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# **Environmental change and anthropogenic impact on lake sediments during the Holocene in the Finnish – Karelian inland area**

**Teija Alenius**

*Academic dissertation*

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Spruce pollen grain

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## Abstract

This thesis discusses the prehistoric human disturbance during the Holocene by means of case studies using detailed high-resolution pollen analysis from lake sediment. The four lakes studied are situated between 61° 40' and 61° 50' latitudes in the Finnish – Karelian inland area and vary between 2.4 and 28.8 ha in size. The existence of Early Metal Age population was one important question. Another study question concerned the development of grazing, and the relationship between slash-and-burn cultivation and permanent field cultivation. The results were presented as pollen percentages and pollen concentrations (grains cm<sup>-3</sup>). Accumulation values (grains cm<sup>-2</sup> yr<sup>-1</sup>) were calculated for Lake Nautajärvi and Lake Orijärvi sediment, where the sediment accumulation rate was precisely determined. Sediment properties were determined using loss-on-ignition (LOI) and magnetic susceptibility ( $\kappa$ ). Dating methods used include both conventional and AMS <sup>14</sup>C determinations, paleomagnetic dating and varve chronology.

The isolation of Lake Kirjavalampi on the northern shore of Lake Ladoga took place ca. 1460–1300 BC. The long sediment cores from Finland, Lake Kirkkolampi and Lake Orijärvi in southeastern Finland and Lake Nautajärvi in south central Finland all extended back to the Early Holocene and were isolated from the Baltic basin ca. 9600 BC, 8600 BC and 7675 BC, respectively. In the long sediment cores, the expansion of *Alnus* was visible between 7200–6840 BC. The spread of *Tilia* was dated in Lake Kirkkolampi to 6600 BC, in Lake Orijärvi to 5000 BC and at Lake Nautajärvi to 4600 BC. *Picea* is present locally in Lake Kirkkolampi from 4340 BC, in Lake Orijärvi from 6520 BC and in Lake Nautajärvi from 3500 BC onwards.

The first modifications in the pollen data, apparently connected to anthropogenic impacts, were dated to the beginning of the Early Metal Period, 1880–1600 BC. Anthropogenic activity became clear in all the study sites by the end of the Early Metal Period, between 500 BC – AD 300. According to *Secale* pollen, slash-and-burn cultivation was practised around the eastern study lakes from AD 300–600 onwards, and at the study site in central Finland from AD 880 onwards. The overall human impact, however, remained low in the studied sites until the Late Iron Age.

Increasing human activity, including an increase in fire frequency was detected from AD 800–900 onwards in the study sites in eastern Finland. In Lake Kirkkolampi, this included cultivation on permanent fields, but in Lake Orijärvi, permanent field cultivation became visible as late as AD 1220, even when the macrofossil data demonstrated the onset of cultivation on permanent fields as early as the 7th century AD. On the northern shore of Lake Ladoga, local activity became visible from ca. AD 1260 onwards and at Lake

Nautajärvi, sediment the local occupation was traceable from 1420 AD onwards. The highest values of *Secale* pollen were recorded both in Lake Orijärvi and Lake Kirjavalampi between ca. AD 1700–1900, and could be associated with the most intensive period of slash-and-burn from AD 1750 to 1850 in eastern Finland.

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## List of original articles

**This thesis is based on the following four papers.**

- I Alenius, T., Grönlund, E., Simola, H. and Saksa, A. 2004. Land-use history of Riekkalansaari Island in the northern archipelago of Lake Ladoga, Karelian Republic, Russia. *Vegetation history and archaeobotany* 13: 23–31.
- II Ojala, A. and Alenius, T. 2005. 10 000 years of interannual sedimentation recorded in the Lake Nautajärvi (Finland) clastic-organic varves. *Palaeogeography, Palaeoclimatology, Palaeoecology* 219: 285–302.
- III Alenius, T. and Laakso, V. 2006. Palaeoecology and archaeology of the village of Uukuniemi, eastern Finland. *Acta Borealia* 23, No.2: 145–165.
- IV Alenius, T., Mikkola, E. and Ojala, A. History of agriculture in Mikkeli Orijärvi, eastern Finland as reflected by palynological and archaeological data. *Vegetation History and Archaeobotany*. In press.

### **The author's contribution to the articles**

Paper I was a part of a research project entitled "*Land-use history of Karelian Isthmus and NW Ladoga region – a palaeoecological and archaeological study*" with E. Grönlund, H. Simola and A. Saksa as the responsible authors. They also conducted the fieldwork in Ladoga region. The author has been in charge of pollen analysis and interpretation of the results.

In the paper II, the author was in charge of the pollen analytical part and author A. Ojala was responsible for physical analyses and documentation of varve structure.

In the paper III, V. Laakso was in charge of the archaeological aspect of the study while T. Alenius was responsible for the palaeoecological part of the study.

In paper IV, E. Mikkola was in charge of archaeological part, Tanja Tenhunen at the National Board of Antiquities was in charge of the macrofossils analyses, author A. Ojala for paleomagnetic dating and T. Alenius in the pollen analytical part of the study.

# 1 Introduction

Pollen analysis, introduced by Lennart von Post in the beginning of the 20<sup>th</sup> century, was originally designed as a dating instrument for Quaternary geologists. Since then, it has developed into an excellent tool for palaeoecological research.

In optimal conditions, lake sediments and peat layers preserve long and undisturbed archives of fossil pollen records. The value of accumulated sequences of pollen in lake sediments and peat deposits lies above all in its possibility of characterizing vegetation over a long time series. While archaeological material is fragmentary and provides a horizontal timeframe, pollen analysis provides a continuum over time. Nowadays, pollen analysis can be considered as one of the fundamental tools in understanding the palaeoecological changes related to vegetation, and development and change of human activities through time.

Pollen is preserved in anaerobic conditions. Small lakes, with the least mixing at the bottom of the sediment and deep for their area, usually record continuous sedimentation and are best suited for reconstructing past terrestrial environments (Bennett and Willis 2001). The main pathways for pollen to be transported to the place of deposition are through trunk space, above the canopy, by rainfall from the higher altitudes, and by surface runoff (Tauber 1977). The local component refers to pollen production from the immediate surroundings, such as pollen from aquatic plants and wetland species growing on the shores, and secondary pollen refers to pollen transported from the catchment (Moore *et al.* 1991). In addition, inflowing streams bring in substantial amounts of local and extra-local pollen (Peck 1973; Bonny 1978). Before its final burial, pollen may be affected by various within-lake sedimentary processes. The degree of resuspension from the shallower areas of the lake basin, redeposition, focusing and biological mixing in the sediment all depend on the morphometry of a lake basin (e.g. Birks and Birks 1980; Jacobson and Bradshaw 1981). Varved sediments that are preserved in meromictic and dimictic lakes with a permanent or seasonal oxygen deficit in the bottom water layers are desirable archives in pollen stratigraphical studies. They reflect the annual cycle of sedimentation because there is little post-depositional disturbance (e.g. Saarnisto 1986; Ojala 2001).

Pollen representation in the lake sediment is distorted by bias in production and dispersal (Prentice 1985). In general, wind pollinated species produce substantial amounts of pollen compared to entomophilous taxa (e.g. Vuorela 1973). Pollen productivity estimates (Broström *et al.* 2004) suggest that most of the common tree taxa produce 6–8 times pollen per unit area than *Poaceae*. That leads to dominance of high pollen producers and long distance dispersal pollen taxa such as *Alnus* and *Betula*. To correct biases in pollen representation, the R-value model (Davis 1963), which expresses the relationship between the pollen percentage and the vegetation frequencies, has been used in a quantitative reconstruction of forest composition (Parsons *et al.* 1980; Prentice *et al.* 1987). The extended R-value (ERV) model (Prentice 1986) takes account the presence of pollen from outside the investigated vegetation area and partitions the pollen counts for each taxon into a component that reflects abundances within the chosen radius and into a constant component coming from beyond the distance that represents the background component. The background models that take the size

and extent of the pollen source area into consideration give a good estimate of the pollen–vegetation relationship at different scales (e.g. Broström *et al.* 1998; Bunting *et al.* 2002; Nielsen and Sugita 2005).

Charcoal particles provide evidence of natural and human-induced fires in the palaeoenvironment (e.g. Tolonen 1986; Whitlock and Larsen 2001; Kangur 2002). Charcoal production depends on the size, intensity and severity of the fire, but the final charcoal record in the sediment is composed by primary and secondary charcoal (Whitlock and Larsen 2001). Primary charcoal refers to material introduced during or shortly after a fire event, and secondary charcoal to material introduced several years after the actual fire as a result of surface run-off and within-lake sedimentary processes (Whitlock and Larsen 2001). According to Patterson *et al.* (1987), smaller particles represent regional fires while the larger particles are more likely to be local in origin.

