Preserving a layered history of the Western Wadden Sea : managing an underwater cultural heritage resource

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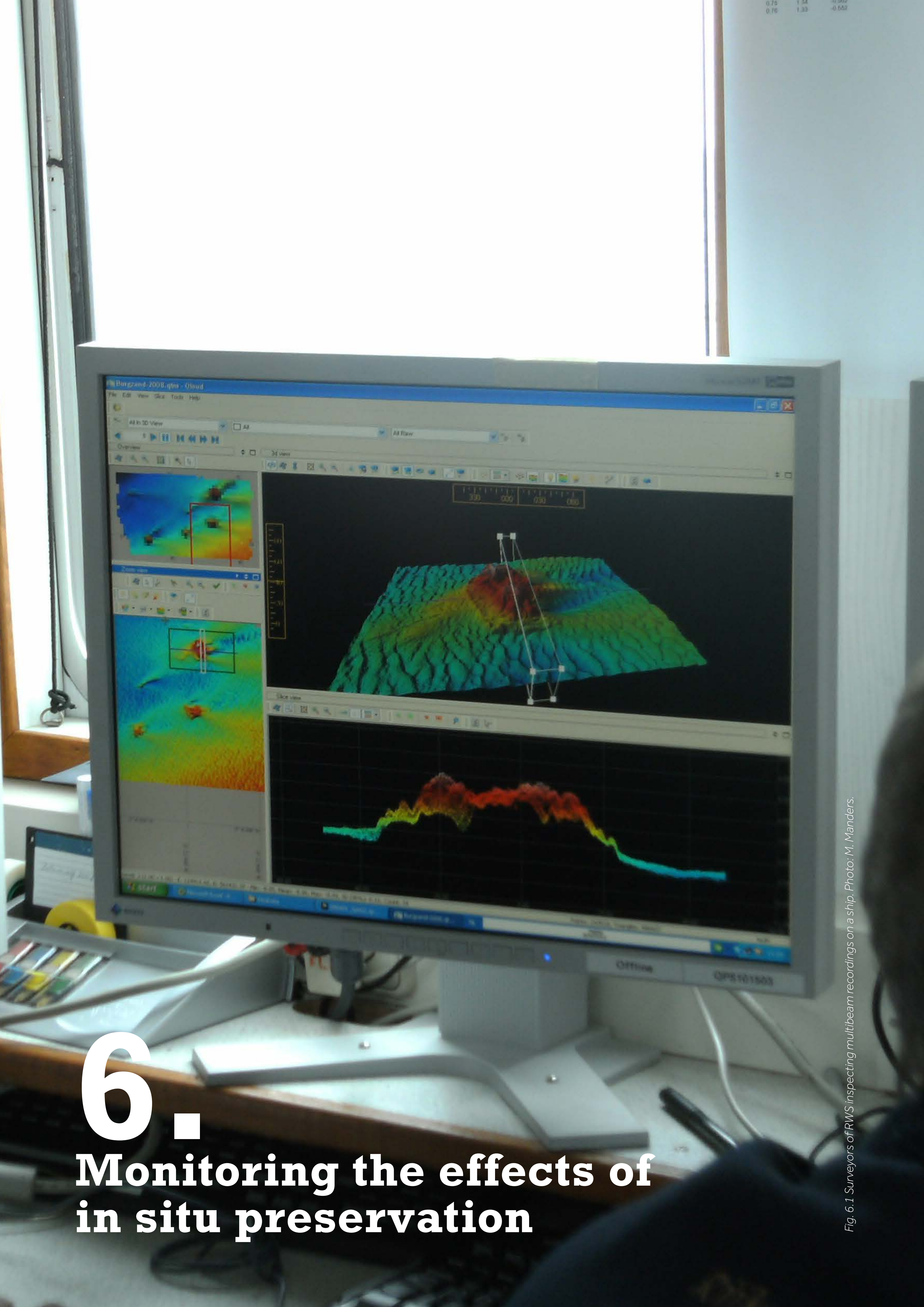

Fig. 6.1 Surveyors of RWS inspecting multibeam recordings on a ship. Photo: M. Manders.

6. Monitoring the effects of in situ preservation

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6.1 Introduction

Installing in situ protection is not the final activity and thus also not the final investment in underwater archaeological sites. In situ protection requires continuous monitoring because long-term stability is often not guaranteed in non-homogenous environments.[1] Single events such as storms or heavy currents may leave a wreck totally or partly unprotected overnight.[2] More gradual, insidious and delayed processes also have effects on these sites, which often remain unseen. Therefore, a management programme or plan aiming to monitor the stability of the protective layer and the erosion of the site is necessary.[3]

Monitoring entails observation. It concerns observing changes at an archaeological site over a certain (often predefined) span of time. As stated previously, in situ preservation without a monitoring programme is indeed similar to brushing sites under the carpet. It would be a sign of pure neglect. Unfortunately, this is still what often happens.

However, what if we do agree to monitor the sites that we preserve in situ? What are the key parameters we should measure when monitoring the condition of a site and the changes occurring in the present or in the future? The way we monitor depends on the budget and staff available, the number and quality of the sites that have to be monitored, the nature of the threats, the aim of sustainable in situ preservation (always a combination of scientific and societal/cultural goals) and the level of detail required. Another important issue to consider is the environmental context: sites in active, 'hostile' environments need, for example, to be monitored more often than those in stable environments.

The information that needs to be collected to assess the current and possible future state of an archaeological site includes:

1. Its present archaeological value or significance (as established in an evaluation)
2. Its size
3. The relationship between the site and its environment
4. Its current condition
5. Roughly which materials are present
6. An overview of past, present and future threats

Technically, underwater archaeological sites can be monitored in different ways and performed using various options, such as divers, through the use of remotely operated vehicles (ROVs) or data loggers (Fig. 6.2). From the water surface, geophysical methods or coring can be used, or a combination of these methods.[4] By using a combination of methods, different elements of a site can be investigated: the site in its broader context, its natural environment and the condition of the wreck and the materials of which it consists. Many of these methods have been tested in underwater cultural heritage management in the Netherlands for a number of years. The Burgzand area has often been used as a testing site.

Monitoring is an essential part of underwater cultural heritage management and also crucial for the in situ preservation aspect of management. In situ preservation should not cease after initial measures have been taken and the site has been stabilized. The physical condition of a site will never improve; it can only become worse. Thus, it is essential to identify and mitigate against the threats and to slow down the degradation processes as much as we can. Determining these threats must be done by an assessment on the site level. This was addressed in Chapter 3. The use of physical protection methods are a way to mitigate against these threats. These, however, cannot guarantee the same protection under all conditions. This was explained in Chapters 4 and 5.

Monitoring is necessary to ensure continued stability, or at least to know whether any changes have occurred compared to the initial assessment stage. It has to be kept in mind that many sites

Kan helaas niet beter...
ik kan het iets frissen maken??

Fig. 6.2 A remotely operated vehicle inspecting a shipwreck.

[1] As we have seen with the previous example of the BZN 10, when monitoring activity in 2009 resulted in the repair of the protection layer that was laid in previous years.

[2] For an onshore example, see http://www.livescience.com/24816-hurricane-sandy-exposes-shipwreck.html (accessed 30-01-2017), for underwater see, for example: http://www.dailymail.co.uk/news/article-2500038/Mysterious-remains-boat-seen-time-fierce-storms-shift-sand-castle.html (accessed 30-01-2017).

[3] See also Chapter 3.

[4] Some experience of monitoring has been gained in European collaborations, including the Culture 2000 MoSS project and BACPOLES, under the EU 5th Framework Programme.

are discovered because the environment has changed.[5] This often also means an immediate threat. Sites that are continuously protected by sediment are predominantly in a stable environment. These sites, however, are often still undiscovered. Those we do discover are often partially or completely uncovered and immediately under threat (except those found in specific areas like the Baltic, see Chapter 5.5). Being exposed, visible and thus in a more oxygen-rich environment means the site is vulnerable to mechanical-physical, biological, chemical and human or anthropogenic deterioration. This is certainly the case in the Wadden Sea, as was shown in Chapter 3.

After discovery, immediate information is required about the situation. This is baseline data with which we can compare data gathered later to determine any changes. Although monitoring is often focused on the physical status of the wreck, it is obviously also important to know what the site consists of and consider its cultural and historical value.[6] Why is a specific site so important and what will we lose if the site deteriorates? This should be part of the initial significance assessment, which needs to be executed prior to in situ protection. By determining the value of the place, we know what we need to protect; we know what may affect it and how we should mitigate through in situ protection.

The overall management of a site in situ thus consists of: a cultural heritage significance assessment of the site (including its relationship to the area); an assessment of the threats; a decision about the prevailing values; determination of in situ preservation methods; and the ongoing monitoring of change, including, if needed, a mitigation strategy when changes are observed.

Monitoring results should provide input to an ongoing monitoring programme for an individual site. All monitoring programmes should provide input to an overall programme for an entire state or country with a longer term focus. Although the development of the Management Plans in the MoSS project and the Geographical Information System (GIS) in the MACHU project were preparatory steps towards the implementation of such a national monitoring programme and decision support system in the Netherlands, it has still not been implemented fully due to the lack of capacity, the vast number of sites, the reliance on various registration systems and the lack of a sense of urgency.[7]

6.2 Managing change

Monitoring is an important aspect of management. It provides the data on the basis of which we can measure and note any changes. However, an effective monitoring programme will also look at the specific qualities of a site: its cultural significance and its condition. Cultural significance is related to the condition of the site. The physical quality has a direct link with the integrity of the site and the information it holds. Therefore, changes may result in loss of significance.

The causes of change, the processes occurring and the physical variability in an area are all part of the process of change. Understanding of how changes arise and what the implications are or will be in terms of altering or affecting the intrinsic value of a site may help to make decisions on its future. Is the change beneficial (e.g. more sedimentation or stability), neutral or adverse (e.g. more erosion)? Is it permanent or temporary? Are the effects direct, indirect, synergistic or cumulative? The risk of changes will be better predicted if the broader area is considered, rather than only the defined limits of one single site. The change in sedimentation – erosion patterns within a larger area, for example – can have a future effect on an individual site. At an even greater macro level, climate change can have a major influence on erosion-sedimentation patterns.[8]

The value or significance of a site may change not only due to physical events but also due to changes in perceptions of what is important or not. Prevailing values may shift. We might think here of the change in significance of First World War shipwrecks to people globally.[9] We need to define the significance of such changes in relation to what we want to protect.

6.3 Types of change

There are different kinds of change that should be considered when monitoring underwater archaeological sites. The following definitions have been taken from Manders et al. (2012).[10] The dynamics of change can be seen as being beneficial, neutral or adverse, as well as permanent or temporary (long, medium or short term) in nature. The latter may also concern whether changes are reversible or irreversible.

[5] See Chapter 1.

[6] See below.

[7] Manders & Luth 2004, Hootsen & Dijkman 2009. We are still waiting for ARCHIS 3 to be fully available (15-1-2017) and made compatible with the maritime GIS developed within the MACHU project.

[8] Kaslegard 2011, 28–31.

[9] One example is the value of the three warships *Aboukir, Cressy* and *Hogue* that were sunk by a German submarine in the North Sea in 1914. In 1953, the British government issued a salvaging contract to a German company for the three wrecks, in which approximately 1,400 people died. Now, 100 years after the sinking of the ships, they have become cultural heritage and are also regarded as war graves. For more about the three British warships and the efforts to protect them against looting and illegal salvaging see, for example, http://gingerliberal.blogspot.nl/2012/02/at-6.html (accessed 31-01-2017). and also https://hansard.digiminster.com/Commons/2015-09-07/debates/1509089000123/ProtectionOfTheWrecksOfHMSCressyHMS*Hogue*AndHMSAboukir (accessed 31-01-2017).

[10] Manders et al. 2012.

Activities, processes and physical alterations to the environment can all give rise to a range of ways in which new effects can occur. This is the process of change. These effects may be direct, indirect, synergistic (i.e. how different factors interact to create a different kind of change) or cumulative. Moreover, the outcome of change can be considered in terms of what intrinsic values are altered, which outcomes may affect physical materials, settings, surroundings and perceptual, cultural and socioeconomic issues (education, amenity and economic aspects).

Thus, the significance of change cannot be determined without understanding both the intrinsic values[11] and the types of change which may occur, including uncertainties that may exist, such as:

- The magnitude of change. This is best thought of in terms of how far the intrinsic values of heritage may be altered and in particular how this would enhance or diminish the value of the site. This will include how much both physical and perceptual aspects will be altered by the various ways that changes arise. There is also a distinction to be made between how much change will happen, where it starts and where it will or could end up (see limits of acceptable change). As an example, one can think of the effect that erosion on the seabed will have on the cultural significance of an underwater archaeological site: how much will change once the erosion has occurred?
- Risk and opportunity prediction. This is normally considered in terms of weighing up the seriousness of a hazard against the likelihood of it occurring. A similar concept can be applied to change in cultural heritage, where either the intrinsic values of a place or asset are not fully understood, or the magnitude of change cannot easily be predicted. The change may be either beneficial or adverse; thus, the uncertainty may be expressed either as a risk or an opportunity. One example of this is the prediction of how likely it is that the erosion of the seabed will occur.
- Uncertainty and predictability. The two are related, as uncertainty is a simple acknowledgement that not everything is known to a level that is desirable. Predictability reflects a more quantitative approach to defining levels of uncertainty, usually based on the sampling parameters of studies undertaken to characterize the nature of the heritage asset (e.g. by non-intrusive survey or physical evaluation) and/or the scale of changes likely to occur. In the case of underwater cultural heritage, these might, for example, include a prediction of increased levels of damage to a shipwreck as a result of increased visits by recreational divers.
- Significance of effects. This concerns a balance between the importance of the cultural heritage in question (an individual site or area) and how much it will be changed for better or worse. If the site changes, how important is this? Would it effect its significance? Thresholds of significance are highly variable but can be related to how far the effects of change support and enhance, or are contrary to, specific cultural heritage objectives, policies or standards. This also encompasses external developments that may concern a variety of international, national, regional and local conventions, treaties, laws, policies, plans and programmes, codes of practice, design briefs, research designs, etc., which help to define standards against which significance can be judged.
- Sustainability of change. This concerns weighing up the balance between the social, economic and environmental needs of society, which extends beyond the limits of how significance is measured in relation to heritage or environmental assessments. The way in which cultural heritage significance is judged may change when these values are weighed against other non-heritage environmental, social or economic needs. As an example: the building of a dam may be necessary for the safety of the people. It will, however, cause erosion of the seabed. Do the negative effects outweigh the benefits or vice versa?
- Limits of acceptable change. There are various ways of looking at this, but often policies and legislation will indicate that significant change (as determined on the basis of considerations such as those outlined above) goes beyond a threshold of what is acceptable. In the public realm, this may be defined by legislation and policy, but for some situations, ethics, professional standards or technical considerations may define the limits of acceptable change. Public and legal opinion may also set the boundaries of what is acceptable and what is not.
- Regulation and management. This is a highly relevant topic related to significance, both because regulatory bodies do much to define standards (e.g. significant criteria) and because they will often help define what is or is not acceptable. By doing so, they ensure the application of measures to avoid, reduce, offset or reverse negative effects, and promote beneficial ones.
- Indicators and monitoring. These are further essential aspects when considering the significance of change, because the actual changes that occur as the result of implementation very often differ from what was expected. This is especially true in archaeology, where unexpected new discoveries are often made that alter the parameters under which the original assessment was made. Monitoring is, therefore, not only a means of checking whether initial assessments were right, but also for determining whether modifying actions are required to account for new conditions. Indicators can be a useful way to collect data of critical interest that enable us to construct a broader picture of what is going on at a site. Monitoring in its fullest sense also means collating information in such a way that it can aid us to make better judgements of significance in the first place.

