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ORIGINAL ARTICLE

Neolithic land use in the northern Boreal zone: high-resolution multiproxy analyses from Lake Huhdasjärvi, south-eastern Finland

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Abstract Two high-resolution pollen and charcoal analyses were constructed from sediments obtained from a small bay in eastern Finland in order to gain information on human activity during the Neolithic Stone Age, 5200–1800 BC. We used measurements of loss on ignition (LOI), magnetic susceptibility and geochemical analyses to describe the sedimentological characteristics. Palaeomagnetic dating and measurements of ^{137}Cs-activity were supported by ^{14}C-datings. The analyses revealed human activity between 4400 and 3200 BC, which is synchronous with archaeological cultures defined through different stages of Comb Ware pottery types and Middle Neolithic pottery types with asbestos as a primary temper. Direct evidence of *Hordeum* cultivation was dated to 4040–3930 cal BC. According to the pollen data, more significant effort was put into the production of fibres from hemp and lime than the actual cultivation of food.

Keywords Pollen analysis · South-eastern Finland · Land use · Neolithic · Lake sediments · Geochemistry

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Introduction

In eastern Fennoscandia (Finland and the Republic of Karelia, Russia), the Neolithic period begins with the appearance of pottery ca. 5300–5200 BC (Pesonen et al. 2012; Nordqvist and Mökkönen 2016). In the Baltic States, this took place a few decades earlier (Piezonka 2012). According to the traditional interpretation, in eastern Fennoscandia and in the Baltic States, the beginning of the Neolithic period was not associated with agriculture. Traditionally, the earliest agriculture in much of northern Europe has been associated with the much later Corded Ware phenomenon, which spread from central Europe to eastern Fennoscandia in the early third millennium BC (e.g. Carpelan 1999; Zvelebil and Lillie 2000). High-resolution pollen analyses obtained from southern and eastern Finland (Alenius et al. 2013; Augustsson et al. 2013), western Russia (Königsson et al. 1997; Vuorela et al. 2001) and Estonia (Kriiska 2003; Poska et al. 2004; Poska and Saarse 2006), as well as archaeological data from the same area (Kriiska 2009; Nordqvist and Kriiska 2015), have challenged the traditional interpretation of northern European prehistory. There is increasing evidence that the initial stage of cereal cultivation in northern Europe took place at the very beginning of the Neolithic Stone Age, ca. 5200–4000 BC, concurrent with the appearance of pottery in eastern Fennoscandia. On the basis of circumstantial evidence, it has been proposed that eastern pottery technology and early cultivation spread concurrently into the north-eastern part of the Baltic Sea through the same networks (Mökkönen 2010, 2011), but until recently, no data were available to actually demonstrate the connection in Finland.

In south-eastern Finland, the evidence from high-resolution pollen analysis indicates Stone Age cultivation around Lake Huhdasjärvi, where pollen originating

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from *Fagopyrum esculentum* has been dated to the transition period between the Mesolithic and Neolithic periods, 5370–5060 cal BC (2δ). This was then followed by *Hordeum* pollen dated to ca. 4260 BC and 2160 BC (Alenius et al. 2013). In Estonia, some pollen evidence shows cultivation during the fifth millennium BC (Kriiska 2009). In addition, several older, less accurate pollen analyses point to disturbances in vegetation and the sporadic presence of Cerealia-type pollen from the fifth millennium cal BC onwards in the area south of the Arctic Circle in Finland (Reynaud and Hjelmroos 1980).

In a wider perspective, more evidence of cultivation and anthropogenic disturbances in vegetation appears around 4000 BC when Typical Comb Ware spread extensively to the eastern part of the Baltic Sea (Kriiska 2009; Mökkönen 2010; Nordqvist and Kriiska 2015). In Estonia, abundant and continuous pollen evidence for different cereals starts around 4000 BC (Kriiska 2009). In Lake Onega, Russia, signs of cereal cultivation dating to ca. 3800 BC have been encountered (Vuorela et al. 2001). In Lake Ahvenainen, southern Finland, Cerealia (possibly *Triticum*-type pollen) was dated to ca. 3400–3350 BC and *Hordeum*-type to ca. 2700–2680 BC (Tolonen 1978). In the pollen data obtained from Lake Lehmilampi in eastern Finland, the first possible indications of human impact, including one *Hordeum*-type, were observed between 3000 and 2500 BC (Augustsson et al. 2013).

Typical Comb Ware (3900–3500 BC), which roughly covers the area of Finland, Estonia, northern Latvia and parts of north-western Russia, represents a pottery tradition originating in the upper Volga region. In addition to increasing signs of cultivation, the appearance of this new pottery style around 3900 BC is marked by new contact networks that are in some regions explained through small-scale migration and in other areas through cultural diffusion, the movement of new ideas and material goods (Nordqvist and Kriiska 2015; Nordqvist et al. 2015). At that time, other exotic materials – flint from the east (Vuorinen 1982; Kinnunen et al. 1985; Mökkönen and Nordqvist 2016), amber from the southern Baltic region (Vuorinen 1984; Núñez and Franzen 2011), rock crystals from southern to south-eastern Finland (Mökkönen and Nordqvist 2016) and copper from the Lake Onega region, Russia (Taavitsainen 1982; Nordqvist and Herva 2013)—were more intensively used as novel raw materials. Rock art flourished (Lahelma 2008; Gjerde 2010), and semi-subterranean pithouses that often occur in village-like concentrations became the dominant dwelling type (Pesonen 2002; Vaneeckhout 2009; Mökkönen 2011). At the same time, there arose a new awareness that included a range of new techniques for manipulating materials and engaging with the material world. As a whole, these are seen as integral elements of Neolithization in

north-eastern Europe and Eurasia (Nordqvist and Herva 2013; Herva et al. 2014, 2017; Nordqvist et al. 2014, 2015; Nordqvist and Kriiska 2015). Although traditional elements of the material culture that defines the Neolithic Stone Age have been known to be present among north-eastern European cultures, which were previously labelled as Subneolithic or even as pottery Mesolithic cultures (e.g. Werbart 1998; Davidson et al. 2009), the new insights concerning changes in the engagement with the material world have enriched the nature of the Neolithization process and thus also altered the context to which the record of early cultivation is considered to belong.

Still, the archaeobotanical record is far from sufficient for understanding the role of cultivation during the Neolithic in north-eastern Europe. In order to capture the earliest, often very slight anthropogenic signals and to understand the role of cultivation, it is necessary to produce accurate and high-resolution pollen data from lake sediments. In this study, we take a closer look at a small body of water, Lake Huhdasjärvi, located within the limits of the modern town of Kouvola in the northern part of the province of Kymenlaakso, beyond the 60th
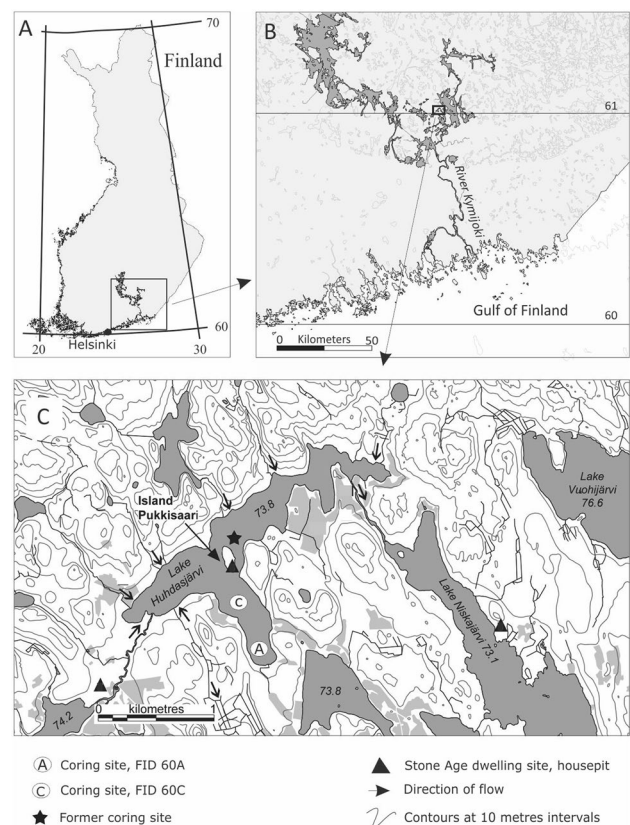

Fig. 1 a Location of the study area in south-eastern Finland. **b** Drainage basin of the Kymijoki river. **c** Lake Huhdasjärvi coring sites and Stone Age dwelling sites

parallel north in Finland (Fig. 1). This is a Y-shaped lake that has evidenced small-scale cultivation of *Fagopyrum esculentum* (buckwheat*), Cannabis* (hemp) and *Hordeum* (barley) during the early phase of the Neolithic, ca. 5300–3600 cal BC (Alenius et al. 2013). Two locations in the bay of Pitkälahti were selected for high resolution pollen analyses in order to find out more detailed information on the Neolithic cultivation and land use phase detected in an earlier analysis (Alenius et al. 2013). The presence of distinctively eastern species, i.e. buckwheat and hemp, dating to the beginning of the Neolithic is not profoundly surprising, as the earliest pottery traditions in north-eastern Europe also originate from the Asian tradition (e.g. Jordan and Zvelebil 2010). Therefore, it has been proposed that the spread of eastern pottery traditions in the boreal forest zone was actually accompanied by some initial small-scale cultivation since the very beginning (Alenius et al. 2013; see also; Mökkönen 2010). In general, scenarios of the journey of eastern plants to Europe during the Stone Age have been proposed before, but the time frames of the movement are still rather unclear (e.g. Janik 2002; Jones et al. 2011; Boivin et al. 2012; Gepts et al. 2012).

