wreckProtect

SEVENTH FRAMEWORK PROGRAMME

Guidelines for Protection of Submerged Wooden Cultural Heritage

2011

Guidelines for Protection of Submerged Wooden Cultural Heritage, including cost-benefit analysis

Editor: M.R. Manders

Texts: Zyad Al-Hamdani, Christin Appelqvist,
Charlotte Gjelstrup Björdal, David Gregory, Martijn Manders

Additional texts and figures: Jon Havenhand, Hans Huisman,
Kristiane Strætkvern, Johan Opdebeeck

Design and layout: Bert van As
Print: Drukkerij Stampij, Amersfoort

wreckProtect

Figure 1: Artificial Seagrass is mounted on a pole and held together with a protective netting. This netting can be removed easily by pulling a handle as demonstrated here. Photo Courtesy WreckProtect Project.

Contents

Summary

This guideline is an aid for the physical protection of wooden shipwrecks and submerged settlements *in situ*. It suggests methods to secure the long term preservation of underwater wooden cultural heritage. Methods discussed will be of interest for the preservation of submerged sites in the Baltic Sea and in other marine and brackish environments worldwide. In order to provide end-users with useful information on estimation of costs associated with *in situ* preservation, the guideline includes cost-benefit analyses.

1 Introduction

1.1 Focus on the Baltic

The Baltic Sea is a brackish marine environment containing a unique and well preserved collection of historical shipwrecks and submerged archaeological settlements. In total nine countries share this unique archive from the past. Today around 16,000 shipwrecks are already registered in the Baltic, many of them of high archaeological significance (Anonymous 2006). The timbers used for ship construction are often extremely well preserved in the Baltic Sea, as the low salinity of the water has prevented growth of aggressive marine borers, which are able to decompose wood within a few years or even months. In this way the Baltic Sea has afforded a good protection for wooden underwater cultural heritage and is one of the few waters in the world where historic shipwrecks and other constructions are found completely intact to provide an unprecedented resource for archaeological and historical research.

During recent decades, signs of a gradual ingress of the wood boring organism *Teredo navalis* into the Baltic Sea have been reported. Especially the attacks of *Teredo navalis* on the German Baltic coast have been the cause of many problems and have resulted in high costs for repairing wooden structures all along that coast. It is thought that some areas were previously free of shipworm and it triggered discussions whether the spread was connected with ongoing climatic changes or just natural variation.

In 2009, the EU-supported project WreckProtect was launched to elucidate the dimensions of the problem. The main aim is to provide museums, archaeologists and conservators responsible for the long term preservation of the underwater cultural heritage with tools for assessing and predicting the threat of the spread of *Teredo navalis* both today and in the future (see also Guideline 3.1). An additional aim is to find reliable and robust methods for protecting shipwrecks and other submerged wooden cultural heritage *in situ* (in this guideline 3.2). With the help of these tools, vulnerable unique shipwrecks in potential 'Hot Spot' areas can be protected before infestation takes place and well- founded decisions can be made as what to do at that moment or in the future (long term planning).

This guideline is a product of the WreckProtect project and will describe various methods for protecting shipwrecks *in situ*. It is important to highlight that the guideline will also be a useful management tool for the protection of wrecks in marine waters outside the Baltic. Marine borers are ubiquitous in the waters of north-west Europe and the Mediterranean and can very quickly degrade archaeological wood. Shipwrecks are continuously attacked by marine borers in saline waters, with the result that all wooden constructions above the seabed are progressively degraded. The only remaining parts of shipwrecks found in the Mediterranean, and other European waters with high salinity, are those which are protected by the sediments because the oxygen level is too low for the activity of marine borers. When sediment is removed by, for example, the dynamic nature of the marine environment, components may become separated from the seabed and are thus accessible to marine borers. In this respect the guideline has a pan-European and even a global relevance and will provide methods to protect newly-exposed wrecks or parts of wrecks from the threat of wood boring organisms, regardless of their geographical location.

The guideline is mainly based on literature studies but unpublished experience is included. Very few protection methods have been thoroughly, scientifically tested and there is a huge potential for development in this field.

Suggested Reading:

Anonymous, 2006. RUTILUS: Strategies for a Sustainable Development of the Underwater Cultural Heritage in the Baltic Sea Region. Swedish National Maritime Museums. Report Number: 1267/03-51, 2006

Djerw, Ulrika and Johan Rönnby, 2003: Treasures of the Baltic Sea. A hidden wealth of culture. Swedish Maritime Museum's Report series no.46.

Monitoring Group on Cultural Heritage in the Baltic States: http://mg.kpd.Lt/LT/7/Underwaterheritage.htm. Website visited 21st of November 2010. Wreckprotect website: www.wreckprotect.eu

1.2 Excavation is an option. Priorities step by step

Although this guideline, and most legal frameworks (see 1.4), emphasize that protection of the underwater cultural heritage in-situ should be seen as a first priority, excavation is still an option. The definition of archaeology is to investigate the material culture in order to learn from the past. This investigation may result in partial or complete excavations. After on-site recording, objects are retrieved for later archaeological analyses, conservation, storage and display. The same principles apply theoretically to underwater archaeology however, marine archaeologists are subjected to many practical difficulties in the aquatic environment which requires specific personnel and technical equipment.

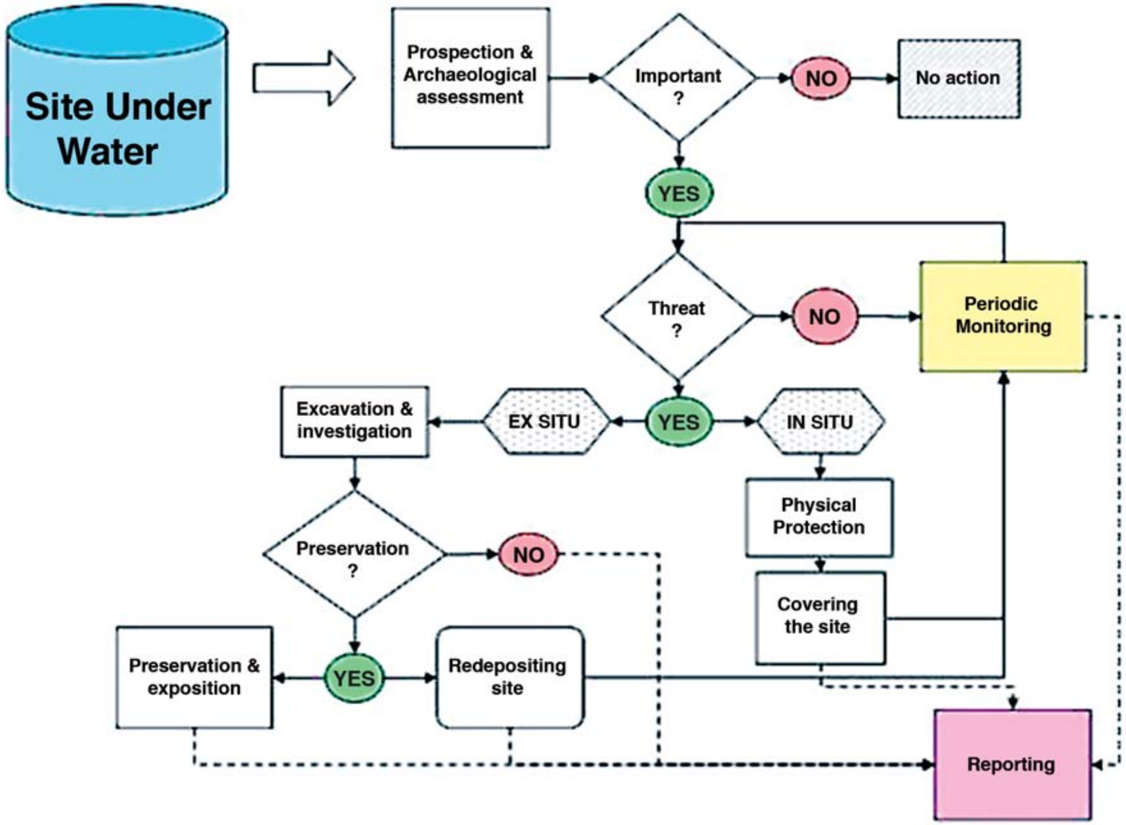
When a new underwater site is located, such as a shipwreck or a submerged settlement, priorities have to be made. As will be discussed in chapter 4.5, the costs associated with the retrieval of a shipwreck are huge and therefore stakeholders responsible for the protection and management of cultural heritage have to make decisions on the approach for a specific object or site. The decision strategy could be as shown in figure 1. The choice will often depend on funding available for the project, but, as the diagram shows, there are many ways to make a good and acceptable choice. Most important is that the project is managed and discussed in a cross disciplinary context involving archaeologists, conservators, divers, engineers, geophysicists, etc.

The Annex (or code of good practice) of the UNESCO Convention for the protection of the underwater cultural heritage (Paris, 2001) shows all the steps that have to be taken into consideration when dealing with intrusive research.

Suggested Reading:

Annex of the UNESCO Convention for the protection of the Underwater Cultural Heritage. http://www.unesco.org/new/en/culture/themes/underwater-cultural-heritage/annex-of-the-2001-convention or at the ICUCH Home page: www.icuch.org [assessed 21-11-2010]

Code of Good Practice for the Management of the Underwater Cultural Heritage in the Baltic Sea Region (COPUCH):



www.nba.fi/tiedostot/e410ebee.pdf [assessed 21-11-2010]
European Convention on the Protection of the Archaeological Heritage (Revised). Valetta, 16.I.1992:
http://conventions.coe.int/treaty/en/treaties/html/143.htm
[assessed 21-11-2010].
ICOMOS Charter on the Protection and Management of Underwater Cultural Heritage of 1996:
http://www.international.icomos.org/charters/underwater_e.htm [assessed 21-11-2010].

Figure 2: The process of Underwater Cultural Heritage Management. Although not taken into account here sites can be partly excavated prior to in situ protection as well. RCE/J. Opdebeeck.

1.3 Significance assessment as part of the decision making process.

Management of a wreck site starts with assessing its archaeological/historical significance and its environment. It determines whether to further investigate a site and its potential for excavation, raising and subsequent conservation. Alternately, in between or after excavation, it may be that the site will be preserved *in situ*. The final option is that the site may only be preserved through documentation known as preservation by record, because it is not deemed to be of significant archaeological or historical significance.

Due to the fact that we cannot investigate everything within the constraints of budgets, staff and time but that we do have to know what our known resources of underwater cultural heritage are, we need to assess sites and prioritise them. We therefore also have to determine their significance in order to be able to prioritise. Determining the significance of a site is highly subjective. By developing objective standards and measures, we can try to make this process as objective as possible or at least comparable. By doing so, we can make the process transparent and open for discussion and improvement.

Underwater cultural heritage management, like all heritage management, is driven mainly by significance. Although it is just one step, it affects and dominates all choices we make in the archaeological heritage management process. Significance determines what we nominate to register. It prefigures the kinds of research questions being asked and it leads us to select what we preserve *in situ* and what we excavate. It determines how we categorise, how we manage, how we mitigate the impacts and even decide whether the site counts as heritage.

By determining the significance of sites, we always have to reflect on the work we have done before. Is one site more important than another? Does the present study have any significance for our understanding of the past?
There are several ways to describe the value and significance in relation to cultural heritage. In the last decade several articles have been published on the philosophy and the methods by which we assess the significance of maritime archaeological sites. Examples are given in the section on suggested reading and are worthwhile consulting in order to get a feeling for the topic and an overview which will help you in selecting or developing a way of assessing significance.

If we look further into value and significance we can distinguish two major types known as the intrinsic value and significance in relation to managing change. These are discussed below.

The Intrinsic Value
This aspect of significance needs to cover a wide range of values in terms of scientific/academic, cultural, social, economic, educative, amenity, community and personal.

Managing Change
This aspect of significance concerns understanding how changes arise, and what the implications are in altering or affecting the intrinsic value considerations. In order to judge this one can apply well- established conservation principles for heritage management. The question is how the Significance of Change is predicted, judged and managed once the key understanding of intrinsic values are established.

Significance of Change cannot be weighed up without considering both the Intrinsic Values and the Types of Change which may occur together with the uncertainties that may exist for both of these. We have to keep in mind the risks and opportunities the site currently has and perhaps the future risks and opportunities. Another area of focus is the sustainability of the site in the long term and the maximum acceptable change. In this way we have parameters for monitoring the site. Predicting changes and setting boundaries for acceptable change are important tools for monitoring, but the actual changes that happen frequently differ from what was expected. Monitoring is therefore a means of checking whether assessments were correct and also for modifying actions to account for new conditions (See more on Monitoring in: 4.4). Determining significance is subjective and it can mean many things. When it has to be assessed several different values should be balanced against each other.

A Management Plan is a tool to structure the work that has to be or has already been undertaken at a site. If structured well, a generic management plan can be used for all sites being investigated and thus compared and used for planning time and budgets.
Within the EU Culture 2000 MoSS project (Monitoring, Safeguarding and Visualizing North European Shipwreck Sites, www.mossproject.com) a structure for a Management Plan was developed. It is especially designed for sites underwater and is not a static but a very dynamic document that is updated each time changes occur on the site. As such, it is an excellent tool in connection to sites that have been, or are going to be, preserved *in situ*. It starts with the assessment of the site, continues with the preservation methods and includes all monitoring actions on site.

Suggested Reading:
Dunkley, Mark, 2008: Hazardous, Bracklesham Bay, West Sussex, Conservation Statement & Management Plan, EH.
English Heritage, 2008: SHAPE 2008: A Strategic Framework for Historic Environment Activities & Programmes in English Heritage, [Online], Available: http://www.english-heritage.org.uk/publications/shape2008/ [Accessed 21-11-2010]
European Communities, May 1999: Guidelines for Assessment of Indirect and Cumulative Impacts as well as Impact Interactions
European Communities, June 2001: Guidance on EIA. EIS Review.
Kenderdine, S., 1997: Culture and Heritage: Shipwrecks and Associated Objects. Australia: State of the environment Technical Paper Series (natural and cultural heritage), Commonwealth of Australia.
Maeer, Gareth, 2007: Values and benefits of heritage: A research Review by HLF Policy and Research Department. Compiled for Heritage Counts.
Management plans used by English Heritage: http://www.english-heritage.org.uk/content/imported-docs/p-t/mgmtplan-rooswijkaug09.pdf [accessed 21-11-2010]
Manders, Martijn, 2004: 'Safeguarding a site: The Master Management Plan', MoSS Newsletter, 3/2004, p. 16-19.
Planarch: Guiding principles for Cultural Heritage in Environmental Impact Assessment (EIA): www.planarch.org [accessed 21-11-2010]

1.4 Reasons to choose *in situ* preservation

With time, the preservation of archaeological sites *in situ* has become more important. This is also the case for maritime archaeological sites under water. The reasons for this are several fold:

- It preserves for the future
- It has a well developed legislative system to protect sites
- The enormous number of newly discovered sites
- It may be cost effective
- There is usually a time gap between discovery and excavation
- It allows for implementation of improved conservation methods in the future

Each of these points is discussed below:

1 It preserves for the future
We have to preserve a representative part of the maritime past for future enjoyment and research. The number of archaeologically interesting submerged sites are immense. It is therefore important to know the extent of the archaeological resource. We also have to investigate the likely meaning of these sites for maritime archaeology and the reconstruction of our past. This can be achieved by assessing each site. Afterwards, the state or condition of sites of high archaeological importance should be preserved. If we don't actively and physically protect the sites, many examples of maritime heritage will be lost forever.

