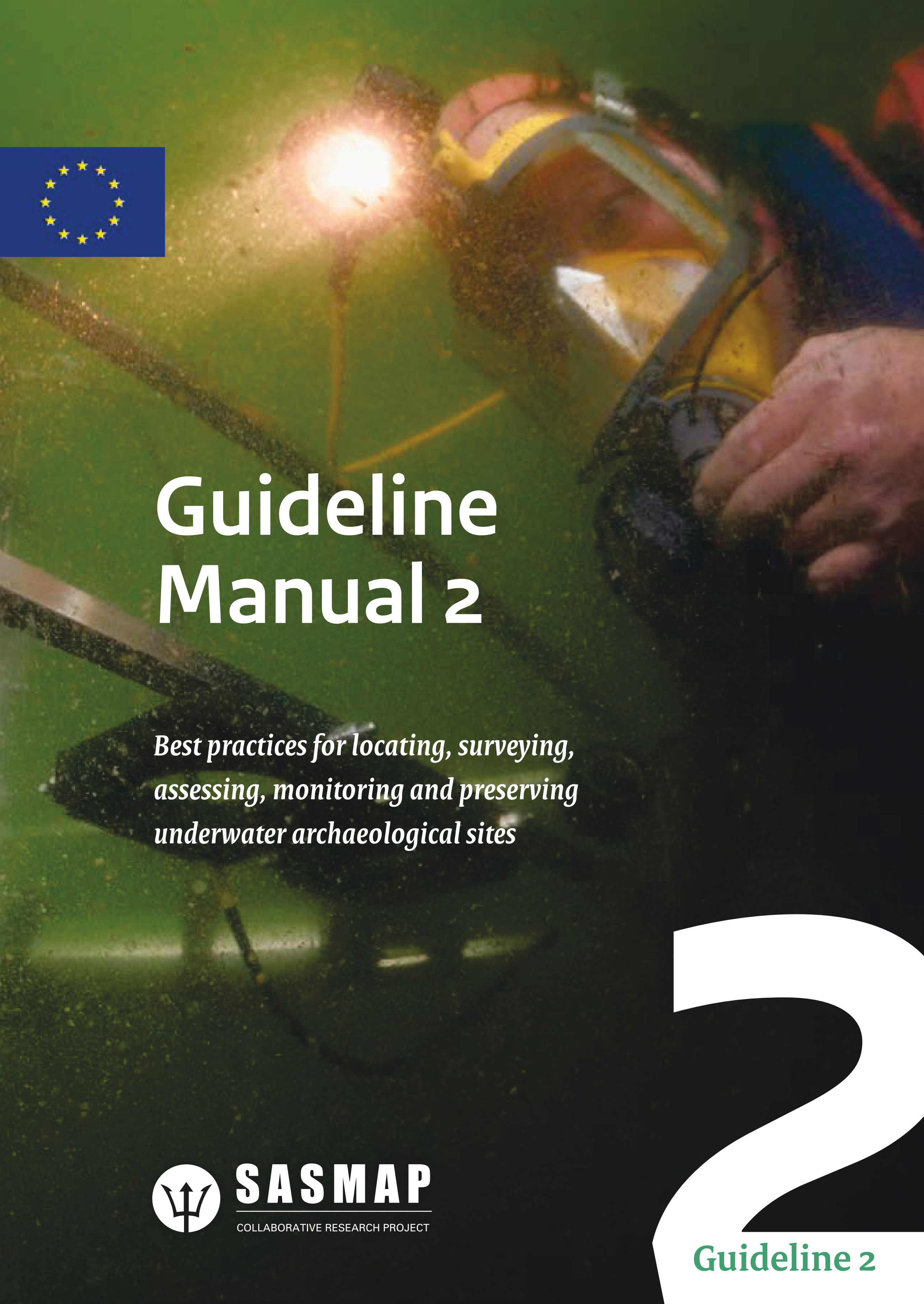

Guideline Manual 2

Best practices for locating, surveying, assessing, monitoring and preserving underwater archaeological sites

SASMAP

COLLABORATIVE RESEARCH PROJECT

2

Guideline 2

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Best practices for locating, surveying, assessing, monitoring and preserving underwater archaeological sites

COLOPHON

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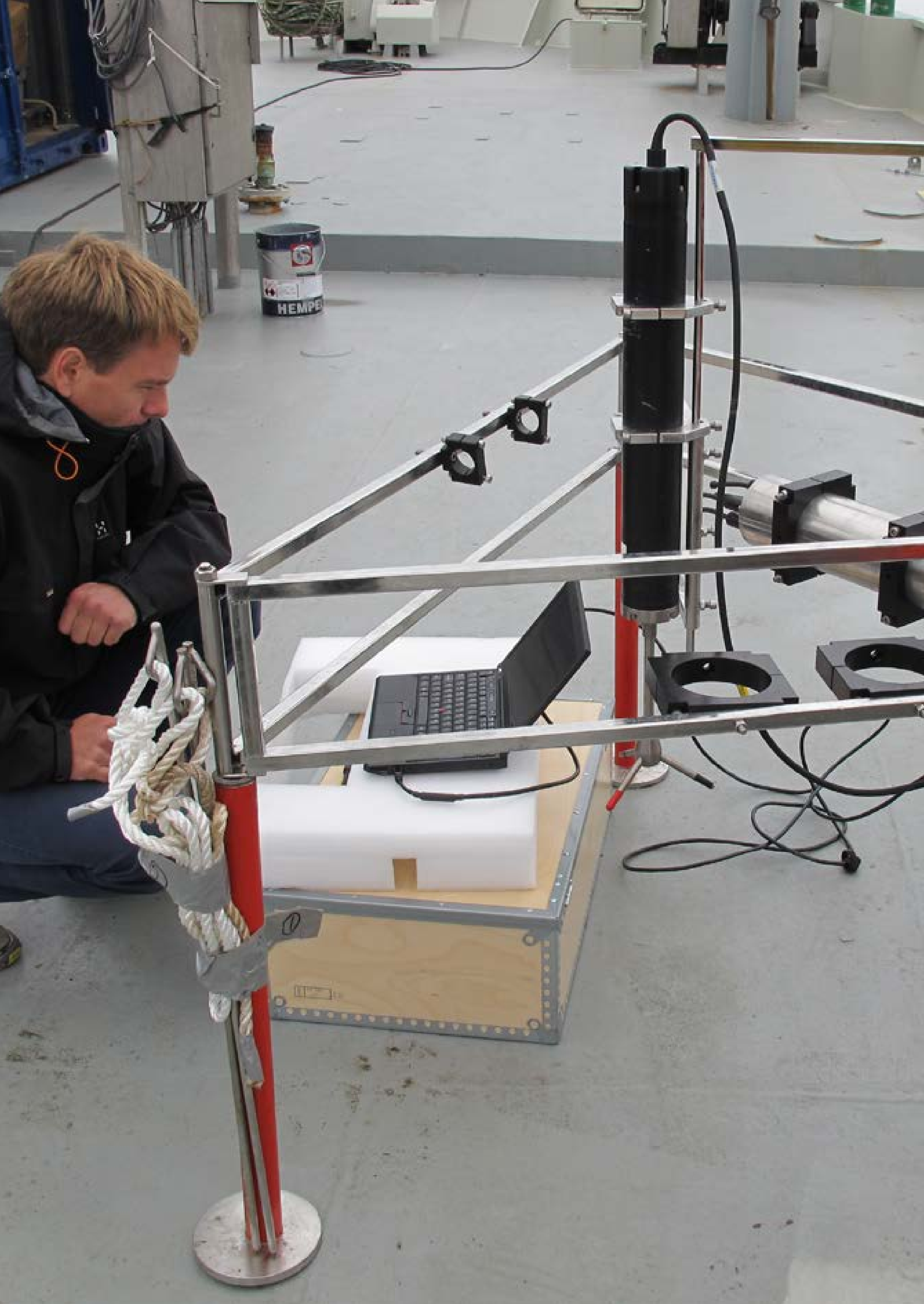

HEMPEL

Introduction to Guideline Manual 2

This set of guidelines, entitled "Best practices for locating, surveying, assessing, monitoring and preserving underwater archaeological sites" (Guideline Manual 2 of the EU-SASMAP project) illustrates the overall process of carrying out the procedures for underwater archaeological research that are outlined in the guidelines "to the process of underwater archaeological research" (Guideline Manual 1 of the EU-SASMAP project). This manual explains the necessary background on methods and techniques (M&T). Many examples are used to explain the work performed in the different process steps. However, the main focus of this second set of guidelines is the work carried out in the SASMAP project.[1]

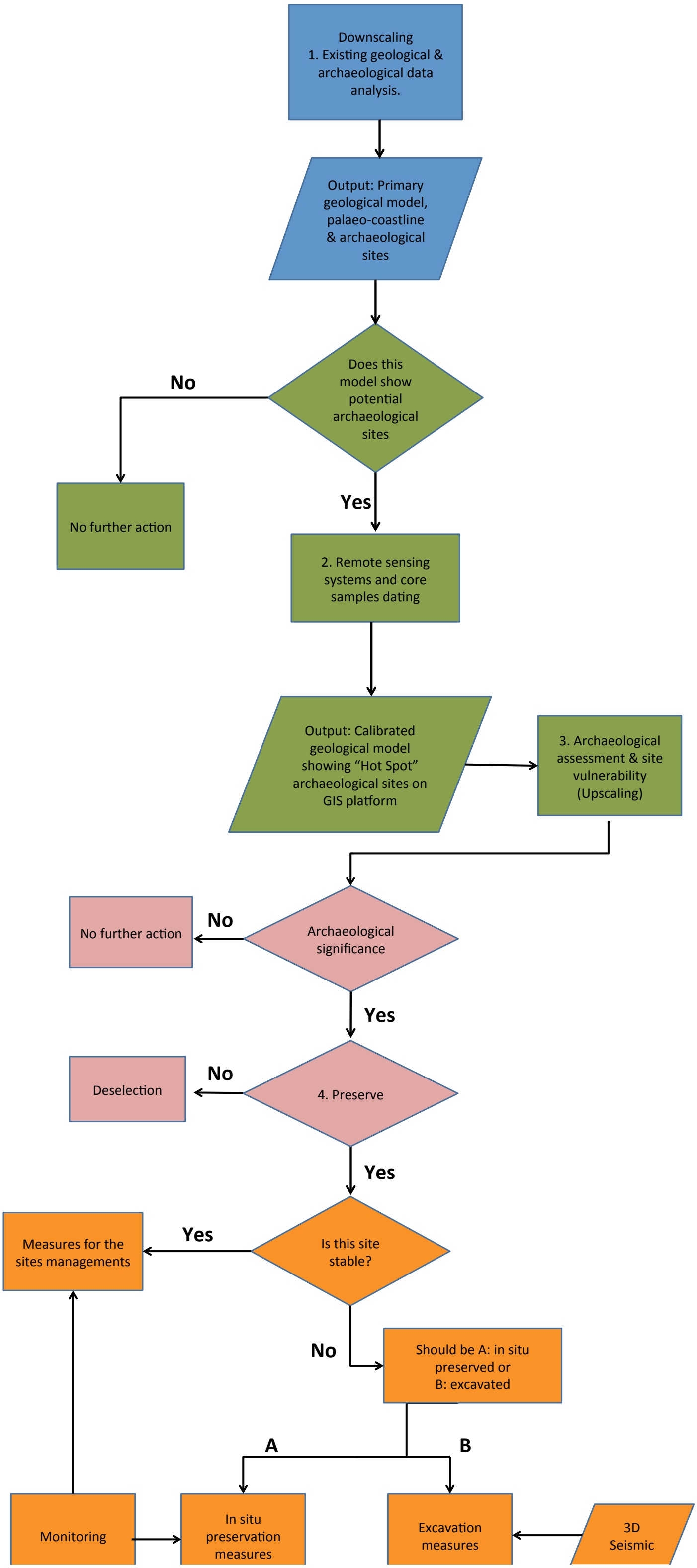
Although downscaling and upscaling are not new concepts, SASMAP has sought to develop and improve existing methods for downscaling. These efforts have focused especially on meeting the EU's requirements for research projects conducted to "diagnose and map" archaeological sites, such as the predictive modelling performed to locate shallow and more submerged coastal underwater sites. As explained in Guideline Manual 1, one of the key goals of a desk-based assessment is to identify the location of underwater sites that do not necessarily show up in existing archaeological databases. The "process" of identifying potential archaeological sites starts with a general and broad-scale exploration of the region. This process begins by delineating areas of interest, and goes on to zoom in on a specific area. That area is then investigated with high resolution acoustic remote sensing systems, the findings of which are verified by ground truthing. This entire course of action is the downscaling aspect. The resulting evaluation of the site's "hotspots" and its archaeological significance, as well as preservation measures, comprise the upscaling aspect of the concept. These two aspects are illustrated in Guideline Manual 2 as part of a holistic approach to the identification and evaluation "process."

The practice of underwater archaeology in the field, especially where divers are involved, can be extremely expensive. It is important, therefore, to gather as much information as possible so as to optimise the resources used during diving operations.

The SASMAP project has highlighted the need for an interdisciplinary approach to desk-based assessments by gathering and assessing information that is not always a focus of attention, or even available to archaeologists. The contribution that SASMAP has made to Desk-based Assessments is the development of geological models based on remote sensing and dating information, which have been used to predict and map where coastal archaeological sites may occur.

Similarly, in terms of upscaling, the EU framework calls for improved methods for "excavating and securing underwater and coastal archaeological sites". Here SASMAP, with its ambitious goals, oversaw the development of new tools and techniques

[1] See www.sasmap.eu


Downscaling
1. Existing geological & archaeological data analysis.
Output: Primary geological model, palaeo-coastline & archaeological sites
Does this model show potential archaeological sites
No
No further action
Yes
2. Remote sensing systems and core samples dating
Output: Calibrated geological model showing "Hot Spot" archaeological sites on GIS platform
3. Archaeological assessment & site vulnerability (Upscaling)
No further action
No
Archaeological significance
Yes
Deselection
No
4. Preserve
Yes
Measures for the sites managements
Yes
Is this site stable?
No
Should be A: in situ preserved or B: excavated
A
B
Monitoring
In situ preservation measures
Excavation measures
3D Seismic

aimed at optimising the diving phase of any on-site investigation. In terms of prospecting, a 3D Sub Bottom Profiler was developed and trialled. To meet diagnostic needs, equipment has also been developed that can characterise open water and burial environments and that can assess the state of preservation for wood. These tools have been used to increase understanding of the deterioration processes of organic materials in underwater environments. In addition, a method of preserving sites in situ has been developed with the production of an artificial seagrass mat. Finally, new methods have also been introduced for raising fragile organic artefacts to the surface.

Guideline Manual 2 discusses current methods and their underlying principles, and summarises key findings from various components of the project.
For more information on the project, see: www.sasmap.eu

Fig. 1: Figure 2 from Guideline Manual 1 presents the different process steps in development-led archaeology. This process flow chart offers an impression of the downscaling and upscaling approaches, using the process steps outlined in Guideline Manual 1, but executed with the methods and techniques used in the SASMAP project.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1. Desk-based assessment – Best practice examples

INTRODUCTION

The aim of a desk-based assessment is to provide a description of the potential archaeological value of a specific area. This is done by using information from existing sources about known or expected (i.e. still unknown) archaeological resources within the specific area. These assessments culminate in a report that describes the site's archaeological potential and offers recommendations on further steps in the archaeological process. These recommendations are to serve as the basis for the competent authority to make a decision on any follow-up research, if necessary. For more information please see Guideline Manual 1.

This chapter presents examples of the most frequent - as well as new and promising - methods and techniques that yield useful information for this stage in archaeological research.

METHODS OF RESEARCH AND BEST PRACTICE EXAMPLES

General methods

Desk-based assessments can draw on a variety of information. The more, the better - as long as validation is available for the different sources (to ensure valuable information) and as long as the data collected can be compared to other datasets. All data may be compared, analysed and assessed manually. However, a very useful current tool for comparing and storing data is a Geographical Information System, or GIS. A GIS workspace may be set up specifically for a certain project, but may also already exist as a national data exchange system. Some Geographic Information Systems are stand-alone and others are available online, often with already exciting data and ready-for-GIS maps. In light of that, we would recommend using a GIS to store, compare and analyse the data in desk-based assessments.

Information that can be useful in desk-based assessments and can also be stored in a GIS includes the geographical area, the geology, shipping routes, historical maps, sea depth data, known archaeological sites or finds, multi-beam echosounder images and geophysical datasets.

A good example of a GIS for archaeological heritage management purposes was produced during the European-funded MACHU project from 2006 to 2009. See the MACHU site for more information.[2]

National, regional and local authorities and institutes (among other organisations) involved in archaeological, geological and oceanographic research and management often have information, maps, databases, or even integrated GIS systems available for use online. Examples include a GIS available for bathymetry data in the UK[3], and a GIS for the geological make-up of the Netherlands.[4]

Historical archival work often requires specialists to interpret and even transcribe official manuscripts. However, these may also be available online in a GIS form, or as scanned

[2] www.machuproject.eu.

[3] https://www.gov.uk/guidance/inspire-portal-and-medin-bathymetry-data-archive-centre

[4] http://www2.dinoloket.nl/nl/download/maps/geologicalMap.html

documents or transcriptions.[5]
A comparison of different environmental data to analyse the threat of shipworm (Teredo navalis) to underwater cultural heritage in the Baltic sea was conducted in a GIS during the European-funded wreckproject.[6]

Scientific publications about the area, or a specific site, can contain a great deal of the information needed to carry out a desk-based assessment adequately. Although many publications can be found on the internet, many reports or publications are not available online. This should always be taken into consideration. The publications can be looked up in public libraries, governmental libraries or online libraries, such as JSTOR[7] or Academia[8].

Multi-beam or side-scan sonar images can be consulted if available for the area. These techniques provide images of the seabed features, (2D images from side-scan sonars and 3D images from multi-beam sonars), and enable researchers to detect anomalies on the seabed. This technique is well suited for mapping archaeological features visible on or above the seabed, but is less usable for the detection of most prehistoric submerged sites because of its inability to penetrate sediments.[9]
A combination of both techniques is advisable. The images might be available from dredging companies or governmental authorities, such as geological survey institutes. It is important to be aware, however, that a multi-beam sonar image is made through the processing of real depth data. The image itself is made for a specific purpose, either to be used as an illustration in a report/publication, or to demonstrate a specific fact. For example: a multi-beam sonar recording may originally consist of millions of depth measurements to monitor the depth of a shipping lane. During processing, however, an image is made with only one depth measurement per 100 m^2. This is enough to show the depth of the shipping lane, but not enough to determine whether there is any archaeological site surfacing the seabed.
By going back to the originally recorded data (the millions of depth measurements that were recorded) one might be able to process that data to a much higher resolution map up to 5 cm^2.[10]

The historical geomorphological map sets developed by the Dutch Cultural Heritage Agency in 2014 for the Markermeer and IJsselmeer lakes and the Western Wadden Sea in the Netherlands are an example of different datasets, (compiled with multi-beam sonars), that have been used for desk-based assessment and predictive modelling. Historical maps, depth data and coring data were combined to develop geomorphological maps of the areas. These maps make it possible to develop an archaeological expectancy map of the area.[11]

5 http://www.maritiemprogramma.nl/WID.htm
6 www.wreckprotect.eu
7 www.JSTOR.org
8 www.academia.edu
9 Although sonars may be able to penetrate the seabed at very low resolutions, the images will not be very useful for archaeological research within the sediments.
10 Depending on the transmitted signal frequency, the quality of the original data and the depth of the seabed
11 http://en.magazine.maritiemprogramma.nl/eMagazine-MP04-ENG/# and http://cultureelerfgoed.nl/publicaties/de-gelaagde-geschiedenis-van-de-westelijke-waddenzee.

Shipwreck databases can be used to identify known shipwrecks. Although not all shipwreck databases are open-sourced, they can offer valuable information. Some databases are established for official use, whereas others are created by e.g. amateur archaeologists. The Western Australian Museum has developed the Maritime Archaeology database as an open source database, where visitors can search for shipwreck information.[12] Another database for shipwrecks and underwater sites, Wrecks In Situ, was developed during the MACHU Project. Using this database, anyone with an interest in maritime archaeology can search for wreck information, and can also contribute to the database. The individual wreck IDs contain information about their (rough) location, history, preservation status and any research that has been done on the wreck site or underwater site.[13] It is also possible to consult databases that contain information on both land and underwater sites, as well as data from other disciplines. The Danish Kulturstyrelsen database is a good example of such an interdisciplinary database. The product of merged databases from other Danish museums, this database contains a vast range of data from all over the country.[14]

To gain information about the sediment, a grain size database can be consulted if available. By studying grain size distribution, it is possible to answer questions about the area's sedimentation. For instance, is the sedimentation continuous, or does it occur during events? Is it transported by waves or is it deposited during times of low energy within the water? Established in the 1970s, the NCEI Seafloor Sediment Grain Size Database is a large grain size database, which contains particle size data for over 17,000 seafloor samples worldwide.[15]

In areas with detailed studies, such as the Danish Tudse Hage site, comparison of sediment grain size and modelled maximum current velocities on the seabed can be plotted in Hjulstrom's diagram[16] in order to determine whether the seabed sediments will favour erosion, transport, or deposition.
Below the seabed seismic reflector, unconformities indicate erosion while conformities indicate deposition or bypass. Supplementary PB 210, OSL and radiocarbon dating gives information on sedimentation rates and the time interval of any possible hiatus. See, for example, Manders et al 2009.

NEW DEVELOPMENTS FOR DESK-BASED ASSESSMENTS

New developments from SASMAP: The downscaling approach

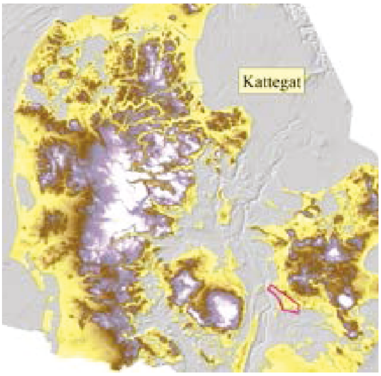
Marine geological investigations are essential to developing models describing the palaeogeographical and depositional

[12] http://www.museum.wa.gov.au/
[13] www.machuproject.eu
[14] http://www.kulturstyrelsen.dk/kulturarv/kulturarvsdatabaser/
[15] http://www.ngdc.noaa.gov/docucomp/page?xml=NOAA/NESDIS/NGDC/MGG/Geology/iso/xml/G00127.xml&view=getDataView&header=none
[16] https://en.wikipedia.org/wiki/Hjulstr%C3%B6m_curve

environments of marine archaeological sites. Using a geological model, it is possible to optimise the process of selecting the target region ideal for non-destructive down-scaling studies, spanning from regional satellite scanning of theoretical optimal target coastal areas, detailed multi-beam echosounder and shallow seismic surveying of selected target areas to 3D-seismic investigations of identified archaeological target sites.

Available information (desk-based assessment phase) including sediment datings, prehistoric and historic archaeological data, markers of coastal zones, changes in flora and fauna, previous marine and terrestrial seismic data, etc., should be included in any evaluations of a potential relative sea level-change curve and the construction of geological models of the region. The evolution of the coastal zone paleogeography depends on relative sea level changes. The estimation of the evolution of the sea level curve should take into consideration the eustatic, isostatic and tectonic factors. Dramatic global sea level changes in the past have resulted in the transgression of the sea and the flooding of large coastal areas. Today, parts of the ancient coastal zone, together with prehistoric and historic human artefacts, are submerged. Evaluation of the regional and local sea level change scenario is crucial to their detection. These geological models are used to produce a palaeogeographic (palaeocoastline) map of submerged landscapes. These types of models are both applicable for assessing submerged landscapes and detecting potential ancient shipwrecks in certain ancient coastal environments, such as those close to river outflows and high tidal coasts. Geological models should also be produced in order to assess the stability of the site in terms of sediment erosion, or deposition.