Modern data sets provide the basis for interpretation of fossil pollen data in terms of analogues. The indicator species approach (e.g. Vuorela 1973; Behre 1981; Hicks 1988, 1992) uses the ecological characteristics of different species and assumes that fossil pollen assemblages have modern analogues. To gain a better understanding of modern pollen/vegetation/land-use relationships, much work has been conducted to correlate pollen records with systems of land use. To establish a relationship between the modern pollen and vegetation producing it, pollen surface samples, vegetation data and numerical methods have been used for example, for human-influenced vegetation types in south Sweden (Gaillard *et al.* 1992, 1994); the cultural landscape in the island of Hailuoto in northern Finland (Hicks and Birks 1996); grazed and mown vegetation types in western Norway (Hjelle 1998); natural and human induced vegetation types in northern Fennoscandia (Räsänen 2001); and for grazed vegetation in the Pyrenees Mountains in France (Mazier *et al.* 2006).

Besides Holocene vegetation history stages, the long and continuous sediment cores preserve evidence of the early prehistoric anthropogenic activity. In the northern latitudes, the early anthropogenic impact is often scarce, and can be seen as slight increase in apophytes, species that belong to the native flora but benefit from human activity, or as the appearance of anthropochores, species that do not belong to the native flora, such as pollen of cultivated species. Also, other indirect evidence, such as small local woodland disturbances or increased erosion phases can be recorded and serve as important indicators of past human activity. While a number of pollen analyses have been conducted in Finland to study human impact, the overall picture of agriculture and settlement history is still incomplete. To be able to trace the often minor traces of anthropogenic activity, pollen analysis within close sampling intervals is needed. This thesis discusses the prehistoric human disturbance during the Holocene by means of case studies using detailed high-resolution pollen and charcoal analyses.

All the study sites are situated on inland areas, where dwelling sites from the Mesolithic (8800–5000 BC) and from the Neolithic (5000–1800 BC) period are known, but are characterized by a scarcity of archaeological remains between 1800 BC – AD 300 (Lavento 2001). This is the time period that covers the Early Metal Period in Karelia and in the Finnish inland areas. Therefore, the existence of Early Metal Age population is one important question. Another study question concerns the relationship between slash-and-burn cultivation and permanent field cultivation. According to historical records, slash-and-burn cultivation remained the major method of cereal-crop cultivation in eastern Finland until the late 19<sup>th</sup> century (Soininen 1974). Permanent Iron Age fields, found at the city of Mikkeli, suggest cultivation on permanent fields from the 7<sup>th</sup> century (Mikkola 2004). This finding is significant, because it is the easternmost permanent prehistoric field complex found in Finland and therefore has a great socio-economic value (Mikkola 2004; Mikkola and Talvio 2000). In addition to different cultivation techniques, the development of grazing is discussed. Not much is known about the early stages of animal husbandry in Finland. The osteological analyses in the Lake Saimaa area provide evidence of domestic species during the Iron Age (Ukkonen 1996), but this matter has not been researched enough to verify these results.

The results are presented as pollen percentages, pollen concentrations (grains cm<sup>-3</sup>) and pollen



accumulation values (grains cm<sup>-2</sup> yr<sup>-1</sup>). The advantage of accumulation values over percentages is that they allow one to estimate the presence of individual species independently for each species, while pollen percentages depend on the presence of all the other taxa in the pollen sum (Davis 1967; Hicks 1997). The ability to trace abundances of individual taxa separately has proven to be important when reconstructing cultural landscape development (Aaby 1988) and also when moving from forest to open situations, such as in tree-line reconstructions (Hicks and Hyvärinen 1999; Hicks 2001; Tinsley 2001; Seppä and Hicks 2006).

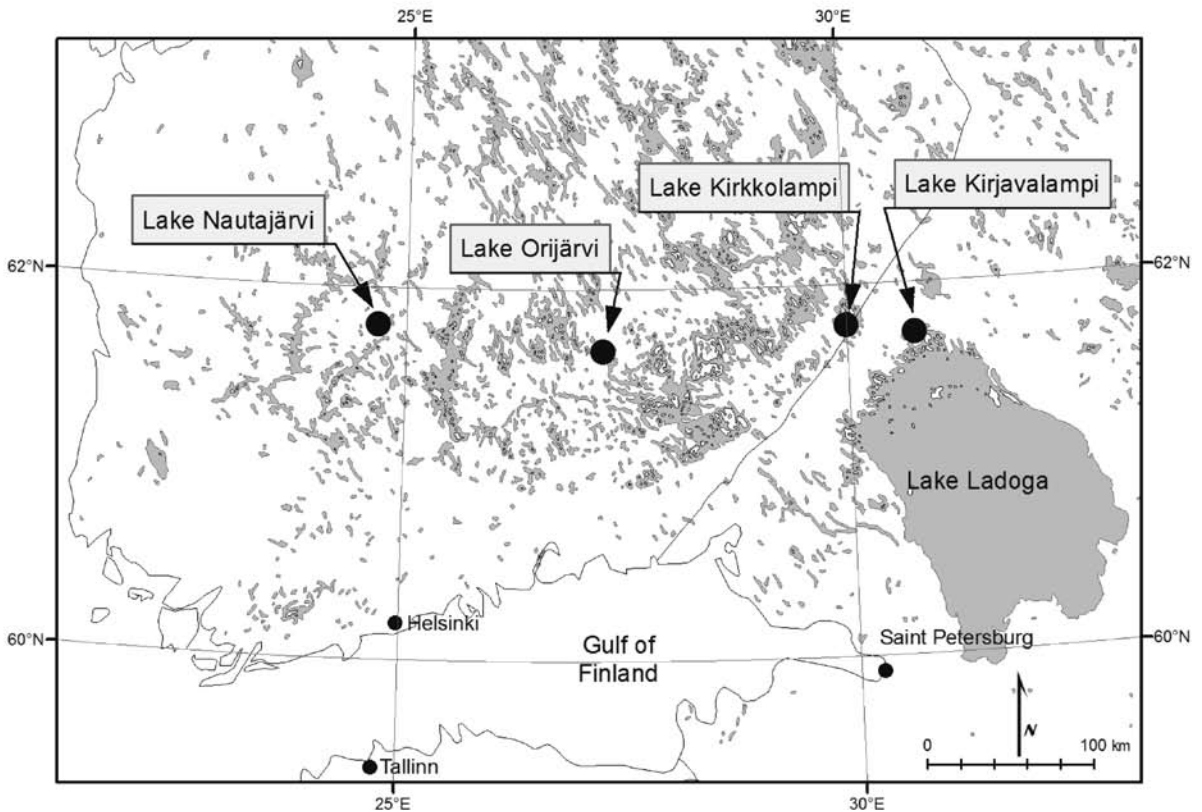
The lakes studied vary between 2.4 and 28.8 ha in size, and therefore vary in pollen source area. In general, the relationship between basin size and pollen source area is well known; larger sedimentary basins collect pollen from larger areas than smaller basins (Jacobson & Bradshaw 1981; Prentice 1985). Prentice (1985) estimated the pollen source area for a point at the center of a sedimentary basin, and referred to local pollen as pollen input from within 20 m of the edge of the basin, extra-local from 20 m to 2 km and regional from 2 km to 200 km. Theoretical and empirical models later provided better and more objective measurement of the pollen source area (Sugita 1994; Sugita *et al.* 1999). Sugita (1994) defined the "relevant source area" (RSAP) of pollen as the area beyond which the correlation between pollen and vegetation data does not improve, that is the background pollen coming from beyond the relevant source area of pollen becomes nearly constant between sites. It has been demonstrated (Sugita 1994; Broström *et al.* 2004) that in very large lakes, small vegetation patches can not be recorded in the pollen data because substantially large amounts of pollen come from source assemblages further away. Vegetation appears homogenous in the pollen record, and very large lakes are therefore well suited for reconstructing regional vegetation. Large lakes also provide an estimate of the background pollen input. Simulation experiments (Sugita 1994) using a model that estimates pollen deposition on the surface of an entire basin in a fully forested environment suggest that a relevant source distance from the lake edge is 50–100 m for forest hollows, 300–400 m for small lakes with a radius of 50 m and 600–800 m for medium size lakes with a radius of 250 m. Since deposition velocity for individual taxa varies, pollen type has a major effect on its source area (Prentice 1985). Source radius of the light pollen types could be 100 times larger than that of heavy pollen types (Sugita 1993).