[11] See also Chapter 2.

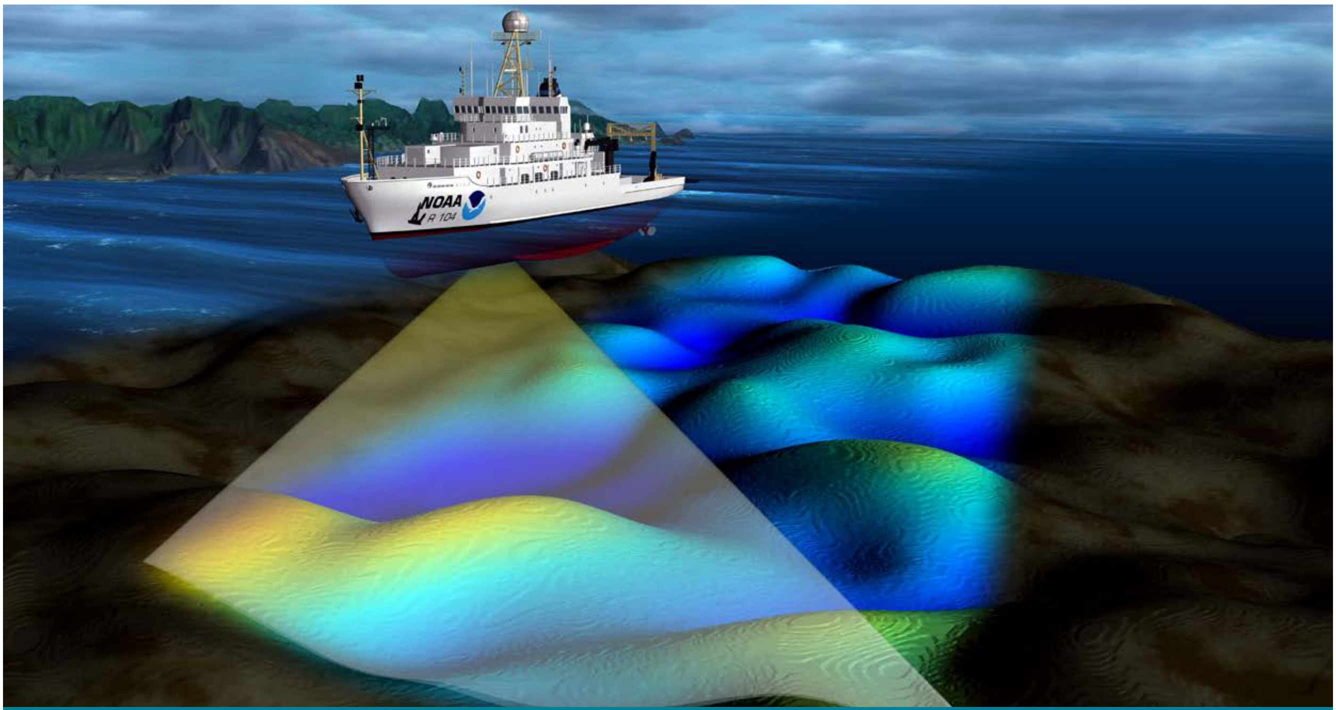

Fig. 6.3 Recording with multibeam. Courtesy NOAA, United States.

As has been illustrated, significance in relation to change can mean a range of things. When it is assessed, several different values must be taken into account and weighed against each other. As a result, it is crucial that when making an assessment of significance or monitoring change, we do so in a structured and consistent manner, related to the original baseline data,[12] and that we make decisions about what we consider to be the most important aspects of a site to protect.

6.4 Measuring the extent of deterioration

6.4.1 Baseline data

Monitoring starts by relating the current situation to previous circumstances. Collecting baseline data is therefore the starting point. This is the information collected at a site ideally as soon as possible after discovery but preferably after or during the cultural heritage significance assessment and at least prior to any mitigation measures. These mitigation measures should, after all, work against further decay, deterioration or loss of value and their effectiveness should be measured.

After mitigation, data on the same variables should be collected and a timeline for further monitoring developed. This timeline is an indication of how often a site needs to be monitored in the future. This may also change over time for a number of reasons. For example, new information might indicate that severe changes are currently occurring or will do so in the near future and the site has to be examined more often. The reverse is also possible: a site may become more stable and less monitoring required. Setting up a timeline for monitoring is not hard science as such, but influenced by observations from subsequent monitoring and can, according to this, be intensified or not. Baseline data consists of the assessment of the site, including its significance assessment (important for determining what to preserve and protect in situ), and a physical condition report, which should be repeated during monitoring.

Although important to establish baseline data for each site individually, there is often data available about the environment that can serve as universal values. If the on-site data deviate from these more or less standard values, then there is a good chance that actions will have to be taken to mitigate against these changes.

Since the early 2000s, several EU funded projects have partly focused on carrying out baseline studies and subsequent monitoring of underwater cultural heritage sites.[13] Some results related to the monitoring of sites in the Wadden Sea will be presented below.

6.4.2 Monitoring

Many processes may cause degradation, while individual processes also influence each other.[14] It is therefore important to determine which process is 'triggered' by what set of circumstances and how severe the destruction associated with that particular degradation process will be.

There are many different methods used to monitor sedimentation and/or erosion of the surrounding seabed, ranging from simple underwater visual inspection to the installation of measurement equipment on site. These, however, only measure the changes on a small scale and in specific locations. Repetitive monitoring can tell us, at the least, something about the process of sedimentation or erosion on the local scale. The European project, Monitoring of Shipwreck Sites (MoSS, 2001–2004), trialled an acoustic system to measure sediment changes on the local scale.[15] Although it was not very successful, due to the fact that it was tested for only a short period of time and the equipment broke down in the highly dynamic environment of the Wadden Sea, the short series of data showed that this kind of method could be used.

[12] See subsection 6.4.1.

[13] See Section 3.1.

[14] See Chapter 3.

[15] See Chapter 2.

In recent years, major developments in marine geophysical techniques have led to the implementation of multibeam sonar in underwater cultural heritage management (Fig. 6.3).

Multibeam recording provides information about what can be detected on the seabed, and due to its exact depth measurements it can also be used to monitor changes in the seabed across much larger areas than can locally applicable equipment. Its resolution depends on depth, with the highest possible footprint being one measurement per 5 x 5 cm. Its vertical accuracy is up to 2 cm.[16] This even makes the installation of measurement equipment – which, as seen above, is work intensive and vulnerable to defects – obsolete in many cases, except when continuous data is required.

Unfortunately, at present, there is still no system that can provide us with a view of material buried in the seabed and which could also be applied over large areas. However, a few systems are currently being developed which are based on sub-bottom profilers. The results are promising, but more research is required before they can be used effectively.[17] As soon as these systems are operational on a large scale, we will be able to use them to detect sites that are still in their protective burial environment and, if necessary, stabilize such sites before they become exposed. In this manner, sites that are still buried and unexcavated can also be integrated into the overall management programme of a specific area or underwater cultural heritage as a whole.

6.4.3 Measurement of various physicochemical parameters

Measurement of various physicochemical parameters in the sediment and surrounding water can provide more insight into the stability of the shipwreck environment and the ongoing mechanical, chemical and biological processes occurring on the site. These parameters include the redox potential, pH, dissolved oxygen levels and sulphide concentrations.

Redox measurements indicate the oxidizing/reducing nature of the local environment. They can give us insight into whether the seabed has a good protective consistency that will remain low in oxygen or rapidly become so. Measurements of pH can tell us how acid the water or the sediment are. Acid environments preserve different materials than alkaline environments, and organisms also behave differently.[18] By measuring dissolved oxygen in water or sediment we can investigate whether corrosion, for example, can take place or organisms that require oxygen can survive. Sulphide concentrations in the sediment are an indication of sulphur reducing bacteria in the sediment.[19]

Some parameters are easy to measure and may remain stable over a longer period of time. Others are more difficult to investigate in situ and fluctuate more often in value. The accurate measurement of dissolved oxygen content in sediments in situ, for example, is difficult because it is easily corrupted by oxygen from the water column. Attempts have been made to minimize this unreliability by measuring these various parameters in situ using electrodes attached to data loggers deployed on a site. In the MoSS project, a data logger was developed and trialled to measure the redox potential and pH of the sediment, and the salinity, dissolved oxygen content, depth, turbidity and temperature of the surrounding water.[2] (Fig. 6.4)

A similar system was also used to measure redox potential and pH in the Marstrand reburial project, while a new type of underwater data logger was developed and tested in the SASMAP project. The parameters for this open water system were: conductivity (to measure salinity), temperature, depth and an acoustic Doppler current profiler. Also, a diver-based data logging system was developed that can measure sediment profiles up to a depth of 50 cm. The parameters for this equipment are dissolved oxygen, pH, redox and sulphide.[22] Tests showed that dissolved oxygen probing is reliable with this system.[22]

Fig. 6.4 Diver with data logger on the BZN 10 wreck. Photo: R. Obst.

[16] Ernstsen 2006.

[17] Plets et al. 2009, IMAGO 2002, 20–25, http://sasmap.eu/progress/2013/wp2/ (accessed 21-10-2015).

[18] See, for example, http://www.fondriest.com/environmental-measurements/parameters/water-quality/ph/ (accessed 21-10-2015).

[19] Mudryk et al. 2000.

[20] Gregory 2004 (1), 8.

[21] EauxSys Ltd. Reburial and Analysis of Archaeological Remains: RAAR, within the SASMAP project, Unisense developed the open water data logger as well as the diver-based data logging system, Gregory et al. 2013.

[22] See http://sasmap.eu/progress/2013/wp3/#c50076 (accessed 30-01-2017).

Deterioration can also be assessed and measured by taking samples from the original shipwreck and/or by placing modern test materials on the wreck site. X-ray photography of submerged modern wood blocks can show the presence of degradative wood borers such as *Teredo navalis*, while microscopic analysis can show the types of bacteria and fungi causing deterioration (Fig. 6.5).[23] In this manner, it is possible to use these results as a 'proxy' indicator of the environment and its specific threats. General parameters can thus be established for specific environments. More importantly, we can study the ongoing processes of deterioration in the area and thereby assess future threats to a site.

Initiatives are now being undertaken to develop techniques to qualify the severity of attack and the state of preservation of wood in situ. Presently, most of the analytical techniques used to measure the extent of degradation of waterlogged wood are laboratory based and require samples recovered from a site. The density of waterlogged wood is a good parameter for assessing the state of preservation,[24] as density will decrease as more of the wood cell wall is degraded by microorganisms. Research investigating the density of waterlogged wood in marine environments in situ by means of relative conductivity is currently being undertaken at the National Museum of Denmark. The principle is that as the wood cell is degraded it becomes more porous and is filled with surrounding seawater, which has a higher conductivity than the undegraded wood. Good calibration curves for the density of wood as a function of relative conductivity have been established in the laboratory and equipment is currently being developed to enable these measurements to be done under water in situ. Using such methods, it should be easier to assess the state of preservation of wood without recourse to sampling, thus gaining insight into the rate of deterioration without damaging the wood.[25] In this way, we can gather information without essentially compromising the integrity of the site. This information can help us to design the best in situ preservation method, with wood quality measurements comparable with baseline data over time. Knowing the state of preservation enables conservators to choose the optimal conservation process in those cases where it may be decided to raise materials.

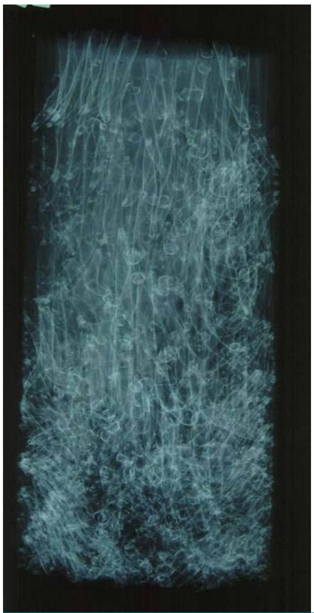

Fig. 6.5 X-ray of a pine block from the aerobic samples on the BZN 10 wreck. Note the severity of attack after one year on the site. Photo: courtesy MoSS project.

6.5 Monitoring in open water, on and in the seabed

6.5.1 Introduction

To monitor sites and determine the changes that are happening, it is necessary to measure and observe changes in the open water environment as well as on and in the seabed. These are basically three different environments with their own characteristics. This also means that the method and techniques for assembling the information may be different, as well as the information gathered. The data acquired may be used to make comparisons with future or past values: as baseline data or monitoring data.

6.5.2 The open water

Data for monitoring the possible effects of the open water environment, above the seabed, can be acquired in the following ways:

1. Technical devices such as data loggers and probes
2. By obtaining this information from large oceanographic institutes that undertake measurements for other purposes
3. Placing sacrificial objects in the water and measuring their deterioration rate over time
4. Taking water samples and post-recovery analyses

As we have seen above, a data logger has been used several times on archaeological shipwreck sites in the Western Wadden Sea to obtain environmental data. For example, during the MoSS project and the BACPOLES project, such data loggers were installed,[26] measuring pH and redox in the sediment and conductivity, salinity, dissolved oxygen (amount and percentage), turbidity, depth and temperature in the water.

