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# Out of the Peat: Preliminary Geophysical Prospection and Evaluation of the Mid-Holocene Stationary Wooden Fishing Structures in Haapajärvi, Finland

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## ABSTRACT

The huge scientific and interpretive value of wetland archaeological sites has been well demonstrated in several studies. The management of the archaeological resource of wetland landscapes is problematic, however, and there is an urgent need for noninvasive techniques to detect waterlogged organic archaeological remains. Stationary wooden fishing structures associated with fishing sites constitute an important wetland archaeological resource in northern Europe. In Finland, similar wooden constructions have been used for fishing from prehistory to the early modern era. The discovery of sites has been accidental, because the waterlogged organic remains have been considered invisible to conventional geoprospection techniques. Because of this, a small project was launched at Lamminoja, northwest Finland, in order to investigate whether it would be possible to improve our chances to detect fishery sites in demanding wetland habitats. New information was obtained through geophysical prospection, trial excavations, and accelerator mass spectrometry (AMS) dating. Geophysical testing was hampered by several factors, including complex sediments affected by modern drainage. New information was obtained, however, on the composition, age, and spatial distribution of the wooden fishing structures preserved in peat over 5000 years.

## KEYWORDS

Wetland archaeology; geophysical prospection; waterlogged wood; prehistoric fishing; Finland

## Introduction

The majority of archaeological sites situated in wetland environments have come to light while already being destroyed through, for example, drainage, dredging, and peat cutting. The huge scientific value of these sites is a well-known fact (Keller 1866; Clark 1954; Coles and Lawson 1987; Coles and Coles 1991, 1996; Menotti and O'Sullivan 2013), but the management of the archaeological resource of wetland landscapes is problematic, mostly because of the lack of functional mapping and prospection techniques. The unusual preservation conditions for organic materials under humid, saturated sediments yield valuable sources for investigating past populations, their material culture, and their technological adaptations. Archaeological fieldwork under the regime of today's developer-led archaeology has, however, concentrated on more mineral-rich sediments where the preservation of organic materials is limited. In research-based investigations, bogs and wetlands have long been considered marginal areas, even though their utilization has been extensive from prehistoric times to the modern era (Nicholas 2013: 769–70). This has resulted in a bias in the archaeological record because our conceptions of technology and of material culture as a whole have been mainly based on lithics, ceramics, metals, and other durables.

In northern Europe, the environmental changes through the Holocene have altered the landscape and its ecosystems profoundly (Kulkova et al. 2016). Especially on the northeastern shores of the Baltic Sea, the isostatic post-glacial rebound, local topography, and climate history have had a dramatic effect on the development of wetlands (Korhola 1995; Seppä 2002; Ojala et al. 2013: 129). Stationary wooden fishing

structures constitute an important wetland archaeological resource in this area (Mazurkevich et al. 2010; Koivisto 2012; Piličiauskas et al. 2012; Lozovski et al. 2014; Koivisto and Nurminen 2015; Bērziņš et al. 2016). In Finland, approximately 90 fishery sites associated with stationary wooden structures have come up in wetlands through various land use practices and during periods of low water (Koivisto and Nurminen 2015). Most of the fisheries have presumably been in use in historical times, as seen in ethnographic sources (Sirelius 1906a, 1906b, 1906c, 1907, 1908; Valonen 1953), but several securely-dated wooden remains have returned prehistoric dates (Koivisto 2012; Koivisto and Nurminen 2015). The discovery of sites has been sporadic and their contexts and composition have usually remained unresolved. After their sudden discovery, the archaeological fieldwork has been focused on revealing the wooden structures without exploring their immediate surroundings.

Because of the dearth of information, the aim of this paper and our research is to move forward from the current inactive state of affairs, and we strive to contribute to the prospection and management strategies of wetland archaeological resources. This article will update the archaeological data concerning stationary wooden fishing structures preserved in wetland habitats in Finland (Koivisto and Nurminen 2015), evaluate them in the light of the ethnographic sources on similar structures, and present the preliminary results of an experimental fieldwork project carried out at one of the most recently discovered fishery sites, Lamminoja, at Haapajärvi, northwestern Finland. In order to further our understanding of these still inadequately-explored archaeological wooden remains, we will consider the circumstances and

settings where the stationary wooden fishing structures have been encountered in Finland; present the results of the geophysical testing, ground truthing, and dating of the prehistoric fishery site of Lamminoja, situated in peatland environment; and examine the possibilities to increase our chances to detect similar sites in archaeological survey and prospection.

## Materials and Methods

### *Stationary wooden fishing structures in Finland*

In order to explore the setting and discovery circumstances of the fishery sites associated with stationary wooden structures in Finland, we gathered information from the archive and online register of the Finnish National Board of Antiquities (NBA) (National Board of Antiquities n.d.), which contains archaeological and ethnological collections, field reports, and published literature. In addition, several personal communications by laypeople and archaeologists to one of the authors (Koivisto) about previously unknown fishing structures were included in this study. Most importantly, the ethnographic materials involve a questionnaire on lath screen fish traps (National Board of Antiquities 1961) circulated by the NBA in the 1960s, which compiled information about the manufacturing and use of this specific fishing equipment in the late 19th and early 20th centuries in Finland and Russian Karelia (formerly part of Finland, currently a part of Russia). We acknowledge that the spatial distribution of ethnographic materials may not necessarily reflect the real occurrence of this fishing equipment in historic times. The large number of sites in more densely populated and urbanized southern Finland may reflect that the fishing structures were already perceived as cultural heritage there in the 1960s, in comparison with the smaller number of sites in northern Finland and Lapland, where several types of weirs and fish traps were still in everyday use and not yet regarded as historically significant. Therefore, no advanced GIS analysis was applied, but some general observations are presented about the spatial distribution of the sites.

