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3. Threats to underwater archaeological heritage

Fig. 3.1 Erosion patterns in the Western Wadden Sea. Figure: courtesy Periplo Archeomare/RWS.
3. Threats to underwater archaeological heritage

3.1 Introduction

The preceding chapter focused on the maritime landscape and the possible presence of cultural heritage in the Wadden Sea area. This chapter will discuss a more negative issue: the threats to underwater cultural heritage (UCH) in the area, more specifically, in the Western Wadden Sea. Threats to UCH can have different causes and can also concern different values of sites. For example, something or some process may threaten the integrity of an entire site or only the condition of a specific material. Threats are always connected to the loss of information and consequently potential knowledge. Thus, an assessment of sites in terms of threats must self-evidently have consequences for future management decisions.

Legislative protection is an important part of an overall management strategy. It defines the ‘playing field’ within which we must make our moves. Legislation also constitutes a form of protection against cultural and industrial threats to a site, but in many cases it is not sufficient. Natural processes (mechanical, biological and chemical) may continue to occur and, therefore, a scientific understanding of the deterioration processes of sites is required to determine how best to preserve them in situ. Thus, we need to understand the environment of underwater cultural heritage and the threats, whether short or long term, that the environment poses to the present and future preservation of that heritage.

When we look into the question of what is threatening our underwater cultural heritage, we see a combination of many processes that often influence each other. In the first instance, we can mention many different threats to heritage objects under water, but what exact impact they have is not always immediately clear. What is the real cause of the threat? Is it a local – site specific – phenomenon or does it have a regional or even supra-regional effect? How long has it been a problem? What is it threatening? The integrity of the site? The condition of the archaeological material (and therefore loss of information) supra-regional effect? How long has it been a problem? What is it threatening? The integrity of the site? The condition of the archaeological material (and therefore loss of information) or the archaeological material (and therefore loss of information) and loss of mechanical strength.

It is important to investigate the environmental parameters of a shipwreck site, as conditions will directly influence the state of preservation of archaeological materials. Parameters may vary within an individual site and, as a consequence, different levels of deterioration may occur on that particular site. When looking at natural deterioration processes we can make a distinction between processes within the seabed and those above the seabed sediment in open water. The factors affecting different materials in the marine environment vary depending upon whether they are exposed to seawater and oxygen or buried within sediments in an anoxic environment. In open seawater (above the seabed), mechanical and biological processes are the major causes of deterioration of wooden and organic materials. Chemical processes can also influence the corrosion of iron. This again may influence the condition of the surrounding wood. Human activity can also cause serious damage. Within the seabed, the main agents of deterioration are microbial and chemical.

The various deterioration processes also interact. Microbial softening of wood may be followed by more severe abrasion due to sediment transport on the seabed in areas with strong currents. The biological weakening of timbers may also be followed by physical damage due to human impact and vice versa.

In this chapter the major causes of deterioration will be briefly described. The focus will be on the processes that have been recorded in the Western Wadden Sea. Since the early 1980s, when professional underwater archaeology in the Netherlands began, the government, through various departments, has been archaeologically involved in wreck sites in this area. From the...

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1 Manders 2015 (1). This defined playing field, with its boundaries formed by laws, needs to be objectively determined, with law enforcement agencies as referees. It should be recognized by all stakeholders, whether they are in favour of the preservation of underwater cultural heritage or not.

2 Only when we know why it is important to preserve a site (its significance) and also what processes are threatening it, are we able to mitigate in the best way.
early 2000s onwards, specific tests were performed to record the processes of degradation on the Burgzand and a few specific sites within this area. Much of the information below comes from these tests and was collected during European projects: the MoSS project, BACPOLES project, MACHU project, WreckProtect project and SASMAP project.

Section 3.2 deals with mechanical deterioration on the site and regional scales. Section 3.3 looks at erosion-sedimentation on individual wreck sites, while in Section 3.4 some conclusions about the seabed morphology based on the previous sections will be presented. Section 3.5 examines the biological deterioration of archaeological sites, and wooden shipwrecks in particular, while Section 3.6 considers chemical processes that pose a threat to the sites. Section 3.7 is concerned with threats from human activities in the water, both above and within the seabed, with a focus on the Western Wadden Sea.

3.2 Mechanical deterioration
Chapter 2 discussed the geomorphological changes in the study area through time, with the timelines of active change combining to offer a history of the area. However, changes also pose threats. When a wooden ship sinks, it may come to rest on or in the seabed. Subsequently, post-depositional processes form the site. In many instances the marine environment is very dynamic, and physical processes around shipwreck sites, such as scour and sediment movement, are potentially the most damaging, as they can destabilize and uncover a site, leading to the rapid loss of archaeological material. At the same time, erosion that leads to the uncovering of a site may consequently result in it being discovered. On the positive side, this discovery may result in more information about the past, but on the negative side it may also result in a more rapid degradation of objects, whether the site is discovered or not. If not mechanically torn apart or washed away, the next danger will be colonization by a variety of biological organisms, chemical reactions such as corrosion, or the looting of the site.

