SEA SURVEY AND ITS IMPACT ON MARITIME ARCHAEOLOGICAL RESEARCH IN THE BALTIC SEA DURING THE LAST 30 YEARS

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More than 70 percent of Earth's surface is covered by water, a surface that is gigantic to map. Through the technical development in hydrographic surveys, we have today a completely different understanding of the seabed's topography and geology than we had just a few decades ago. This has also meant that we find more and more shipwrecks, but also sunken landscapes and other remnants of human activity. This article is a summary of this development.

The discovery of spectacular new well-preserved shipwrecks at the bottom of the Baltic Sea has increased significantly in the past ten years. We all remember the Vasa and the discovery in 1956, which created a sensuous and concrete image for the first time over the cultural treasures that can be preserved in our waters.

The conservation conditions in the Baltic Sea are ideal for much organic material, including shipwrecks. The low-salinity, which prevents "the shipworm" *Teredo navalis* eating up the archaeological material combined with cold and darkness, increases the chances of preservation. It is therefore possible to find wrecks with totally preserved hulls, riggings, equipment and remains for many hundreds of years. Of course, there are more factors than that, which makes the Baltic Sea unique from a maritime archaeological perspective, but the preservation conditions is one of the most important things that makes it possible for us to interpret whole structures such as shipwrecks.

The reason for the major discoveries in recent years is entirely dependent on the increasingly sophisticated technology in sea survey and the development of multibeam sonar, combined with the GPS (Global Positioning System) technologies, which since 1995 have become widely available and more accurate. A multibeam echo sounder is a type of sonar that is used to map the sea bottom. Like other sonar systems, multibeam systems emit sound waves in a fan shape beneath a ship's hull. The amount of time it takes for sound waves to bounce off the seafloor and return to a receiver is used to determine water depth. Unlike other sonars, multibeam systems use beam-forming to extract directional information from the returning soundwaves, producing a swath of depth readings from a single ping. It should be mentioned in this context that the Russian research vessels *R/V Akademik Vavilov* and *Akademik Loffe* used multibeam echo sounder as early as in the 1980s and became important for the development of this technique.[1]

Side-scan sonar is a category of sonar system that is used to efficiently create an image of large areas of the sea floor. It may be used to conduct surveys for maritime archaeology; in conjunction with seafloor samples it is able to provide an understanding of the differences in material and texture type of the seabed. Side-scan sonar imagery is also a commonly used tool to detect debris items and other obstructions on the seafloor that may be hazardous to shipping or to seafloor installations by the oil and gas industry. In addition, the status of pipelines and cables on the seafloor can be investigated using side-scan sonar. Side-scan data is frequently acquired along with bathymetric soundings and sub-bottom profiler data, thus providing a glimpse of the shallow structure of the seabed. Side-scan sonar is also used for fisheries research, dredging operations and environmental studies. It also has military applications including mine detection.

The technology has advanced so much since the mid-1990s, and is still rapidly developing, which means what we see today of maritime archaeological finds is just the tip of the iceberg. Furthermore these technologies have also become cheaper, which makes it possible for smaller companies or individuals, without major investments in equipment, to search for shipwrecks.

But all that is found at the bottom of the Baltic Sea by hydrographic survey does not provide a complete picture of the maritime archaeological landscape. Any technology has its limits and basically requires human interpretation of all the collected data. There are of course various research technologies in underwater archaeology. One of the best methods is diving survey, especially on identified anomalies or objects. The benefit of using a diver is that humans can directly process the data and make interpretations of the objects. A diver can also take measurements, notes and use photography for analysis, just as archaeologists do on land. In deeper waters however, where divers can't be used, or when the visibility in the water is poor, different technological help methods are necessary. Of course, these technological methods also have their limits, so it is important to choose right method in relation to the unique circumstances of the area to be surveyed. For example, sub bottom profilers have been developed for providing profiles of the upper layers of the ocean bottom, but are unable to image through gas bubbles and are influenced by weather conditions and the depth of the seafloor. I hope through this article to provide the reader a background to the development and limits of these methods, and to give a picture of future challenges.