In the past, active *in situ* preservation was carried out with the

Figure 3: Debri-netting just installed on the Avondster Wreck in the Bay of Galle, Sri Lanka. Photo Courtesy Avondster Project.

intention of leaving archaeological sites for future generations or even for eternity. Today we know that protection *in situ* is a way to slow down degradation, but that it is impossible to stop the deterioration of sites totally. This is also the case for shipwrecks and objects which have been raised, conserved and preserved *ex situ*. It is therefore important to have some idea about how long a site can be protected under water by taking certain kinds of measures. The protective measures have to be selected in a way that deterioration of the site can be minimised but so that it is still possible to access the site in the future for archaeological and other scientific research. See for possible methods Chapter 4.

2 It has a well developed legislative system to protect sites
Most countries nowadays have well developed legislation and regulatory systems concerning the protection of maritime archaeological heritage. These countries take the responsibility of preserving not only their own but also common maritime past. The preservation of archaeological sites under water in a legal and physical way is a logical method to manage these sites in a responsible way.

Some international regulations concerning the protection of maritime heritage underwater even go further by stating that *in situ* preservation should be considered as the first option (The Treaty of Valletta of 1992, UNESCO Convention on the Protection of Underwater Cultural Heritage of 2001 and the ICOMOS Charter on the Protection and Management of Underwater Cultural Heritage of 1996).

3 The enormous number of newly discovered sites
The number of submerged sites, notably shipwrecks discovered is steadily increasing and there are insufficient resources to examine them all. Nowadays it is not unusual l to dive as a hobby. Equipment that can look through even the dirtiest water is available as well as equipment that can

penetrate into the seabed. This has caused an increase in the number of archaeologically interesting sites underwater being registered in sites and monuments registers and other archaeological databases all over the world. These more advanced survey methods make it possible for almost everyone to explore the underwater world at a reasonable cost. This increased accessibility to our maritime past has created an immense problem. To be able to keep pace between the amount of sites reported every year and the ones that can be investigated, the maritime archaeological community would need thousands more archaeologists to do the job.

4 Excavation underwater is very expensive
Even though diving is no longer exclusive, all interventions underwater are still expensive. It is still necessary to use special equipment and to be able to work accurately requires many hours under water. In some countries, the underwater archaeologists need special training and licences and are exposed to the challenges posed by weather. This makes an underwater excavation far more expensive than an average excavation on land.
For governments it has been a priority to preserve sites *in situ*. However, this approach also costs money, usually over a long period of time. Costs include monitoring and maintenance of the site.

5 There is usually a time gap between discovery and excavation
Even if a site is likely to be excavated, there is usually a long period of time between discovery and actual excavation.
The following things have to be carried out or established before excavation can be started:

- a non intrusive assessment first, where possible
- a project design
- advance funding for the whole project
- a time table;
- research objectives where details of the methodology and techniques to be employed are defined in the project design
- a competent, suitable and qualified investigating team must be established
- any political or legal issues have to be solved, including ownership of a wreck

The research objectives of an excavation are essential to know. If something is excavated it will never again attain its original form because excavation is destructive and therefore requires strict regulation. It will be impossible to obtain all information encapsulated in a site. Maybe there are hundreds of potential questions if, for example, a cargo or the construction of a ship is studied. By excavating the cargo alone and trying to answer a few questions, you take away the source this limiting the number of answerable questions. It is therefore important to have experience in the field of research and to be acquainted with past research and research agenda before starting an excavation in order to select the most important questions.

6 Awaiting improvement of conservation methods
Another reason to promote *in situ* preservation of shipwrecks, is to keep them in safe underwater storage until new and better conservation methods are developed. For example, the traditional polyethylene glycol (PEG) conservation treatment has lately been questioned because problems with increased sulphur and iron concentration have been identified in timbers of, among others the Vasa Warship in Sweden and the Mary Rose in the United Kingdom. The conservation of iron wrecks has always been a big problem. See also 2.1.3.

Suggested Reading:
European Convention on the protection of the archaeological heritage (Malta/Valletta Convention):
http://conventions.coe.int/treaty/en/treaties/html/143.htm
ICOMOS Charter on the protection and management of the underwater cultural heritage, Sofia 1996;
http://www.international.icomos.org/charters/underwater_e.htm
Manders, Martijn, 2004: 'Why do we safeguard shipwrecks?', MoSS Newsletter, 3/2004, p. 4-6.
UNESCO Convention on the protection of the underwater cultural heritage, Paris 2001:
unesdoc.unesco.org/images/0012/001260/126065e.pdf

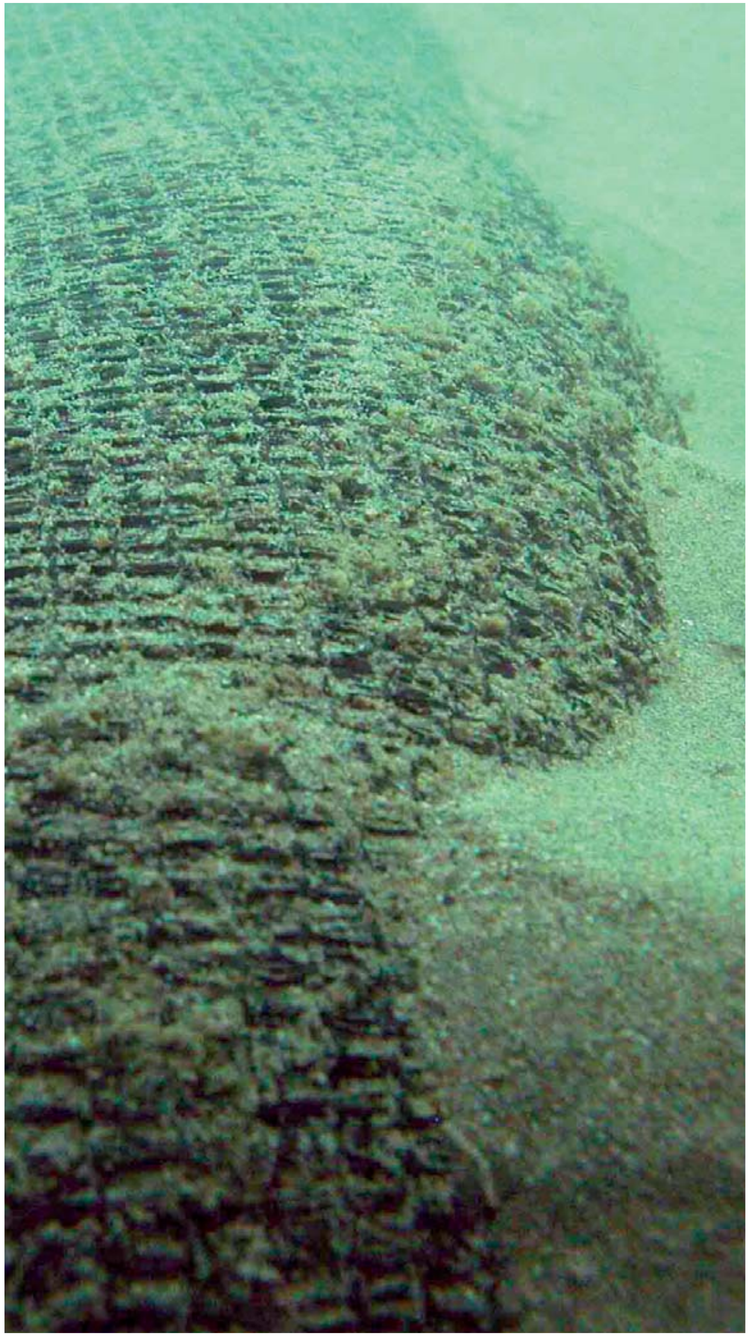


Figure 4: Photo Courtesy WreckProtect Project.

2 A threat must be identified. Submerged archaeological sites under threat

2.1 Introduction

A process based approach to understanding both the site environment and the processes of deterioration of wooden shipwreck sites is essential in order to select the best method of *in situ* preservation.
A scientific understanding of the deterioration processes of wooden shipwrecks is required in order to understand how best to preserve them, where they lie (*in situ*). Thus, a pre-requisite for *in situ* preservation of shipwrecks, is to understand the environment in which the wreck lies and which threats that environment poses to its future preservation.
In the open seawater, mechanical and biological processes are the major causes of deterioration of wooden and organic materials. Chemical processes can also affect the corrosion of iron fastenings and fittings, this again may influence the condition of the wood. Human impact can also cause serious damage. At the seabed the main deterioration agents are microbial and chemical.
The various deterioration processes interact. The microbial softening of the wood may be followed by more severe abrasion due to sediment transport on the seabed in areas with strong currents. The biological weakening of timbers may

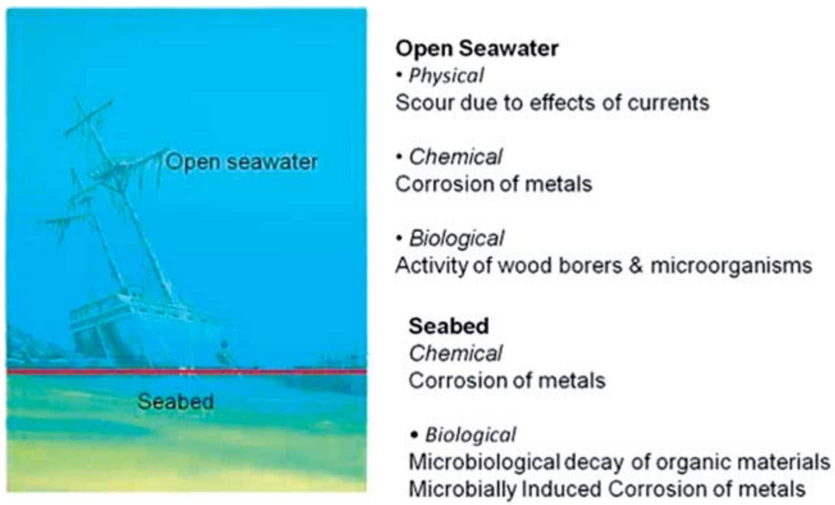


Figure 5: An idealised view of a wooden shipwreck as it may appear after sinking. Effectively the wreck and its component parts will be exposed to two very different environments – the open seawater and the sediments of the seabed.

be followed by physical damage by human impact. The crystallization due to freezing of the seawater first may have an abrasive effect on the soft and deteriorated wood surface and, when the ice becomes a dense mass, the destructive effect will become even more drastic. Ice can also block or reroute currents which will affect the site even more.
Below you can find the major causes of deterioration described briefly.

2.2 Mechanical deterioration

There are several mechanisms which may result in the mechanical deterioration of the underwater heritage. In this chapter the effect of currents, surf, swell,waves and ice on a submerged archaeological site will be discussed.

Currents (at any depth)
Currents can potentially transport many sand particles which in turn have an abrasive effect on all objects protruding from the seabed. This happens even at low current speed. Many wooden waterlogged objects have lost a lot of their sturdiness through biological deterioration and are thus become more susceptible to the abrasive action of the currents. This sanding effect not only weakens the wooden structures, but destroys all the details on the surface of the object.

Another negative effect of the currents are the Eddy currents which develop around objects in the seabed. These local currents will wash away the protective seabed soils, dislocate the coherence of the archaeological layers and potentially expose more of the object, which consequently under further threat by other deterioration processes including attack by *Teredo navalis*, fungi, bacteria and human attack for example by looting.

There are many sources of currents, from the tidal action of the sea to the outwash of river systems. On a larger scale, sea currents can have an enormous impact on the potential archaeological heritage, not because of their abrasive action, but their ability to change the seabed topography on a larger scale. Not only natural, but also human interferences are often the cause of such extreme changes.

Swell and waves (from the high tidal mark to approximately -20m)
Swell or waves have a certain length. The energy of their motion also works downward to the extent of half the distance of the wave length. A storm creates waves which can easily stir up the sea bed to a depth of 20m. The consequences can be drastic on fragile materials such as waterlogged wood. More important, however, is that the surge exposes objects in protective sediments, stirs up the site and redistributes the objects. Uncovered archaeological remains are more vulnerable

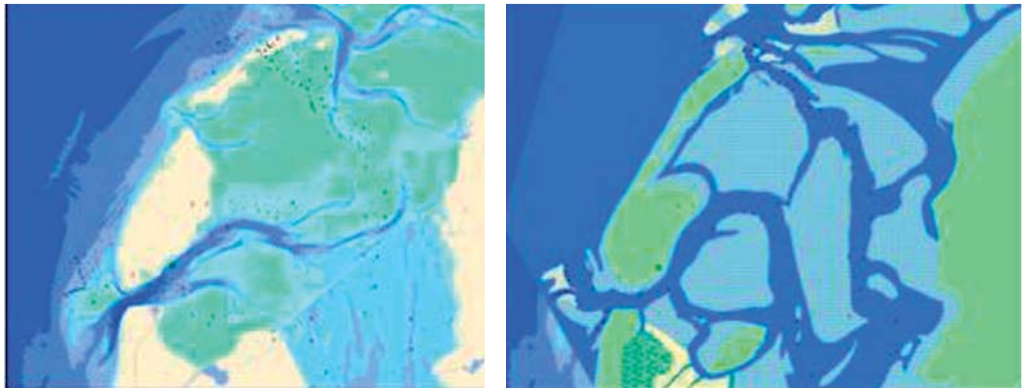


Figure 6: The pattern of gulleys and ditches of the Waddenzee (North of Holland) is still changing today as a result of the closure of the Zuiderzee in 1932. The bathymetry at present (left) and in the 17th century (right). Pictures RWS/RCE/M.Kosian.

to other deterioration such as the *Teredo navalis*. The destructive effect of seasonal storm surges has been examined at archaeological sites throughout the world (Spenneman 1998) .

Surf (from the high tidal mark to approximately -5m)
The surf zone is a high-energy zone. The effect is similar to the swell or wave action.

Ice
In severe winters, the low temperature sometimes freezes the sea water (in normal sea water of 35 ppt the freezing temperature is -1.8˚C). When the seawater begins to freeze, frazil will be formed. This is a scientific name for the forming of tiny crystals only millimetres wide. In rough waters or waters with a high current velocity, the energy and turbulence leave the new ice as a dense suspension of frazil (Wadhams n.y.). The miniscule ice crystals have, like sand particles, an abrasive effect on the archaeological remains. In calmer waters the ice forms thin sheets. The rafting and build up of these ice sheets creates an irregular surface not only above but also under water. This ice mass can reach the bottom in shallow waters and plough the sea bottom. Any archaeological remains will be literally bulldozed away.