There are several mechanisms that may lead to the deterioration of the underwater heritage. A more detailed understanding of these mechanisms is important for developing strategies for in situ preservation.

3.2.1 Currents
We can distinguish different types of currents. In seawater, currents may be caused by tidal movement, by wind or be driven by thermohaline circulation. In rivers, currents are caused by gravity. Currents can influence the stability of a site and, due to their transport by currents, sand particles can have an abrasive effect on all objects protruding from the seabed. This occurs even at low current speeds; however, the faster the current, the heavier (and larger) the particles that can be displaced. Wood may have already lost its sturdiness through biological deterioration and thus may become more susceptible to the abrasive action of currents. This sanding effect not only weakens wooden structures but destroys all the details on the surface of the object, which may be vital for an understanding of the former manufacturing and use of the object.

The effects of currents can be seen at different spatial scales. On a large scale, sea currents can have an enormous impact on archaeological heritage in general; that is, on both the known and unknown resources. Currents have the ability to change the seabed topography, which in turn may change the characteristics of an area and physically uncover sites. Change in the large-scale characteristics of an area may even – in extreme cases – cause discontinuity in the attachment of its inhabitants to that landscape or seascape. This may (or may not), in the long run, lead to a regional detachment in the appreciation of maritime features. The physical change of the seabed topography may also lead to different behaviour in existing currents until a new equilibrium is established.

The erosion of the seabed caused by currents is an enormous threat to underwater cultural heritage due to the fact that it literally exposes the resource to other deterioration processes.

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8 We might think of iron-hulled ships, but certainly also of wooden ships and their iron fastenings, cannons and anchors.
12 WreckProtect: Decay and protection of archaeological wooden wrecks (2009–2011). Financed through the EU 7th Framework programme.
17 This especially counts for those who have made a transition from a sea-bordering area to an area far from the coast. When new means of living are introduced that have no connection with the use of water, this detachment is even more rapid. In some way, the cities around the former Zuiderzee, which is now closed off from the Wadden Sea, have made that change. The effect is even more visible on the east side, where the coast has been blocked by the Flevopolders. Kuno, an early modern small Zuiderzee fishing village in the northeast is now completely disconnected from the sea.
18 See, for example, Dongfeng 2008, or Wang et al. 2013, 163–164, Kragtwijk et al. 2004.
Not coincidentally, most underwater sites have been discovered in highly dynamic areas in the Netherlands, such as the Wadden Sea, the coastal zones and the Delta area of Zeeland. Some sites have clearly been discovered not long after being uncovered, some after having been exposed for quite a while.

Not only natural but also human interference may be the cause of extreme current changes. Examples include all efforts to control the water by building dikes, bridges, dredging and other ways of shaping the landscape. Ultimately, climate change — either caused by humanity or nature — may also cause new currents to flow, or flow in different directions, gain strength or disappear.

The Wadden Sea is under the influence of currents caused by tidal movement. This movement causes an asymmetrical tidal current. The maximum High Water (HW) is approximately +1 metre, while the maximum Low Water (LW) is more or less – 1 metre. This means a two metre difference. This is not much compared to other areas in the world and even Europe. The maximum difference in the Netherlands is approximately 4 metres. The maximum current speed in the western part of the Wadden Sea is 4 knots near the entrances to the North Sea and less further inshore and on the shallow banks. The higher the current speed, the more sand and the larger the particles that may be transported by the water, causing more erosion and abrasion on site.

Since 2002, the Burgzand area in the Wadden Sea has been the subject of systematic, large-scale (1200 m x 600 m) and site-specific monitoring. This research area is situated 6 km from the harbour of Oudeschild. Fifteen historic shipwrecks have been located within the area. The Burgzand area will be the main focus of discussion in this chapter (and in fact the thesis). It is by far the best researched and monitored underwater area in the Netherlands and all activities executed for the above-mentioned European projects have been undertaken in this area. The individual wrecks of the Burgzand area will be described in Section 3.3.