Study area and site description

Environmental setting

Lake Huhdasjärvi (61.17109 N; 26.59148 E in WGS84 coordinates) is located in the province of Kymenlaakso in south-eastern Finland, approximately 140 km north-east of the capital, Helsinki (Fig. 1a, b). The lake belongs to the drainage basin of the Kymijoki river and is situated at an altitude of 73.8 m a.s.l. Judging by its present altitude and the rate of land uplift, which is ca. 7 mm per year (Saarnisto 1970), the lake emerged from the Baltic Sea during the Early Holocene, or around 8500 BC. At present, the lake is Y-shaped and each arm has a radius of about 1.5 km (Fig. 1c). The lake is fed by one small river and several small brooks, and it has one outlet.

The area belongs to the Southern Boreal zone, where the length of the growing season is 160–175 days. The vegetation is characterized by coniferous forests of *Picea abies* (spruce) and *Pinus sylvestris* (pine) and deciduous trees, namely *Betula pendula* and *B. pubescens* (birches), *Populus tremula* (aspen), *Alnus incana* and *A. glutinosa* (alders) (Alalammi 1988). Today, the mean annual precipitation is 550 mm, of which about 200 mm is received as snow. The mean annual temperature is +3.5 to +4 °C, the warmest month being July (+17 °C) and the coldest January and February (between −9 and −8 °C) (Alalammi 1987). The dominating relief amplitude is of the order of 30–75 m. The dominating soil type around Lake Huhdasjärvi is moraine, although there are also large areas of exposed bedrock. The narrow stripes of former grove vegetation on the shores of the lake have currently more or less been transformed into agricultural land.

Archaeological context

An archaeological survey of the area was conducted in connection with the earlier studies (Alenius et al. 2013). Despite the thorough survey, the total number of Stone Age sites found within a radius of ca. 10 km around Lake Huhdasjärvi is rather small, altogether 25 sites. Most of the dwelling sites are small in size, and they are characterized by infrequent finds, such as quartz flakes and fragments of burnt bones, that could not be dated on their own. The total number of sites includes five locations with rock paintings (see Alenius et al. 2013).

There are no structures visible on the surface at 12 of the Stone Age sites. Permanent dwelling structures, namely the bases of semi-subterranean pithouses, are recorded at eight sites, and they occur alone or in pairs. The housepit sites, with the exception of two sites—the one located in the Lake Huhdasjärvi area and another one by a small lake nearby—are located on the shores of larger lakes and waterways (Alenius et al. 2013). The shape of the housepits varies from round to oblong or rectangular and the size varies between 20 and 60 m². In Finland, housepits are increasingly found in archaeological data from around 4000 BC (Pesonen 2002; Mökkönen 2011). The smaller roundish housepits are most typical for the period between ca. 4000 and 3400 BC, even though they continue to occur in small numbers until the end of the Stone Age, while the rectangular and more oblong housepits, which are often larger in size and deeper, date distinctly to the latter part of the Stone Age, starting from ca. 3500 BC (Mökkönen 2002, 2011). Four of the housepits in the area definitely belong to the latter group.

There are only three Neolithic sites with pottery shards that could be identified as a certain type. One is located on the island of Pukkisaari in the middle of Lake Huhdasjärvi, just next to locations where the current and previous samples for pollen analysis were cored. One of the two pithouse bases at the Pukkisaari site is partly excavated; in addition to quartz debris, the finds included pottery (an organic-tempered variant of Pöljä Ware), two grindstone slabs, an amber button, and three small scrapers made of slate (Miettinen 1998, 2004, 2012). Based on radiocarbon dates, the site is dated to ca. 3020–2630 cal BC (Alenius et al. 2013). The second site with identified pottery is the Nuumanniemi site, which is located slightly less than 10 km from Lake Huhdasjärvi, with shards of Early Comb Ware of the I:2 style (Miettinen 2004). This pottery style is dated to ca.

4500–4200 BC (Pesonen et al. 2012; Nordqvist and Mökkönen 2016). In addition, a housepit site called Hintteri has produced a few pieces of asbestos-tempered pottery that can be dated roughly to 3500–2500 cal BC.

To sum up, the archaeological finds indicating Stone Age habitation are modest, and most of the sites could not be dated more accurately than to the Stone Age or to the subsequent Early Metal Period (in the inland areas of Finland, this is dated to 1800 BC-AD 300). In general, during most of the Neolithic Stone Age, the area could be described as a periphery—an area that was only passed through or occupied on a limited scale. The Nuumanniemi site with Early Comb Ware of the style I:2 is the only datable site older than ca. 3500 BC. Radiocarbon dates, detected pottery (even small amounts), and certain housepit types indicate more active habitation in the area during the latter part of the Neolithic, after 3500 BC, although this picture could be at least partly an illusion created by the unequal archaeological visibility of different periods.

Materials and methods

Coring, sediment stratigraphy and geochemistry

Sedimentological methods used in this work include measurements of loss on ignition (LOI), magnetic susceptibility, geochemical analyses, palaeomagnetic dating and measurements of ^{137}Cs-activity. The sediment samples were cored standing on the frozen surface of the lake in February 2014, using a light, rod-operated piston corer (Putkinen and Saarelainen 1998). Sediment samples were taken from two different locations in Lake Huhdasjärvi. The first set (FID 60 A) was taken from the end of the Pitkälahti bay (61.1626833 N; 26.59653162 E in WGS84), where the water depth was 9.40 m. The second core (FID 60 C) was taken from the middle of the Pitkälahti bay (61.16581451 N; 26.59327747 E in WGS84), where the water depth was 12.70 m (Fig. 1c).

From the end of the Pitkälahti bay (FID 60 A), we retrieved two parallel sets of cores. Both sets of cores consist of two overlapping sediment sequences: core 1a (0–198 cm) and core 1b (160–360 cm), and core 2a (0–195 cm) and core 2b (160–360 cm). From the middle of the Pitkälahti bay, one set of sediment sequences, FID 60 C, was obtained: cores 1a (0–201) and 1b (160–360 cm). The correlation of the three sets of sub cores was verified by LOI, measurements of magnetic susceptibility, and visual sediment stratigraphy.

LOI was determined at 1-cm resolution by burning previously dried (105 °C, overnight) sediment samples in a furnace for 2 h at 550 °C. Volume magnetic susceptibility (κ) was determined at 5 mm intervals using a Bartington MS2E1 surface-scanning sensor.

The core 1a and core 1b samples, which were obtained from the end of the Pitkälahti bay, were analysed using a portable energy-dispersive X-ray fluorescence spectrometer (pXRF) in order to detect chemical signals in the sediment sequence possibly linked to anthropogenic activities in the catchment area (e.g. Wilson et al. 2008). PXRF analysis of unprepared sediment samples can generate semi-quantitative concentration values of high-Z elements applicable for the chemical discrimination of different sediment layers. However, values in the low/mid-Z range should be treated with caution given the analytical limitations of this instrumentation, mainly the lack of vacuum and suitable calibration (Davis et al. 2012; Hunt and Speakman 2015; Holmqvist 2017). In particular, accuracy issues affect the elements Na, P, V, Cr and Ni, which cannot be accurately quantified (Hunt and Speakman 2015). However, of these elements, P was included our analysis, as it was detected at several sediment depths.