## 2. Study area

The studied lakes are situated between 61° 40' and 61° 50' latitudes in the Southern Boreal vegetation zone (Figure 1, Table 1). Lake Orijärvi and Lake Kirkkolampi are situated in south-eastern Finland and Lake Nautajärvi is in south-central Finland. Lake Kirjavalampi is situated in Karelian Republic in Riekkalansaari Island, which is the largest island in the North Ladoga archipelago. The selection

	Lake Kirkkolampi	Lake Orijärvi	Lake Nautajärvi	Lake Kirjavalampi
<b>Location</b>	61°47'N 30°00'E	61°40'N 27°14'E	61°48'N 24°41'E	61° 44'N 30° 46'E
<b>altitude (m a.s.l.)</b>	79.6	89.7	103.7	17
<b>area (ha)</b>	Lake Kirkkolampi: 72 Ertonlahti bay: 4	28.8	17	2.4
<b>max. depth (m)</b>	6.7	8.4	20	4

**Table 1. Statistics of the study lakes**



**Figure 1. Location of the study sites.**

of Lake Orijärvi, Lake Kirkkolampi and Lake Kirjavalampi is based on the vicinity of archaeological sites because they are interdisciplinary projects with archaeologists with an aim of solving the problems encountered in archaeological material covering the settlement history.

The selection of Lake Nautajärvi was based on the existence of annually laminated sediments because the primary aim of the case study from Lake Nautajärvi was to discuss the varve-formation process versus climate information and primary factors controlling sediment influx into a lake. Lake Nautajärvi contains clastic-organic type varves that consist of a light mineral material layer transported into the basin during the spring floods and a dark organic material layer mainly the result of biological production within the lake (e.g. Ojala 2001). A calibrated calendar year chronology (BC/AD) will be used throughout this paper because of the prehistorical and historical context.

## **2.1. Isolation of the lakes from the Baltic Sea basin and Lake Ladoga**

Salpauselkä I and Salpauselkä II, large ice-marginal formations that were deposited at the glacial front during deglaciation, stretched for more than 600 km across southern parts of Finland and were formed during the Younger Dryas between 10 300 BC and 9640 BC (Saarnisto and Saarinen 2001). Lake Kirkkolampi, the easternmost study lake in Finland, is situated outside Salpauselkä II and was isolated in the early stage of evolution of the Baltic Sea, when the Baltic Ice Lake drained to the level of the Atlantic Ocean due to the opening of the Billingen strait in southern Sweden around 9640 BC. When the continental ice sheet started to retreat north-westward from Salpauselkä II, the Mikkeli area

was deglaciated ca. 100 varve years after the drainage of the Baltic Ice Lake, during the Yoldia Sea phase (Sauramo 1923; Björck 1995). The highest shore of the Yoldia Sea in the Mikkeli area is about 110 metres above the present day sea level (Saarnisto 1970). The emergence of the deglaciated terrain proceeded rapidly, and the Yoldia Sea and the following Ancylus Lake stages were regressive in eastern Finland. As a result, Lake Orijärvi became isolated around 8600 BC. The third of the studied lakes, Lake Nautajärvi in central southern Finland was deglaciated ca. 9200 BC (Sauramo 1923; Saarnisto and Saarinen 2001) and became isolated during the Lake Ancylus stage at 7675 BC (Ojala *et al.* 2005).

Both Lake Kirkkolampi and Lake Orijärvi in eastern Finland belong to the Lake Saimaa watershed, and were affected by the complex history of Lake Saimaa. Due to the rapid land uplift after the Ice Age, the water level of Lake Saimaa water complex started to rise. All the independent isolated lakes in the south were submerged, forming the ancient Great Saimaa. Transgressive waters of Lake Saimaa extended to Lake Kirkkolampi around 5500 BC and to Lake Orijärvi around 4500 BC (Saarnisto 1970). Finally, the waters of Great Saimaa broke through Salpausselkä I at Imatra, and drained into Ladoga ca. 3800–3700 BC forming the Vuoksi River (Saarnisto 1970). Lake Orijärvi became isolated for a second time just before the waters of Suursaimaa broke through Salpausselkä I at Vuoksenniska (Saarnisto 1970). The shore level that developed before the opening of the Vuoksi River outlet is the highest of the ancient Great Saimaa shores, and is situated in the village of Uukuniemi about 80 m a.s.l., which is only half a meter above the present shoreline (79.6 m a.s.l.) (Saarnisto 1970).

The isolation history of Lake Kirjavalampi on the northern shore of Lake Ladoga is linked to the history of Lake Ladoga. The drainage of the Lake Saimaa complex resulted in a rise in the Lake Ladoga water level by 1–2 metres and accelerated the transgression in Lake Ladoga. As a result, the new outlet at the south, River Neva was formed ca. 1460–1300 BC (Saarnisto and Grönlund 1996). The level of Lake Ladoga rapidly sank close to the present, 5 m a.s.l., and as a result, Lake Kirjavalampi became isolated.

## 2.2. Transition to farming in Finland

Archaeological evidence proves that the first pioneer stage of the settling of Finland took place ca. 8850–8250 BC (Carpelan 1999a; Takala 2004; Pesonen 2005). Hunting, fishing and gathering were the main sources of subsistence for Finland's Stone Age inhabitants. The transition from food gathering societies to food-producing ones was a gradual process with a long continuation of foraging adaptations and a long delay before the appearance of a predominantly agricultural economy (Zvelebil and Rowley-Conwy 1984).

Outside Finland, the Corded Ware (the Battle-Axe) culture has been associated with agriculture and animal husbandry (Carpelan 1999b). This culture spread to Finland about 3200 BC, existing on the marine shoreline in southern and western areas of Finland. According to Nunez (1999), the Corded Ware people were probably responsible for bringing farming practices into southern Finland in the late 4<sup>th</sup> millennium BC, but contrary to west Estonia and Sweden, the actual evidence in Finland supporting farming by the Corded Ware people is very thin (see e.g. Siiriäinen 1981). In western Estonia, the cultivation of cereals connected to the Corded Ceramic Culture is found in the Middle Neolithic around 3400 BC (Veski 1998), and in Sweden, cultivation and agriculture apparently started around 3900 BC with the introduction of wheat, cattle, sheep, goat and pig (Welinder 1998). Siiriäinen (1981) hypothesizes that farming as a subsistence source failed in Finland because of the adverse environmental conditions, and the Corded Ware people gradually adopted foraging as the principle means of subsistence.

In Finland, the earliest pollen analytical evidence suggesting cultivation (see e.g. Vuorela and Hicks 1996; Vuorela 1999 for the references) is mainly from southwest Finland and places the onset of cultivation to the beginning of Kiukainen culture around ca. 2200 BC. The Kiukainen culture was a hybrid of Corded Ware and indigenous Combed Ware groups and existed between 2350–1900/1700 BC

in a narrow coastal zone in southern Finland (Carpelan 1999b). According to archaeological material, it is traditionally thought to have been a mixed economy of hunting, fishing, sealing and some farming (Siiriäinen 1981). In Estonia, the Bronze Age economy was already based mainly on cattle breeding and agriculture, with permanent fields of *Triticum* and *Hordeum* as cultivated species (Poska *et al.* 1999).

All the studied lakes in this thesis belong to the Finnish interior. In contrast to the southwestern coastal areas of Finland, that were influenced by Scandinavian culture during the Bronze Age, the interior parts were orientated to the east, and the pottery of the interior represents the eastern tradition of asbestos ceramics and Textile Ware (Lavento 2001). The settlement sites in the interior parts diverge from those in southwestern Finland. They are small in size and are interpreted as reflecting smaller populations or a moving lifestyle (Lavento 2001). In inland areas between 61° and 63° latitudes, the earliest Cereal type pollen findings suggesting cultivation are found in central Finland ca. 2300–2100 BC in Lammi (Tolonen 1980) and in Keuruu (Vuorela 1994). Other Cereal type pollen findings in central Finland are ca. 1880–1730 BC in Jämsä (Koivula *et al.* 1994) ca. 1440–1190 BC in Pälkäne (Tolonen 1981) and < 940–750 BC in Kuhmoinen (Tolonen 1990). In Hankasalmi and Hattula evidence of cultivation are found in the Pre-Roman Iron Age (500 BC – AD 1) (Vuorela 1975; Koivula *et al.* 1994).

In Eastern Finland and Ladoga area, Cereal type pollen suggesting cultivation in the Early Metal Period are recorded in Outokumpu ca. 750 BC (Saastamoinen 1995) and in Siilinjärvi > 665 BC (Grönlund *et al.* 1992). In Taipalsaari, Joutseno and Valkeala the oldest Cereal pollen record date back to 1400–1200 BC (Vuorela and Kankainen 1994; Tolonen and Ruuhijärvi 1976), and in Valamo Island to the 8<sup>th</sup> or 9<sup>th</sup> century BC (Vuorela *et al.* 2001). Later Tomminen (2005) has demonstrated the regular occurrence of *Hordeum* pollen grains from the beginning of Christian Era in Taipalsaari. A short cultivation period was also dated to the Early Metal Period, ca. 1400–1260 BC in Luumäki, and a new beginning of cultivation was then recorded in the 7<sup>th</sup> century (Tomminen 2005). This agrees well with previous results from eastern Finland, where onset of cultivation has been dated to AD 600–800 in Kerimäki, Punkaharju, Sulkava, Juva (Grönlund 1995; Simola *et al.* 1988, Taavitsainen *et al.* 1998). Similar results have been obtained also in western and northern Lake Ladoga area and from Valamo Island (Taavitsainen *et al.* 1994; Saksä *et al.* 1996; Vuorela and Saarnisto 1997; Vuorela *et al.* 2001; Miettinen *et al.* 2002). In general, the intensifying land-use is recorded ca. AD 1000–1300 in eastern Finland and Ladoga area.

