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Pollen Evidence in Exploring Settlement Dynamics, Land Use, and Subsistence Strategies in the Åland Islands through Multiproxy Analyses from the Lake Dalkarby Träsk Sediment Record

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ABSTRACT
In this study, which presents pollen, charcoal, and 'soot'-particle records from a lacustrine sediment core, the development of the cultural landscape around Lake Dalkarby träsk on the Åland Islands in Finland is scrutinised and discussed within a broad temporal setting in order to clarify the long-term interplay between the environment and human activities in this part of the archipelago. Special emphasis is given to the transition period from the Late Iron Age to medieval times due to the dominating humanistic discourse on the settlement dynamics in this region, as in the Åland archipelago in general, arguing for an approximately 150-years-long hiatus in habitation between these two periods, from AD 1050 to 1200. Our results do not support the hiatus theories but show a long and continuous history of the utilisation of land and forest resources starting from prehistoric times. The forests were first cleared with fire for slash-and-burn cultivation. Thereafter, structural diversity in the landscape started to increase. By 1240, the pollen data portrays a picture of a developed agrarian community with a subsistence economy based on arable farming and animal husbandry in which hemp seems to play a substantial part.

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Åland Islands; settlement dynamics; land use; Late Iron Age; medieval period; pollen

Introduction

In this article, we present a pollen-inferred reconstruction of past vegetation cover from a sediment core obtained in 2020 from Lake Dalkarby träsk, situated in the municipality of Jomala, in the southern part of the Åland Islands (an autonomous, Swedish-speaking province of Finland), approximately 1 km north of the city of Mariehamn (Figure 1). The development of the cultural landscape around this lake is scrutinised through a combination of palaeoecological data and archaeological material, which is discussed within a broader temporal setting in order to clarify the long-term interplay between the environment and human activities in this part of the archipelago. The main aim is to investigate the development, intensity, continuity, and changes in different human activities, such as the use of forest resources, fire, and subsistence sources such as cultivation and animal husbandry. Our special attention and effort is directed toward clarifying one of the most controversial questions in the history of the islands – whether Åland was depopulated and/or suffered a prolonged devastation starting from the early eleventh century.

The cultural, social, and economic transformations affecting the Åland Islands during the Late Iron Age (AD 550–1050) were truly radical in nature, distinguishing the archipelago within the contemporaneous northern world. At the beginning of the Late Iron Age, and in contrast to the greater parts of the surrounding mainland territories, the archipelago saw its greatest increase in human population and activity, a phenomenon that cannot be understood as an endogenetic demographic process (Hackman 1924; Kivikoski 1962; Dreijer 1979; Callmer 1994; Núñez 1995; Tomtlund 1999; Gustavsson et al. 2014). This rapid population growth is interpreted as a large-scale colonisation process following the global climatic disturbances and related social unrest of the climate event(s) of AD 536 (Ilves 2018a). Throughout the Late Iron Age, Åland was directly linked to extensive and vital northern maritime trade routes to both the west and the east (cf. Ahola, Frog, and Lucenius 2014) – in fact, the period constituted an apparent golden age for the islands that resulted in the construction of a new identity expressed in new artwork, new rituals, and new ways of interacting with resources (Callmer 1992, 1994; Rundkvist 2009; Ilves 2015, 2018b, 2019; Ilves and Lindholm 2021).

Interestingly and controversially, however, the dominating humanistic discourse on the settlement

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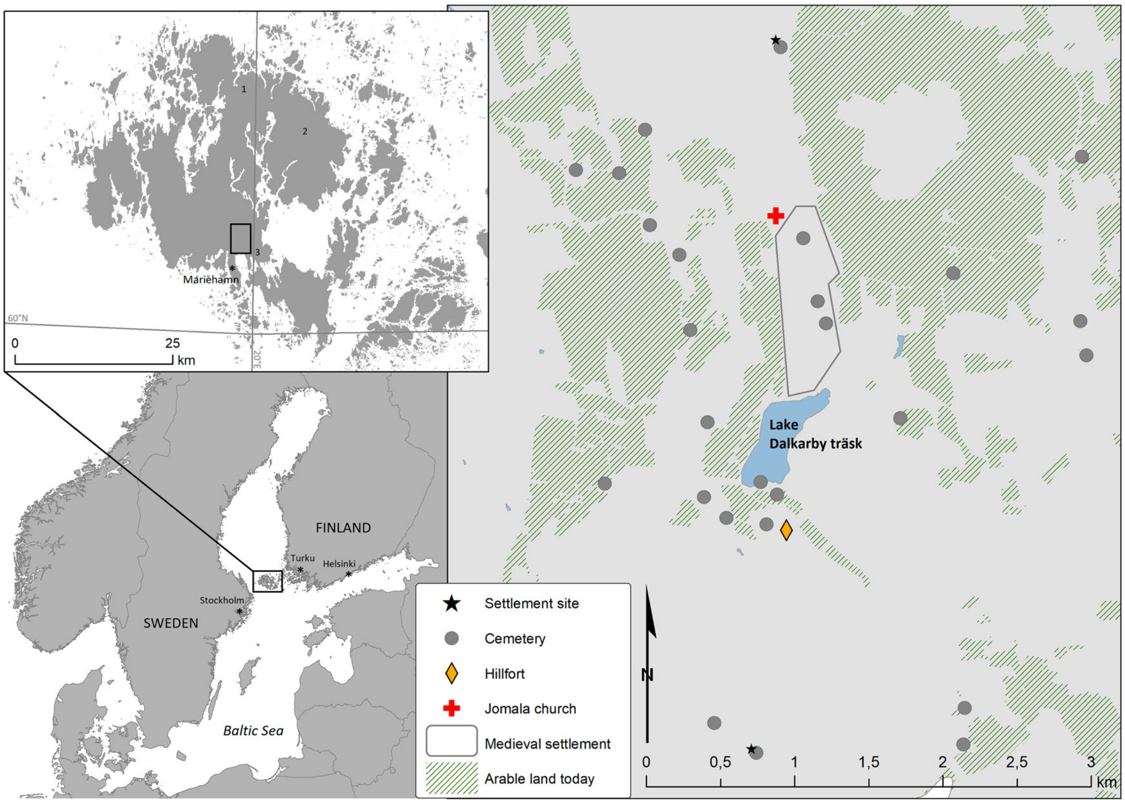

Figure 1. Left: the location of the Åland Islands in between present-day Sweden and Finland, with the study area marked with a rectangle on the map of Åland; areas for the previous pollen investigations marked with numbers: 1) Kvarnträsk, 2) Kolmilaträsk and 3) Flyet. Right: Lake Dalkarby träsk and its archaeological surroundings, as discussed in the article; present-day arable areas are represented to suggest the extent of agriculturally viable land during Late Iron Age and medieval periods.

dynamics in the Åland archipelago argues for an approximate 150-years-long hiatus in habitation, commencing with the end of the Late Iron Age and lasting through the period of AD 1050–1200. This theory is largely based on an apparent discontinuity of place-names between the prehistoric and medieval periods. Since the study of Ålandic place-names by Lars Hellberg (1980) concluding which concluded that Åland, having had a rather dense population during the Late Iron Age, was depopulated in the early eleventh century and rapidly re-colonized at the beginning of thirteenth century, many researchers – as well as the local community – believe that the archipelago was deserted during the time period in question (e.g. Talvio 1982, 2017; Orrman 1990; Törnblom 1993; Masonen 1995; Hiekkanen 2010, 2020; Sjöstrand P 2014). There seems to be an agreement among researchers favouring the theory that the re-colonisation process was suggested to have been initiated by the state of Sweden, whereby the sparse Finnish population that had managed to establish itself on Åland during the intervening period was pushed out and/or 'swedified'.