Within SASMAP, geological models were produced of two case study areas: Cape Sounion in Greece and Tudse Hage in Denmark. The sea level variation since the early Holocene was investigated, using information available from seismic profiles, biostratigraphic information, sediment cores and radiocarbon dating. Bathymetry data extracted from satellite images were used in the formation of a seamless morphological map of the areas investigated. Archaeological datasets and information were used to supplement the geological model and the sea level variation curve for the study areas. As part of SASMAP, bathymetry data extracted from satellite images proved to be very useful in the shallow waters of the study areas. Shallow waters are often inaccessible to normal survey ships, because of large rocks and boulders and survey system limitations. A further advantage of this method was that such maps can contain both offshore - as well as on-shore – features, i.e. seamless morphological maps of the coastal zones. This was done by using the satellite images, after processing for the water column, and extracting the reflection from the seabed to determine the seabed bathymetry. Control bathymetry points collected with more conventional survey tools were used to calibrate the bathymetric measurements from the satellite image.
A new development for this stage in the

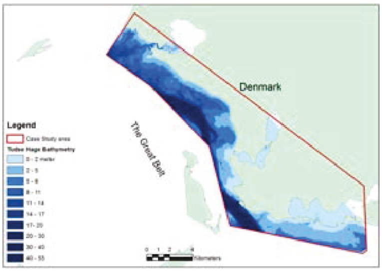
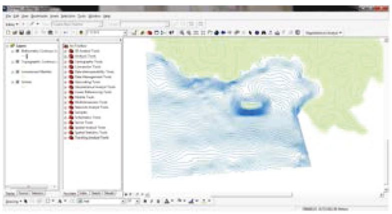
Case studies	Tudse Hage	Cape Sounion
Location	Baltic Sea, Denmark 	Aegean Sea, Greece 
Archaeological importance	Possible buried Mesolithic (~5000yrs BC) remains	Possible submerged coastal installation dating to the 5th century BC
Sea floor texture	Mainly organic rich gyttja with layers of sand and gravel	Sandy and rocky, often covered by seagrass

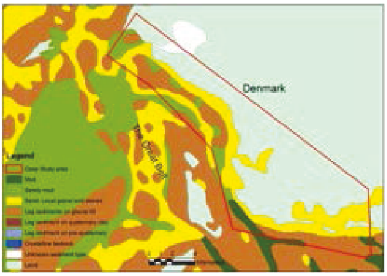
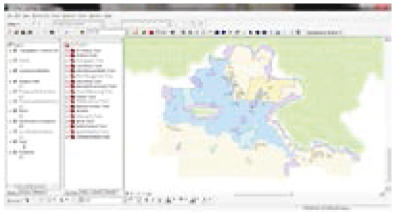
archaeological process is research on sea level variations since the early Holocene on the two case study areas. To this end, C-14 dating data were compiled in an archive, and the results of that dating were standardised in a GIS dating database with a BP calendar age end product. The SASMAP radiocarbon GIS database contains approximately 1,650 dating data points from Denmark and the nearest neighbouring countries. The Carbon 14 GIS database was a very important tool in constructing the sea level curve for Tudse Hage, Denmark. With the construction of that sea level curve, the chronology of the area was established. The aim was to improve the sea level curve as an input for the development of a geo-archaeological model. The synthesis and comparison of all the available datasets in an interactive GIS environment enabled the identification and mapping of areas with potential archaeological sites. The construction of a GIS database is considered as fundamental in the framework of identifying and detecting submerged cultural heritage sites, as it is expected to effectively reduce the extent of the areas to be investigated.

The table below presents a general overview of the basic steps developed in the SASMAP project, illustrated by the case studies. See the SASMAP Work Package 1[17], for more information.

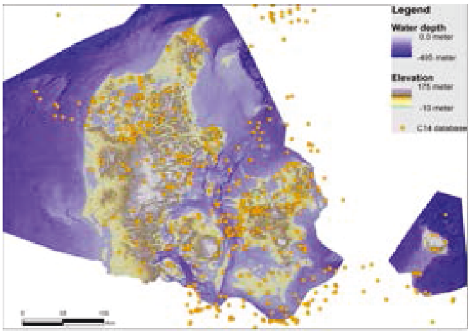
[17] www.sasmap.eu

Step 1: Building the GIS database from existing and acquired datasets

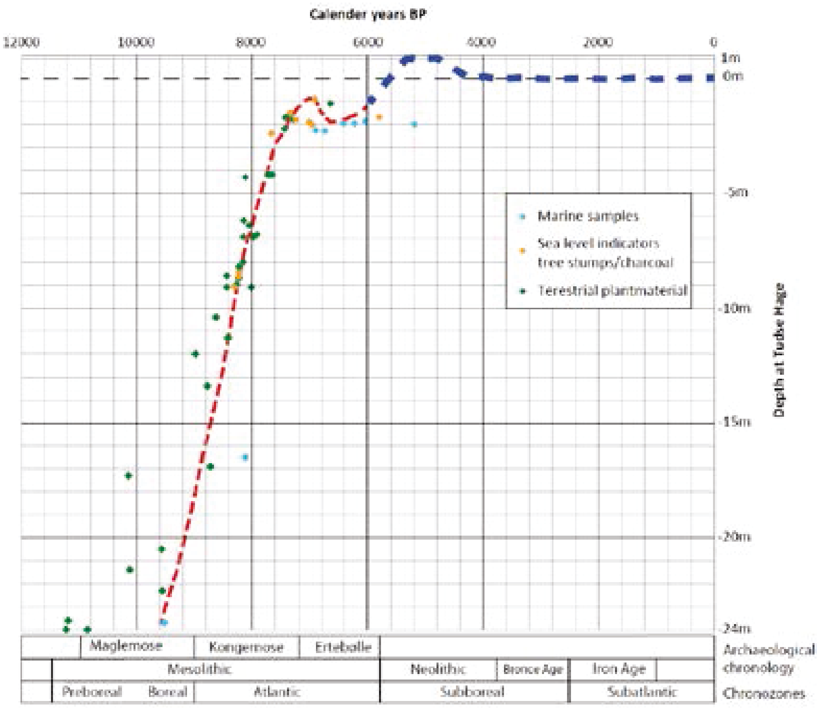
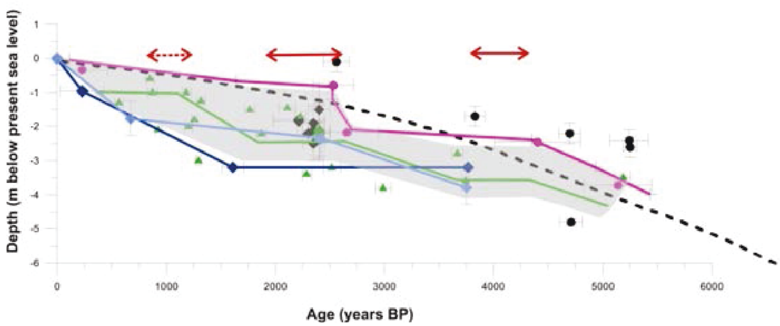
	Tudse Hage	Cape Sounion
Data bases used	• Geological survey of Denmark & Greenland) GEUS • National coring dataset (Jupiter) • Marine shallow-geophysical dataset (Marta) • Geodatastyrelsen • Kulturstyrelsen • National Museum database • Scientific literature	• Institute of Geology & Mineral Exploration of Greece (IGME) • Laboratory of Marine Geology and Physical Oceanography of the University Patras • Scientific literature
Construction of Maps-layers	• Geological • Topographic • Satellite imagery (Acquired data) • Orthophotos • Tracklines of previous marine geophysical surveys • Bathymetry • Marine sediment thickness • Location of bore holes • Location of known archaeological sites	• Geological-tectonic • Topographic • Tracklines of previous marine geophysical surveys • Bathymetry • Marine sediment thickness • Seafloor geomorphology • Location of archaeological sites
Examples of maps –layers Constructed	Bathymetric map  	Bathymetric map 

	Tudse Hage	Cape Sounion
	Seafloor sediment map	Seafloor geomorphological map
		
Considerations	All available coordinates of the datasets had to be converted to the same projected coordinate system	• All available coordinates of the datasets had to be converted to the same projected coordinate system • Availability of datasets

Step 2: Collection of datings

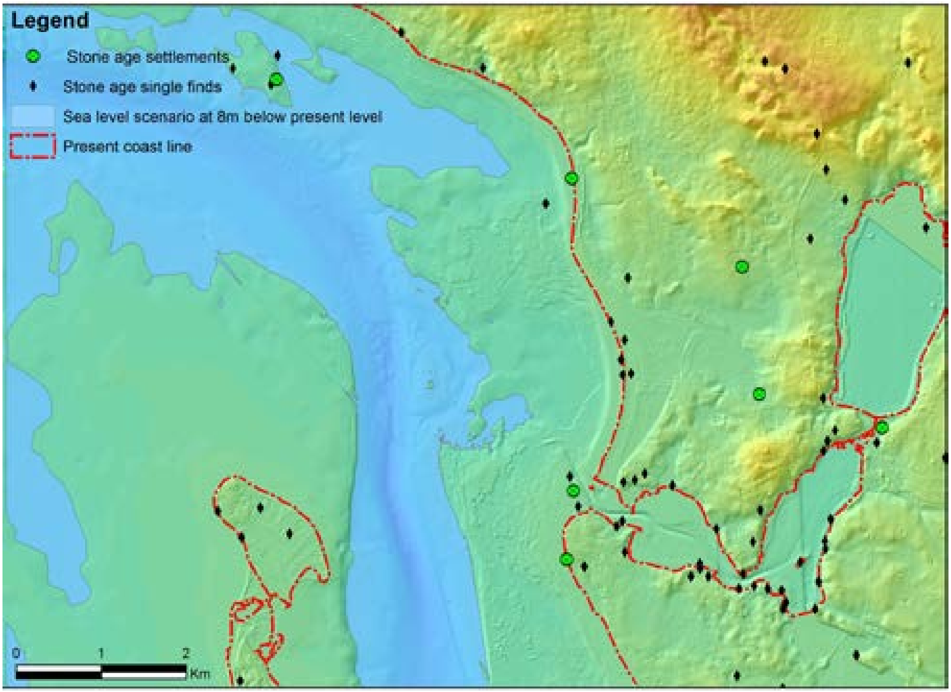
Tudse Hage	Cape Sounion
Existing ^{14}C dates Archaeological data Scientific literature	Existing datings of *Beach rock formations, and of submerged archaeological markers and paleo-coastal markers*
Map of the location of the datings used	Map of the location of the datings used
	
Considerations All available datings had to be calibrated	Considerations All available datings had to be calibrated No available ^{14}C datings from the study area - other sources had to be examined

Step 3: Evaluation of local Relative Sea level Curve (from Step 2)

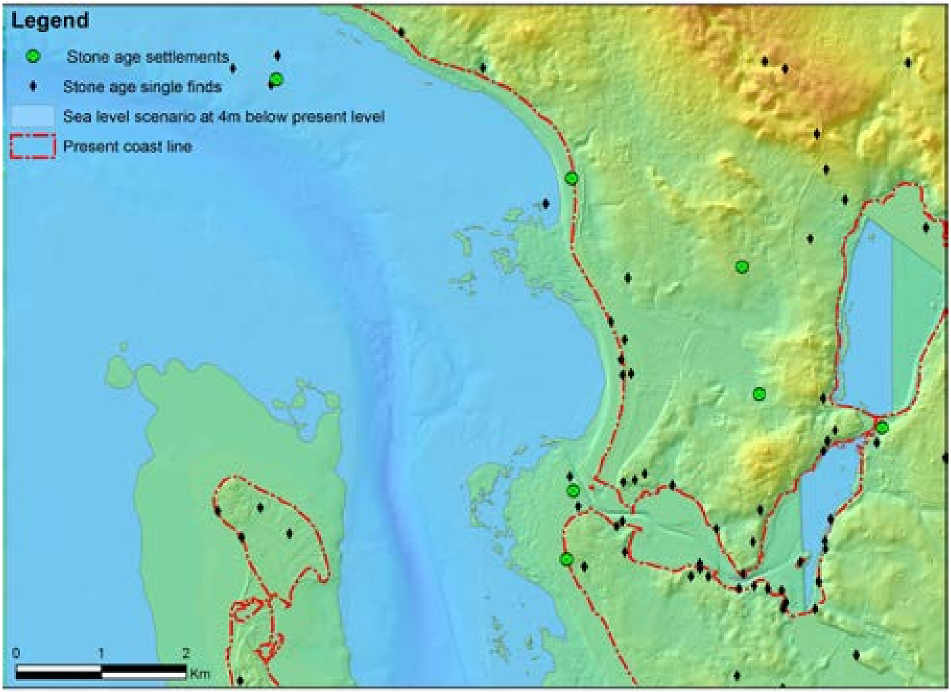
	local Relative Sea level Curves
Tudse Hage	
Cape Sounion	
Considera-tions	The sea level changes in the Tudge Hage region are effected mostly by eustatism, in contrast to those caused by tectonism in Cape Sounion.

Step 4: Construction of possible paleaogeographic coastal evolution –geomodels (Synthesis steps 1 &3)

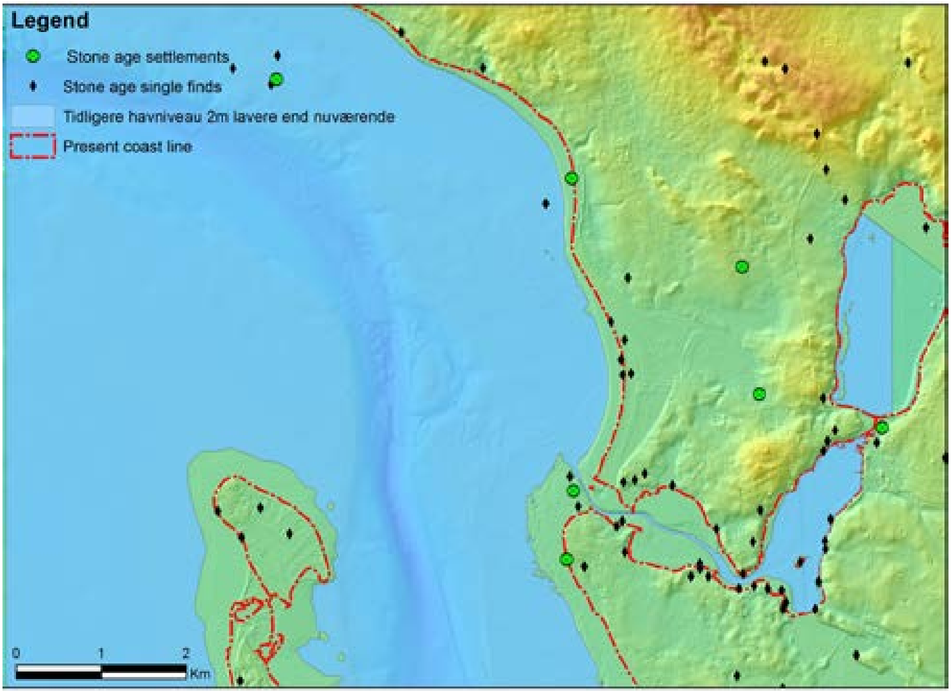
Tudse Hage



Geo-archaeological palaeogeographical scenario 8m below present sea level (~8000calendar years BP)

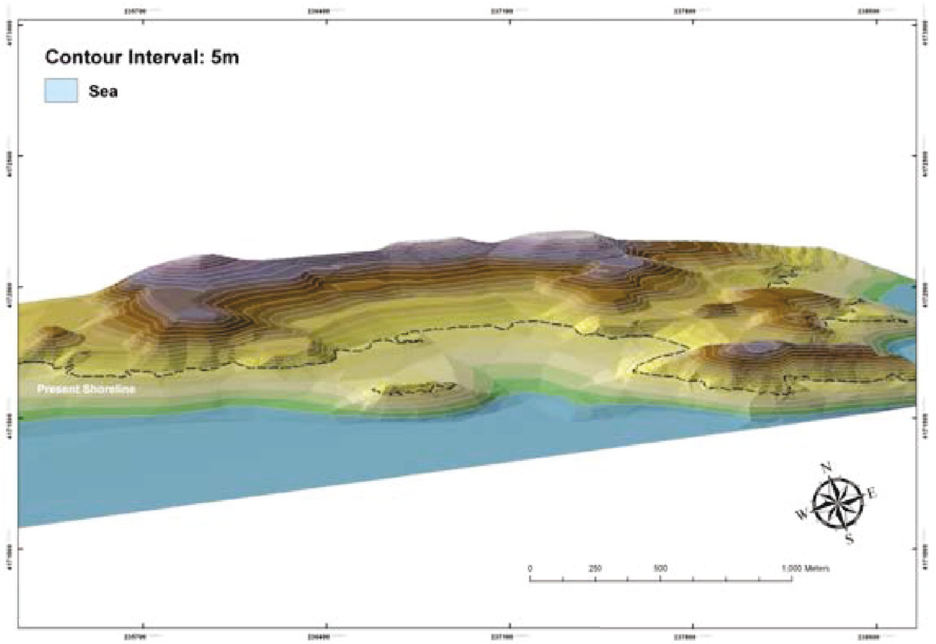


Geo-archaeological palaeogeographical scenario 4m below present sea level (~7700calendar years BP).

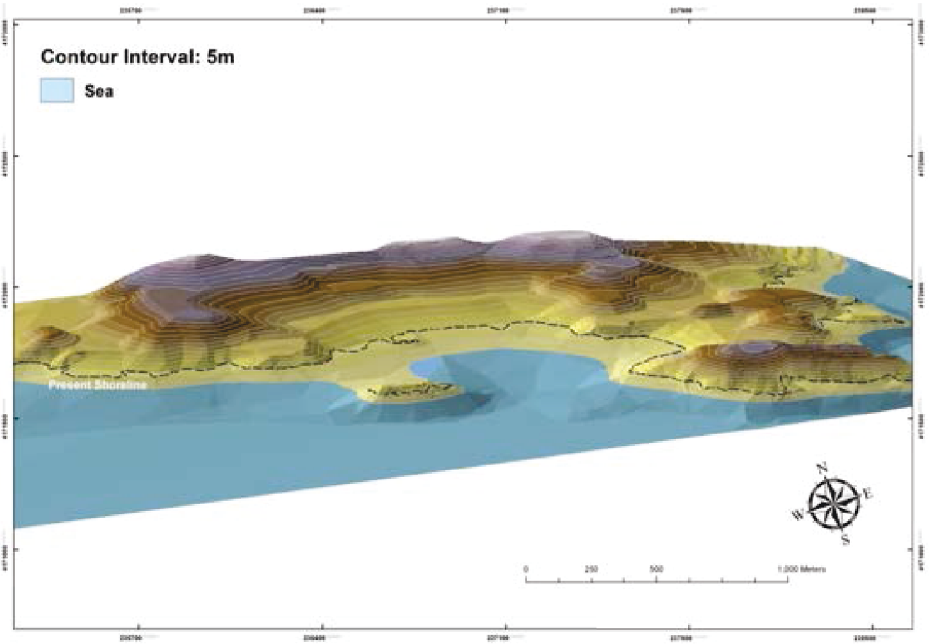


Geo-archaeological palaeogeographical scenario 2m below present sea level (~7400 calendar years BP and possibly ~6800 calendar years BP).

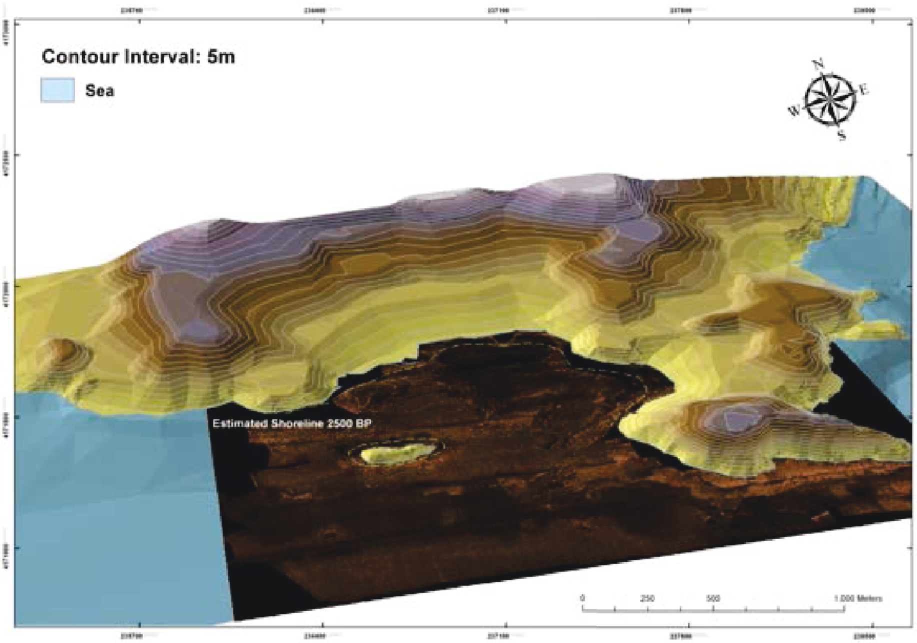
Cape Sounion



Schematic presentation of the study area during the Late Glacial period



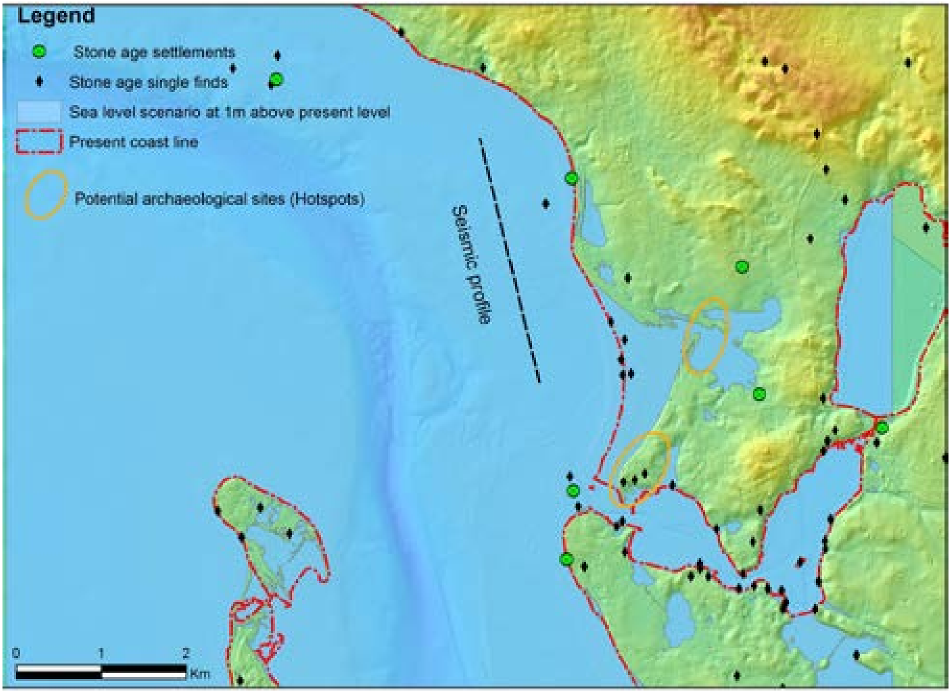
Schematic presentation of the study area at 7000ka BP (sea level: 10m below present).