## 3. Methods

### 3.1. Coring, and stratigraphical methods

Sediment cores were obtained from the deepest point of the lake in winter when lakes were ice-covered. In Lake Orijärvi and Lake Kirkkolampi, sediment samples were cored using a light model of a piston corer (Putkinen and Saarelainen 1998) operated with a series of two metre long rigid aluminium rods. In Lake Nautajärvi, a gravity piston corer (Putkinen and Saarelainen 1998) was used. In Lake Kirjavalampi, a hammer-piston corer (Huttunen and Meriläinen 1975) was used for the deeper parts of the sediment. In addition, the freezing technique (Shapiro 1958; Saarnisto 1975) was used to obtain undisturbed sample from the uppermost loose sediment sequence in Lakes Kirjavalampi.

The relative amount of organic matter was determined in Lake Kirjavalampi, Lake Kirkkolampi and Lake Orijärvi as loss-on-ignition (LOI) (Bengtson and Enell 1986). To measure loss-on-ignition, 1 cm thick subsamples were overnight dried (105°C) and then weighted and ignited in a furnace at 550°C for 2 hours. Weight lost on ignition is a measure of organic content of the sediment. Magnetic susceptibility ( $\kappa$ ) is a measure of the concentration and grain size of magnetic minerals and was

determined for Lake Orijärvi and Lake Nautajärvi using a Bartington MS2E1 surface-scanning sensor. Magnetic susceptibility can be used to detect increased erosion within the lake catchment resulting from lake isolation, water level changes and human activities in the catchment (Sandgren and Snowball 2001). In Lake Nautajärvi, annual mineral and organic matter accumulation were determined using digital image analysis of X-ray radiographs. The method used is described in detail by Ojala (2004).

### 3.2. Pollen and charcoal analysis

In the case of homogenous sediments, sub-samples of 1 cm<sup>3</sup> were taken at the uppermost parts of the sediment cores at 1-cm resolution and in the lower parts of the cores 2,5 or 10-cm resolution (see e.g. Bennett and Willis 2001; Whitlock and Larsen 2001). The treatment for pollen samples followed standard procedures, with KOH, acetolysis and HF treatments (Berglund and Ralska-Jasiewiczowa 1986). Safranin-stained glycerine was added to the pollen sub-samples for staining and mounting.

To follow changes in each pollen taxon individually, pollen concentrations (grains cm<sup>-3</sup>) were determined in all the studied lakes by adding *Lycopodium* tablets (Stockmarr 1971) to a known volume of the sediment. In the case of homogenous sediments, a plastic syringe with the nozzle removed, was used to obtain samples of 1 cm<sup>3</sup> (Bennett and Willis 2001). To obtain an equal amount of each varve in Lake Nautajärvi, a rectangle sampler 10 cm long, open from one side and both ends and with a cross-section of 1.74 cm<sup>2</sup> was used. The sampler was pushed into the sediment and sub-samples for pollen analysis were taken with ca. 1.2 cm resolution. Since the sediment accumulation rate was precisely determined in Lake Nautajärvi and Lake Orijärvi sediment, pollen and charcoal accumulation values in species (grains cm<sup>-2</sup> yr<sup>-1</sup>) were calculated in Lake Nautajärvi by dividing the concentrations by the number of varves each sub-sample contained, and in Lake Orijärvi by dividing the concentrations from the years obtained by the age–depth transformation obtained from palaeomagnetic dating.

About 700 arboreal pollen grains (AP) were counted from the subsamples, except for Lake Kirjavalampi where about 500 arboreal pollen grains were counted. Identification of pollen species was based on publications by Erdtman *et al.* (1961), Faegri and Iversen (1989), Moore *et al.* (1991), Reille (1992, 1995) and on the pollen and spore reference collection kept at the Geological Survey of Finland and at the Karelian Institute Dept. of Ecology. The pollen and spore nomenclature is according to Moore *et al.* (1991). The pollen percentages of arboreal (=AP incl. *Picea*, *Pinus*, *Betula*, *Alnus*), non-arboreal pollen (NAP) and broad-leaved trees (=QM incl. *Populus*, *Corylus*, *Ulmus*, *Quercus*, *Tilia*, *Carpinus*, *Fraxinus*, *Fagus*) were calculated from the basic sum of terrestrial pollen grains, P = AP + NAP + QM. The aquatic pollen and spores were calculated from the sums P + AqP and P + Spores. Charcoal particles were counted from the pollen slides against 30% of the *Lycopodium* count achieved in the pollen analysis. The charcoal particles were measured along the longest axis and divided into two size classes. For Lake Kirjavalampi and Lake Nautajärvi the classes were 10–50 µm and >50 µm and in the other lakes 10–25 µm and >25 µm.

Biostratigraphical data treatment and diagrams were handled with Grimm's (1993) TILIA, TILIA GRAPH and CONISS programs and with POLPAL program (Walanus and Nalepka 1999). For the comparison of species richness between samples, a rarefaction analysis (Birks and Line 1992) was carried out that enables a comparison of species richness between samples, as the pollen count is standardized to a single sum. To reduce the element of subjectivity, the pollen sequences in Lake Nautajärvi, Lake Kirjavalampi and Lake Orijärvi were divided into pollen assemblage zones numerically using the CONISS – program and POLPAL program (Grimm 1991; Walanus and Nalepka 1999). Aquatics, spores and pollen types not exceeding 1% of the sum were excluded from the calculation.

### 3.3. Dating

For Lake Kirjavalampi, dating of the profile was based on three conventional  $^{14}\text{C}$  determinations. For Lake Kirkkolampi, two conventional dates from bulk sediment, and three accelerator mass spectrometry (AMS) dates from terrestrial macrofossils were determined. Conversion from radiocarbon ages to calibrated calendar years was performed using the radiocarbon calibration program CALIB version 5.0 (Stuiver and Reimer 1993) with the IntCal04 calibration dataset (Reimer *et al.* 2004). An age-depth model was constructed with the PC program TILIA (Grimm 1991) using linear interpolation between the median probabilities of the calibrated dates. For Lake Nautajärvi annually laminated sediment, dating was based on constructed varve chronology. The subsampling methods and physical analyses used to document Lake Nautajärvi varves are described in detail in Tiljander *et al.* (2002) and in Ojala and Francus (2002).

Paleomagnetic dating is based on the orientation of small magnetic grains parallel to the Earth's prevailing magnetic field during the sedimentation process (see e.g. Thompson and Oldfield 1986; King and Peck 2001). In an undisturbed sedimentary environment, the orientation remains unchanged and sediment deposits possess records of natural remnant magnetization (NRM) of the palaeosecular variations (PSV) of the Earth's magnetic field. Both Lake Nautajärvi (Ojala and Tiljander 2003) and Lake Orijärvi provided a strong and stable signal of paleosecular variation (PSV). With an independent varve chronology for paleomagnetic dating, Lake Nautajärvi was used as a reference curve to construct an age-depth transformation for homogenous sediment of Lake Orijärvi by visually matching NRM elements – declination, inclination, and intensity. Sediment sampling for paleomagnetic measurements and testing of the stability of NRM followed Ojala and Tiljander (2003).

## 4. Summary of papers

### 4.1. Paper I

*Alenius, T., Grönlund, E., Simola, H. and Saksa, A. 2004. Land-use history of Riekkalansaari Island in the northern archipelago of Lake Ladoga, Karelian Republic, Russia. Vegetation history and archaeobotany 13: 23–31.*

This study formed part of the research project entitled "Land-use history of Karelian Isthmus and NW Ladoga region – a palaeoecological and archaeological study" financed by the Academy of Finland, at the University of Joensuu, Karelian Institute, Department of Ecology. The objective of the project was to determine the history of human settlements and development of agriculture on the Karelian Isthmus and northwest Ladoga region.

The study site was situated near the town of Sortavala in the northern archipelago of Lake Ladoga, northwest Russia. The study lake on Riekkalansaari Island was selected because it is situated close to the dwelling site of Nukuttalahti, which according to Saksa (1998) represents an example of the scanty traces of the indigenous Metal period culture. The samples for pollen and charcoal analyses were taken from the sediment of Lake Kirjavalampi on Riekkalansaari Island.