Due to Åland's legally confirmed special political position as an autonomous province of Finland, in which much of the *raison d'etre* of autonomy is the preservation in perpetuity of the Ålanders' unilingual Swedish culture against encroachment by the Finnish majority population in mainland Finland (Lindström 2000, 108), there has been much aggressiveness, but also a politically motivated drive associated with the question of settlement continuity on Åland in the transition from the Late Iron Age to the early medieval period. Many researchers thus choose to stay away from this topic (Wickholm 2008, 62). Therefore, there have been hardly any attempts to seriously engage with these discussions, and the trajectories of change in the Åland archipelago are still unresolved. The present state of knowledge is far from sufficient for understanding the population dynamics during the period in question. In order to shed light on the population movements, as well as to understand the land use and the subsistence strategies in this maritime environment, we consider the analysis of high-resolution pollen data from lake sediments an effective way to produce new knowledge. Pollen analysis, based on material obtained from lake sediments, is one of the fundamental tools for understanding the development, continuation, and intensity of past human activities.

Previous Pollen Studies

Lake Dalkarby träsk has been the subject of an earlier pollen analysis, conducted by Fries in 1961 (see also Fries 1963). This pioneering study, which aims to clarify both the vegetation history and the past human impact, estimated cultivation in the region to have started around AD 450, and although there was an undated regression in the intensity of cultivation noted, the study did not substantiate a settlement discontinuity in the transition from the prehistoric to historic periods. However, this research was conducted in low resolution and dated with only two radiocarbon dates. Therefore, although valuable in itself, this study remains insufficient for drawing reliable conclusions on the matter. In addition, Roeck Hansen (1991) conducted pollen analysis from the parish of Jomala, from the peat bog Flyet, close to the current study area (see also Figure 1). These investigations revealed the onset of the region's cultivation during the first centuries AD, and suggested an established economy based on animal husbandry and farming prevalent during the latter part of the Late Iron Age. Similarly to the study conducted by Fries, a period of devastation was indicated by the pollen data but not properly dated (cf. Roeck Hansen 1991, 132).

Other pollen investigations conducted on the Åland Islands include those by Sarmaja-Korjonen, Vasari, and Haeggström (1991) in the northern half of the archipelago, from the lakes of Kvarnträsk and Kolmilaträsk (see also Figure 1). The pollen analysis conducted from Lake Kvarnträsk shows that small-scale cultivation started from about AD 450, and after a decrease in the anthropogenic indicators in the beginning of the Late Iron Age the landscape was opened up during the second half of the period. By 1070, the environment had turned into an open cultural landscape with cereal pollen starting to occur on a continuous basis. According to the pollen data from Lake Kolmilaträsk, small-scale cultivation seems to have begun around this lake ca. AD 370, yet also in this region, the latter part of the Late Iron Age appears as a transition period with the increase in the anthropogenic indicators.

Thus none of the previous pollen investigations on the Åland Islands have demonstrated settlement discontinuity in the transition from the prehistoric to historic periods, rather they focused on identifying the beginning of agricultural cultivation. In most cases, however, poorly understood and insufficiently dated regression in the intensity of cultivation has been noted. The impetus for our study came from the theories of the settlement hiatus and the high-resolution approach applied in this study is therefore paramount in clarifying the trajectory of the hitherto largely enigmatic settlement dynamics, especially in regard to the possible period(s) of decline.

Study Area

Environmental Setting

The Åland Islands are located at the entrance of the Gulf of Bothnia in the Baltic Sea, about halfway between Sweden and Finland (Figure 1). Since deglaciation, the coastlines in the northern part of the Baltic basin have been dominated by the emergence of new land. As a result of this shore displacement, the highest peak of Åland (Orrdalsklint, 129 m) rose from the Baltic Sea around 8000 BC (Rosentau et al. 2021). Using the generalised isostatic rebound rate of 5 mm per year (cf. Ekman 2017), we can determine that Lake Dalkarby träsk (60°8'27.751 N, 19° 56'55,806 E; ETRS89), situated at 15 m a.s.l., was isolated as an independent small lake about 3000 years ago. Today, the lake is about 17 ha in size and has a maximum depth of 5.1 m. The bedrock in the area consists of quartz porphyritic rapakivi granite overlaid by podzols and, to a lesser extent, stagnosols.[1] The lake is surrounded by high exposed bedrock areas to the east with conifer forests; the western and northern shores are characterised by quite extensive arable land and settlements, while the areas to the south are also rocky, with a few small pockets of agriculturally suitable land bordering the city of Mariehamn.

Archaeological Context

Empirical and theoretical studies in Scandinavia (e.g. Sugita 1994; Nielsen and Sugita 2005; Hellman et al. 2009; Hjelle and Sugita 2012; Mazier et al. 2015) have demonstrated that the 'Relative Source Area of Pollen' (RSAP, Sugita 1994) for relatively small lakes, such as Lake Dalkarby träsk, correspond to a large area (ca. 900 to 3000 m). It is therefore reasonable to assume that, to a large extent, the pollen data represents the vegetation within a maximum 3 km radius around the lake, even when part of the pollen in this small lake represents the regional 'background pollen' (Sugita 2007a, 2007b). Thus, in the following, we concentrate mainly on the archaeological remains within a 3 km radius around the lake.

The surroundings of Lake Dalkarby träsk are rich in archaeological traces, especially from the Late Iron Age, although the area also has remains that are estimated to belong to the Stone, Bronze, and Early Iron Age periods,[2] indicating the popularity of the region for settlement even in earlier times. There are 26 known cemeteries with almost 700 grave mounds estimated to belong to the Late Iron Age in a radius of 3 km from the lake (Figure 1). These cemeteries vary in size, with the smallest having only two registered grave mounds and the largest 150 registered grave mounds; the latter being the second largest Late Iron Age burial ground on Åland. Archaeological excavations of varying scope and quality have been carried out at nine of these sites, but only 33 grave mounds have been investigated in the course of these excavations. Unfortunately, almost no material from these investigations has been radiometrically analysed, and the mounds are dated to the Late Iron Age based on artifactual and contextual evidence alone. So far, there are only two Late Iron Age settlement sites registered in the discussed region. One of these sites, situated south from Lake Dalkarby träsk adjacent to a quite large site-contemporary cemetery close to the former seashore – now in the middle of the city of Mariehamn – has been archaeologically studied and recently dated by means of radiocarbon dating, which points towards the period of AD 650–980 (Darmark and Ilves 2016, 31, tab. 7). Although, at the present state of knowledge, we know of only the two settlement sites in the area, this likely does not reflect the actual state of habitation during the period in question. Every burial ground presumably had a farm or farms attached to it, while a few farms probably also lacked their own cemetery. The high number of Late Iron Age cemeteries around Lake Dalkarby träsk, however, suggests a considerable population in the region. In addition to the cemeteries, a few hundred metres from the southern shore of the lake there is a hillfort estimated to belong to the Late Iron Age positioned on the northern plateau of the hill of Borgberget.