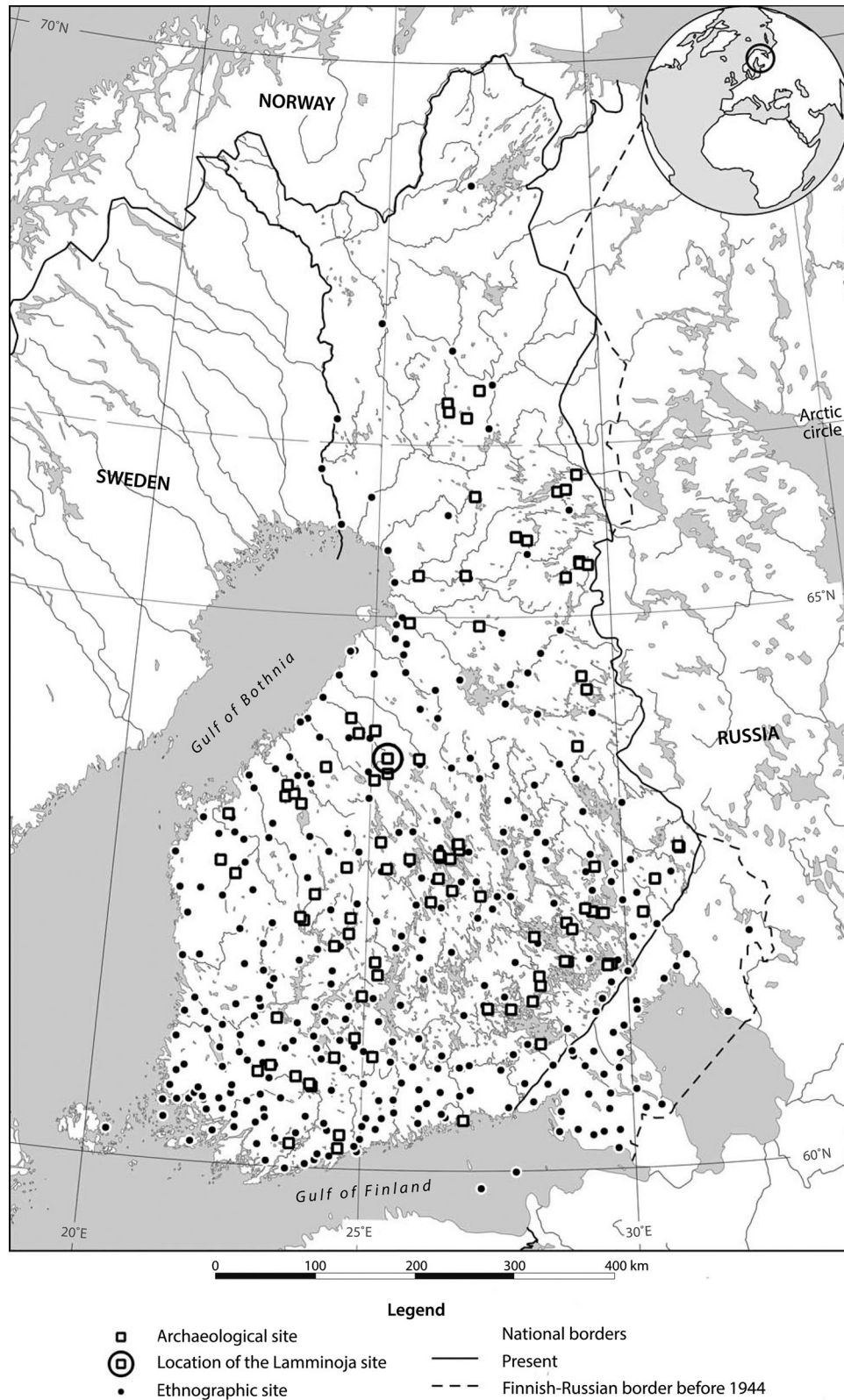
Stationary wooden fishing structures have been exposed in peatlands and shallow water through processes like drainage, dredging, and peat cutting. Approximately 25% of the wooden remains have been buried in peatlands due to various environmental processes, such as strong isostatic land uplift, lake terrestrialization, and other factors enhancing paludification. The remaining sites (75%) have been discerned in shallow water or muddy lake sediments through dredging and during periods of low water. Most of the fishery sites have been found by local people. Only a handful of the fishing structures have been detected by archaeologists during field survey or site evaluation.

The spatial distribution of the stationary wooden fishing structures is illustrated in Figure 1. The archaeological sites (squares in Figure 1) are located broadly in all areas where the respondents of the fish trap questionnaire (dots in Figure 1) had seen or used similar structures, except in Russian Karelia, where archaeological fishery data was not at hand for this study. Dense concentrations of archaeological fishing structures are located by the major Ostrobothnian rivers in western Finland, in the area of large lakes in central and eastern Finland, and in Häme, southwestern Finland. The dense distribution of the ethnographic materials in the

traditional agricultural area in southern Finland and the sparse distribution in the north may reflect the perception of fishing structures as culturally significant in the south, in contrast to the more sparsely populated north, where many types of stationary structures were still in use in fishing in the 1960s when the questionnaire was circulated. In addition, only a fraction of the archaeological sites have ended up in the archives and site register, because fishing structures have not been regarded as archaeologically relevant until quite recently (Koivisto 2012). Contrary to the ethnographic record, the archaeological wooden remains are not known in the southwestern and western coastal parts of the country. Especially in central and northern Ostrobothnia, western Finland, the fishery sites seem to occur ca. 20–60 km inland from the current coastline. This may indicate that the fishing structures have not been preserved in the coastal belt, that they have been used only in lake fishing, or, alternatively, that their distribution indicates the previous stages of the Bothnian coastline affected by rapid postglacial rebound (suggesting older dates). Further investigations and a systematic dating program are essential to test these hypotheses.

Judging by ethnographic parallels (Sirelius 1906a, 1906b, 1906c, 1907, 1908; Valonen 1953; National Board of Antiquities 1961), lath screen traps and weirs have been used primarily in lacustrine spawn fishing during the historic period. Archaeological remains, however, suggest that similar structures were also utilized in estuary fishing in prehistory, for example, by the mouth of the Iijoki River in coastal Finnish Ostrobothnia in ca. 3000 CAL B.C. (Koivisto 2012: 28–30), and at the confluence of the Russian rivers Okhta and Neva in St. Petersburg, western Russia in ca. 3500 CAL B.C. (Kulkova et al. 2012: 1048, 1055–1059). The dates of most Finnish fishery sites have remained unknown, but a certain proportion of the undated sites may be convincingly interpreted as prehistoric due to their location, context, or sedimentary characteristics. Several of the radiocarbon dated fishing structures have yielded prehistoric dates ranging from the mid (Sub-)Neolithic (typically referred to in Finland as non-agricultural Neolithic or pottery Mesolithic) to the Early Iron Age, between ca. 3934–118 CAL B.C. (2 $\sigma$ ) (Koivisto and Nurminen 2015). Only one radiocarbon sample has been dated to the historic period (16th century A.D.) and three dendrochronological samples have returned early modern dates, falling in the 18th–19th centuries A.D. (National Board of Antiquities n.d.).

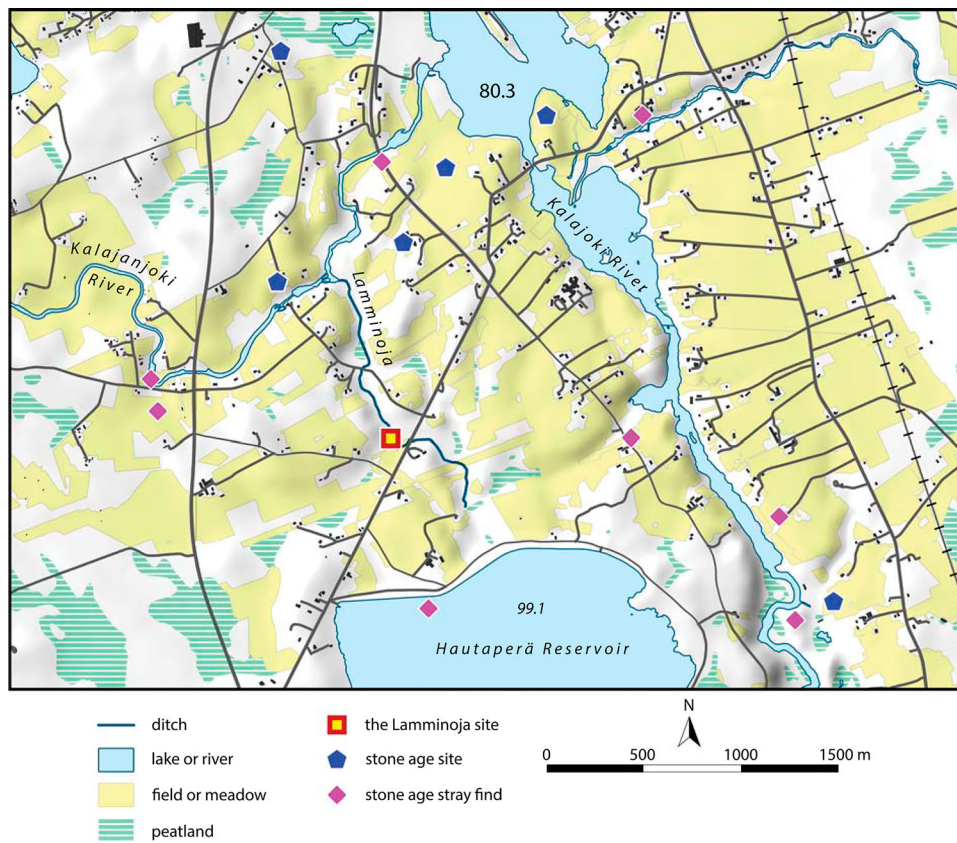
The stationary fishing structures were manufactured of wooden laths, bound together with plant materials, and erected in advantageous fishing locations. They represent a relatively common type of wetland archaeological resource in the northeastern Baltic Sea region. Laths—typically made of pine wood with bast cord, wicker, or birch bark bindings—seem to be the most typical materials used for making vertical panels for weirs and traps that take advantage of the regular movements of fish in both running and still water (Vankina 1970; Loze 1988; Kraynov 1991; Rimantienė 1992, 1998; Lozovski 1999; Burov 2001; Bērziņš 2008; Koivisto 2012; Lozovski et al. 2013; Koivisto and Nurminen 2015; Bērziņš et al. 2016). Several examples of the stationary fishing structures known from both the archaeological and ethnographic records demonstrate that similar designs have remained unchanged for several millennia (Pedersen 1995: 81; Koivisto and Nurminen 2015). According to the Finnish ethnographic sources (Sirelius 1906a, 1906b,