The instrument employed was a portable hand-held Bruker S1 Titan energy-dispersive X-ray fluorescence spectrometer equipped with a silicon drift detector (SDD), available at the University of Helsinki. The instrument has an Rh-target X-ray tube, and it was operated using the Geochem calibration mode provided by the manufacturer (voltage 45 kV, current 8.9 µA with TiAl filter for the heavy element detection and 15 kV/30 µA with no filter for light element analysis). Each centimetre of the core sample was analysed individually (acquisition time 120 s per sample) after the samples were dried and burned for the LOI determination to exclude any interference from organic materials or moisture. In order to examine the sedimentary geochemistry, the elements P, S, Cl, K, Ca, Ti, Mn, Fe, Zn, Rb, Sr, Y and Zr were selected for the final analysis. The instrument software was used to quantify the fluorescence peaks to concentration values, treated as semi-quantitative markers of the sediment geochemistry in our analysis.

Dating

Dating of the Lake Huhdasjärvi sediment sequences is based on a combination of palaeomagnetic dating (e.g. Thompson and Oldfield 1986; King and Peck 2001), radiocarbon dating (AMS ^{14}C) and analysis of anthropogenic ^{137}Cs-activity of the recently deposited sediments. Cs measurements were conducted at a resolution of 1 cm at the Geological Survey of Finland (GSF) using a gamma spectrometer EG&G Ortec ACE™-2K equipped with a four-inch NaI/TI detector.

Sediment sampling for palaeomagnetic measurements and testing of the stability of natural remanent magnetization (NRM) followed Ojala and Tiljander (2003), and

the palaeosecular variation (PSV) results from the Lake Huhdasjärvi sequence were compared with the FEN-NOSTACK (Snowball et al. 2007) Lake Nautajärvi (Ojala and Tiljander 2003) varve-dated reference curves. These reference curves are based on carefully documented sedimentary varve chronology with an estimated error of less than ±1%. Palaeomagnetic measurements were made at GSF with a 2G-Enterprises SRM-755R tri-axial SQUID magnetometer and the PSV inclination and declination curves were matched with the reference curves to construct an age-depth transformation for the Lake Huhdasjärvi sediment sequence.

The result of the palaeomagnetic dating was supported by three radiocarbon analyses from sediment depth levels 175, 206, and 210 cm to specify certain points in the time-depth curve for the core location FID 60 A (Table 1). In addition, with both sequences, the age-depth chronology was anchored to the rise of *Picea* pollen grains in the sediment sequences, which were radiocarbon-dated in the previous study by Alenius et al. (2013), and *Tilia* pollen grains, which were radiocarbon-dated earlier by Tolonen and Ruuhijärvi (1976). We used a Bayesian P-sequence deposition model in Oxcal 4.2 software by Bronk Ramsey (2008, 2009) to calibrate the radiocarbon dates and to fit PSV characteristics to the age-depth model in order to provide a sediment chronology for the Lake Huhdasjärvi sediment sequence. Henceforth, we use the prefix "cal" with BC dates when referring to a specific calibrated ^{14}C sample, but the prefix "cal" is omitted when referring to the interpolated age-depth model or archaeological periods.

Pollen and charcoal analysis

For calculations of pollen and charcoal concentrations (number of pollen grains or charcoal particles per cm³ of sediment), two *Lycopodium* tablets (Stockmarr 1971) were added to samples of 1 cm³ in volume. Subsamples for pollen analysis were prepared according to the procedure suggested by Bennett and Willis (2001). No acetolysis treatment was used. Glycerol was used as a mounting medium. In order to obtain a high temporal resolution, all the sediment samples were analysed in each cm from the part of the sediment that covers the range between ca. 6000 and 1000 BC.

A minimum of 900 pollen grains per sample were identified using publications of Erdtman et al. (1961), Fægri and Iversen (1989), Moore et al. (1991), Reille (1992, 1995) and Beug (2004). Microcharcoal fragments >10 µm were counted on the pollen slides. Different authors have different size criteria for the limit of *Humulus/Cannabis*-types. In the identification key by Fægri and Iversen (1989), all the *Humulus/Cannabis*-types larger than 20 µm are identified as *Cannabis*. Erdtman et al. (1961) use a size limit of 22.5 µm. According to Beug (2004), the mean value for *Humulus lupulus* is 23.4 µm, and for *Cannabis sativa* 28.1 µm, in pollen samples that are treated with acetolysis and mounted in glycerin-gelatine. In order to avoid the classification of *Humulus*-type pollen into *Cannabis*, all the *Humulus/Cannabis*-types of pollen grains ≥ 30 µm were determined as *Cannabis sativa*. Cereal pollen identification was based on the following criteria: grains between 40 and 60 µm with an annulus diameter >10 µm and a distinct outer margin were identified as cereals and distinct from the wild grass group. *Secale* was distinguished from other cereal pollen by its oblong outline, scabrate surface, and the undulating outer margin of its annulus. *Hordeum* was identified based on its annulus diameter of 10–12 µm, while grains with an annulus diameter larger than 12 µm were assigned to the *Avena–Triticum* group.

Calculations for pollen percentages were based on the basic sum of terrestrial pollen grains, P, that includes arboreal pollen [AP = including *Picea, Pinus, Betula, Alnus*], non-arboreal pollen (NAP), and noble deciduous trees [=QM including *Corylus* (hazel), *Ulmus* (elm), *Quercus* (oak), *Tilia* (lime), *Carpinus* (hornbeam), *Fraxinus* (ash) and *Fagus* (beech)]. The aquatic pollen and spores were calculated from the sums P + AqP and P + Spores.

Biostratigraphical data treatment and diagrams were handled with Grimm's (1991) TILIA and TILIA GRAPH programs. Constrained Incremental Sum of Squares (CONISS) (Grimm 1987) was used to assist zonation. We used stratigraphically constrained analysis and square root transformation. In order to avoid the dominance of main tree species, which would likely illustrate regional forest development history, only pollen taxa originating from herbs were included in the analysis. To estimate palynological richness, rarefaction analysis (Birks and Line 1992) was carried out using the POLPAL program (Walanus and

Table 1 Radiocarbon dates of the Huhdasjärvi sediment sequence obtained from core FID 60 A. The calibration was made with the OxCal 4.2 software (Bronk Ramsey 2009), which employs the Intcal09 calibration curve (Reimer et al. 2009)

Lab. code	Depth (cm)	^{14}C age year BP	cal age (1σ)	cal age (2σ)	Median
Poz-79,592	175	4,330 ± 35	2942–2898 BC (41.1%)	3024–2890 BC (94.8%)	2950 BC
Poz-79,593	206	5,195 ± 35	4001–3968 BC (40.4%)	4055–3951 BC (94.6%)	4001 BC
Poz-79,594	210	5,150 ± 35	3995–943 BC (57.9%)	4041–3932 BC (76.0%)	3964 BC

Nalepka 1999). In both cores, the sum for rarefaction analysis was set to 600.

Results

Sediment description, chronology and geochemistry

Sediment stratigraphy, LOI and magnetic susceptibility indicated that cores FID 60 A and FID 60 C and their overlapping sequences contained similar sedimentary data and provided a solid basis for their correlation (Fig. 2). The sediment deposits consist of homogeneous fine-detritus gyttja with only a few weakly laminated sections down to a sediment depth of about 250 cm. Below that lies faintly laminated clay gyttja (partly gyttja) that gradually shifts to sulphide-bearing gyttja clay at a depth of 350 cm.

The sedimentary signal of chemical components is rather flat throughout the sequence, excluding the lowermost part of the sediment (below 260 cm) and the uppermost ca. 27 cm (about 1500 cal AD), where Rb, Sr and Zr increase rapidly (Fig. 2). Fe, Zn and Y first decrease and then increase in the topmost 5 cm. However, small fluctuations can be seen throughout the sediment core in the values of Fe, Rb, Zn, Sr, Y and Zr, although the absolute differences between the measured concentrations are not great. Detected levels of phosphorus (P) in the pXRF analysis appear mostly in the lower part of the section (below 150 cm), in the deposit older than 2000 BC.

The PSV comparison and age-depth curve (dating) for the Lake Huhdasjärvi sediment sequence is presented in Figs. 3, 4 and 5. It is shown that results from these three independent dating methods agree very well, thus supporting the reliability of the sediment chronology. The P-sequence deposition model was constructed based on ^{137}Cs, three AMS radiocarbon dates (Table 1), two pollen dates and 11 PSV age constraints in Oxcal 4.2 (Bronk Ramsey 2008, 2009).

The dating results demonstrate that the Huhdasjärvi sediment sequence covers a continuous sedimentary archive since about 6500 BC with an average deposition rate of 0.36 mm year^{-1} down to a sediment depth of 313 cm. Given the uncertainties with radiocarbon calibration, varve-based PSV chronology and age-depth modelling, we provide an overall confidence level of ±2% for the dated sequence seen in Fig. 4, shaded in grey.