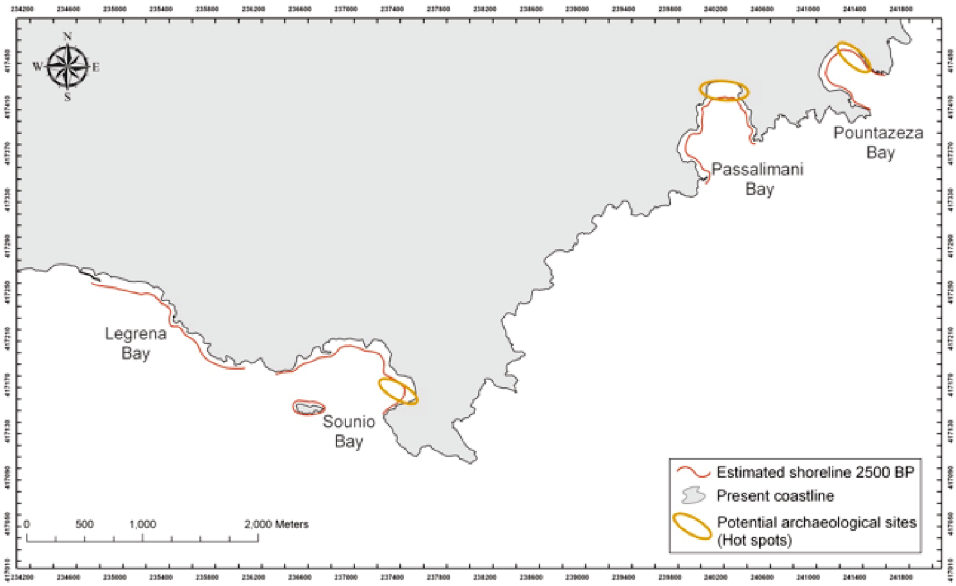
Side-scan sonar mosaic, showing the isobath of -2.5m (white-coloured line) representing the shoreline at 2500 yrs BP

Step 5: Location of potential Hot spot areas

Tudse Hage (Hot spot areas are marked with orange ellipse)



Cape Sounion (Hot spot areas are marked with orange ellipse)



2. Prospection – Best practice examples

INTRODUCTION

If the competent authority decides the desk-based assessment calls for follow-up research, an archaeological prospection will be carried out. The presence of any potential - or expected - archaeological heritage will then be tested. The archaeological prospection will result in an archaeological report, which contains recommendations for any necessary further steps. This chapter presents methods and techniques that are useful in this stage of the archaeological process, as well as a number of best practice examples.

METHODS OF RESEARCH AND BEST PRACTICE EXAMPLES

General methods

Prospection can be carried out in two phases: 1) non-diver prospection with remote sensing, and 2) prospection by divers. The remote sensing methods from the water surface are non-intrusive methods that do not disturb any archaeological remains. Prospection underwater can provide more specified analyses of the archaeological remains, but the seabed will probably be disturbed in order to obtain samples. [18]

Non-diver prospection with remote sensing

Bathymetric data can be acquired by echosounders, such as multi-beam (MBES), single-beam (SBES) and interferometric sonars. These systems have been used in underwater archaeological surveys for mapping, investigating and monitoring seabed topography and detecting potential archaeological sites on the surface of the seabed.

Multi-beam echosounders transmit multiple adjacent narrow beams forming a broad, acoustic, fan-shaped pulse. From each narrow beam, the return signals received from small areas on the seabed will result in a high resolution bathymetry chart of the sea-bottom. The acoustic frequencies of the multi-beam usually range from 70 to 700 kHz. Using higher frequencies will often result in bathymetry with better resolution than the quality obtainable with lower frequencies; however, the range of coverage will be limited. In shallow water, a multi-beam sonar can create an image of the seabed with detail of as much as one depth measurement per 5 cm^2.

The side-scan sonar (SSS) is an acoustic imaging device used to provide high-resolution 2D images of the seabed. They emit acoustic pulses in a wide angle (Swath) and, when received, create a detailed image of the reflectivity of the seabed sediments and its features. The reflectivity depends on the roughness and sediment type of the top layer of the seabed. Hard and compact sediments will have a higher reflection than will softer sediments. The frequencies used often vary from 100 kHz to 1000 kHz, and depending on the frequency, depth and vessel speed resolutions of up

[18] Coring can be done from the water surface and underwater. Coring operations are intrusive, and in some countries require an additional (excavation) permit, even if the work is performed during the prospection phase.

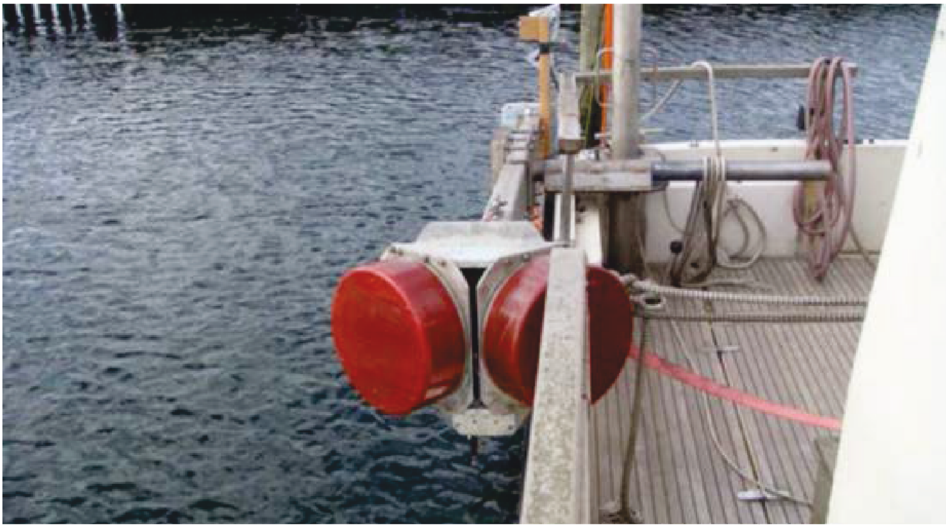


Fig. 2: Example of a MBES system

to a few centimetres can be achieved.[19] Low frequency systems serve to depict information on seabed morphology and broad sediment texture, and are used primarily for general reconnaissance surveys. High frequencies are used in detailed surveys for detection, mapping of the overall seabed morphology and monitoring of possible archaeological sites on the seabed. Mosaicking of SSS data produces an almost photo-realistic picture of areas of the seabed.

Both methods (MBES & SSS) provide images of the seabed features, 2D images from side-scan sonars, and even 3D images from multi-beam sonars, thus enabling researchers to detect features on the seabed. By combining side-scan and multi-beam sonars, a 3D side-scan sonar mosaic can also be produced.[20] These techniques are highly useful for mapping the archaeological features visible on or above the seabed, but are less suitable for detecting most prehistoric submerged sites because of their inability to penetrate sediments. A combination of techniques is desirable: multi-beam and side-scan sonars for the seabed surface, as well as sub-bottom profilers and magnetometers for in the seabed (see below). Interferometer systems can provide multi-beam and side-scan sonar type datasets with relatively high resolution. Both can be operated from small vessels and can currently operate in relatively shallow waters. For more information

[19] For archaeology a minimum of 400 kHz is advised. This is a general statement. Ultimately, the choice will depend on a variety of factors (e.g. water depth, size of archaeological target, texture of the target)

[20] http://www.km.kongsberg.com/ks/web/nokbg0397.nsf/AllWeb/AE0A2B345BA57F70C1257306003C313F/$file/US_HYDRO_2007_lr.pdf?OpenElement

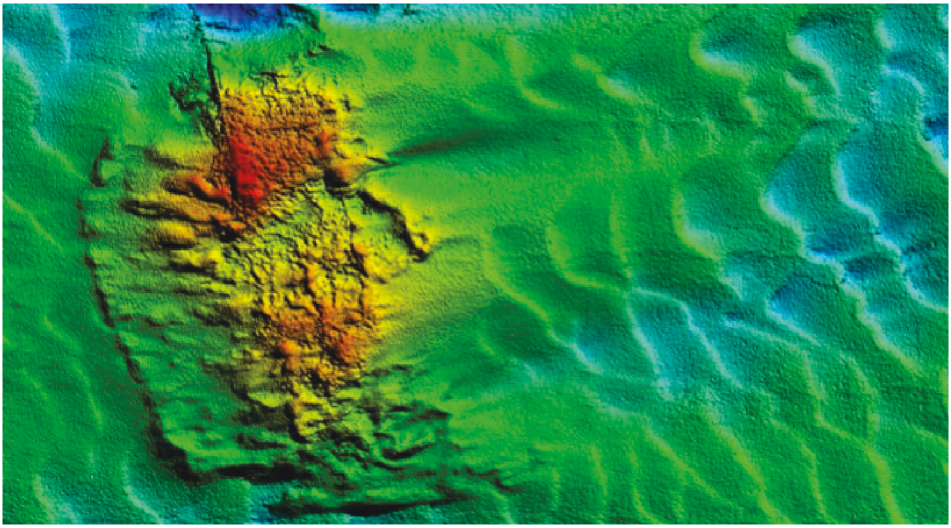


Fig. 3: Multi-beam image of the Burgzand Noord 3 wreck site. Source: RCE

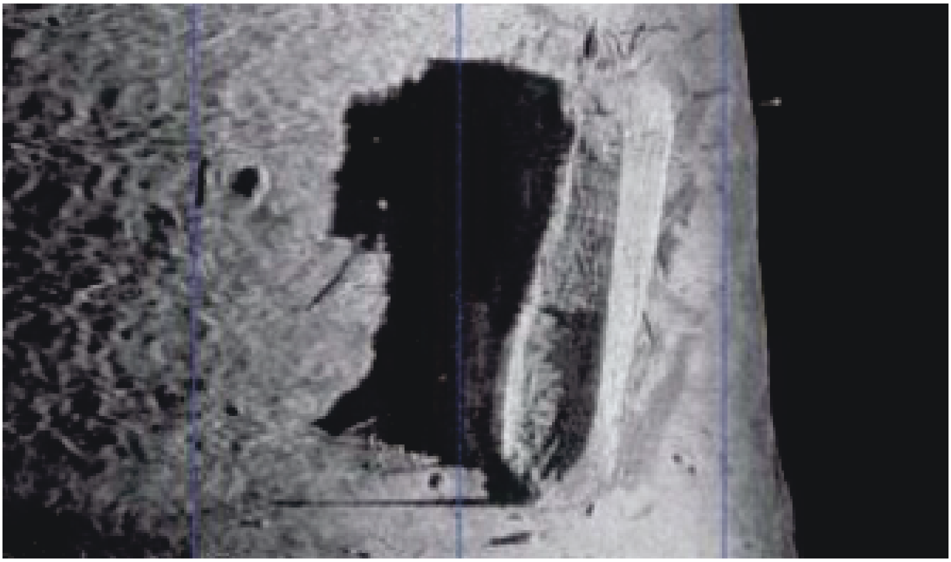


Fig. 4: Side-scan sonar image of the Anna Maria wreck. Source: SMM

about archaeological prospection with multi-beam and side-scan sonars, see for example, Quinn et al., 2005, and the Rasse project[21].

While side-scan, multi-beam and single-beam sonars are used for mapping the seabed, it is also possible to gain information from within the seabed sediment. This can be done by marine magnetometers, which measure the intensity of the Earth's ambient magnetic field. Their application in geophysical prospection is founded on the principle that they can measure and record deviations from the earth's magnetic field due to the presence of ferromagnetic material. In underwater surveys, they can be used not only for detecting metallic objects but also any materials producing magnetic anomalies, such as ancient shipwrecks and submerged harbours. Marine magnetometers have been used mostly for the detection of possible metallic objects at known archaeological sites and for the detection of buried archaeological sites of large scale. Given that not all underwater archaeological sites contain metallic objects, the use of a magnetometer should always be accompanied by another non-intrusive prospection method, such as multi-beam or side-scan sonars. For the use of a magnetometer as a prospection method, see Camidge et al., 2010.

A sub-bottom profiler system emits acoustic pulses in the form of acoustic conical beams. These beams produce images of the shallow sub-bottom succession of layers based on the seismic reflector's characteristics. This system thus provides the stratigraphy of the seabed. The interpretation of the seabed stratigraphy will be used to construct the area's geological evolution scenario, and potentially to detect buried archaeological objects. A good example of the application of this technique occurred in a research campaign by the National Museum of Denmark, where it was used in detecting archaeologically valuable buried artefacts in the waters of Denmark's Haithabu Viking settlement. In that case, a wreck completely covered by sediment was discovered using a 2D sub-bottom profiling system. For more information, see Grøn and Boldreel, 2014, or Missiaen et al., 2009.

Prospection by divers

Prospection underwater usually requires divers. Although a diving inspection is time consuming, and is therefore often unsuitable for large areas, it will give archaeologists the opportunity to (visually) examine archaeological remains in context. Quick analyses can be done to identify the nature of the site: whether it is a wreck, consists of a wooden construction, or offers a rough estimation of its age and condition. When a diver is at a site, samples can be taken for further research, including of the sediment. Such sediment samples can be used for characterizing the open water and burial environment and obtaining palaeo-environmental data, (e.g. pollen, macrofossils) all of which become useful in the later process phase of the archaeological significance assessment. A variety of techniques are

[21] http://www.st-andrews.ac.uk/rasse/

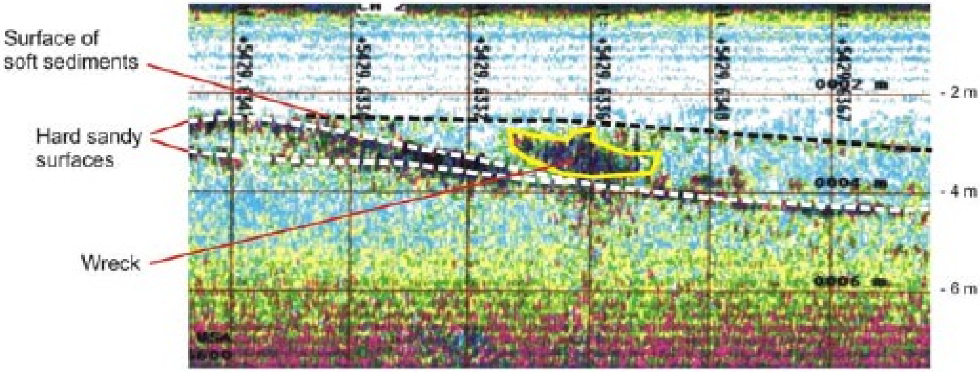


Fig. 5: The Haithabu wreck found by using a sub-bottom profiling system.

available for sediment assessment, ranging from “grab” samples to sediment cores with various devices. The downside of sediment sampling is that the original structure of the sediment may potentially be lost, depending on the method used. Some devices may preserve the original structure and possible stratigraphy in the core. However, sampling is always intrusive for the site itself. A diver-held sediment sampling device has been developed in SASMAP, and the results are discussed in detail in Section 3 on Archaeological Significance Assessments. Keeping in mind the intrusive nature of core sampling, some measurements can be taken in situ. In SASMAP, an in situ sediment profiler was also developed in order to characterise the nature of the burial environment in terms of its effect on the preservation of archaeological material. The results of this are discussed in more detail in Section 4.

Further to environment / sediment sampling, archaeological materials at the site should be assessed during this phase of the archaeological process. For example, waterlogged archaeological wood is one of the most frequently encountered materials in underwater archaeological sites, and sampling wood objects to gauge their state of preservation *in situ* can be advantageous. This type of advance knowledge makes it possible in excavation and lifting operations to determine the best course of action. For instance, should a shipwreck, poles or structure, be raised and subsequently conserved, or are the objects strong enough to withstand *in situ* preservation? Development of a diver-held device to assess the state of preservation of waterlogged archaeological wood was also developed in SASMAP and is discussed in Section 3 on Archaeological Significance Assessments. Wood may be sampled not only for its state of preservation, but also to determine the age of a site. This can be an important parameter in deciding whether or not to further investigate a site. Besides Carbon 14 dating, dendrochronology is currently the most common method of dating archaeological wood, especially in a European context.[22]

New developments for prospecting

Mapping and monitoring of an archaeological site is necessary in determining its location and extent, and in assessing its physical stability. Remote sensing techniques are one of the most cost-effective tools for regional scanning of the seabed surface sediments and their morphology, as well as for assessing the physical stability of archaeological sites. State-of-the-art satellite imagery techniques have been used in SASMAP to monitor changes in coastal morphology and sediment transport in shallow water environments (up to depths of 6-8 metres). Side-scan sonars, sub-bottom profilers, magnetometers, and single- and multi-beam echosounders have been used in underwater sites to locate and map archaeological sites both on and within the seabed. Although the use of these tools is not new to marine archaeology, further development of these existing technologies has been one of the significant impacts of the SASMAP project. By contrast, 3D shallow seismic is a cutting-edge method and, together with other new technologies developed in the project, will provide detailed 3D imagery of archaeological sites and their environs. Prospection facilitates more thorough site investigations, and enables divers to gauge potential natural threats, examine the kinds of materials present and take samples of archaeological materials or deposits as part of the archaeological significance assessment.

LiDAR

Although not used in the SASMAP project, airborne Light Detection And Ranging (LiDAR) systems are another relatively new technique that can be employed. This technique uses laser pulses emitted from an aeroplane, to measure the elevation of the terrain. In underwater archaeology, this technique is used mainly for bathymetry measurements, and is called Airborne LiDAR Bathymetry (ALB). Bathymetry measurements make it possible to detect archaeological heritage based on the spatial variation in seabed morphology (very similar to the multi-beam output dataset). Although the technique may not yield resolutions as high as multi-beam images, it makes it easier to survey larger areas in less time. Nonetheless, the operational and processing costs are relatively high. It should be noted that LiDAR can only be used in waters up to 50 meters in depth. For more information about the use of LiDAR in underwater archaeology, see the research study in Brazil[23], or Doneus et al., 2013.

Remotely operated vehicles and autonomous unmanned vehicles (ROV & AUV)

These platforms can support a wide range of sensors and equipment, and can provide real time visual identification of the seabed (ROV). AUVs can be used for location identification of areas with potential archaeological sites. Although AUVs are not yet routinely used in

[22] In Europe, millennia long dating curves have been observed, especially for oak. However, curves for a few other wood types are also available. See http://dendro.dans.knaw.nl/ . Consequently, this is the number one current method for dating shipwrecks from Roman to modern times.

[23] http://www.ideatrophy-freudenberg.com/page/images/uploads/ideas/media/59e82c.pdf

underwater archaeology, the EU-funded Arrows project[24] has sought to develop this technology for archaeological purposes.
Remotely Operated Vehicles (ROVs), using operators on the surface, eliminate the constraint on the bottom time of divers and can offer good visualization of the seabed and exposed archaeology. Robotic vehicles are often used for seabed surveys in deep water. They do have limitations in what they can achieve and are expensive to use. They are also less effective with heavy current. Moreover in deep water surveys, they require deployment of a dynamically positioned support ship, which is also expensive.

New developments from SASMAP

The prospecting activities in SASMAP were designed to localise and map potential underwater archaeological sites, especially those close to coastal zones. To achieve this, conventional and innovative remote sensing techniques were used in two areas of archaeological interest: Cape Sounion (Greece) and Tudse Hage (Denmark). Cape Sounion's site consists of structural remains from a naval base that Athenians had built to protect the metropolis of Athens in the 5th century BC. The Tudse Hage site features the well-preserved remains of Mesolithic settlements. Both areas are near the shore and contain differentials in seabed substrates, ranging from rocky to fine-grained organic sediments, thus providing an opportunity for testing the total approach in different environmental and archaeological regimes.

[24] http://www.arrowsproject.eu/

Subsequent surveys with conventional remote sensing techniques were conducted in the two case-study areas. These non-destructive methods utilised a variety of echosounders to acquire bathymetric data, a variety of sub-bottom profilers to examine seismic stratigraphy within the seabed and detect potential archaeological sites. In addition, a variety of side scan sonar systems were used to examine the seabed texture and detect potential archaeological sites lying on the seabed. A marine magnetometer was employed to examine possible magnetic anomalies. Processing of all the datasets, together with the bathymetric data revealed from the satellite imagery, led to the development of GIS maps. The GIS environment facilitated comparison, combination and synthesis between the multi-faceted datasets. This, in turn, enabled a seamless examination of the seabed from the coastline to a long distance away (horizontally/spatially) and over a long period of history (temporally) from the present to several millennia in the past (vertically). The establishment of the GIS database appears to be fundamental in the studies and management of underwater cultural heritage. The synthesis of all the multidisciplinary datasets in one platform can provide information regarding the local sedimentary/geological regime, and thus enable assessment of the area's physical and geochemical stability. Furthermore, the datasets in the GIS environment are capable of renewal and restoration. This, in turn, provides information useful for evaluating possible local erosion, a process that typically occurs in the dynamic environment of coastal zones. All of the above are considered prerequisites for

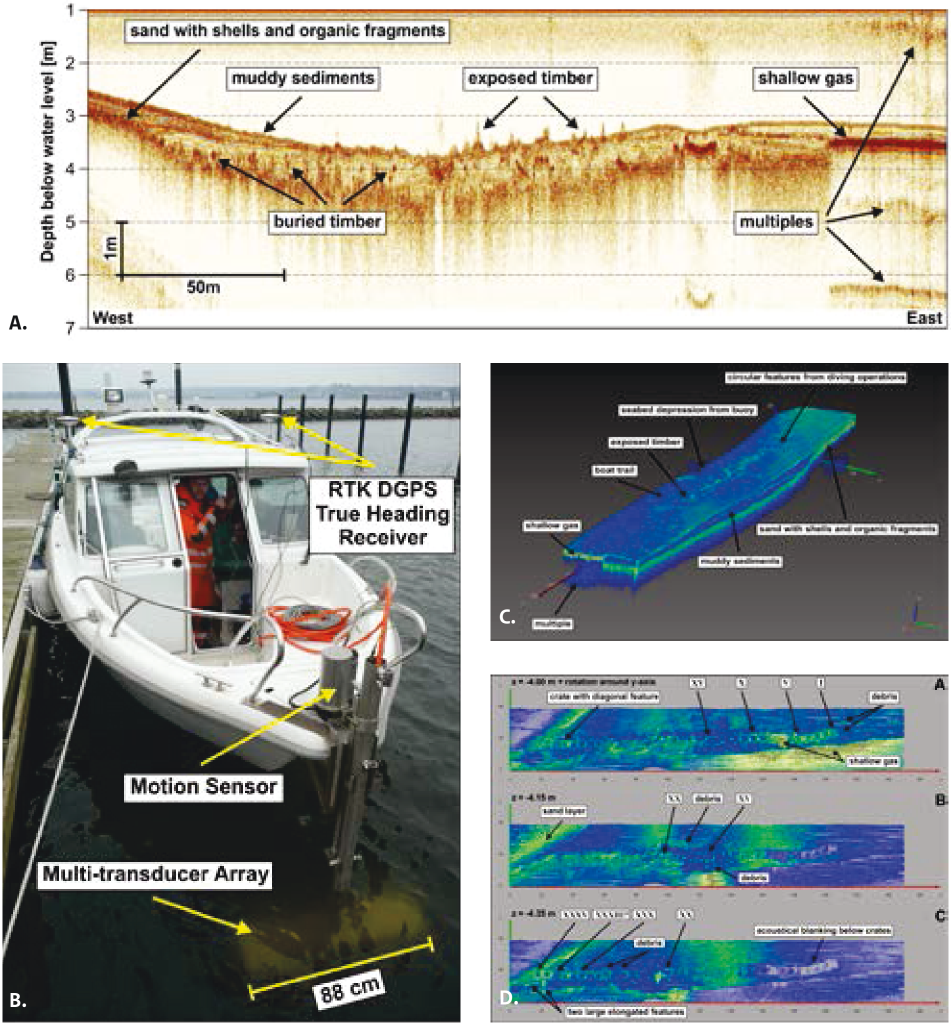


Fig. 6A: Parametric sub-bottom profiler seismic section from the central region of the study area near Schleswig (Northern Germany) showing several reflectors caused by sediment boundaries, a locally confined (South East) high amplitude reflector caused by a shallow gas layer, numerous small diffraction hyperbolas and some short linear reflectors caused by exposed and buried objects. Time to depth conversion was performed with a constant velocity of 1500 m s-1. Vertical exaggeration = 16:1.
Fig. 6B: Setup of acquisition hardware with SES-2000 quattro transducer array, motion sensor and dual-antenna RTK DGPS mounted on the survey boat.
Fig. 6C: 3D visualization of gridded data set showing the coloured and shaded sediment floor, some lateral seismic reflectors, exposed rectangular and irregular reflectors above the sediment floor, linear features probably caused by boats (keel marks) and circular features caused by divers during recent archaeological investigation (ground search pattern). Axis labels are metric and relative to the lower left corner of the study area.
Fig. 6D: Time slices through the volumetric data set at increasing depth (A to C). Axis labels are metric and relative to the lower left corner of the study area. Interpreted wooden crates of Viking age barrier structure are numbered with Roman numerals starting in the East.