Suggested Reading:
Spennemann, Dirk H. R. ,1998 [2004]) 'Conservation management and mitigation of the impact of tropical cyclones on archaeological sites', in Dirk H. R . Spennemann & David W. Look (eds), Disaster Management Programs for Historic Sites San Francisco and Albury: Association for Preservation Technology (Western Chapter) and The Johnstone Centre, Charles Sturt University. Pp. 113-132. Available on: http://csusap.csu.edu.au/~dspennem/PDF-Articles/SFO-19-Spennemann1.pdf [accessed 21-11-2010].
Wadhams, Peter, n.y.: How does Arctic Sea Ice Form and Decay? Available on: http://www.arctic.noaa.gov/essay_wadhams.html [assessed 21-11-2010].

2.3 Biological threats

Organic materials in the ocean are decomposed by microorganisms and invertebrates. Specialized fungi and bacteria are able to degrade wood by relatively slow biochemical processes in contrast to bivalves and crustaceans that effectively fragment wood thus contributing to a fast degradation process. Read more about them in chapter 3.3.

Invertebrates
Wood-boring bivalves, generally called shipworms, belong to the families Teredinidae and Pholadidae. Together they constitute the suborder Pholadina of the Eulamelli-branch order Myoida (Turner, 1966). Shipworms are able to totally decompose a timber structure, such as a shipwreck within a decade and serious damage can be observed after only one year. In contrast to shipworms that penetrate the wood, other wood-deteriorating crustaceans mainly gnaw and burrow at surfaces. At present it is unclear whether wood boring crustaceans host cellulolytic bacteria that can break down the cellulose. However, in the family Limnoriidae, cellulose is degraded during passage through the gut. Members of the family Sphaeromatidae, that don't ingest wood, break down the wood mechanically and in that way also cause enormous damage.

Microorganisms
Specialised fungi and bacteria degrade wood in all types of aquatic environments. The fungi belong mainly to the group of Ascomycetes and Fungi imperfecti, and form what is known as soft rot decay. Using filamentous growth, hyphae penetrate into the wood structure and utilize the woodcomponents (cellulose, hemicelluloses and lignin) via enzymatic processes. Soft rot decay results in a loss of wood cell wall material in the outermost surface layer of the wood, as the fungi are dependent on access to higher levels of dissolved oxygen from the water. Two types of bacteria have been recognized as wood degraders, namely erosion bacteria and tunnelling bacteria. Both groups probably include a wide variety of species. Little is known about their taxonomy and growth as they have not yet been successfully isolated or cultivated in

pure cultures. Tunnelling bacteria require higher concentrations of oxygen for activity, whereas erosion bacteria are able to degrade wood under near anaerobic conditions including interior parts of the wood.

Suggested reading:

Björdal, C. G., Nilsson, T., 2008: Reburial of shipwrecks in marine sediments. A long term study on wood degradation. Journal of Archaeological Science 35, 862-872.
Björdal, C. G., 2010: Evaluation of microbial degradation of shipwreck in the Baltic Sea. Manuscript to be submitted to Journal of Internation Biodeterioration and Biodegradation.
Eaton, R.A., Hale, M.D.C. 1993. Wood. Decay, Pest and Protection. Chapman and Hall, London.
Turner, R. D., 1966: A Survey and Illustrated Catalogue of the Teredinidae, The Museum of comperative Zoology, Harvard University.
Waterbury, J. B., Calloway, C. B. & Turner, R. D., 1983: A Cellulolytic Nitrogen-Fixing Bacterium Cultured from the Gland of Deshayes in Shipworms (Bivalvia: Teredinidae). Science 221, 1401-1403.

2.4 Chemical Threats

Chemical processes can also affect the integrity of archaeological objects. One of the most common processes is the corrosion of iron and other metals. In marine environments, this occurs in oxygen rich environments as well as under anaerobic (reducing) conditions. When oxygen is present, iron corrodes to form iron oxides or hydroxides. Under reducing conditions, typical corrosion products are iron mono sulphides. Iron corrosion products can precipitate in the structure of organic materials including wood, that are in contact with or in close proximity to the corroding iron. Iron monosulphides and disulphides such as pyrite are also formed under reducing conditions in sea floor sediments and can precipitate in organic materials. Iron monosulfides and disulphides may be oxidized in the presence of oxygen. This can happen when shipwrecks that were buried under reducing conditions under seafloor sediment are exposed (e.g. through erosion) to oxygenated water. It is, however, also a common occurrence once the organic materials are recovered from a site. These oxidation reactions produce sulphuric acid and a range of intermediate iron-sulphur species. The strong acidification that results causes a range of degradation reactions in wood, bone and metals. The above-mentioned processes have been identified on several ships, ship fragments and artefacts recovered from the seabed, such as the Vasa Warship in Sweden, the Mary Rose in England, the Batavia in Western Australia and the BZN 3 and 15 and the Ventjager and Roompot wrecks in the Netherlands.
Very slow hydrolysis of polysaccharides and loss of soluble extraxtives are also considered as factors of wood degradation in aquatic ecosystems.

Suggested Reading:

Hamer, Mick, 2002: Ships wrecked, NewScientist, 5 October 2002, 38-40
Huisman, D.J., 2009a: Iron In: D.J. Huisman, Degradation of archaeological remains, SdU, Den Haag, 245 pp.
Huisman, D.J., 2009b: Where does it all start? The origin of reduced sulfur species in archaeological wood, In: K. Straetkvern & D.J. Huisman, 2009, Proceedings of the 10th ICOM Group on Wet Organic Archaeological Materials Conference, Amsterdam 2007, Nederlandse Archeologische Rapporten (NAR) 37, RACM, Amersfoort pp. 577 - 588
Sandström, Magnus, Yvonne Fors & Ingmar Persson, 2003: The Vasa's New Battle. Sulphur, Acid and Iron, Vasa Studies 19, Stockholm.

2.5 Human threats

The threat of man to the underwater cultural heritage (UCH) is enormous. One clear problem is treasure hunting which may cause considerable loss of data and information about UCHs. The primary aim may be making money and not to learn more about the past. This fundamental difference leads to – among others - different selection criteria and different working methods and techniques; for profits and not for the benefits of all. Treasure hunting also attracts a lot of attention from the media and thereby sends the wrong message to the public. However, other threats are at least as destructive as treasure hunting, especially in relation to the quantity of sites being disturbed or even lost. Examples include:

- Sports diving
- Fishing
- Dredging
- Development works
- Pollution
- Ship movements
- Archaeology

The negative effects on a site can be diminished by legal and physical protection, good law enforcement and also by raising awareness. Dredging, infra structural and development works are in many countries included in the Treaty of Valletta legislation and therefore the cultural heritage is, or at least should be, taken into account. Difficult to control are the human effects like ship movements and pollution because it is difficult to make others responsible for the negative effects on the underwater cultural heritage when the direct impact is difficult to measure and to prove.

Although often forgotten, archaeologists themselves may become a threat to the underwater cultural heritage if research is executed in the wrong way resulting in immediate deterioration of the site due to sections the wreck breaking off, trenches being excavated incorrectly, etc. But the effects can also be negative in the longer term. Poor re-covering of the site with sediment may result in deterioration of places that have been stable for centuries.

Some human behaviour may result in damaging the underwater cultural heritage over decades or even hundreds of years. These effects may be taken into consideration when protecting a site *in situ*. One example is climate change, but on a smaller scale this can also be the influence of a newly built bridge, windmill farm or dyke on current patterns and the gulleys on the seabedwhich may result in the erosion of newly exposed sites.

Suggested Reading:

Robert Grenier, David Nutley & Ian Cochran (eds), April 2006: Heritage at Risk –Special Edition- Underwater Cultural Heritage at Risk.

Olsson, Andreas, 2009: Some reflections on underwater cultural heritage management, MACHU Report Nr.2, 48-50.

Figure 7: With sacrificial wood blocks one can also monitor the biological threats a site is facing. Here some woodblocks that have been deployed at the BZN 10 site in The Netherlands for the MoSS Project. After more than a year the free hanging oak and pine wood blocks are heavily degraded by Teredo navalis*. Some blocks are protected with Terram Geotextile. Only the ones with the finest woven Terram 4000 seem to protect against the* Teredo *larvae. See also www.mossproject.eu. Photo Courtesy RCE/MoSS project.*

3 How to identify infestation of *Teredo navalis* on a submerged archaeological site

3.1 Identify risk areas for shipworm attacks

WreckProtect has developed a GIS model for this purpose. See the *Guidelines for predicting decay by shipworm in the Baltic Sea.*

3.2 Detection of shipworm attacks

Shipworms settle onto submerged wood as larvae that undergo a metamorphosis and become a tiny juvenile that grows to an adult, living inside wood. The entrance hole where the larvae first settle is small and enlarges only slightly during the life span of a shipworm. The internal damage could be enormous but with relatively little trace at surfaces (figs. 8 and 9). The organisms filter feed and obtain oxygen by pumping water in and out through their siphons. These tube-like organs are the only part of the animal that is visible outside the wood (fig. 10). The siphons are normally extended out of the entrance holes but will quickly be retracted if they get disturbed. As long as a shipworm places its siphons in an oxygenated environment, it can bore deep into a wreck lying in sediment. Shipworms can survive with wood as the only food source but need oxygen rich water in their burrows for respiration. They can seal their burrows for several weeks if the surroundings become unfavourable.

An additional challenge when looking for signs of shipworm is to find the siphons or the small entrance holes of shipworms among all the other biofouling organisms. There is a lack of hard bottom habitats in the oceans of the world. Therefore, when a ship sinks to the seabed, various marine invertebrates will colonize it relatively quickly and there is strong competition among species for space. Many sessile marine organisms are filter feeders that consume plankton such as shipworm larvae. Consequently the structure of a biofouling community will affect the risk of shipworm attack. However, even a well-developed biofouling community on a piece of wood does not necessarily protect against infestation by

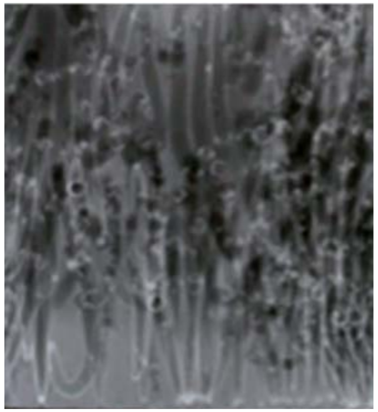


Figure 8 and 9: It is difficult to detect shipworm attacks just by looking at the wood surface. X-ray technique is the best way to visualize the abundance and intensity of attacks within wood. Fig. 8 and 9 are the same piece of wood. Photo credit C. Appelqvist

Figure 10: Shipworms are pumping water in and out through their siphons. Photo credit C. Appelqvist

Figure 11a-d: Examples of biofouling on wood panels 20 x7.5 cm. a) green algae, b) Mytilus edulis, *c)* Ciona intestinalis, *d) X-ray photo of panel c showing hundreds of shipworms inside the panel despite the massive colonisation of tunicates. Photo credit C. Appelqvist.*

Figure 12: Rag worm – not to be confused with shipworm. Photo from www.torbayfishing.com.

Figure 13: Calcium lined tubes by Teredo navalis*. Photo credit J. Havenhand.*

shipworms (figs. 11c and 11d). Dominant biofouling taxa include other bivalves (fig. 11b), bryozoans, anemones, hydroids, polychaetes, barnacles, seastars, porifera, tunicates (fig. 11c), and algae (fig. 11a). The simplest way to detect if a piece of wood is attacked by shipworms is to remove all the biofouling and then search for entrance holes. If living specimens are present, they will extend their siphons after a few minutes.

In addition to biofouling organisms there are also animals which like to live in the tunnels created by the shipworm. Commonly, if an old piece of wood is found, where shipworm are no longer alive and actively degrading the wood, 'Rag worms' (*Nereididae*) can often be found in the holes (fig. 12).

Despite extensive internal damage a wreck that has been attacked by shipworm of the family Teredinidae may remain intact for a long time after infestation because the burrows of these shipworms are lined with calcium (fig. 12). This supporting structure helps to hold the piece of wood together, although the material strength is severely reduced. Such infested wood is very fragile and may easily break upon impact with other objects. In marine environments where small wood eating crustaceans are found in the same habitat, the calcified tubes of the shipworms can be exposed (fig. 13).

Dead or alive

Finding calcified tubes inside a wooden wreck doesn't define whether there is an active (i.e. living) shipworm population in the geographical area or when the attack occurred. To determine this, living specimens must be found either by detecting extruded siphons at the wood surface or pulling the wood apart and find individuals living inside. Dating an attack is sometimes desirable, but inexpensive methods for assigning the time of attack are not available. Isotopic analysis of tube walls and trace elemental fingerprinting of shell material may be suitable methods for addressing these questions.

Suggested reading:

Nair, N. B. and M. Saraswathy, 1971: 'The biology of wood-boring teredinid molluscs.' Advances in marine biology 9: 335-509.

3.3 Distinguishing between damage caused by different shipworm species and other wood boring organisms.

Wood-boring bivalves

The largest morphological difference between shipworms and other bivalves are the reduced shells that function primarily as a drilling tool rather than for protection. In Teredinidae the nearly hemispherical shells cover only the anterior part of the animal (fig. 14), and a thin calcareous layer deposited on the walls of the burrows protects the rest of the worm-like body. Species in this family have also two associated calcified structures at the posterior end, called the pallets. These are used to close the small hole connecting the burrow to the external environment. Pallets and calcified tube walls are absent in the family Xylophagidae (fig. 15). The shells, the pallets and sometimes even the soft parts of the animal are used to identify individuals to species. After settling, shipworms bore into the wood and seldom along the wooden surface. They avoid joints and knots and turn around if they reach the end of timber. The wood looks almost intact except for the entrance holes. The damage is therefore hard to detect by eye, especially underwater. The devastation is often discovered late in the degradation process when the burrows are exposed (figs. 16 and 17).

Figure 14: The anterior end of a half individual of the species Teredo navalis. *Photo credit C. Appelqvist.*

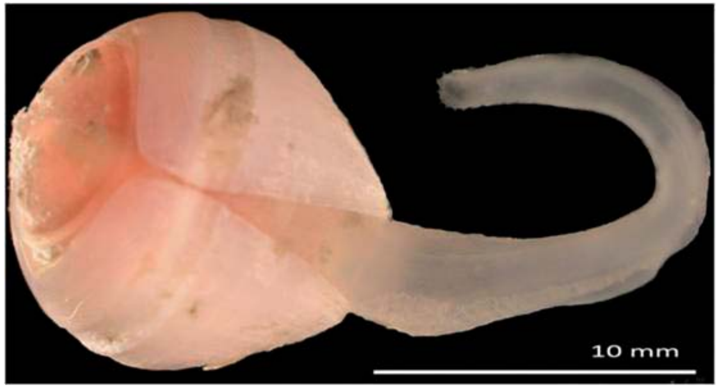


Fig. 15: The wood boring pholad Xylophaga dorsalis. Photo credit C. Appelqvist.