The region of Lake Dalkarby träsk was also notable during the medieval period. The oldest remaining stone church in Finland (Hiekkanen 2020) – constructed in the thirteenth century, close to the largest Late Iron Age burial ground in the current region – the Church of St Olaf, is about 1 km north of the lake. Immediately adjacent to the church, to the east, there are also traces of at least 17 stone foundation houses; one of the houses has been partially investigated and dated to the end of the fourteenth century/beginning of the fifteenth century (Cederhvarf 1910). Centrally placed on the Late Iron Age cemetery, to the south of the church, a stone cellar house with quite massive walls and several floors, surrounded by a moat, has been discovered and investigated (Hörfors 1988; 1990). This building was in use from the end of the thirteenth century until the beginning of the sixteenth century. In addition to the stone cellar house, there are about 20 more settlement remains at this site that are also estimated to be medieval. Another stone cellar house of a similar character was identified by the northern shore of Lake Dalkarby träsk. Although the remains of this building have not been investigated, it has been estimated to belong to the late medieval and early modern periods (Hörfors 1988, 161). Thus, at least in the area near the church, stretching all the way to the northern shore of Lake Dalkarby träsk, there are plentiful traces of settlement indicating intensive use of this region during the medieval period. However, the archaeological visibility of the transition from prehistoric to historic times remains low.

The modern history of this region is characterised by population growth and concentration, especially from the eighteenth century onward (de Geer 1960; Jaatinen, Peltonen, and Westerholm 1989); today, the municipality of Jomala is the next largest after Mariehamn, the capital of Åland (ÅSUB 2020). The settlement around the Church of St Olaf continues to grow and many of the archaeological traces described are within the modern village.

Materials and Methods

Coring, Sedimentological Methods, and Dating

A single 2 m long sediment core was taken from a central part of Lake Dalkarby träsk, at a point where the water depth was 3.75 m, using a lightweight model of piston corer (Putkinen and Saarelainen 1998). To describe the sedimentological characteristics, we used measurements of loss-on-ignition (LOI) and magnetic susceptibility (κ) (Bengtsson and Enell 1986; Grinter 2005). The sediment sequence was dated by six accelerator mass spectrometry (AMS) dates in the Tandem Laboratory at Uppsala University (Table 1). Conversion from radiocarbon ages to calendar years was performed with the radiocarbon calibration programme OxCal v4.4 (Bronk Ramsey 2009), using atmospheric data from Reimer et al. (2020). To create an age-depth model, a deposition model P_Sequence was used (Bronk Ramsey 2008).

Pollen, Charcoal, and Soot Analyses

From the sediment core, subsamples of 1 cm^3 were taken for pollen, charcoal, and soot particle analyses at a 1 cm resolution. Pollen slides were prepared following standard procedures, using glycerine as a mounting medium (e.g. Berglund and Ralska-Jasiewiczowa 1986). The results are presented as pollen percentages and pollen concentrations (grains in cm^3). 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).

For the determination of the pollen, charcoal, and soot particle concentration (grains/cm^3), two *Lycopodium* spores from batch 3862 (Stockmarr 1971) were added to each subsample. A minimum of 500 arboreal pollen grains were counted from each subsample. Along with the pollen, soot and charcoal particles were also counted. ‘Soot particles’ are black particulate matter created by combustion (Renberg and Wik 1985). Charcoal particles were measured along the longest axis and divided into two size classes: 10–30 and >30 μm. The identification of pollen was based on the literature by Faegri and Iversen (1989), Moore, Webb, and Collison (1991), Reille (1992; 1995), and Beug (2004). Regarding the identified pollen taxa, *Humulus* and *Cannabis* types of pollen

Table 1. 14C data from the Lake Dalkarby träsk sediment. pMC: 'percentage Modern Carbon'.

Laboratory no.	Sample depth (cm) from water surface	Dated material	14C age year BP	68.2% cal age ranges (from) (to)	95.4% cal age ranges (from) (to)
Ua-70512	1	macrofossils	103.9 ± 0.4 pMC	*Sample is younger than from 1950.*	
Ua-70513	27	macrofossils	100.4 ± 0.8 pMC	*Sample is younger than from 1950.*	
Ua-70515	77	sediment	526 ± 28	AD 1403 – AD 1428 (67.7%)	AD 1327 – AD 1347 (9.2%) AD 1395 – AD 1440 (85.9%)
Ua-70849	114	sediment	839 ± 28	AD 1178 – AD 1192 (16.8%) AD 1202 – AD 1229 (35.1%) AD 1244 – AD 1257 (13.9%)	AD 1165 – AD 1263 (95.1%)
Ua-70516	175	sediment	1 065 ± 29	AD 904 – AD 912 (8.2%) AD 976 – AD 1021 (60.0%)	AD 895 – AD 926 (19.8%) AD 948 – AD 1027 (75.5%)
Ua-70850	208	sediment	1 141 ± 28	AD 777 – AD 779 (2.3%) AD 884 – AD 900 (14.7%) AD 916 – AD 974 (50.6%)	AD 776 – AD 786 (5.3%) AD 829 – AD 857 (7.7%) AD 872 – AD 991 (82.3%)

resemble each other, and the size of the pollen grain is an important criterion facilitating distinction between these two types. *Cannabis* type pollen is slightly larger than *Humulus*. However, the exact size limit between *Humulus*/*Cannabis* types varies between the identification keys. For example, according to the identification key by Beug (2004), the mean value for *Humulus lupulus* is 23.4 µm, and for *Cannabis sativa* 28.1 µm. The identification key by Faegri and Iversen (1989), on the other hand, places the limit at 20 µm, where all the grains over 20 µm are identified as *Cannabis* type. In order to avoid the classification of *Humulus* type pollen as *Cannabis*, three size classes were used. All of the *Humulus*/*Cannabis* types that are 25 µm or under were identified as *Humulus*, and the ones that are 30 µm or over were identified as *Cannabis*. The ones falling into size classes in between were merely classified as *Humulus*/*Cannabis* type. Cereal pollen identification was based on the following criteria: grains between 40 and 60 µm with an annulus diameter >10 µm and a distinctive 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, and grains with an annulus diameter larger than 12 µm were assigned to the *Avena*–*Triticum* group.