Sea survey and the development until the 1990s

Hydrographic survey has always been of great importance for navigation, but very little is known about how it was organized and used before the 17th century. Experience was probably crucial for navigation as was the use of pilots. Hand-leads and sticks were used, of course, during voyages, and the results were probably recorded in some form. One of the oldest types of navigation sources were the so-called sailing descriptions, which verbally described the fairways, water and the characteristics of islands, islets and ports. The oldest known sailing description concerning the Baltic Sea originates from the reign of the Danish king Valdemar from the 13th century and describes the sailing route from Utlängan in Sweden to Reval (Tallin) in Estonia.[2]

During the 17th century survey was conducted by smaller rowing vessels and later by sailing boats or ships. Positioning was done using leading lines between significant points. Compass was also used with calculations of the estimated distance. During winter mapping was conducted from the ice. One tried to add the sounding lines parallel to one another to systematically find the depths. The lake Hjälmaren in Sweden was sounded in this way in 1690.[3]

In the end of the 17th and beginning of the 18th centuries the sea charts is increasingly filled with depth figures and deep curves. Sounding was mainly conducted in ports, at anchorage places and in narrow waterways. Fairway straits were usually only dashed without depth information.

In the 18th century, sea surveyors tried to get deep curves symmetrically distributed over the map by sounding in parallel lines – just like today. The mid-18th century is known as the "great chart improvement" in the Baltic Sea. The scale was set to 1: 20 000. Vertical lines were put up between capes and well-defined objects in a pattern, which has been termed "Star-sounding". This system was used until about 1860.

In the early 19th century deep curves and depth figures were introduced and they were also coloured on the sea charts. From the 1860s surveyors reverted to sounding in parallel lines and the scale of the sea charts was enlarged. In 1879 steam boats were used for the first time in shallower waters, but deep-sea measurement was done with larger survey vessels in scales from 1: 50,000 to 1: 200 000.

Later on at the end of the 19th century the surveys accuracy was improved by introduction of mechanical sounding. Also, during the First World War the quality of surveys was increased.[4]

In 1930 the first sonar system was introduced.[5] However, the idea to carry out hydrographic survey with sound waves is older than that. In the German technical journal "Mitteilungen aus dem Gebiete des Seewesens" the method was presented as early as 1908. The development of this technique resulted from a problem with sounding lines being heavily burdened by water currents when using conventional survey vessels thus affecting accuracy. In the article the author describes how a tube could be vertically attached from the deck of the ship down to the bottom of the hull, where in its funnel opening a bell was placed to sound in all directions. When the bell tolled, a receiving phone then picked up the reflecting sounds and ocean depths could thus be determined. The method was considered reliable, especially when measuring deeper than 120 meters, but by installing a resistance roll, a fully accurate measurement could be received regardless the depth. The article also explains how this acoustic equipment could be attached on the ship's side with the advantage of more frequent cleaning of the clock.[6]

Photogrammetry made its entry in 1931 and came over several decades to provide a convenient and relatively safe base for the coastline and the choice of angle points to sea survey.

Positioning was carried out in the archipelago areas right up to the 1950s mainly by means of horizontal bias against known objects. At sea a system of triangulation seamarks was used for mapping and survey. In the 1930s, a system of radio and acoustic means was developed, but it was not until after the Second World War, that navigational systems, such as the British Decca Navigator, were introduced and tested for hydrographic survey.

The big breakthrough for positioning came during the 1980s when the GPS was introduced. New sounding techniques like laser bathymetry were also developed. This technology could be used to survey from airplanes or helicopters in shallow waters with great accuracy. During this time the first multibeam sonars were introduced for sea surveys. On the Baltic Sea, the first multibeam sonar was installed on *HMS Jacob*