Investigations on the dynamics of the Holocene sediment layer in the Western Wadden Sea, with its core consisting of the Burgzand area through time, comparing historical navigation maps, coring and ‘recent’ sounding data have revealed enormous dynamics, causing shipwrecks to be covered by sediment quickly, but also eroding and exposing the sites to a range of deterioration processes (see also Chapter 2). This area of the Wadden Sea was probably subject to tidal currents long before it became a navigable inner sea in the twelfth century, especially due to a large channel running north-south that is already visible in the data on the Roman period. However, the dynamics that the Western Wadden Sea is now subject to are not so old. This is largely due to the building of the Balgzand dike in 1924 and the Afsluitdijk in 1932. Before these dikes were built, at high tide, water could flow into the Zuiderzee Basin through the Wieringen Vlaak and Friese

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**Fig. 3.2** The Afsluitdijk, which closed off the IJsselmeer and the Markermeer from the Wadden Sea. Photo: RCE.
Preserving a layered history of the Western Wadden Sea will also be accompanied by extra capacity for the sluices (more outgoing capacity), tidal sluices to generate energy and the development of nature and tourism.

What the implications will be for underwater cultural heritage is not yet clear but needs to be part of the archaeological/cultural heritage assessment.

38 Including invasive species.

39 Although salinity is an important parameter for the existence of the shipworm. See Section 3.5.

40 The ‘De Nieuwe Afsluitdijk’ (-2020) project has the aim to prepare the dikes for maximum storm events occurring once every 10,000 years. This reinforcement of the dikes will also be accompanied by extra capacity for the sluices (more outgoing capacity), tidal sluices to generate energy and the development of nature and tourism.

Vlaak, thus water with suspended sediment could flow deep into the Zuiderzee, depositing the smallest particles of sediment on the seabed furthest away from the North Sea inlet.29 Now, water is pushed through the narrow influxes such as Marsdiep with greater force, but cannot flow further due to the Afsluitdijk (Fig. 3.2).30 In the Western Wadden Sea, the tidal range also changed by 0.5 metres between 1926–1933 (8 years), probably caused by the construction of the two dikes. This tidal increase led to the destabilization and shifting of sandbanks, which is still causing the threat of exposure 90 years. In comparison, between 1933 and 2003 the tidal change was 0.1 metres.31

The Texelstroom gully is moving in a southerly direction and the Scheer gully is deepening and extending.32 This change is causing shipwrecks that have been under a layer of sediment for centuries to be exposed again. This has probably also caused further erosion of the seabed in the Burgzand area, although this relationship is not indisputable.33 A comparison with historical data and consequent monitoring since 2002 certainly reveals a deepening of the average seabed depth from 3.60 m below NAP in the 1852–1857 period to 9.59 m in the 2003–2008 period. This considerable change in seabed depth has obviously caused the severe degradation of many individual shipwrecks34 and this process of deepening will temporarily continue.35 However, some of the erosion may have already begun before the building of the Afsluitdijk.36 The outlet capacities of the sluices in the dike form another threat to cultural heritage located as far as 1 km from the dike, directly north of the outlets, as a direct effect of heavy erosion of the seabed (Fig. 3.3).37

Another negative effect of currents on cultural heritage is that they can bring a constant flow of ‘fresh’ water into the area, introducing new degrading species,38 chemicals, dissolved oxygen or, for example, more or less salinity. By definition, this has a negative effect on the stability of the environment, and stability is what is needed for in-situ preservation of archaeological sites.39 During the research executed under the MoSS project, some parameters in open water and in the sediments were established with a data logger (Fig. 3.4).40 The salinity recorded on the BZN 10 site – situated in the centre of the Burgzand area – fluctuated in that period between 12 and 33 PSU.41 Although 12 PSU seems to be too low, more or less the same values were fluctuating in the BZN 15 site.42

A comparison with historical data and consequent monitoring since 2002 certainly reveals a deepening of the average seabed depth from 3.60 m below NAP

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29 See, for example, Oost 1995, 77.
30 Ibid.
31 Astley 2016, 137–139.
32 Brenk & Manders 2014.
33 Changes in gully patterns have always occurred in the Wadden Sea. See, for example, the differences in the historic maps in Chapter 1. With respect to the Burgzand area, this is a much smaller but central part of the Western Wadden Sea.
34 We may not have seen some of these wrecks before they disappeared.
35 According to Wang et al. (2012, 42), since 1927 and until 2010, each year, 7,000,000 cubic metres of sediment has been deposited in the total Western Wadden Sea area.
36 See Fig 3.7.
37 The ‘De Nieuwe Afsluitdijk’ (-2020) project has the aim to prepare the dikes for maximum storm events occurring once every 10,000 years. This reinforcement of the dike will also be accompanied by extra capacity for the sluices (more outgoing capacity), tidal sluices to generate energy and the development of nature and tourism.
What the implications will be for underwater cultural heritage is not yet clear but needs to be part of the archaeological/cultural heritage assessment.
38 Including invasive species.
39 Although salinity is an important parameter for the existence of the shipworm. See Section 3.5.
40 The WaterWatch 2681 data logger was fabricated by the English manufacturer EauxSys Ltd. The data collected in the open water concerned: temperature (in Celsius), depth (in metres), salinity (in Parts per Unit, PSU), turbidity (Nephelometric Turbidity Units, NTU), dissolved oxygen (mg/L). In the sediment: Redox potential (millivolts) and acidity/basicity (pH). Gregory 2004 (3), 40.
measured at the BZN 15 site (Fig. 3.5). Recent research has revealed that salinity fluctuates in the Western Wadden Sea. It is also tending to become less saline due to climate change, combined with an increase in fresh water discharging from the rivers, to the extent that the salinity fluctuations in the water column have become stronger. 42