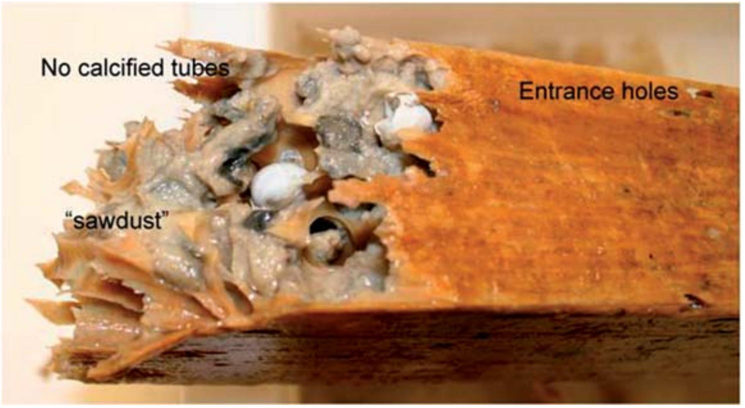


Figure 16: Almost complete degradation of wood caused by Xylophaga dorsalis. Photo credit C. Appelqvist

Crustaceans

In contrast to shipworms that penetrate the wood, wood-eating crustaceans mainly gnaw and burrow at the surface (fig. 18). The species causing most problems are members of the genera Limnoria, Sphaeroma and Chelura. These crustaceans are collectively called gribbles. In areas with very little tidal movements, such as Skagerrak and Kattegat, wood attacked by gribbles often develops an hourglass-shaped

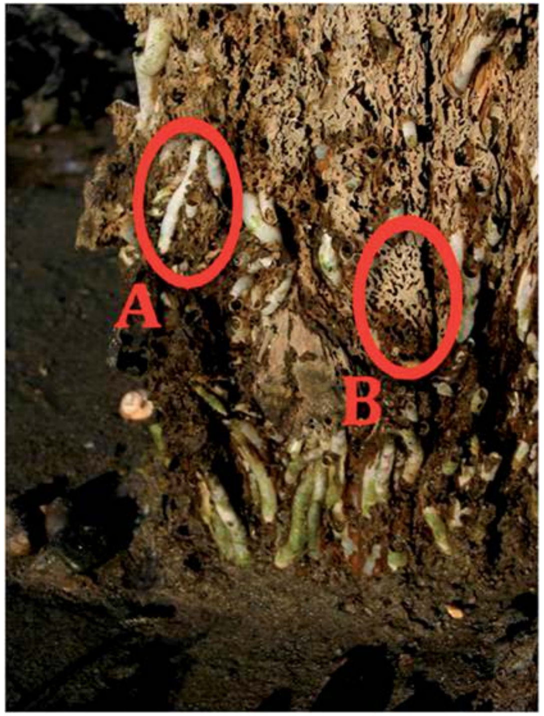


Figure 17: *An infested wooden pole.*
A= calcified tube by the shipworm T. navalis*,*
B= trace of the gribble Limnoria lingnorum*.*
Photo credit J. Havenhand.

Figure 18: A wooden pole degraded by shipworms and gribbles. Photo credit J. Havenhand.

appearance because the predominant attacks occur close to the mean sea water level (fig. 19). However, gribbles also degrade wood in deeper waters. At present it is unclear whether wood- boring crustaceans host cellulolytic bacteria, however it is known that cellulose is degraded during gut passage in the Limnoriidae. Members of the family Sphaeromatidae, which don't ingest wood, break down the wood mechanically and in that way also cause enormous damage.

Micro-organisms

Apart from the ultimate degradation of shipwrecks in the saline water column by shipworm, one should not forget that continuously slow degradation of shipwreck timber takes place in the whole Baltic Sea today. Aquatic fungi and bacteria adapted to wood degradation in both fresh water, brackish water and saline water, makes sure that shipwrecks whether in rivers, estuaries, lakes and seas, will slowly decompose as a part of the carbon cycle in nature. The consequences of microbial degradation of timber is a softening, starting in the outermost layer of the wood, which makes it more sensitive to mechanical erosion of the surface by strong streams and sediment. The decay is invisible to the naked eye, but fungal attack can often discolour the wood black whereas the bacterial decay does not affect the colour. More information on these processes can be found in the references below.

Suggested reading:

Björdal, C. G., Nilsson, T., 2008: Reburial of shipwrecks in marine sediments. A long term study on wood degradation. Journal of Archaeological Science 35, 862-872.
Turner, R. D., 1966: A Survey and Illustrated Catalogue of the Teredinidae, The Museum of comparative Zoology, Harvard University.

Figure 19: A sacrificial woodblock with geotextile forms a perfect hard substrate for sea organisms to grow on. On archaeological wood, this growth may make it more vulnerable for breaking off. Photo Courtesy RCE/MoSS Project.

4 Methods for physical protection of wrecks *in situ*

4.1 Introduction

If an initial assessment of a site's environment reveals that there are 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 of whether it is feasible, both practically and economically, to leave the site *in situ* should be made. It is argued that *in situ* preservation is not a panacea for managing the submerged cultural resource but just one option. Depending upon the nature of the environment and the historical and archaeological significance of a site, excavation followed either by conservation or re-deposition in a more benign environment, may be the only responsible option to ensure that it is preserved.
For wooden wrecks, the two most significant threats are the possibility of further physical deterioration and biological deterioration caused by wood boring organisms. Until we have a better understanding of the nature of the bacteria causing decay within sediments there will always be a very slow degradation of wood due to bacterial decay. To mitigate these processes, sites are often covered using different methods. In the right circumstances, this can both alleviate scour and prevent the activity of wood boring organisms. Generally, covering of wooden wreck sites falls into two categories, known as covering methods and barrier methods.

Covering methods involve covering the timbers with sediment. Barrier methods involve wrapped materials directly around the timbers themselves. Both of these methods effectively create an anoxic environment that the shipworm cannot survive in. In other cases, where the local environment is not conducive to these methods, a site can be excavated and re-deposited / reburied in a more benign environment underwater or on land. Methods which have, and could be used, for the protection of sites will be discussed below with some tips for their use.

4.2 Evaluation of methods

Covering Methods
Covering sites with sediment or other materials functions by limiting the access of oxygen to the shipworm. In environments where sediment transport is not prevalent, a covering of just a few centimetres is sufficient to prevent the diffusion of oxygen and thus the growth of shipworm.

Sandbags
Sandbagging has often been used in the past as the unit costs are low and they effectively act as a barrier against shipworm by creating an anoxic environment in which the shipworm larvae cannot settle.

Tips for use
Deployment is often expensive and time consuming in terms of person hours used and the difficulty of moving sandbags underwater.

Figure 20: An example of sandbagging over the Duart Point Wreck site. Photo courtesy of Dr. C. Martin.

Quite often sand bags are overfilled so that they create an obstruction on the seabed which, if currents are present on the site, can cause scour around the edges of the sandbagged areas. This undermines them and exposes new areas of wreck to exposure. As a rule of thumb only fill a sand bag a third to half full. Try to use fine grained sand with a low organic content. It is then possible to 'mould' the sand bags around structures and keep as low a profile as possible.
It is extremely important that synthetic sandbags are used as any made of natural material will be microbially degraded very rapidly, probably within months.
Sandbags have been used in many instances, see further reading. Although as with many of the methods researched there is a lack of systematic assessment or long term monitoring of the efficacy of *in situ* stabilization methods it may be seen as a temporary method to stabilize. Sandbagging is effective for small areas and those where currents threaten to totally remove archaeological material.

Suggested Reading:

Oxley, I., 1998: The *in situ* preservation of underwater sites. In: M. Corfield, P. Hinton, T. Nixon and M. Pollard (eds.), Preserving archaeological remains *in situ*, London, 159-173.
Richards, V, Godfrey, I., Blanchette, R., Held, B., Gregory, D. and Reed, E., 2009: *In situ* monitoring and stabilisation of the James Matthews shipwreck. In K. Strætkvern and D.J. Huisman (editors), Proceedings of the 10th ICOM Group on Wet Organic Archaeological Materials Conference, Nederlandse Archaeologische Rapporten 37, Amersfoort, The Netherlands, 113-160.
Steyne, H., 2009: Cegrass, sand & marine habitats: a sustainable future for the William Salthouse. In V. Richards and J. McKinnon (editors), Public, Professionals and Preservation: Conservation of Cultural Heritage. Archaeology from Below: Engaging the Public. AIMA/ASHA/AAMH Conference 24-28th September 2008, Adelaide.
Soulsby, R., 1997: Dynamics of Marine Sands, A manual for practical applications. Thomas Telford, London, 174-179.

Figure 21: Sandbags should be placed needly together and filled only approximately 1/3rd to create large well protected surfaces and to prevent scouring as much as possible. Photo Courtesy WreckProtect project.

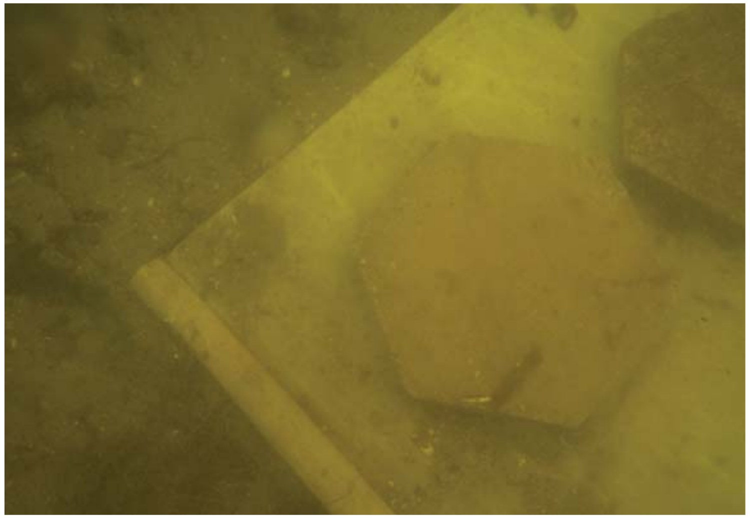


Figure 22: Geotextile has a large buoyancy. It is therefore important to weight it down during and after deploying. Photo Courtesy WreckProtect Project.

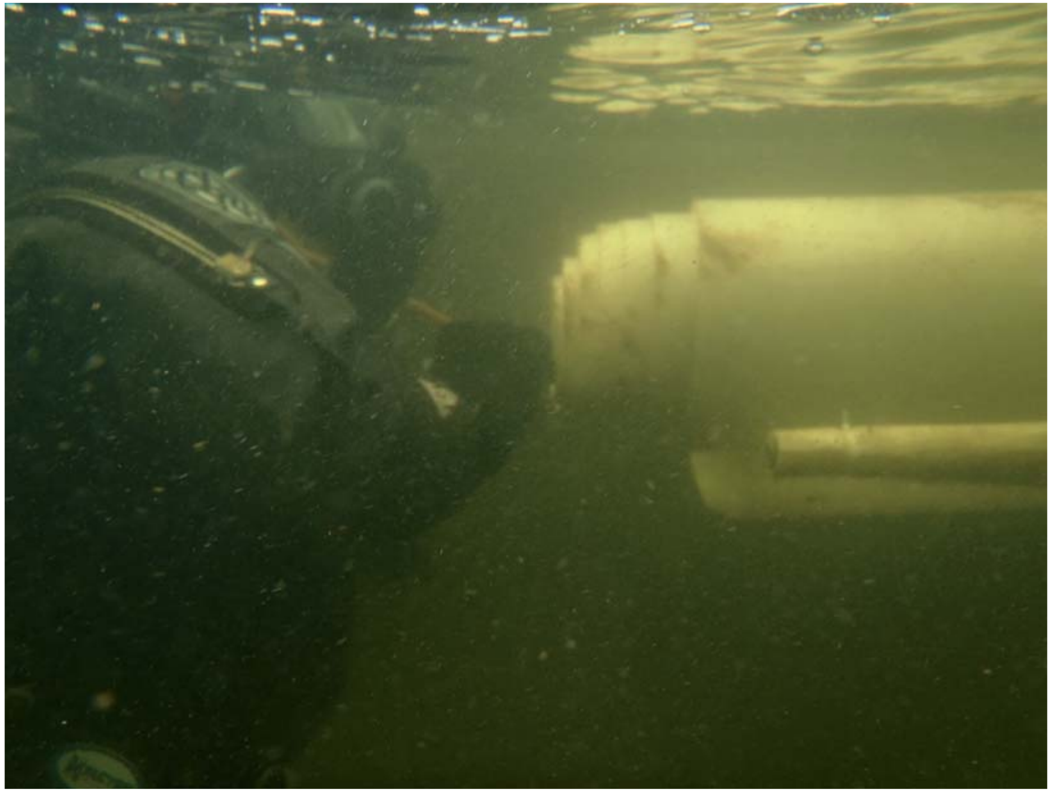


Figure 23: A role of geotextile (on an iron pole) being taken down by a diver. Photo Courtesy WreckProtect Project.

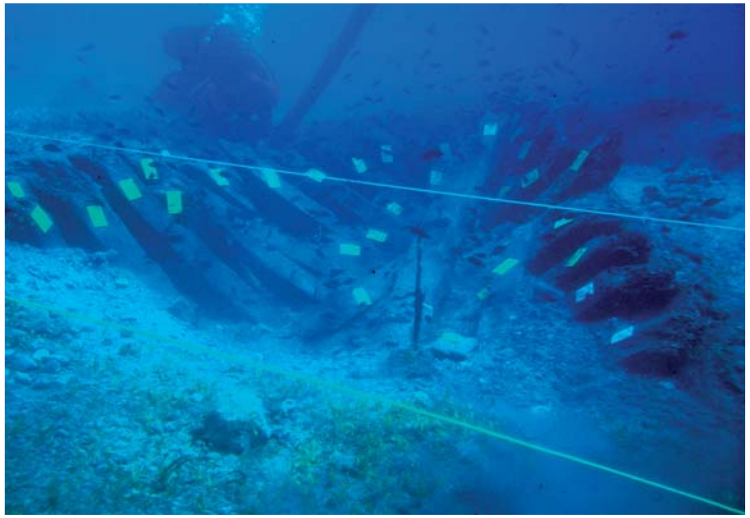


Figure 24: The Zakynthos wreck (Courtesy of Katerina Delaporta).

Figure 25: Timbers covered with geotextile (Courtesy of Anastasia Pournou).

