpath and ruderal communities (Behre 1981; Gaillard et al. 1992) and *Pteridium*-spores, associated with increasing light factors in the forests (Vuorela 1986; Grönlund 1995), increase in the pollen diagram.

So far the archaeological material does not, unfortunately, corroborate the earliest possible human impacts on the local vegetation demonstrated in the pollen data. However, the radiocarbon dates and the cereal pollen prove that an Iron Age farming settlement was already established in the Mikkeli area in the seventh century A.D., possibly as early as in the sixth century A.D. Previously, the establishment of a permanent settlement in this area has been seen as a result of wide-range hunting with occasional swidden cultivation from the Viking Age onwards (Taaivitsainen 1987).

Major changes are visible in the pollen data from around A.D. 830 onwards as the overall proportion of tree pollen starts to decrease and the proportion of shrub and herb pollen, especially Poaceae and *Salix*, indicative of fields (Hicks and Birks 1996), begins to increase. A clear change in sedimentation environment, a decrease in LOI and increased total pollen influx suggest substantial terrestrial input from the inflows. A sharp increase in the proportion of aquatic *Nymphaea* is related to human presence in the lake vicinity. A clear increase in the fire regime is visible from around A.D. 900 onwards, when high charcoal particle influx values and the continuous occurrence of *Secale*, *Rumex* and Poaceae pollen and *Pteridium* spores indicates slash-and-burn cultivation in the area (Linkola 1916, 1921;

Vuorela 1986; Sarmaja-Korjonen 1992; Grönlund 1995; Pitkänen 1999).

A marked intensification of agricultural activities is visible in the pollen data from about A.D. 1050 to 1080. Taxa commonly associated with local settlements and ruderal communities include cultivated *Humulus* and *Cannabis* together with *Plantago*, *Urtica*, Ranunculaceae and *Potentilla*. An increasing proportion of *Juniperus* obviously reflects increasing proportions of grazed meadows and the continuous occurrence of *Hordeum* from A.D. 1220 onwards can be related to cultivation in permanent fields.

The most extensive phase of land use with an open cultural landscape is evident in the uppermost part of the diagram from A.D. 1300 onwards. The rarefacted numbers of species are at their highest, obviously as a result of different land use activities, clearings, fields, pastures and meadows, as earlier demonstrated in eastern Finland by Grönlund (1995). The pollen data show the largest presence of apophytes and anthropochores in the entire core. Taxa typical of fields such as Asteraceae, Cichoriaceae, *Centaurea*, *Melampyrum* and Caryophyllaceae are abundant and the pollen of the cultivated plants *Avena/Triticum* and *Fagopyrum* is recorded. *Salix*, *Filipendula* and Cyperaceae can be associated with the wettest fields and ditches (Hicks and Birks 1996) and have been found to correlate with cultivation and NAP taxa (Broström et al. 1998). From about A.D. 1300 onwards the abrupt increase in spores of *Isoetes* probably indicates catchment disturbance and field erosion around the lake (Vuorela 1980). Regardless of the clear signs of permanent settlement and cultivation, high proportions of *Secale* together with high values of charcoal and *Pteridium* spores indicate that slash-and-burn cultivation was still widely practised in the area. The highest values of *Secale* are visible in the pollen data between A.D. 1760 and 1900 and can be associated with the most intensive slash-and-burn period in eastern Finland, when the landscape of the area was generally open and largely devoid of mature coniferous forests (Soininen 1974).

In the Orijärvi pollen record *Secale* is the earliest cereal crop, whereas in the archaeological record the oldest cultivation markers in the permanent fields are charred grains of *Hordeum*, which as a species appears in the pollen data some 500 years later. A charred grain of club wheat (*T. compactum*) in the macrofossil data demonstrates another discrepancy between the macrofossil and pollen data. It can be assumed that the full impact of permanent field cultivation is not reflected in the pollen data during the first 600 years. The difference in this data can be partly explained by the differing pollen productivity and dispersal characteristics of the cultivated species. It has been observed that the pollen of *Hordeum* is poorly represented

even in the immediate vicinity of fields (Hall 1989; Vuorela 1973; Bakels 2000). In contrast to wind pollinated *Secale*, the pollen of autogamous *Hordeum* remains trapped between the glumes, and very little pollen is released into the air (Fægri and Iversen 1989). The highest values of pollen are found in samples collected from beneath the harvested cereal crop (Hall 1989).