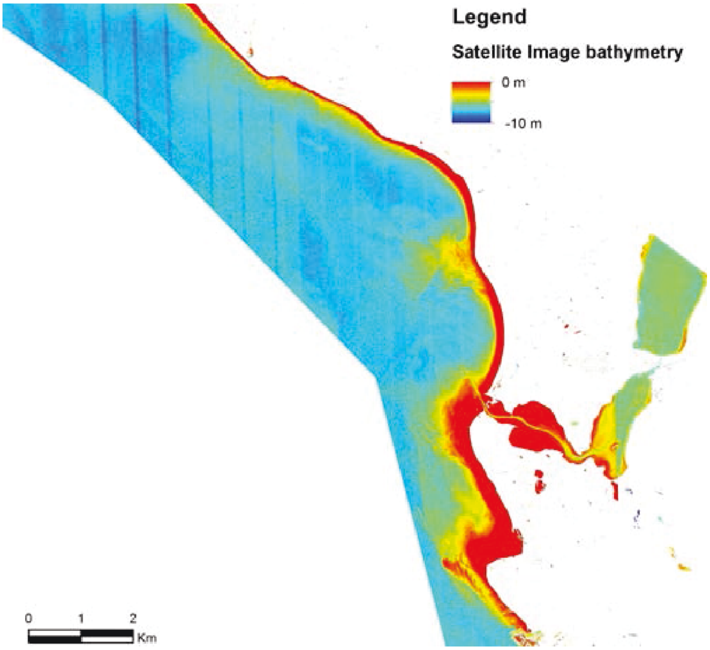
the development of management strategies for underwater cultural heritage sites. Should these be adopted at a European-wide level, they will provide heritage agencies with powerful tools to help in planning subsea/coastal development projects in accordance with the Valletta Treaty/ Malta Convention.
Parallel to these activities, Innomar[25] designed and developed a prototype sub-bottom profiler capable of acquiring high resolution profiles from very shallow waters, which after processing could provide 3D sceneries of the sedimentary environment and potential buried archaeological remains. This cutting-edge technology is expected to be beneficial not only in underwater archaeological studies, but also in marine studies focusing on coastal reconstructions (i.e. harbour installations), marine-protected areas (ecosystems and habitats) and more generally, in studies and research requiring the highest resolution results in the shallow waters. This technique was trialled at six different sites and proved effective at all of them. For more information about this interesting development, see SASMAP Work Package 2.[26]

Submerged coastal remains were detected in the Greek gulfs of Sounion and Pasalimani. The combination of GIS maps provided evidence for the foundation level of the ancient coastal installations, as well as for the passages for approaching the ancient ship shed at the Athenian naval base located in Cape Sounion and those for approaching the coastal structures of the ancient Pasalimani gulf. Similarly, in Tudse Hage, seamless morphological maps and geological models developed on a GIS platform provided accurate coastal and seabed reconstructions of the past, thus providing evidence useful in detecting potential Mesolithic settlement sites. In addition, surveying with the SBP prototype provided detailed evidence of the sedimentological patterns of each study area, and thus of the palaeogeographic evolution of these areas. However, the most remarkable achievements of this device were the detection and the 3D mapping of submerged and buried archaeological remains, which featured variations in size, material and age.
The results show that seamless and integrated maps produced in a GIS environment (see also Desk-based assessment), which can be continually updated and compared, are a powerful tool for determining seabed stability and monitoring and hence for managing submerged cultural heritage sites.
The basic steps developed in the SASMAP project, illustrated by the case studies, are briefly shown below. See SASMAP Work Package 2, for more information[27].

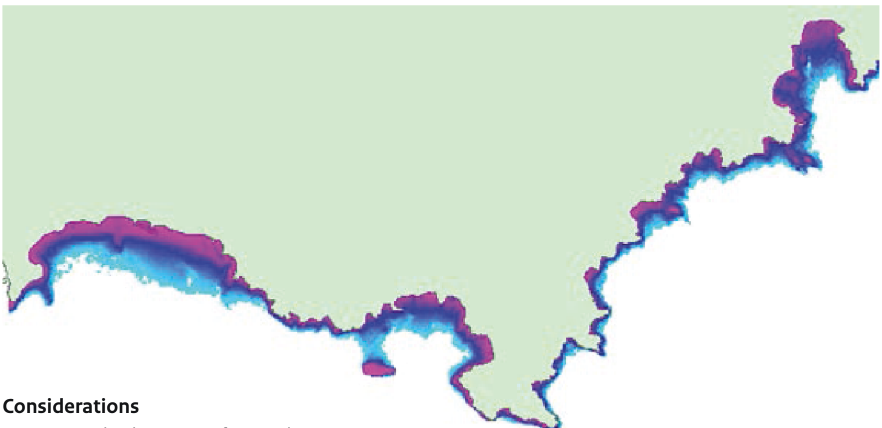
Step 1.a. Airborne remote sensing techniques
The downscaling concept started with the acquisition and use of satellite and orthophoto images for mapping morphological features and generating bathymetric estimations of the shallow, near-shore zone.

[25] www.innomar.com
[26] www.sasmap.eu
[27] www.sasmap.eu

Tudse Hage



Cape Sounion



Considerations

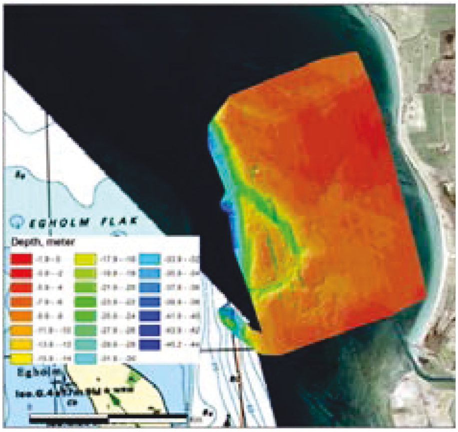
- Low-cost bathymetry of near-shore areas.
- Effective primarily at water depths, where there is no vessel accessibility.
- Waves, clarity and seafloor texture can reduce the effectiveness of this technique

Step 1.b. Acoustic remote sensing techniques

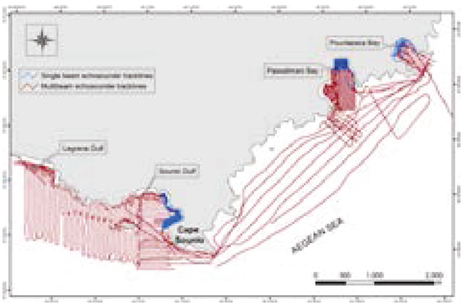
Acoustic Bathymetry-- use of MBES (Multi-beam echo sounder) and SBES (Single-beam echo sounder)

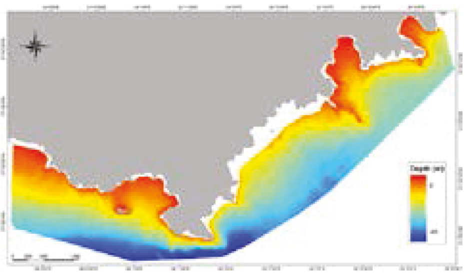
Maps of Tracklines	Bathymetric maps

Tudse Hage



Cape Sounion





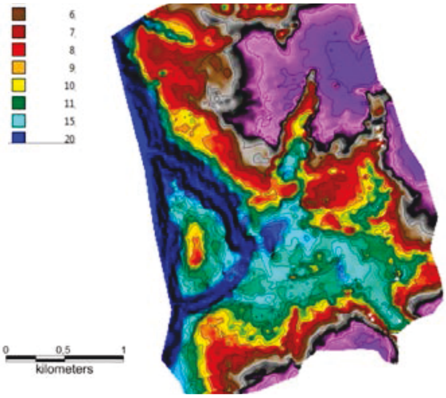
Considerations:

Track lines of MBES have to follow a grid designed to achieve overlapping of the acquired data. The coverage of the acquired data depends mainly on the swath range of the device, together with the water depth. The effectiveness of MBES may be reduced in very shallow waters (depending on the type of the device and size of the vessel). If appropriate, SBES should be used instead.
Positioning and navigation system must be extremely accurate (i.e. RTK)

Sediment profiling- use of sub-bottom profilers

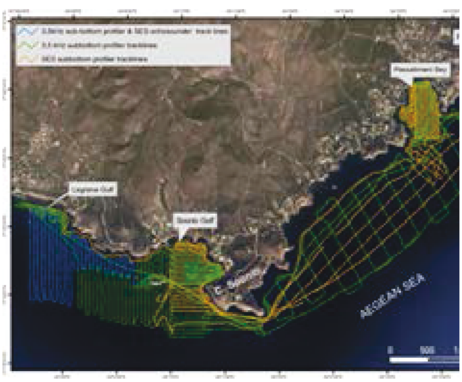
Maps of Tracklines	**Maps of sediment thickness**

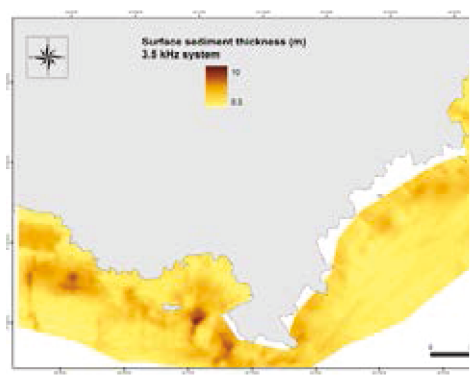
Tudse Hage



Glacial surface depth

Cape Sounion

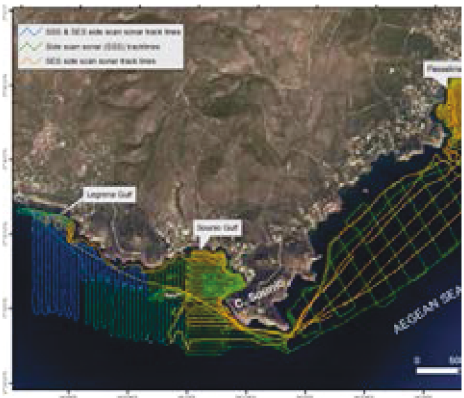
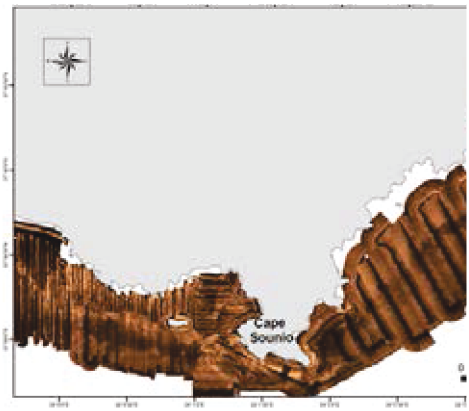




Considerations

If the aim of the survey is to focus on coastal evolution, the tracklines of the profiling must include lines vertical to the present coastline. Low operational frequencies are used in deep waters, and high frequencies in shallow waters. The effectiveness of the method may be lower in shallow waters due to multiple echoes. Line spacing should be chosen based on the type, size, and spatial extension of the archaeological site under investigation.

Side scan sonar

Maps of track lines	SSS mosaics
Tudse Hage	
	Acoustic seabed image Grass Mat image 
Cape Sounion	
	

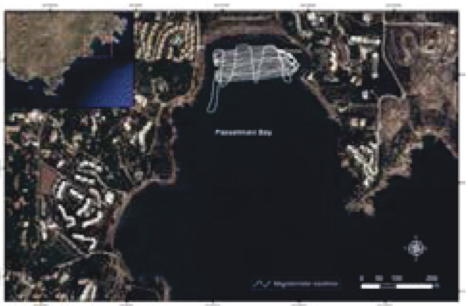
Considerations

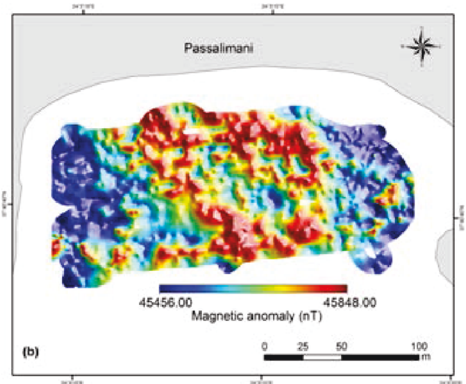
Tracklines of side scan survey should follow a grid designed to achieve overlapping of the acquired data. Low operational frequencies are used to examine seafloor texture, and high frequencies for detailed mapping (i.e. archaeological sites).

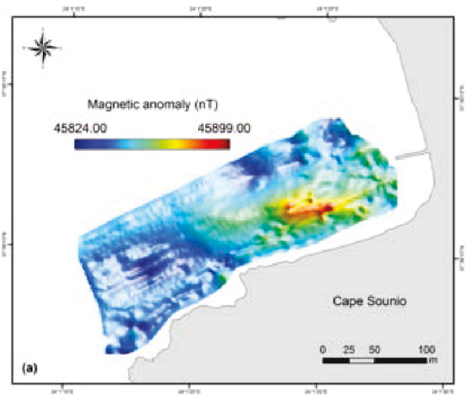
Marine magnetometer

Maps of Track lines	Maps of magnetic anomalies

Cape Sounion



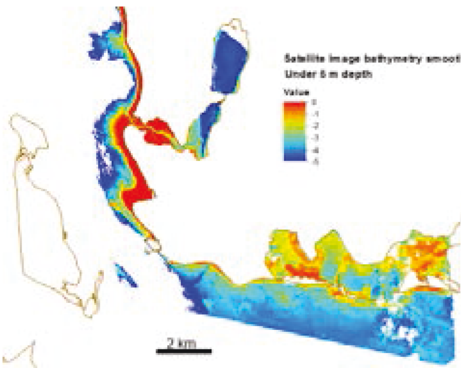
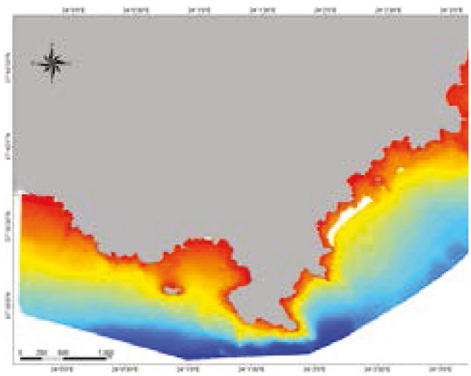




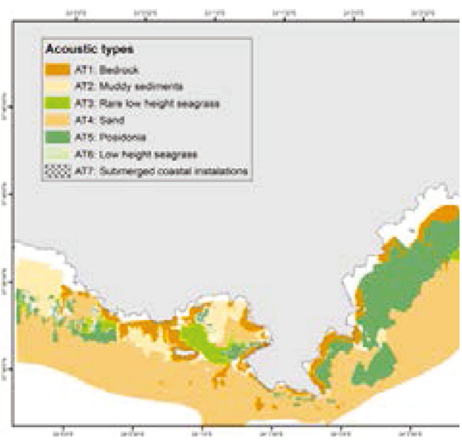
Consideration

Processing and interpretation requires special attention and a skilled operator, due to different variables affecting the acquired data. Contaminations of the signal are very common.

Step 2. Construction of seamless GIS maps of horizontal and vertical integration

Synthesis of satellite and acoustic bathymetry produced a seamless GIS bathymetric map for the areas examined.	
Tudse Hage	**Cape Sounion**
	

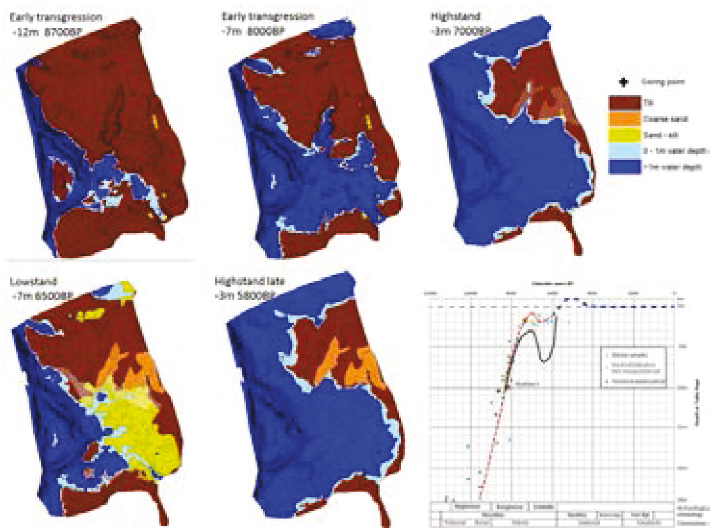
Synthesis of profiling and side-scan sonar data produced a geomorphological map providing information for the seafloor texture, and at the same time for the seismic stratigraphy.



Step 3: Location and identification of underwater archaeological sites

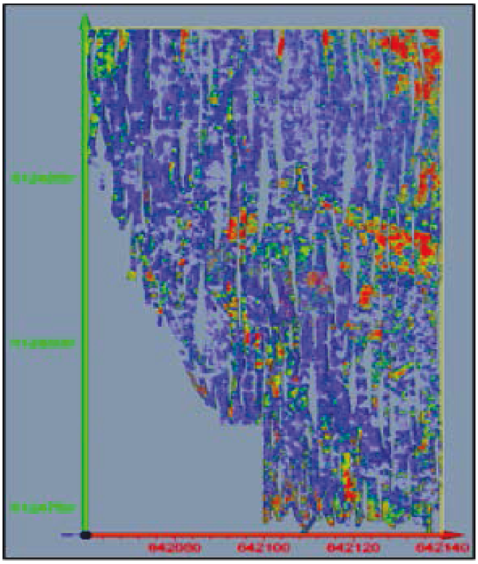
Tudse Hage

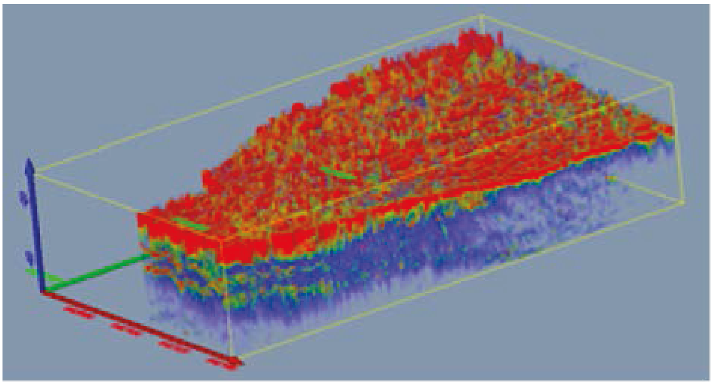
Paleo-morphological maps of Tudse Hage area. Maps represent sea level depths that correspond to different time intervals.



Locations of cores for ground truthing and datings. Red boxes represent 3D seismic survey locations.

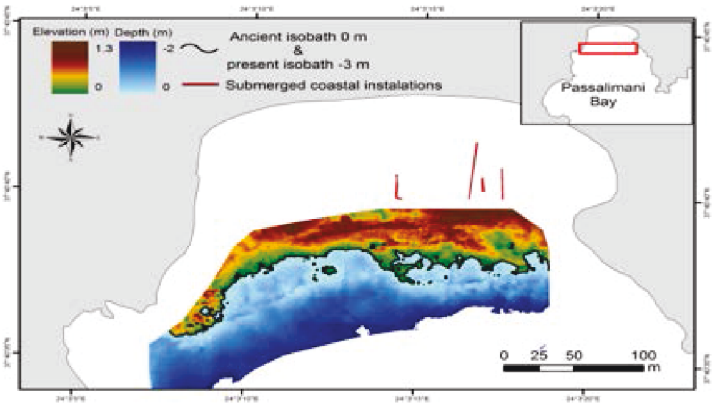
3D prototype SBP (innovative technique) Location of buried potential artefacts and environmental parameters at the archaeological sites



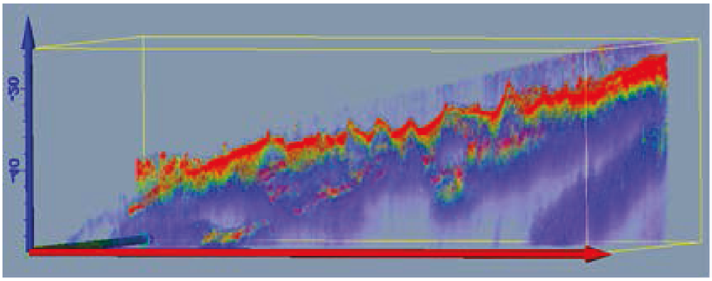
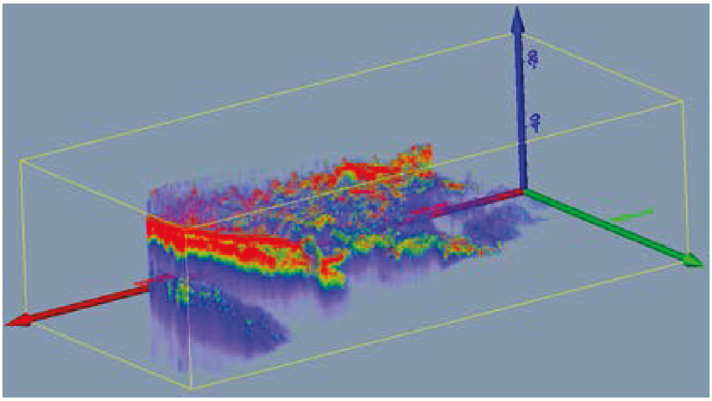


Cape Sounion

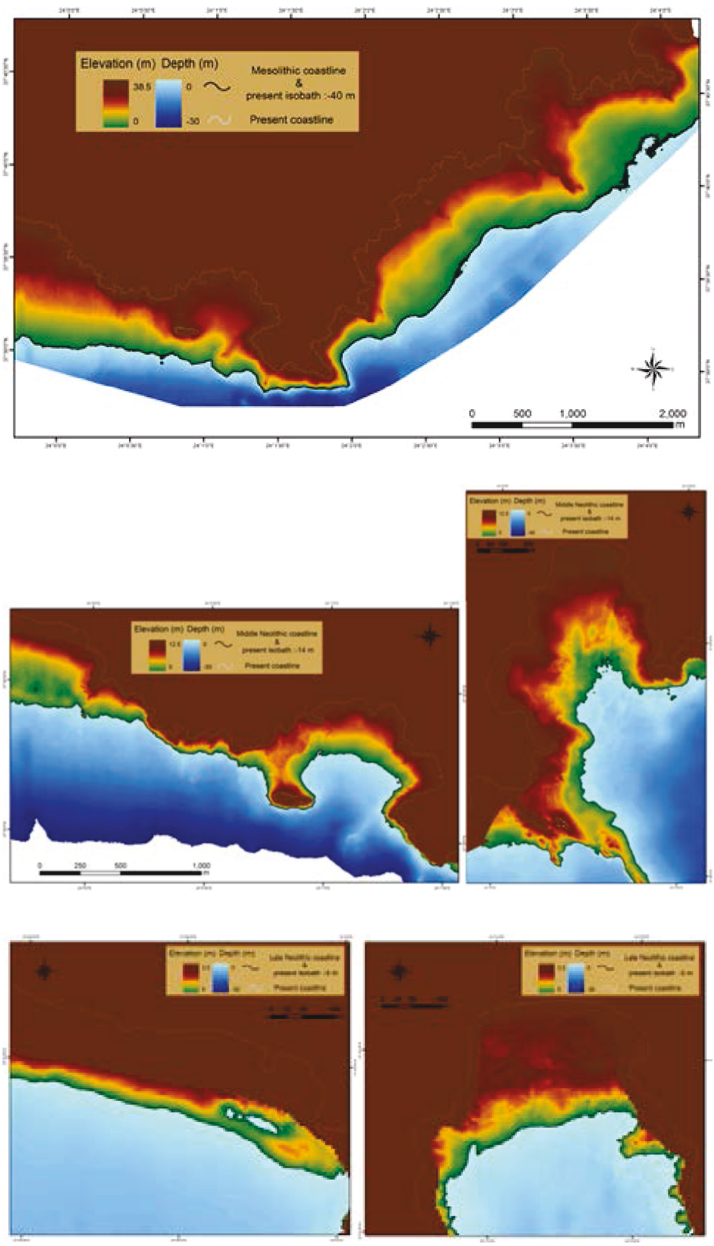
Location and mapping of the coastal zone of the 5th century BC



Detection, location, mapping and visualization of surficial archaeological sites

3D prototype SBP (innovative technique) Location of buried potential artefacts and environmental parameters at the archaeological sites	 

Map of the coastal zone configuration at time intervals of the Lithic period.