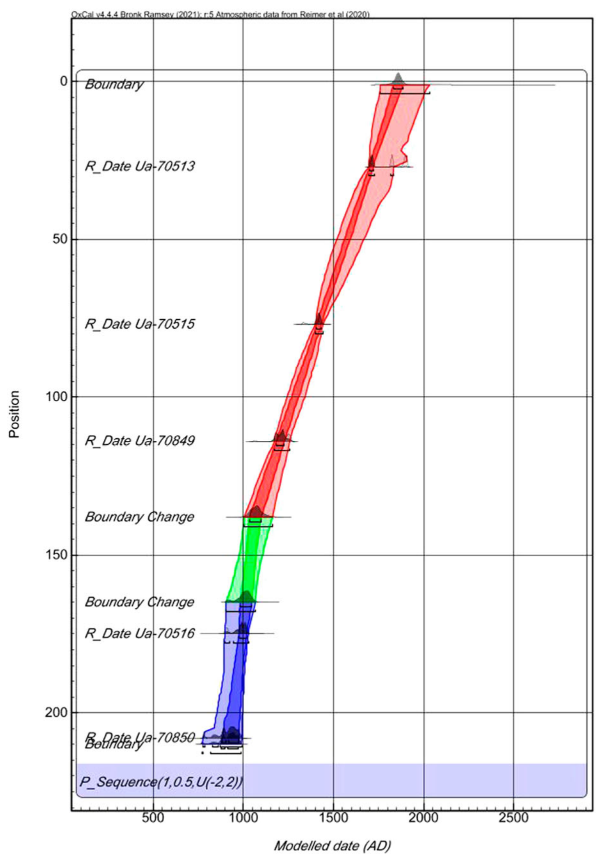

Figure 2. Age-depth transformation for the Lake Dalkarby träsk sediment sequence based on six 14C dates and boundary changes at the depths of 165 and 138 cm. The two uppermost dates, obtained from the levels of 1 and 27 cm, were both 'modern', i.e. younger than 1950.

Pollen percentages for arboreal (AP) and non-arboreal pollen (NAP) were calculated from the basic sum of terrestrial pollen grains, $P = AP + NAP$. The percentages of aquatic pollen and spores were calculated from the sums P + AqP and P + spores. Biostratigraphical data treatment and diagrams were handled with Grimm's (1991) TILIA and TILIA GRAPH programmes.

Coniss and Rarefaction Analyses

The pollen sequence was numerically divided into pollen assemblage zones using Constrained Incremental Sums of Squares cluster analysis with the CONISS programme (Grimm 1987). Aquatics and spores were excluded from the calculation. For the comparison of species richness between samples, a rarefaction analysis was carried out using the POLPAL program (Walanus and Nalepka 1999), as the pollen count is standardised to a single sum ($n = 500$).

Results

Chronology

The age-depth model (Table 1, Figure 2) suggests a continuous sedimentary archive starting about AD

885 and continuing steadily to 77 cm, which according to the radiocarbon dating belongs to ca. 1420, i.e. the late medieval period. During this period, the average deposition rate is 2.2 mm per year. The topmost two dates from 27cm and 1 cm produced modern ages, i.e. after 1950.

Stratigraphy: Loss-On-Ignition and Magnetic Susceptibility

The 208 cm long sediment profile from Lake Dalkarby träsk consists of dark brown homogenous and structureless coarse detritus gyttja with LOI mostly varying between 30% and 55%. Four litho-stratigraphical units based on LOI and magnetic susceptibility can be distinguished (Figure 3). (1) The lowest part, 208–165 cm, is characterised by high LOI (>40%) and low susceptibility ($<10 \times 10^{-6}$). (2) From 170 cm LOI decreases (<40%) and susceptibility value increases. (3) From 125 cm the LOI values then stabilise to ca. 40% and to ca. 10×10^{-6} until ca. 28 cm. (4) The uppermost part of the sediment (20–1 cm) is characterised by increased susceptibility and a decrease in LOI.

Pollen, Charcoal and Soot

According to the CONISS analysis, six pollen zones (PAZ 1a–1b, 2a–2d) were identified. The CONISS zones and the pollen results, expressed as pollen percentages are presented in Figure 3. The pollen, charcoal, and soot particle concentrations are presented in Figure 4. Below, a brief description of each zone is presented. A more detailed description (the results for the pollen percentages and concentrations for pollen, charcoal, and soot particles) for each CONISS zone is presented in Table 2.

Zone 1A (208–175 cm, AD 885–965) is dominated by woodland taxa (84.1% in total) including *Picea, Pinus, Betula* and *Alnus*. Thermal deciduous trees are present in 2.6%, with *Quercus* (1.3%) and *Corylus* (0.7%) the most abundant. Herbaceous taxa are present in 10.5%, with *Filipendula, Rubus* the most abundant. *Juniperus* is present in 1.7% and pollen originating from cultivated plants is present in only 0.1%. The total pollen concentration is the highest (130,687 grains/cm^3) of the entire core.

Zone 1B (175–136 cm, AD 965–1090) is still dominated by woodland taxa (74.6%), but herbs, shrubs and dwarf shrubs, and cultivated pollen taxa show an increasing trend throughout the zone. The most prominent increase is visible in *Juniperus,* Cyperaceae, Ranunculaceae, *Rumex*, *Humulus* and *Cannabis*. From the beginning of the zone, total pollen concentration stabilises to 80,400 grains/cm^3, remaining between 80,000 and 86,000 grains/cm^3 for the rest of the zone. High charcoal particle concentration values (mean 291,200 particles/cm^3) are recorded in this zone.

Zone 2A (136–114 cm, 1090–1212) is characterised by an increase in pollen originating from cultivated taxa, especially *Secale* and *Hordeum. Juniperus* pollen proportions increased to an average of 14.9%. Compared to the previous zone, arboreal (64%) and thermophilous tree pollen (1.9%) taxa decrease.

Zone 2B (114–77 cm, 1212–1420) is characterised by the lowest proportions of arboreal pollen (60.2%) and highest proportions of herb pollen (16.8%). Of the herb pollens, Poaceae (10.9%) and Cyperaceae (1.6%) are most abundant. The proportion of *Juniperus* pollen remains high (13%). The proportion of pollen originating from cultivated plants is still growing, with *Secale* (4.9%), *Hordeum* (2.7%) and *Cannabis* (0.2%) the most abundant. From 48 cm upwards, the concentration of soot particles suddenly increases.

Zone 2C (77–28 cm, from 1420 to industrial age). In this time zone, the proportion of pollen originating from cultivated species is highest (8.2%). Zone 2D (28–1 cm) was deposited after 1950 and is characterised by the recovery of arboreal tree species and the reduction in pollen originating from herbs and cultivated species. The proportion of *Juniperus* pollen is reduced. This is also a zone where high charcoal particles (mean 282,260 particles/cm^3) and soot concentrations (58,380 particles/cm^3) are recorded.

Zone 2D (28–1 cm, deposited after AD 1950). The dominant elements in this zone are increasing percentages and concentrations of *Pinus*, *Betula* and *Alnus*, while *Picea* values decrease. Pollen types originating from herbs and cultivated species decrease to 11.7% and 3%, respectively. The proportion of shrubs and dwarf shrubs decreases to 5.1%. The concentration of soot particles and small charcoal fragments remains at elevated levels.