**Figure 1.** Map of Finland showing the distribution of the archaeological stationary wooden fishing structures (squares) and the ethnographic information on fishing with similar structures in Finland and Karelia (former Finland) in the late 19th and early 20th centuries (dots). The study area at Lamminoja is highlighted. Background data provided by National Board of Antiquities and Natural Earth. Map by Niko Latvakoski.

1906c, 1907, 1908; National Board of Antiquities 1961), spawn fishing of pike (*Esox lucius*), perch (*Perca fluviatilis*), burbot (*Lota lota*), and roach (*Rutilus rutilus*) was a profitable and reliable livelihood and was conducted with stationary structures in historic Finland. The fishing structures were designed for catching certain species in a specific habitat. Similar designs are known worldwide: examples include

the fish weirs among the Ob-Ugrian Khanty and Mansi of western Siberia (Sirelius 1906c: 46–47), the Mesolithic and Neolithic hazel rod wattle-work and wicker screens in northern Europe (Christensen 1997: 151–156; Myrhøj 1999: 167; McQuade and O'Donnell 2007: 574, 581; Kloöß 2015: 332), and the wooden tidal weirs manufactured by the Tlingit, Haida, and Chinook ethnographic groups in



**Figure 2.** Map showing Lamminojoki and the other Stone Age sites in the vicinity of the study area. Background data provided by Natural Earth, National Land Survey of Finland, and National Board of Antiquities. Map by Niko Latvakoski.

the Pacific Northwest Coast of North America (Stewart 1977; Moss and Erlandson 1998; Losey 2010).

#### *Case study: Lamminojoki in Haapajärvi, Northwestern Finland*

One of the most recently discovered fishery sites was revealed in a very typical way—during drainage improvement—in 2008. Lamminojoki, in the town of Haapajärvi, is located in the northwestern part of Finland (63°43' N, 25°19' E) (FIGURES 1 AND 2). A large end moraine, the Suomenselkä ridge, runs across the study area from the southwest to the northeast, forming a major watershed in the area. Geologically, the area belongs to the western Finnish coastal district, which is characterized by strong isostatic post-glacial rebound, which causes shoreline displacement at a current uplift rate of 6–8 mm per year

(Kejonen and Johansson 2004: 211–222; Ojala et al. 2013). The Lamminojoki brook runs in a shallow valley from the Hautaperä reservoir in the south towards the Kalajanjoki River in the north. The valley is surrounded by low-lying hills and small bogs with meadow, heath, and bog vegetation. The soil type on the wet valley floor is silt and peat covered with dense willowherb, grass, and meadowsweet vegetation (FIGURE 3). A natural brook used to run northwards through the valley even before the channel was improved in the 1930s. By that time, the springtime flooding caused run-off extending to the nearby agricultural fields, which hampered cultivation. However, no wood finds were observed (or, at least, reported) during that drainage project.

The first observations of wooden finds in Lamminojoki were made after the drainage was improved in 2008. At this time, the channel was dug nearly 1 m deeper than before with an excavator. The landowner noticed a number of wooden piles



**Figure 3.** Fieldwork in progress by the banks of the Lamminojoki channel. Photo by Satu Koivisto.



**Figure 4.** Waterlogged wooden remains exposed in the Lamminoja channel after drainage improvement. Photo by Satu Koivisto.

and rows of laths at the bottom of the freshly dug ditch and informed archaeologists about the discovery. The wooden finds were observed in a belt ca. 10 m long and some of the structures seemed to extend underneath the ditch banks (FIGURE 4). The diameters of the piles varied between 5 and 8 cm and the pine laths were approximately 25 mm wide and 15 mm thick. The rows of laths were several meters long, and bound up with narrow strips of birch bark to create longitudinal lath screen fences supported with wooden piles. The burial depth and the structural resemblance that the wooden finds bear to the securely-dated mid-Holocene fishing structures of Purkajasuo (Koivisto 2012), ca. 200 km north of Haapajärvi, resulted in the registration of Lamminoja as a protected archaeological site (National Board of Antiquities n.d.). Compared to the extensive horizontal wood find area of Purkajasuo, the stationary structures exposed in the Lamminoja brook seem to be still in a vertical position, in their original configuration.

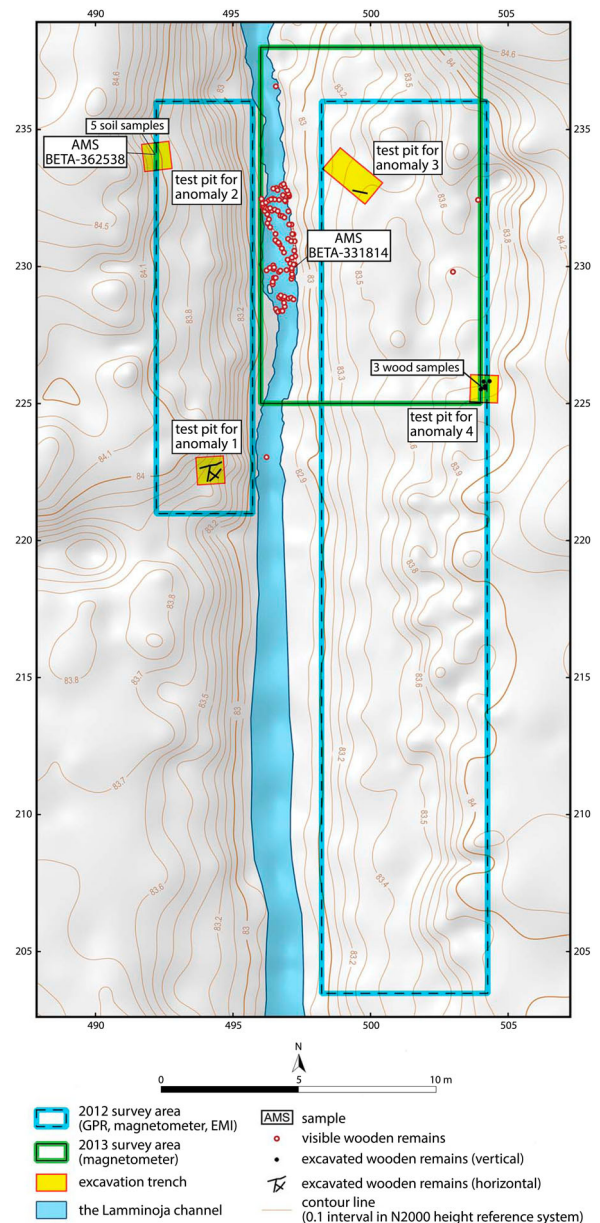
Because of the rarity of research on similar structures, the presumed prehistoric dating, and the vulnerability of its preservation, a small project was launched at Lamminoja by the authors in 2012–2013 (Koivisto et al. 2014). Here, the aim was to date and document the wooden structures exposed in the drainage channel and to test the suitability of three geophysical techniques for prospecting the waterlogged wooden remains and their immediate surroundings. Some of the geophysical anomalies were chosen for ground truthing with trial excavations. In addition, the palaeoenvironmental potential of the site was preliminarily evaluated through palynological and macrofossil analyses.