Lake Kirjavalampi was isolated from Lake Ladoga between 1460–1300 BC, when the River Neva was formed as a new outlet for Lake Ladoga and the water level rapidly fell. The oldest pre-agricultural phase, indicated by a decrease in *Picea* and an increase in mineral content, was recorded in Riekkalansaari ca. AD 70. Direct evidence of the beginning of cereal crop cultivation on Riekkalansaari Island is from the Merovingian period, about AD 600. A marked intensification in agricultural activities occurs around AD 1200, and the most intensive period of land-use is recorded between AD 1700–1850. This stage can be interpreted as a combination of slash-and-burn and

permanent field cultivation. A clear decline in agricultural activities can be seen in the uppermost zone. This zone represents the twentieth century, when the western and northern shores of Lake Ladoga were ceded to the Soviet Union in World War II, and the main role of the area became providing timber for the city of Leningrad (Laine 1999).

## 4.2. Paper II

*Ojala, A.E.K. and Alenius, T. 2005. 10 000 years of interannual sedimentation recorded in the Lake Nautajärvi (Finland) clastic-organic varves. Palaeogeography, Palaeoclimatology, Palaeoecology 219: 285–302.*

This paper discusses the formation and structure of varves in Lake Nautajärvi, central southern Finland and primary factors controlling sediment influx into the lake. Varved lake sediments provide a high-resolution proxy record of the palaeoenvironment and potentially provide information about the past winter snow accumulation via spring snowmelt discharge, and catchment erosion and transportation of detrital mineral matter into the lake. Vegetation has an important role in the sediment yield from the catchment. Forest fires and clearance, ditching and agriculture all typically increase the sediment transportation into the lake. Distinguishing the primary factors controlling sediment influx into the lake from the alterations caused by human activity is important. A detailed pollen analysis was carried out to distinguish and estimate the magnitude of the human impact from the changes caused by climatic variability on varve formation and thickness.

Lake Nautajärvi was isolated around 7675 BC. Sedimentary evidence shows a distinct decrease in the rate of catchment erosion and transportation into the lake between 8000 and 7000 BC due to the stabilization of the lake-catchment system and the dispersal of vegetation around the exposed lake. Evidence from the sediment's physical properties and pollen analysis suggests that the primary stabilization of the catchment took about thousand years, but in fact a slowly decreasing supply of erodable material in the drainage system is actually seen throughout the entire evolution of the Lake Nautajärvi basin.

More pronounced phases of catchment erosion, likely related to severe winters in Scandinavia, occurred in 7590–7530 BC, 7450–7400 BC, 7220–7110 BC, 7000–6000 BC, 5400–5200 BC, 4400–4000 BC, 2700–2400 BC, and ca. 1500 BC–AD 300 and culminating around 100 BC. A period of very low catchment erosion and sediment transportation can be seen in the sediment data around 7000 BC, and between AD 1000 and AD 1200 possibly indicating attenuated spring floods caused by milder and wetter winters and considerably lower winter precipitation in the form of snow. The latter period corresponds with the last historically recorded warm interval in Europe, known as the Medieval Climate Anomaly.

Human activity, seen in the pollen data clearly from AD 300 onwards makes the climate-related interpretation of the sediment data more difficult. A marked intensification of agricultural activity is seen in pollen data around AD 1427 onwards, and it is likely that the maximum mineral matter input in AD 1420–1470 can be related to land-use. In the uppermost parts of sediment, increased mineral matter influx into the lake is likely related to the intensive land-use in the 19<sup>th</sup> and 20<sup>th</sup> centuries.

## 4.3. Paper III

*Alenius, T. and Laakso, V. 2006. Palaeoecology and archaeology of the village of Uukuniemi, eastern Finland. Acta Borealia 23, No.2: 145–165.*

This article discusses the history of settlement in Uukuniemi village, eastern Finland in the light of archaeological and palaeoecological studies. The vicinity of Papinniemi, Greek Orthodox settlements that existed in Karelia in the 14<sup>th</sup>–17<sup>th</sup> centuries (Laakso 2003) was an important factor

in the selection of the basin for pollen analysis. Archaeological evidence of settlement preceding the Greek Orthodox settlements is very scarce. In this respect, the region is a typical example of the vast territories in eastern Finland that lay outside the quite compact settled areas such as Mikkeli area.

Altogether four meter long sediment cores were analysed for loss-on-ignition, pollen and chacoal particles. Both sediment percentages and concentrations were calculated. Two conventional dates from bulk samples and three AMS dates from macrofossils were determined.

There is no archaeological evidence of permanent settlement from Early Metal Period or Iron Age settlement in the area of Uukuniemi. Palaeoecological results, however, indicate that anthropogenic impact, possibly grazing, has influenced the vegetation from about 1950–1800 BC onwards. Cultivation has been practised in the area during the Middle and Late Iron Ages (AD 400–1300) starting from ca. AD 300. Marked intensification of agricultural activities and cultivation in permanent fields took place around AD 800. An increase in the role of field cultivation and a decline in the use of fire is visible from AD 1520–1600 onwards.

The most probable explanation for the discrepancy between archaeological and palaeoecological material is that the archaeological material is underrepresented. It could be, that archaeological material has not been found because land use and archaeological research has been limited. Other plausible explanations for the lack of Iron Age sites is that they were destroyed, imprecisely dated, have not been reported to archaeologists, or were not recognized by local people. It seems plausible that settlements small in area were isolated from each other by large forested areas, which makes them difficult to find by archaeological methods.

#### 4.4. Paper IV

*Alenius, T., Mikkola, E. and Ojala, A.E.K.: History of agriculture in Mikkeli Orijärvi, eastern Finland as reflected by palynological and archaeological data. Vegetation History and Archaeobotany. In press.*

Kihlinpelto fields, situated in the province of South Savo, ca. 4 km from the centre of the city of Mikkeli is of great socio-economic value because it is the easternmost permanent prehistoric field complex found in Finland (Mikkola and Talvio 2000; Mikkola 2004). Radiocarbon dated macrofossils from the lowermost field layer suggests that the oldest field phase dates to the Merovingian period, AD 600–780.

To determine the exact date of the introduction of cultivation at permanent fields, a detailed and high resolution pollen and charcoal analysis that provides a continuum of vegetation dynamics over the past 9000 years was constructed from the sediment sequence from Lake Orijärvi. The lake is situated in the immediate vicinity of the permanent prehistoric fields of Kihlinpelto, the distance between fields and the coring position being ca. 700 metres. This paper discusses the onset of cultivation and the relationship between swidden and permanent field cultivation. The Lake Orijärvi sediment sequence was dated using the palaeomagnetic dating method.

The earliest changes in the pollen diagram, possibly anthropogenic in origin, are visible in the pollen data from 1630 BC onwards. Indications of human impact become more evident by the end of the Early Metal Period, from around 500 BC onwards, when pollen data suggests human impact, probably grazing in a forested environment. The actual onset of cultivation dates to the Merovingian period around AD 600. The date agrees well with the timing of the onset of cultivation as shown by the AMS dated *Hordeum* grain found in the oldest field phase. Comparisons between macrofossil and pollen data revealed a major discrepancy between these two data. Of the 87 specimens of *Cerealia* found at the prehistoric fields, as many as 57 are *Hordeum vulgare*, 3 *Secale cereale*, and 3 *Avena sativa* (or *Festuca pratensis*). However, in the pollen data the



earliest cultivated pollen type is *Secale* and it remains the only cultivated pollen type in the pollen data until AD 1220, when *Hordeum* pollen appears in the pollen data. Discrepancies between the macrofossil and pollen data suggests that the full impact of permanent field cultivation is not reflected in the pollen data during the first 600 years. This likely results from the distance between the fields and the coring position; the relatively large size of the lake in relation to the relatively small size of the prehistoric field area, and the differing dispersal and productivity characteristics of cultivated species.

## 5. Discussion

### 5.1. Early Holocene (8000 to 6000 BC)

The isolation of Lake Kirjavalampi on the northern shore of Lake Ladoga has been a relatively recent event, taking place ca. 1460–1300 BC compared to long sediment cores from Lake Kirkkolampi, Lake Orijärvi and Lake Nautajärvi. All cores extend back to the Early Holocene and isolation from the Baltic basin took place ca. 9600 BC, 8600 BC and 7675 BC, respectively. The isolation then corresponds to the beginning of Mesolithic period, which took place from 8800–5000 BC. At the initial phase of sedimentation after isolation, the gradually decreasing content of mineral matter and magnetic minerals together with low pollen accumulation and influx values suggest reworking of the sediments either in the drainage area or in the lake itself. Dispersal of vegetation around the exposed Lake Nautajärvi, Orijärvi and Kirkkolampi is demonstrated at the basal parts of the sediment sequences. High values of local lakeshore vegetation, especially *Salix*, *Cyperaceae*, *Poaceae* and *Polypodium* are abundant around the basins. In the open landscape, the amount of long-distance transport may be substantial. Of the surrounding vegetation, *Pinus* and *Betula* dominate, and *Corylus*, *Ulmus* and *Populus* occur in 1–3% proportions. Decrease in magnetic susceptibility, increase in LOI together with increase in pollen accumulation and influx values reflects the stabilization of the sedimentary conditions, as sediment changes to more organic sediment, typical for small lakes. A summary diagram joining the 4 sites is presented on the figure 2.