3. Archaeological significance assessment – Best practice examples

INTRODUCTION

Once archaeological remains have been detected and localised during prospection, the next step is to assess the archaeological value or significance of the site. This is called a significance assessment and is carried out for site evaluation purposes. The main focus of this part of the process is to determine whether archaeological remains are valuable, and what should be done with archaeological remains that are in danger of being disturbed. However, as part of this assessment, the physical, chemical and biological conditions of the site and artefacts (material types) should also be taken into consideration. For more information about the significance assessment in the archaeological process, and its importance, please read Guideline Manual 1. This chapter presents the methods and techniques that are suitable for significance assessments, and explains how these methods can be used to assess sites.

METHODS OF RESEARCH AND BEST-PRACTICE EXAMPLES

General methods

Assessing archaeological significance

A survey by diving archaeologists is the most common standard way to assess the archaeological significance of a site. A diver can see small objects on the seabed and can directly recognise important features of a site, such as key information about a ship's construction. It is also possible for divers to inspect the archaeological remains for deterioration and decay. The diver can then assess, perhaps in combination with sampling, if the site is worth protecting, should be excavated or can be dismissed as an archaeologically insignificant site. While intrusive techniques, such as test trenches, coring and cleaning, are available for site assessment, it should be noted that some intrusive techniques require an excavation permit (even if it is part of the significance assessment process step).

Standard information that should be collected during a significance assessment of a wreck site is information about the:

- Provenance
- Representative value
- Rarity/uniqueness
- Condition/completeness
- Interpretive potential
- Capacity to inform us about the past

Intrinsic value:

- Potential to yield important information
- Association with important events or people
- Distinctive characteristics of a period
- Representative value
- Social or spiritual significance
- Significance in experience aspects
- Economic value in the present and future

In an effort to compare different sites with each other, the significance of a site may be rated, based on the above subjects.
The significance assessment for underwater sites in the Netherlands is done through a

Value	Criteria	Scores		
		High	*Middle*	*Low*
Experience	Beauty	Will not be scored		
	Memory value	Will not be scored		
Physical quality	Completeness	3	2	1
	State of preservation	3	2	1
Archaeological aspects	Rarity	3	2	1
	Information value	3	2	1
	Assemblage value	3	2	1
	Representative value	Will not be scored		

scoring system like the one above[28]:

Assessing the significance of change

The state of the underwater environment and sediment are crucial factors in determining the preservation status of the archaeological remains. By understanding the nature of the environment and the processes in the environment that can affect the preservation / deterioration of the site's archaeological materials, it is possible to assess how conducive the site's environment is to preservation. Effectively, an underwater archaeological site and its component parts will be exposed to two very differing environments – the open sea water and the sediments of the seabed.
In the open sea water, physical processes, namely scour and biological processes, are the major causes of deterioration in wooden and organic materials. For more on the role of scour on underwater shipwreck sites, see for example Quinn, 2006. Important factors controlling scour are the presence and strength of water currents and the type of seabed sediments (clay, silt, sand and gravel). Effectively, these two parameters - along with the nature of any solidly standing structures on the seabed - will determine both the likelihood of scour occurring and its nature. Often, remote sensing techniques, such as side-scan and multi-beam sonars can be used to assess sediment transport and scour by examining the form of the seabed: sand waves and ripples are caused by sediment transport, and thus indicate that the area is dynamically active. Other parameters can also be studied to better understand the processes of sediment transport. In determining the likelihood of sediment transport, it is useful to take samples of the sediment in order to classify the sediment types present and their degree of sorting, along with measurements of the water currents (velocity).
Apart from the physical process of scour, biological organisms in the open water environment are the main threat to organic archaeological materials, such as wood. These organisms have specific tolerances to the level

28 http://www.sikb.nl/upload/documents/KNAwaterbodems32/Deel%20II%20bijlage%20IV%20wb%20Waarderen%20van%20vindplaatsen%20versie%203.2%20definitief.pdf

Parameter	a) Scenario I	a) Scenario II
Temperature (°C)	≥ 12	≥ 11
Salinity (PSU)	≥ 8	≥ 8
Oxygen (mg O_2/l)	≥ 4	≥ 4

Lowest tolerance limits for three environmental parameters used as classification criteria for the Teredo Scenarios in the GIS model.
a) Scenario I: possible reproduction by adults and metamorphosis of larvae
b) Scenario II: possible reproduction by adults

of dissolved oxygen, salinity, temperature and other nutrients in the seawater, and can be measured in samples of seawater, or can be monitored, using automatic logging equipment (dataloggers) to determine if the conditions are conducive to their growth and survival. One such organism, the shipworm, *Teredo navalis*, is presented in the table above, along with the conditions for the survival of larvae and adults. More information about this organism is available from the EU-funded project Wreck Protect[29]. A good supplementary method for measuring these parameters is to use sacrificial samples of material to see if they will be attacked. This has often been done with wood objects to determine physically whether they would be attacked. See, for example, the work done in the EU-funded MoSS project.[30]
In optimal conditions for wood borers, wood can become totally degraded within a matter of months or years, rather than centuries. Wood borers will effectively weaken the wood and when strong currents are present the wood can easily be broken away.
However, should the site be covered by sediment, as a result of sediment accretion rather than erosion, the processes of deterioration are predominantly microbial. Deterioration of wood will be mediated through the action of microorganisms (fungi and bacteria), which can be active in the near anaerobic conditions typically found within marine sediments and within the wood interior. Buried waterlogged environments provide unique conditions for organic materials, such as wood, bone, antler, textile, skin and plant remains to be preserved for millennia, partly due to the low oxygen levels. Microbial deterioration in marine sediments is caused to a certain extent by fungi, which can survive in environments with limited amounts of oxygen. However, deterioration is predominantly caused by bacteria and is a very slow process; in the right circumstances, organic archaeological materials can survive for tens of thousands of years[31]. Assessment of archaeological materials often has to be done through laboratory analysis of samples taken from the site as part of the dive assessment. Optimally, and as with all assessments of the environment, it is desirable that as much assessment as possible be carried out in situ by a diver, or using other, automated systems. This is what SASMAP has focused on, and the development of automatic and diver-held tools to assess the environment and archaeological wood will be discussed.
Although repeated in the monitoring process

[29] www.wreckprotect.eu
[30] http://moss.nba.fi/
[31] Björdal, 2000.

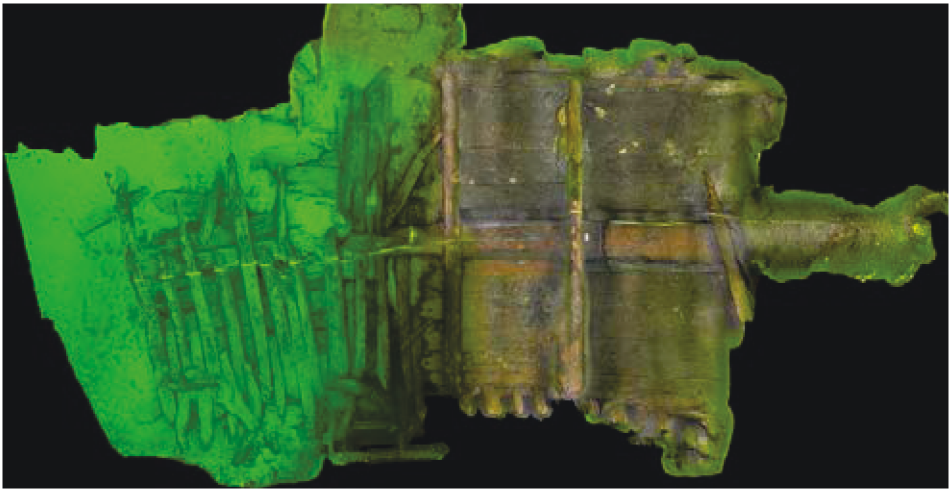


Fig. 7: Computer Vision Photogrammetry image of the Dutch Straatvaarder wreck.

step, the environment should be assessed during the significance assessment, as well as the likelihood of future change. A basic set of parameters serve as a baseline study with which to compare future monitoring data.

To assess the significance of change, or in other words, the effect change would have on the significance of a site, the following should be investigated:

- Dynamics of change
- Beneficial/ neutral/adverse
- Permanent/temporary
- Process of change
- Sources (causes) of change
- Direct/indirect
- Synergistic/cumulative
- Outcomes of change
- Conditions of the physical fabric
- Setting and surroundings
- Perceptual and cultural issues
- Socio-economic aspects

More information can be found in Manders et al., 2012.

To limit the dive time during the significance assessment, Computer Vision Photogrammetry can be applied. The diver who is at the site can record the wreck with a small high resolution camera, which allows the archaeologists back on deck to load a series of overlapping pictures of the shipwreck into dedicated software in order to automatically generate an accurate three-dimensional model. Computer Vision Photogrammetry reduces underwater recording time during surveys, and produces an accurate, detailed and objective three-dimensional result. The created model can also be used for measurements and further research, which can all be done on land, or on a vessel. This is a good tool to map any archaeological remains. Limiting factors are scattered sites and poor visibility under water. It should also be noted that the more images available of a site, the better the 3D model of the site will be after processing. The effectiveness of this method has been shown during research on the Straatvaarder wreck in the Netherlands[32].

If a wreck or other archaeological site has been discovered in very deep waters, a Remotely Operated Vehicle (ROV) can be used. ROVs can be operated from a boat, or from land, and can be manoeuvred around a wreck or submerged site. Ideally, an archaeologist should be present during the assessment of the site with an ROV to analyze the images and provide instructions regarding the way the site should be recorded. The video images can also be analyzed at a later time, if necessary. An ROV was used during the investigation of the Ghost Wreck in the Baltic Sea, and provided great images of the wreck and its details.[33]

Optically Stimulated Luminescence (OSL) is a technique used to determine the time of deposition and burial of sediments. The method determines the last exposure to light, or sand, or silt-sized materials. It makes it possible to determine when a site was buried under the sediment, and also whether it was exposed afterwards due to scour and large-scale erosion. The use of this technique has been trialed underwater on the BZN 10 shipwreck in the Wadden Sea. See Manders et al., 2009 and Manders et al, 2010.

[32] http://www.int-arch-photogramm-remote-sens-spatial-inf-sci.net/XL-5-W5/231/2015/isprsarchives-XL-5-W5-231-2015.pdf

[33] http://www.hydro-international.com/issues/articles/id1236-The_Ghost_Ship_Expedition.html.

New developments for archaeological significance assessments

New developments from SASMAP: SASMAP tools for assessing the environment

Tools and techniques have been developed to assess both open water and burial environments.

A datalogger, termed the open water in situ data logger was developed to measure open water parameters: salinity, dissolved oxygen, temperature, depth and current water data. For assessing the burial environment, two diver-held systems were developed;

1. An in situ spear profiler that can measure profiles of the concentrations of dissolved oxygen, sulphide and redox potential at 5 cm increments to a maximum depth of 50 cm within the sediment. These parameters help to assess the general nature of the environment, whether or not it contains oxygen and the general biological processes ongoing in the sediment .
2. A diver-held vibracorer which obtains sediment cores for analysis.

Measuring in the open water

To trial the artificial seagrass mats (see section on in situ preservation), the open water datalogger was deployed on the Dutch wreck site BZN 10 in order to study the currents and sediment transport over the site and seagrass mats. The datalogger measures what is termed CTD (conductivity (salinity), temperature and depth) data. A new addition to the datalogger was a Nortek Vector Acoustic Doppler Current

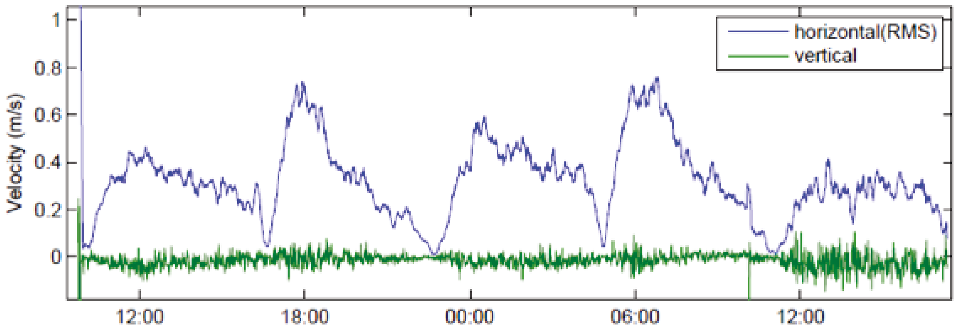


Fig. 8:

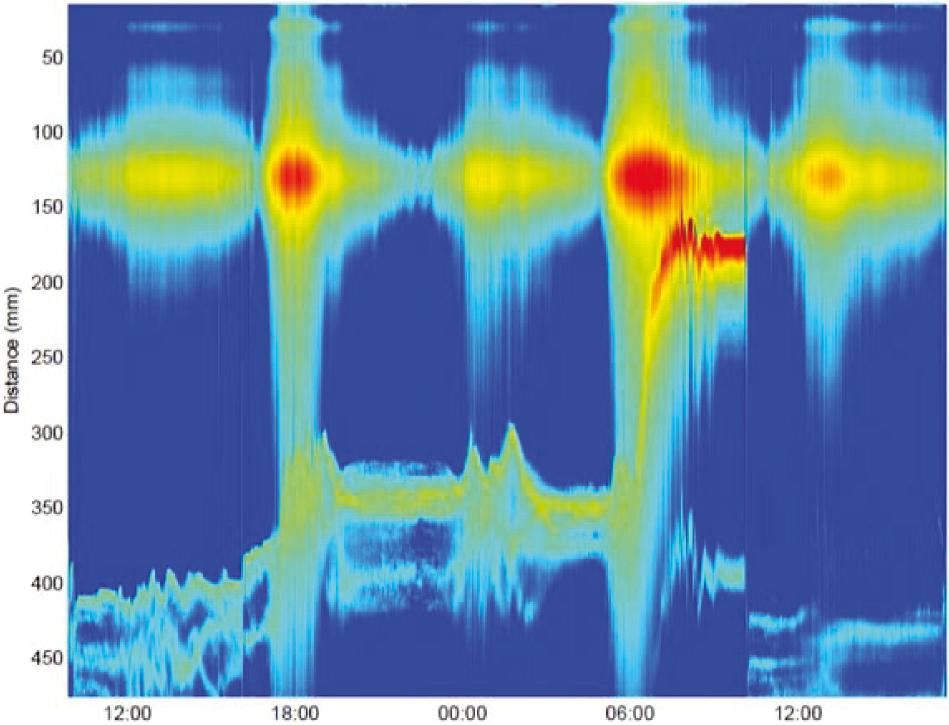
Profiler, which measures the strength and direction of currents, as well as the amount of sediment build-up underneath the logger. Typical current velocities recorded from the datalogger are shown in figure 8 above. As this figure demonstrates, the different velocity profiles during ebb and flood tides are obtained where the ebb -> flood velocities tend towards high velocities in the beginning (up to 0.7 m/s), while the flood -> ebb velocities are lower and more constant.

By establishing the current velocity and assessing the particle size of the sediment, it was possible to determine that conditions were extremely dynamic over the site and that local sediment transport was feasible. The product of sediment transport in relation to the effects of the artificial seagrass was also measured by the data logger. The seagrass mats were successful in trapping sediment as evidenced by the buildup of sediment and the data recorded by the data logger; see figure 9.

Measurements in the seabed
A diver-held data logger with sensors for measuring dissolved oxygen, sulphide, pH and redox potential was developed in the project. This was used in conjunction with a hollow spear, which is easily pressed or hammered into the sediment to the desired depth (max. 50 cm). Different sensors are then placed within the spear to take the desired measurements. The spear takes profiles of the various parameters in the sediment in order to obtain information about the sediment's biochemical processes and in this instance used to assess the potential for preservation of organic archaeological remains. For more information, see SASMAP Work Package 3.[34]

Coring in the seabed
It is recommended to obtain samples of the seabed whenever possible, which are often taken up as cores. These can be used for a number of purposes, including: characterizing sediment type, studying the biogeochemical

[34] www.sasmap.eu



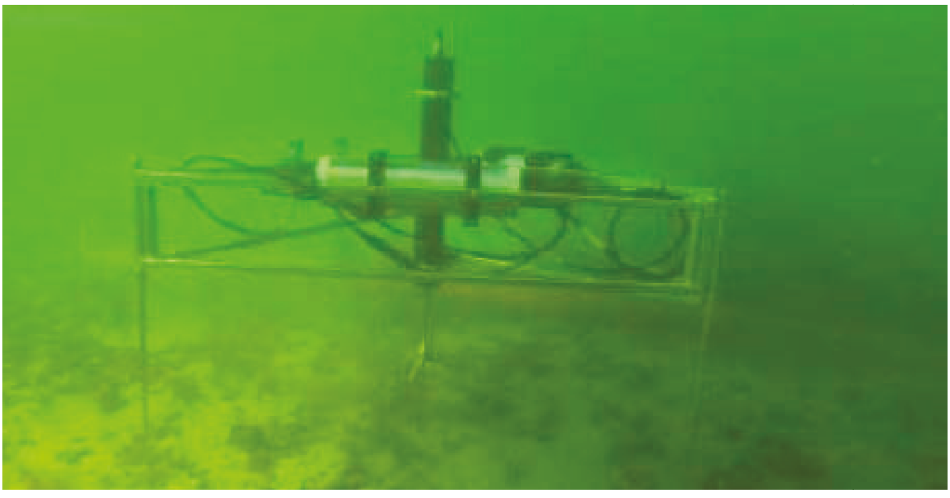


Fig. 9: The open-water data logger deployed on the seafloor.

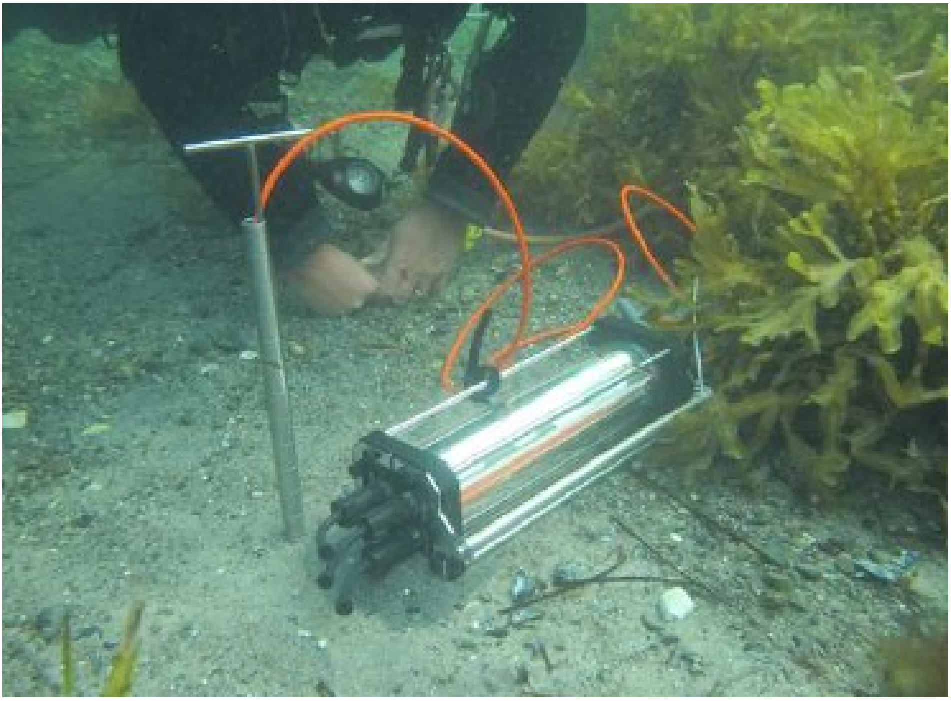


Fig. 10: The diver-operated datalogger with spear sediment profiler.

processes ongoing in the sediment, obtaining palaeo-enviromental data and ground-truth geophysical data, such as sub-bottom profiler data (i.e. sub-seabed data). There are two methods of coring: diver-held coring, and coring from a vessel. Coring from a vessel is often done with a machine-operated vibracore system. This system is capable of very deep corings. Underwater diver-held coring and drilling for scientific purposes is generally confined to the top few meters of the substrate. An existing method for this is a hand-held coring system that divers use to drill down manually. This is very time consuming and labour intensive. A new method, developed in the SASMAP project, is a hand-held vibracoring device. During vibracoring, the sampler is vibrated to allow penetration into the sea or riverbed. Vibracoring is considered the most cost-effective technology for collecting large numbers of sediment cores efficiently with minimal distortion to the actual core. The Vibracorer is a system in which a pneumatic vibrator can vibrate polycarbonate tubes up to 80 mm in diameter in order to ease the passage of the corer into the sediment. In the SASMAP project, cores of over 1 metre have been taken with this developed system. In the seabed itself, it is notoriously difficult for divers to retrieve cores. To this end, a novel lifting device

was developed that features a combination of pneumatically inflatable cushions and a tube holder, which serve to pull sediment core tubes gently out of the seabed. New techniques for sealing the end of the cores, to prevent loss of sediment, were also developed. In SASMAP, the sediment cores were used to assess the burial environment in terms of its effects on the preservation of organic material and obtain material for dating, the results of which would be used in the geological models.
On-land profiles of dissolved oxygen, pH, redox potential and sulphide were measured using microsensors. For more information, see SASMAP Work Package 3.[35]
The cores also provide information about the stratigraphy of the sediment, the biochemical process of the sediment and its preservation potential. They may also contain archaeological information, in the form of artefacts, wood or preserved seeds. All the information, including the data from the sediment profiler and datalogger, can contribute to a decision on what the next step in the archaeological process should be. See also Guideline Manual 1.

[35] www.sasmap.eu

Degradation and assessment of the state of wood preservation underwater

Degradation of wood
Waterlogged wood is one of the most commonly found materials in underwater archaeological sites. An exact assessment of its state of preservation is necessary in order to select the optimal conservation process for excavated and raised wood, or to obtain benchmark data for wood that is to be preserved in situ or re-buried.
Archaeological sites may have been exposed to degradation processes for centuries, making them fragile and vulnerable to collapse when handled. The decay process can be in different states of advancement, depending on the materials of the finds. Since wooden shipwrecks and other wooden constructions represent a large part of all discoveries, wood deterioration and related decay processes are important.
Trees are divided into two groups; softwoods (e.g. pine, spruce) and hardwoods (e.g. oak, lime). Both groups consist of wood fibers that run mainly in a longitudinal direction. Their main chemical components include cellulose (40-50%), hemicelluloses (25-40%), lignin (18-33%), and extractives. Relatively large variations in chemical composition exist between softwoods and hardwoods as well as within both groups. The wood structure, together with the actual chemical composition, gives each wood species its specific physical properties (e.g. strength, elasticity) and durability, or relative resistance to such processes as biological attack.

Fig. 11: Example of Chelura spp.

In the marine environment, oak heartwood, for example, is more durable than pine heartwood. For a shipwreck where the hull is made of oak and the decks or the ceiling from pine, the latter constructions will deteriorate to a poor state of preservation much faster, whereas the hull will remain seemingly intact over a longer period of time.

Biological degradation

Specialised wood degrading micro-organisms and marine borers are responsible for the biological degradation processes of wood in marine waters worldwide. In saline waters, aggressive marine borers are able to turn thick timbers into a very fragile material in a matter of a few years. Teredo navalis, also called shipworm, settles as larvae on the wood surface and bores into the wood where it grows, while forming tunnels that soon penetrate the entire wood. Gribbles are another type of "marine borer" that attack the surface of wood. For more information on Marine borers, see the WreckProtect project[36], or Björdal and Gregory, 2012.