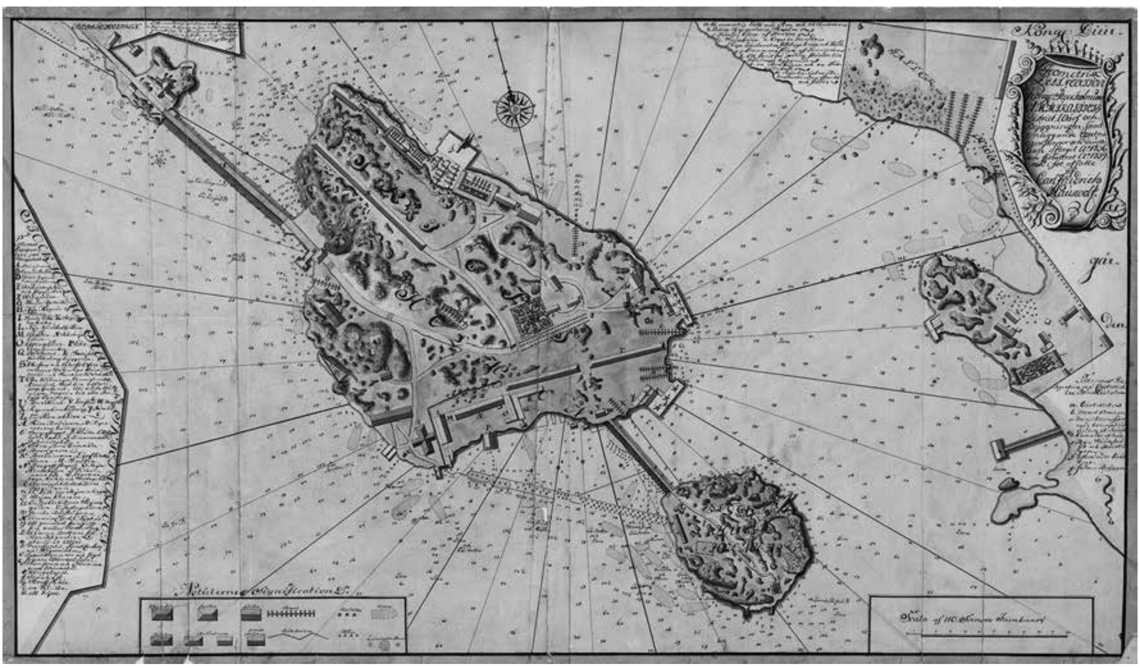
Hägg in 1993 (ELAC, Honeywell). It had 56 individual rays directed from the sounding line vertical 60 degrees to each side.[7]

Hydrographic survey and detecting of shipwrecks until the 1990s

Among older maritime surveys, where shipwrecks have been identified, the concern has almost exclusively been on harbor areas, where wrecks have been dotted out and in some cases even been named. The reason these early maritime surveys were performed was usually because the wrecks would be destroyed or that they would be used as a basis for various types of marine structures such as bridges or piers. In some cases, however, wrecks are also marked on maps of sounds or straits.[8] The straits were often of a military strategic nature, such as at Oxdjupet North of Stockholm, the sea-fortress Tre Kronor outside Copenhagen or at Suomenlinna in Finland.

The best known early hydrographic map of Stockholm's water was performed in two versions by Carl Friedrich von Hauswolff in the 1730s (1736 and 1739). On Hauswolffs map from 1736 43 wrecks are marked, which may indicate that a number of these ships were sunk during this period, and were under the supervision of Hauswolff. We know the names of three of the vessels and also exactly where they were sunk, but whether the wrecks are still there on the seabed is not known. The first is the frigate *Ruschenfelt*, the only wreck named on Hauswolffs map. The other ship is named *Förlovade landet (=The Promised Land)*. It was launched in 1723 and the wreck is marked on a detail map conducted by the well-known Swedish sea surveyor, captain Jonas Hahn in 1750. Hahn printed an engraved

Hydrographic map of Stockholm's water performed by Carl Friedrich von Hauswolff in 1739. Swedish War Archives.



sea chart over the Baltic Sea and Skagerrak the same year.[9] The third ship, *Halland*, also marked on Hahn's detail map, was built by Robert Turner in Karlskrona 1682 and was nearly 40 meters long and 10 meters wide. It was built for a crew of 290 people and had an armament of 56 guns. The ship was scuttled in 1737.

After the rediscovery of the *Vasa* by Anders Franzén in 1956, maritime archaeological excavations started in other part of the Baltic Sea as a spin-off effect.[10] In Finland salvaging attempts were made on the then newly located well-preserved 17th-century merchant ship *St Michel* and in Denmark salvaging was made of five Viking age or early medieval clinker built ships in the Roskilde fjord in 1962. Also on St. Nikolai, found 1948 outside of Ruotsinsalmi in Finland, excavations started in the 1960s.

Consequently, the interest for maritime historical research increased in the Baltic Sea, but old survey results were not used as a background source for maritime archaeological discoveries. There were older sea charts available at this point; it is quite interesting to note that in some cases they could have been helpful in maritime archaeological research. An example of this is a sea chart from the 1830s where the wreck site of *Vasa* is marked. The marking of the wreck on the map was made around the same time as the Swedish diving pioneer Anton Ludvig Fahnehjelm applied for diving permit at the *Vasa*.[11]

Anders Franzén, however unaware of this older information, developed new technology for further research after famous naval vessels, the *Kronan (=the Crown)*, sunk in 1676, not the least among them. *Kronan* was discovered in 1980, six kilometers outside of the southeastern Öland by Anders Franzén, Sten Ahlberg, Bengt Börjesson and Bengt Grisell. The ship was found thanks to the help of side-scan sonar, a magnetometer and a remote operated vehicle (ROV).