### Geophysical survey and trial excavations

In spite of previous observations that wood and peat do not differ strongly in their relevant physical properties (Weller and Bauerochse 2013), three geophysical techniques were employed in order to test whether archaeological remains deposited in the Lamminoja valley would produce a signal or reflection that could be detected with the methods chosen. Similar surveys had not been previously performed on stationary wooden fishing structures in peatland environment. Ground-penetrating radar (GPR), magnetometry, and electromagnetic induction (EMI) with slingram were employed and the survey served as a test of the recently acquired equipment in a demanding peatland habitat. First, the study area was cleared of very dense vegetation on both sides of the drainage channel around the wooden structures. A two-part survey area

was tagged with wooden sticks in the terrain. Due to the topography of the forested peatland surrounding the cleared area, the eastern rectangle was 32.5 × 6 m in size, and the western rectangle measured 15 × 3.5 m (FIGURE 5). Compared to the advisable minimum measurement area of 40 × 40 m (Gaffney and Gater 2003: 94), the survey area was very small, which makes the interpretation of the geophysical data more difficult. On the other hand, this type of terrain and vegetation is very typical for drained and forested peatlands in the Scandinavian boreal forest zone.

The cross-line sampling spacing for all the techniques used was 50 cm to provide sufficient resolution for this type of testing, to speed up data acquisition, and to facilitate the integration and comparison of the results. The sampling frequency used may be seen as an absolute maximum transect spacing when targets no smaller than 0.5 m across are pursued (Armstrong 2010: 91; Leckebusch 2011: 15). This is because it was assumed (as a working hypothesis) that, in addition to the vertical lath screen fences, piles, and stakes exposed in the drainage channel, some more densely



**Figure 5.** Geophysical survey and trial excavation areas at Lamminoja. Map by Niko Latvakoski.

accumulated wood might occur in the vicinity of the wooden structures, as had previously been observed at Purkajasuo (Koivisto 2012). It was also presumed possible that there could be other types of archaeological features and structures at the site that might be detected with geophysics.

Although deeper layers of mineral soil and bedrock may affect the survey results, their depth was not determined. However, according to the low altitude aeromagnetic maps provided by the Geological Survey of Finland, no apparent magnetic anomalies lie in the vicinity of the site.

#### GROUND-PENETRATING RADAR

The GPR survey was carried out with a Radar Systems Zond-12e using a 500 MHz antenna. In wet soils, a lower frequency is often preferred because the waterlogging slows down the emitted radio waves, therefore reducing penetration of the signal (Clarke et al. 1999: 108; Utsi 2007: 213). The 500 MHz antenna was chosen with the foreknowledge of the wooden structures being relatively close to the surface; therefore, we were able to sacrifice deeper penetration for better resolution. During data acquisition, a time window of 100 ns and a cross-wise sampling interval of 50 cm were used. The positioning on the lines was achieved with a wheel that was set to trigger a measurement every 5 cm. In local conditions, a time window of 100 ns was equivalent to a depth of ca. 2.2 m. The total length of the measured lines was 1080 m. During the data acquisition “High pass filter” was set to “Soft.” The principles of the GPR method for archaeological purposes can be found in, for example, Scollar et al. (1990), Leckebusch (2003), Watters (2009), Conyers and Leckebusch (2010), Viberg et al. (2011), and Conyers (2012).

Prism 2.5 and Voxler 3 software were used to visualize the GPR data. The following operations were conducted in Prism to generate the timeslices: set zero time, set gain (linear: 0 dB at 0 ns and 30 dB at 100 ns), background removal, moveout correction, Ormsby bandpass, topographic correction, Stolt (F–K) method, and envelope. The dielectric permittivity of the ground was estimated to be 40 ( $\approx 0.047$  m/ns) on the basis of hyperbolae in the profiles. The permittivity was quite low if compared with other reported permittivity values on peatlands, which typically fall between ca. 50–70 (Clarke et al. 1999: 111). This may be caused by the drainage channel traversing the survey area, and the silty, more mineral-rich soil mixed into the peat matrix in places, probably a consequence of the modern ditch digging.

#### MAGNETOMETRIC SURVEY

At Lamminoja, a Scintrex ENVI CS Cesium Vapour gradiometer was used, which measures the total magnetic field. In a gradiometer configuration, the two sensors are placed in vertical position and the gradient is calculated, thus reducing the background geological and diurnal effects (Watters 2009: 184). The sensors of the gradient array were placed in a vertical position at a 1 m distance from each other, and the lower sensor was moved at a height of ca. 40 cm above the ground surface. An area with 50 cm inline and cross-line sampling was surveyed. The survey lines were subsequently extended above the wooden structures observable in the Lamminoja channel in order to attain magnetometer gradient values on the waterlogged wood as well. The magnetometer data was gridded and visualized in Surfer 11. Further information on the method can be found in, for example, Weymouth (1986), Clark (1990, 1996), Gaffney

and Gater (2003), Aspinall and colleagues (2008), Gaffney (2008), and Watters (2009).

#### EMI WITH SLINGRAM

The slingram survey was performed with a GSSI Profiler EMP-400 at 5, 10, and 15 kHz frequencies. During the device calibration process, the in-phase zero levels were measured to be respectively –562, –374, and –196, and the same levels were used in the data visualization. The data was collected in “inline vertical dipole mode” where the instrument was held lengthwise along the measurement lines with the two coils facing downwards. The EMI survey was performed at a height of ca. 20 cm from the surface with a low carry handle. The measurements were attained with 50 cm cross-line sampling at steady walking pace at 0.5 sec intervals, which were scaled in place with fixed points positioned and tagged in the terrain. The EMI data was gridded and visualized in Surfer 11. More detailed information on the method may be found in, for example, Tabbagh (1986), Clark (1996), Scollar and colleagues (1990), and Persson and Olofsson (2004).

#### TRIAL EXCAVATIONS AND SOIL SAMPLING

Because ground truth validation of the results has been considered as the key to the success of any geophysical survey (Bates and Bates 2000), four of the detected anomalies were evaluated through trial excavations (FIGURE 5). All together, three test pits of 1 m<sup>2</sup> and a test trench of 1 × 2 m in size were placed over the anomalous features. No archaeological finds were recovered because of the preliminary stage of the investigations, but the wood finds encountered were exposed, mapped, and documented before refilling the trenches. Five soil samples and three wood samples were collected from the anomalous features for environmental archaeological analyses and later dating.

The palaeoenvironmental information was considered a key part of the site record. Therefore, partial pollen and archaeobotanical analyses were carried out. The volumes of the soil samples varied between 1.2 and 2.5 l and these were divided into smaller units of 0.5–1 dl for pollen and 0.6–2.2 l for macrofossil analyses. The environmental archaeological investigations were carried out at the University of Helsinki by Dr. Teija Alenius for pollen and Santeri Vanhanen for macrofossil analyses.

Due to exceptional dryness during the fieldwork, the water table in the Lamminoja channel was relatively low, which caused more archaeological wood to be exposed above the water table and to deteriorate. The channel walls had begun to collapse and slide down towards the wooden structures, thus narrowing the channel. During the fieldwork, the wood finds were mapped with a total station, drawn to scale, and photographed in digital and 3D format.

## Results and Discussion

### *Lacustrine fishing with stationary structures at Lamminoja ca. 3300 CAL B.C.*

The dating of the Lamminoja fishery relies on two AMS dates (see sample locations in Figure 5): the wood sample of a pine lath collected from the fishing structure produced a date of 4560 ± 30 B.P. (Beta-331814), ca. 3487–3107 CAL B.C. (2σ) (Oxcal v4.2.3) (Bronk Ramsey 2009; Reimer et al. 2013), and a small fragment of wood/pine bark from a brushwood

and bark layer next to the fishing structure produced a ca. 1000 years later date of  $3700 \pm 30$  B.P. (Beta-362538), ca. 2199–1981 CAL B.C. ( $2\sigma$ ).