The currents may also have an effect at the micro-level. Negative effects concern turbulence or eddy dynamics, which develop around objects in the seabed. 43 These local currents create scour and will wash away the protective seabed sediments, dislocate the coherence of the archaeological layers and potentially expose more of the object (Fig. 3.6). 44 Consequently, this will lead to further threats from other deterioration processes, including attack by Teredo navalis, fungi, bacteria and human interference, for example, by looting or fishing. These currents can therefore be responsible for loss of integrity of the site, but also loss of information about individual items.

Much research has been done on the local erosion patterns around obstacles on the seabed, such as shipwrecks, but also windfarms. 45 During the MoSS project, on-site turbidity measurements were taken at different wreck sites. 46 Turbidity refers to how clean (amounts of particles) the water is: the greater the amount of total suspended solids (TSS) in the water, the murkier it appears and the higher the measured turbidity. High turbidity may be an indication of the amount of suspended sediment in the water and thus sediment transport. 47 The data logger was deployed at five sites on the Burgzand, BZN 3, BZN 4, BZN 10, BZN 11, and BZN 15. It was also deployed more than once (seven times) on the BZN 10 site. 48 Fluctuations can be seen, as can a strong correlation between the tidal cycles and when the sediment transport is at its highest. The sediment loading within the water column increases in the last phase of the ebb tide and then drops off significantly with the flood tide, only to be repeated with the next tidal cycle. 49 The data logger showed that the Burgzand area is very dynamic, with sediment movement correlated with the tidal movement and being at its highest point in the last phase of the ebb tide.

The data logger was also equipped with a Sediment Layer Device. This was an experimental design developed by EauxSys Ltd, using an acoustic attenuation method also used for sludge density measurement. 50 The change in strength of the acoustic signal indicates the relative amounts of sediment being deposited between the transducer and the receiver. This apparatus became available for use in testing on the BZN 10 site at the end of the MoSS project. It functioned, therefore, only for a short period of time in late 2003 and was also heavily damaged after deployment. It has not been reinstalled. 51

Regular multibeam recordings of the seabed surface around several shipwreck locations in the Burgzand area from 2002 onwards has given us much information about the processes of erosion and sedimentation round shipwrecks. 52 The comparison of older sounding data from historic maps has given us an indication of when sites have emerged from the seabed and when the open water environment must have started to threaten the sites. See Fig. 3.7. For the analytic results, see Section 3.3.

41 Gregory 2004 (2), 46–47. The reason for the strong fluctuation may partly be due to fouling of the conductivity sensor: however, the profiles also indicate that another reason may be the tidal influence, bringing fresh water to the site.
42 http://www.wadgids.nl/wadgidsenweb/index.php/waddenzee2007-2012/4-zout-gehalte.html (accessed 29-01-2017). See also Aken 2008 and Duran-Matute et al. 2014. Aken 2008 mentions a difference between 22 and 32.5 PSU. This is still significant and is caused by tidal movements and the influx of fresh water from the Rhine and especially the IJsselmeer.
43 Quinn 2006.
44 See also Smyth & Quinn 2014.
48 Of which it was able to record data six times. See Table 6.1.
49 Gregory 2004 (3), 46–47.
50 Gregory 2004 (3), 40.
51 An overlay between depth data and the sediment layer device that was recorded does not show a strong correlation.
52 Manders 2009 (2).


3.2.2 Swell and waves
Swell or waves, which have a certain length, may also threaten underwater sites. The energy of their motion also works downward to the extent of half the distance of the wave length. A storm creates waves that compels the water onto the site and can easily stir up the seabed to a depth of 20 metres. The consequences can be drastic for fragile materials such as waterlogged wood. More importantly, however, is that such a surge may expose objects in protective sediments, stir up the site and even redistribute the objects. Uncovered archaeological remains are even more vulnerable to other causes of deterioration, such as the Teredo navalis. The destructive effect of seasonal storm surges has been examined at archaeological sites throughout the world. The shallow Markermeer and IJsselmeer (part of the former Zuiderzee) are especially vulnerable to wave erosion. However, the Wadden Sea and the coastal zones of the North Sea are also vulnerable to storm induced waves. Shipwrecks are often located in shallower areas, as the dangers of running aground were much greater there. Although no specific analytical data on the effect of waves on cultural-historical sites in the Wadden Sea seabed is available, we can assume that this may be considerable. Previous research has shown that the mega-ripples that run along the Dutch North Sea coast are formed by wind waves. Two multibeam recordings made shortly after one another on the BZN 10 site also revealed the movement of sand waves or ripples due to wave action (Fig. 3.8). Moreover, the patterns and the sizes of these waves changed, possibly due to a storm event.