It is, however, also possible to obtain data for specific areas from governmental institutions that monitor standard water quality parameters.[27] In situations that appear to be relatively stable, it is

[23] See Chapter 3.

[24] See, for example, Palma 2004 (2), 11.

[25] Gregory et al. 2013.

[26] Water samples were taken just above the seabed of the BZN 3 and BZN 15 sites. The environmental conditions of water and soil were measured with a WaterWatch 2681 data logger (manufactured by EauxSys Ltd, UK). This device measured salinity, dissolved oxygen, turbidity, depth and temperature of the water while employing two probes to determine pH and redox in the sediment. Experience with the data logger, which was still in an experimental phase, was gained in the EU funded MoSS project on the BZN 10 site.

[27] For example, Stanev et al. 2011.

not always necessary to collect continuous or even repetitive data. New sites, however, should have environmental parameters included in the initial baseline studies. Data can be obtained specifically through data loggers and sampling, but may also be extrapolated from already known data.[28]

To investigate the open water environment, water samples can also be taken. This was done for the BZN 3 and 15 sites during the BACPOLES project. Water surrounding the wrecks was found to be alkaline, with no dissolved organic carbon, low in nitrogen, low in nitrate, without immonium, low in phosphate, high in base cations,[29] high in sulphate, low in iron and high in conductivity (due to the salt).[30] Analyses of the water sampled close to the wooden wreck parts also showed extremely high Na, K, Cl- and SO42-, Ca and Mg levels.[31]

The data logger gave the following values:

	BZN 3	BZN 10	BZN 10	BZN 11	BZN 4	BZN 15
Temp (Celsius)	18, 9-21, 53	14, 48-18, 21	16, 97-19, 41	16, 97-18, 73	15, 98-17, 03	19, 79-20, 34
Turbidity (FTU)	10-58	0-7827	0-9546	8-60	8-118	6-1002
Depth (m)	5, 27-7, 16	7, 02-8, 28	6, 16-8, 22	8, 43-10, 35	8, 32-10, 32	8, 73-10, 7
Diss.Ox-1 (% saturation)	73, 9-94, 6	27, 7-145, 6	54, 3-110, 1	121, 0-163, 1	118, 6-163, 7	66, 4-81, 2
Conductivity (mSiemens/cm)	41, 66-47, 78	X	X	X	X	22, 74-45, 63
pH	6, 54-8, 39	X	X	7, 7-8, 24	7, 25-8, 76	7, 71-8, 42
Redox (mVolt)	227- -9	36- -482	X	116- -156	318- -177	134- -33
Salinity	29, 89-34, 89	X	8, 81-38, 28	X	X	15, 26-33, 2
Diss.Ox-2 (ml/L)	5, 5-8, 34	2, 7-20, 67	4, 34-12, 18	11, 46-15, 62	11, 47-15, 77	5, 11-6, 53
Date	27–28 Aug 2002	12/6/02–11/7/02	12/7/02–25/7/02	18/6/02–19/6/02	16/6/02–17/6/02	13/8/02–14/8/02

Table 6.1 Data logger values per BZN site.

The datalogger at times gave some extreme readings (See table 6.1, the measured low salinity at BZN 10), which on hindside cannot be double checked. Some conclusions can be made though. As we can see, many of the parameters for BZN 3 and 15 are comparable, as are those for the BZN 10 site that was monitored during the MoSS project. This is logical, as the sites are all close to each other and the measurements were taken more or less in the same period (summer 2002). In different seasons, however, there can be differences in parameters. For the BZN 10 wreck, for example, the temperature ranged between a reasonably stable 17 °C in July 2002 to as low as 1 °C on 17 December that same year.[32] We can assume that these data are representative of the water surrounding all the wreck sites on the Burgzand and thus can serve as baseline data for most of the wrecks in the area.

6.5.3 On the seabed

Information from the seabed surface – on the seabed – can be measured in several ways:

1. Visually, by divers or ROV
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 Remote Operating Vehicles (ROVs) with a camera mounted. Visual inspection can tell us about the pure physical conditions of a site. This can be done when parts of a wreck are exposed. Divers can also identify whether a site is being attacked by wood borers or if the integrity of the site has

[28] Either through oceanographic institutes or from earlier activities on nearby shipwrecks.

[29] Cations are ions or groups of ions having a positive charge and characteristically moving towards the negative electrode in electrolysis. Base cations are defined as the most prevalent, exchangeable and weak acid cations in the soil.

[30] Gelbrich et al. 2005, 80–81. The samples were taken in August 2002.

[31] Huisman et al. 2008, 37.

[32] Most measurements with the EaxSys WaterWatch data logger were taken on the BZN 10. See also Chapter 3. Coldest temperature measured on site with a Suunto computer was -1 °C.

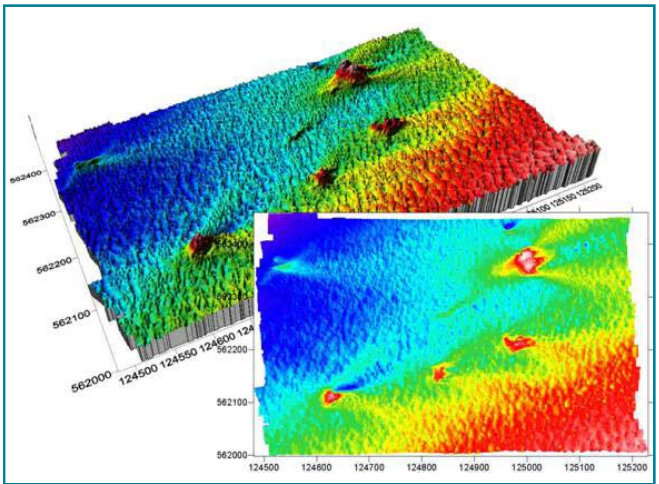

Fig. 6.6 Multibeam consists of real depth measurements, and is thus three dimensional. It can therefore be looked at from different angles. Figure: courtesy Periplus Archeomare/RCE.

been compromised.[33] One limitation to the use of divers and ROVs is the fact that it is more difficult to obtain a good insight into the location and thus an overview of the site.

6.5.4 Marine geophysics to monitor sediment change

This creation of an overview is not a problem when using bathymetric systems such as multibeam, side scan and single beam sonar. These techniques were developed to create maps of the seafloor. Some equipment can even give us a rough insight into what is happening in the seabed, such as sub-bottom profilers and magnetometers. These have been highly specialized equipment for a long time and expensive to deploy. Today, they are not only becoming more accurate, but have also dropped considerably in price. They have thus become available to many people, professionals as well as avocational groups.

Obviously, many government institutions have access to marine geophysical technical devices that can be used to monitor the effects of sediment transport over a wreck site. In the Netherlands, the RCE works with the Rijkswaterstaat (RWS, Directorate-General for Public Works and Water Management, part of the Ministry of Infrastructure and Water Management) to obtain multibeam data and also with commercial survey companies such as Periplus and DEEP.[34] Repeated surveys carried out at different times using multibeam can be digitally subtracted from each other in order to map where there are areas of sedimentation and/or erosion of sediment. This was trialled in the Burgzand area, with the longest repetitive monitoring survey on the BZN 10 wreck.[35]

Single beam can also be used for the monitoring of larger landscapes in particular. It – as the name suggests – records the depth of the seabed using a single sound beam rather than multiple (as in the multibeam). It has been used, for example, to map the overall Western Wadden Sea seabed.[36]

Although it does not record actual depth, side scan sonar can also be used to monitor changes at protected submerged cultural heritage sites and in their environment. This equipment, which can scan large areas of the seabed in a relatively short time, has become very cheap in the last couple of years and its use is now widespread.[37]

Multibeam recording as a way to monitor shipwreck sites[38]

If we had to mention one type of equipment that is of enormous help in the monitoring of sites on the seabed, then it would have to be the multibeam echo sounder, which is an instrument used in hydrography to plot the seabed. The multibeam sends multiple sound pulses to the seabed in a narrow path under a ship, accurately measuring depth. Usually, the higher the frequency, the better the accuracy.[39] At present, in ideal conditions, some systems can produce images as good as the side scan sonar, but including actual depths.[40]

Multibeam is very useful for mapping an area of the seabed rapidly and can be used for the detection of shipwrecks on the seabed. It does not cover as much seabed in one single track as a side scan sonar, but it does give an accurate overview of an area in actual depths in just a short period of time. Since it produces actual depth measurements, it can quantify environmental changes such as sedimentation or erosion processes. It is, therefore, a cost-effective method for monitoring archaeological sites – including their environment – under water.[41]

Multibeam data can also be processed in such a way as to create a three-dimensional image. This is highly effective for research, making it possible for a researcher to virtually swim around the wreck site and understand issues in 3D. In an age in which visualization is becoming increasingly important, these kinds of images can also be very useful in communicating with a broader audience (Fig. 6.6).

Multibeam can also be a highly effective tool for regular or specific monitoring. One example of specific monitoring is an investigation of the possible looting of a site near the Dutch town of Hoorn. The Cultural Heritage Agency had been informed by local divers that looters were active at an eighteenth-century

[33] It is not, however, always easy to detect living Teredo in wood.

[34] See, for example, Brenk & Manders 2015.

[35] See Chapter 3.

[36] See Chapter 1.

[37] See, for example, http://www.fws.gov/panamacity/resources/An%20Illustrated%20Guide%20to%20Low-Cost%20Sonar%20Habitat%20Mapping%20v1.1.pdf (accessed 31-01-2017).

[38] This chapter has to a great extent been published in the MACHU Final Report, Manders 2009, 59–68.

[39] The highest resolution in the Burgzand research was 10 x 10 cm.

[40] A side scan sonar also detects obstacles on the seabed using sound frequencies. However, this system sends out the sound waves at an angle and, instead of measuring depths, creates an image of hard reflections, soft reflections and shadows.

[41] See also the final report of the Rasse project by Bates et al. (2007) and the article by Mayer et al. (2009) for their conclusions on the use of multibeam for underwater cultural heritage management.

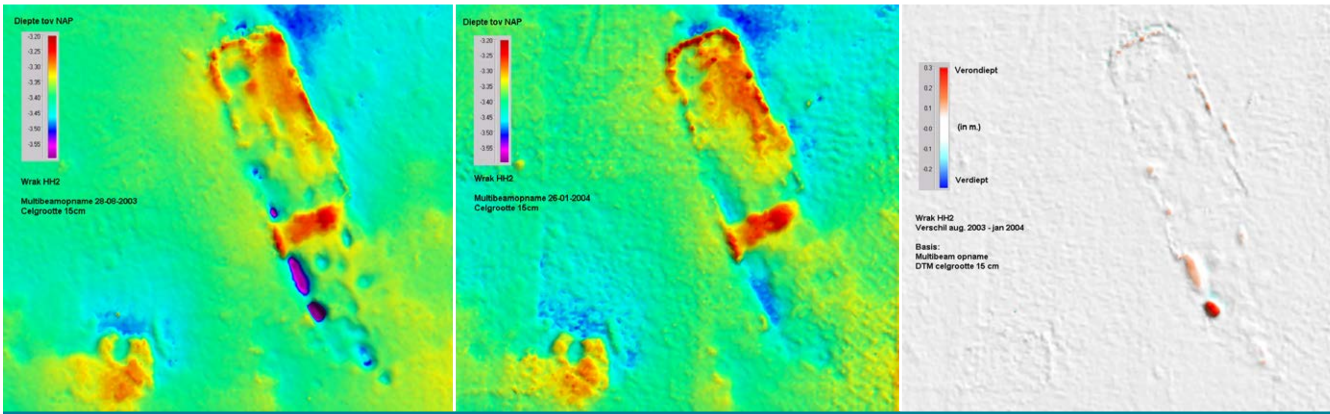

Fig. 6.7 A, B, C Two different multibeam recordings (A + B) made on the Hoornse Hop 2 wreck near Hoorn in the Netherlands to investigate possible illegal excavation on the site. Picture C is the result of a comparison. The results revealed that there had been more sanding in, and this was not consistent with supposed illegal excavation. Figures: RWS-IJsselmeer.

shipwreck looking for Makkum earthenware that was known to be part of the cargo. However, comparison between an earlier multibeam recording and one made just after the information was passed on revealed that the site had not been touched for a while (Fig. 6.7 A, B, C).

At the Banjaard area in Zeeland, old wreck positions have been reanalysed on the basis of new multibeam recordings. The nineteenth-century 'Spot by 11' wreck, for example, was found to be approximately 100 metres south of its original position.[42]

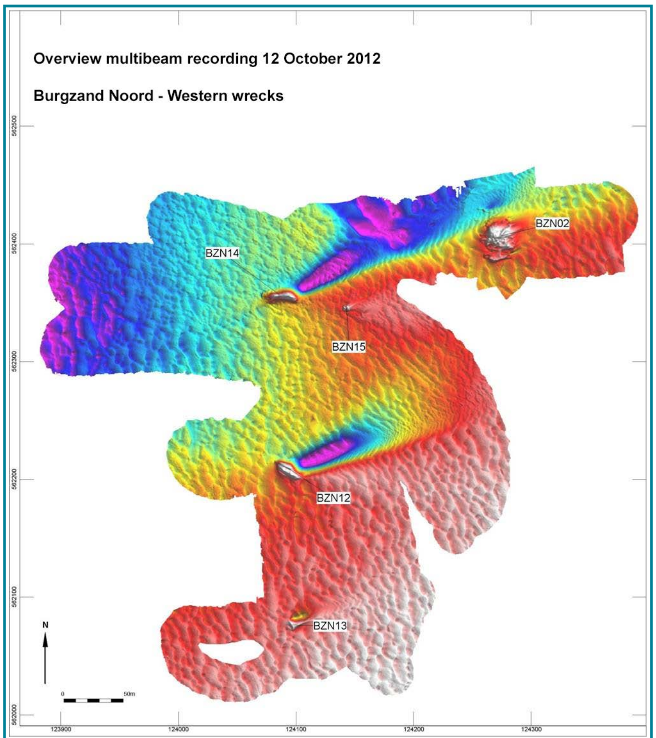

Fig. 6.8 Multibeam on a regional scale. Figure: Periplus Archeomare.