Based on the AMS dating of the fishing structure (Beta-331814) and local topography affected by strong isostatic rebound, the Lamminoja fishery was situated in a small lake in the proximity to the Bothnian coastal zone. A narrow lake with two extensions was situated ca. 70 km southeast of the contemporary seashore. The lake may have been initially formed in the northern outflow channel of the ancient Lake Päijänne, the water of which drained into the Gulf of Bothnia via the present day Kalajoki River between ca. 8300–6100 B.P. (Ristaniemi 1987; Tikkanen 2002: 32–33). After the rising waters had broken through the Heinola esker in the south, ca. 6100 B.P., the outflow channels north of the Kotajärvi threshold were gradually isolated as smaller basins (Tikkanen 2002: 32–33). The fishing structures had been erected in one of the lakes situated in the present day Lamminoja valley ca.

3300 CAL B.C. The lake contained several bends and channels, which may have served as excellent habitats for several fish species. Furthermore, the lake was located by the confluence of three local rivers, which presumably constituted an alluring and logistically well-situated procurement area for the mid (Sub-)Neolithic foragers of northern Ostrobothnia. Resource utilization may have been seasonal or related to more or less semi-permanent hunting, fishing, and gathering sites. All together, six Stone Age settlement sites and seven stone tool find spots are situated within a ca. 2 km radius of the Lamminoja fishery (FIGURE 2) (National Board of Antiquities n.d.). The dates of these sites are uncertain, though, since no excavations have been carried out on them. Based on the prehistoric shoreline development data, the types of stone artifacts, and the absence of ceramics, most of these sites are thought to date to the Mesolithic (Huurre 1983: 49, 116, 446). There is, however, abundant material evidence from the upper lakes and streams of the Kalajanjoki River suggesting that its basin was also



**Figure 6** Lamminoja area ca. 3000 CAL B.C. The water level of the lake (85 masl) has been visually estimated on the basis of a threshold situated presumably by the north-easternmost corner of the lake. The visualization is based on the LiDAR elevation data provided by the National Land Survey of Finland. Visualization by Niko Latvakoski.



inhabited during the (Sub-)Neolithic period and even later in the Bronze Age (National Board of Antiquities n.d.). Figure 6 illustrates the reconstruction of the prehistoric lake ca. 3000 CAL B.C.

The soil samples from the dark, organic-rich, peaty layer in a test pit for anomaly 2 (FIGURE 5) were preliminarily investigated with environmental archaeological methods. Even from this small amount of sediment, it was possible to achieve good results for the evaluation of the environmental archaeological potential and preservation of the site. Through the analyses, it became evident that the preservation conditions for pollen and uncharred plant macrofossils are exceptionally good as compared with conditions at sites situated in mineral soils. All three pollen samples contained major tree species: pine (*Pinus sylvestris* t.), birch (*Betula* undiff.), spruce (*Picea abies*), and alder (*Alnus* undiff.) (T. Alenius, personal communication 2014). In addition, there were a fair number of Sphagnum spores in the samples. This may indicate that the prehistoric lake situated in the Lamminoja valley was surrounded by pine-dominated forests with an abundance of Sphagnum, thus indicating an advanced infilling phase of the lake by ca. 2000 CAL B.C. It is noteworthy that similar eutrophic, shallow lakes have constituted important procurement areas for spawn fishing in the historic period (Valonen 1953; National Board of Antiquities 1961).

Plant macrofossils were investigated in three subsamples (numbered 1–3) of a total volume of ca. 3.8 l (Vanhanen 2014). The quantity of charcoal was also estimated. The samples contained mostly organic material and a small amount of charcoal. Uncharred plant remains were well preserved, and, in addition, many well-preserved insect remains were collected for later analysis. The plant remains represent species connected with human occupation, enriching the soil with nutrients, especially common nettle (*Urtica dioica*), and common chickweed (*Stellaria media*). In addition, there were some wet meadow plants, such as creeping buttercup (*Ranunculus repens*) and meadowsweet (*Filipendula ulmaria*). Only one aquatic plant, pondweed (*Potamogeton* sp.), was identified: all the other species reflect lush lakeside vegetation.

The continuous wood find area was observed in the channel in a belt ca. 5 m long (FIGURE 7). A few sporadic piles and stakes were also found outside the core find area. The flow of water in the channel had caused the accumulation of solid material on top of the wooden finds. In addition, some piles and stakes began to protrude in the eastern part of the study area during the fieldwork due to trampling of the unstable surface. In the southern part, a heart-shaped lath screen structure ca. 1.5 m in diameter may be observed. It consists of a few curved lines of lath screen panels and extends under the western bank of the channel. Two lath screen fences diverge from the structure towards the north-east and east-southeast. Another suggested fish trap nest may be discerned in the northern part of the wood find area: a somewhat similar feature with a few curved lath screen modules had been supported with wooden piles. Between these structures are two diverging linear fence modules, ca. 2.5 and 1.8 m long, respectively, that may have been attached to another trap structure still buried underneath the ditch banks. It is plausible that the wooden finds observable in the channel today may not originate from a single fishing system, but that the site may contain the remains of several wooden constructions, possibly from different dates, erected on