3.2.3 Surf
The surf zone, up to approximately 5 metres in depth, is a high-energy zone and thus hostile to sites. The effect is similar to swell or wave action. Usually, cultural heritage located in surf zones is heavily eroded. The constant waves cause protective sediment to disappear and sediment with larger grains to be more abrasive. In the Western Wadden Sea, no examples of such degradation are known of at this moment; however, the effects of strong erosion have been noted in many other parts of the world. Examples are the wreck of the Avondster in Sri Lanka and that of a possible Dutch shipwreck found in Portuguese waters.

3.2.4 Ice
Crystallization due to freezing of the seawater may have an abrasive effect on soft and deteriorated wood surfaces of archaeological objects. When the ice becomes a dense mass, the destructive effect is even more drastic. In calmer waters, the ice forms thin sheets and the rafting and build-up of these ice sheets creates an irregular surface, not only above but also under water. This ice mass can reach the seabed in shallow waters and plough the sea floor. Any archaeological remains will be literally bulldozed away. Ice can also block or reroute currents which will affect the site even more.

In the Wadden Sea, during severe winters the low temperature sometimes freezes the seawater (in normal seawater of approximately 35 ppt the freezing temperature is -1.8 °C). When the seawater begins to freeze, 'frazil' will be formed. This is the scientific name for the formation of tiny crystals only millimetres wide. In rough waters or waters with a high current velocity, the energy and turbulence mean the new ice remains a dense mass, the abrasive effect on soft and deteriorated wood surfaces of archaeological objects. When the ice becomes a dense mass, the destructive effect is even more drastic. In calmer waters, the ice forms thin sheets and the rafting and build-up of these ice sheets creates an irregular surface, not only above but also under water. This ice mass can reach the seabed in shallow waters and plough the sea floor. Any archaeological remains will be literally bulldozed away. Ice can also block or reroute currents which will affect the site even more.
the seabed and may well speed up erosion of the top sandy layer and any protruding (wooden) ship elements.

3.3 An example: erosion in the Burgzand area

Due to shallowness, tidal movements, change of gullies and wave action on the Burgzand area, many wrecks are subject to continuous erosion or a changing cycle of sediment erosion processes. The very high level of sedimentation facilitates anaerobic conditions, and in the exposed parts of the wrecks a high concentration of destructive organisms and fouling activities have been found. The seabed is ever changing and sites are considered unstable. Between 2002 and 2014, an area of 79,800 m² in the Burgzand was monitored at regular intervals of one year. In this area there are four wrecks, BZN 3, 8, 10 and 11. From 2003 to 2009, the average deepening of the seabed measured in the first test area was 53 cm, which means there had been a loss of 31,849 m³ of sediment from this area. The most pronounced deepening occurred between 2004 and 2005, by approximately 50 cm in just one year.

In later years, the monitoring area was extended to obtain more data from more sites. In this extended area, we also see the constant erosion of the seabed. Since the building of the Afsluitdijk in 1932, the area has deepened by an average of 5.1 cm per year until 2014. After correcting this number with the bottom decline (0.6 cm/y), this means annual erosion of 32,830 m³.

In the case of the erosion of the Holocene seabed it is important to understand that shipwrecks do not – as previously often thought – sink into the soft sediment of the Holocene of the Wadden Sea until they reach the more compact Pleistocene layer. They may become stuck in sand layers of a much later date. This has been proven through Optical Stimulated Luminescence Dating (OSL) research, which was carried out during the MACHU project. This implies that it is not sufficient to know how deep the Pleistocene layers are to ensure the good preservation of shipwrecks, as would have been suggested by the previously developed theory.

Analyses of the data shows that roughly between Vogelzwin and Vaarwater naar de Cocksduip, parts of the Lutjeswaard, Zuidoostrack and Balgzand areas remained relatively stable between 1925 and 2005. The historical maps dating from 1584 to 1852 record – although in less detail – more or less the same information. This means that although most areas within the Western Wadden Sea have been under the influence of ever-changing gullies and thus erosion of the Holocene and sometimes even the Pleistocene seabed, some shallow areas remained relatively stable. These places may never have been ideal for navigational purposes, but early settlements and shipwrecks that ran aground may be found here. If so, they will likely be in a relatively good state (Fig. 3.9). Cultural heritage in the eastern part of the Burgzand area and on and in Vogelzand, Scheer, Texelstroom and Scheurrak are most at risk of being exposed and degraded by erosion and subsequently other threats (Fig. 3.10).