Lake Nautajärvi pollen records the establishment and expansion of *Alnus*, associated with rises in the *Corylus*, *Ulmus* and *Betula* curves, which is visible between 7200 BC and 7000 BC. This date agrees well with regional pollen diagrams in central Finland and in the Salpausselkä region, where the expansion of *Alnus* dates to ca. 7000 BC – 7300 BC (Hyvärinen 1972; Tolonen and Ruuhijärvi 1976; Vasari *et al.* 1996). At Lake Orijärvi, expansion of *Alnus* is visible around 7270 BC, and at Lake Kirkkojärvi around 6840 BC. When *Alnus* became established in the vegetation, the mean pollen accumulation values in Lakes Nautajärvi and Orijärvi were 1000 and 850 grains  $\text{cm}^{-2} \text{yr}^{-1}$ , respectively. Pollen of mixed pine–deciduous forest dominates in the diagrams, *Betula* (50%), *Pinus* (30%) and *Alnus* (10%) being the most common pollen types.

### 5.2. Middle Holocene (6000 to 2500 BC)

Between 6000–2500 BC, the annual mean temperatures were ca. 1.5–2 °C higher than at present (Heikkilä and Seppä 2003) and this period represents the Holocene thermal maximum. In archaeology, this roughly corresponds to the Neolithic period covering the time span from 5000–1800 BC. The average age of the rise in the *Tilia* pollen curve in the southern half of Finland is approximately 5480–5300 BC (Tolonen and Ruuhijärvi 1976). In Lake Kirkkolampi, the arrival of *Tilia*, as deduced from increasing pollen concentrations, is seen around 6600 BC. In Lake Orijärvi, the *Tilia* pollen accumulation rate exceeds 100 grains  $\text{cm}^{-2} \text{yr}^{-1}$  by 5000 BC, a value that

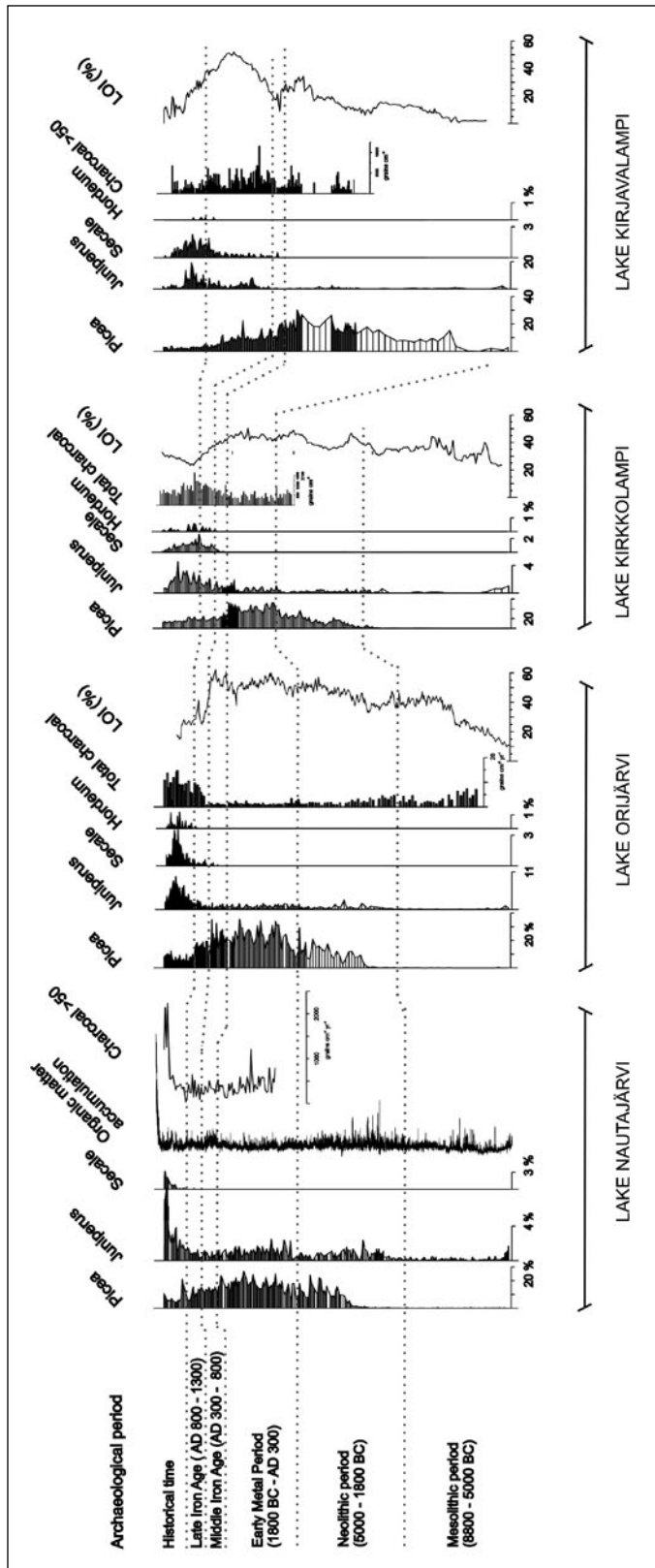


Figure 2. A summary diagram of the study sites showing only *Picea*, *Juniperus*, *Secale*, *Hordeum*, charcoal and loss-on-ignition (LOI) values. Instead of LOI, organic matter accumulation is presented for Lake Nautajärvi. The archaeological periods discussed in the text are on the left side of the diagram and separated on the diagram by horizontal lines.

can be interpreted as a local presence (Eide *et al.* 2006). Compared to Lake Orijärvi, the general accumulation rate in Lake Nautajärvi remains substantially low, indicating that *Tilia* was never as abundant around Lake Nautajärvi as it was around Lake Orijärvi. At Lake Nautajärvi, the expansion of *Tilia* is demonstrated from 4600 BC onwards, reaching the highest influx values, over 50 grains  $\text{cm}^{-2} \text{yr}^{-1}$  by 4555 BC.

During the latter part of Middle Holocene, a steep rise in *Picea* values and a decreasing trend in the pollen percentages and accumulation rates of broad-leaved trees like *Populus*, *Corylus*, *Ulmus* and *Tilia* are the dominant factors in the pollen diagrams. *Picea abies* spread to Fennoscandia in the mid- to late Holocene in high population densities from east to west into the Baltic Republics (Giesecke and Bennett 2004), and begins to expand south of Lake Ladoga and Finland about 6000 BC. To indicate local or regional presence in forested areas, Giesecke and Bennett (2004) used a threshold of 1% *Picea* of terrestrial pollen criterion, and 5% and 10% values limit for the final expansion. In the commune of Uukuniemi, easternmost Finland, *Picea* pollen are recorded sporadically from 6040 BC onwards, reaching 1% of total terrestrial pollen by 4340 BC. An increase from 5% to 10% is visible between 3540 BC and 2440 BC. At Lake Orijärvi, *Picea* pollen is recorded continuously from 6850 BC onwards, reaching 1% by 6520 BC, 5% by 6310 BC and 10% by 3460 BC. In Lake Nautajärvi sediment, the limit of 1% is reached at 3500 BC, the 5% limit around 3300 BC, and the 10 % limit around 3010 BC.

### 5.3. Late Holocene (2500 BC to present)

#### 5.3.1. Early Metal Period (1800 BC – AD 300)

Temperature reconstructions (Heikkilä and Seppä 2003) show a gradual cooling of the climate ca. 1.5 °C from ca. 2500 BC. A gradual decrease in broad-leaved tree species such as *Alnus*, *Corylus*, *Quercus* and *Tilia* is shown in the pollen diagrams.

In the studied lakes in eastern and central Finland, the first modifications in the pollen data, apparently connected to anthropogenic impacts, date to the beginning of Early Metal Period. Forests disturbances are reflected by an increase in light demanding *Juniperus*, likely connected to grazing and animal husbandry (Behre 1981; Vuorela 1986; Hægström 1990; Gaillard *et al.* 1992; Grönlund 1995; Pykälä 2001; Poska and Saarse 2002). This change takes place in Orijärvi ca. 1630 BC, in Lake Kirkkolampi ca. 1950–1800 BC and in Lake Nautajärvi ca. 1600 BC onwards.

Increases in *Juniperus* values in low degrees are associated with apophytes such as *Rumex*, *Plantago major/media*, *Plantago lanceolata* and *Urtica*, which are favoured by anthropogenic activity. At Lake Orijärvi, a decrease in deciduous trees like *Betula*, *Alnus*, *Populus* and *Ulmus* is seen. Pollen productivity estimates (Hjelle 1998; Broström *et al.* 2004) have shown that *Rumex acetosa* -type, *Juniperus communis* and *Plantago lanceolata* have high pollen productivity estimates, suggesting a significant background pollen influence. This suggests that sporadic and low percentages of those species need not necessarily be indicative of local pastoral activity, but may indicate human activity on a regional scale. In Lake Kirkkolampi increase in *Isoëtes*, supports the assumption of local anthropogenic activity. Vuorela (1980) demonstrated in her studies from southern Finland that the microspores of *Isoëtes* increase significantly at the stage of sedimentation at which evidence of incipient land use is visible.