Pollen and charcoal records

The pollen, charcoal data, numerical zonation and palynological richness are presented in Fig. 6. The descriptions of the main events in vegetation and land-use history and charcoal data during the Early Neolithic (5200–3900 BC), Middle Neolithic (3900–3200 BC), and Late Neolithic (3200–1800 BC) are presented in Table 2. The periodization of the Neolithic follows Halinen (2015). The pollen data display the major features of pollen stratigraphy in southeastern Finland (Donner 1971; Hyvärinen 1972), with the colonization of *Tilia* and *Picea* as the most distinguishing features. In addition, the pollen data display anthropogenic pollen types (Behre 1981; Vuorela 1986), possibly connected to anthropogenic impact (Table 2).
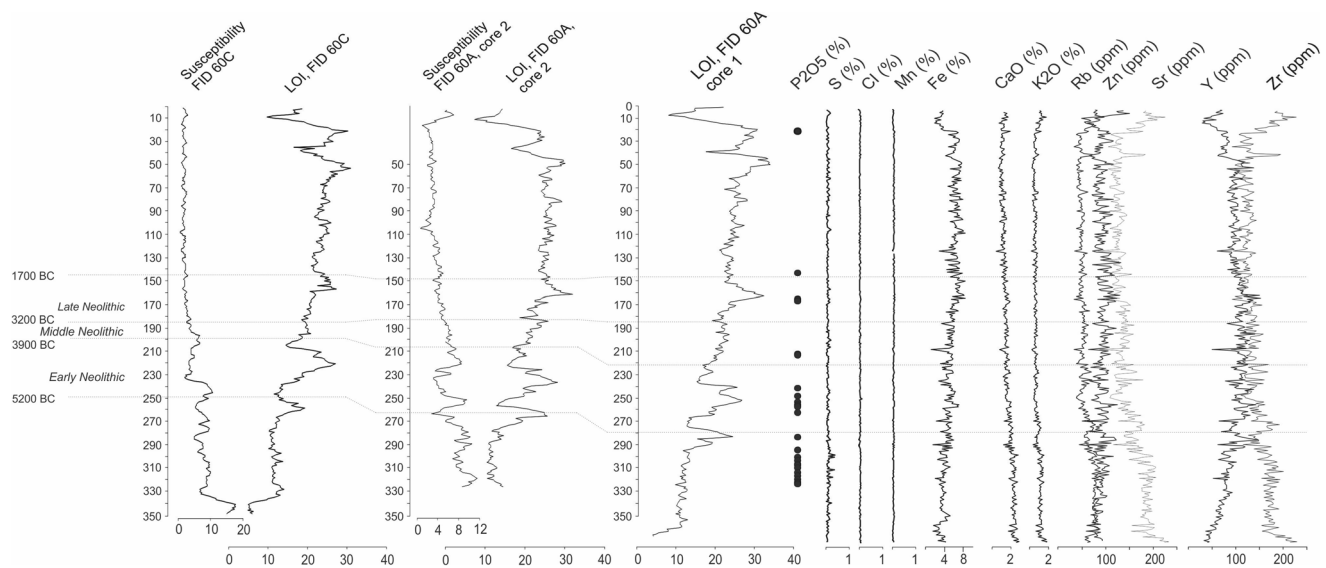

Fig. 2 Characteristics of sediment chemical and physical parameters of the Huhdasjärvi sediment sequence. Geochemistry is measured from FID 60 A, core 1. The values of P are presented with *dots*, meaning presence or absence

Fig. 3 Lake Huhdasjärvi paleo-magnetic age-depth. Records of NRM inclination and declination from the Huhdasjärvi sediment sequence compared with Nautajärvi PSV reference curves (Ojala and Tiljander 2003). Typical features are marked with *different letters*
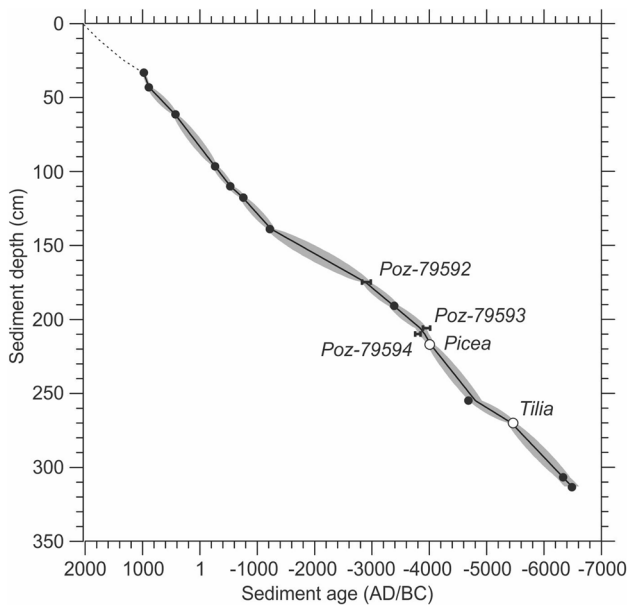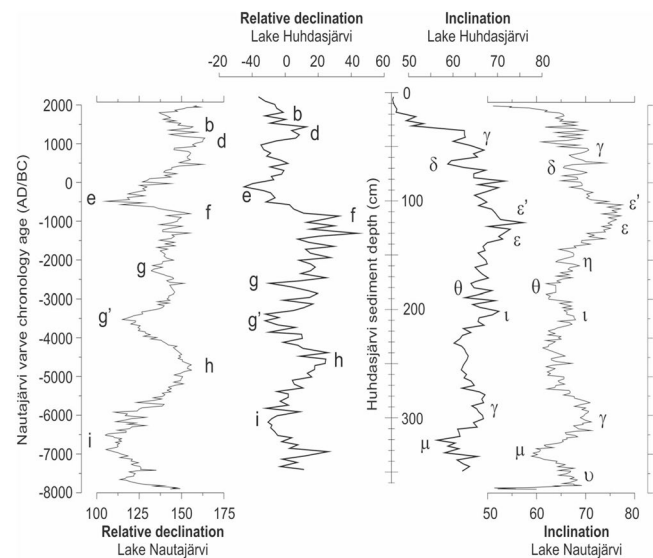

Fig. 4 An age-depth curve of the Huhdasjärvi sediment for coring location FID 60 A based on the Bayesian P-sequence deposition model with Oxcal 4.2 (Bronk Ramsey 2008, 2009). Calibrated AMS ^{14}C dates (2σ) are indicated with lines, *Tilia* and *Picea* chronomarkers with *open circles*, and tagged PSV characteristics with black circles. The *shaded area* represents chronological uncertainty levels

Fig. 5 An age-depth curve of the Huhdasjärvi sediment for coring location FID 60 C. *Tilia* and *Picea* chronomarkers are indicated with *open circles* and tagged PSV characteristics with *black circles*. The *shaded area* represents chronological uncertainty levels

The numerical zonation identified four statistically significant zones of major change in the pollen assemblages in FID 60 C and 60 A, based on changes in herb pollen data. In FID 60 C, the zone boundaries were at the levels of 153, 185 and 259 cm. In FID 60 A, the zone boundaries were at the levels of 121, 185 and 246 cm.