Fig. 3.9 Stable and well-preserved areas (in yellow) in the Western Wadden Sea. In blue the eroded areas. Figure: courtesy Periplus Archeomare/RCE.

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70 With a minimum depth on the former sandbanks of just 0.5 metres and a maximum depth in the Texelstroom of 25 metres at LLW.
71 In addition to erosion, two further processes contribute to the decrease in bed-level elevation: 1. natural gas extraction (subsiding at a rate of 3–6 mm/year); 2. large-scale geological processes (glacial rebound) also contribute to subsidence at a much lower rate of 0.2 mm/year. Astley 2016, 138. Although adding up to a larger depth, they do not seem to have as great an influence on the condition of cultural heritage on the seabed as erosion.
72 Palma 2004 (1), 5.
73 Brenk & Manders 2014. This is the core area of the National Monument and also the area that has been monitored most.
74 Brenk & Manders 2014.
75 See also Chapter 6.
76 Brenk & Manders 2014, 15.
77 Manders et al. 2009 (1) and 2009 (2).
78 Manders & Maarleveld 2006, 128.
79 Manders et al. 2014. See also Fig. 3.8.
80 Manders et al. 2014, 27.
81 See also Chapter 1.
82 Brenk & Manders 2014, see also Brenk 2016. Analyses of the Vogelzand wrecks based on the geomorphological data not only revealed the sedimentation and erosion patterns throughout the decades, but also the erosion of the Pleistocene layer (boulder clay) after 2010, causing the area to erode to an even deeper level.
Large-scale models show that the deepening or erosion of the seabed on the Burgzand is caused by the movement of the Texelstroom tidal channel towards the southeast (Fig. 3.11). Therefore, the wrecks in the Burgzand area are eroding from the northwest. This process seems to have come to a halt or at least to have slowed considerably, if we look very carefully at the actual sites themselves. These sites are quite stable due to the in-situ preservation that has been applied, while the ambient areas usually continue to erode. However, here we can also see a decline in the speed of erosion from the northwest over recent years. This clearly shows that the erosion pattern is temporary.

In the sections below, the erosion and sedimentation patterns that have been monitored in the Burgzand area will be described for each wreck site. Physical in-situ measures on some of the wrecks have influenced the effect and patterns on site.

BZN 2

The Burgzand Noord 2 (BZN 2) wreck is that of an armed seventeenth-century merchant ship loaded with scrap bronze cannons. The first multibeam recordings of the site are from 2012. The recordings from 2013, 2014 and 2016 show slight sedimentation of the area. The wreck is protected – at least partly – by polypropylene nets. Divers from the Texel sports club have observed that parts of the protective nets have disappeared or been torn (Fig. 3.12), which has been repaired in 2017.

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83 Brenk & Manders 2014, 58.
84 Brenk & Manders 2014, 58.
85 See also Ashtley 2016.
BZN 3
The Burgzand Noord 3 (BZN 3) wreck is that of the East Indiaman De Rob, a VOC vessel that sank during a storm in 1640. It was declared the first Dutch national underwater monument in 1991. The wreck was physically protected in 1988, and this was extended in 2000, 2003 and 2013. In 2003, the site was protruding from the seabed over an area of approximately 50 metres by 50 metres. Multibeam data from 2004 to 2011 show an ongoing deepening of the surrounding area. A clear edge on the west side, from where the net protection starts, has also become visible. Some sediment had been deposited on the east side. The erosion around the net continued in subsequent years, and the wreck has become largely exposed on the northwest side in particular, as well as some parts in the southern area. In the middle of the wreck, a small channel was visible running from west to east. In the south, a small part of the wreck appeared to have become separated from the main protected part. This shows that even with protection, small erosion gullies can easily form within a wreck.

In 2004, the whole site seemed to have been levelled, with a great deal of sand caught in the nets. On the eastern side of the wreck mound, two to three erosion gullies started to appear, reaching a maximum depth of 2 metres in 2006. Afterwards, they disappeared again and were no longer visible in 2008. The west-east channel in the middle of the wreck was slowly disappearing and one year after the covering was applied, the bow section also seemed to be covered in sand. Sedimentation was visible on both the west and east sides of the wreck mound. From the middle of the wreck, this was the case for up to 60 metres to the west and also approximately 60 metres to the east. In some places, small erosion pits were visible, probably due to bad connections between the strips of netting. The erosion-sedimentation erosion map produced for the period 2003–2004 clearly shows the deposition of sediment around the older protective materials from 1988 as a result of the new protective measures. While the height remained the same in the area of the original wreck mound, in newly covered areas, more than a metre of additional deposition had occurred.