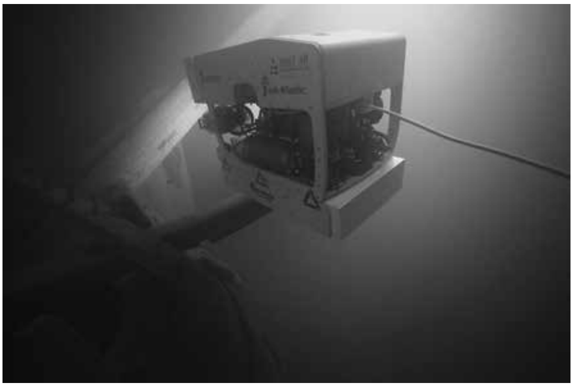
During this time in the early 1980s the side-scan sonars were very expensive equipment and were mainly used by navies for submarine chase, but increasingly tested more and more for research purposes.

From the 1990s until today

The big breakthrough for maritime archaeological surveys came in the mid-1990s when side-scan sonars started to be used together with a better positioning system than before and with the introduction of multibeam and computers.

Onboard bigger survey vessels today the main instruments are different types of sonars and differential GPS (DGPS). The sonars are usually side-scan sonars and multibeam. As a complement to this sea bottom penetrating echo sounders are also used. For this great computing power is also needed. The different techniques save large amounts of data in the form of depth and position numbers and the computer must constantly calculate the position of all depth registrations, which can involve several hundred positions per second. This is because sound pulses go out in many different angles and hit bottom in many different positions.

To get the most accurate depth possible, it is necessary to determine the speed of sound through the water exactly at the current depth. Sound speed also depends on the water's salinity, temperature and density. The exact audio speed is therefore determined by using a probe. This is lowered down to the maximum depth in the area. It then sends a light pulse up to the ship's hull to a sensor that records how long it takes for the sound to come up. When you know the distance that the sound has gone and



ROV equipped with multibeam sonars and HD cameras during the study of the Ghost ship. Photo: Marin Mätteknik AB/ the Ghost ship project. Reproduced with the permission of Johan Rönnby, MARIS.

the time it took, a computer can calculate the audio speed. If there are significant sea conditions there is another computer that receives signals from the sensors that register movements, and then compensates these so that hydrographic survey can be conducted despite these conditions.

In the Baltic Sea there are formations on the seabed, from huge mountains to small gaps that now are quite easy to explore. The Baltic Sea Bathymetry Database (BSBD) is developed in cooperation with the Baltic Sea countries, with the purpose of visualizing and providing depth data for the whole of the Baltic Sea. The BSBD has been developed as part of the TEN-T-funded EU project MONALISA, within the framework of the Baltic Sea Hydrographic Commission, which is an integrant part of the International Hydrographic Organization. The Baltic Sea Hydrographic Commission promotes the technical cooperation in the domain of hydrographic surveying, marine cartography and nautical information among the Baltic Sea area countries.

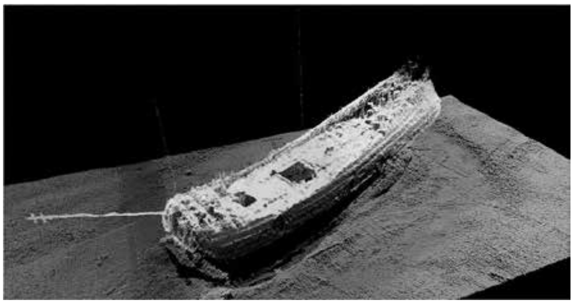
The BSD provides a consolidated picture of the seabed's topography across national borders and will provide researchers and stakeholders in the marine environment with the knowledge of the entire Baltic Sea. Work on the improvement of the model will continue as new data becomes available.

From an archaeological point of view there are efforts being made to put national wreck registers into a pan-European database of underwater cultural monuments. This would enable all interested parties to find information quickly and easily from one place.[12] However, the information in national databases is at the moment not accessible in English with the exception of Estonia. This tightens the circle of data users, but hopefully these databases will be translated in the coming years. This is an important task, because sailing is international and a shipwreck might only be understood by international research cooperation.

Major exploitation of the seabed

Major exploitations on the seabed have been of great importance for maritime archaeological research. One of the best examples of this is The Nord Stream AG, which was founded in 2005 to plan, construct and operate a pipeline system through the Baltic Sea from Vyborg in Russia to Lubmin near Greifswald in Germany. The pipeline passes through the economic zones of Russia, Finland, Sweden, Denmark and Germany and the territorial waters of Denmark and Germany.