Brackish waters, like the Baltic Sea, are hostile to marine borers due to the water's low salinity. Here, the specialised bacteria and fungi are

[36] http://wreckprotect.eu/fileadmin/site_upload/wreck_protect/pdf/Guidelines_Predicting_web_1.PDF

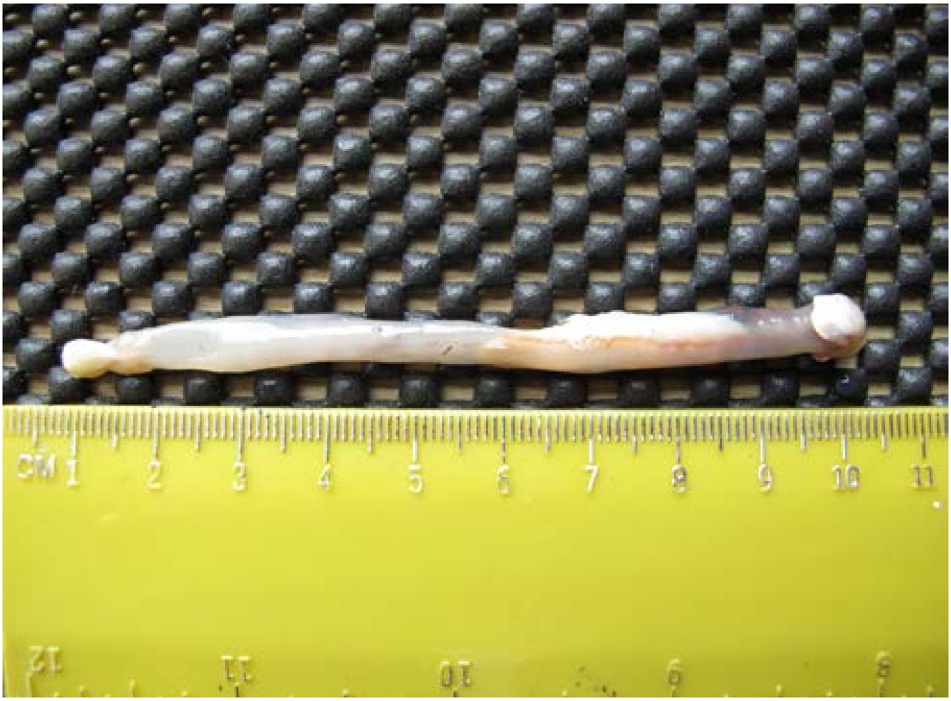


Fig. 12: Shipworm Teredo navalis

the main degraders. This degradation is extremely slow compared to decay by marine borers. Consequently, shipwrecks have been found still standing on the seafloor, seemingly intact despite centuries of exposure in nature. However, the impression of an intact wood surface is misleading. Erosion bacteria are known to enter the wood surface and, penetrating through structural openings in the wood, to slowly degrade the cellulose and hemicellulose rich parts of the individual fibers. As they are able to be active in near-anaerobic environments they are able to penetrate deep into the wood structures. Soft rot fungi are also an important group of wood degraders, but have higher demands for oxygen. Therefore, they are restricted to the exterior surfaces of the wood, where they penetrate the fibers by hyphae - more effectively than do erosion bacteria - and prefer to digest the cellulose and hemicellulose rich parts of the cell walls. See Björdal 2012.

The effect of microbial attack is often characterised as a softening of the wood exterior/surface, although to the naked eye, the wood looks intact in terms of colour, dimension, and form. The observed softness is often described as spongy, and when a needle or knife is pressed into the material, it will sometimes go right through. This is because as degradation proceeds the hemicelluloses and celluloses are degraded by the aforementioned microorganisms and replaced by water. The physical properties of the wood are drastically altered – a key parameter being density; the more degraded the wood is, the lower the density. This parameter was used in SASMAP when developing a non-destructive wood tester (see below).

In sediments (both marine and brackish environments) where oxygen concentrations are extremely low, erosion bacteria are the only active wood degraders. Detailed information on the complex degradation processes of shipwrecks are available in Björdal and Gregory, 2012.

In marine saline waters, both marine borers and microbial degraders are active. The majority of decay takes place inside the wood, and can only be detected by technical evaluation and analyses.[37] The remaining strength and physical properties of the wooden finds are strictly related to the actual degree of biological decay. In selecting any preservation strategies, whether those include lifting, conservation, or preservation in situ, it is vital to know the degree and type of deterioration, and to estimate the structure's load capacity and need for physical support.

Assessing the state of preservation of waterlogged archaeological wood

Although there are numerous devices available to assess wood[38], they are not specifically designed for waterlogged archaeological wood. Nor do they provide quantitative data about the state of wood preservation. Currently, there are no devices commercially available that can provide absolute data on wood objects in situ under water.

In SASMAP, a non-destructive diver-held wood profiler was developed and tested in order to quantitatively assess the state of preservation of fully waterlogged wooden artefacts both in the laboratory and in situ under water.

The result was the underwater wood profiler (christened WP4UW). The WP4UW can measure density profiles quantitatively in increments of 1 mm in both recent and waterlogged archaeological wood to a depth of 10 cm. The data is stored in the equipment, and then transferred to a PC for processing in specially developed software. The WP4UW performs equally well above as under water, without any need for compensation factors regarding the surroundings (i.e. above or below water). Moreover, it is not hindered by any problems from intruding particles (e.g. sand) from the sea, which was often the case when measuring the density of wood with traditional instruments, such as a pilodyne.

The WP4UW is also able to make profiles with a higher resolution than is possible with

[37] This is actually the case for all waterlogged wood: the level of deterioration is not always easy to see and may occur mainly inside the wood.

[38] See, for example: http://www.sibtec.com/digitalmicroprobe.html, https://www.flickr.com/photos/searoom-sf/sets/72157607222166611 and http://www.rinntech.de/content/view/8/34/lang,english/

traditional methods. The profiles obtained are consistent with density measured as wet volume per weight and with the results found by light microscopy. In addition, the results shows that it is necessary to take several profiles on a given piece of archaeological wood in order to accurately assess its state of preservation, as there can be enormous differences between density profiles only a few centimetres apart. One of the advantages of the present WP4UW is its capacity to obtain many profiles in a short time. Depending on the size of the scuba tank, depth and divers' skills, the profiler can sample one profile every 5 minutes with an estimated total of 10 profiles on a 4-litre scuba tank at a depth of 10 metres. The profiles still need subsequent interpretation by the developed software and a trained archaeologist/ conservator.

4. In situ preservation – Best practice examples

INTRODUCTION

If a site is deemed of archaeological significance, and it is not going to be excavated, it should be preserved in situ. If, during the archaeological significance assessment it is evident that the site could be affected by cultural or natural threats, or the site is unstable, strategies should be implemented to mitigate for these threats. It is at this stage that an overall evaluation should be made of whether it is feasible and responsible to leave the site in situ. The most significant threats to sites are the possibility of further physical deterioration, due to scour and human interference, and biological deterioration caused by various decay organisms. The methods demonstrated below are mainly focused on creating a protective shield between the environment and the archaeological site as well as an anaerobic environment to considerably slow down biological deterioration processes. Not all known methods and techniques will be demonstrated. The in situ protection of metal shipwrecks, for example, by using sacrificial anodes will not be included here. For these and other methods, see, for example, Heldtberg et al, 2004, Bartuli et al. 2008 and Manders et al. 2008 & Manders (ed) 2009.

METHODS OF RESEARCH AND BEST-PRACTICE EXAMPLES

General methods

In situ preservation may involve protection by law as well as by taking physical measures. This depends on the (natural) conditions at the site and the reason why a site is being preserved. However, it may also be influenced by factors such as budgets and political priorities.
To mitigate for the aforementioned deterioration processes, sites are often physically covered using different methods. In the right circumstances, this can both alleviate scour and prevent the activity of organisms.
In other cases, where the local environment is not conducive to simply covering, a site can be excavated and re-deposited / reburied in a more benign environment underwater, or on land.
Sandbags are often used as a means of covering and stabilizing archaeological sites underwater. However, their deployment is labour intensive.
More recently, attempts have been made to stabilise sites in situ by entrapping sediment particles carried in the water column and creating an artificial seabed, or burial mound, over the threatened site. Notable examples of this are the use of artificial seagrasses on the wrecks of the William Salthouse, the James Matthews and the Hårbølle wreck. Similarly, various types of netting (shade cloth, debris netting, wind netting) have been used on several wrecks in the Netherlands and Sri Lanka and also trialled on the James Matthews and the Hårbølle wreck.[39]

[39] Manders, Gregory and Richards, 2008.

The artificial sea grass and the various types of net effectively function in the same way. The plastic fronds of the artificial seagrass trap sediment particles in the water column as water passes through them. Due to viscous drag (friction), the water is slowed, causing the sediment particles to fall out of the water column and resulting in an artificial seabed, or mound. In the case of netting, the net is fixed loosely over the structure to be protected, so that it "waves" in the water column. As with the artificial sea grass, suspended sediment in the water column passes through the net but as it does it is slowed by friction: the sand falls out of suspension and creates a mound under the net. These materials only function in the right conditions: the presence of sediment transport and the particle size of sediments being transported must be assessed prior to applying these methods on sites. Obviously particle size is more relevant with the various types of netting due to the mesh openings than with artificial seagrass, which is a more open system.
Should the immediate site environment not be conducive to in situ stabilization of the site, or if, due to subsea development, a site has to be excavated, excavation and re-burial in a more benign environment is a further option. Re-burial as a means of long-term storage is not a new idea and has been proposed and practiced for many years around the world. One of the first attempts at controlled reburial of archaeological remains underwater was carried out in the 1980s. From 1980 to 1984, Parks Canada excavated the remains of the Basque whaler San Juan in Red Bay, Labrador. Following the excavation, raising and documentation of the wreck, the timbers were reburied to protect them against biological, chemical and especially physical deterioration due to ice floes. What sets this early project apart from other reburial attempts of the time was that monitoring of the reburied timbers and the surrounding reburial environment was planned from the outset. Sandbags and the ballast from the ship were used to construct an underwater cofferdam, where the timbers were placed in several layers, each separated by a layer of sand. Modern wood blocks were placed alongside each layer for subsequent removal and analysis, and a series of sealed dip wells were installed to enable removal of pore water samples from the mound for analysis. The burial mound was then covered with a heavy-duty plastic tarpaulin anchored by concrete filled rubber tires. See also: Stewart, et al. 1995.
A similar project building on this work was the re-burial of artefacts from the wreck of the Fredericus (1719) in the Swedish island port of Marstrand. Full conservation treatment of all excavated artefacts was considered both impractical and unnecessary from an archaeological perspective, and it was decided that 85-90% of the finds were to be re-buried after proper archaeological documentation. Trenches were dug for the various material types found and covered with at least 50 cm of clay/sand sediment in 2002. The depth of burial was based on previous experiments, which sought to identify the optimal burial depth for materials. See also: Gregory, 1999.
Different techniques for physical in situ protection of archaeological sites underwater have been trialled in the last couple of

Fig. 13: Diver inspecting an Artificial Seagrass Frond Mat. Photo Viking Ship Museum.

decades. More information on these different techniques and their effectiveness can be found in: Wreckprotect[40] and Manders, Gregory and Richards, 2008.[41]

New developments for in situ preservation

New Developments during SASMAP

Over the past 30 years, the company Seabed Scour Control Systems (SSCS), one of the small companies (SMEs) involved in the SASMAP project, has become a world leader in the design and manufacture of specialised scour protection systems for the protection and stabilisation of subsea installations. In 1984, the company developed an artificial seagrass frond mat to harness the natural effects that create scour (erosion of the seabed) in order to produce a permanent, maintenance-free scour protection system. The mats were mainly used to protect pipelines against scour.

The original designed SSCS anchor-fixed frond mat is lowered to the seabed as a roll. After fixing one side with anchors, driven into the seabed, divers roll out the mat in the area to be protected or over the cable / pipeline or structure and fix it in position with further anchors. The mat functions by the polypropylene fronds, which float in the water column. This effectively slows any currents running through them, thus reducing

[40] www.wreckprotect.nl
[41] For a focus on activities in the Mediterranean Sea Petriaggi & Davidde-Petriaggi 2015, pp 238-251

Fig. 14: The artificial seagrass being deployed on the wreck of BZN10. Photo Paul Voorthuis

turbulence and hence erosion, or scour, of the sediment. In this way, the fronds trap sediment from the water column creating a sediment layer between the fronds and on top of the site that needs to be protected.
In SASMAP, the mats were developed for use on archaeological sites. The anchors used on the mats, although extremely effective in securing the mats to the seabed, were thought to be too intrusive. New mats with various combinations of dimensions, frond size, colour, and anchoring weighting methods were developed in the project. Two new types of mat were developed in the project: an "edge-weighted mat" and a "sandbag-weighted mat".

Edge-weighted mat
The edge-weighted mat used during the SASMAP project was a standard frond mat (2.5 by 5 metres), but instead of using anchors to fix it to the seabed, it was held in place by the use of a weighted apron, which consisted of a heavy-duty tube filled with small gravel. Deployment of these mats was different. Instead of being lowered down and rolled out by divers, a frame was used to lower the mat from the surface to the seabed. With simple handling by one or two divers underwater, the mat can be positioned and released on site.

These mats were deployed at two sites; in Denmark at Tudse Hage and at the wreck site of the Burgzand Noord (BZN) 10 in the Wadden Sea. The site in the Dutch Wadden Sea was optimal for the mats due to the high sediment transport in the area. The BZN 10

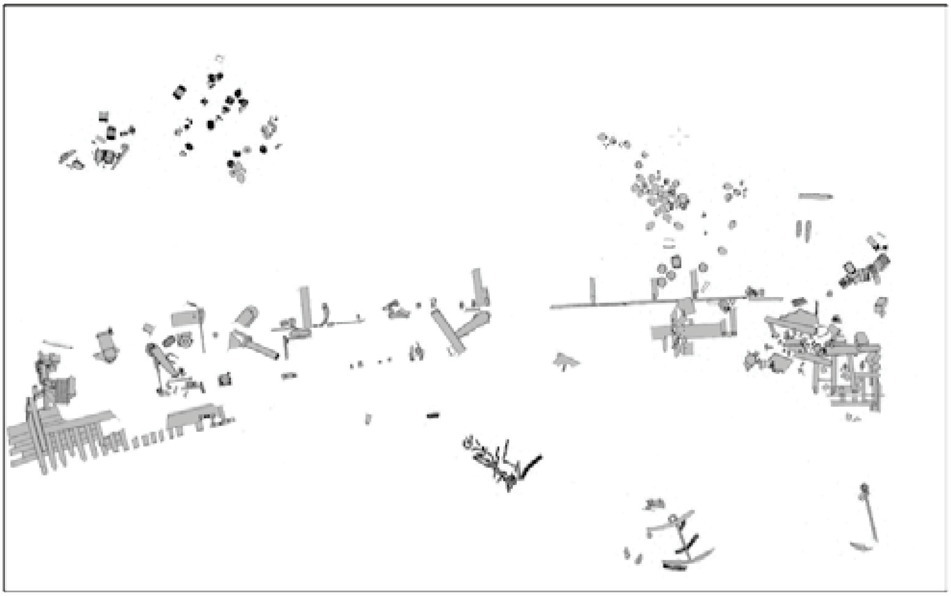


Fig. 15: site map of the Burgzand Noord 10 wreck. Drawing by RCE

wreck is a 17th-century shipwreck, which sank on the Texel Roads, east of the island Texel. This location is mainly threatened by natural erosion. Although the wreck has been protected for over 10 years, additional methods remain necessary to maintain the preservation in the coming years. Mats were deployed on two occasions in 2013 and 2014.

A large vessel with lifting capacity (2 tons) was used for deployment of the mats. Using the deployment frame, it was possible to place each mat within 8 minutes. Diving inspections showed that the mats were collecting sediment within hours, and after a 24-hour tidal cycle, the mats had collected significant amounts of sediment. Monitoring with multi-beam sonars was carried out on the artificial seagrass of BZN 10. This monitoring confirmed the observations from the diving inspections that a significant amount of sand was caught by the mats. The monitoring also revealed a second effect. Because the fronds slow down the current, sediment had been deposited even up to two meters behind the mats. The mats are thus not only effective exactly on the spot where they are placed, but also create sedimentation in the near vicinity. One characteristic of the seagrass is its dynamic function. The fronds may not keep the sand permanently trapped, the sediment remains in contact with the open water and the currents. If by any chance – for example due to storm surge - the sand washes away, the fronds will rise again and start slowing down the current again; as a result, sedimentation will take place again.

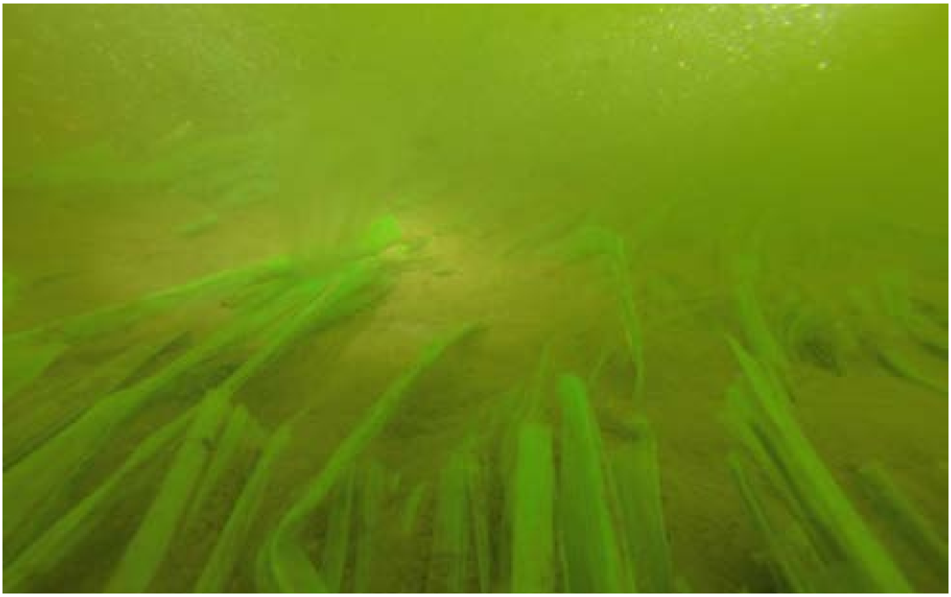


Fig. 16: 2014 mat of artificial seagrass covered with sand. Photo RCE)

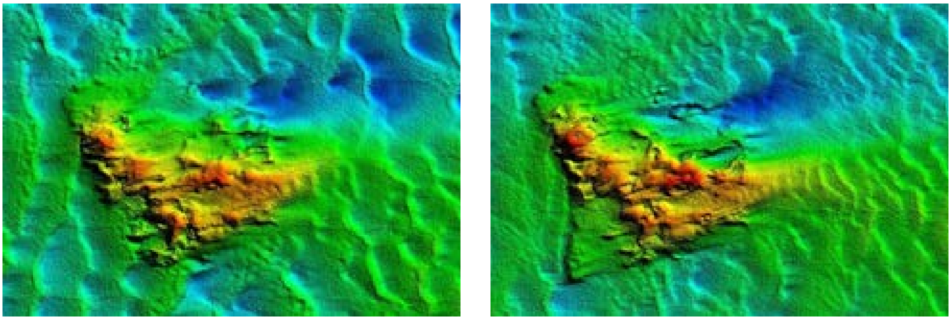


Fig. 17: On the left, the monitoring from 2012, without the seagrass. On the right, the monitoring from July 2013; the clearly visible effects of the mats are encircled in red

Sandbag-weighted mats

The sandbag weighted mats were also based on standard frond mats. However, instead of anchors or the edge-weighted system, they have a surrounding apron upon which sandbags can be deposited to weigh the mats down. These mats have been deployed and tested on the Roman site of Baiae (2nd century B.C. to 4th century A.D.) near Naples, Italy.

The coastal region has been characterised by a periodic volcanic and hydrothermal activity, and it has been subject to bradyseism, i.e.,

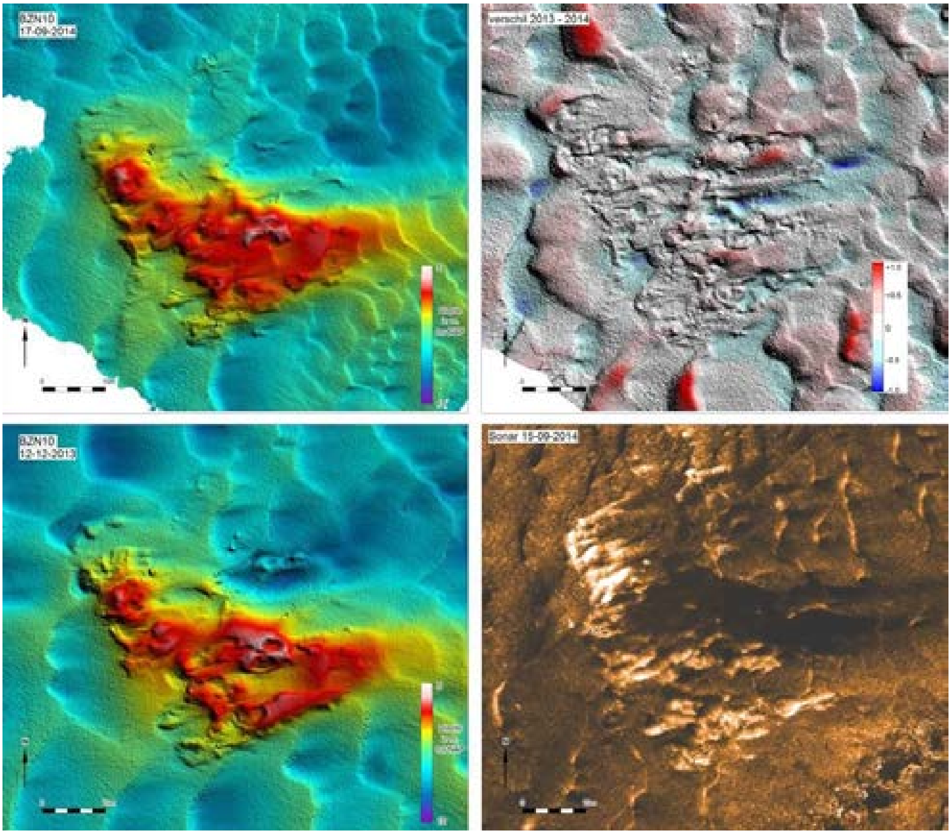


Fig. 18: Comparison between multi-beam surveys from December 2013 and September 2014. At the top left is the multi-beam of 2014; lower left, the multi-beam of 2013. The top right shows the difference in sedimentation; red indicates incline, blue a decline. The lower right is a side-scan sonar picture from September 2014.

gradual changes in the level of the coast as related to the sea level. These processes have had positive and negative effects. With the passing of millennia, the archaeological remains of the building complexes are still submerged. These include the remains of the luxurious maritime villas and imperial buildings, more modest houses, private thermae, tabernae, roads and warehouses, and all the architectonic structures that characterise the cities of the Roman Period. The submerged area includes part of the territory of the ancient city of Baiae and Portus Iulius, comprising the Roman harbour and numerous constructions used as warehouses. In 2002, an Underwater Park (Marine Protected Area (MPA)) was created covering around 176.6 hectares.