The multibeam data from 2006 shows the existence of deep erosion pits on the east side of the wreck. The height differences from the top of the wreck mound to the deeper areas on the east side were now 5 to 6 metres.

A sediment build up of at least 85 metres along the west side of the wreck that was visible in 2009 was probably caused by the BZN 11 wreck, which lies approximately 180 metres west of BZN 3. This shows the influence that other objects (such as other shipwrecks) can have, not only on the surrounding seabed, but also on other sites in the area.

During the dives in 2013, the uncovered parts on the west side of the wreck – part of the hold – were documented and covered with polypropylene nets. The effect is clearly apparent in the multibeam data for July, immediately after the protection measures had been taken, but unfortunately the multibeam data for December of the same year shows an abnormal deepening around the anchors. This may be an indication of illegal excavation between July and December. The 2014 multibeam data shows a further deepening of the surrounding area. A comparison with historical data shows us that since 1850 the area around the wreck site has eroded by approximately 6 metres. However, the protection is working. The sandbag mound that was originally used to protect the site in 1988 has remained stable throughout the entire monitoring period and the west part of the wreck has sanded in after the protective additions in 2013.

Fig. 3.12 Compilation of BZN 2 erosion-sedimentation history. Two multibeam recordings for comparison: one from 2012 and the other from 2016. Figure: courtesy Periplus Archeomare/RCE.

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87 Vos 2012, 143.
88 In 1991, it was registered as a National Monument under no. 361751.
89 On the basis of the models made from the subsequent years of multibeam data.
The Burgzand Noord 4 (BZN 4) wreck is that of a possible West Indianman that sank in the middle of the eighteenth century. It was discovered in 1985 and after intrusive research protected in situ in 2000.\textsuperscript{96} The site was monitored with multibeam sonar between 2005 and 2013.\textsuperscript{96}

The morphological changes that have occurred on this site include sedimentation on the east side of the wreck after 2007 and sedimentation on the south side since 2009. Throughout the monitoring period, the wreck mound itself remained stable.\textsuperscript{97} Since 1850, the area immediately around the site eroded by approximately 4 metres. However, in the last 10 years this process seems to have been reversed and the area has started to sedimentate (Fig. 3.14 A, B).\textsuperscript{98}

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\textsuperscript{97} Brenk & Manders 2014: 32.  
\textsuperscript{98} Brenk & Manders 2014: 32.
BZN 8
Burgzand Noord 8 (BZN 8) is the wreck of a seventeenth-century armed ship. It was long thought to be the remnants of the VOC galleon De Lelie; however, this has turned out to be incorrect. It was discovered in 1997 and physically protected in 2003. The first multibeam recording made on this site was in 2003.

The wreck site is approximately 20 metres wide and 30 metres long. The maximum height differences inside and outside the wreck were 3.5 to 4 metres in 2009. At this time, on the southwest side, sharp edges had formed around the polypropylene protection nets. Before the physical protection was put in place, the stern area to the south was already the most protruding feature. Strong erosion here posed a major threat to the entire site.

In 2004, the protective layer was clearly catching sand and most height differences in the wreck had levelled out. However, in the southeast and northwest areas, some individual uncovered ship parts were being revealed and, east of the wreck mound, a large but shallow erosion pit approximately 4 by 8 metres was becoming visible in the middle of the wreck. East of the wreck mound, in the north and south regions, more sand had been deposited and two large sand ridges had formed. Especially in 2006, a lot of sand seems to have been deposited on the wreck site. On the west side, the edges of the protection nets were covered with sand. In 2008, the erosion pit in the east had deepened, and this continued in 2009. Inside the wreck, the mound was levelling out due to sediment build up.

From 1850 until around 1950, the wreck area eroded by approximately 3 metres, after which sedimentation took over. However, from 1980 onwards, the area started to erode again, by another 4 metres. Since 2003, when the protection measures were put in place, the wreck mound has hardly changed, while the surrounding area has further eroded (Fig. 3.15 A, B).

BZN 9
The Burgzand Noord 9 (BZN 9), a seventeenth-century armed merchantman, was recorded for the first time in 2007. The wreck was found in the 1990s and investigated in 1998. The sediment layer in the wreck area eroded approximately 5 metres between 1850 and around 1985. Subsequently, the area has remained fairly stable, but from 1995 on the area began to erode yet again, by another 1.5 metres. Over the last couple of years, sedimentation and erosion seem to be fluctuating irregularly, with some net sedimentation in recent years, but more pronounced individual wreck parts visible on site (Fig. 3.16 A, B).

BZN 10
The Burgzand Noord 10 (BZN 10) wreck is that of a seventeenth-century trader. It was discovered in the 1990s and physically protected in 2000, which was extended in 2001 to 800 m² and in 2003 to 2000 m². Subsequently, the protection has been maintained, and in 2013 and 2014 a for the Netherlands new method of in-situ preservation using artificial seagrass was trailed.