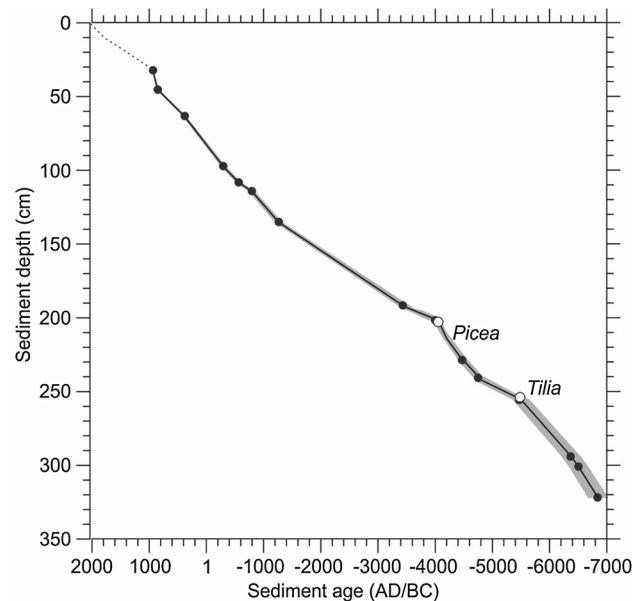In general, palynological richness remains stable in the study period in both cores. The only fluctuations in palynological richness are visible in the pollen data from core FID 60 C, where the rarefacted number of taxa is somewhat lower during the late Mesolithic, until 5600 BC. A slight increase is visible between 208 and 213 cm. The mean charcoal concentration in both cores is highest during the levels of the Early Neolithic, and the mean concentrations decrease in both cores during the Middle Neolithic. Another decrease in charcoal concentration is visible during the Late Neolithic.
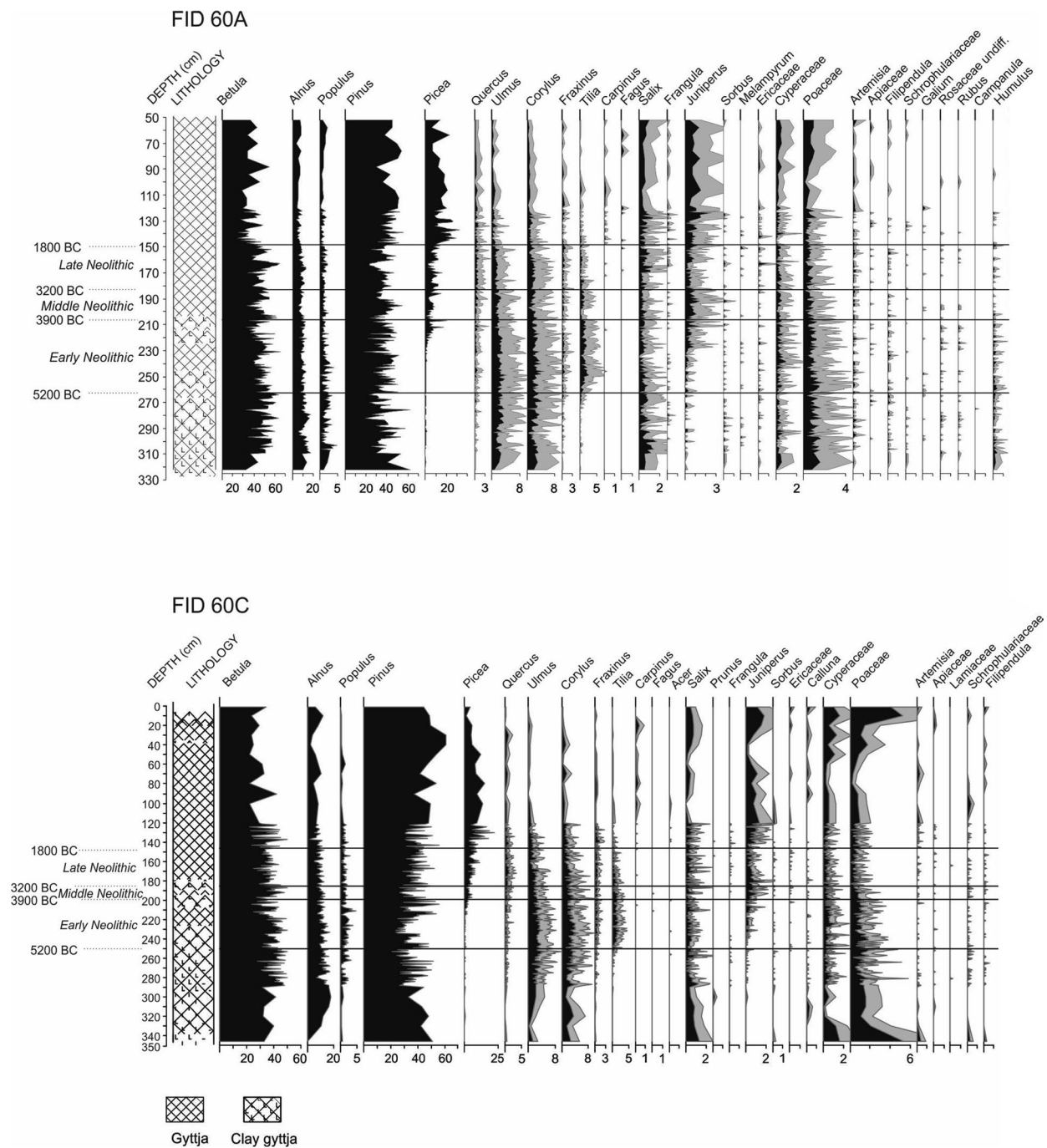
Fig. 6 Pollen percentages (%) and charcoal particle concentrations for FID 60 A and C. Black silhouettes indicate the percentage values and grey silhouettes indicate the exaggeration factor (×2). *Horizontal lines* mark the Neolithic periods. ZONISS zones based on herb and cultivated pollen taxa are presented with dashed lines

Discussion

Distinguishing between the pollen of wild Poaceae species and cereals

It is difficult to make a distinction between the pollen of cultivated cereal crops and that of naturally occurring wild grasses (Tweddle et al. 2005; Behre 2007; Tinner et al. 2007). Behre (2007) has listed species belonging to the Cerealia-type that can be confused with wild grasses. Of these species, *Aegilops ovata, Agropyron intermedium, Lygeum spartum, Secale montanum, Triticum aegilopoides, Triticum dicoccoides* and *Glyceria plicata* do not grow in Finland. *Bromus erectus, Hordeum*
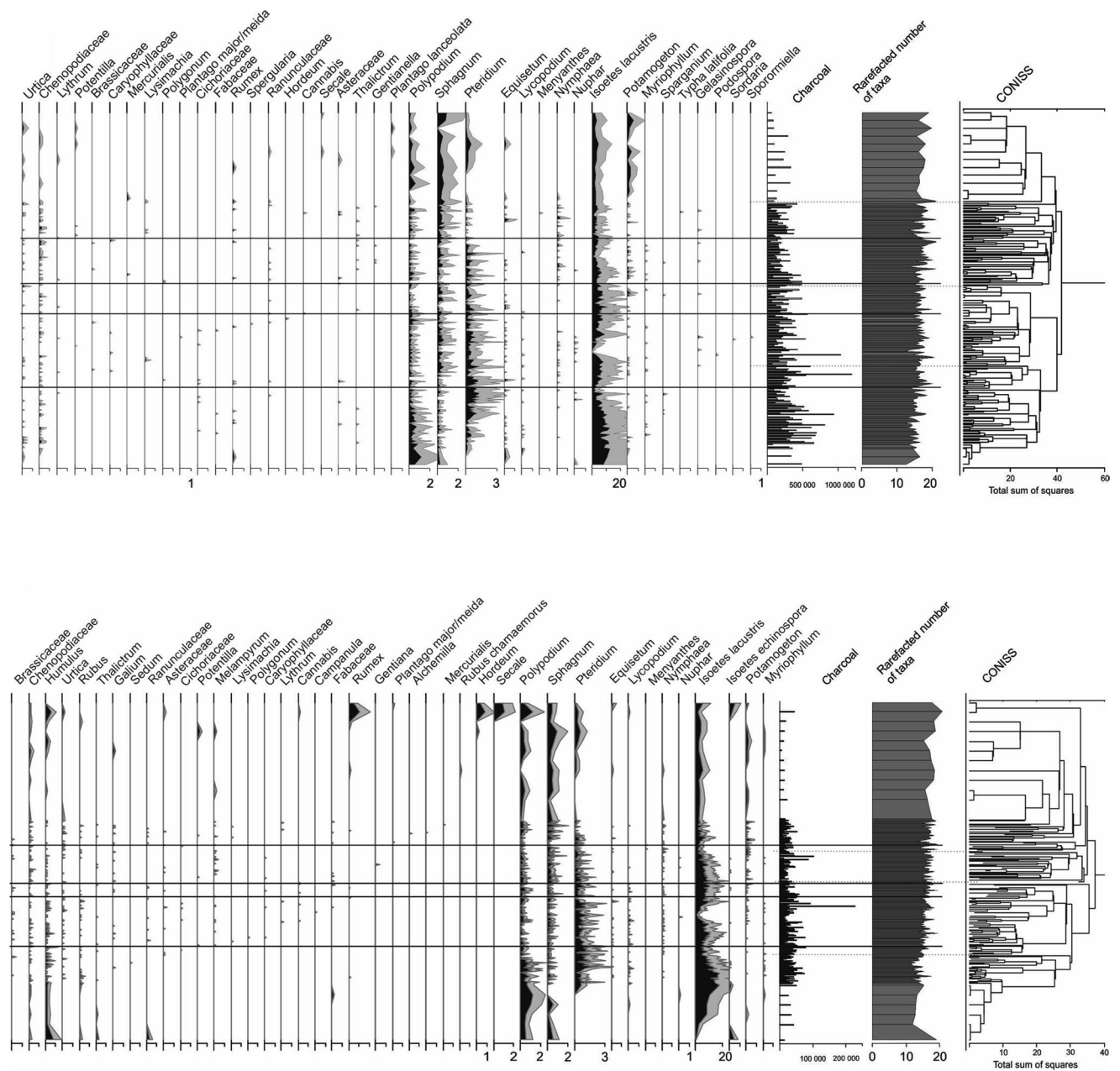
Fig. 6 (continued)