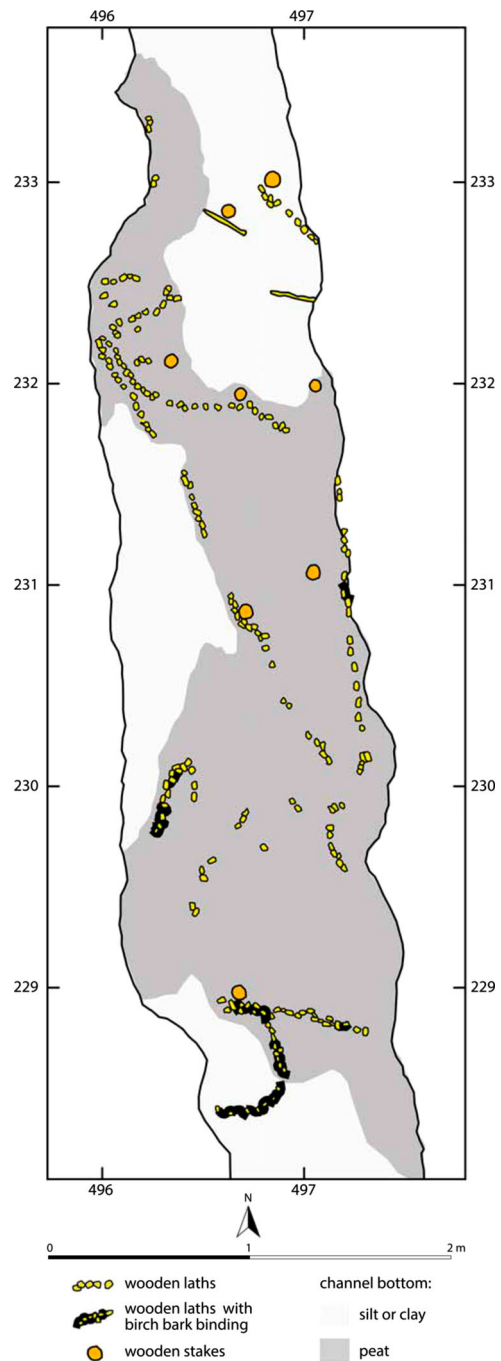
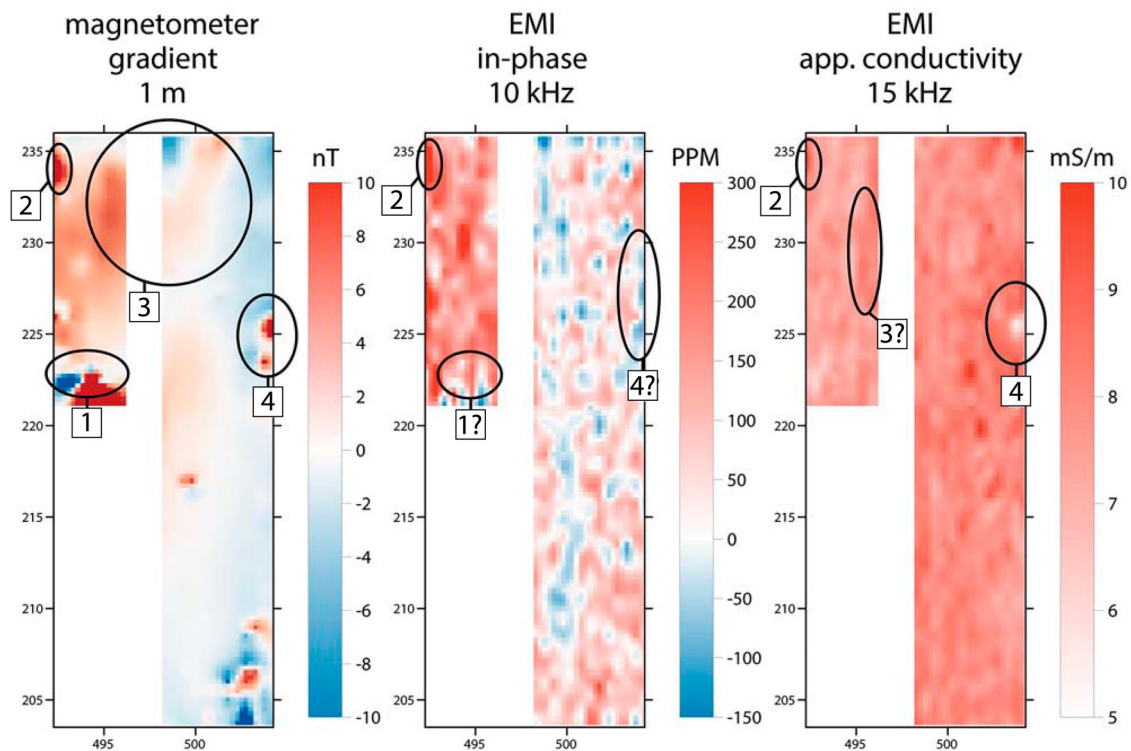


Figure 7. Wooden structures observable in the Lamminoja channel. Illustration by Satu Koivisto and Niko Latvakoski.

the bottom of a shallow lake and in the smaller stream that eventually succeeded it. More radiocarbon dates and proper wetland excavations are necessary, however, to verify this suggestion.

#### Geophysical anomalies and the ground truthing data

The results obtained from the geophysical survey were complex and somewhat confusing. Four anomalies of varying types and dimensions were observed and chosen for further study. They were selected with the aims of finding out what had actually produced the anomalous reflections and testing the newly acquired geophysical equipment in this type of environment. There were certain points of resemblance in the results produced by all the techniques. The locations of the anomalies chosen for ground truthing (1–4) are marked



**Figure 8.** Results from the geophysical survey: magnetometer gradient, EMI in-phase with 10 kHz frequency, and EMI conductivity with 15 kHz frequency. Visualization by Wesa Perttola.

in Figures 8 and 9, and their detection with different instruments are listed in Table 1. A GPR profile with anomaly 3 is visualized in Figure 10. The likely causes of anomalies are listed in Table 2.

The conditions for conducting a successful geophysical survey at Lamminoja were not good at all. The local topography and vegetation hindered the adequate use of GPR. The survey had to be performed on uneven and slightly sloping surfaces. Such features have proven problematic (Watters 2009: 189) because GPR measures reflections on an angle perpendicular to the ground. The surface was bumpy and uneven, which resulted in unstable contact between the antenna and the ground surface and uneven rotation of the odometer wheel. Disrupted continuous contact causes problems in data acquisition by introducing a degree of interference, reducing reliance on positional information, and lessening the penetration depth (Clarke et al. 1999). Such conditions, though, are typical for various forms of wetland environments in Finland. The easiest way to counteract these problems would be to perform the survey during the winter, when the snow flattens the uneven ground. Using vehicles (with the exception of snowmobiles) would be ill-advised, however, considering the soft ground and shallowness of the wooden fishing structures at Lamminoja.

The longitudinal streaks in the amplitude time-slices were affected in the direction of the measured lines, but not by any subterranean objects (Figure 9). In addition, certain areas were wetter than others to the point of forming puddles, especially in the northern part of the study area. Furthermore, the bumpiness of the ground and the softer spots caused by the puddles made keeping a steady pace difficult during the slingram measurements. Therefore, the magnetometer measurements were made as single measurements while standing still, which would not be a feasible tactic over wider areas.

Ground truthing the anomalies proved essential. Even though the waterlogged wood was not detected with any of

the techniques used, information on what had actually produced the anomalies in wetland habitat was considered valuable. Furthermore, waterlogged wood was observed at each trench, suggesting dismantled, scattered, and partially even intact (near anomaly 4) fishing structures still preserved underneath the Lamminoja banks. The likely causes of anomalies were modern or unknown, except with anomaly 2, located in the northeast corner of the survey area, which was observable with three out of four of the techniques (Figure 8). The soil type in this area was organic-rich clay with partly decomposed wood. At the depth of ca. 30 cm, the soil type changed gradually to darker, more organic-rich, and moister peaty sediment. In the western half of the test pit, a brownish-red, iron-rich concretion of ca. 80 × 30 cm in size was revealed. The surrounding area was investigated with an auger and the phenomenon seemed to continue at least 1.5 m south from the test pit at a depth of at least 50 cm. The concretion had a rounded surface and created a ca. 3–7 cm thick interphase underlying the greyish, peaty clay and overlying the dark, organic-rich peat. The organic layer was composed of peat and clay with pieces of charcoal, wood, and bark. It was greasy and tough in consistency and formed an evenly-distributed brushwood, pine bark, and birch bark layer. All together, five soil samples were gathered from the concretion and the surrounding sediments. No archaeological finds were uncovered, except for a tiny piece of glass, which was revealed in the eastern part of the test pit. Apparently, it had ended up underneath the peat layers through ditch digging or when the trench walls had collapsed towards the channel. The organic-rich, sooty layer continued to at least ca. 75 cm from the surface, the level of the water table. Some larger tree trunks were lying at the bottom of the pit in a horizontal position, extending outside the test pit sections. No tool marks were discerned in the observable parts of the wooden finds, but apparently they represent broken parts of the fishing structures.