Geotextiles

Geotextiles are finely woven or non woven synthetic fabrics and have been used in coastal engineering to prevent coastal erosion. They have also been used as physical barriers to protect against shipworm on archaeological sites. Research carried out on the wreck known as the Zakynthos wreck (Pournou, Jones & Moss 1999) has shown that a specific grade of geotextile, Terram 4000, was effective at preventing the larvae of shipworm settling on the wood. Similarly in the EU MoSS project, work with geotextiles showed the same results, as has research on the wrecks of the HMS Colossus (Camidge 2009) and the Swash Channel wreck (Palma, 2009). The flexibility of the fabrics makes them ideal to mould around timbers which are standing proud of the seabed.

Tips for use:

- Geotextiles can be extremely buoyant and it is good idea to wrap the geotextile round a metal rod or use other methods in order to add weight.
- If large areas are to be covered, insert eyelets in the geotextile, which can then be joined using cable ties in order to cover a larger area.
- When unrolling it is often easier if there are two divers to do this.
- Ensure that any current is behind the divers which will also facilitate unrolling of the geotextile.
- A following diver can place sand bags to weight the geotextile as it is being rolled out in order to prevent it floating.

Producers of geotextile:

Terram: www.terram.com
Propex: www.geotextile.com

Suggested reading:

Camidge, K., 2009: 'HMS Colossus, An experimental Site Stabilization', Conservation and Management of Archaeological Sites, vol. 11, no. 2, pp. 161-188.
Pournou, A., Jones, A. M., & Moss, S. T., 1999: '*In situ* protection of the Zakynthos wreck'. In: Proceedings of the 7th ICOM Group on Wet Organic Materials Conference, Grenoble 1998, ICOM, 58-64.

Figure 26: Artificial sea grass

Initial sediment build-up covering mat base and the foot of the fronds

Continued sediment build-up in centre of the mat and sloping to and beyond the mat edges.

One year after installation at the previously scoured pipeline with a fully developed sediment bank formed over fronds with marine life colonies on the final bank.

Figure 27: How artificial sea grass functions (Seabed Scour Control Systems LTD).

Palma, P., 2009. Environmental study for the *in situ* protection and preservation of shipwrecks: the case of the Swash Channel wreck. In: Ars Nautica, 7-9 September 2009, Dubrovnik. (Submitted)

Covering with the help of sediment transport

Although these Guidelines are to protect sites from the threat of wood borers, in particular Teredo, underwater archaeological sites are also threatened by sediment transport. There are several methods which could be used where sediment transport is used to our advantage. They work on the principle that if there is sediment transport in the waters around the site this can be trapped and held in position in order to cover the site.

Artificial Sea grass

A method which is used in the offshore industry for stabilising pipelines and cables involves the use of artificial sea grass. There are several proprietary makes on the market all of which function on the same principle. One of the major suppliers of artificial sea grasses is Seabed Scour Control Systems (http://www.sscsystems.com). The way the system works is graphically described below.

Tips for use:

- Ensure that there is sediment transport on the site. Look for bed forms i.e sand ripples on the seabed.
- Where possible align the long edge of the net perpendicular to the direction of any current in order to trap the maximum amount of sediment.
- Make sure that if there is any current when positioning the mats that it is behind the diver in order to facilitate the rolling out of the net.
- After installing it is beneficial to regularly 'rustle' the fronds to make sure they are not filled with seaweed or other detritus.
- The mats can be quite expensive, especially in the scheme of archaeological projects. The artificial sea grass from Seabed Scour controls are supplied as 5 x 3 m rolls.
- Relatively easy to deploy from smaller vessels. However, these mats are fastened by anchors which penetrate 50 cm into the seabed and could damage underlying archaeology.
- In strong currents the sea grass fronds can actually lie down flat and are ineffectual at collecting sediment
- Collected sediment can be scoured out

Notable examples where artificial sea grasses have been used or trialled are on the wrecks of the William Salthouse (Steyne 2009) the James Matthews (Richards et al, 2009) and the Hårbølle wreck (Gregory et al, 2008).

Producers of Artificial Sea grass:

Seabed Scour Control Systems (http://www.sscsystems.com)

Suggested reading:

Gregory, D., Ringgaard, R. & Dencker, J., 2008: From a grain of sand a mountain appears. Sediment transport and entrapment to facilitate the *in situ* stabilisation of exposed wreck sites. Maritime Newsletter from Denmark, Syddansk Universitet. 23, 15-23.

Richards, V, Godfrey, I., Blanchette, R., Held, B., Gregory, D. and Reed, E., 2009: *In situ* monitoring and stabilisation of the James Matthews shipwreck. In K. Strætkvern and D.J. Huisman (editors), Proceedings of the 10th ICOM Group on Wet Organic Archaeological Materials Conference, Nederlandse Archaeologische Rapporten 37, Amersfoort, The Netherlands, 113-160.

Steyne, H., 2009: Cegrass, sand & marine habitats: a sustainable future for the William Salthouse. In V. Richards and J. McKinnon (editors), Public, Professionals and Preservation: Conservation of Cultural Heritage. Archaeology from Below: Engaging the Public. AIMA/ASHA/AAMH Conference 24-28th September 2008, Adelaide.

Debris Netting/Shade cloth

Debris netting is the net like material which is used when carrying out construction work on buildings in order to prevent any building debris falling on passersby. It was first developed for archaeological use in the Netherlands and was

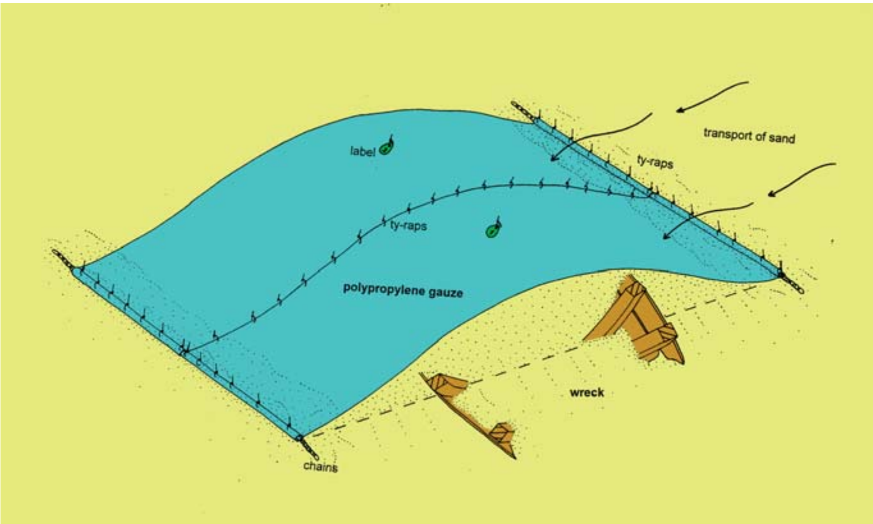


Figure 28: Schematic of how the debris netting functions. Drawing M. Manders.

further developed in the EU MoSS Project (Manders 2004). The debris netting functions in a similar way to the artificial sea grass. The idea is that the net is fastened loosely over the structure to be protected, so that it floats in the water. As with the artificial sea grass the method is dependent upon there being currents and sediment transport in the water. If there is sediment transport and the sediment is of a fine enough grain size to pass through the mesh then, because of friction, the sediments will be slowed and come out of suspension and become trapped under the net creating a burial mound underwater (figure 28).

Tips for use:

- Ensure that there is sediment transport on the site and that you have an idea of what kinds of sediment are being transported in terms of their particle size.
- Select debris netting which has a mesh size large enough for the sediment being transported to pass through. A good type of net where there is a compromise between strength and mesh size is what is termed a 'Windbreak net' 230 gm-2 mesh size 5 x 2 mm.
- Most debris nets are supplied in 50 meter rolls which are 2-3 m in width. Cut the length desired and wrap the net around a metal rod to give weight as the net is extremely buoyant.
- Insert eyelets on the edges of the net both to enable fixing of the net into the seabed and joining nets together.
- When joining the nets together, make sure there is an overlap between the two. In this way you avoid getting holes between the nets when they tighten due to the sediment build up.
- Where possible align the long edge of the net perpendicular to the direction of any current in order to trap the maximum amount of sediment.
- Make sure that any current is coming from behind the diver when positioning the net in order to facilitate the rolling out of the net and also to avoid entanglement.
- The net must not be stretched tight on the seabed but should be loose. For example when trying to cover a length of 5 meters, a 6 meter length of net is cut and only rolled out to 5 meters so that there is enough loose material to float in the water column.
- The net can be fixed to the seabed either with long pegs which penetrate the seabed or heavy material such as anchor chain or sandbags.
- In order to give the net buoyancy, attach small fishing buoys to raise the net from the seabed.
- After initial installation monitor the net and shake it to remove any sediment which is lying on top of the net and attach further buoys if necessary.
- Ensure the net is not tearing where pins have been used for anchoring it.
- Parts of the wreck that protrude from the seabed may initially damage the nets which are loosely placed on the site. To avoid this, one can cover these parts with sandbags or add sediment with a water pump before or just after installing the nets.

The method has been used successfully on several sites notably the wreck of the Burgzand Noord 10 in the

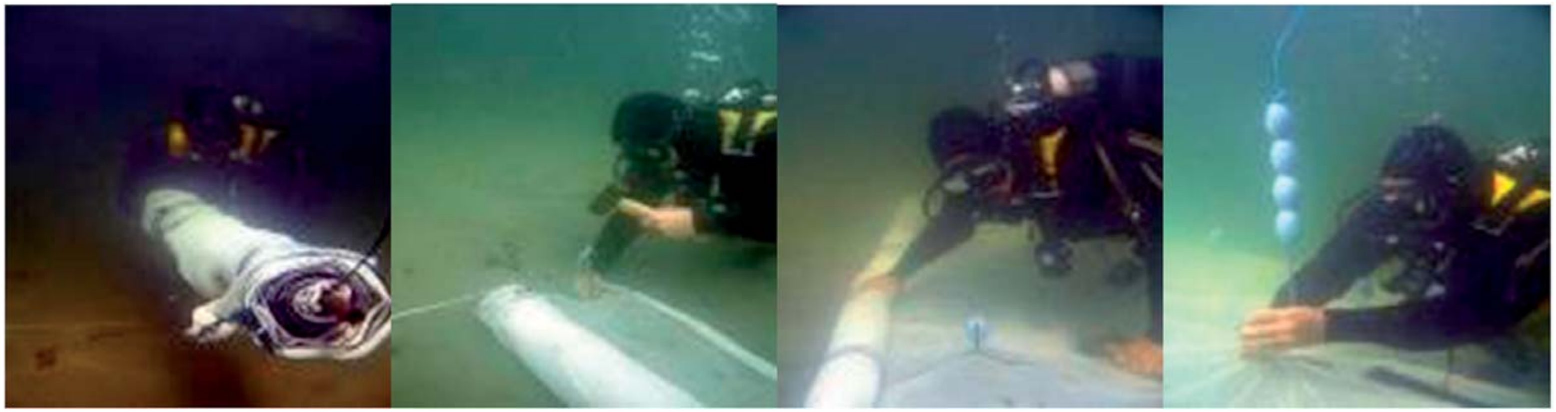


Figure 29: from left to right: A prepared net being carried to the site. Fixing the leading edge of the net with metal hooks. Rolling out the net. Fixing extra fishing buoys for extra buoyancy.

Netherlands (Manders 2004, 2006 (b)), the Avondster in Sri Lanka (Manders, 2006 (a)) and the Darsser Cog in Germany (Jöns 2003) and was successfully trialled around the wreck of the Hårbølle site in Denmark (Gregory, 2008). However, trials of the netting on the HMS Colossus (Camidge, 2009) and the wreck of the Swash Channel (Palma, 2009) were not deemed successful. This again stresses the need to understand the way *in situ* stabilisation method works and that they are not necessarily going to be effective on every site.

Debri net producers:
UK: Coastal nets:
http://www.coastalnets.co.uk/industrial_main.htm
USA: Several: http://www.macraesbluebook.com/search/product_company_list.cfm?prod_code=5182050
South Korea: Tasco Ltd: http://www.alibaba.com/product-free/102525712/Scaffolding_Net.html

Suggested reading:

Camidge, K., 2009: 'HMS Colossus, An experimental Site Stabilization', Conservation and Management of Archaeological Sites, vol. 11, no. 2, pp. 161-188.
Gregory, D., Ringgaard, R. & Dencker, J., 2008: From a grain of sand a mountain appears. Sediment transport and entrapment to facilitate the *in situ* stabilisation of exposed wreck sites. Maritime Newsletter from Denmark, Syddansk Universitet. 23, 15-23.
Jöns, Hauke, 2004: Safeguarding the Darsser Cog, MoSS Newsletter, 3/2004, p. 8-11.
Manders, Martijn, 2004: 'The Safeguarding of BZN 10', MoSS Newsletter, 3/2004, p. 6-8.
Manders, M.R., April 2006a: 'The *in situ* protection of a Dutch colonial vessel in Sri Lankan Waters', in: Robert Grenier, David Nutley & Ian Cochran (eds); Heritage at Risk –Special Edition- Underwater Cultural Heritage at Risk, 58 – 60. Manders, M.R.,April 2006b: 'The *in situ* protection of a 17th century trading vessel in the Netherlands', in: Robert Grenier, David Nutley & Ian Cochran (eds); Heritage at Risk –Special Edition- Underwater Cultural Heritage at Risk, 70-72.
Manders, Martijn, David Gregory, Vicki Richards, 2008: The in-situ preservation of archaeological sites underwater: an evaluation of some techniques, in: Eric May, Mark Jones, Julian Mitchel (eds): Heritage Microbiology and Science. Microbes, Monuments and Maritime Materials, The Royal Society of Chemistry, 179-204
Palma, P., 2009. Environmental study for the *in situ* protection and preservation of shipwrecks: the case of the Swash Channel wreck. In: Ars Nautica, 7-9 September 2009, Dubrovnik. (Submitted)

Covering with sediment

Reburial underwater

As discussed, shipworm cannot survive for long periods in the absence of dissolved oxygen and it is the fact that wood when buried in the seabed will only be susceptible to slow microbial degradation caused by fungi and bacteria due to the lack of oxygen in marine sediments. Thus, covering or re-burying wood is one way of preventing further attack by shipworm. Covering or re-burial has been achieved by several methods including natural or intentional backfilling of timbers after excavation, sediment dumping or deflection of sediments to cover a site *in situ*. Furthermore artefacts have been re-buried after raising and documenting. These methods and where they have been used will be discussed.

Backfilling

It is rare that a shipwreck site will be completely excavated during the course of a single excavation period. Alternately a site may not be completely excavated if the whole hull is not to be removed. Thus between excavation periods sites are often either purposely re-covered with sediment or left to naturally be covered by sediment. This covering is essential if the area is known to be affected by shipworm. The summer months, when most excavations take place, are prime breeding time for shipworm, thus it is extremely important that sites are not left uncovered. However, for backfilling to be successful it should be known that the these sediments will not be removed due to sediment transport.