From 2005 to 2009 several large-scale geophysical investigations using different methods were made as part of the planning process for the natural gas pipeline.


A multibeam view over the Ghost ship. Photo: Marin Mätteknik AB/the Ghost ship project. Reproduced with the permission of Johan Rönnby, MARIS.

The 140m wide pipeline corridor and the 1.6 km wide anchoring zone were investigated separately. In all, 74,000 hectares of bottom were surveyed. One of the most interesting aspects in this project from an archaeological point of view was that the pipeline was supposed to lie partly on deep waters, were multibeam surveys had not usually been done before.

Following interpretation of the survey materials, target reports were made and targets were selected for inspection by a ROV. During the different surveys close to 20,000 targets were inspected by a ROV. The bottom survey materials and the inspected targets were evaluated from a culture heritage point of view and an impact assessment for each target considered to be cultural heritage was carried out. As a result of the investigations circa 40 wrecks and some other targets were evaluated from a cultural heritage point of view.[13]

This large-scale survey also became the starting point for several new archaeological studies of well-preserved shipwrecks, even if they did not lie in the path of the planned pipeline. There are several private operators, who have successfully combined their survey skills with collaboration with researchers in maritime archaeology, such as the German Innomar, Finnish Subzone and Swedish Marin Mätteknik (MMT). One interesting example is the SASMAP –project with its geological modeling and sea floor survey in Stone Age dwellings. The MMT has started several new projects together with MARIS (Maritime Archaeological Research Institute of Södertörn University) and a production company (Deep Sea Productions).

One of their main objects, which are also of interest because it is located at 125 meters, is a flute from the 17th century with the working title *the Ghost ship*, discovered in 2003. One of the purposes of the study of *the Ghost ship* was to evaluate new methods for measurement without using divers but instead using ROVs equipped with multibeam sonars and HD cameras. The results were above all expectations and the archaeologist managed to make a detailed drawing of the ship's structure thanks to these survey experiments. The technique did not only give great opportunities to bring out the shape of the hull, the archaeologist also received data from inside the wreck with indications of different deck levels.

In recent years the MMT have, among other objects, tested and developed its technology at the wreck sites of *Svärdet (=the Sword)*, sunk in 1676 and *Mars*, sunk in 1564.

At the wreck site of *Mars* a so-called 3D Mechanical Scanning Sonar (Blueview BV 5000) was used. The combination of using the ROV with a multibeam from above and a Blueview allows one to move around the wreck and provides a great opportunity to produce an accurate picture of the wreck site. The 3-dimensional measurement data obtained can then be "dressed" in pictures by photographing the wreck site. In this way a photogrammetric model that is so precise that it would not have been possible to get similar information using diving archaeologists is obtained.

The photogrammetric documentation means that digitally documented details – or the whole wreck site – can be printed out via a 3D-printer, which is a tremendous breakthrough in maritime archaeological research, not least from the perspective of preservation. In principle, valuable shipwrecks can in the future be allowed to remain on the seabed while all relevant information can be retained on land digitally for further research. One of the major benefits of this is that it has now suddenly become possible to visualize a wreck site on land.

One of Sweden's ongoing maritime archaeological projects is entitled "Landscapes Lost" and is aiming to study sunken landscape that has been populated since the Stone Age. In connection with this, a high resolution seabed penetrating sonar was used to try to identify potential landscapes covered by sediments. Known locations of Stone Age finds can be related to the data sets to find a method that can streamline their identification. Several other methods have been used in the project to document mud embankments with remnants of ancient trees, photogrammetry among them.

As with the investigations of *Mars* the combination of photogrammetry and multibeam has been very successful to get a 3D model of the landscape. This sunken landscape extends far out from the borders of Sweden towards Poland and in the long run, we will most likely get a very different picture of geological development of the area.[14]

Amounts of data and problems of interpretation

An inventory of already conducted marine surveys shows that national databases hide archaeological information both in the form of hitherto unknown shipwrecks but also in the form of tracks from maritime activities. Multibeam mapping creates very large datasets, which can be difficult for human to interpret. New archaeological knowledge may be found by processing data from a designated area. By making use of a so-called backscatter analysis it might for instance be possible to detect flat wrecks that are not visible as increases in the height model. By looking at the signal strength from a multibeam survey anomalies in the sea bottom hardness can be detected. These can be explained by natural geological formations or as a result of human activity.[15]

Barriers to accessibility?