Discussion

The End of the Late Iron Age

The lowermost pollen assemblage zone (PAZ 1a, 208–175 cm) covers the time period from AD 885 until 965 and is composed of coarse detritus gyttja (with LOI >40% and low susceptibility) representing the earliest stages of sedimentation after isolation from the Baltic Sea. The abundance of *Filipendula*, *Rubus*, and *Salix* reflects the early stages of vegetation development around the lake after isolation, with local lakeshore vegetation as a significant element in the pollen diagram. The high total pollen concentration relates to high LOI values (>40%) and low susceptibility ($<10 \times 10^{-6}$) inthe initial part of the sedimentation.

During this time interval, the pollen data displays a picture of a forested landscape with small-scale human impact including the cultivation of at least *Hordeum*

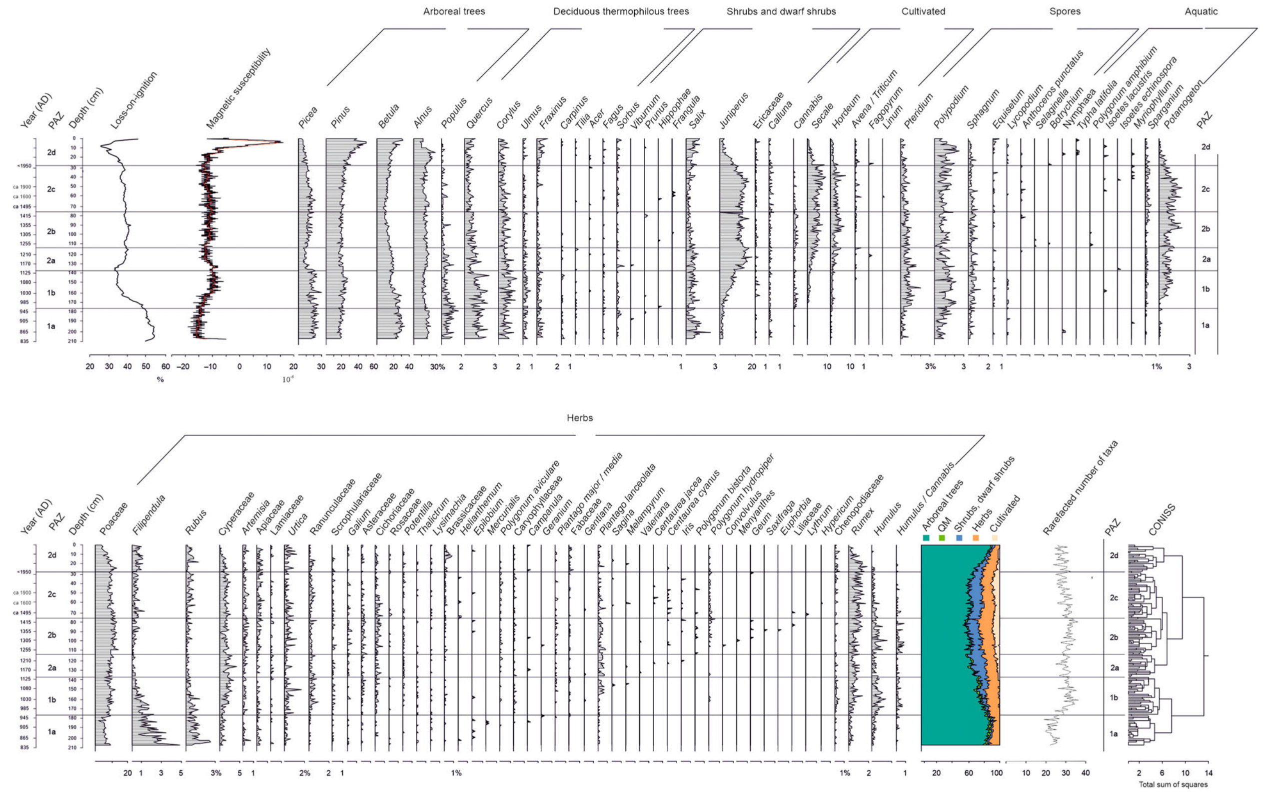

Figure 3. Lake Dalkarby träsk pollen frequencies, expressed as percentages with rarefaction and CONISS analyses, loss-on-ignition and magnetic susceptibility.

(barley), *Cannabis* (hemp), and *Humulus* (hop). The occurrence of *Plantago lanceolata* (ribwort plantain) is also connected to human activity in the area. *Plantago lanceolata* can grow in natural habitats, but it is more common in open, disturbed landscapes; therefore, it is often used as an indicator of land use and pastoralism (Behre 1981, 1990). Nevertheless, because of the dominance of forested areas, species richness visible in our data for this period remains low.

From AD 965 onwards (beginning of PAZ 1b, 175–136 cm), forested areas around Lake Dalkarby träsk started to decline and the landscape gradually opened up. This is represented by a slight decrease in *Picea* (spruce) and decline in the broad-leaved trees *Alnus* (alder), *Populus* (aspen), and *Betula* (birch). The decrease in LOI and increase in the susceptibility value from 165 cm indicates the stabilisation of the sedimentation environment after the transition from the Baltic basin into a smaller isolated basin. From the beginning of this zone, a period of intensive use of fire is evident. The concentration of charcoal particles starts to increase, and peaks around AD 1000. Deducing from the simultaneous increase in charcoal particles and decrease in tree species, it seems reasonable to suggest that this period marks the extensive clearance of the forests with fire for slash-and-burn cultivation.

Slash-and-burn cultivation was the traditional Nordic means of clearing the land for cultivation. Slash-and-burn clearings (Swe: *svedjebruk*; Fin: *huuhta*) were made in primarily spruce-dominated forests that had preferably not been burnt previously (Heikinheimo 1915; Soininen 1974). Pollen studies in Finland have demonstrated that the decrease of *Picea* often accompanies the beginning of slash-and-burn cultivation (e.g. Tolonen 1978; Pitkänen and Huttunen 1999; Pitkänen 2000). The burning of spruce-dominated forests was best suited for growing swidden rye, due to the resulting acidity of soils. Therefore, *Secale* formed the most important crop in slash-and-burn plots, whereas *Hordeum* was less well suited, but was among the first to be cultivated in permanent fields (Soininen 1974). In the Lake Dalkarby träsk pollen record, both *Secale* (rye) and *Rumex* (sorrel) increase from AD 965, and the cultivation of *Hordeum* continues to be slightly more intensive than in the previous period. *Rumex* is a disturbance indicator which is particularly typical of the weed flora that indicates slash-and-burn cultivation (Heikinheimo 1915; Behre 1981; Vuorela 1986). In addition, *Cannabis* starts to notably increase during the period in question. Most probably, *Hordeum* and *Cannabis* were cultivated in the permanent plots, close to settlements. After the period of intensive fires in the region under study, the use of fire gradually ceased by ca. AD 1040, evidenced by a decline in charcoal particles in the charcoal record.