Sediment drop

Backfilling is usually carried out by divers on the seabed using suction dredges or buckets and spades to simply fill in the trenches created during the excavation. However, this can also be carried out in combination with a sediment drop. As the name suggests sediments in a boat or barge are dropped over the site and they are either left to naturally settle on the site or are moved by divers to backfill any exposed trenches. This approach has been used on many sites as it is seen to be cost effective as divers do not have to be used so much, and that large areas can be carried out at a time. However, as with all these methods one has to understand the environment the methods are being carried out on. For example if there are currents in the water sediment may not reach the site. Furthermore, if the sediment is not covered with a geotextile, sandbags, geomembrane or another form of barrier sediment, it can be lost due to subsequent sediment transport. Even though a relatively thin coating of sediment is enough to prevent the action of shipworm the depth of sediment cover needs also to be deep enough to reduce the effects of microbial deterioration.

Reburial

One of the first attempts of 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 flows. What set this early project aside from other reburial attempts at the time was that monitoring of the reburied timbers and the surrounding reburial environment was planned from the outset – as will be discussed in the next section. 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. The burial mound was then covered with a heavy duty plastic tarpaulin anchored by concrete filled rubber tyres.

A similar project was recently started in Sweden, which set out to validate the efficacy of reburial of archaeological materials in the marine environment. The Reburial and Analysis of Archaeological Remains project focuses on the reburial of artefacts from the wreck of the Fredericus (1719) in the Swedish island port Marstrand. Archaeological investigations were initiated in the harbour because of the need to reinforce the quay. Two major investigations were undertaken. One was an excavation of the wreck of the frigate Fredericus, sunk in a battle between Sweden and Denmark and the other was an investigation of an area alongside the quay, which revealed cultural remains dating back to the 17th century. These two excavations yielded approximately 10,000 artefacts. 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 should be re-buried after proper archaeological documentation.

Amongst other materials (a shipwreck rarely consists of just wood) modern wood samples were left exposed to seawater and reburied at various depths down to 50cm. Preliminary results after three years of re-burial show that those samples left exposed to seawater were rapidly and heavily degraded by wood borers whereas those covered by sediments were microbially degraded. The results reflect the Red Bay wreck and other experiments on re-burial of wood that even a thin covering of sediments is significant enough to limit the amount of oxygen in the sediment for the shipworm to survive.

Figure 30: Example of a flexible PVC barrier material on a timber pile.

Tips for use:

- Assess whether there is sediment transport over a site. If there is and it is significant one of the previously described methods may need to be applied or the re-buried site covered with a geotextile, plastic geomembrane or coarser grained material (gravel) to ensure the sediment is not removed.
- Local sediment from surrounding areas is often used for reburial and should be characterised for its suitability. It is recommended that the porosity and organic content of any sediment should at least be assessed. Sediment should ideally be fine grained sands, which are less porous and naturally contain less organic material due to their larger particle size. This leads to lower rates of mineralisation when the dominant process is sulphate reduction, which is typical of marine sediments. This contrasts with the higher rates of mineralisation in more porous finer grained sediment with higher organic contents.
- An optimal depth of burial is dependent upon the nature of the sediment to be used. However, even a thin covering of sediment will limit the oxygen content sufficiently to prevent the survival of wood borers.
- Try to re-bury artefacts in one layer so that it is easier to return to the area and remove timbers which may be required for further analysis
- Ensure that there is a good site plan for any reburial and that it is easy (relatively) to come back and find specific timbers
- Ensure that any materials used in the reburial, including labels, containers are durable. See further reading.

Suggested reading:

Pomey P. (1999): Remarques sur la consevation *in situ* du bois de quelques épaves antiques de Méditerranée, in: Proceedings of the 8th ICOM WOAM, Grenoble 1998, 53-57.

Stewart, J., Murdock, L.D. and Wadell, P., 1995: Reburial of the Red Bay wreck as a form of preservation and protection of the historic resource. In P.B. Vandiver, J.R. Druzik, J.L.G. Madrid, I.C. Freestone and G.S. Wheeler (eds), Materials Issues in Art and Archaeology IV, 352: 791-805. Pennsylvania.

Barrier Methods
Geotextiles have already been discussed and they can serve as a barrier method. Other materials include plastic films such as PVC barrier materials. Flexible barrier materials which have been placed around pilings may also have potential applications for archaeological timbers which are standing too far proud of the seabed to cover with sediment. These to the best of the authors' knowledge have not been used archaeologically. However, they would function by creating a physical and oxygen free barrier around the timber to be protected. In this manner the shipworm larvae cannot attach themselves to the wood surface. Furthermore, any living shipworm in the timber will not be able to respire due to the lack of oxygen. There are several proprietary manufacturers of these materials. One of the major manufacturers is Pile-gard (http://www.barrierimp.com) and the flexibility of the material would appear to allow the material to be moulded to timbers.

4.3 Choice of method

Introduction
At present several methods for the physical protection of underwater cultural heritage sites are used. Most of them are developed specifically for the use at a particular site or environment. However, the used methods may often be partially applied to other situations. Below are two tables. The first (Table A) explains the effectiveness of different methods for different types of environments. The second table (Table B) shows how different methods of *in situ* preservation mitigate against specific threats. The authors of this guideline realize that it is very difficult to compare the use and effectiveness of the different *in situ* preservation methods. However, we hope that with the help of the guideline and the overview created with the tables below you can decide which physical method to chose to preserve your underwater cultural heritage site *in situ*.
The table consists of +, ++, - and 0. A single + means that to our knowledge the methods works in this typical environment. ++ means that it works excellently. Symbol – means that the particular *in situ* method has a negative effect on the site for this environment. Symbol 0 means that it has no specific effect (neutral). We have tried to isolate the specific elements in an environment. In practice an area always consists of several of the parameters mentioned. Sometimes only one of these parameters prevails, sometimes a combination of several.

The BZN 10 site in the Netherlands lies in the Wadden Sea, The Netherlands. This area consists of a sandy seabed, some flat areas and undulated seabed with salt water and strong tidal currents. It also lies totally submerged in 9 meters of water. It has been protected physically with polypropylene (debri) nets. These nets score + to ++ on all parameters and in practice the polypropylene nets work excellently. A site which is situated in 10 meter of fresh, still water cannot be well protected by either debri nets or sea grass, due to the fact they are at their best when the waters aremoving and sediment is in suspension. Geotextiles may be used in two different ways, as a layer in between sediments and archaeological objects or alone as a barrier method, wrapping the objects and the structure in geotextile. These different uses make it effective in different cases. The rubber sheeting method that has been used on the Stora Sofia in Sweden represents various methods that cover a site, but which do not actively capture sand. These kinds of methods should always be used in combination with for example additional sand deposits.

Table B works in the same way as table A, with +, ++, - and 0. We see that cages are effective against looting, but not against any other deterioration factors. They may even have a more negative effect, especially when there are currents around the site (see also Table A). However, on the other hand, this is also the only method of physical *in situ* protection that helps to raise awareness unlike all the other covering methods (out of sight, out of mind). We also see that there is not much effect on the bacterial deterioration by any of the methods. Some(erosion) bacteria can continue to deteriorate the wood in near anaerobic conditions. We have to keep in mind however that these processes are slow.

Conditions	Type of method							
	Sandbags	Polypropylene nets	Geotextiles	Sand layer	Stone layer	Cages	Rubber sheeting[12]	Sea grass
Sandy seabed	+	++	++	++	(+)[8]	(+)[10]	+	++
Rocky seabed	++	-	++ as a barrier method	+	++	+	-	-
Pebbles	++	-	++ as a barrier method	+	++	+	-	-
Clay	+	+	+	+	(+)[8]	(+)[10]	+	+
Silt	+	++	+	+	(+)[8]	(+)[10]	+	+
Tidal movements	+	++	+	-	++	(+)[10]	+	++
Currents	+	++	+	-	++	(+)[10]	+	++
Still water	+	-	+	+	+	+	+	-
Wave action	++	(+)[2]	+	-	++	(+)[10]	+	+
Brackish water	++	++	++	+	++	+	+	+
Fresh water	++	++	++	+	++	+	+	+[11]
Salt water	++	++	++	+	++	+	+	++
Shallow water (0-10 m)	++	++	++	(+)[5]	++	+	+	++
Partly submerged	+	-	+ not as barrier method	+	+	-	0	-
Temporarily submerged	+	(+)[3]	+ not as barrier method	(+)[6]	+	-	0	-
Depth range 10-50 m	(+)[1]	++	++	+	+	+	+	+
Deepwater (below 50 meters)	(+)[1]	(+)[4]	+	(+)[7]	+	0	+	0
Flat seabed	++	++	+	+	+	+	+	+
Undulated seabed	++	+	+	+	+	-	0	+
Object slightly protruding from the seabed	+	++	+	+	+	+	0	+
Object strongly protruding from the seabed	-	-	++ as a barrier method	-	-	++	-	-
Ice forming (icebergs)	+	0	0	0	(+)[9]	0	0	-

1 It may be difficult to get all the sandbags in the right place at large depth
2 Before all the sand has been caught by the nets, this kind of protection is vulnerable to damage
3 This will only work when the nets had got the time to catch enough sand particles when submerged
4 This method will be difficult to install at higher depths, and sediment transport is still needed
5 As long as these shallow waters are calm. However, in shallow waters the effects of storms are usually high.
6 Temporarily submerged means there is water movement, the less intensive this is, the better.
7 It may be difficult to deposit the sand at the right place.
8 A stone coverage on a soft soil is usually instable
9 Stones may give some protection, however icebergs are often strong enough to push the blocks away.
10 Cages are protruding the seabed and thus vulnerable for all sorts of things being entangled in them. If used, one should create a good foundation for them, especially in soft sediments.
11 Polypropylene nets and seagrass need tidal movements to be really effective. These do not exist in fresh waters.
12 We consider rubber sheeting not directly as a specific *in situ* preservation method on its own. It does keep sediment on the site but will actively promote sedimentation on it. The sheeting on its own doesn't make the environment anaerobic.

Table A: the effectiveness of different methods for different types of environments.

Mitigating negative effects	Sandbags	Polypropylene nets	Geotextiles	Sand layer	Stone layer	Cages	Rubber sheeting	Sea grass
Abrasion	++	++	++	+	++	-	++	+
Erosion seabed on site	++	++	++	-	++	-	++	++
Erosion seabed larger area	-	+	+	+	-	-	+	+
Teredo navalis	+	++	++	+	+	-	+	+
Gribble	+	++	++	+	+	-	+	+
Fungi	+	++	++	+	+	-	+	+
Bacteria	0	0	0	0	0	-	0	0
Looting	+	0	0	-	++	+	0	0
Fishing	+	+	+	+	+	-	+	0

Table B: Various physical protection methods and the way they mitigate against specific deterioration processes.

4.4 Follow up: monitoring as part of management

Introduction

Protection methods cannot guarantee equal protection under all conditions. It is therefore important to monitor protected sites and thus to manage anychange. *In situ* preservation should not stop once the site has been stabilised. Monitoring of stabilised sites is necessary to ensure continued stability. Furthermore, although a newly discovered site may be relatively stable and thus not immediately require any active mitigation strategies, environmental and/or physical changes may occur which require additional mitigation strategies at a later date. In this context, monitoring is essential. As discussed, shipwrecks exist in a dynamic equilibrium with their environments and subsequent changes may occur through storm events or impacts of a cultural nature. This is equally valid for sites where active mitigation strategies, such as reburial, have been implemented. Monitoring means keeping track of the condition of a site and its protection methods and registering all changes.

Therefore, monitoring should be compared with baseline data. The most ideal procedure would be to have data prior to undertaking physical *in situ* protection. After installation the same data is collected and a time line for further monitoring developed. This time line is an indication of how often a site needs to be monitored in the future. However, this can change over time for a number of reasons. For example new information might indicate that severe changes are currently occurring or will in the near future and the site has to be examined more often.

As with the various processes of deterioration, monitoring should consider the two broadly different environments of open seawater / seabed and within the seabed. Within the open seawater we are concerned with physical and biological processes of deterioration namely sediment transport (erosion / accretion) and the activity of wood boring organisms. Furthermore, the condition of timbers should be assessed to ensure that they are not further degrading.

Open water and the surface of the seabed

Introduction

Data for monitoring the open water can be acquired in the following ways:

1 Technical devices such as data loggers.
2 By obtaining this information from large (oceanographic) institutes that are measuring them for other purposes.

3 Another way to measure the water column is to place sacrificial objects in the water and measure their deterioration rate over time.
4 Taking water samples and post-recovery analyses.

The seabed can be measured in a few ways:
1 Visually, by divers.
2 With marine geophysics such as single beam, multibeam, side scan sonar.
3 Traditional sounding (sounding lead).
4 Laser, aerial photography and satellite.

The visual inspection of a site can be achieved by sending down divers or by using camera mounted Remote Operating Vehicles (ROVs). Visual inspection can tell us something about the pure physical conditions of a site and if e.g. parts of the wreck are being exposed. Also, divers can identify if a site is being attacked by *Teredo navalis*. Ways to recognise attack by *Teredo navalis* are detailed in Chapter 3.

Marine Geophysics

Many governmental institutions now have access to marine geophysical methods, such as multibeam echo sounder (MBES) which can be used to monitor the net effects of sediment transport over a wreck site. Repeat surveys carried out at different times using MBES, can be digitally subtracted from each other in order to map where there are areas of net accretion and net scour of sediment (fig. 31). Although this shows formation products rather than processes, in terms of *in situ* preservation it provides a reproducible method to quantify changes over an entire site.

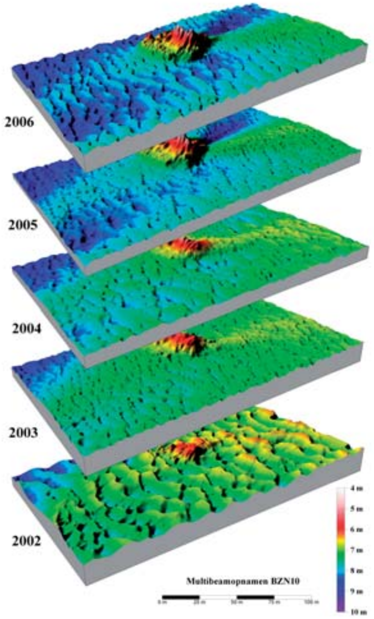


Figure 31: Digitally subtracting multibeam recordings from different years to analyse net accretion or scour. MACHU.

Although not recording actual depth, side scan sonar can also be used to monitor the changes on protected submerged archaeological sites and their environment. This equipment, which can scan large areas of the seabed in relatively short times, has become very cheap in the last couple of years and its use is now widespread. In order to study ongoing sedimentary processes, current profilers and sediment sampling (through coring or using sediment traps) can be placed on sites in order to model the likelihood of sediment transport. The presence of actual suspended particulate matter in the water column can also be monitored using turbidity sensors/loggers. This is a relatively simple method of ascertaining if there is sediment transport and in particular when considering the use of artificial sea grass or netting materials to stabilise a site.