The multiple depth measurements taken with multibeam can also be used as input for erosion-sedimentation models on a regional as well as on a larger scale, such as that produced by Southampton University (UK) for the southern North Sea basin and the Burgzand area at large (Fig. 6.8).[43]

A coring plan for Optically Stimulated Luminescence (OSL) dating was also developed as part of the MACHU project on the basis of the multibeam recordings of the BZN 10 site in the Wadden Sea (Fig. 6.9).[44]

Another use for multibeam is in archaeological assessments and excavations. Its accurate positioning, depth measurements and the overview it provides offer an accurate basis for site plans. This not only saves valuable time, but also often proves to be more accurate than measurements done by hand.[45]

The multibeam echo sounder is used by many organizations whose remit includes managing the waters and seabeds of Europe. In the Netherlands, they include the RWS and the

Fig. 6.9 Using multibeam recording on the BZN 10 wreck to plan OSL dating. Photo: Paul Voorthuis, Highzone Fotografie.

[42] The site location was registered incorrectly in ARCHIS. Its position was corrected after multibeam recording of the site in 2008, Konsberg EM 3002D.

[43] See Dix et al. 2009 (1).

[44] See Manders et al. 2009 (1), 2009 (2).

[45] The use of multibeam as a basis for making site plans is becoming standard practice. In the Netherlands, multibeam formed the basis of the archaeological recordings at the first underwater excavation, executed by a private archaeological company in 2006: the excavation of the ship De Jonge Jacob (1858). See Waldus (ed.) 2009 (http://www.rtvoost.nl/tv/uitzending.aspx?uid=335462&_ga=1.146288626.730270569.1452855246, accessed 30-01-2017).

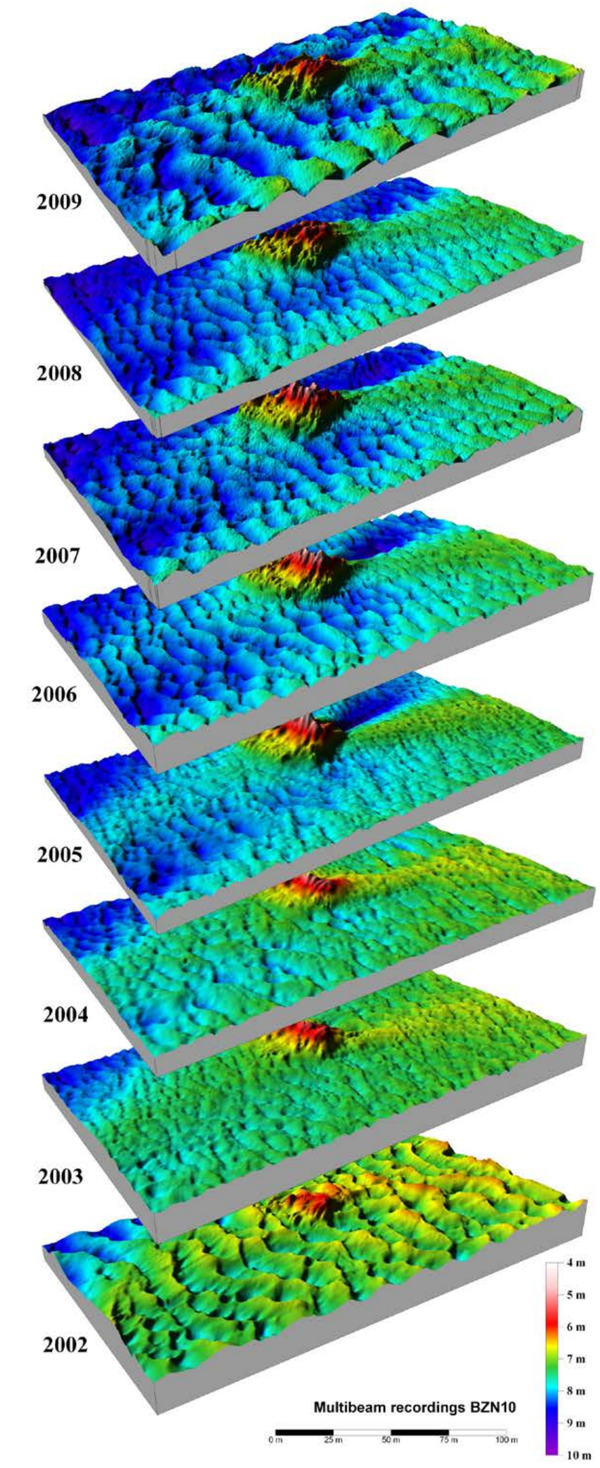

Fig. 6.10 Monitoring by using annual multibeam recordings and comparing them with each other. Figure: Periplus Archeomare/RCE.

Ministry of Defence's Hydrographic Service.[46] Data they collect for other purposes can – in many cases – be used for archaeological monitoring.[47] Harvesting of information from third parties makes monitoring even more cost effective.[48]

Multibeam monitoring on the Burgzand, Texel

With this in mind, the Burgzand area was extensively monitored using multibeam echo sounder. In 2002 and 2004, the system used was a Reson Seabat 8101, while in 2003 and from 2005 onwards the equipment used was a Reson Seabat 8125, a top-of-the-range system.[49] The latter has an operating frequency of 455 KHz that can cover a 120° swathe of the seafloor with 240 dynamically focused beams. This means that 240 depth measurements are taken with each pulse, at 40 pulses every second. The 8101 has a lower resolution, using only 101 beams.

From 2002 onwards, the monitoring was performed in collaboration with the RWS, the main management agency for waterways in the Netherlands.[50] The first recordings (2002 to 2005) were made for the EU MoSS project (Monitoring of Shipwreck Sites) and were later taken over by the MACHU project.[51] After the MACHU project in 2009, the monitoring continued until the present day (Fig. 6.10).[52] This long series of continuous data offers a detailed insight into what is happening on the seabed in this area. The multibeam recordings are made each year, usually around October-November. Specific events, such as storms, have not been taken into account, although it is known that these can have a strong and sudden impact on the seabed and the shipwrecks in and on it.[53] The focus has been on long-term effects on the sites, and this also means more flexibility when it comes to the availability of the surveyors and their equipment.

To begin with, four archaeological shipwrecks (BZN 3, 8, 10 and 11), which lie in an area of 200 x 250 metres – the heart of the Burgzand area and the former Texel Roads – were monitored with multibeam.[54] While BZN 3, 8 and 10 were physically protected in situ, BZN 11 was not and this wreck served as a benchmark.[55]

[46] As a comparison, in Belgium, the Flanders Marine Institute (VLIZ), which coordinates scientific research in the North Sea, and Flemish Hydrography, serve as centres of expertise for this kind of work. See also Demerre 2009.

[47] When multibeam is used for the monitoring of shipping lanes, the main focus is to detect any obstacles, such as protruding shipwrecks or a shallow seabed, that might endanger the ships passing through. The maps produced of these usually quite large areas are of a lower resolution than is needed for archaeological assessment or monitoring. However, by analysing the data originally recorded, this more detailed information may be obtained without having to go back to the site. The use of multibeam echo sounders in underwater cultural heritage management was also promoted in the IMAGO project (innovative measuring of sunken objects). See IMAGO 2002.

[48] See also Chapter 5.

[49] Talbot 2005.

[50] RWS has responsibility for waterways in the Netherlands, while the Dutch Cultural Heritage Agency is responsible for managing the cultural heritage (including the underwater cultural heritage).

[51] See also Brenk 2003.

[52] This is arranged within the covenant with Rijkswaterstaat and is believed to be the longest shipwreck monitoring of this kind in the world.

[53] Extreme examples of the effect of storms and hurricanes on the seabed and shipwrecks are known. See, for example, Gonzalez 2015.

[54] See also Chapter 3.

[55] See Chapter 3.

As quickly as the wrecks can be uncovered by the highly dynamic environment, they can quickly be covered again with a protective layer of Holocene sand.[56] This process is continuous.

6.5.5 In the seabed

Data for monitoring the effect of the sediment on the physical quality of the site can be acquired in the following ways:

- Probes and data loggers[57]
- Sacrificial objects
- Sampling

Nearly all of the biogeochemical processes in young sediments (e.g. the dynamic Holocene sand layers in the Wadden Sea) are directly or indirectly connected with the degradation of organic matter.[58] Organic matter in the seawater and the seabed may be produced by algae and other organisms in open water, which subsequently sink to the seabed and become incorporated into the sediment. There may also be remains of plant material, such as seagrass or seaweed, or shipwreck material deposited within the sediment.[59] The utilization of organic matter by organisms within sediments involves oxidation reduction (redox) reactions.[60]

Usually, only the first few millimetres of the seabed sediment are oxygenated. Through bioturbation by invertebrates and advection, this oxygen zone may, however, extend downwards. A few centimetres under the oxygenated zone, nitrate serves as the oxidizing agent, followed by manganese and iron oxides deeper in the sediment. Below this, sulphate is the principal oxidizing agent, and sulphate reduction is often the dominant process in shallow marine sediments due to the high concentrations of sulphate in seawater.[61]

The seabed in the Western Wadden Sea consists mainly of sand. Small and large blocks of peat are a reminder of the time that the Wadden Sea was still a swampy area.[62] Often, as part of the many post-depositional processes, a layer of fine clay settles between the construction parts of a shipwreck. During sampling on the BZN 15 site, little lumps of this clay were observed, while on other sites with more intact wreck structures this clay can be found as continuous layers covering archaeological material.[63] These observations tell us something about the wrecking process and the dynamics of the seabed. A continuous layer of fine clay usually means that everything that is below it is in relatively good condition, while lumps and blocks of peat tell us something about the dynamics of erosion in the area.[64]

In terms of monitoring within sediments, the dissolved oxygen content, concentrations of various chemical species, porosity and the 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. The following parameters may be assessed to obtain an idea of the nature of the buried environment:

- Dissolved oxygen content
- Redox potential, through measurements or the presence of monosulfides
- Sulphate/sulphide and also total sulphur content
- Organic content of sediment
- Porosity of sediment
- Water flow[65]

These parameters will give a good indication of whether the environment is oxic or anoxic and which dominant process are taking place in the sediment.

A characterization of the soil of the Wadden Sea seabed can be provided through analyses of samples taken during the BACPOLES project on the BZN 3 and BZN 15 sites in 2002. The soil on both these sites consisted of pure sea sand, it was alkaline, very low in carbon content, no nitrogen was present, it was low in phosphorus, low in base cations, low in sulphur and medium in iron. We can assume this will also be similar to the top layer of the seabed on the Burgzand and in the Western Wadden Sea in general.

When removing the top layer on the wreck sites in the Burgzand area of the Western Wadden Sea, it can be noted that the sand is usually black. This was also noticed during sampling on the BZN 3 and 15 wrecks.[66] This black colour is indicative of reducing conditions, as it is caused by the presence of Fe (II) minerals. In contrast, Fe (III) minerals would give the soil a more yellow-brown or orange-brown colour. In anoxic sediments influenced by a marine environment and with organic matter and iron, there is usually a high concentration of sulphur (S) present. In such

[56] See also Chapter 3.

[57] Sub-bottom profilers may also be available for in-sediment monitoring. However, at present, no clear information is available on the possibility of identifying different qualities of wood through the sub-bottom profiling signals (Plets et al. 2008).

[58] Rullkötter 2000.

[59] See also Chapter 3.

[60] Schulz 2000.

[61] Kasten & Jørgensen 2000.

[62] See also Chapter 1.

[63] Observations made by the author during assessments and excavations in the Western Wadden Sea area, such as on the Scheurrak SO1 wreck and also BZN 10 wreck. See also Manders 2005 (1).

[64] Of course, as long as the lumps of clay do not have a direct human origin, for example, excavation.

[65] Klaassen (ed.) 2005.

[66] Huisman et al. 2008, 36.

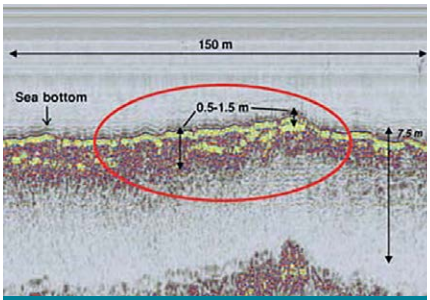

Fig. 6.11 Sub-bottom profiler recording of the BZN 3 wreck. Figure: Deltares/RCE/MACHU project.

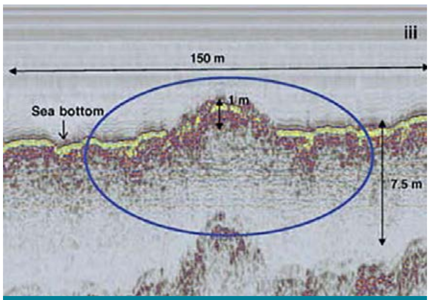

Fig. 6.12 Sub-bottom profiler recording of the BZN 10 wreck. Figure: Deltares/RCE/MACHU project.

environments, ample pyrite (FeS_2) can form in the soil mass. The BZN 3 and 15 sites had very low sulphur contents, which can be explained by the very sandy, organic-poor sediment in which pyrite usually does not form. Phosphorus (P) is also quite low in the minero genic sediments. However, the sites showed high concentrations of Ca, which is logical in relation to the presence of calcite in the sand.

The Fe contents were highly variable. This probably reflects variations in redox conditions that cause local dissolution and precipitation of Fe minerals, especially Fe (hydr)oxides. The pH was neutral to basic, which conforms to the more or less uniform hydrogen carbonate (HCO3--) concentrations that were detected. A depth profile of redox potential confirmed that reducing conditions had been reached at BZN 3 and 15.[67] Measurements with the same data logger at the BZN 10 site revealed that redox values dropped from an aerobic +36 mV to an anaerobic -460 mV within 12 days, after which it stabilized.[68] The pH of the sediment was constantly around 8 on the BZN 10 site during measurement with the data logger.

It is not easy to monitor conditions within the seabed without physically removing the sediment or physically penetrating the soil with sensors. However, to investigate the position of an archaeological site within the seabed and to monitor the effectiveness of physical in situ protection methods added to the site, sub-bottom profiling can be considered.[69] This technique was, for example, in use for the monitoring of the BZN 3 wreck (protected with sandbags and debris netting) and the BZN 10 wreck site (protected with debris netting alone) in 2009. Within the MACHU project, a seismic chirp sub-bottom profiler was used in combination with a side scan sonar. The primary reason for this research was to investigate the use of this technique in monitoring, and especially to see whether the combination of the two systems could detect disturbances in sedimentation processes on the seabed. A second reason was to map the thickness of the sand layers that had settled on the wreck site after the physical protection measures were taken.