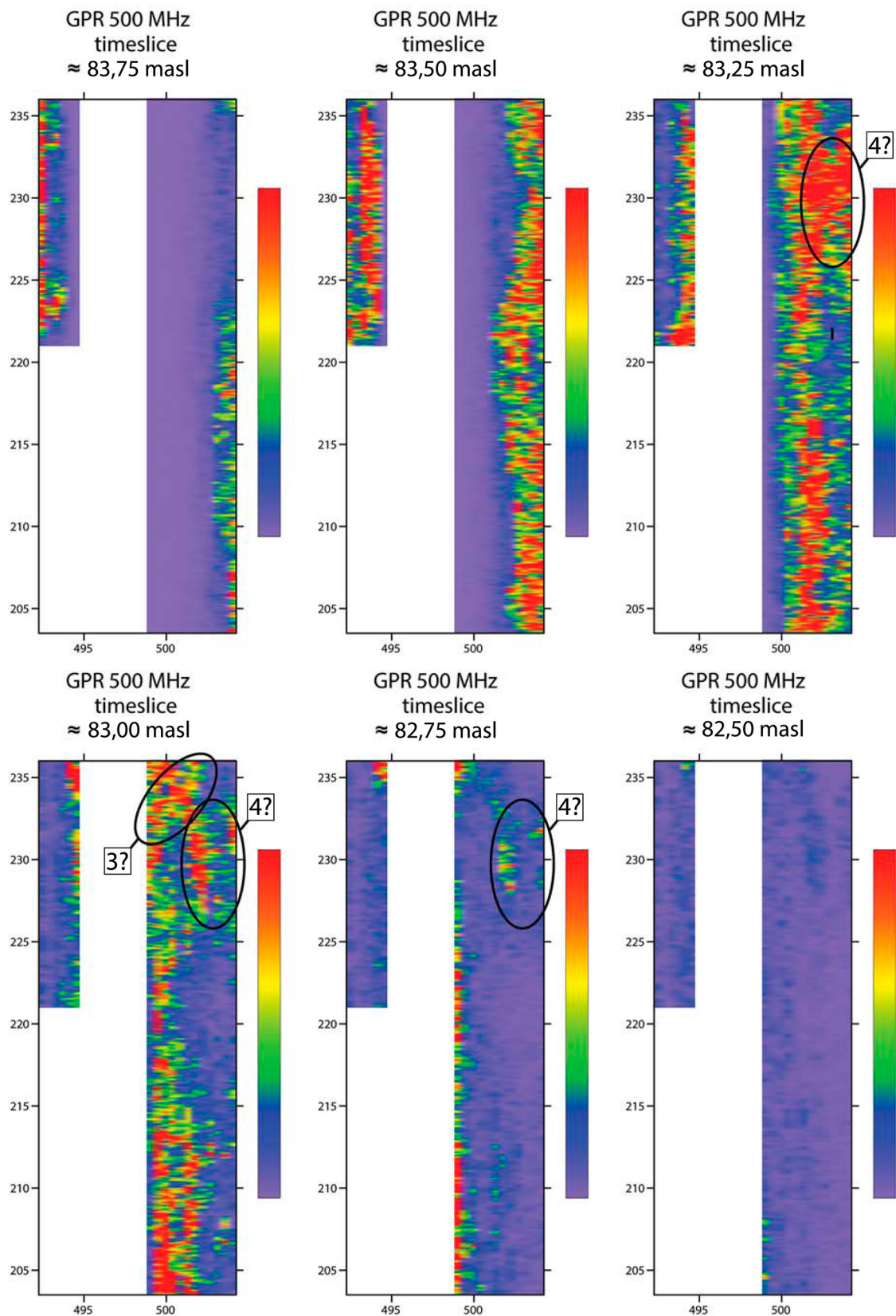


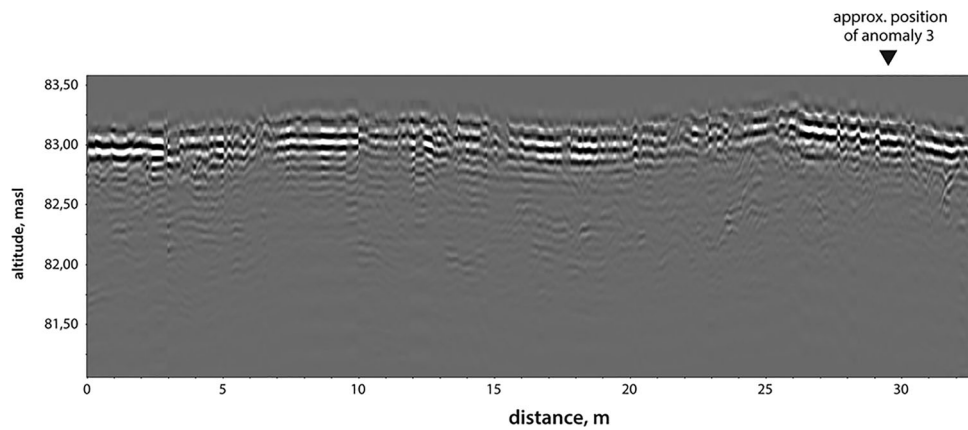
Figure 9. GPR topographically corrected timeslices with 500 MHz antenna. Visualization by Wesa Pertola.

Table 1. The geophysical anomalies 1–4 chosen for ground truthing and their detection with different techniques.

	1	2	3	4
Magnetometry	X	X	X	X
EMI slingram – in-phase	X?	X	–	X?
EMI slingram – conductivity	–	X	X?	X
GPR	–	–	X?	X?

Table by Wesa Pertola.

Anomaly 2 is suggested to have been formed by prehistoric anthropogenic activity. An AMS date (Beta-362538) of a wood and pine bark fragment from the black, organic-rich layer may indicate that the banks of the Lamminoja brook (and presumably the shallow lake preceding it) had been used in the long term by the (Sub-)Neolithic foragers. That the anomaly showed up like this in the magnetometry gradient may be related to certain sediment properties shown as a



**Figure 10.** A topographically corrected GPR profile over the easting 499.75 with the approximate position of anomaly 3 marked. The profile has been processed with the following operations: background removal, moveout correction, and Ormsby bandpass. Visualization by Wesa Perttola.

ferrimagnetic concretion. Such a phenomenon may be the result of the formation of iron sulfides under conditions of high sulfur availability with metallic ions and organic matter under low redox conditions (Wiltshire et al. 1994; Ariztegui and Dobson 1996; Brown et al. 2010; Fassbinder 2015). Later oxidation may have produced the extreme natural acidity through the oxidation of disulfide. Sulfur-rich properties have been associated with high natural remanent magnetism and such sediments have been recorded in eutrophic lakes (Wiltshire et al. 1994) and palaeochannels (Brown et al. 2010: 21–29). Sulfur-rich sediments have also been considered to be taphonomically important for the preservation of organic material in wetland environments (Brown et al. 2010), which may have had an effect on the good preservation stage of the Stone Age wood at Lamminoja. In palaeolake studies, greigite has been responsible for a dramatic increase in sediment magnetic susceptibility, which has coincided with a rise in sediment sulfur content (Ariztegui and Dobson 1996). There may be implications concerning similar natural remanent magnetic signatures at Lamminoja because of the overgrowing of the prehistoric lake, but such suggestions, though, require further testing and analysis.

#### *Detection and prospection of wetland sites on a European scale and some recommendations for further testing*

The detection and registration of stationary wooden structures associated with fishing sites seems random in Finland: there were no options for encountering new sites except for being in the right place in the right time. GPR and side scan sonar have been successfully used in shallow water at fish weir foundations built of stones in northern Finland (Moisio et al. 2012), but wooden fishing constructions buried in peat and muddy lake sediments seem to be much more problematic. At Hiidenniemi in Kesälahti, eastern Finland, a test trench was placed over the anomalous GPR reflections and remains of a suggested fishing structure were revealed at the bottom of a filled-in bay (Forsberg et al. 2009), but,

unfortunately, the GPR data was collected with insufficient spatial resolution to be able to understand the features.

Our testing at Lamminoja, especially with GPR, provided a realistic view of the use of geophysical techniques in drained peatlands. The previous observations of the contrasts in the relevant physical properties between wood and peat being rather weak, the insufficient size of the target object, and the complex sediments affected by modern drainage were demonstrated again (Utsi 2007: 215–217). In addition, an extra limitation caused by vegetation hampering the use of some of the techniques was proven significant. Due to vegetation, placing the survey transects with adequate spacing is, in many cases, challenging or even impossible. The survey circumstances also play a role because the successful use of GPR is highly dependent on moisture, while magnetometer prospecting is almost independent of weather conditions. We thus recommend repeating the GPR survey in the winter when the terrain is solid and frozen, which could enhance the penetration depth of the radar wave and ensure more suitable topographic conditions for conducting the survey.