Presence or absence of wood borers

In terms of monitoring the presence and activity of wood boring organisms over a site it is not always easy to monitor their activity directly on exposed timbers (see also chapter 2). However, this can be monitored by the placement of sacrificial blocks of modern wood around a site and recording organisms' presence or absence. If they are present it is highly likely that any newly exposed timbers will also be colonised and thus steps to mitigate their effects can be taken. As can be seen from Guideline 1, the temperature, dissolved oxygen and salinity of the water will also have an effect on the growth of wood boring organisms. These parameters can similarly be logged using data loggers but it is now often possible to obtain such data from Governmental institutions that are monitoring water quality parameters.

Within the seabed
Nearly all biogeochemical processes in young sediments , for example during early diagenesis, are directly or indirectly connected with the degradation of organic matter (Rullkötter; 2000). Organic matter may be produced by algae and other organisms in open water, which subsequently sinks to the seabed and becomes incorporated within the sediment. It may also be the remains of plant material such as eelgrass or seaweed or shipwreck material deposited within the sediment.

The utilisation of the organic matter by organisms within sediments involves oxidation – reduction (Redox) reactions (Schulz, 2000). These reactions follow a well-documented succession with various chemical species or electron acceptors being utilised based on the amount of energy they yield (Froelich et al., 1979).
From the pool of potential electron acceptors, the microbial community selects the one that maximises energy yield from the available substrate. This is partly due to metabolic regulation within a single population and partly due to the competition between several populations with diverse metabolic capabilities. In marine sediments, the sequence of electron acceptor utilisation can be observed spatially in horizontal layers of increasing depth. In typical coastal marine sediment, only the first few millimetres of the sediment are oxygenated, though bioturbation by invertebrates and advection may extend this oxygenated zone downwards. For a few centimetres under the oxygenated zone, nitrate serves as the electron acceptor followed by manganese and iron oxides. Below this, sulphate is the principal electron acceptor and sulphate reduction is often the dominant process in shallow marine sediments due to the high concentrations of sulphate in seawater. Methanogenesis is usually confined to the sulphate-depleted deeper sediment layers, though the generated methane may diffuse upward into the zone of sulphate reduction. Thus, the deterioration of organic matter still occurs in anoxic environments due to the activity of anaerobic organisms, albeit at a slower rate.

In terms of monitoring within sediments, the dissolved oxygen content, concentrations of various chemical species, porosity and organic content of the sediment can all yield information about the ongoing biogeochemical processes in the sediment and the rate of deterioration of organic matter. A monitoring programme can use data logging devices or analysis of pore water taken from core samples. Summing up, the following parameters should be assessed in order to get an idea of the nature of the buried environment:
Dissolved oxygen content.
Redox potential
Sulphate / Sulphide and also total sulphur content
Organic content of sediment
Porosity of sediment

The aforementioned parameters will give a good indication of whether the environment is oxic or anoxic (with or without oxygen) and which dominant process are taking place in the sediment(see further reading).

In order to check what is happening to wooden materials, small sacrificial samples of wood can be included as part of a monitoring programme as the rate and cause of deterioration can be assessed microscopically in order to confirm biogeochemical monitoring of sediments. For monitoring of physical *in situ* protection within the seabed, one can consider subbottom profiling (Manders 2009b, Plets et al. 2009). This technique has been in use for monitoring wreck sites that have been protected with debri netting (see chapter 4.2).

Condition of timbers
It is important to get an overview of the actual state of preservation of the wood when considering its *in situ* preservation. Simply put, is the wood in a stable enough state to be left where it is? Are there threats of further deterioration if the wood is left *in situ*? What effects will any proposed mitigation strategies have on the wood?

In terms of assessing for the effects of wood boring organisms, a simple metal probe made of a thin rod can be used and simply pressed into the wood. Often, if shipworms are present, or have previously been active in the wood, there is little or no resistance. This is unfortunately only a qualitative assessment but will give an indication of the presence of shipworms. Alternately a more elaborate, yet similar method to the metal probe, can be used, known as the Pilodyn. The Pilodyn was originally developed to assess the extent of soft rot decay in telegraph poles in service. The Pilodyn works by firing a spring-loaded blunt pin into the wood, to a maximum depth of 40 mm. The depth of penetration of the pin is indicated on a scale on the side of the instrument. The more degraded the wood, the further the pin will penetrate. In the hands of an experienced diver, it is a relatively cheap, simple and robust tool for non destructively mapping the state of preservation of timbers on the seabed. In order to assess the overall state of preservation of the wood that remains, density is a good parameter. As discussed, microorganisms operate on a cellular level and, as they remove cell wall material this is replaced by water. As a result, the more degraded the wood is, the lower the density of the wood. Density can be assessed using cores taken *in situ* with an increment borer which are subsequently processed in the laboratory. The more accurate method for examination of the condition of the timber is microscopic analyses of core samples, which will reveal state and degree of degradation and the actual cause of degradation.

Suggested reading:

Dix, J., T. Rangecroft, D. Lambkin, R. Sullivan, C. Pater, I. Oxley, 2009: Physical Modelling as a tool for Underwater Cultural Heritage Management, MACHU Final Report Nr.3, 54-56.

Froelich, P.N., Klinkhammer, G.P:, Bender, M.L., Luedtke, N.A:, Heath, G.R., Cullen, D., Dauphin, P., Hammond, D., Hartman, B. and Maynard, V., 1979: Early oxidation of organic matter in pelagic sediments of the eastern equatorial Atlantic: Suboxic diagenesis. Geochim. Cosmochim. Acta, 43: 1075-1090

Gregory, D.J., 1999: Re-burial of timbers in the marine environment as a means of their long-term storage: experimental studies in Lynæs Sands, Denmark. In The International Journal of Nautical Archaeology, 1999, 27:4, 343-358.

Gregory, David, 2004: Data loggers, MoSS Newsletter 2/2004, 8-9

Gregory, D., 2007: Environmental monitoring. In T. Bergstrand and I. Nyström Godfrey (editors) Reburial and Analyses of Archaeological Remains. Studies on the effects of reburial on archaeological materials performed in Marstrand, Sweden 2002-2005, The RAAR project. Kulturhistoriska dokumentationer Nr 20, Bohuslans Museum, Uddevalla, Sweden, 59-90.

Gregory, D., Jensen, P., Matthiesen, H. & Strætkvern, K., 2007: The correlation between bulk density and shock resistance of waterlogged archaeological wood using the Pilodyn. Studies in Conservation, 52, 289-298.

Huisman,D.J., M.R. Manders, E. Kretschmar, R.K.W.M. Klaassen & N. Lamersdorf, 2008: Burial conditions and wood degradation on archaeological sites in the Netherlands, International Biodeterioration and Biodegradation 61, 33–44

Jensen, P., and Gregory, D.J., 2006: Selected physical parameters to characterize the state of preservation of waterlogged archaeological wood: A practical guide for their determination, Journal of Archaeological Science 33, 551–559.

Manders, Martijn, 2009a: Multibeam recording as a way to monitor shipwreck sites, MACHU Final Report Nr. 3, 59 – 67

Plets, R.M.K., Dix, J.K., Adams, J.R., Bull, J.M., Henstock, T.J., Gutowski, M. and Best, A.I., 2009: The use of high-resolution 3D Chirp sub-bottom profiler for the reconstruction of the shallow water archaeological site of the Grace Dieu (1439), River Hamble, Journal of Archaeological Science, 36, 408-418.

Rullkötter, J., 2000: Organic Matter: The Driving Force for Early Diagenesis. In Schulz HD & Zabel M (editors), Marine Geochemistry: 129-153. Springer-Verlag, Berlin.

Schulz, H.D., 2000: Redox Measurements in Marine Sediments, in Sch ring J, Schulz HD, Fischer WR, Bõttcher J and Duijnisveld WHN (ed.), Redox: Fundamentals, Processes and Applications: 235-246. Springer Verlag, Berlin.

Quinn, R., 2006: The role of scour in shipwreck site formation processes and the preservation of wreck-associated scour signatures in the sedimentary record, Journal of Archaeological Science, 33 (10), 1419-1432.

Underwater data logger suppliers

http://www.ysi.com/applicationsdetail.php?Ocean-and-Coastal-Monitoring

4.5 Cost of *in situ* preservation versus excavation, conservation, and curation

Introduction
Whether to raise a historical shipwreck or not, is a topic that generates long discussions (see also chapter 2.1). Working professionally in this area demands, however, careful analysis not at least on the economical consequences prior to such decisions being made.

There are at least five obvious alternatives for managers of cultural heritage to consider (see also chapter 1.4):
1 A wreck can be preserved for future generations *in situ*
2 A wreck can be preserved *in situ* temporarily until planned excavation
3 A wreck can be excavated, raised and conserved
4 A wreck can be excavated and reburied
5 A wreck can be left in the sea without intervention

The fifth alternative is unfortunately what mostly happens today, and the consequence is that wrecks are continuously degraded until they have disappeared, which is ultimately the loss of cultural heritage objects. The process is invisible as it takes place in the sea, out of the public eye

This chapter will give an insight into the costs that are associated with the *in situ* protection of shipwrecks. The costs are compared to those associated with the physical raising of a shipwreck, full conservation, and display for the public in a suitable museum building.
There are some difficulties in giving the true costs for these actions since only a few wrecks in the world have been protected *in situ*, and only a few large size wrecks have been excavated, raised, conserved and exhibited.

However, the reader will soon realise that there is a great difference in cost between *in situ* preservation and the raising and conservation of a wreck. It is the intention of this chapter to give stakeholders and managers an insight into the costs associated with both actions, so that the decision of future management of important wrecks can be made on realistic economical backgrounds.

***In situ* protection**
Factors that influences the costs As each site has its own individual characteristic, one has to bear in mind that the costs will always vary from wreck to wreck. There are however some parameters which always will affect the total expenses more than others. These are primarily related to the site and the environment surrounding the wreck, and secondly to the hull itself.

The factors that will have the highest impact on the costs are identified below:
- Environment (streams, sights, sediment, etc.)
- Depth (work related difficulties increase with increased depth)
- Size of the wreck above seabed (vertical and horizontal dimensions)
- Size of the site and what should be included in the protection

Another type of parameter affecting the costs is related to particular countries. Salaries, costs of ship rental and work related policies and legal frameworks vary within Europe. The costs for materials are usually relative small.

Experiences of costs associated with *in situ* preservation
In order to clarify the approximate costs associated with *in situ* preservation, information from some of the few institutes and persons who have been involved with a full scale, *in situ* preservation action were obtained. It was evident from all experiences that the personnel costs for professional divers and maritime archaeologists were the major expenses, followed by costs for rental of diving vessels and equipment necessary for diving. In the table below you will find some of the successful projects and their total costs.

Name of the wreck	Size length (m)	Country	Year	Method	Costs* approx.	Working days
Stora Sofia	40	Sweden	2000	Gravel, rubber sheet	71000 €	10
Hårböllebro	8	Denmark	2004	Sandbags	46000 €	7
Burgzand noord 10	35	The Netherlands	2009	Debris netting	70000 €	10
An estimation, based on the Zakyntos wreck	15	Greece		Geotextile, sandbags, gravel	35000 €	7

* The listed costs were obtained by personal information by: Thomas Bergstrand, Bohuslänsmuseum, Sweden (Stora Sofia); Jörgen Dencker, Vikingskibsmuseet, Denmark (Hårböllebro); Johan Opdebeeck. RCE, the Netherlands, (Burgzand noord 10); and Anastasia Pournou, Education Institute of Athens Ag., Greece (Zakynthos wreck).

Tabel 1

The Burgzand Noord example
Geophysical monitoring of the area in 2009 revealed strong erosion and damage around an already physically protected wreck site in the Wadden Sea, The Netherlands. The Dutch Cultural Heritage Agency decided to act by repairing and extending the physically protection of the BZN 10 wreck. A diving team was appointed to protect the wreck from erosion due to the tidal currents. The method applied to the site was debri netting (scaffolding nets), aimed to accumulate and cover the remains with sediments. The team was made up of 4 professional divers and 1 maritime archaeologist. The work was done in 2 weeks (10 diving days) and in that period a protected layer of debri netting was re-installed over the whole site again. The biggest expenditures were the personnel costs, ship and diving equipment.

- Travelling expenses 5300 €
- Personnel costs 30.000 €
- Professional divers / 650 € / day
- Maritime archaeologist / 900 € / day
- Ship (excluding outward/return journey) 17.500 €
- Equipment (diving, sea container etc.) 14.000 €
- Material (tie raps, labels, scaffolding nets (120 € / roll of 3 / 50m) 1500 €

Total 70.000 €

Extra costs associated with long term management of protected sites
The present methods used today for protection of sites require a continuous monitoring because long-term stability is not guaranteed in non-homogenous environments (see also chapter 4.4). In case of storms and strong water currents, erosion and transport of sediment from the site might take place and leave the wreck partly un-protected. Therefore a management program aiming to follow the stability of the protective layer and the erosion of the site is necessary.

Monitoring could be done via a diving operation, where sacrificial wood samples are retrieved for analyses at regular intervals, perhaps every three years, and the stabilities of sediment and protective layers are controlled at the same time. Alternatively, non diving operations involving a ship with sonar multi-beam and ROV facilities can be used for studying the sediment movements (see also chapter 4.4). A rough estimation of cost for each one of these actions is listed below.

Method	Costs/day
Monitoring by diving	6200 €
Ship rental with sonar/multi-beam (no personal costs included)	3000 €
Ship rental with ROV facilities (no personal costs included)	15 – 20.000 €

Information from RCE, The Netherlands

Costs for conservation (including raising and storage or display)
There are only a few shipwrecks in the world that have been excavated from a marine environment and subsequently conserved and displayed. The warship Vasa in Sweden is probably the most well known example, followed by the other North European wrecks, the Mary Rose, the Bremer Cog, and the Viking ships in Roskilde. In the Mediterranean well known examples are Kyrenia, Yassi Ada I and Serçe Limani in Turkey, Ma'agan Mikael in Israel, Grado and Gela in Italy. The modest number of shipwrecks exhibited to the public today, are strictly related to the enormous costs involved.
From the raising and treatment of Vasa there are no exact costs published. The decision to raise the ship in 1961 was not controlled by economic matters per se, but rather driven by enthusiasm. A similar situation was the case for the Viking ships in Roskilde fjord, excavated in 1962. This is different from decisions made today when we want to know all the implications in advance. When the question of costs is asked of stakeholders of the Vasa museum, the answer is that it has paid off. The Vasa ship is today the number one tourist attraction in Sweden, and is of great economic importance for the city and the museum itself. But for other shipwrecks, the situation may not be as positive. The fact is that the daily costs for storage, maintenance and display might endanger the economy of a smaller museum.
We have to be aware that not all negative and positive effects can be readily taken into account when deciding whether to excavate, conserve and display a site. Indirect positive effects may be for example also the creation of awareness, identity building and capacity building in underwater cultural heritage, underwater archaeology and conservation. It is also difficult to quantify the effect of gaining knowledge. Then there is the economic effect of countries and cities becoming known by the general public and thus triggering touristic traffic. All these have a long term effect and cannot always easily be pinpointed and related to what has been invested in excavating, raising and conservation of a specific site.