murinum, Setaria pumila and *Setaria glauca* are all new-comers, appearing in Finland starting from 1950 and even then only occasionally. Also *Avena fatua* and *Bromus inermis* are newcomers and rare species in Finland. *Bromus mollis* only grows in the coastal areas of southern Finland and is only occasionally known from other parts of Finland (Hämet-Ahti et al. 1984). The species that are common in Finland are *Agropyron caninum* and *Glyceria fluitans*. Of these, *Agropyron caninum* grows in groves

and grove-like spruce swamps, along brooks and on seashores. As the dominant soil type around Lake Huhdasjärvi is moraine, it seems unlikely that the Cerealia-type pollen originates from *Agropyrum caninum*. The only species left in Behre's (2007) list that is likely to grow in the surroundings of Lake Huhdasjärvi is *Glyceria fluitans*. According to the pollen key of Küster (1988), however, the *Glyceria* type has a diffuse (indistinct) outer annulus boundary, and in our analysis, one important

Table 2 General descriptions of the dominant pollen types in sediment cores FID 60 A and C and separate interpretations with special emphasis on principal anthropogenic pollen types (Behre 1981) for both cores

Period	General description	Pollen related to human impact, charcoal; FID 60 A	Pollen related to human impact, charcoal; FID 60 C
Late Neolithic 1800–3200 BC FID 60A 148–183 cm FID 60C 146–185 cm	Dominance of *Pinus* (39%), *Betula* (36%), *Alnus* (9.4%) and *Picea* (5.8%). Noble trees: 6.1%, with *Corylus* (2.1%), *Ulmus* (1.8%), *Quercus* (0.9%) and *Tilia* (0.7%) as the most abundant species. Herbs and shrubs: Cyperaceae, Poaceae, *Salix* and *Juniperus* are present in proportions ranging from 0.4 to 0.6%	Caryophyllaceae: 1795 BC; *Rumex*: 1841 BC; Brassicaceae: 1886 BC; Brassicaceae: 2800 BC; *Rumex*: 3060 BC; Ranunculaceae: 3091 BC; *Polygonum*: 3123 BC; Regular occurrence of Chenopodiaceae and *Humulus*; Sporadic occurrence of *Urtica* and Apiaceae; Mean charcoal conc.: 213,526	Cichoriaceae: 1734 BC; Caryophyllaceae: 2198 BC; Caryophyllaceae: 3010 BC; Regular occurrence of Chenopodiaceae; Sporadic occurrence of Fabaceae, Brassicaceae, Apiaceae, *Galium* and *Urtica*; Mean charcoal conc.: 277,851
Middle Neolithic 3200–3900 BC FID 60A 183–206 cm FID 60C 185–199 cm	Dominance of *Betula* (38.8%), *Pinus* (35.9%) and *Alnus* (10.5%). Noble trees: 7.1%, with *Corylus* (2.7%), *Ulmus* (2.2%), and *Tilia* (1.1%) as the most abundant species. *Picea* constitutes 3.4%. Herbs and shrubs: most abundant Poaceae (0.8%), Cyperaceae (0.5%), *Juniperus* (0.7%) and *Salix* (0.4%)	Ranunculaceae: 3585 BC; Decrease in *Tilia* values upper limit: 3647 BC lower limit: 4055–3950 cal BC; **Cannabis**: **4055–3950 cal**BC; Ranunculaceae: 4055–3950 cal BC; Regular occurrence of Chenopodiaceae and *Humulus*; Sporadic occurrence of *Urtica*, Ranunculaceae and Apiaceae; Mean charcoal conc.: 248,611	**Cannabis**: **3203** BC; **Cannabis**: **3240** BC; Fabaceae: 3280 BC; *Rumex*: 3396 BC; Caryophyllaceae: 3503 BC; **Cannabis**: **3640** BC; Regular occurrence of Chenopodiaceae; Sporadic occurrence of Ranunculaceae, Brassicaceae, Apiaceae, *Galium* and *Urtica*; Mean charcoal conc: 324,033
Early Neolithic 3900–5200 BC FID 60A 206–263 cm FID 60C 199–249 cm	Dominance of *Betula* (39%), *Pinus* (36%) and *Alnus* (11%). Noble trees: 8.8%, with *Corylus* (3%), *Ulmus* (3%) and *Tilia* (1.4%) as the most abundant species. By the end of the period, *Picea* reaches > 2%. *Juniperus* pollen shows a slight increase during the period. Herbs: most abundant are Poaceae (1.2%) and Cyperaceae (0.6%)	**Hordeum**: **4040–3930 cal**BC; Brassicaceae: 4014 BC; *Rumex*: 4058 BC; Fabaceae: 4114 BC; Caryophyllaceae: 4155 BC; *Plantago ma.lmedia*: 4216 BC; Caryophyllaceae: 4462 BC; Brassicaceae: 4730 BC; Caryophyllaceae: 4750 BC; *Polygonum*: 4937 BC; *Rumex*: 4978 BC; *Rumex*: 5061 BC; Regular occurrence of Chenopodiaceae and *Humulus*; Sporadic occurrence of *Urtica*, Apiaceae and Cichoriaceae; Mean charcoal conc.: 306,170	**Cannabis**: **3913** BC; *Rumex*: 3981 BC; **Cannabis**: **4127** BC; Caryophyllaceae, Fabaceae: 4165 BC; *Campanula*: 4230 BC; **Cannabis**: **4403** BC; Caryophyllaceae, *Polygonum*: 4790 BC; Regular occurrence of Chenopodiaceae and *Urtica*; Sporadic occurrence of Cichoriaceae, Ranunculaceae, Brassicaceae, Apiaceae and *Galium*; Mean charcoal conc.: 397,371

Pollen taxa that are introduced (anthropochores) and do not belong to the native flora are shown in bold type. The interpretations are provided only for Neolithic periods

criterion for cereals was an annulus with a distinct outer annulus boundary. It therefore seems unlikely that pollen originating from *Glyceria fluitans* would have been confused with Cerealia-types.

Geochemical data

The data accuracy of the geochemical data may be affected by the heterogeneity (e.g. varying density and mineral content) of the sediment samples, as elemental concentrations of unprocessed samples measured by pXRF are prone to accuracy issues (e.g. Holmqvist 2017). These effects were controlled by performing LOI and focusing on mid- or high-Z elements, which can be more accurately measured by this portable instrument. We can conclude that the data patterns acquired by pXRF are consistent with the results provided by other methods. The concentrations of phosphorus (P) are of interest in relation to human activity. However, P was rarely detected in our samples, probably due to instrumental limitations in measuring light elements in sediments by pXRF (Hunt and Speakman 2015). Most of the detected P signals do not correlate with the apparent human activity phases, such as the Iron Age field erosion (at the uppermost ca. 50 cm), and thus appear to be linked to natural processes.

For the most part, the detected geochemical signals and variation in the sediment samples represent natural geochemical events and sediment production processes. In the uppermost and lowermost parts of the sediments, the values of Fe, Rb, Zn, Sr, Y and Zr follow the changes in the LOI values. Such changes are typical for early lake stages after isolation and also for recent anthropogenic influence, although it is often not straightforward to interpret them in relation to increased catchment erosion, atmospheric input, and fluctuations in oxygen and redox conditions in the water column (e.g. Bengtsson and Enell 1986).

Fire frequency

Microscopic charcoal concentration in the Lake Huhdasjärvi sediment records suggests that, apart from a few individual peaks, the general fire activity did not increase significantly during the Neolithic period. In eastern Finland, the mean interval of 220–260 years for forest fires has been recorded at a dry forest site prior to significant human impact between 4300 BC and AD 1500 (Pitkänen et al. 2002), and in central Finland, local fire history studied from a small forest hollow has shown a 430-year return period between 3000 and 1 BC (Clear et al. 2013). This, in general, agrees with fire frequency on the European scale, where sedimentary charcoal records suggest only little fire activity during the Early and Middle Holocene compared to recent millennia (Molinari et al. 2013).