On a European scale, many of the results of the previous geophysical surveys within waterlogged wooden constructions have not been properly evaluated in order to detect previously unknown sites or prospect extensive wetland areas, for example, for land-use and planning purposes. The testing has concentrated on the detection of previously known archaeological remains (Jørgensen 1997) and many of the organic structures pursued have been very robust and heavy, like the nearly nine-meter-wide oak plankway at Federsee Lake in Germany (Schleifer et al. 2002: 243–253; Weller and Bauerochse 2013: 421–422). Even when satisfactory results were not obtained, it usually has not been acknowledged that the survey provided additional data, mostly palaeoenvironmental and geological. For detecting deeply buried archaeological resources in large areas, wide-ranging prospection is essential by way of integrating geophysical survey, geological coring, and trial excavations. Such campaigns have often been considered as too labor-intensive and expensive, and therefore wetlands have typically been forgotten, either intentionally or by oversight in archaeological mitigation and land-use planning processes. To our knowledge, field-worthy multi-sensor array systems have not yet been tested in wetland environments and most of the surveys have been very small in scale. There are important differences between wetland site types, even in similar settings, and ground truthing of the anomalies is essential for validating

**Table 2.** Anomalies 1–4 and their likely cause based on ground truthing.

Anomaly number	Ground truthing	Likely cause of anomaly
1	1 sq m test pit	Unknown
2	1 sq m test pit	Iron-rich concretion
3	2 sq m trench	Overgrown drainage ditch
4	1 sq m test pit	Modern iron pot

Table by Satu Koivisto.

the results. Peatland environments are unique in initiation and character, and the methods that have been tested in Britain or Germany, for instance, cannot be adapted straightforwardly to other areas or different wetland habitats. More testing and integration of methods, with different site types and varying wetland settings, is essential in the search for a more representative archaeological record provided by wetland archaeological resources.

Promising large-scale wetland evaluations and palaeolake studies have been conducted with integration of digital terrain modeling, GIS applications, and geophysics (Chapman and van de Noort 2001; Bergman et al. 2003; Gething et al. 2013). Mesolithic lakeside settlements have been sought in Sweden with the help of topographic modeling of filled-in lakes and allocating fieldwork in archaeologically potential lakeshore areas (Bergman et al. 2003; Lagerås 2003). Invasive methods, such as mechanical coring and excavation, have been widely applied in the detection and registration of the stationary wooden fishing structures at wide-spread Fehmarn Belt construction site on the island of Lolland, southeastern Denmark (B. Måge, personal communication 2016). A more radical approach has been introduced: cooperation between archaeologists and peat extraction companies with the object of creating opportunities for research in between the peat extraction periods. This method has been applied for several years in the study of the Late Palaeolithic and Mesolithic lake settlement complexes at Ageröd, Viss, and Rönneholm mires in southern Scania, Sweden (Larsson and Sjöström 2010, 2013; Sjöström and Käm Tayanin 2013) and similar work has recently begun in the lake Saimaa area in eastern Finland (Koivisto 2015).

It has been observed that the velocity of the GPR wave in peat is relatively low (Conyers 2012), which may reduce the effective depth of operation (Clarke et al. 1999: 108; Utsi 2007). Instead, magnetometers have worked better in more mineral-rich areas between the lakes and allowed identification of former shoreline stages with potential for prehistoric habitation (Bergman et al. 2003; Lagerås 2003; Gething et al. 2013). Landscape reconstruction, systematic survey, visual inspection of drainage sections, coring, and field-walking, especially when dealing with extensive wetland areas, should not be abandoned but should be used alongside other techniques, such as geophysics. In many areas, artificial drainage after the early modern period has effectively changed the landscape. Therefore, historical maps may be helpful in reconstructing former water systems suitable for prehistoric fishing activities. It is a well-known fact that good fishing locations have been used for centuries, even longer, where the ecological circumstances have sustained the abundance of fish. Historical and ethnographic sources are useful when potential areas for archaeological fishery sites are sought. The usefulness of LiDAR prospection has long been esteemed in dryland archaeology, but it has only occasionally been applied for wetland archaeological prospection purposes (Chapman and van de Noort 2001). The availability of LiDAR data in many countries by the state authorities provides good opportunities for various wetland archaeological approaches, such as landscapes reconstruction and site detection.

## Conclusions

Stationary wooden fishing structures constitute an important wetland archaeological resource in northern Europe; in

Finland, lying on the northeastern shore of the Baltic Sea, approximately 90 sites associated with wooden structures have been discerned in peatlands and muddy lake sediments through various land use processes and during periods of low water. Many of the securely-dated structures have yielded prehistoric dates ranging from the (Sub-)Neolithic period to the Early Iron Age. In this paper, the stationary wooden structures associated with fishing sites found in Finnish wetlands were compiled and evaluated based on their distribution, characteristics, and ethnographic sources. Some typical locations for encountering fishing structures were distinguished by the major Ostrobothnian rivers in western Finland, in the area of large lakes in central and eastern Finland, and in southwestern Finland. The fishing structures have been deposited in peatlands due to strong isostatic land uplift, lake terrestrialization, and other factors enhancing paludification, or they are still located in shallow water. In order to further our understanding on the detection, characteristics, and dating of these still inadequately explored archaeological wooden remains, an experimental project was launched by the authors at Haapajärvi, northwestern Finland, and a ground-penetrating radar (GPR), magnetometry, and electromagnetic induction (EMI) were tested in peatland habitat for cross-verification between surveys and ground truthing data. In addition, the wooden structures were documented and AMS dated, and the palaeoenvironmental potential of the site was preliminary evaluated with environmental archaeological methods.

Our results indicate that these relatively lightweight wooden structures buried in peat are very difficult to detect with the help of applied geophysics alone. Insufficient physical contrast, the burial depth, and the small size of the target object combined with complex sediments affected by modern drainage, uneven terrain, and dense vegetation render most of the techniques ineffective. It became obvious, however, that the magnetometer responded to remanent magnetic anomalies underneath saturated sediment and that there may be other types of archaeological features associated with the wooden structures detectable by geophysics. It was also possible to draw conclusions on the extent and some of the properties of the buried objects evaluated via trial excavations. Our recommendation is that topographic modeling of terrestrialized lakes, palaeoenvironmental investigations, subterranean modeling (e.g., geological coring and geophysics), and conducting fieldwork in archaeologically potential areas may be applied when fishing constructions are sought in lake environments. Historical and ethnographic sources provide additional and useful materials for investigating potential areas for prehistoric fishing activities.

The age, distribution, and composition of the over 5000-year-old stationary wooden fishing structures at Lamminoja, however, were revealed quite unique on a European scale. The vertical structures are relatively well preserved, even though the upper parts of the lath screen panels and piles have been cut off with an excavator scoop during drainage improvement operations. What makes the site exceptionally interesting is the fact that the remaining structures are still standing in an upright position, in their original configuration as erected at the site by the mid-Holocene fishermen. The other similar wooden remains in Finland and the neighboring areas have either been too fragmented, collapsed, or poorly preserved to be reconstructed, or they came to light so long ago that the archaeological assemblages were not

studied or documented properly. Based on our ground truthing data, the wooden structures at Lamminoja cover a much larger area than previously thought, at least an area of ca. 100 sq m in size. In addition, the Late (Sub-)Neolithic organic-rich sediment formation and charcoal in the vicinity of the visible wooden structures, which presumably have been formed under the influence of prehistoric anthropogenic activity offer some alluring materials for further investigations. The interpretive potential of the Lamminoja fishery, as well as other similar sites, is tremendous because the quality and quantity of the organic material preserved are exceptional compared to dryland sites. Therefore, aside from excavation and documentation campaigns, it would be appropriate to conduct large-scale environmental archaeological assessments for investigating human response to environmental change in the long term as an integration of archaeological, geophysical, palaeoecological, and geological data.

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