Hydrographic survey is something that every country takes care on its own, primarily for the production of nautical charts. Through varied national legislations hydrographic surveys are largely licensable, primarily for reasons of defense. Consequently this knowledge is not widespread among all surveying for wrecks. In addition to the licensing issue, laws may demand that data must be kept in a safe way without spreading it. Legislation on the protection of geographic information, including hydrographic information, has a long tradition. Several of the 200-hundred-year-old charts that we today can study in various archives were once highly secret information.[16]

Despite the fact that there is an ongoing debate that the information on the bottom of the Baltic Sea should be widely available, legislation does not need to be a major obstacle to maritime archaeological research. Through applications, one can very well be allowed to survey and also to get the excerpt of the survey data from various government agencies.[17]

The inland waters – the next challenge?

Within the next ten years, the bottom of the Baltic Sea is likely to be that well surveyed with modern technology that it will be possible to see any major sunken ship. How many there will be found in total is impossible to say, but we can certainly say that we are facing a completely new cultural landscape.

Maritime Archaeology, however, is so much more than sunken ships. It also means sunken landscapes, fishing traps, harbors, maritime fortifications and cultural layers.

The technology will likely never be able to replace the human eye, or the human analysis, because much of the maritime archaeological material is so fragmented or covered by sediments or other layers that it cannot be detected by survey vessels alone. But with help of more advanced survey technology we will be able to detect so much more than was possible just a few years ago.

Maritime archaeologist Minna Leino working in lake Saimaa in the 1990s. Our inland water systems present a future challenge in archaeological knowledge. Photo: Reino Hemmilä. Reproduced with the permission of Minna Leino, Finnish National Board of Antiquities.

Our inland water systems, the lakes and rivers – areas that may not be intended to be surveyed – present a future challenge in archaeological knowledge. As a pioneer project in this context the University of Helsinki has just started a project in the Saimaa Lake complex called "Lost Inland Landscapes".

The Saimaa Lake complex in the eastern part of Finland has constituted one of the major inland water systems throughout our prehistory. In the earlier stages, the water level of the ancient lake was relatively low. Due to the post-glacial lake land uplift and tilting, the Saimaa basin continued to transgress into a southeasterly direction and thus inundated earlier lakeshores. Circa 6000 years ago, the Ancient Lake Saimaa reached its maximum extent, nearly 9000 km^2 in size culminating in the outburst of the Vuoksi River in the south c 4000 cal BC.

Because of this, the Mesolithic and Early Neolithic sites predating the transgression are to be found under water and the wetlands surrounding the lake. An experimental project was launched at the turn of the millennium with the aim of finding submerged settlement sites by means of underwater archaeology.[18] A few new observations were made under shallow water and mud into the lake in the municipality of Taipalsaari and the results make it most likely that new, submerged and paludified sites in the region.

The new project is both ambitious and innovative. New techniques and experiences in wetland and underwater archaeology make it possible to find hitherto unknown prehistoric sites on wetlands as well as on the lakebed in the SEE Saimaa area. The experiences from the southern shore of the Lake Vättern in Sweden, for example, are encouraging and it is highly possible that something similar has survived on the lakebed and shallow shores of the Lake Saimaa. On dry land conditions, practically all the organic materials from the Mesolithic and Early Neolithic period have deteriorated, but in wet environments quite much of these might have survived. If successful the project may produce scientifically highly important new information on the Mesolithic and Early Neolithic period in Finland.

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This article has been peer-reviewed. Tekniikan Waiheita would like to than the reviewers for their valuable comments.

[1] Jäntti 1989:306-313.

[2] Ehrensvärd 2006:261.

[3] Ehrensvärd & Frithz 1993:30.

[4] Ehrensvärd & Frithz 1993:25-41.

[5] Söderman 1995:38.

[6] Tidskrift i Sjöväsendet 1909.

[7] Ehrensvärd & Frithz 1993:50-51.

[8] Cederlund 1983:23.

[9] Ehrensvärd 1998:69.

[10] Hjulhammar 2010:22-23, 33.

[11] Cederlund 2012:14-18.

[12] Russow 2013:314-315.

[13] Wessman 2011.

[14] Holmlund 2014:4-9.

[15] Flood & Törnqvist 2010:13-16.

[16] Ehrensvärd 2006:287.

[17] Karlsson-Ottosson 2014:4-5.

[18] Koivikko 2000.

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