Early Neolithic

The earliest human impact dates to the Early Neolithic, between ca. 4400 and 3900 BC. It includes some use of fire and cultivation of hemp and barley, as deduced from the occurrence of three *Cannabis*-type pollen grains from the core obtained from the middle of the bay and one *Hordeum*-type obtained from the end of the bay and dating to this period. Two peaks in charcoal values, obtained from the middle of the bay, date to ca. 4140 and 4178 BC and are associated with *Cannabis*-type pollen. More precisely, the *Hordeum*-type was dated to 4040–3930 cal BC (2δ) (Poz-79,594). A likely explanation for the sudden erosion phase, visible in LOI and susceptibility values between 4090 and 4165, is the land use activity around the lake. The land use activity has also generated new biotopes, deduced from a slight increase in the rarefacted number of taxa between 4200 and 4140 BC, visible in the pollen record obtained from the middle of the bay. In addition to the cultivated plants *Hordeum* and *Cannabis*, apophytes such as *Plantago major/media, Rumex*, Fabaceae, *Campanula* and Caryophyllaceae are recorded. Of these, *Plantago major/media* is a plant species that is associated with more or less nitrogen-rich footpaths and ruderal communities (Behre 1981).

As discussed above, the misidentification of Cerealia-type as pollen belonging to wild grasses seems unlikely, as most of the wild grasses that produce pollen similar to that of Cerealia-types either do not grow in Finland at all or are newcomers from 1950 onwards. Also *Glyceria fluitans*, a species common in Finland, can clearly be separated from Cerealia-type by its indistinct outer annulus boundary. However, if we assume that Cerealia-type pollen did in fact originate from wild grasses, one might expect to find this pollen evenly scattered through the Holocene, also in the Mesolithic period. In Lake Huhdasjärvi, no pollen of Cerealia-type dating to the Mesolithic period has been found. Furthermore, the dating (4040–3930 cal BC) of the *Hordeum*-type closely agrees in age with the former analysis from the lake (Alenius et al. 2013), where a single occurrence of *Hordeum* pollen was dated to ca. 4260 BC. The dates for the *Hordeum*-type also agree in age with the wider context in Finland, Estonia and the Karelian Republic in Russia, where the earliest cultivation dates to the Early and Middle Neolithic (between 4300 and 3200 BC) (Tolonen 1978; Vuorela et al. 2001; Poska et al. 2004; Poska and Saarse 2006; Kriiska 2009; Mökkönen 2010; Nordqvist and Kriiska 2015). It also seems unlikely that Cerealia-type pollen from more recent layers could have been included in the samples as down-core intrusions. In all cores from Lake Huhdasjärvi, the outer parts of the cores were first removed and the sample for pollen analysis was obtained from the middle of the sediment core.

In addition to misidentification, one potential source of error concerns the datings. In this work, the dating was based on two independent dating methods, namely palaeomagnetic dating and ^{14}C dating. As these two methods gave similar results for the *Hordeum*-type, we have no reason to doubt the datings. In the first analysis (Alenius et al. 2013), the chronology was based on ^{14}C datings. Because of the absence of limestone in the local bedrock, we do not expect a freshwater reservoir effect (Olsson 1986) to be a factor affecting radiocarbon ages.

Middle Neolithic

After the Early Neolithic land use, direct evidence of human activity again becomes visible during the Middle Neolithic, in the pollen analysis obtained from the end of the Pitkälahti bay (FID 60 A). A sudden and atypical decrease in *Tilia* pollen values starts at ca. 4000 BC (Poz-79,593) and is connected with a single *Cannabis*-type pollen grain. In our charcoal data, it seems reasonable to assume that the peak at the level of 3890 BC is locally human-induced, as this coincides with the onset of the abrupt decrease in lime trees. The decrease in *Tilia* then lasts about 350 years until ca. 3650 BC. In contrast to a natural, long, and gradual process, where *Tilia* was replaced by *Picea* during the Middle and Late Neolithic (Seppä et al. 2009) due to their overlapping ecological niches, the decrease in *Tilia* in the Lake Huhdasjärvi diagram is very abrupt. Coinciding with the start of decrease in *Tilia*, a clear increase in *Juniperus* values is recorded from ca. 4000 BC until ca. 3200 BC. A plausible explanation is forest clearing, which increased light and open patches in the forest, creating a favourable environment for this shade-intolerant species. After the ca. 350 years of *Tilia* use around the end of the bay, direct evidence of human activity can again be seen in the core obtained from the central part of the bay, where three *Cannabis*-type and one *Rumex* are recorded from the layers dating between ca. 3640 and 3200 BC.

The ^{14}C dates taken at the depths of 206 and 210 cm in FID 60 A show a very minor reversal (Fig. 4; Table 1). In the LOI, there is a peak in mineral matter content, and also in geochemistry, small decreases in Zr, Sr and Zn values are recorded around 206 cm. The minor reversal in the ^{14}C result could then be explained by instability in the catchment through disturbance, likely caused by people.

It is worth noting that in addition to human activity, also natural disturbance dynamics, such as wind throw, natural animal/plant interactions, diseases or natural forest fires can create openings within the canopy that could have replaced *Tilia* and generated niches within which *Juniperus* could grow. In this case, interpreting the change to have been caused by human impact rather than natural disturbance dynamics is supported by the simultaneous occurrence of several *Cannabis*-type pollen finds in the pollen data. This

species is not native to Finland, but has been introduced to the area. The misidentification of *Humulus* as *Cannabis* seems unlikely, as in our analysis, the size limit of *Cannabis* was set to ≥30 μm, a criterion that is higher than that recommended by most authors. If one assumes that the pollen identified as *Cannabis* actually originated from *Humulus*, one might expect this pollen to be scattered evenly in the sediment. However, in Lake Huhdasjärvi, all the *Cannabis*-type pollen grains date to the Neolithic, between 4400 and 3200 BC.

Hemp and lime

Both hemp and lime are known to be an important source of bast fibres. Coarse hemp textiles have been used for different purposes and strong hemp fibre is especially well suited for making ropes. In addition to providing fibre, hemp is also a food plant: for humans, it is an oil-producing plant with edible seeds that could be consumed as a raw or roasted whole grain snack, and for animals, it can be used as fodder (Barber 1991; Mannering et al. 2012; Clarke and Merlin 2013; Zohary et al. 2013).

The domestication of hemp had taken place in central Asia, probably in the southern margin of the taiga forest or the forest steppe region (Clarke and Merlin 2013; Zohary et al. 2013; Long et al. 2017) and it does not belong to the natural vegetation in Finland. Hemp is proposed as having spread into Europe in two main stages:

1. The earliest distribution to Europe is dated to the Neolithic, ca. 5000 BC, as shown by a few Linearbandkeramik sites, one in Romania and another in Germany, which have produced charred hemp seeds and hemp seed imprints in pottery
2. The second stage, connected to the spread of the peoples from the Eurasian steppe, dates to about 3500–3000 BC and probably also included the use of narcotic species, (Sherratt 1991; Mallory and Adams 1997; Clarke and Merlin 2013).

The early *Cannabis* species found in northern Europe and in the northern part of eastern Europe were most likely species with a notably low psychoactive chemical content, which were not as suitable for use as drugs as a few other *Cannabis* species with a more southern and eastern distribution (Clarke and Merlin 2013). The early European utilization of hemp was likely concentrated on the production of fibres and seeds, as it was during the early phase in eastern Asia (Clarke and Merlin 2013). In the eastern part of the Baltic Sea, pollen and seeds of hemp were present early on. The earliest hemp pollen is dated to the transition between the Mesolithic and Neolithic Stone Ages and the Early Neolithic—in Estonia ca. 5600 BC (Poska and Saarse

2006). Further to the south, the evidence for hemp is a bit more recent. In Latvia, hemp seeds have been found at the Sãrnate dwelling site (Vasks et al. 1999). The pottery found at the Sãrnate site represents Early and Late Sãrnate Ware, with some Typical Comb Ware as well as Late Comb Ware, and the complex is dated to ca. 4300–2900 BC (Bērziņš 2008). In Lithuania, a wider spectrum of evidence is provided from the wetland dwelling sites in Šventoji. At the Šventoji 3 site, hemp seeds were recovered, and at the Šventoji 23 site, hemp seeds and pollen were detected, and even a piece of hemp rope was discovered in the layers of the dwelling site (Rimantienė 1979, 1999, 2005, but see also the critical discussion of these finds in Piličiauskas et al. 2017). The former site is dated to 3200–2500 cal BC, and the latter to 2900–2000 cal BC (Rimantienė 2005).