No pollen of cultivated species was found to be connected with grazing evidence at the beginning of the Early Metal Period. In Finland, the first cultivated cereal was barley (*Hordeum*). Rye (*Secale*) was established as a cultivated species in Finland as late as the Iron Age (Vuorela 1999; Lempiäinen 1999). The lack of wind pollinated *Secale* on the cultivated species composition before the Iron Age causes substantial bias in registering the cultivation events in the pollen diagrams before

the Iron Age. Cultivation of rye in relatively large slash-and-burn plots in the Iron Age is likely to be first registered in the sediments, compared to relatively small permanent fields with barley as a cultivated species. The picture provided by cultivated pollen types is likely to become more distorted by the fact, that the pollen of *Hordeum* is poorly represented even in the immediate vicinity of the fields (Vuorela 1973; Hall 1989; Bakels 2000). In relation to wind pollinated *Secale*, pollen of autogamous *Hordeum* remains trapped between the glumes releasing very little pollen into the air (Faegri and Iversen 1989). This was well demonstrated by Vuorela (1973) and Bakels (2000). In the study by Bakels (2000) pollen analysis from a core obtained from a peat deposit only 10 m from the field's border revealed only a weak signal of a possible field, with no *Cerealia*-type pollen connected to excavated Middle and Late Bronze Age fields. All in all, since other indicators pointing to cultivation of cereals are missing, cultivation of cereals around the studied sites before the Early Iron Age seems unlikely.

By the end of the Early Metal Period, between 500 BC – AD 300, a clear anthropogenic impact becomes visible in the eastern study lakes. Interestingly, according to palaeorecords, an expansion of human impact in the Pre-Roman Iron Age (500 BC – 1) is traceable all over Estonia (Poska *et al.* 1999). In the eastern study sites, anthropogenic impact is registered in the sediments somewhat differently, but nevertheless is likely to be anthropogenic in origin. In Lake Orijärvi, a decrease in broad-leaved trees like *Corylus* and *Ulmus* together with increasing values of *Urtica* and apophytes characterized by long-distance transport such as *Calluna* and *Rumex* (Hjelle 1998; Mazier *et al.* 2006) is recorded from ca. 500 BC onwards. *Urtica* can be related to soil richness (total N) and is associated with foothpaths, ruderal communities and settlement (Behre 1981; Gaillard *et al.* 1992; Mazier *et al.* 2006) together with *Rumex*, which is also related to settlement (Hicks and Birks 1996; Räsänen 2001). In Lake Kirkkolampi, the increase in *Juniperus*, *Melampyrum*, *Filipendula*, *Ranunculus* together with a decrease in *Alnus* is recorded ca. 260–60 BC onwards, and in Lake Kirkkolampi, a simultaneous increase in *Isoëtes* can be associated with erosion around the lake (Vuorela 1980). In general, apophyte taxa in the studied sites indicate increasing areas of fields and pastures with some grazing pressure (Behre 1981; Gaillard *et al.* 1992; Hicks and Birks 1996; Räsänen 2001).

Pollen studies in Finland have demonstrated that the decrease of *Picea* accompanies with the beginning of slash-and-burn cultivation (e.g. Tolonen 1978; Pitkänen and Huttunen 1999; Pitkänen 2000). Spruce is susceptible to fires and does not survive even weak surficial fires (Sarvas 1937). Simulations have shown that the heavy pollen of *Picea* has a considerably smaller pollen source area compared to light pollen types such as *Betula* and *Alnus* (Sugita 1994). Therefore, *Picea* pollen values reflect the nearest forest areas to the study sites, becoming more underrepresented with increasing distance from the forest edge, while long-distance dispersed *Betula*, *Alnus* and *Pinus* become overrepresented in the pollen diagrams. In the palaeorecords, decreasing *Picea* pollen values are first seen from ca. AD 70 onwards at Lake Kirjavalampi in Sortavala, and from around AD 300 onwards both at Lake Nautajärvi in central Finland and at Lake Kirkkolampi in Uukuniemi. At Lake Kirkkolampi, decreasing pollen values are accompanied by *Rumex* and *Secale* pollen, likely connected with slash-and-burn cultivation. At Lake Nautajärvi, decreasing *Picea* pollen accumulation rates are associated with increasing *Poaceae* and *Rumex* values, but without presence of pollen from cultivated species.

In addition to decreasing *Picea*-values, changes in the catchment area likely reflect local anthropogenic presence (e.g. Simola 2000). Increasing proportions of mineral matter content from the catchment due to erosion is recorded in Lake Kirjavalampi in Sortavala from AD 70 onwards, and the general rate of erosion into the lake also increases in Lake Kirkkolampi in Uukuniemi from ca. 260–160 BC onwards. In Lake Orijärvi, a sharp erosion peak is visible ca. AD 30. In Lake Nautajärvi, increased influx of nutrients from the catchment have increased primary productivity in the lake, and therefore increased accumulation of organic matter between AD 300 and AD 600.

### 5.3.2. Middle Iron Age (AD 300–800) and Late Iron Age (AD 800–1150/1300)

#### Slash-and-burn cultivation

In Lake Kirkkolampi in Uukuniemi, *Secale* pollen, likely connected to slash-and-burn cultivation, was recorded continuously from the beginning of the Middle Iron Age ca. AD 300 onwards. *Secale* pollen is also recorded continuously in other two eastern study sites, Lake Kirjavalampi and Lake Orijärvi, from the beginning of the Merovingian period, ca. AD 600 onwards. At Lake Nautajärvi in central Finland, a similar trend of increasing human impact in the form of a more prominent decrease in pollen accumulation values of *Picea*, *Betula* and *Alnus*, is demonstrated from AD 600 onwards, but still without direct cultivation evidence until the Late Iron Age, ca. AD 880, when the *Secale* pollen appears in the pollen assemblage.

At Lake Kirkkolampi and Lake Orijärvi in eastern Finland, increased amount of charcoal particles are recorded from the 19<sup>th</sup> and 20<sup>th</sup> century, and in both lakes is associated with high abundances of *Secale*, *Rumex*, *Poaceae*, *Pteridium* and *Juniperus*, clearly indicating slash-and-burn cultivation and the existence of fields in the area (Sarmaja-Korjonen 1992; Pitkänen 1999; Grönlund 1995). At Lake Kirjavalampi, in Sortavala, the increase in the number of charcoal particles coincides with the beginning of the rye cultivation ca. AD 600 onwards, but is not associated with an increase in field pollen values of *Poaceae*, *Rumex*, *Pteridium* and *Juniperus* until the beginning of 13<sup>th</sup> century. It can be argued, that the slash-and-burn plots were likely situated somewhere in the region, but not in the local pond surroundings.

At Lake Nautajärvi, in central Finland, the general trend of charcoal particle accumulation was decreasing, reaching the lowermost values around AD 1300 until an increasing trend is recorded from AD 1300–1500 to the uppermost analysed levels. Seasonal accumulation of minerogenic matter suggests that Lake Nautajärvi is receiving a lot of material from the catchment. Since the charcoal curve shows a similar trend until AD 1300–1500, it could be hypothesized, that the charcoal record up to AD 1300–1500 may represent terrestrial input from the inflows and maybe cultivation along them. The slash-and-burn cultivation around the lake is recorded in the charcoal data from around AD 1500 onwards.

Even when no general conclusions can be made on the basis of single case, it could also be hypothesized, that the late registering of slash-and-burn cultivation is connected to differences in cultivation methods between western and eastern Finland. In old traditional agriculture, arable and slash-and-burn cultivation were the principle methods of crop cultivation, and while both cultivation methods were common during the 18<sup>th</sup> and 19<sup>th</sup> centuries, in the western parts of Finland arable cultivation was more important, and in eastern parts slash-and-burn cultivation remained the predominant method of cereal-crop cultivation in eastern Finland until the late 19<sup>th</sup> century (Heikinheimo 1915; Soininen 1974).

#### Permanent field cultivation and local settlement

According to macrofossil and archaeological data, an Iron Age farming settlement that included *Hordeum* cultivation in permanent fields was established in the Mikkeli area as early as the 7<sup>th</sup> century AD, possibly by the 6<sup>th</sup> century AD. Of the 87 macrofossils of *Cerealia* found at the prehistoric fields, as many as 57 were *Hordeum vulgare*; only 3 were *Secale cereale*; and 3 were *Avena sativa* (or *Festuca pratensis*). In the pollen data, *Secale* pollen, however, remains the only cultivated pollen type until AD 1220, when *Hordeum* pollen is first recorded. According to Soininen (1974) due to acidity, the "huuhta" -cultivation of primal forests consisting mainly of conifers was best suited for swidden rye. Therefore, *Secale* formed the most important crop in slash-and-burn plots, whereas *Hordeum* was least suited for slash-and-burn cultivation, and it was first to be cultivated on permanent fields.