From ca. AD 970 onwards, the *Juniperus* (juniper) concentrations and percentage values start to increase. *Juniperus* thrives in open areas and in improved light

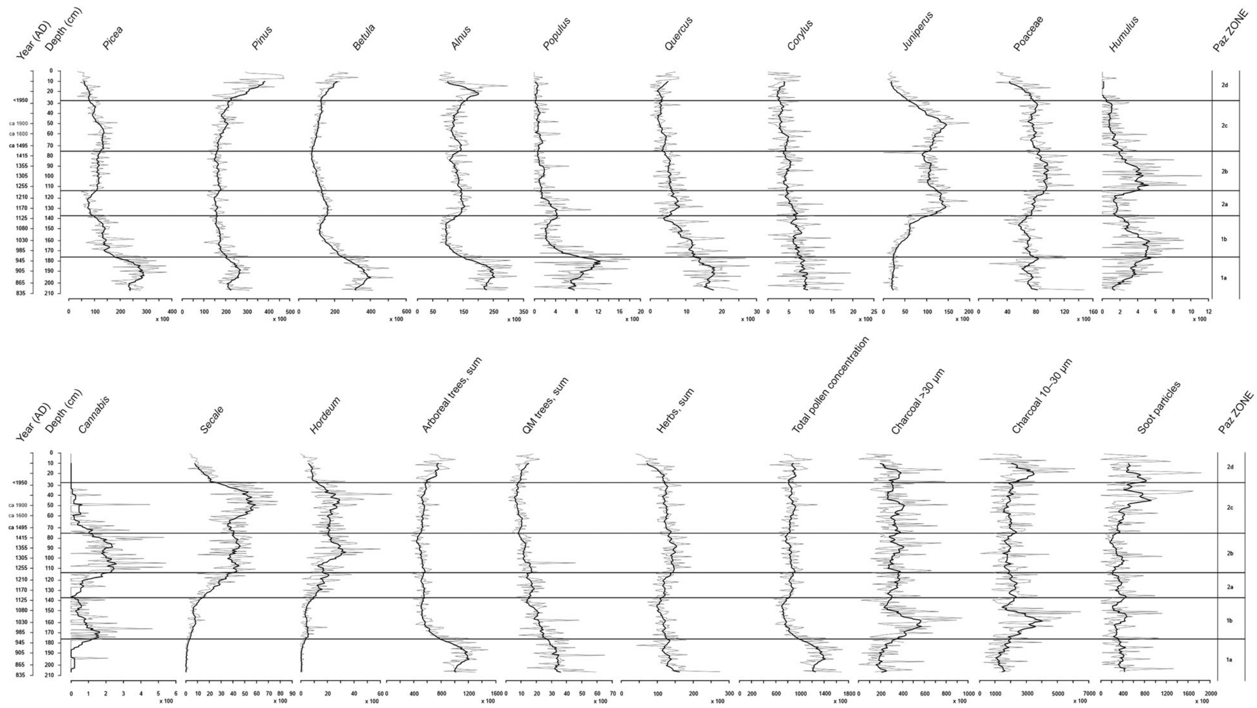

Figure 4. Lake Dalkarby träsk pollen frequencies, expressed as concentrations (grains in cm^3).

conditions and is therefore commonly associated with grazing and animal husbandry (Behre 1981; Vuorela 1986; Hæggström 1990; Pykälä 2001). Former slash-and-burn clearance areas are suitable pastures for livestock, thus it is likely that once the land was cleared of forest through burning, the open landscape was maintained by grazing animals. In addition, *Plantago lanceolata* suddenly increases from ca. AD 1030 onwards, and therefore further supports the presence of grazing animals. It also seems reasonable to assume that first the slash-and-burn clearing activities and then the grazing of animals, both practised in the surroundings of the lake, caused the increased erosion from the shores, visible in the decrease in LOI and increase in magnetic susceptibility values from ca. AD 970 onwards (170 cm) and lasting until ca. 1150 (125 cm).

The present results correlate well with other pollen evidence from the islands. The earlier pollen analyses from the lakes of Kvarnträsk, Kolmilaträsk, Flyet and Dalkarby träsk also showed an opening up of vegetation from AD 800 onwards (see also Alenius 2014). By AD 1070, the environment around Kvarnträsk and Kolmilaträsk was turned into an open landscape with cultivated fields and grazed areas. A notable increase in the hemp/hop pollen type during the Late Iron Age is visible, especially in the Kolmilaträsk pollen data. Unfortunately, none of the earlier pollen analyses from Åland distinguished between hemp and hop.

Rather extensive osteological studies of both settlements and cemeteries on Åland consistently reveal the prominence of domestic species, sheep/goat in particular, but also cattle, in different parts of the archipelago (e.g. Storå et al. 2012; Gustavsson et al. 2014). In general, therefore, these results indicate that, despite the maritime setting of the Åland Islands and the importance of the maritime economy (cf. Storå et al. 2012), the main subsistence strategies during the Late Iron Age still revolved around animal husbandry, although the societies were also engaged in growing their subsistence crops. Archaeobotanical studies from the Late Iron Age settlement sites on Åland show that mainly barley, but also oats, wheat and rye, as well as hemp and even flax, were part of the islands' economy from the beginning of the Late Iron Age (e.g. Núñez and Lempiäinen 1992; Andersson 2017; Lempiäinen-Avci 2021). However, these studies also indicate that there was variation in cultivation between different farms and different regions of Åland. Pollen data from Lake Dalkarby träsk point towards barley, but also rye, having the strongest importance for the communities in the region at the end of the Late Iron Age. On the other hand, However, rye as a wind-pollinated species produces substantial amounts of pollen compared to insect-pollinated or autogamous species such as barley, and therefore the pollen proportions or concentrations cannot be directly translated into estimates of proportions of the levelof cultivation (Vuorela 1973; Faegri and Iversen 1989). Osteological studies that have been conducted for the only firmly dated settlement site in the current study region (see also above) indicate a strong maritime economy for the way of life of this particular community (Gustavsson 2011). Archaeobotanical material from the same site was very meagre

Table 2. Summary of the vegetation composition changes for the main local Pollen Assemblage Zones. Percentages and concentrations represented in the brackets are the average values over the time interval. *AP* = arboreal trees, QM = Quertum mixtum, i.e. thermophilous deciduous trees.