Short description of the raising, conservation, and display process
After archaeological underwater investigations, the wreck will be raised in parts or as a whole structure by advanced engineering work at sea. Archaeologists will examine, document, and register every part of the ship on land, in cooperation with conservators, who will clean and store the wood in water tanks. After cleaning, the conservation treatment can start usually by impregnation with polyethylene glycol. This process may take from 2 to 10 years, depending on the physical state of the wood and the process of drying, either by freeze-drying or controlled drying. After treatment the wooden parts are cleaned, reshaped if necessary, and put together for display. Special support construction for the timber and climatic control for the humidity in the building is a requirement.

Costs
In the tables below, relevant information on the shipwrecks and their costs are described.

It is evident that the costs for full excavation, conservation and display in most cases are incomplete, but summed up the individual case stories give a good impression of the huge costs that will arise at the different stages of the process,- from excavation to display.

Ship	Country	Size/length	m³ timber
Found in marine environment			
Mary Rose	United Kingdom	38 m	
Bremer cog	Germany	23 m	
Kolding cog	Denmark		9 m^3
Found on land site			
Götavraket	Sweden	11 m	
New Port	United Kingdom	25 m	700 m^3
Roskilde 2	Denmark		1.6 m^3

Ship	Archaeological excavation	Lifting and management	Conservation	Display	Total costs (€)
Found in marine environment					
Mary Rose	3.9 M + 11 M	8.5 M	5.8 M + (n.i.)	48 M	**77 M**
Bremer cog	n.i	n.i	4.5 M	n.i	**4.5 M + ?**
Kolding cog	0,2 M	n.i	0,58 M	n.i	**0.8 M + ?**
Found on land site					
Götavraket	1.1 M	0.3 M	0.5 M	1.9 M	**1.9 M**
New Port	4 M	n.i	n.i	4 M + ?	**4 M + ?**
Roskilde 2 (under treatment)	0.15 M	0.24 / 0.38 M	n.i.	0.5 M + ?	**0.5 M + ?**

*The listed costs were obtained by personal information from Sara Wranne at SVK, Sweden (Götavrak), Kristiane Streatvern, National Museum of Denmark (Roskilde 2, Kolding Cog), Christopher Dobbs from the UK (Mary Rose: from ARC Nautica conference Dubrovnic Croatia, 2009), but also through literature study: Bremer Cog (Hoffman, P. 2009), Newport Wreck (Hunter, K., 2004).
n.i = no information, +? = additional unknown sum

As indicated by the Roskilde 2 ship, costs for conservation treatment can be on two levels depending on the scenarios of the ship being conserved for storage or display? It is evident that the storage alternative will only give slightly lower expenses for conservation, whereas it is highly likely that the costs for storage will be notably less that the costs of display.

The Mary Rose, which today is receiving a full conservation treatment for display, in Portsmouth, UK, givies us the best information of the full cost for a large shipwreck from raising to display.

Examples

The Bremer cog
Per Hoffman, responsible for conservation of the Bremer cog, presented at the ICOM/WOAM conference in 2007, that the total costs for conservation were around 4,5 M . The conservation and reconstruction work finished in 1999. Construction and running of buildings, two offices for the Conservation Department and a laboratory were not included in the cost, neither was the raising or archaeological examination of the hull. The Bremer cog (23 m) is a much smaller ship than the Mary Rose (38 metres) and the Vasa (62 metres).

The Mary Rose
In 2009 at the ARC-Nautica Conference in Dubrovnic, Croatia, Christopher Dobbs ofthe Mary Rose Trust, gave an account of the total cost related to the Mary Rose. He was able to divide the cost into following groups:

2.8 M £ (3.9 M €) for the raising
6.1 M £ (8.5 M €) management until today
4.2 M £ (5.8 M €) for impregnation/conservation of the hull (estimation)

A total of 13 M £ (about 18 M €) for raising and conservation. Much of the work for the underwater excavation was done on a voluntary basis, and was not included. This work was estimated at 11.5 person months in active diving time, which could be roughly estimated to cost 8.M £ (11 M €). The future costs for an adequate building for display is estimated as 35 M £ (about 48 M €) and all services are not included. It is important to remember that the Mary Rose is not a whole wreck but only about 1/3 of the ship (originally 38 m long and 11 m wide). The number of objects related to the ship, have caused considerable conservation expenses too. If we summarize the cost and include diving and building, the estimated total cost will be about 77 M €.

Conclusions
The examples presented describe a wide variation in costs for both *in situ* preservation and full conservations. Both are related to the size of the hull. The costs involved in a full conservation process are not complete for most of the examples, but they complement each other and they give a good impression of the level of costs for each step from raising to display. The Mary Rose example gives us the most complete information on costs, and therefore also an idea of the expected cost for raising of a similar-size wreck in the Baltic sea. As there recently have been discussions on raising the Ghost Wreck found outside Gotland, in international waters, these figures could have great importance in the discussion of strategies for the management of these finds. It is very clear that the costs related to the marine archaeological underwater excavations are extremely high as they involve divers with special underwater equipment, ships with all relevant technical instruments, as well as a generally high safety level.

In situ protection techniques provide stakeholders with a useful and cheaper alternatives for protection and preservation of important cultural heritage. It provides an alternative to raising , that is conservation and display of a wreck. The Mary Rose, which is of the same size as the Stora Sofia, costs about 77 M € to conserve and display, whereas the *in situ* protection of Stora Sofia cost around 0.07 M €.
A simple calculation tells us that a large number of historical ships (in this example 1100) could be preserved for future generation for the same cost as of one single wreck could be conserved and displayed.

Suggested reading:
Hoffman, P, 2009: On the efficiency of stabilisation methods for large waterlogged wooden objects and how to choose a method. In: Huisman & Strætkvern, Proceedings of the 10th ICOM Group on Wet Organic Archaeological Materials Conference, Amsterdam 2009, pp.323-350.
Hunter, K., 2004: The Newport Ship: The first two years, In: P. Hoffmann et al, Proceedings of the 9th ICOM Group on Wet Organic Archaeological Materials Conference, Copenhagen 2004, ICOM-WOAM, pp 411-428

5 How to protect the unknown resource against the *Teredo*

Hundreds of sites in the Baltic are already known, but many others are not. Can we protect this unknown resource against deterioration?

First legal protection can be set up in such a way that not only known and named, but also the unknown sites are protected before they are discovered, in the form of a a blanket protection. The protection and management of an area can be focused on the known and unknown cultural heritage, but still consider the relationship between cultural and natural heritage.

Although valuable, this kind of protection is not very effective against for example the attack by *Teredo navalis*. How can we make sure that the unknown archaeological resource is protected against mechanical, chemical and biological attack? This requires focus on the unknown sites as well as the environment they might be in. It is possible to predict the chances of sites being present in certain areas. Even their possible condition and the threats they will be facing can be predicted. Attack by *Teredo navalis*, can be predicted based on the guidelines of WreckProtect's Work Package 3.1. Predictions of seabed changes have been made in projects like MACHU. Models, based on past data and combined parameters, are thus valuable tools for predictingpresent and future risks. They help us in monitoring changes in areas, but can also provide us with important information on how specific conditions can be maintained.

As an example, ensuring a maximum salinity lower than 4 PSU ensures a lethal environment for the *Teredo navalis*, a salinity lower than 8 PSU ensures that there will be no reproduction of the species. Another way to protect not only the known, but also the unknown archaeological sites is for example to prohibit ships to empty their ballast water in areas where the living conditions of the Teredo may be nearly or fully favourable. The same approach can be taken with other variables. The impact of human interference in an area on short term, mid term and long term can be estimated and mitigated. The effects this have are not only beneficial to the sites we know, but also the ones still unknown.

Most important however is to acknowledge that the known archaeological resource in the Baltic Sea is only a fragment of the total archaeological resource that the unknown archaeological resource is much greater than the known resource.

Suggested reading:
MACHU Final Report no. 3, Amersfoort 2009
Nordic Blue Parks: www.nordicblueparks.com
WreckProtect: Guidelines for predicting of decay by shipworm in the Baltic Sea

Figure 32: Debri net being rolled out on a site. Photo Courtesy WreckProtect Project.

6 Conclusions

This guideline has provided stakeholders with tools to physically preserve submerged archaeological sites *in situ* and to mitigate against major threats. Among them, the most severe in salt water may be *Teredo navalis*. In the Baltic Sea, mainly a brackish environment, it is still only present in the south west (see for future spread of *Teredo navalis*, WreckProtect's guideline for predicting decay by shipworm in the Baltic Sea). This guideline contains many different techniques to preserve the sites that are exposed in the south western Baltic waters, where currents and sediment transport take place.

As also shown, physical *in situ* preservation has to have a purpose and a goal. For the cultural heritage manager it is therefore important to make the select *in situ* or excavation based on the correct data and with the knowledge that *in situ* preservation requires taking responsibility for a long period of time.
At this moment there are no effective methods to protect the unique well-preserved shipwreck sites in the more eastern and northern parts of the Baltic Sea. The threat of *Teredo navalis* is not currently extremely high in those regions, but because of the unique character of the archaeological resource, it is wise to start thinking about the choices we have and don't have regarding the protection of sites including the Vrouw Maria, Ghostship, Sea Horse and Lion wrecks.

Each year many sites of high archaeological significance are found on and in the seabeds of the world. Usually when they are found, these sites are already at risk. Being exposed means being under threat from biological, mechanical, human and even chemical deterioration. This guideline, although primarily focusing on the Baltic Sea, has provided tools for sites underwater wherever in the world.

The WreckProtect group would like to emphasize the need to continue developing new methods in order to find the best solutions for every circumstance. The group believes that the best way to develop new techniques and ideas is to work in a multidisciplinary way with researchers, engineers, conservators, marine archaeologists and practitioners in, for example, the field of maritime construction. Although many ships are still getting wrecked and land masses disappear into the sea, the cultural heritage underwater that exists today is only getting smaller. These cultural objects are not only part of our own history, but also make up part of a common history. This is especially the case in maritime archaeology where ships would cross borders and connect the peoples of the world almost continuously.

The protection of the underwater cultural heritage is therefore not just something to strive for by an individual, by a single stakeholder group or even by one country alone, it is of concern for all of us. Therefore the WreckProtect consortium calls upon the European commission and the UNESCO to continue supporting initiatives aimed at the protection of our common underwater cultural heritage.

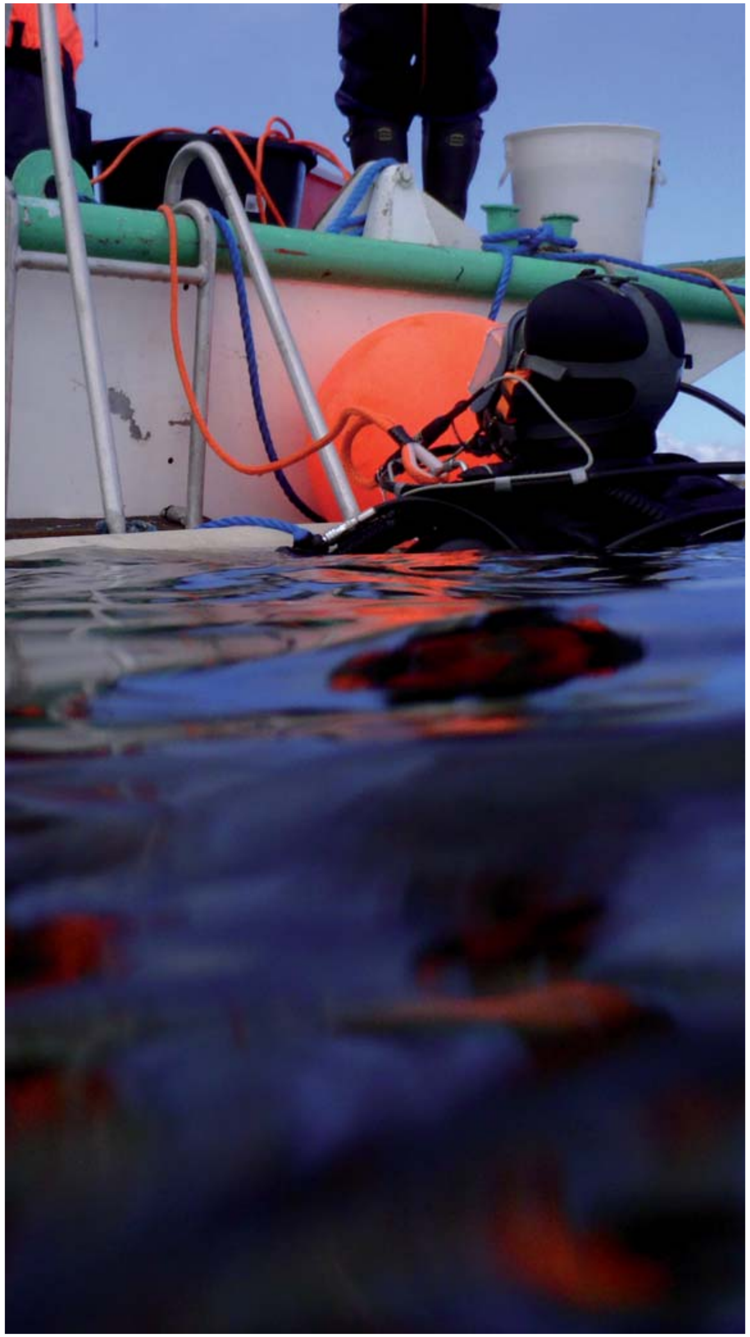


Figure 33: Photo Courtesy WreckProtect Project.

Acknowledgements

This guideline is a result of the interdisciplinary co-operation within the consortium of the EU project WreckProtect (Project No. 226225). The European Commission's 7th Framework Programme Environment, is gratefully acknowledged for promoting this cross-disciplinary research.
WreckProtect gratefully thanks Sara Wranne at SVK, Sweden, for information on the Götavrak, Thomas Bergstrand, Bohuslänsmuseum, Sweden, for information on the Stora Sofia and Anastasia Pournou, Education Institute of Athens Ag., Greece, for information on costs related to the Zakynthos wreck. Christopher Dobbs is gratefully acknowledged for his presentation of valuable information on costs regarding Mary Rose at the ARC-Nautica conference, Dubrovnic, 2009.
Special thanks to our External Advisory Group (EAG) that comprises Giulia Boetto from the Centre Camille Jullian (Aix-Marseille Université-CNRS) in France, Friedrich Lüth from the Römischer Germanische Kommission, Frankrfurt, Germany and Stefan Wessman from National Board of Antiquities, Maritime Archaeology Unit in Finland.

The partners in the project

SP Technical Research Institute of Sweden (SP)

The Geological Survey of Denmark and Greenland (GEUS)

Cultural Heritage Agency (RCE)

National Museum of Denmark (NM)

University of Gothenburg (UGOT)

The Viking Ship Museum, Roskilde (VM)