The work was performed by Deltares using a side scan sonar CM2 system from C-MAX, with a frequency of 325 kHz, a resolution of 0.1 metres and a search path of 100 metres.[70] The sub-bottom profiler was an SB-0512i system from Edgetech. This seismic chirp system can easily distinguish different sediment layers and objects (in particular large objects) in the first 15 metres of the seabed.

Different frequencies were used in the Wadden Sea, between 0.5 and 7.2 kHz. A measurement was taken every 0.75 metres.[71]

Unfortunately, due to the presence of sport divers while recording, it proved impossible to investigate the whole area. Only a few measurements were taken at the BZN 3 and BZN 10 wrecks but some interesting conclusions can be drawn from the data collected, which will be discussed briefly here.

» First, the BZN 3 site is clearly visible on the side scan as well as in the chirp data (Fig. 6.11). The chirp profile shows us a sedimentation layer of approximately 0.5 metres on top of the wreck mound. This means that the protection measures put in place in 2003, with polypropylene nets on top of the old protective layer of sandbags added in 2009, had managed to hold another half a metre of sand. On the flanks of the mound, as much as 1.5 metres of sediment had been caught with this protection technique. This is the area where no sandbags had previously been deposited (in 1988).

» Second, the chirp data from the BZN 10 site show relatively sharp flanks with low reflections in some places (Fig. 6.12). This means that there was less sediment under the polypropylene nets and that the nets were more or less hanging loose. Measurements with the sub-bottom profiler showed a sediment layer at least 1 metre thick on top of the wreck.

This research, although not extensively executed, with only two profiles, demonstrates the use of seismic chirp data in monitoring physically protected wreck sites. The data allow us to monitor the amount of sediment caught in the polypropylene nets.

New research using 3D seismic data will, in the near future, allow us to monitor the sedimentation rate over a whole site.[72] Tests with a new 3D system on the BZN 10 site in 2014 for the SASMAP project were unfortunately not very successful due to the roughness of the sea surface at the time of recording (Fig. 6.13). However, the Innomar 3D parametric sub-bottom profiling system tested did give good results on other sites.[73]

[67] Huisman et al. 2008, 39.

[68] Measured between 11/6/2002 and 11/7/2002.

[69] Manders 2009 (1).

[70] Paap & de Kleine 2009.

[71] Two measurements per second at a sailing speed of 3 knots (1.5 m/s). The side scan and seismic chirp data were processed using Petrel (3D modelling software) to visualize the results in 3D, Paap & De Kleine 2009.

[72] Early attempts to use 3D seismic on archaeological sites in the UK are described by Bull et al. (2005). In the Netherlands, the first attempts were made in the IMAGO project, Brenk, Romein & Missiaen 2003.

[73] Al-Hamdani et al. 2013, Gregory & Manders (eds) 2016.

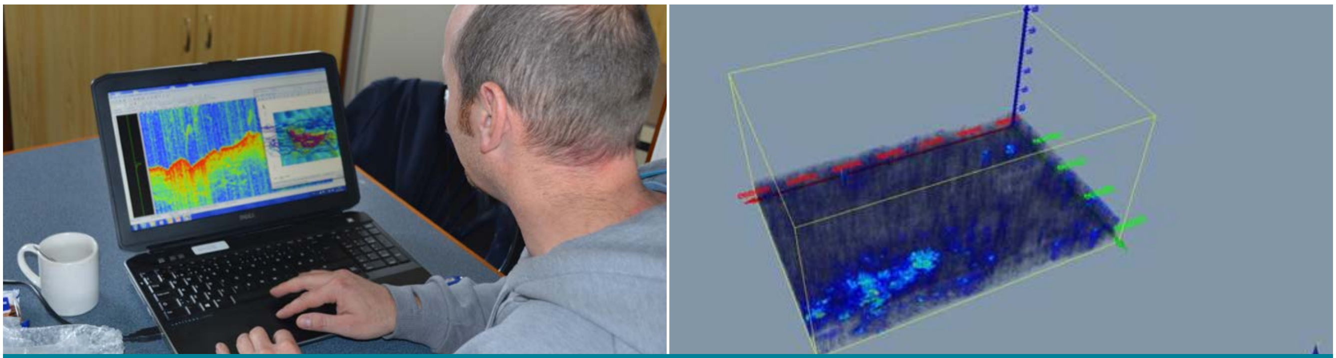

Fig. 6.13 3D sub-bottom profiling from the BZN 10 wreck. Figure: INNOMAR/RCE/SASMAP project.

6.6 Optical dating: potentially a valuable tool for underwater cultural heritage management[74]

Coring can be used to investigate what is in the seabed. It can be used to search for a site, to interpret, for example, sediment layers or areas with archaeological finds, or to investigate environmental parameters within an area. However, for the interpretation and monitoring of a site, another kind of analysis can be added to the toolbox. As we have seen, knowledge about sediment dynamics is of great importance for the management of shipwrecks on the seabed. On the one hand, transport of sediment will allow for rapid burial of the wreck. On the other hand, sediments transported by currents can be highly erosive, which can eventually lead to the complete destruction of a wreck site.[75] In order to understand more about the sediment dynamics in and around a shipwreck, a study was conducted in the MACHU project using OSL dating, grain-size analysis and anthropogenic metal analysis. This integrated research was designed to provide greater understanding of the history of post-depositional processes at particular sites. The effectiveness of in situ preservation using polypropylene netting could also be investigated in this way.

6.6.1 Optical dating, grain-size distribution and anthropogenic metals

For the first time ever,[76] an underwater shipwreck (the BZN 10) was investigated and its surrounding sediments successfully dated using the OSL method (Fig. 6.14). Optical dating is used to determine the time of deposition and burial of sandy deposits. The method determines the last exposure to light of sand or silt-sized minerals.[77] It may thus give some valuable information about the stability of a site over time as well as the effectiveness of in situ protection methods.

OSL dating has been applied regularly on sediments from land sites.[78] However, application of the same method to sediments in the Wadden Sea is not straightforward. Light exposure of the grains prior to deposition and burial may be too limited (due to filtering of sunlight through the water) to completely reset the OSL signal (i.e. to set the OSL clock to zero). Any remaining OSL signal will result in a positive age offset, with the OSL age on such deposits overestimating the true burial age. To counteract such problems, one can use the part of the OSL signal that is most light sensitive (i.e. has the best chance to be reset) and attempt to use only those grains for which the OSL signal was reset (i.e. the grains or subsamples giving the youngest results). Both approaches have been successfully used to determine the age of fluvial deposits. A prerequisite for optical dating to be successful is that the most light-sensitive part of the OSL signal should be erased to negligible levels for at least part of the grains at the time of deposition. Given the highly dynamic environment of the Wadden Sea, it was expected that this prerequisite would be met.

The study not only applied OSL dating but also looked at grain-size distribution and anthropogenic metals to investigate the sedimentation process and the provenance of the deposits.[79] By studying grain-size distribution, it is possible to determine whether sedimentation is continuous or occurred during specific events, as well as whether sediment has been transported through waves (fining upward sequences) or is deposited from the water column during periods of low energy. In addition to grain-size analyses, anthropogenic trace metals and stable lead isotopes can be used.

Fig. 6.14 Executing coring with the Ackermann core on the BZN 10 site. Photo: Paul Voorthuis, Highzone Fotografie.

[74] This section is a summary of Manders et al. 2009 (1) and Manders et al. 2009 (2).

[75] See Chapter 1.

[76] As far as is known by the researchers.

[77] See, for more about OSL, Chapter 2.

[78] See, for example, Bluszcz 2005.

[79] Manders et al. 2009 (2).

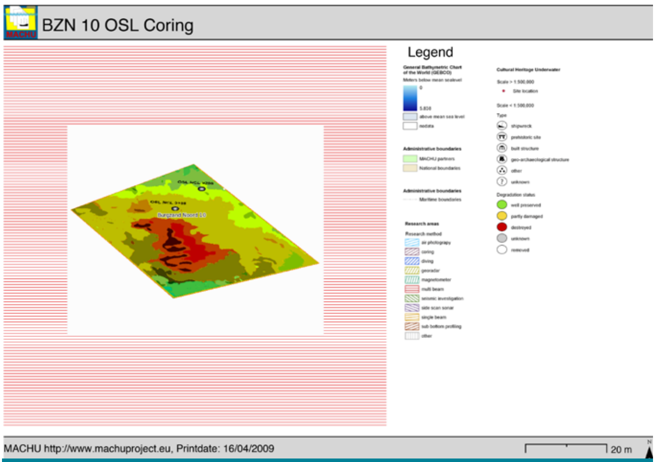

Fig. 6.15 Position of the two Ackermann cores on the BZN 10 wreck site. Figure: RCE/MACHU project.

Fig. 6.16 The Ackermann core. Photo: Paul Voorthuis, Highzone Fotografie.

Stable lead isotopes allow the creation of a fingerprint of anthropogenic lead. From 1950 to 1983, lead was added as an anti-knock agent in petrol. This lead originated from Broken Hill, Australia, having a very different lead isotopic ration compared with European industrial lead and natural lead. By studying metal profiles in the sediment, the onset of the industrial revolution, the introduction and use of the anti-knock agent and the last 25 years could be dated.[80] In addition, if the metal profiles and stable lead isotopes could be used to identify sedimentation events, this would provide useful information, such as rate and frequency of burial or erosion events of shipwrecks in dynamic sandy environments in shallow (less than 30 metres) continental seas.

By measuring major elements, as well as carbon and sulphur content in the sediment, the occurrence of sulphate reduction could also be established.[81] Sulphate reduction can cause sulphidization of metal (iron) objects in shipwrecks, such as nails. It will also hamper the exhibition and conservation of the ship after removal because of oxidation of the previously formed sulphides. These will produce sulphuric acid, causing all kinds of problems.[82] Erosion events may also be marked by changes in grain size and heavy mineral concentrations that may be indicated by trace elements such as rare earth elements (REE), zirconium (Zr) and titanium (Ti). Major element concentrations, and carbon and sulphur content reflect lithological changes (such as calcium carbonate and clay content) and can therefore add to our understanding of the sedimentation history.

The optical dating, grain-size analysis and chemical pollution studies were applied to the sediment taken from two cores (no. 9108 and no. 9208). The specific aims of this study on the BZN 10 wreck were:

- To investigate the application of OSL dating in relation to sediment transport and deposition in the Wadden Sea and to evaluate the application of OSL dating to shipwrecks in a dynamic environment.
- To date sand layers below, in and on top of a physically protected shipwreck. By accurately dating sand, in theory, the age of a wreck can be narrowed down, making identification easier. In addition, transport of 'bleached' sand after the sinking of the ship could give an indication as to when and how fast the ship was buried. If younger sand is found in or below a shipwreck, it is likely that the wreck moved after sinking and that the environment is highly dynamic. This would imply the threat of the ship being repeatedly exposed. This information may be important for the significance assessment of the site, and for determining whether to preserve in situ or ex situ (through excavation).
- To test, underneath the wreck, the hypothesis that shipwrecks sink into the Holocene sediment of the Wadden Sea, which appears to be less consolidated than the hard Pleistocene subsurface.[83]
- To use drilling in the wreck to find in situ shipwreck-related debris and sediment layers. In this way, it may be possible to establish whether a site contains relatively undisturbed sediment layers that may contain artefacts from the wreck site.
- To investigate, above the wreck, the relative intactness of the site and, in the case of physically protected sites, to investigate the effectiveness of in situ preservation in the Wadden Sea. Seven shipwrecks in the Wadden Sea have been physically protected in situ with polypropylene nets. These nets could be used as independent age markers and thus serve as a control for the OSL dating.

6.6.2 Fieldwork and sample selection

The two core samples were taken from the site by the Geonaut, operated by BAM-De Ruiter Boringen en Bemaling BV.[84] These were drilled 8.75 metres (9108) and 5.95 metres (9208) respectively into the seabed. One of these Ackermann cores was intended to go through the wreck (no. 9108) and one just next to it (no. 9208). The aim was to go through the whole Holocene layer and one or two metres into the Pleistocene sediments below.[85] It was hoped that the core through the wreck site (no. 9108) would

[80] Walraven et al. 1996.

[81] See also Chapter 3.

[82] See also Chapter 3.

[83] See also Chapter 1.

[84] On 27 November 2007.

[85] For more information about the sampling, see MACHU Report 2: Manders et al. 2009 (1).

strike timbers from the ship structure. This could then be used as a reference point for dating the sediment (Fig. 6.15).

Ackermann cores consist of RVS tubes 350 mm long and 66 mm wide (Fig. 6.16). No light can penetrate to the undisturbed samples, which together make up one continuous sample. The core taken near the wreck (9208) was almost 6 metres long and consisted of 17 separate samples. The core inside the wreck was almost 9 metres long and consisted of 25 samples. Unfortunately, the latter core did not hit the ship structure, but probably passed between two parts of the wreck, as parts of the protective nets were present in the samples.

6.6.3 Analyses
To select a suitable sampling depth for full OSL dating analysis, some 20 samples from the two cores were examined in a 'quick and dirty' investigation. Unfortunately, the results were too scattered to convincingly guide sample selection. After discussion between the Netherlands Centre for Luminescence Dating (NCL) and the Dutch Cultural Heritage Agency, ten samples were selected for full analysis.

For both cores, the samples from the upper metre below the seabed were not reliable for dating.[86] However, the age of these sediments is very likely to be 100 years or less. At the location of the BZN 10 (9108), the results from underlying sediments (1.5–3.5 metres below the seabed) indicated an age of around 300 years; these age estimates are likely to be valid. Hence, optical dating suggests these sediments are of a similar age to the BZN 10 wreck, which has been dated to the second half of the seventeenth century.[87] The optical age obtained from a sample from the other core (9208) at a similar depth (1.6 metres below the seabed) gave a much older age (~700 years). The samples from more than 4 metres below the seabed at the wreck position (9108) indicated ages between ~600 and 800 years, with the results on the oldest sample likely to be unreliable. It was concluded that the core did not penetrate the entire Holocene sedimentary body and that Holocene sediments were present below the wreck. This was an important conclusion, since it addressed one of the aims of the study, which was to investigate the theory that wrecks in the Wadden Sea sink through the soft Holocene sediment to finally rest on the harder Pleistocene layer.[88] The answer was no, or at least not always (Fig. 6.17).