PAZ Cm Age (AD)	Percentages	Concentrations (grains/cm^3)
1a **208–175 cm** **AD 885–965**	AP: 84.1% (*Picea* 20.2%, *Pinus* 18.5%, *Betula* 26.8%, *Alnus* 17.8%) QM: 2.6% (*Quercus* 1.3%, *Corylus* 0.7%) Shrubs and dwarf shrubs: 2.7% Herbs: 10.5% Cultivated: 0.1% Spores: 1.1%, Aquatics: 0.1%	Total pollen concentration: 130,687 AP: 109,849 QM: 3,423 Shrubs and dwarf shrubs: 3,465 Herbs: 13,795 Charcoal: 167,066 Soot: 40,290
1b **175–136 cm** **AD 965–1090**	AP: 74.6% (*Picea* 18.2%, *Pinus* 22.2%, *Betula* 20.5%, *Alnus* 13.3%) QM: 2.7% (*Quercus* 1.3%, *Corylus* 0.9%) Shrubs and dwarf shrubs: 6.6% Herbs: 14.6% Cultivated: 1.5% Spores: 2.6%, Aquatics: 0.7%	Total pollen concentration: 80,456 AP: 60,497 QM: 2,187 Shrubs and dwarf shrubs: 5,005 Herbs: 11,611 Charcoal: 291,201 Soot: 30,346
2a **136–114 cm AD 1090–1212**	AP: 64% (*Picea* 9.9%, *Pinus* 18.6%, *Betula* 18.3%, *Alnus* 16.8%) QM: 1.9% (*Quercus* 0.7%, *Corylus* 0.7%) Shrubs and dwarf shrubs: 15.7% Herbs: 14.2% Cultivated: 4.3% Spores: 2.2%, Aquatics: 0.9%	Total pollen concentration: 84,450 AP: 54,130 QM: 1,599 Shrubs and dwarf shrubs: 13,246 Herbs: 11,951 Charcoal: 267,622 Soot: 39,924
2b **114–77 cm AD 1212–1420**	AP: 60.2% (*Picea* 13.2%, *Pinus* 19.5%, *Betula* 12.2%, *Alnus* 15.2%) QM: 1.5% (*Quercus* 0.7%, *Corylus* 0.6%) Shrubs and dwarf shrubs: 13.5% Herbs: 16.8% Cultivated: 7.8% Spores: 1.8%, Aquatics: 1.2%	Total pollen concentration: 85,389 AP: 51,354 QM: 1,379 Shrubs and dwarf shrubs: 11,679 Herbs: 14,314 Charcoal: 211,798 Soot: 45,831
2c **77–28 cm** **From AD 1420 to industrial Age**	AP: 62% (*Picea* 14.1%, *Pinus* 21.2%, *Betula* 11.8%, *Alnus* 14.8%) QM: 1% (*Quercus* 0.4%, *Corylus* 0.4%) Shrubs and dwarf shrubs: 13.6% Herbs: 14.8% Cultivated: 8.2% Spores: 1.7%, Aquatics: 1.4%	Total pollen concentration: 85,472 AP: 52,984 QM: 834 Shrubs and dwarf shrubs: 11,805 Herbs: 12,601 Charcoal: 227,356 Soot: 45,831
2d **28–1 cm** **Deposited after AD 1950**	AP: 78.9% (*Picea* 8.4%, *Pinus* 34.6%, *Betula* 19%, *Alnus* 16.8%) QM: 1.3%: (*Quercus* 0.4%, *Corylus* 0.3%) Shrubs and dwarf shrubs: 5.1% Herbs: 11.7% Cultivated: 3% Spores: 1.8%, Aquatics: 0.4%	Total pollen concentration: 86,736 AP: 68,670 QM: 1,084 Shrubs and dwarf shrubs: 4,373 Herbs: 10,043 Charcoal: 282,256 Soot: 58,380

and in terms of cultivated species indicates only the presence of rye(Ahlqvist 2012).

Early Medieval Period

Between 1090 and 1210 (PAZ 2a, 136–114 cm), the forest areas continued to decline and the cultivation of *Hordeum* and *Secale* increased. The few finds of *Avena/Triticum* and *Fagopyrum* pollen indicate that oats/wheat, as well as buckwheat, were cultivated, though on a small scale and sporadically. It can be deduced from the high proportion of *Juniperus* and Poaceae that the area of meadows and open grasslands was already extensive.

Regarding the tree species, the most notable change is a profound drop in *Picea* values between ca. 1090 and 1210. In addition, the concentrations of *Quercus* decline, most profoundly in the period of 1060–1130. It is difficult to pinpoint the exact reasons behind the sudden decline in these tree species. The low charcoal concentration suggests there was no intensive use of fire during this time period. Therefore, one plausible explanation is that the decline is due to clearance of forest areas to expand pastoral and arable lands. On the other hand, it might be due to using wood as raw material for the construction of dwellings and ships, furniture, and tools. Most probably, however, it is the combination of both.

Emanating from the archaeological traces around the church, following the habitation dated to the prehistoric periods, intensive settlement and building activity in the Jomala region is once again clearly visible in the archaeological record from the fourteenth century onward. At the same time, we do know that the stone church in Jomala was constructed during the thirteenth century (Hiekkanen 2020, 489). Although there have been no archaeological traces of any possible wooden structures discovered that relate to the existing stone church, several other stone churches on Åland (as well as elsewhere) have documented remains of wooden structures preceding the stone buildings (e.g. Ringbom 2010; Ruohonen 2016; Hiekkanen 2020). The building of wooden churches as well as the subsequent ecclesiastical building activity on Åland, connected to this particular time period when Christianity expanded in the region, would explain the sudden demand for large amounts of timber. Also, in addition to the current case in Jomala, on the Åland Islands in general there is a very strong connection between Late Iron Age cemeteries and churches (Ringbom 2010). This is actually a well-known and widespread phenomenon in the Nordic countries – church sites were located in close proximity to Iron Age burial grounds and in assembly landscapes (Andrén 2013). Therefore, as also evidenced by the pollen data, it is hardly likely that the church in Jomala was built in an unsettled landscape, but rather the opposite, that Jomala was one of the centres of early medieval Åland.

The palaeoecological evidence from Lake Dalkarby träsk does not support the theories of an approximately 150-years-long hiatus in habitation between 1050 and 1200, nor a possible population decline during this period. If there was a total settlement hiatus and/or severe population decline in the region, one would assume a break or downturn in cultivation and, to some extent, a recovery of forests and tree species. In the pollen data, however, there are no signs of such processes. On the contrary, the *Quercus* concentrations drop between 1060 and 1130 and a decline in the *Picea* values, starting from ca. 1090 and lasting to ca. 1210, suggests the intensive use of trees, which in the absence of fire-based cultivation could have been used as building timber or as firewood. Also, grazed meadow areas in fact increase throughout the suggested period of 'population hiatus'. Furthermore, the cultivation of *Secale* and *Hordeum* notably increases from the beginning of PAZ 2a, dating to 1090, but the pollen concentrations show an increasing trend already from the end of PAZ 1b (ca. 1070 onwards). In addition to the cultivated species, increasing and regular occurrences of *Plantago lanceolata* from 1030 onwards demonstrate a continuity of the settlement and land use. Interestingly, however, a decline in *Humulus* and *Cannabis* indicates a regression in the cultivation of these particular species. It can be hypothesised that the cultivation of hemp and hops either diminished or moved further away from the lake.

Traditional Agriculture

Between 1210 and 1420 (PAZ 2b, 114–77 cm), the pollen data displays a picture of an agrarian community with a subsistence economy based on arable farming and animal husbandry. The forested area was at its lowest level. *Betula* values are the lowest recorded, and stay low until modern times. *Secale* and *Hordeum* were cultivated intensively, and the cultivation increased compared to the previous time period.