Assuming that *Secale* indicates slash-and-burn cultivation and *Hordeum* cultivation on permanent fields on the Middle and Late Iron Age, the pollen data in Lake Orijärvi reflects predominantly slash-and-burn cultivation during the first 600 years. From around AD 800 onwards, a rapid increase in allochthonous material influx in Lake Orijärvi clearly indicates increased erosion and the presence of permanent fields. This may coincide with the increased size and number of the fields, all five ancient fields may have been under cultivation during the 9<sup>th</sup> century with a total field area about 1000 m<sup>2</sup>. Intensive modification of the environment indicating permanent settlement and intensive human presence can be seen in increase in apophytes of pollen indicative of meadows and pastures such as *Humulus/Cannabis*-type, Brassicaceae, Ranunculaceae, *Potentilla* and *Urtica*, about hundred years later, from AD 900 onwards and also taxon characterized by long-distance transport such as *Juniperus*, *Poaceae* and *Rumex*. In contrast to long distance transported taxa, Ranunculaceae and *Potentilla* can be related to grazing at a local scale (Mazier *et al.* 2006). Additional evidence of local settlement around Lake Orijärvi is provided by the changes observed in aquatic pollen. As a result of external input of nutrients, a sharp increase in *Nymphaea* proportions is demonstrated between AD 800–1000 at Lake Orijärvi.

In the Lake Kirkkolampi pollen data, pollen of *Hordeum* was recorded from ca. AD 800 onwards, pointing to cultivation on permanent fields. Also pollen types traditionally connected to permanent settlement such as *Humulus/Cannabis*-type, *Centaurea*, *Urtica*, Brassicaceae and Campanulaceae appear in the pollen assemblage from ca. AD 800 onwards. An increase in *Juniperus* can be associated with an increase in field area, and a general trend of opening up of the vegetation can be seen in the decreasing portion of tree pollen and an increasing proportion of non-arboreal pollen. NAP percentages, however, are insufficient to quantify the percentage cover of open land in open and semi-open landscapes and they are likely to underestimate the proportion of open area in the pollen source area (Gaillard *et al.* 1992, 1994; Broström *et al.* 1998; Sugita *et al.* 1999). In the open landscape, Cerealia -pollen percentage is expected to be overestimated, whereas in semi-open landscape, the values are likely to be underestimated (Sugita *et al.* 1999).

Even when the pollen and charcoal data in Lake Kirjavalampi in Sortavala clearly indicates slash-and-burn cultivation in the region from the beginning of the Merovingian period, ca. AD 600 onwards, local occupation and the presence of livestock are traceable in the pollen diagram considerably later, from the beginning of the Crusade period, ca. AD 1260 onwards. At this time, an increase in *Poaceae*, *Rumex*, *Pteridium* and *Juniperus* values are recorded. The steadily increasing organic content can be interpreted as signs of eutrophication together with a strong increase in pollen of aquatic *Nymphaea*, and wetland species such as Cyperaceae, *Equisetum*, which together with an increase in *Salix* and *Filipendula* point to wet meadows in the surroundings of the pond.

At Lake Nautajärvi, the pollen data shows the strong presence of apophyte and anthropochore taxa including *Poaceae*, *Rumex*, *Secale*, and *Juniperus* from ca. 1430 AD onwards, but all these taxa are high pollen producers (Broström *et al.* 2004), and could be regional in origin and need not to represent intensive local habitation. The maximum mineral matter input in AD 1420–1470, however, implies that shores have been affected by land-use. Pollen of *Hordeum* is recorded from 1560 AD onwards, likely reflecting cultivation in the immediate vicinity of Lake Nautajärvi.

### 5.3.3. Historical time (AD 1150/1300 – present)

According to Soininen (1974) Finland's population increased sixfold between the 1720's and 1870's, which led to an increasing demand for agricultural output. Charcoal analyses constructed from eastern Finland (Pitkänen 2000) show that the average local fire interval was ca. 70–80 years before settlement in the area increased the fire frequency considerably. According to dendrochronological studies, during the most intense period of slash-and-burn, from AD 1750 to AD 1850, the average fire

rotation time was shortened to only 30–40 years in eastern Finland (Lehtonen 1997). The highest values of *Secale* pollen are recorded both in Lake Orijärvi in Mikkeli and Lake Kirjavalampi in Sortavala between ca. AD 1700–1900, and can be associated with the most intensive slash-and-burn period, when the landscape in eastern Finland was generally open and largely devoid of mature coniferous forests (e.g. Grönlund 1995). In the pollen diagrams, the change in tree pollen composition from *Picea* dominated forests to young forests with *Betula* and *Alnus* as dominating species can be seen.

In the 18<sup>th</sup> and 19<sup>th</sup> centuries, arable cultivation was expanding, while slash-and-burn cultivation was diminishing (Soininen 1974). In Lake Kirkkolampi in Uukuniemi, a decline in the use of fire is visible from ca. AD 1520–1600 onwards, and may be connected with an increase in the role of field cultivation. The absolute and relative field cultivation area per house in the village of Uukuniemi was multiplied between AD 1637–1690, and in the parish of Sortavala, crop cultivation was also predominantly based on permanent fields by AD 1637 (Saloheimo 1977). Since hay production was based entirely on meadows of poor standard, extensive meadow areas were needed (Soininen 1974). In Uukuniemi, the high values of *Juniperus* and *Poaceae* are likely connected with the extensive meadow areas during the old traditional agriculture in Finland, when livestock was mainly kept for haulage power in fieldwork and for manure to fertilizing the fields.

## 6. Conclusions

Four lakes small to medium size, situated between 61° 40' and 61° 50' in central and eastern Finland and Russian Karelia, where studied. Lakes Kirkkolampi, Orijärvi and Nautajärvi were all isolated in the early Holocene, at the beginning of Mesolithic period between 9600 BC and 7675 BC, whereas the isolation of Lake Kirjavalampi on the northern shore of Lake Ladoga was a relatively recent event, taking place after the formation of the River Neva about 1460–1300 BC.

No indications of anthropogenic impact were found in the studied lakes at the time of Mesolithic or Neolithic Stone Age. In long sediment records from Lake Kirkkolampi, Lake Orijärvi, and Lake Nautajärvi, an anthropogenic impact is visible from 1880 BC – 1600 BC onwards, dating to the beginning of the Early Metal Period. Changes in the forest composition, especially with an increase in *Juniperus* with special demands of light, coincides with the type of landscape created by grazing animals. According to pollen data, it appears that primitive cattle rearing was adopted around the studied lakes in Finland at the beginning of the Early Metal Period ca. BC 1900/1700.

By the end of the Early Metal Period, between ca. 500 BC – AD 300 apophyte taxa, indicating increasing areas of fields and pastures, becomes gradually visible in all the eastern study lakes. In the eastern study sites, *Secale* pollen is recorded in the Middle Iron Age, from AD 300–600 onwards, and can be associated with slash-and-burn cultivation, with an increase in fire frequency in Mikkeli–Uukuniemi area from the beginning of the Viking Age, AD 800–900 onwards, and in the northern shore of Lake Ladoga from AD 600 onwards. Compared with eastern study sites, cultivated pollen types in the study site in central Finland are registered relatively late, from AD 880 onwards, even when a clear anthropogenic impact was recorded from AD 300 onwards.

Pollen data alone could not demonstrate the onset of cultivation on permanent fields indicated by macrofossil and archaeological data as early as in the 7<sup>th</sup> century AD, possibly in the 6<sup>th</sup> century AD in Lake Orijärvi. This demonstrates the limitations of pollen analysis as a tool to study prehistoric cultivation events. Cultivation of rye is overrepresented in the pollen diagram in relation to poorly produced and dispersed barley. In addition, cultivation of barley will be registered in the sediment only when the fields are situated in the immediate surroundings of the sampling site. On the basis of palaeoecological and macrofossil data, however, it can be argued that slash-and-burn cultivation, grazing and small-scale cultivation on permanent fields occurred simultaneously from ca.

AD 600 onwards around Lake Orijärvi in Mikkeli. Permanent settlement becomes visible in Lake Kirkkolampi in Uukuniemi from ca. AD 800 onwards. In Sortavala, local activity becomes visible from ca. AD 1260 onwards, even when slash-and-burn cultivation was being practiced on the region from ca. AD 600 onwards.

In general, the picture provided by palaeoecological material is the low intensity of human impact in the Early Metal Period until the Late Iron Age, which seems the most plausible explanation for the scarcity of archaeological material in the Early Metal Period.

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