The sandbag-weighted mats have been placed

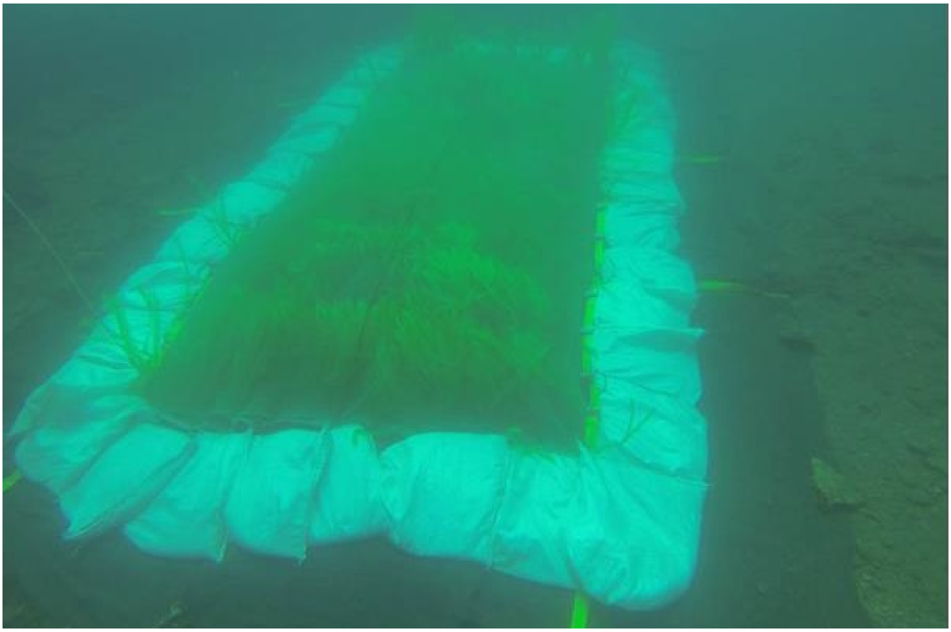


Fig. 19: Artificial seagrass mat. Sandbags are placed on the apron around the mat to keep it in place. Photo Nationalmuseet

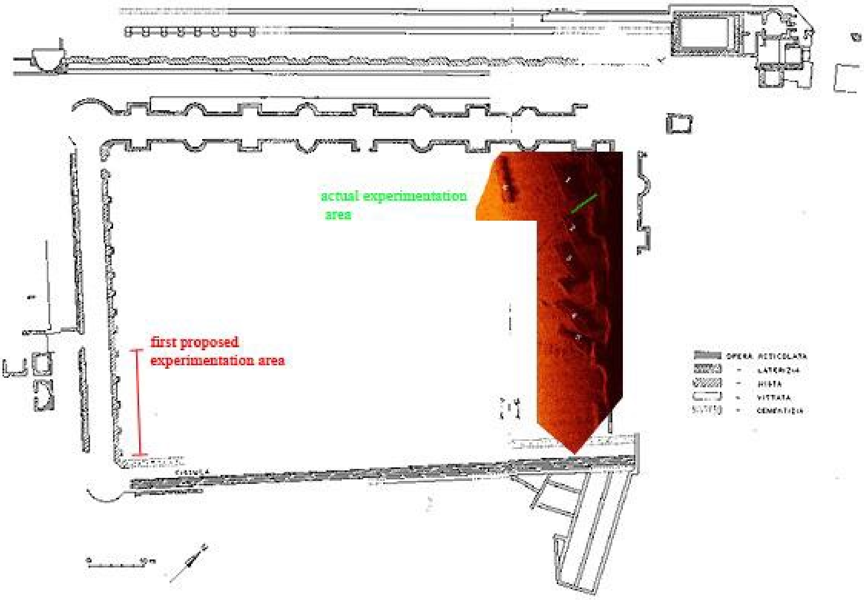


Fig. 20: The apron is secured around the sandbag to keep the mat in place Photo Nationalmuseet

near the wall of the viridarium of the Villa dei Pisoni , where erosion has undermined the wall, exposing wooden timbers.

Six sandbag-weighted mats with 62.5 cm fronds were deployed. Although the system requires use of a large number of sand bags (in Baiae, 150 bags filled with around 4500 kgs of sand were used), it proved to be easily implemented with smaller boats. Moreover, the sandbags keep the mats very well in place. No mats have been displaced due to storm activity. The mats trap sediment well, but this sand may also be removed if there is significant storm activity. Nevertheless, the mats in Baiae are still protecting the wood remains at the Villa.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5. Monitoring – Best-practice examples

INTRODUCTION

In situ preservation does not stop once on-site protection measures have been fully implemented. Monitoring of sites preserved in situ is necessary to ensure continued stability. Furthermore, although a newly discovered site may be relatively stable and consequently not require immediate implementation of active mitigation strategies, environmental and/or physical changes may occur, which necessitate mitigation strategies at a later date. In this context, monitoring is essential, as underwater archaeological sites exist in a dynamic equilibrium with their environment, and may undergo subsequent changes due to storm, cultural or other events. This is equally valid for sites, where active mitigation strategies, such as reburial, have already been implemented.
The monitoring of a site preserved in situ should be compared with baseline data: environmental and site data collected prior to implementation of physical in situ protection measures. This baseline data is often collected during the significance assessment phase, as the investigative focus extends beyond archaeological significance and includes the significance of (future) changes. This type of assessment is vital for monitoring research.
Following implementation of protective measures, the same data collected during baseline research should be collected again, and a timeline developed that indicates how often the site should be monitored. This timeline will depend on an expert estimation of the site's stability and environment.
As with other processes of deterioration, monitoring efforts should take account of the great differences between the open seawater environment and the seabed environment. Concerns regarding open (sea)water include the physical and biological processes of deterioration, namely sediment transport (erosion and sedimentation) and the activity of wood-boring organisms. In sediments, characteristics such as the dissolved oxygen content, concentrations of various chemical species, porosity and organic contents can all yield information about ongoing biogeochemical processes and the rate of deterioration of organic matter.
This chapter discusses several general methods, new developments and best-practice examples for the monitoring phase.

METHODS OF RESEARCH AND BEST-PRACTICE EXAMPLES

General methods

Monitoring by divers is an effective strategy for archaeological sites preserved in situ. During surveying operations, divers can inspect the archaeological remains from up close, take samples and/or corings and gain information about the current status of the in situ preservation method used. These procedures are useful in identifying problems that can arise, such as the partial exposure of a preserved wreck. Divers can also ascertain whether a site is being attacked by wood-boring organisms, such as *Teredo navalis*. Use of a Remote Operated Vehicle (ROV) as a visual aid is another option. In some environments – especially deep sites –

it may even be the best option. However, diving operations may offer more flexibility in on-site research. During surveys, divers can also use Computer Vision Photogrammetry to compare changes on site. This method creates an accurate 3D image of the site, using photos and video stills. Repeated use may help in detecting changes on site. It also makes it possible to do further research back on deck or on land, which, in turn, reduces diving time and related expenses. For more information on Computer Vision Photogrammetry, see Guideline Manual 2: Archaeological significance assessment.
Comparison of distance measurements (for example, between data points) over a period of time can be an effective strategy for monitoring the movement and collapse of structural elements at the site.
Monitoring the degradation of materials on site (wood, other organic materials, iron, etc.) can also be done by using sacrificial samples. These samples can be installed on site either above the sediment (in the open water) or in it. This is very labour intensive since the material has to be made (often in large quantities), installed on site and retrieved repeatedly (in set periods) for (laboratory) research. This method can, however, be valuable in areas where the degradation processes are still unknown. For more information about this approach to monitoring, see the results of the EU-funded MoSS project.[42]
Archaeological sites preserved in situ can also be monitored, using echosounders, such as multi-beam (MBES), single-beam (SBES) and interferometric sonars, as well as side-scan sonars. These techniques obtain bathymetric data and seabed images. For the purpose of monitoring archaeological sites, at least two area surveys should be performed for comparison with each other. This way, changes in sediment can be detected and the effectiveness of the preservation method can be tested. This technique is often used and has proven to be very effective. In fact, it was employed frequently to monitor the BZN 10 wreck in the Netherlands, and the multi-beam images derived from the surveys showed a positive difference in sediment composition on a yearly basis. A more detailed explanation of how echosounders work is available in the chapter on prospection in this guideline manual. For more information about the use of echo sounders at the BZN 10 wreck, see the monitoring research done in the MACHU project.[43] In addition, Brenk and Manders (2014) provide a more detailed view of the use of echosounders in monitoring large submerged areas.

If any changes in the sediment need to be measured, sub-bottom profiler systems can be used. This system emits acoustic pulses in the form of acoustic conical beams, thereby producing images of the shallow sub-bottom succession of layers based on the seismic reflector method, and thus providing the stratigraphy of the seabed. The images of the archaeological remains in the seabed can then be compared to earlier sub-bottom profiling

[42] http://moss.nba.fi/

[43] www.machuproject.eu

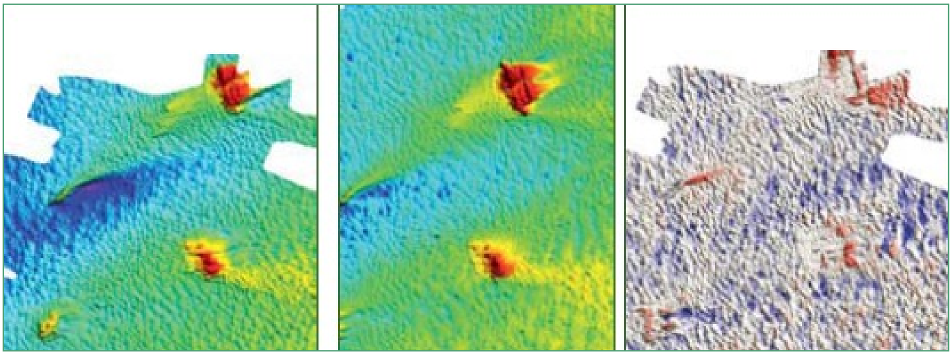


Fig. 21: Multi-beam images of the BZN 10 wreck in 2003 and 2004, and a map which shows the changes in sediment.

images: the depth of the buried wreck, or site, can be compared, and any distortion of the site can be detected. This was trialled at the BZN 3 wreck and showed promising results for monitoring physically protected sites. The data from sub-bottom profiling images is useful in monitoring the amount of sediment caught in the polypropylene netting. See the MACHU Project[44] for more information, as well as Guideline Manual 2: Prospection (for a more extensive discussion of sub-bottom profiler systems).
LiDAR and Satellite Image Processing can be used for bathymetric research, especially in larger areas. It works well in shallow (coastal) clear waters. When comparing images from before and after preservation efforts, differences in bathymetry can indicate whether the selected preservation method (e.g. seagrass mats) is sufficiently effective and traps enough sediment to cover the site for protection. For more information on LiDAR, see Guideline Manual 2: Prospection. This guideline manual also offers more information on the use of satellite image processing in the chapter on Desk-based assessment.

New developments from SASMAP

During SASMAP, the deployment of the artificial seagrass at Tudse Hage was accompanied by the placement of an open water data logger. This open water data logger was used to monitor the site and check whether the artificial seagrass mats were adequate for the site's protection. Although this technique can be implemented initially during the significance assessment of a site (significance of change), repetitive research over a longer period of time can be a useful strategy for monitoring the environmental conditions (if there are indications that these may change), as well as the long-term effectiveness of the physical protection measures selected, such as the artificial sea grass.
The open water data logger developed in SASMAP is relatively easy to install. A single diver was able position it correctly on the seabed and on the artificial seagrass mat that

[44] www.machuproject.eu

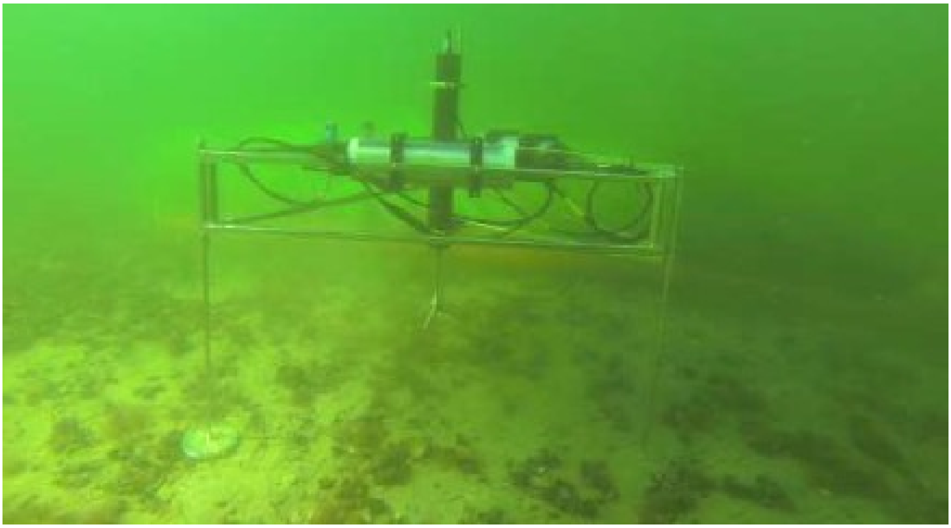


Fig. 22: Open water data logger deployed on the seabed.

was monitored. In two days, the data logger was moved from an on-shore position to an off-shore position for comparison, using a diver on the seabed and support on the surface. CTD (conductivity (salinity), temperature) and current data were successfully collected and the salinity and oxygen concentrations appeared to be very stable throughout the deployment. The data logger clearly showed how the seagrass mat reduced the speed of the water, which would eventually result in increased sedimentation of suspended solids from the water column.
In using this method to monitor a site's environmental data, changes may be detected that can be mitigated in an early stage, e.g. by adjusting the protection strategy. As stated before, baseline data – collected before implementation of in situ protection measures - are required for monitoring with an open water data logger. For more about the use of the open water data logger, see Guideline Manual 2: Significance assessment.

SASMAP also developed a spear-like sediment profiler to measure environmental parameters (pH, Sulphide, Redox Potential) in sediment profiles in situ, using a diver-based data logging system that runs to a depth of 50 cm. A diver-operated underwater meter manufactured by Unisense was re-developed for this purpose. The result of this extensive development was a hollow spear, which could be hammered into the sediment to the desired depth and which was equipped with sensors to take the desired measurements. See also Guideline Manual 2: Archaeological significance assessment.
The sediment profiler was tested in Denmark on the submerged prehistoric site of Tudse Hage, at the same place the open water data

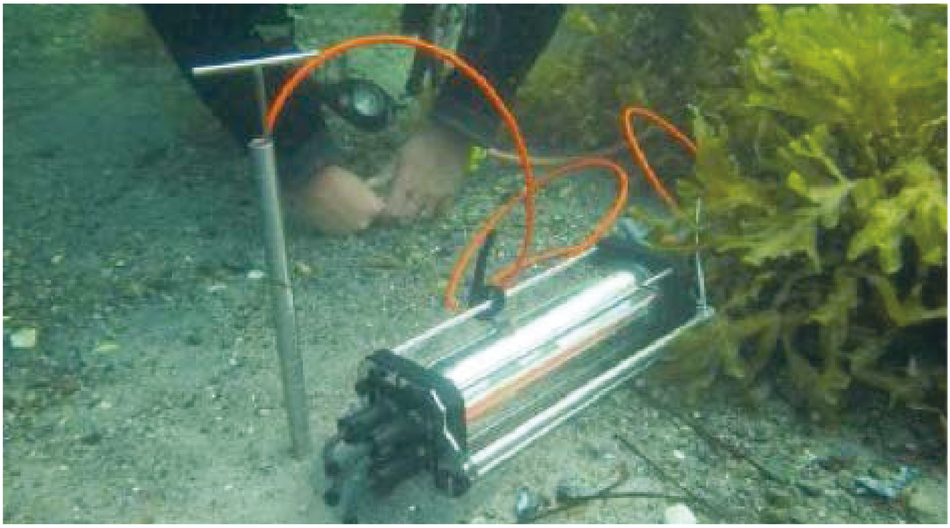


Fig. 23: The spear-like sediment profiler tested at Tudse Hage.

logger was used. A 1 x1 m test pit, which had been previously excavated and re-buried, was selected as the test area. This pit yielded a ca 50 cm profile of sand / gravel and organic gyttja with numerous fragments of wood (both processed and natural) overlaying the natural clay, and thus providing the perfect area to test the spear sediment profiler in situ. In itself, the meter was extremely simple to use with magnetic keys controlled by a “wand” from outside the underwater housing to enter commands and log data. The spear itself was easy to press, or hammer into the sediment. In this way, measurements were taken every 5 cm down to a depth of approx. 60 cm. It proved to be important to ensure that sand does not get into the open end of the spear, as this can damage the micro sensor. In the monitoring phase, this method can be used to measure changes in the sediment. Once again, baseline data obtained prior to preservation measures, are important for comparison purposes.

Vibracorer from SASMAP

During the SASMAP project, a vibracoring system was developed. The core, a polycarbonate tube 80 mm in diameter, is vibrated into the sediment by a pneumatic vibrator. This vibration feature can also be used to retrieve the core again from the seabed. During the significance assessment phase, it is possible to measure sediment parameters in the cores, such as dissolved oxygen, pH, redox potential and sulphide, to evaluate the sediment’s preservation potential. By measuring sediment parameters on a regular basis, archaeological sites preserved in situ can be monitored. If necessary, in situ preservation methods can be adjusted or changed. For more information on the use of the Vibracorer,

see Guideline Manual 2: Archaeological significance assessment and SASMAP work package 3[45].
Coring also makes it possible to use Optically Stimulated Luminescence for monitoring the burial of preserved sites. If baseline data is available, the findings of an OSL study can offer more insight into the activity in the sediment covering an archaeological site. For more information, see Guideline Manual 2: Archaeological significance assessment, and Manders et al. 2009. In addition, the MACHU project[46] provides more information on the use of OSL at a wreck site.
In summary, the monitoring operations developed in SASMAP have shown that the collection of material samples, (which were primarily wood in this project), is vital in assessing the preservation status of the materials present at a site. That information, in turn, is necessary to determine whether future deterioration is likely in the environment in which preservation is envisioned. Studies of the wood fragments taken from the Tudse Hage site revealed extensive deterioration. However, it was also found that, should conditions remain the same, further deterioration was unlikely due to the ecological constraints of the micro-organisms responsible (i.e. they do not survive).
These results also highlight the importance of understanding post-depositional formation processes on archaeological sites in general (i.e., how artefacts were deposited and incorporated in a site). As already noted, the analysis of the wooden fragments showed that deterioration occurred in the very distant past: no significant differences were observed in the state of wood preservation at different depths (increasing age) within the sediment. When this was correlated with carbon 14 dates, it was found that the formation of the site took place between the years 6390 and 5990 (±30) BP. In other words, this period spanned over 400 years, during which no significant differences emerged in the overall state of the preservation of wood objects.
Thus, in terms of archaeological wood, processes in the sediment are irrelevant once wood is totally degraded. Naturally, this highlights, yet again, the importance of evaluating the material to be preserved in situ, since it is not always fully degraded as was the case in Tudse Hage. Furthermore, if these results are to be relevant to other sites, especially if more recent - and better preserved - archaeological wood is present, then it is important to establish an accurate profile of the environment. The main factors affecting the deterioration of organic materials are related to the amount of oxygen in the environment (oxic or anoxic) and the ongoing processes associated with the physical characteristics and organic contents of the sediments in which the materials are buried.

Sulphate reduction and the measurement of hydrogen sulphide

In anoxic environments, especially those in shallow coastal sites, sulphate-reducing bacteria that produce hydrogen sulphide are primarily responsible for the deterioration

45 www.sasmap.eu.
46 www.machuproject.eu

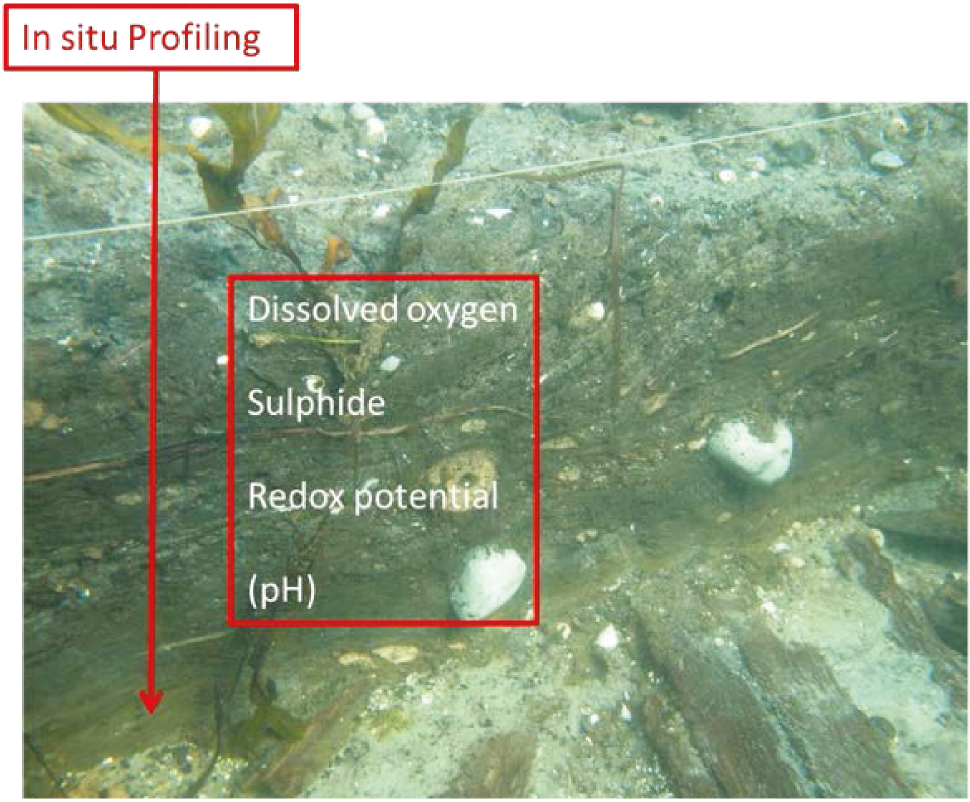
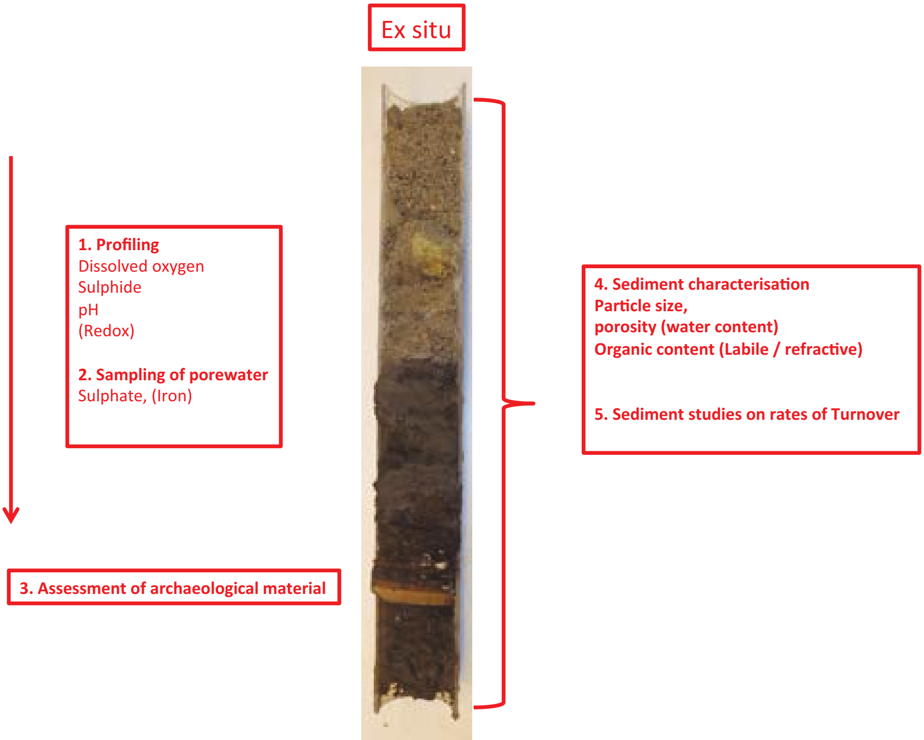


Fig. 24: In situ profiling to characterise whether a site is oxic or anoxic.

processes that take place below the layer containing oxygen. Hydrogen sulphide was measured, using the in situ profiler and cores for ex situ measurements. Results from both the in situ and ex situ profiling revealed the sulphate- reducing zone at the Tudse Hage site, which is good for preservation.