6.6.4 Grain sizes
Prior to the coring, the BZN 10 wreck had been covered with a polypropylene debris net in 2000, 2001 and 2003.[89] In core 9108, the net from 2000 or 2001 was found at a depth of 40 cm.[90]

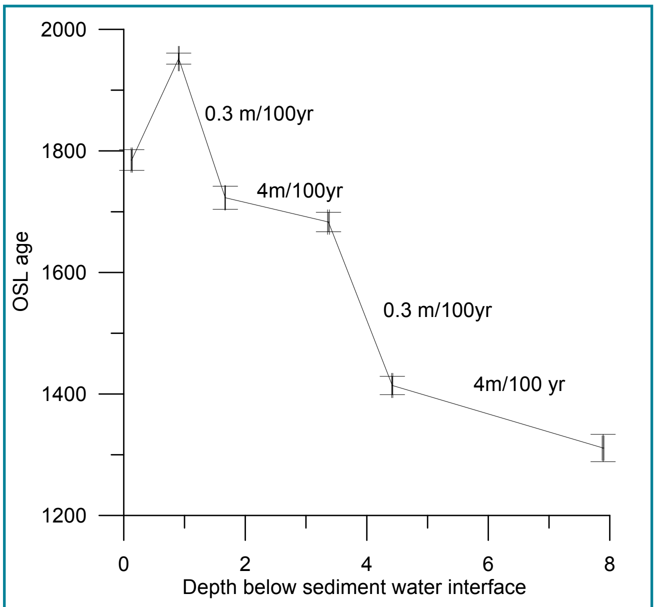

Fig. 6.17 Depth vs age plot for core 9108. The plot shows two periods of rapid deposition (1300–1400 and 1650–1700). In the intervals between and after these periods, sedimentation rates were much lower and might even be erosional. Figure: RCE/MACHU project.

Distinct regions of similar grain-size distributions could be recognized in both cores. In core 9108, in addition to the clay lenses occurring 4 metres below the surface, clay lenses were also found in the interval from 3–4 metres below the seabed surface. The pattern of median grain sizes and distribution between approximately 4 metres below the surface in core 9108 seemed to correspond with the level below approximately 1.5 metres in core 9208. This again corresponded with the measurement data from both cores. The 9108 core was taken at a water depth of -5.66 metres, while 9208 was taken at -7.97 metres, a difference of 2.31 metres.

The deposition of the upper 3 metres of core 9108 was possibly related to the sinking of the ship (post-depositional processes). This would have caused lower water velocity and the deposition of sand, which buried the wreck. The grain-size distribution of this sand did not differ much from the deeper sand and the sediment in core 9208. The sediment in core 9108, thought to have been deposited after the placement of the in situ preservation debris net (upper metre in core 9108), was characterized by a similar grain-size distribution to the rest of the core. However, the carbonate (shell) content seemed to be somewhat higher. The higher carbonate content at the top of core 9108 coincided with a heavy mineral-rich layer. This suggests that

[86] Manders et al. 2009 (2), 43.

[87] See Chapter 3.

[88] See Chapters 1 and 3.

[89] After the coring, more in situ protection was carried out on site.

[90] The net from 2003 was removed before coring.

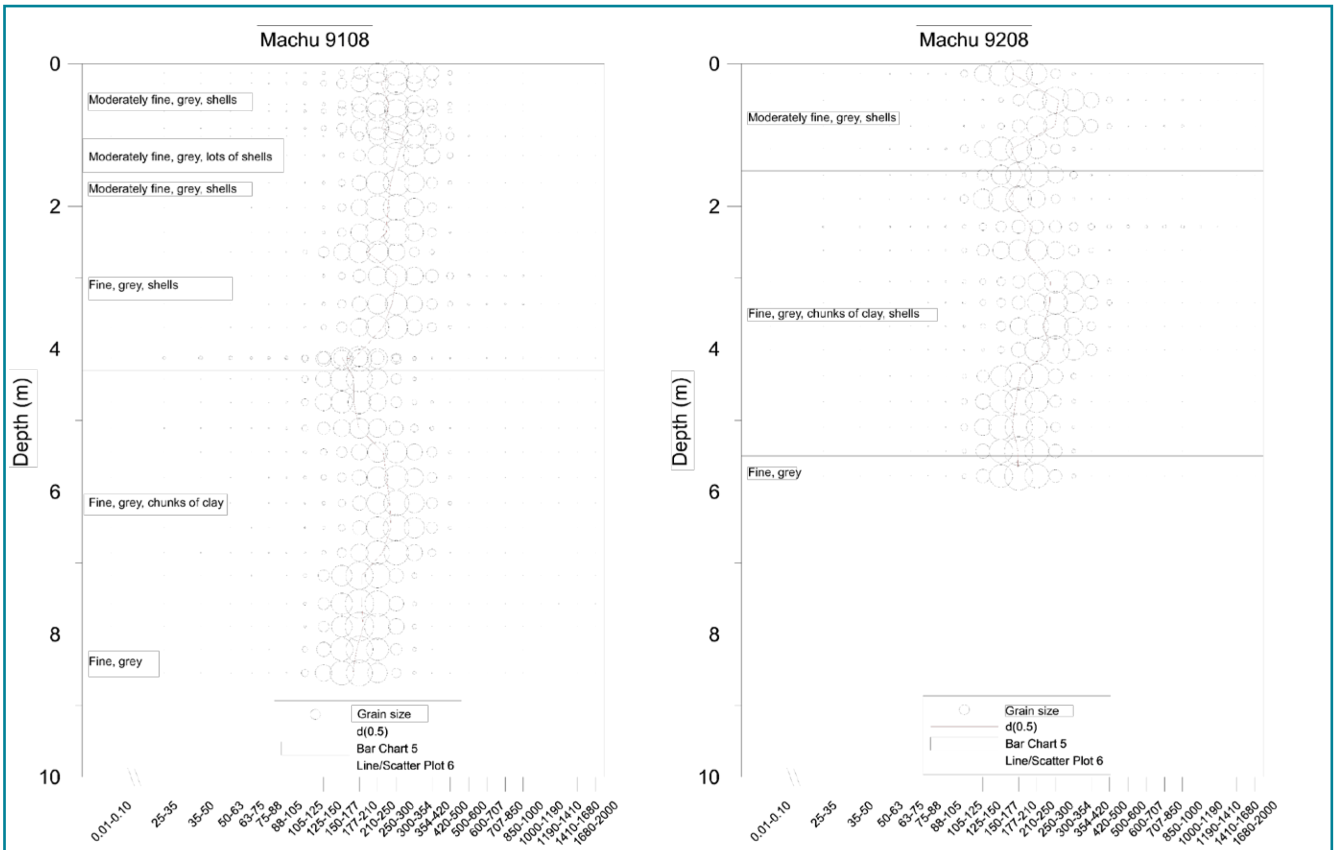

Fig. 6.18 Grain-size distribution for both cores (9108 and 9208). Figure: RCE/MACHU project.

high carbonate content correlates with a more dynamic environment (Fig. 6.18).

6.6.5 Geochemical patterns

The observed changes in grain-size distributions were also reflected in the geochemical patterns. At the top of core 9108, the clay mineral content was somewhat higher, also reflected in the finer grain size. At the top of core 9208, there was an increase in the d50 of the sand fraction, recorded as a decrease in the aluminium (Al) content. The high iron content at the top of core 9108 was accompanied by an increase in titanium (Ti), lanthanides (Ln),[91] chromium (Cr), uranium (U) and thorium (Th). This indicates an increase in heavy minerals such as ilmenite ($FeTiO_3$), magnetite ($Fe^{3+}{}_2Fe^{2+}O_4$), zircon (ZrSiO4) and chromite (FeCr2O4) in this core. Such an increase can be brought about by sorting and winnowing caused by dynamic sedimentological conditions. It is interesting to note that the increase in heavy minerals coincides with the in situ protection net. It is possible that the currents preferentially caused movement of lighter quartz and feldspars grains, which eventually led to a relative enrichment with heavy minerals. These enriched heavy mineral layers were therefore indicative of erosion events.

Anthropogenic metals generally showed almost no trends from the top to the bottom of the cores. The content of these metals were, however, very low and fell in the natural range for these elements, suggesting that all the sediment was of local unpolluted origin. Anthropogenic metals are transported as very fine particles, often associated with organic matter, which only settle under very low energy conditions. Only during events in which the mixing of sand and clay occurs in the water column, such as heavy storms, may such particles be trapped in the sediment.

Lead isotopic ratios in core 9108 showed some very high radiogenic values (between 1.22 and 1.35), especially at the top. These values indicate the presence of the parent isotopes U and Th.[92] The high values for the 206Pb/207Pb ratio coincide with high values for REE, Cr, Fe, Zr and Ti,[93] which indicate the presence of heavy minerals such as chromite (FeCr2O4), ilmenite (FeTiO3) and zircon (ZrSiO4), and phosphate minerals such as monazite ((Ce, La)PO4) and xenotime (YPO4). Sands containing percent-level values of these minerals are known to occur on the Wadden Islands.[94] These minerals, especially the phosphates, are also known to contain high concentrations of U and Th, which would explain the radiogenic lead isotopic values. In the deeper parts of both cores, higher values for the 206Pb/207Pb ratio, between 1.19 and 1.22, coincide with an Al content which is indicative of clay mineral content.[95] Clay minerals also have higher levels of U and Th than quartz grains.

No industrial-age 206Pb/207Pb ratio values were found (values lower than 1.175), indicating that anthropogenic lead from the period after 1850 was not present; nor were any petrol-derived 206Pb/207Pb ratios observed, indicating that the fine fraction of the sediment was certainly pre-1950 (Fig. 6.19 A, B, C, D).

6.6.6 Summarizing the results

The OSL research at the Burgzand Noord 10 site has shown that it is possible to use optical dating in a highly dynamic submerged environment, and specifically in the Wadden Sea. However, it

[91] Often also collectively known as rare earth elements (REE).

[92] U = Uranium, Th = Thorun.

[93] Pb = lead, Cr = Chromium, Fe = Iron, Zr = Zirkonium, Ti = Titanium.

[94] Meijer et al. 1996 (1), 1996 (2).

[95] Al = Aluminium.

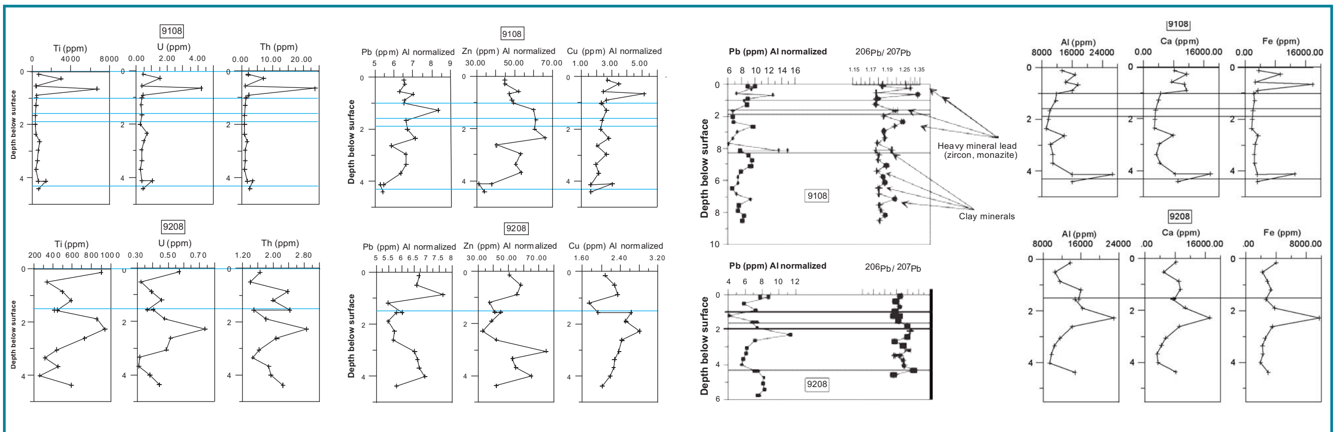

Fig. 6.19 (A) Major element variations for both cores, (B) Indicator elements for heavy minerals in both cores, (C) Al normalized Pb and 206Pb/207Pb versus depth, (D) Al normalized metal profiles in both cores. Figures: RCE/MACHU project.

should be noted that there may be an incomplete resetting of the OSL signal in some grains at the time of deposition. Although 'quick and dirty' analyses of the samples did not offer any useful results, full analyses were successful.[96]

The OSL dates show that neither of the two cores reached the Pleistocene sediment.[97] This means that the wreck parts are lying in and on Holocene sediments and not directly on top of the Pleistocene layer. The sediment – particularly that in the wreck – was well graded, with layers of coarse and fine sand and clay. It consists of compact Holocene sediment in several layers. Considering the long cores that were taken, the Holocene layer is extremely thick at the Burgzand location. On this basis, we can conclude that it is also possible to find wrecks at a greater depth under the seabed surface. The sites deeper in the sediment may be older, since the OSL dating tells us that at 4 to 8 metres, the sediment was last uncovered in the fourteenth and fifteenth centuries. Historical maps, for example, tell us that shallow areas – sandbanks – have always existed in the Burgzand area, but they have changed their form and location over time.[98] Remnants of these old sandbanks may still exist at greater depths. These relics of the ancient maritime landscape may not have been uncovered by changing current patterns for centuries, and are therefore likely to contain wrecks of high archaeological value.[99] There is definitely such potential in the case in the eastern part of the Wadden Sea, which is dominated by strong sedimentation, and where large areas fall dry at low tide.[100]

Core 9108, which was taken in the middle of the site location, gives a sediment dating of 1723 +/-38 years (between 1685 and 1761), 1.575 metres under the seabed. At 3.325 metres, the sediment is dated to 1683 +/-32 (between 1651 and 1715). These dates coincide with the age of the wreck. Below that level, at 4.375 metres, the age increases, dating to 1414 +/-30 (between 1384 and 1444). Although we have to be careful not to jump to conclusions on the basis of only a few dating samples, we may conclude that there is a 'find layer' that dates from around the time of the wreckage between approximately 1.5 and 3.5 metres below the seabed that was not subsequently eroded. This consists of fine sand with shells.[101] According to the OSL dates, the 2 metre thick layer of sand was deposited between 1650 and 1700.

This information is important for establishing the value of the site. The existence of a sediment layer from around the time of the wreckage allows us to conclude that the protective layer in the BZN 10 wreck has not completely eroded away over time. Parts of the ship structure may, therefore, still be in excellent condition and it can be assumed that part of the cargo and inventory still lie undisturbed in the wreck. This was already confirmed by the archaeological assessment performed in 1999,

[96] Manders et al. 2009 (1), 42.

[97] Wallinga et al. 2009.