From 1300 onwards, the cultivation of *Hordeum* as well as *Avena* (oats)/*Triticum* (wheat) increased. From ca. 1300 until 1420 species richness was at its highest, and pollen originating from the species typical to agrarian communities such as *Plantago lanceolata, Rumex, Urtica,* Asteraceae, and Cichoriaceae are abundant. Also, there is a slight increase in the number of other pollen types, such as Fabaceae (pea family), *Plantago major*/*media* (plantains), Caryophyllaceae (carnation family), *Polygonum* (knotweed), and Chenopodiaceae (goosefoot family), which are all typical for rural communities (Behre 1981; Vuorela 1986). The species richness of plant communities has been shown to be highest in heterogeneous and disturbed environments (Birks and Line 1992), and it seems reasonable to assume that mosaics created by many simultaneous land-use patterns such as pastures, footpaths, yards and other rural ecosystems are the reason behind the increase in species richness.

During the early medieval periods the practice of a two-year rotation system, where half of the field area was cultivated and the other half was left as fallow land, spread from Sweden to south-western Finland, together with an open field system (Ericsson 2012; Alenius et al. 2014). Along with the two-year rotation system, field areas were expanded and the cultivation of winter rye started (Orrman 2003). It can be hypothesised that from 1210 onwards, rye and other cultivated species were grown on permanent fields using a two-year rotation system.

During this period, *Cannabis* and *Humulus* pollen concentrations were once again high, suggesting that these species were cultivated intensively. Historically, coarse hemp textiles have been used for various purposes, whereas strong hemp fibre was especially well suited to rope making (Barber 1991; Mannering, Gleba, and Bloch Hansen 2012). Also, according to the historical sources, *Cannabis* was rather extensively used as a raw material for fishing nets, sails, and clothes on Åland (Leppänen 2018). *Humulus* was often used as a medicinal plant, as well as in beer making. According to a law from 1734, each house was even ordered by law to grow hops to keep up with the demand for beer (Thunaeus 1970) – the principles of this may well have been established earlier.

Deducing from the high proportion of *Juniperus* and Poaceae, the area for meadows and open grasslands during these medieval times was extensive. On the Åland Islands, keeping cattle was an integral and important part of traditional agriculture (Jaatinen, Peltonen, and Westerholm 1989). The manure was needed in order to fertilise the fields, and therefore farmers kept as many animals as they could feed (see also Orrman 2003). In this practice, the keeping of cattle was restricted by the long indoor feeding season, which required the collection of fodder from natural meadows. Therefore, one possible explanation for the decline in *Betula* values is grazing animals; the branches were probably also collected as fodder for the cattle. On the other hand, birch has a high calorific value, and is thus well suited for heating wood-burning ovens and fireplaces (Alakangas et al. 2016); the decline could accordingly also result from birch being used as firewood. Obviously, the combination of both factors cannot be excluded.

Industrial Age

From ca. 50 cm, 'soot' particle concentration suddenly increases in the Lake Dalkarby träsk data. This can roughly be dated to the 1890–1930s, when society changed from agrarian to industrial (Kuisma 1990; Möttönen 2017). Coal became important during the Industrial Revolution when the production methods became intimately connected to coal-driven machines. Coal was used to heat buildings, power steam engines, and generate electricity. Also, on Åland the use of coal can be seen as connected to the introduction and increasing use of steamboats. In this regard it is important to note that a harbour, open for use all year round, started operating in the town of Hanko in 1890, and regular connections, operated by steamboats, were established between the towns of Turku and Stockholm around the same time (Kaukiainen 1991); Åland was a natural stop-over between these destinations.

In addition to the increase in soot particle concentration, *Juniperus* values start to decrease from the 50 cm level. This decrease has continued until the present time and indicates the diminishing proportions of grazed meadow areas. At the same time, *Secale* and *Hordeum* continued to be intensively cultivated. A sudden increase in Brassicaceae (the cabbage family) might represent the intentional growing of cruciferous vegetables such as cabbage, cauliflower, and broccoli. However, *Cannabis* cultivation was steadily decreasing already from the beginning of this zone, from the 77 cm level, and it is nearly absent by 50 cm. According to historical sources, cotton was increasingly imported from Stockholm, and started to replace hemp as well as flax in the 1870s (Leppänen 2018), a practice that can be directly connected to the disappearance of *Cannabis* in the pollen data. With modernisation, the use of tree species also changed. Decreasing *Picea* values might reflect the intensive use of spruce during this period, while other tree taxa slightly recover.

The uppermost part of the sediment (PAZ 2d, 28–1 cm) is modern. The erosion from the lake's threshold area represented in the LOI and susceptibility values, as well as small charcoal fragments in the data, stem from recent human activity, such as waterworks located on the southern shore of the lake and roads on the western and southern sides of the lake.

Conclusion

In this study, we analysed the development, intensity, continuity, and changes in different human activities, such as the use of forest resources, fire, and subsistence sources such as cultivation and animal husbandry on the Åland Islands. Our main aim was to clarify one of the most controversial questions in the history of the islands – whether Åland was depopulated and/or suffered a prolonged devastation starting from the early eleventh century, in the transition from the Late Iron Age to the medieval period.

Looking at the general picture provided by the present and earlier pollen analyses, archaeological, macrofossil, and osteological data, it can be concluded that the Late Iron Age on Åland was a period of expansion. In different parts of the archipelago, the latter part of the period was characterised by the deforestation of new areas and the expansion of settlements, with an increase in cultivated fields as well as grazed areas. The growth in animal husbandry and cultivation visible in the environmental data, together with the abundance of archaeological sites and finds related to the Late Iron Age, is clearly connected to the increase in human population and activity on Åland, which reached its climax in the latter part of the period.

The previous pollen analyses conducted on Åland did not quite reach their full potential for understanding landscape and settlement development in the archipelago. The question of a possible population hiatus during the transition from the Late Iron Age to the medieval period, between AD 1050 and 1200, in particular remained unresolved. Our results do not support the theories of an approximately 150-years-long hiatus in habitation, nor a possible population decline during this period, at least for the specific region investigated. Therefore, the high resolution and well-dated pollen analysis proved its value in the study of the period when archaeological and historical data are sparse.

From the methodological point of view, the well-dated pollen series and the grouping of the *Humulus/Cannabis* types of pollen to three different size classes allowed the cultivation of *Cannabis* to be studied in more detail for the first time. The data revealed a long history of cultivation of *Cannabis* in this maritime environment, with the most intensive phase dating to ca. 1210–1420. Although it remains to be investigated what role hemp production played in prehistoric and medieval Åland, it is a clear anthropogenic signal and as such underlines the potential of further pollen analysis in illuminating historical processes for periods and questions that for various reasons are poorly represented in other sources.

Notes

1. Data retrieved from https://gtkdata.gtk.fi/maankamara/
2. The current register of ancient monuments on Åland – digitally available at https://aland.maps.arcgis.com/apps/webappviewer/index.html?id=9d7cc07ab4004f0ca620038c4fd416ca – is the source for all quantitative and chronological information on the archaeological background, if not otherwise stated.

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