Tilia bast was widely in use as a raw material for different textiles and cordage during the Stone Age. Textiles made of lime bast have been found, for example, in Neolithic Denmark (Bender Jørgensen 1990; Mannering et al. 2012), and plenty of carbonized debris from the extraction of bast fibres has been discovered in central Europe (Schweingruber 1990). In the Baltic States, bast fibre products include cordage, mats or clothes, fishing nets and braided baskets, which were used in addition to products made of birch bark and fibres of nettle and hemp. Such artefacts have been found, for example, at the Šventoji sites, Lithuania, dated to ca. 4000–2000 BC (Rimantienė 2005; Rimkuté 2010). In addition, imprints of different textiles in pottery since the third millennium BC show indirect evidence for Neolithic textiles in Estonia (Kriiska et al. 2005). In Finland, archaeological data does not include any Stone Age artefacts made of *Tilia* bast, even if such artefacts must certainly have been used, and the imprints of any kind of textiles in pottery are rather limited and date no earlier than the Late Neolithic (Lavento 2001).

Late Neolithic

In our new pollen data, there is no prominent human impact on vegetation after ca. 3200 BC during the Late Neolithic (3200–1800 BC). Interestingly, the Pukkisaari housepit site, situated on a small island in the middle of Lake Huhdasjärvi, with Pöljä Ware and some poorly known Neolithic pottery, dates to 3020–2890 cal BC (Alenius et al. 2013). This period, then, seems to be connected with the people who used Pöljä Ware pottery and built the largest housepits in the area. Although direct evidence of human impact is absent, there is, however, a phase of increased charcoal concentration visible in the core obtained from the end of the bay, lasting from ca. 3370 to 2970 BC. In addition, two peaks in charcoal data in the core obtained from the middle of the bay date to ca. 2275 and 2160 BC. With the exception of these, a low

charcoal concentration indicates only low fire activity in the area. A clear increase in organic matter input into the bay is detected at both coring sites between ca. 2600 and 1840 BC, the highest peak in organic content dating to ca. 2300 BC. This could be connected to a slight eutrophication of the lake. Coincident with the organic peak, the measured Yttrium (Y) proportional values also peak in the geochemical data, also possibly associated with changes in trophic level. After ca. 2300 BC, a decreasing trend in the concentration values of Sr, Rb, Y and Zr can be seen, possibly connected to the diminishing land use in the surroundings of the lake. After ca. 2300 BC, also the measured Fe (and possibly Zn) values are consistently higher than in earlier sediment layers.

In addition to geochemical changes in the sediment, which may possibly be associated with the trophic level and later with decreasing land use in the surroundings of the lake, there are changes in the CONISS zonation, indicating a change in herb vegetation in the surroundings of the bay. In the CONISS zonation in FID 60 C, one major division was dated to ca. 1965 BC, that is, close to the transition between the Late Neolithic and Early Metal Period according to Finnish periodization. This transition period is characterized by a scarcity of archaeological remains in the Finnish inland in general (Taavitsainen et al. 1998; Lavento 2001, 2015), as well as around Lake Huhdasjärvi.

Despite the scarcity of archaeological remains in the Late Neolithic period (between 2500 and 2100 BC) in Finland, this is the phase which in Finland and Estonia in general show quite a diverse range of evidence connected to agriculture, evidently indicating that the custom of cultivation was becoming more common in the Northern Boreal Zone (Tolonen 1980; Alenius 2008; Alenius et al. 2009; see also; Vuorela 1999). In the earlier study, a single *Hordeum*-type was found at the level dating to ca. 2160 BC from Lake Huhdasjärvi. Further, the earliest macrofossil evidence for cultivation (Vuorela and Lempiäinen 1988; see also; Vanhanen and Pesonen 2015), biomarker lipids and δ^{13} values have revealed the presence of milk in pottery around 2500 BC (Cramp et al. 2014). Also, the earliest bone of sheep/goat recovered from a dwelling site of the Kiukainen Culture (ca. 2200–1950 BC) in southern Finland (Bläuer and Kantanen 2013) dates to this transition period, which shows quite a diverse range of evidence connected to agriculture.

Conclusions

In general, all three independent studies provided similar sedimentary data and pollen data describing the vegetation development in the region, such as the spread of *Tilia*

and *Picea abies* to eastern Finland from ca. 5400 BC and 4100 BC onwards. Based on the empirical studies, the relevant source area (RSAP; Sugita 1994, 1998) of pollen is ca. 1,500-2,000 m in similarly sized sites (Sugita et al. 2010; Poska et al. 2011). As the distance between the coring sites is about 450 m, the source areas of all the sediment cores partially overlap. There are, however, clear differences in the pollen data that can be connected to local vegetation. Six of altogether seven *Cannabis*-type pollen findings originated from the sediment core that was obtained from the middle of the bay, indicating that hemp cultivation has been practiced somewhere around the central part of the bay rather than around the end of the bay, whereas the use of *Tilia* trees was only visible in the pollen analysis obtained from the end of the Pitkälahti bay. These differences indicate that the archaeological sites were small in size and land use was very local in origin and concentrated on different areas during different periods, resulting in differences in the vegetation.

The earliest human impact, only detected in the earlier pollen analysis (Alenius et al. 2013), dated to the very beginning of the Neolithic, 5370–5060 cal BC, when a single pollen find indicated the cultivation of *Fagopyrum esculentum* by the lake. This was connected to forest clearance, deduced from the simultaneous and abrupt decrease of *Betula* and *Pinus* and increase in charcoal concentration. In archaeology, this phase refers to Early Comb Ware, style I:1. No pollen originating from *Fagopyrum esculentum* was found in the new analyses. This is not surprising, as this is an entomophilous cross-pollinating plant in which pollen is carried from the anther of one flower to the stigma of another by insects. It has large dimorphic pollen grains (60×35 μm in brevistyled and 45×24 μm in longistyled flowers) (Erdtman et al. 1961). Although pollen grains originating from *Fagopyrum esculentum* are occasionally found in sediments, they are always rare in the pollen rain (de Klerk et al. 2015).

The most active land use phase can be seen in all three pollen diagrams and dates to between ca. 4400 and 3200 BC. According to new pollen analyses, an important part of the human activity seems to be connected to producing fibres from hemp and lime. *Cannabis*-type pollen was found in the layers dating to 4400 and 3200 BC, and the utilization of lime trees dates to between ca. 3890 and 3650 BC. *Hordeum*-type pollen date to ca. 4260 BC and to 3960 cal BC. The mosaic of land use activities has resulted in an increase in open patches in the forest, in which *Juniperus*, which demands light, and other apophytes such as *Plantago major/media*, Caryophyllaceae and *Rumex* can grow.

In the surroundings of Lake Huhdasjärvi, the beginning of hemp and barley cultivation and beginning of lime use roughly dates to the turn of the 5th and 4th millennia BC,

when the Younger Early Comb Ware, style 1:2, was to be overridden by the subsequent pottery style, Typical Comb Ware (3900–3500 BC). The appearance of the first *Cannabis* and *Hordeum* pollen during this particular time is not unexpected, as this period shows increasing evidence of cultivation and human impact on vegetation within the sphere of Typical Comb Ware distribution (Kriiska 2009; Mökkönen 2010). In addition, this period is associated with a profound cultural change, which spread rapidly over vast areas in the north-north-eastern European forest zone through highly active contact networks that incorporated new technologies, new raw materials, and obviously new ideas that affected the way people engaged with the material world (Núñez and Okkonen 2005; Mökkönen 2011; Herva et al. 2014, 2017; Nordqvist and Kriiska 2015; Nordqvist et al. 2015). At the same time, sedentary habitation in village-like arrangements of pithouses became established (Zhul'nikov 1999, 2003; Núñez and Okkonen 2005; Vaneeckhout 2009; Mökkönen 2011), a high tide of rock art was about to begin (Lahelma 2008; Gjerde 2010), and the number of furnished burials with intense red-ochre usage increased (Halinen 1999; Zagorska 2006, 2008). Although not all of these phenomena are found in the current study area, these changes are part of the Neolithization process that took place in the north-north-eastern European boreal forest zone (Herva et al. 2014, 2017; Nordqvist and Kriiska 2015).

The actual crop cultivation was small scale and sporadic, and did not play a significant role as a subsistence source. Osteological data (Ukkonen 1996; Mökkönen 2001; Nurminen 2007; Seitsonen et al. 2017), fishing structures (Koivisto and Nurminen 2015) and lipid analysis (Cramp et al. 2014), all beyond the 60th parallel north, suggest that the subsistence base was aquatically oriented in the economy of Neolithic populations. Various nuts, fruits, roots and seeds, such as hazel, water chestnut, dropwort and wild strawberry were gathered in Finland during the Stone Age (Vanhanen and Pesonen 2015). Evidently, the period from the introduction of cultivation to the point where it actually acted as a key factor in subsistence in north-eastern European boreal forests was a long-term process that took several thousands of years.

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