[98] Oost 1995, Kosian 2009.

[99] Examples of relatively intact shallow areas in the Western Wadden Sea have also been identified. See Chapter 2.

[100] In December 2008, M. Manders (RCE) and M. Dominguez (RING) investigated and dendro-dated an old wooden ship frame dredged up several years ago from great depth in the eastern Wadden Sea and now exhibited at the Shipwreck Museum in Terschelling. This frame from a clinker-built ship turned out to be from the fourteenth century (after 1321). *RING* Internal Report number: 2009023, 2009.

[101] Whether these are shells of creatures that lived on the site or were transported into the wreck at a later stage remains uncertain.

when parts of well-preserved cargo, inventory and ship were surfacing the seabed. However, we also now know that at some locations on the site almost 2 metres of practically undisturbed contemporary sediment is still present. The older date at almost 4.5 metres deep shows that, from that point at least, no finds from the wreck can be expected.[102] The OSL dates from just outside the wreck mound (core 9208) show a considerable increase in age at a relatively low depth (at 1.575 metres, dating to 1313 +/-33 = 1280–1346). Eventually, with more coring, the extent of the archaeological site might be determined with OSL.

The two cores show a striking similarity between the pattern in median grain sizes and distribution of the layer 4 metres below the surface in the wreck and the layer 1.5 metres below the surface outside the wreck. The water depth at both locations also differs by approximately the same amount (2.31 metres). We can therefore assume that these two layers are the same. If we assume this, then the conclusion can be drawn that a considerable amount of the top sediment outside the wreck has been disturbed over time and affected by heavy erosion. These dynamics can be confirmed at least for the last few years by the analyses of the multibeam echo sounding sequence taken at this site.[103]

It can be concluded that OSL can add to the understanding of site formation processes and can also help to determine the quality of the archaeological resource without using excavation.

The question here, however, is whether OSL is useful for monitoring the in situ protection methods used on the BZN wrecks. Although the results from this research – consisting of only two cores – are too limited to draw many conclusions, some preliminary conclusions can be made. In theory, the amount of deposition under the nets should be measurable by the cores. However, in the study, while the age of the sedimentation could be determined as recent, it was not possible to distinguish recent age differences in sufficient detail to establish sedimentation rates and events over a few years. Nevertheless, a comparison between sedimentation layers in and outside the wreck showed clear erosion outside, with older sedimentation layers protruding from the surrounding seabed at the protected wreck site. In addition, in the first metre of core 9108, carbonate-rich and heavy mineral-rich deposits were found, suggesting that although protection with debris nets works, there is still movement of sand, and dynamic sedimentary conditions prevail.

While this shows the effectiveness of in situ preservation with polypropylene nets in the Wadden Sea, it also reveals that the sediment steady state remains fragile and can easily become unbalanced. This result supports the argument for the use of multibeam echo sounder surveys to regularly to monitor these dynamics.[104] If monitoring reveals a sharp decline in the protection of the wreck, action should be taken to reapply in situ protection or, if important archaeological values are lost, to launch an excavation of the wreck or part of it.

OSL is potentially a valuable tool for monitoring. If the most recent sand particles can be dated, it can be used to evaluate build-up of sediment prior to and after protection measures have been installed on site. The method can also provide valuable information on whether a site has been eroded and/or if sand has been deposited over the longer period after wreckage. This information can help to determine the archaeological significance of a site and also give an indication of the preservation condition at the location. However, this study also showed the importance of combining OSL research with grain-size analyses and data on anthropogenic trace metals and stable lead isotopes.

6.7 Wood analyses for baseline data and monitoring

Most shipwrecks from the Burgzand area are from the seventeenth century and thus made of wood. Wood can be monitored visually in situ or it can be sampled. Visually, wood can be inspected for growths, integrity of the construction, and also previous or present attack by shipworm or gribble, for example.[105] The presence and activity of wood deteriorating organisms on exposed timbers under water is not always easy to monitor directly. However, it can be monitored in other ways, such as taking samples from the original construction or by the placement of sacrificial blocks of modern wood around a site and recording the presence or absence of organisms.[106] If they are present, it is highly likely that any newly exposed timbers will also be colonized. If so, steps to mitigate their effects can be taken. The temperature, dissolved oxygen and salinity of the water will have an effect on the growth of the main degraders, the wood-boring organisms.[107] These environmental parameters can – as we have seen – be measured using data loggers.

We can identify wood degraders and possibly develop mitigation strategies against them, perhaps by altering the environmental parameters. If we cannot find suitable mitigation strategies, we should reconsider the decision to maintain the site in situ. However, even if we decide to conserve or even study the wreck ex situ, it is important to have some information about the condition of the wood first. Is it strong enough to be raised?

[102] Only ten OSL measurements were taken, so we cannot establish at exactly what depth the sediments predate the shipwreck. Nor can we precisely establish erosion-sedimentation cycles, although the method seems to be suitable for this purpose.

[103] See Chapter 3.

[104] See also Manders 2009 (2).

[105] See Chapter 3.

[106] See also Chapter 3.

[107] See Chapter 3.

Fig. 6.20 (A) Pilodyn, (B) Pilodyn as used under water. Photos: courtesy National Museum of Denmark.

What kind of conservation strategy is needed to preserve the site?

In terms of assessing wood deterioration, a simple metal probe made of a thin rod can be pressed into the wood. When the wood is badly degraded, there will be little resistance. Alternatively, a more elaborate, yet similar method, can be used, known as the Pilodyn (Fig. 6.20 A + B).[108]

The more degraded the wood, the further the pin will penetrate. Within the EU SASMAP project, an even more accurate instrument to measure the density of wood (the WP4UW) was developed, which could be used under water (Fig. 6.21).[109] Wood density in general is a good parameter for determining levels of degradation. Micro-organisms 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, the lower its density.[110]

Density can also be assessed using cores taken in situ with an increment borer, but with wood that has been degraded by Teredo it is best to take larger samples, as the holes the shipworm makes may influence the measurements. This is the reason why in the MoSS and BACPOLES projects parts of the ship construction were sawn off and removed from the water to be investigated in the laboratory. In comparison to only investigating the density and subsequent water content of the wood, a more accurate method for the examination of the condition of the timber is microscopic analyses of samples, which will reveal the state and degree of degradation and the specific cause.[111]

Fig. 6.21 The WP4UW equipment to measure the condition of wood under water. Photo: courtesy National Museum of Denmark/SASMAP project.

When sampling archaeological wood from a site, it is important to not only pay attention to the specific find conditions, such as depth within the sediment, type of sediment and location, but also the type of wood and the former function of the object that is sampled. The latter is important because this may tell us something about the former (contemporary) exposure to degradation that the wood was subjected to. Different types of wood may be subjected to different forms of attack and at different rates.

On the BZN 15 site, one oak plank lying 20–30 cm below the surface was sampled, while a pine plank lying 30–40 cm below the surface was also sampled (Fig. 6.22). Both planks had been covered with sand for some time, but the oak plank had probably been in contact with the open water a few times. The oak plank was part of the outer planking of the ship, while the pine plank was part of the doubling (sacrificial planking), possibly to protect the ship against attack by *Teredo navalis*.[112] While the ship was in use, the outer double planking of pine would have been in

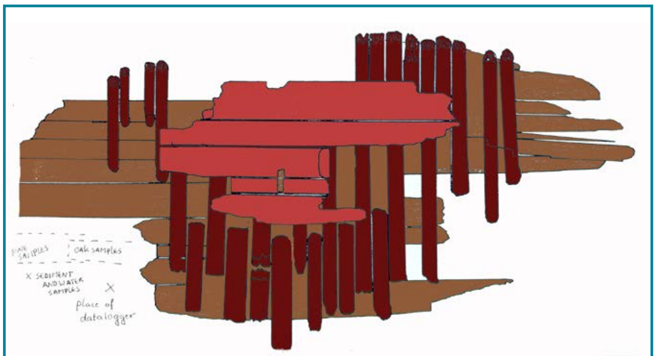

Fig. 6.22 The location of the sampled wood at the BZN 15 wreck site. Figure: M. Manders/BACPOLES Project.

[108] Gregory et al. 2007.

[109] Gregory & Manders 2016, 61.

[110] See Chapter 3.

[111] Klaassen (ed.) 2005.

[112] See also Chapter 3.

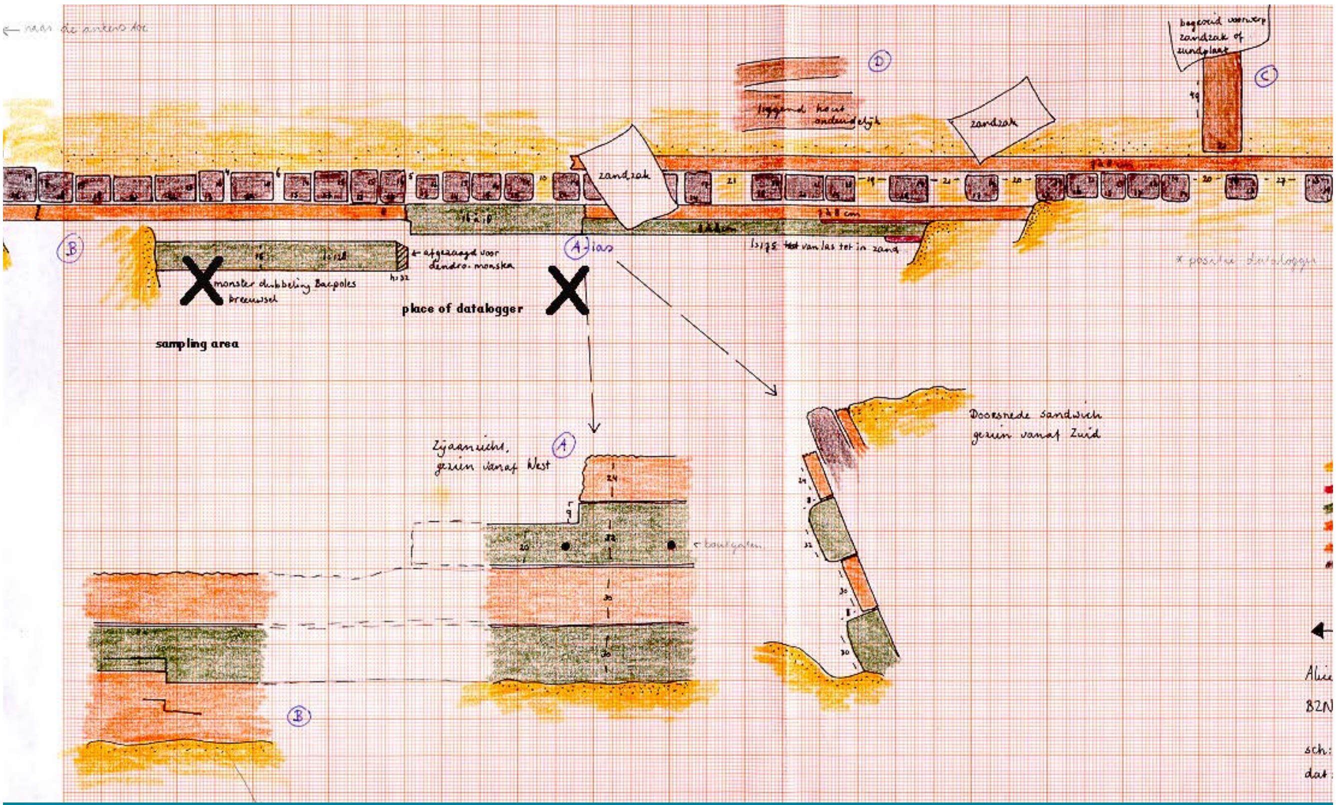

Fig. 6.23 The location of the sampled wood at the BZN 3 wreck site. Figure: M. Manders/BACPOLES Project.

constant contact with the open water. The oak planking may have been protected by the pine layer. After wreckage, the ship was most probably lying on its side with the pine planking now below the oak planking.[113]
On the BZN 3 wreck, two wood samples were taken from a thick oak plank which turned out to be a wale (Fig. 6.23).[114] The wood was covered with 30 cm to a maximum of 110 cm of sediment.[115] This wale would have been on the outside of the ship. However, its position would have meant it was mainly above the water.

The analyses of the samples revealed degradation of the cell walls by erosion bacteria for both of the wrecks investigated on the Burgzand, the BZN 3 and 15, and both wood species, oak and pine.[116] The same was true for active wood degrading bacteria.[117] The intensity of the degradation, however, varied.

All samples were degraded by erosion bacteria; non-degraded tissue in the wood was rare. Sapwood, if present, was always severely degraded. One result derived from the research in the BACPOLES project was that the original dimensions of the timber are negatively correlated with the degree of degradation but not the exposure time.[118] At all of the sites – on (wet) land as well as underwater sites – sampled within the BACPOLES project, thicker oak piles were severely degraded on the outside, while in deeper layers the degree of degradation was less and sometimes even absent. The thinner sawn oak timbers were severely degraded. The oak shipwreck timber from the marine sites only consisted of sawn heartwood, but in all cases, wood degradation was still found (severe to moderate). Furthermore, the pine from BZN 15 was severely degraded. However, compared to the other sites in the overall project, the marine samples were still less degraded than those surrounded by fresh water.[119]

The relatively smaller degree of bacterial decay at the marine sites could indicate that marine seafloor conditions are less favourable to erosion bacteria than fresh water soil conditions. This was also observed in the samples that were taken on the BZN 10 site during the MoSS project, compared to the Darsser cog and the *Vrouw Maria* in more brackish to fresh water environments.[120] Apparently, the factors mentioned above (size and salinity) affect the speed of degradation to such an extent that the effect of age (and therefore the exposure time) is minimal.[121]

In relation to in situ protection of archaeological wood, it has also been suggested that water flow through wood may be an important factor that determines the degree of degradation by erosion bacteria.[122] It is possible that only minor changes in the hydrology of a site may have major effects on the level of degradation – positively or negatively. This seems not to be of great concern to the underwater sites. However, it should be kept in mind that the protection installed also minimizes the water flow around the wreck as much as possible.