Evidently the selection of the lake was not optimal for estimating the earliest signals of cultivation. The oldest field was ca. 200 m<sup>2</sup>. The distance between the fields and the coring position in Lake Orijärvi is ca. 700 m, and the radius of the lake is ca. 300 m. “The relevant source area of pollen” has been defined as the area beyond which the correlation between pollen loading and plant abundance in the surrounding vegetation does not improve (Sugita 1994). According to simulations, the relevant source area for medium size lakes with a radius of 250 m is ca. 600–800 m from the lake edge, with about 30–45% of total pollen loading coming from within this distance (Sugita 1994). It has been demonstrated that vegetation heterogeneity, e.g. patch size, interacts with lake size and the size of relative source area of pollen (Sugita 1994; Calcote 1995; Sugita et al. 1999; Bunting 2002; Nielsen and Sugita 2005). A large lake has a reduced ability to register vegetation patches that are much smaller than the size of a sedimentary basin thus making the vegetation appear as homogenous. With large vegetation patches, a larger radius has to be included before the correlation between pollen loading and plant abundance in the surrounding vegetation ceases to improve.

Simulation results (Sugita 1994; Calcote 1995; Sugita et al. 1999; Bunting et al. 2002; Nielsen and Sugita 2005) show that the NAP percentages are insufficient to quantify the percentage cover of open land. They also demonstrate the important role of high regional background arboreal pollen. Pollen productivity estimates (Broström et al. 2004) suggest that most of the common tree taxa produce six to eight times as much pollen per unit area as do Poaceae. This leads to dominance of high pollen producers and long distance dispersed pollen taxa such as *Alnus* and *Betula*. Pollen coming from the undisturbed area overwhelms the pollen signal of any disturbance at a few hundred meters or so, and results in relatively low NAP percentages even for lakes located near or within an open area, as is obviously case in Lake Orijärvi. In contrast to the lightweight, long distance dispersed pollen taxa, the 50% pollen source radius for the heavy pollen of *Picea* is only 528 m in a simulation, when the radius of lake was set to 250 m (Sugita 1993). Heavy pollen of *Picea* therefore plays an important role in indicating local changes in tree composition. In the Lake Orijärvi pollen data, a decrease in *Picea* influx values from A.D. 1180 onwards, associated with high charcoal particle influx values and the continuous

occurrence of *Secale*, *Rumex* and Poaceae pollen, probably indicates slash-and-burn cultivation at the local scale.

In the palaeoecological data the most reliable indicator of permanent field cultivation seems to be the changes observed in the LOI curve from around A.D. 800 onwards. At this stage a rapid increase in allochthonous material influx clearly indicates increased erosion, possibly as a result of ploughing of the fields. This may well coincide with the increased size and number of fields; all five fields seem to have been under cultivation during the ninth century with a total field area of ca. 1,000 m<sup>2</sup>.

Traditionally, swidden cultivation and arable cultivation have been seen as a hierarchical and temporal continuum from the more primitive swidden cultivation to the more advanced permanent field cultivation (e.g. Taavitsainen et al. 1994). However, if one maintains that *Secale* by itself indicates swidden cultivation and *Hordeum* and *Triticum* indicate permanent field cultivation, both methods were in use from the seventh century onwards. The combination of these techniques together with animal husbandry and hunting created a subsistence strategy for the farmers living in the climatic border-zone outside the centres of the agricultural core areas.

## Conclusions

According to macrofossil data and pollen analytical evidence from the sediment sequence of Lake Orijärvi, the oldest field phase in Kihlinpelto prehistoric field complex dates to the Merovingian period, A.D. 600–780. Comparison of macrofossil and palynological data revealed the major discrepancy between the cultivated species. Of the 87 macrofossils of Cerealia found at the prehistoric fields, as many as 57 were of *Hordeum vulgare*, while three were of *Secale cereale*, and three of *Avena sativa* (or *Festuca pratensis*). However in the pollen data *Secale* pollen remained the only cultivated pollen type until A.D. 1220, when *Hordeum* pollen is first recorded. The results imply a very significant underestimation of cultivation in permanent fields in the pollen data from a lake of 28 ha in size, with the ancient fields situated about 700 m from the coring position. Archaeological, pollen and macrofossil data together indicate, that the two, distinctly different cultivation methods, swidden and permanent field cultivation, were in simultaneous use during the Iron Age from the seventh century onwards in Eastern Finland.

**Acknowledgements** The pollen analytical part of this study was financed by a scientific grant from the Finnish Cultural Foundation. We sincerely thank Tanja Tenhunen for the macrofossil analyses, and Kari Hjelle and an anonymous reviewer for the comments of the manuscript. The Geological Survey of Finland provided facilities for pollen analysis.

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