Physical characterisation of sediment type and ongoing processes

Using the ex situ cores, sediment samples were characterised by means of general methods for assessing the turnover of organic material. The aspects analysed included the particle size, water content (porosity), organic content (labile and refractive) and the pore water content. In terms of the required equipment, these are relatively simple parameters for the majority of archaeological and conservation laboratories to measure. The analyses showed that, in general, coarser grained sediments have a higher porosity, lower organic material



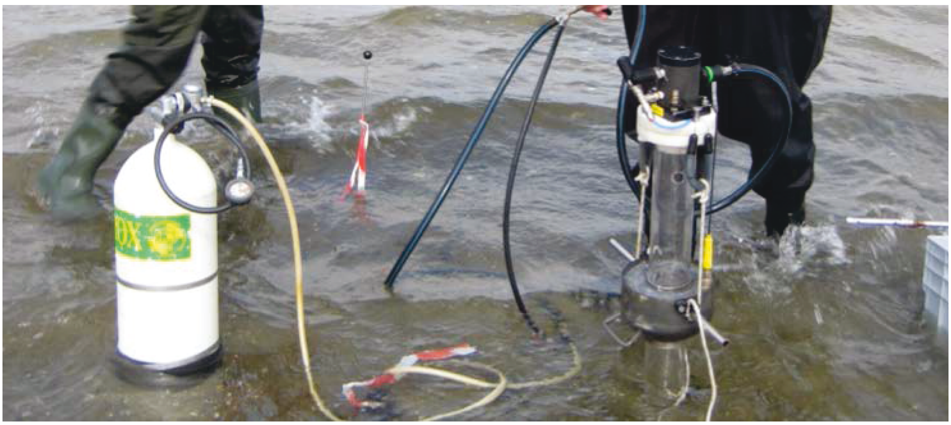


Fig. 25: Characterising the site environment ex situ by taking cores with the vibrocorer that has been developed within the SASMAP project

content, and thus lower turnover rates.[47] Once again, however, we cannot stress enough that it is absolutely crucial to determine the preservation status of the materials to be preserved. In the case of the wood from Tudse Hage, as long as that wood remains buried in the present low-oxygen, sulphate-reducing conditions, it should be preservable for the future, as there is insignificant material remaining that can be degraded under the present environmental conditions. Furthermore, this is why it is also important to understand the overall ongoing physical processes in sites, as these processes may cause the erosion of sediments.

Figures 22 and 23 present flow diagrams for generic best practices (in situ and ex situ) for characterising the site environment in relation to the preservation of archaeological wood in underwater sites.

[47] The sorting, shape and packing play also an important role in the porosity of sediments.

6. Excavation – Best-practice examples

INTRODUCTION

Underwater archaeological excavation represents a traumatic and essentially destructive event for artefacts, especially organic ones, and their underwater context. Because of their fragility, organic archaeological remains from underwater sites can be challenging to excavate, support, raise and transport to conservation facilities. An excavation often takes place if in situ preservation is not an option, but may also be initiated if important new information can be gained to understand our past. Because every excavation and site is different, the excavation should always be tailored as a best fit for the particular site. An underwater archaeologist with the proper authority should make this decision. For more information about the process of underwater archaeological excavation, see Guideline Manual 1.

METHODS OF RESEARCH AND BEST-PRACTICE EXAMPLES

General methods

When starting an archaeological excavation, a measuring system should be established. To ensure accurate measurements and documentation of a site, this measuring system should not be changed during the research process. A grid system can be used, but the choice of a rigid or non-rigid grid system will depend on the environment and the submerged construction. A non-rigid grid system is more likely to have deviations than a rigid system. In some environments, the choice may be to use off-set or triangulation, especially on sites with height differences, currents and active sedimentation. Repeated recording by multi-beam during excavation, scuba laser scanner or the use of computer vision photogrammetry are also aids in the measuring and documentation of a site underwater.
Using a water dredge or airlift, it is possible to remove excess sediment from a site to expose the archaeological remains. The water dredge and airlift not only clear sites, but can also be a valuable asset in excavation, provided it is possible to regulate the suction power. However, these powerful tools need to be handled carefully onsite. The water dredge and airlift will suck up loose sediment and transport it to the desired location. This can be done by dispersing the sediment a few meters from the site, or by transporting the sediment to the surface to be filtered and investigated for any artefacts it contains. Airlifts are used in deep(er) water because the pipes need to stand upright and to be long enough to enable the passage of air required to create a significant vacuum. Pipes not connected to the surface may dispose the sediment in the water column; from there, the current can take it away from the site. Water dredges can be used in shallow water since the sediments suspended in water can be transported (almost) horizontally to either the surface or to some place outside of the archaeological site.

When a site is cleared of any excess sediment, smaller archaeological objects can be gathered and documented. If required, any sampling

Fig. 26: An archaeologist, using a water dredge to clear a site.

can also be done. All vulnerable finds, fragile or organic, will need extra care and should be handled accordingly. All visible archaeological aspects, such as stratigraphy, archaeological layers and structures should be documented. For accurate documentation, a drawing, either digital or analogue, should be made of the site. The drawing should be made by using the measuring system of the site implemented there. The detail in the drawing will depend on the physical conditions and the equipment (that can be) used. In some European countries, there are standards for such drawings. See, for example, the Dutch Archaeology Quality Standards (KNA).[48]

By taking photographs or video images, it is possible to continue research back on land once the excavation is complete. In working with Computer Vision photogrammetry, the video images can be used to create a 3D model of the site, which can be a great source of information before, during and after the excavation. A 3D model of the site where excavation is envisioned can be very useful in refining excavation plans. It can also make it easier for underwater archaeologists to become thoroughly familiar with the site. By studying the images on land, the archaeologists will become acquainted with the site before exploring it under water. This can help to reduce diving time.

It is necessary to document the entire site properly before starting an excavation. In some cases, this process may have already been completed during the archaeological assessment. Archaeological remains can be excavated and documented by drawings, photographs and video images. This can

[48] http://www.sikb.nl/upload/documents/KNA40ontwerp/Protocol%204104%20Opgraven%20%20tbv%20openbare%20reactieronde%20-%20definitief.pdf

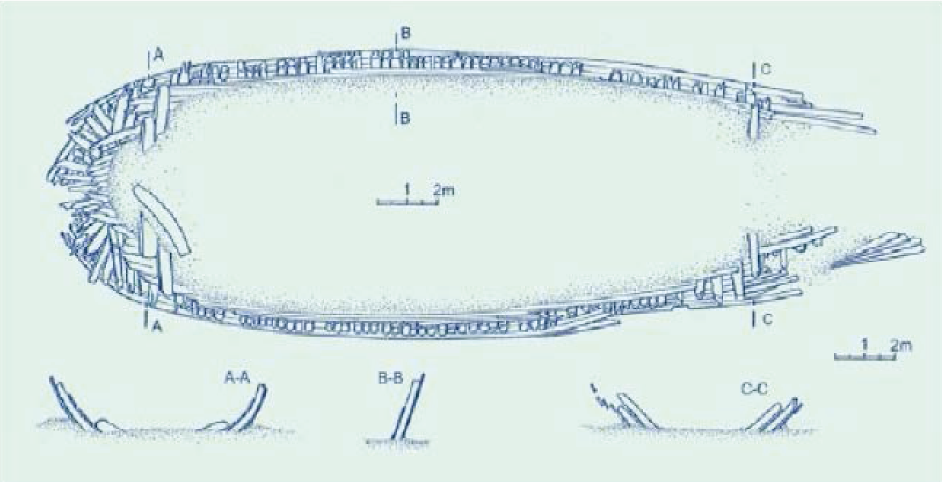


Fig. 27: Drawing of an 18th century Swedish shipwreck in the Gdansk area.

be done with individual objects, but more especially, with objects in their archaeological context. Since excavation will destroy such contexts, they need to be well documented. Archaeological remains should be lifted securely and registered. Some archaeological finds, like ship canons, can be strong enough to withstand lifting. However, many archaeological remains are deteriorated and fragile and require special attention. Smaller metal objects, for instance, can be removed from the sediment by hand if strong enough. If the metal is fragile, it may be wise to perform block-lifting. The metal should not be cleaned when lifted, as that should be done in an environment that is safe for the object. The same applies to smaller pieces of wood. When strong enough, they can be lifted by hand. The more fragile objects, however, can be block-lifted to provide additional support. Waterlogged wooden objects should always be kept wet, preferably with the water in which they were preserved before the excavation.
In each underwater archaeological excavation, different methods are adopted to support and lift finds, including: special containers lined with protective foam, flat sheets, stretchers or polyethylene box-lids, plastic bags, bubble-wrap, plastic string or cotton ties, purpose-built pallets and large trays to support boxes, bags or large objects.

Block-lifting of fragile archaeological materials is regularly carried out on land, but can also be executed underwater. Besides providing support, block-lifting is effective in keeping the components together of fragile objects, including of those that have already fallen apart. Depending on the size of the block, this technique also removes objects with their context until further excavation can continue in a laboratory under controlled conditions. In the

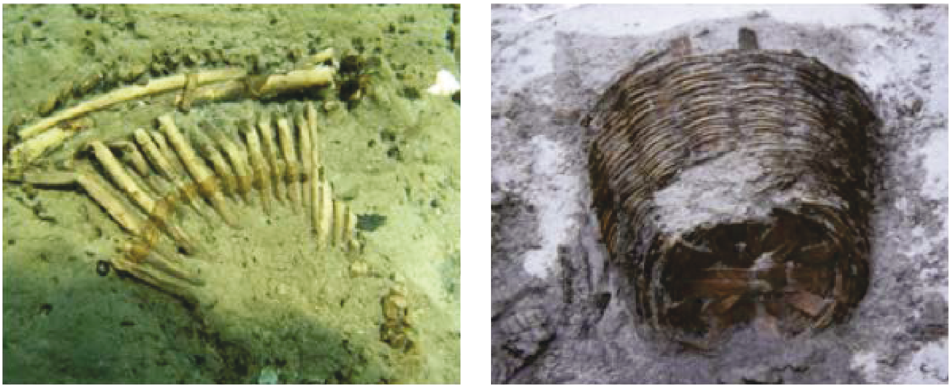


Fig. 28: Two examples of fragile objects retrieved during archaeological excavations. A fish trap (left) and a woven basket (right). Photos VM and MBACT-ISCR respectively.

past, block-lifting underwater was done from time to time, but the procedures are very time consuming.

New developments from SASMAP

In SASMAP, techniques were developed to consolidate objects within sediments for block-lifting purposes. Other products were also developed to stabilise fragile organic artefacts in unconsolidated sediments (such as sand). These techniques make it possible to raise fragile organic artefacts securely and transport them to conservation facilities.
Organic and inorganic consolidates were specially tested in order to determine their suitability. Subsequently, polymers were also tested as consolidates by MBACT-ISCR. These can both encapsulate and consolidate sediments. Finally, tests were conducted, in which artefacts were frozen in sediments in order to facilitate the safe lifting and transport of waterlogged organic archaeological objects. This testing led to the development of four techniques:

- A water and sediment consolidation system that uses superabsorbent polymers to transform the water and sediment containing archaeological finds into a gel, in order to carry them to the surface with no risk of damage.
- A carbon fibre structure as an alternative procedure to block-lifting in different conditions and case studies for block-lifting.
- A fibre glass casting tape as an alternative procedure to block-lifting in different conditions and case studies for block-lifting.
- The freezing of sediments in order to assess the feasibility of using these methods to stabilise and raise fragile organic artefacts.

The results of the SASMAP project are outlined below, together with specific protocols that can be adopted by underwater restorers to recover very fragile artefacts during underwater excavations.

Table 2. Protocol for water and sediment consolidation system

1	Selection of the artefacts being recovered and construction of a box, based on the size of those artefacts. In SASMAP, a cylindrical box was tested, but its shape may vary depending on the size and shape of the artefact being recovered.
2	Preparation of the S.A.P. in a waterproof box.
3	The polymer is taken underwater in this waterproof box.
4	The cylindrical box is positioned on the artefact(s) being placed (in the sediment) and recovered with the aid of a water pump.
5	The polymer is mixed with fresh water or salt water (this depends on the different polymers tested) inside the cylinder.
6	The polymer is distributed underwater over the entire area that needs to be transformed into gel.
7	Once the water has solidified in the sediment, the system (the solidified sediment and/or artefact) can be carried up to the surface and brought to a laboratory.
8	In the laboratory, the S.A.P. is solubilised, using deionised water or fresh water, or is removed, using spatulas. The cylinder also secures the archaeological artefact against moving around. Once it is transported to the conservation laboratory, it can be used as a holding tank for further treatment by sectioning it longitudinally.

Water and sediment consolidation system

Carbogel, a Super Absorbent Polymer (S.A.P.) that has often been used in restoration works, is a neutralised poly-acrylic acid that absorbs water and sediment, with controlled molecular expansion and controlled hardness. By varying the cross-linking agent, it becomes possible to change the polymer's properties, namely the:

- water solidification time (from 10 seconds up to several minutes)
- polymer expansion volume
- hardness of the water gel
- acidity of the system

The Water and Sediment Consolidation System works according to the Protocol in Table 2:

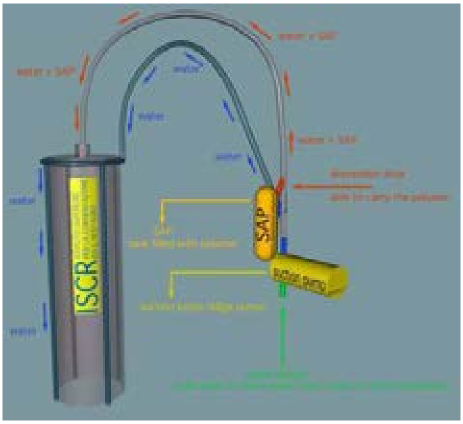


Fig. 29: Diagram of the S.A.P impregnation system. Drawing by MBACT-ISCR

Fig. 30: Phase 3 of the protocol. Photo MBACT - ISCR

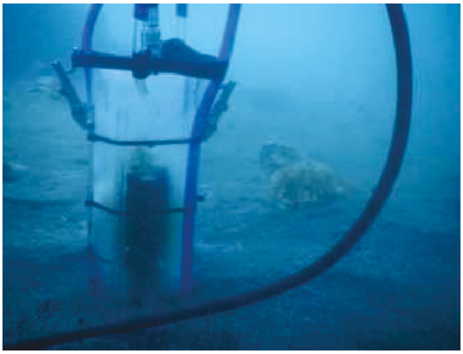


Fig. 31: Phase 5 of the protocol. Photo MBACT - ISCR

Fig. 32: Phase 7 of the protocol. Photo MBACT - ISCR

Fig. 33: Phase 8 of the protocol. Photo MBACT - ISCR

Fig. 34: Phase 5 of the protocol. Photo MBACT - ISCR

Sheet of carbon fibre treated with cured epoxy-time in a plastic bag vacuum

Table 3 outlines the procedures for “composite materials” that encompass sheets of carbon fibre previously treated with cured epoxy-time in a plastic vacuum bag. This structure provides support and protection during the recovery of fragile artefacts in underwater archaeological excavations.

The carbon fibre fabric, impregnated with

Fig. 35: Phase 6 of the protocol. Photo MBACT - ISCR

Fig. 36: An artefact in a carbon fibre shell. Photo MBACT - ISCR

Table 3. Sheet of carbon fibre treated with cured epoxy-time in a plastic bag vacuum system.

1	Selection of the artefact being recovered.
2	A polyethylene vacuum waterproof bag is shaped in the form of the artefact being recovered.
3	Insertion of a multi-layer structure composed of Peel Ply tissue, carbon sheet and Peel Ply tissue. The stratification of the sandwich depends on the dimension and weight of the artefacts.
4	Closing of the plastic bag and creation of vacuum.
5	The two mats in carbon fabric are positioned above and below the artefacts.
6	After waiting for the resin to harden (about 12 hours), the upper and lower mats are placed with plastic clamps and brought to the surface.
7	The carbon fibre fabric, impregnated with epoxy resin, forms a protective shell that adheres to surfaces, protecting the artefact by drying rapidly and preventing potential trauma due to the material's poor state of preservation.

epoxy resin, acts as a solid shell of protection that adheres to surfaces and protects artefacts by drying rapidly and preventing potential trauma caused by the poor state of the material's preservation. One of this system's advantages is its suitability for small and large artefacts (light and heavy), with or without sediment, as it is modular and can be adapted to many different conditions (depending on the state of the artefact's preservation, environmental conditions etc.). It can also serve as an effective temporary storage container for waterlogged organic artefacts.

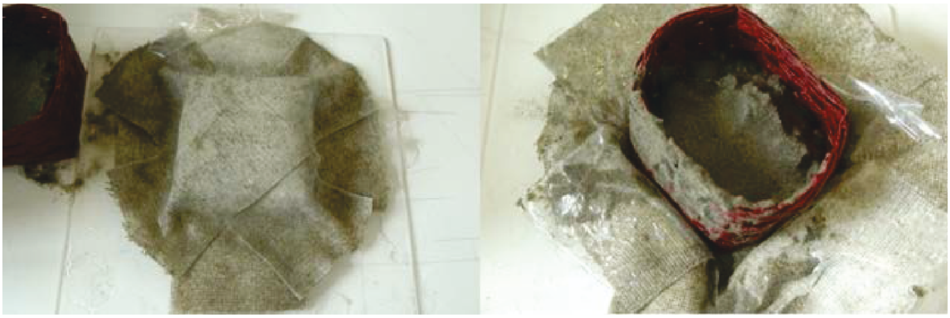


Fig. 37: The 3M™ Scotchcast ™ Plus Casting Tape tested in laboratory. Photo MBACT - ISCR

3M™ Scotchcast ™ Plus casting tape

The 3M™ Scotchcast ™ Plus casting tape is a lightweight, strong and durable casting tape used in orthopaedics that combines the benefits of a fibre glass casting tape with the handling ease of plaster. The tape (bandage) contains a synthetic polyurethane resin, which hardens in contact with water or when simply exposed to moist air, thus enabling immobilization of fragile artefacts. At the same time, it is extremely lightweight and durable. Moreover, the 3M™ Scotchcast ™ Plus casting tape is environmentally friendly and is easily removed post lifting (even if it is in direct contact with the archaeological find). This product is useful for first aid interventions because it is easy to find on the market. Its limitation, however, is that it can only be used for small objects. In fact, the maximum size of the tape measures approximately 4 m by 10 cm.

Freezing of artefacts within sediments

Laboratory tests conducted by the National Museum of Denmark demonstrated that the freezing of artefacts with liquid nitrogen, both alone and within typical sediments, had no detrimental effects on the ultra structure of wooden artefacts. However, it was no longer possible to see the signs of microbial degradation typically formed in the secondary cell wall, an effect which, in certain instances, may not be desirable. Efforts have focused on learning how to scale up from these initial laboratory experiments to a laboratory proof of concept, and how to freeze sediments in practice. In the SASMAP project, the proofs of concept developed outside the laboratory ultimately proved unsafe for use under water. In light of that, further research is needed.

A lifting frame for sediment blocks containing complex and fragile organic artefacts

Block-lifting of sediments containing fragile organic artefacts was developed and trialled during SASMAP.
A frame was developed for block-lifting with a partly modular design so that future designs could be created to expand both in length and width. The frame had separate bottom and top components that were connected with vertical posts of adjustable lengths. Thus, the height of the frame was adjustable, depending

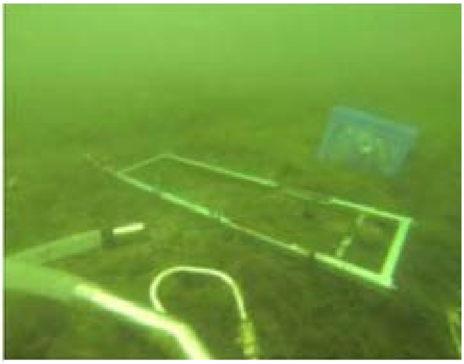
Fig. 38

Fig. 39

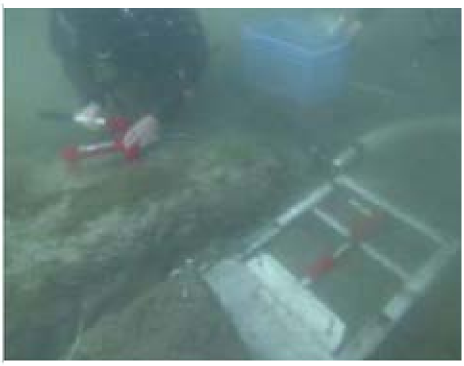
Fig. 40

Fig. 41

Figs. 38-40: Preparation phase of the proof of the modular frame. Photos: The National Museum of Denmark
Fig. 41: Both the bottom and the top components of the frame are mounted with lifting eyes, spreading the weight evenly on the frame during the lifting process. Following the actual mounting stage, the upper/top surface of the sediment block and the exposed section of the artefact would then be covered by stable (soft) material topped with a plate. This is done to protect it against damage during lifting through the water column, especially when breaking the water surface, which is the most critical part of the lifting process.


a.


b.


c.


d.


e.


f.

Fig. 42: Phases of frame assembling underwater

g.

h.

Fig. 43: Trialling of the lifting frame for consolidated sediments. A short film of the process can be seen on the project homepage: www.sasmap.eu

on the thickness of the sediment block; this can vary significantly depending on the shape and structure of the artefact being raised, as well as the type of sediment and method of stabilisation.

The modular construction of the lifting frame ensured easy access to excavate the sediment block under safe conditions on the seabed, and subsequently, in the laboratory, as both the top components and vertical iron posts are removable (Figs. 38-41).

The frame system is assembled in the field, as shown in fig. 42 (a-b-c-d-e-f).

Following lowering of the frame to the seabed (Fig. 42 a), a narrow channel needs to be cut to the required depth around the sediment block that is being lifted. The sediment at the end of the frame is removed (Fig. 42 b) and the block is "undercut" by strong, thin, electroplated iron plates, which are pressed in under the block with the aid of a manual hydraulic pump (Fig. 42 c). In this instance, a manual hydraulic pump was used and functioned well. This pump had a pressure of 4.5 tons; however, manual pumps equipped to handle up to 10 tons of pressure can be used for dealing with very consolidated sediments, such as clays. Following this, rods are fitted to the sides and top of the frame (Fig. 42 d), which allows the aluminium side plates to be fitted (Fig. 42 e). Finally, lifting eyes are mounted on the lower frame (Fig. 42 f) in preparation for lifting the frame and sediment block to the surface. (Fig. 43 g, h).

RESULTS/CONCLUSIONS

The philosophy of intervention with the methods in these guidelines is common to all the materials and techniques tested (whether innovative and fairly unknown, or widely available on the market): artefacts and sediments can be raised as complete units without having to be separated into smaller components. All of these methods and techniques are environmentally friendly and do not damage the artefacts with which they come into direct contact. Furthermore, all of them will be designed to enable excavation to take place under controlled, completely secure conditions.
The lifting frame and sheet of carbon fibre in a plastic bag vacuum are modular techniques useful for lifting small and large artefacts alike. With larger objects, such as hull remains and log boats, sheets of carbon fibre in a plastic bag may prove more suitable, as they can bear tremendous weight without becoming heavy themselves. In fact, the shell itself may also serve as an effective container for temporary storage and first aid restoration treatments.
The 3M™ Scotchcast ™ Plus casting tape is useful only for small objects, and can be considered a good material for our purposes.
The water and sediment consolidation system is an innovative method that could pave the way for new scenarios in recovering fragile waterlogged artefacts from underwater or land excavations. The freezing method may prove to be a useful technique; however, it requires further investigation before it can be used under water.

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Partners

The purpose of the European Collaborative Research Project SASMAP, which develops ‘tools and techniques to survey, assess, stabilise, monitor and preserve underwater archaeological sites’ (2012-2015) is to forge new technologies and best practices in order to locate, assess and manage Europe’s underwater cultural heritage. This final report offers guidelines to the process of underwater archaeological research, in order to support stakeholders and managers in their assignment to improve the decision-making process in the management of underwater cultural heritage.

SASMAP
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