In the samples investigated from the submerged marine sites of BZN 3 and 15, wood colonizing fungi was present throughout,

[113] Manders 2005 (1).
[114] Manders 2005 (2).
[115] Manders 2005 (2).
[116] Gelbrich et al. 2005, 81.
[117] Gelbrich et al. 2005, 81.
[118] Klaassen (ed.) 2005.
[119] See also Chapter 3.
[120] See also Chapter 3.
[121] See also Björdal et al. 1999.
[122] Huisman & Klaassen 2005, Klaassen 2005 and Klaassen 2008.

but no traces of the severely degrading soft rot was found.[123] However, two other shipwrecks from Almere in the Flevopolders in the Netherlands (reclaimed land), also sampled within the BACPOLES project, did have soft rot. It is unclear whether this was already present while the ships were still in use or whether the wood was affected when the polder was reclaimed. It is well known that soft rot occurs in ships even when they are still in use.[124] If present, fungi in wood removed from the seabed may become active again when it comes into contact with oxygen, thus destroying the wood rapidly.[125]

A study of degradation patterns confirmed that the wood from the BZN 3, BZN 15 and also the two wrecks in the Flevopolders contained substantial amounts of pyrite (FeS_2).[126] This can cause severe degradation of the wood.[127]

6.8 Structuring the monitoring of a site

As we have seen, there are many methods, tools or instruments that can help us to determine the condition of a site, either as part of a baseline study or subsequent monitoring. All of these aid management of changes in the environment, the wreck or even the material the site consists of. They are, however, of no value if we do not work systematically. Above all, monitoring concerns the systematic follow up and comparison of observations and measurements. New developments in technology, such as the introduction of multibeam sonar, can help us to detail our observation grid, but the comparison of results also relies on data collected previously. With coring, OSL, seismic research and research using historical maps, we can go back in time to reconstruct developments. A baseline study, however, needs to be more thorough and systematically executed, not only on one, but on all sites. A protocol with premises and operational principles to standardize the process for this is indispensable.

The same can be said concerning subsequent regular monitoring on site. Although many sites have been assessed over the years in the Netherlands, and the Wadden Sea in particular, baseline data has only been systematically collected during EU projects and thus not taken up as an inclusive task during the cultural heritage significance assessments.[128] A management plan that was developed within the MoSS project could serve as a standard for these baseline studies, in combination with the actual significance assessment and subsequent monitoring.[129]

MONITORING PROTOCOL FOR UNDERWATER SITES (as executed in the Netherlands)
ADMINISTRATIVE
DATE: date of monitoring
TIME: time of monitoring
PLACE: place of monitoring: Name of area, toponym of site, geographical position
TRANSPORT: way of transport: name of ship executing the work
DIVERS: names of divers executing monitoring
DIVE MINUTES: total time spent underwater

WHEATER CIRCUMSTANCES
TEMPERATURE: outside temperature
WIND: wind on location and direction
CLOUDS: yes or no
RAIN: yes or no

DIVE CIRCUMSTANCES
TEMPERATURE WATER: temperature of the water on surface and on the seabed
VISABILITY: visibility under water
CURRENT: details on velocity and direction
TIDAL MOVEMENTS: yes or no and at what stage
DEPTH: depth of working, of shipwreck

SONAR
DATE: when executed
NUMBER: following number
DETAILS: what kind of sonar, technical details (like resolution), coverage of the area

DEGRADATION PROCESSES
PH WATER: parameter pH
TEMPERATURE WATER: parameter temperature in Celsius
SEDIMENT MOVEMENTS: description
GROWTH ON WRECK: organic growth of organisms, yes or no and what kind
TEREDO NAVALIS: yes or no, life or death and how much
OTHER BORING SPECIES: gribble, etc.
BACTERIOLOGICAL DEGRADATION: Any present and how observed?
SPEED/FORCE OF CURRENT: parameter velocity in m/s
SALINITY: parameter salinity in ppm and how measured
WATERTRANSPORT: parameter turbidity: amount of sediment dissolved in water.
FYSICAL DEGRADATION BY HUMAN SOCIETY: looting? Fishing? Etc.
GENERAL QUALITY OF WOOD: Visual observations
DIFFERENCES IN WEB: differences in new and old measurements. Initially for triangulation measurements of the site, Web-it was used. Nowadays other systems like Site Recorder are more often used.[1]
GENERAL QUALITY OF THE WRECK: in comparison to earlier monitoring.

NEW ARCHAEOLOGICAL INFORMATION:
FINDS: which finds have been taken from the wreck and what are the results.
SAMPLES: which samples have been taken from the wreck and what are the results.
PROTECTION: what has been done in order to protect further degradation.
FUTURE PROTECTION: What has to be done in order to protect further degradation.
DOCUMENTATION: yes or no, how and where to find the information.
WRITTEN BY:

Fig. 6.24 A monitoring plan, as developed for monitoring actions at the Cultural Heritage Agency of the Netherlands (RCE). Figure: M. Manders.

Although implemented for the management of Dutch shipwrecks outside of the Netherlands, it has not, however, been standardized for the management of underwater archaeological sites in the Netherlands itself.[130]

A brief monitoring guideline was developed and applied within the MoSS and the BACPOLES projects.[131] The parameters on which to collect data were based on the deterioration of wood in the marine environment, but most of the guideline is straightforward and contains important points to consider for general monitoring.

Monitoring protocols have been developed for terrestrial sites in the Netherlands as well.[132] However, there is still no widely accepted protocol on how to monitor underwater archaeological sites, either nationally or internationally. There are also no rules about what constitutes best practice in monitoring. We are actually still seeking acknowledgement of the fact that monitoring is an important part of cultural heritage management. The guideline, presented above (Fig. 6.24), was developed within subsequent European projects and used for the wrecks on the Burgzand.[133] Efforts are being made to include the monitoring of underwater sites as well. At the time of writing, there is discus-

[123] For soft rot attack, oxygen is needed. See also Daniel & Nilsson 1998.
[124] See, for example, Sylvester 1976, Tromp 1835.
[125] For more on bacterial, fungi and Teredo deterioration, see Chapter 3. See also http://inspectapedia.com/mold/Activity_of_Mold.php (accessed 31-01-2017).
[126] Klaassen (ed.) 2005.
[127] See Chapter 3.
[128] Baseline data for degradation research was collected on the above-mentioned MoSS, BACPOLES, MACHU, WreckProtect and SASMAP projects.
[129] See Manders 2004 (3) and Manders 2012 (3).
[130] It is not a requirement to use the Management Plan for sites within Dutch territory. The manner of reporting is laid out in the Dutch Archaeology Quality Standard (KNA: www.sikb.nl). For management of Dutch-owned shipwrecks overseas (WIC, VOC, Admiralty and Navy ships), the Maritime Programme of the RCE uses the Management Plans http://www.maritiemprogramma.nl/magazine/print/MP_eng_01_print_version_utrecht.pdf (accessed 31-01-2017).
[131] See Section 3.1.
[132] Smit et al. 2006, Os et al. 2012.
[133] These were the MoSS, BACPOLES and MACHU projects. See also Chapter 3.

sion about whether this should be an overarching protocol for both terrestrial and underwater sites or whether these protocols should be distinct.

As the environmental parameters and threats differ so much, the question of whether an effort should be made to standardize the archaeological monitoring protocol for both land and water or whether they should be kept separate must be considered. The way a site needs to be monitored depends on the forms of mitigation against significant and potentially large threats, but also on how we have protected the site (what kind of method and against what kind of threat) and the reason why – in the first place – a site has been protected. All the above may differ for underwater and terrestrial sites.

Not many countries have a monitoring programme in place. English Heritage contracts a diving unit to monitor all the designated wreck sites.[134] Although most countries – including the Netherlands – have a budget for underwater cultural heritage management, no structural funds have been allocated for active in situ protection or monitoring.[135] This seems, in fact, to be contradictory to the primary aim to preserve 'archaeological' sites in situ. By explicitly selecting sites to be preserved in situ, governments are implicitly suggesting that it is worth doing so. The consequences of these decisions, however, are clearly not being considered if there are no budgets for protection and monitoring.

A large problem for in situ preservation, conservation and monitoring may lie in the perception of it. Systematically following the process of protection and monitoring will show that in situ preservation is not such a cheap option after all. This is especially the case if increasing numbers of sites are to be preserved and physically protected in situ. Only by acknowledging this can solutions be found to control budgets. Cooperation between stakeholders might be one of these solutions, but strong selection and deselection procedures are also required.[136]

The introduction of new techniques in monitoring will not only make the data collected better and the observation grids finer, they may also be more cost effective.[137] When we look specifically at the costs of monitoring, the introduction of the multibeam echo sounder is a huge cost saver, due to the fact that divers are not required. Agreements with survey companies and between ministries can make the process of recording even more effective and, thus, also cheaper.[138] Multibeam data is collected for all sorts of reasons but can also be used in cultural heritage management.

In the Netherlands, including the Western Wadden Sea, baseline studies have mainly been conducted within large-scale European projects. The character of such projects is experimentation and finding the best solutions. This, by definition, makes the research relatively expensive. However, integrated, good-quality baseline studies can be executed in a more cost-effective way. Information about environmental parameters can be obtained from other oceanographic institutes, from large-scale preliminary studies, such as the Historical Geomorphological Map Sets, as described in Chapter 2, or from former baseline studies carried out in proximity. It is, therefore, not always necessary to include data loggers, or the introduction of and research on sacrificial or sampling in general. All these require a lot of labour and large (long-term) budgets.

Basic environmental information can allow us to identify the greatest threats to cultural heritage, on the basis of which a risk inventory can be made and efforts to mitigate against these threats can be undertaken. Dunkley (2008) describes the same kind of procedure for the above-mentioned designated wreck sites.[139] This kind of system, including a risk decision tree, could be developed and implemented for the wrecks in the Wadden Sea and for underwater archaeological management in the Netherlands overall.

This all depends on the threats that are dominant, the environment, budgets and the significance of the site when choosing the methodology and techniques for monitoring the site.[140] A

[134] The English Dive Contract is currently with Wessex Archaeology.

[135] However, for a few years, money from the BRIM fund has been made available for monitoring of national monument sites, including archaeological sites.

[136] With cooperation, costs may be shared, strong and clear selection may not only keep the number of sites down, but also may avoid the suggestion that archaeologists always want to preserve everything. Lennon & Foley 2006, 34.

[137] See, for example, the huge benefits of Computer Cision Photogrammetry: https://maritiemprogramma.wordpress.com/tag/computer-vision-photogrammetry/ (accessed 31-01-2017).

[138] MP: The Maritime Programme of the RCE has made agreements with survey companies to make such recordings of pinpointed wrecks for a fixed price. This price is much lower than usual multibeam recording assignments due to the fact that the companies can decide themselves when to record the wreck and, therefore, can schedule the work during low season and when passing the site on their way to or from other jobs.

[139] Dunkley 2008.

[140] See also Chapter 3.

rough estimation of costs for different monitoring actions is listed below.

Monitoring BZN 10, 2009[141]	
METHOD	**COST/DAY in €**
Monitoring by diving	6,200
Ship rental with sonar/multibeam (no personnel costs included)	3,000
Ship rental with ROV facilities (no personnel costs included)	15,000-20,000[142]

Table 6.2. Costs of monitoring BZN 10.

UCH management comprises all the steps needed to preserve or investigate underwater archaeological sites in the best possible way. It involves making choices between excavation and in situ preservation, and taking measures to ensure the quality of underwater cultural heritage resources over a longer period of time. Here, in particular, lies a threat: the 'maintenance' of UCH involves a lot of time, people and money. This is the 'downside' of extensive inventories and a preference for preserving sites in situ. The more sites we know about, the more sites will be marked as being of national or even international importance. The more sites that are preserved in situ, the more time and money will have to be allocated to their preservation and maintenance. This message is not very popular with government agencies, but it is a direct consequence of the policy developed by them, and therefore extremely important.

6.9 Conclusion

If in situ preservation is taken seriously, then preserving and protecting sites in situ means taking full responsibility for them. Applying protection methods should lead to longer and better preservation. Having taken the measures on site, this needs to be followed by monitoring of the effects. Has there been any change? Is the protection doing its job? Is further action needed? The monitoring of sites can be standardized with forms or protocols. Some parameters should be measured on all sites to allow comparison. Other parameters, however, may only have to be investigated once and can be used for a larger area.

The introduction of new techniques has led to more accurate data collection and the opportunity to answer new scientific questions in archaeology and cultural heritage management. The multibeam echo sounder provides a tool for better monitoring of the seabed, 3D sub-bottom profiling gives us a better understanding of what is happening in the seabed, and OSL, grain size and anthropogenic metal analyses can be used to investigate the history of sedimentation and accretion on site. Due to specific and detailed research undertaken in various European projects, data has been collected with data loggers and laboratory research on archaeological material has been undertaken, which can be regarded as baseline data for all the wrecks in the Western Wadden Sea area.

Taking the responsibility to monitor the sites that have been preserved in situ is not yet common practice. There are no budgets to do so. As more sites are selected for in situ preservation – the basis of our current archaeological system – this will eventually lead to more sites needing to be taken care of and hence higher costs for management. This will also be repetitive and thus the costs cumulative.

Monitoring is executed over a longer period of time, keeping in mind the circumstances, the natural conditions of the site, the reason why a site was chosen for in situ protection, the method of protection and a time frame for future actions. With the decentralization of cultural heritage management, provinces and municipalities in particular have become directly responsible for the management of underwater cultural heritage. In relation to the Western Wadden Sea area investigated here, the Municipality of Texel will have to take up responsibility for the largest area, but others will also need to introduce the management of this often invisible cultural heritage resource into their policy.

The national government will also have to take up its role in the management of the proclaimed National Monuments. At the moment, there are only seven underwater sites.[143] This is not a particularly representative collection of our maritime past. The in situ preservation, protection and monitoring of 50 to 100 sites (from the 60,000 locations we have in our databases) would form a workable core to establish these 'stepping stones'.[144] However, it is still unclear who will pay the bill for their management, which consists of a significance assessment, preservation and protection, ongoing monitoring and maintenance. But if we go this direction we should also start thinking about how to use these as national icons and archaeological windows to a common past.

[141] Information from RCE, the Netherlands, see also Manders (ed.) 2011.

[142] The costs of ROVs have dropped dramatically in recent years. However, cheap instruments, such as the RB Micro-50 (approx. €2,000) http://www.cheaprov.com/, accessed 30-1-2017), or the ROV-in-a-Box Project Kit (approx. €250) http://www.nventivity.com/roviab.html, accessed 31-01-2017) are not suitable for the Wadden Sea environment.

[143] At the end of 2016, the *Aanloop Molengat* wreck was made the seventh National Heritage Site under water. http://www.monumentaal.com/scheepswrak-aanloop-molengat-eerste-rijksmonument-noordzee/ (accessed 31-01-2017).

[144] Manders 2015 (2).