Multibeam recordings of the BZN 10 wreck since 2002 are available for this research (Fig. 3.17). The first recording was produced for the MoSS project and focused only on this wreck site. The physical protective nets are clearly visible in the image. The site was still relatively flat, but some archaeological features were already protruding, including one cannon to the north of the site. On the edges of the nets, on the north, south and west sides of the site, sharply defined edges were visible. In areas with clear signs of strong erosion, archaeological features were also surfacing on the seabed.
In 2003, after the extension of the covering, the site was 30 metres wide, with strips of netting extending another 10 metres on the east side. The length of the site was 40 metres. More sediment had settled on the wreck, covering all the archaeological material. From the west side to the middle of the wreck mound, we measured 20 metres, while from the middle of the mound to the east as much as 40 metres. In the south, a sand ridge had formed, extending towards the east. In 2004, the site was 45 metres wide and 47 metres long. Even more sediment had been caught in the wreck and the sand ridge in the southeast had extended. The edge of the protective nets to the west was becoming more visible, due to the lowering of the seabed around the wreck site. This was even more pronounced in 2005. More sediment had been caught on the east and to a lesser extent on the west side of the wreck. However, in the middle part, east of the wreck mound, an area outside the protective nets had deepened severely.

In 2006, parts of this erosion pit had again been filled with sand. Erosion continued in the north and south, however. The erosion in the east was worst in the middle of the wreck site. In the north, individual ship parts were becoming visible. Moreover, in the area around the wreck site, the seabed had deepened further and by 2007 the situation had worsened. On the north-northeast side, a strong erosion gully had formed and more individual ship parts were being revealed. A slight sedimentation ridge had become visible in the middle part of the west side as a result of wreck BZN 8, which is situated 180 metres to the west of BZN 10.

The proximity of this wreck has, however, exposed the seabed to stronger erosion on the south side of BZN 10. The seabed at and immediately surrounding the BZN 10 wreck site deepened by an average of over 80 cm between 2002 and 2009. If we take into account the fact that the physically protected part of the site has gained more sediment over that same period, the deepening has been much greater in the surrounding seabed. The most severe erosion took place in 2004–2005, with the average deepening approximately 34 cm. Strong erosion also occurred in 2003–2004, 2006–2007 and 2007–2008. A small positive sedimentation rate was detected in 2007–2008 and 2008–2009, mainly due to the filling of some deep erosion gullies in the east and north. It is striking, however, that in these two years, the area on top of the wreck site seemed to lose sediment for the first time. The reason for this is that the nets had reached their maximum extension and sand...
started to flow out from under the protective nets in some areas. From 2010 onwards, gullies started to form on top of the protective nets.111

In 2013, the wreck was used as a test location for the European SASMAP project, ‘Development of tools and techniques to Survey, Assess, Stabilise, Monitor and Preserve underwater archaeological sites’.112 As the name suggests, this project was developing all sort of tools for archaeological heritage management under water. Part of this is the development and trial of artificial seagrass as a method to preserve shipwrecks. On the southwest side of the wreck, four mats were initially installed in 2013. They were not only designed to function as protection for what lies underneath them, but also to protect the polypropylene net edges, which are vulnerable to underscouring, and for additional sand catching. In the first instance, this has worked remarkably well.113 Sand has been deposited in between the fronds of the mats as well as immediately before and after, thereby protecting the edges of the nets. The fronds also slow down the current but do not form a hard edge. Therefore, sedimentation proceeds more gradually.114 On this basis, in 2014, another four mats were installed in the mid-east section, on the edge of an impression that had formed due to erosion.115 In 2015, it was observed that the sandbags holding the artificial seagrass mats down on the site had been underscour. However, it may in the future be possible to fix this by installing the mats using a different technique.

The wreck was recorded twice by multibeam in 2013, immediately after the installation of the first four artificial seagrass mats in July that year and again in December. This gives us a unique opportunity to compare the seabed morphology and effectiveness of the nets over a short period of time. The seabed morphology in July 2013 showed a pattern of small sand ripples, while in December this has changed into large (mega) ripples. This may be a seasonal phenomenon (due to wave action (?), see also 3.2.2), but no specific research has yet been done.116

In 2015, it was decided that the north part of the BZN 10 area has vertically eroded by 77 cm since 2002. Since 2008, it remains more or less stable, with a slight increase in sedimentation in recent years. Natural changes to the seabed (changing of the course of the Texelstroom) may have a strong influence on the continuous sedimentation on the south side of the wreck and the forming of an erosion gully in the north part (Fig. 3.18 A, B, C).117

**BZN 11**

The Burgzand Noord 11 (BZN 11) wreck was probably a seventeenth-century merchant vessel. It was discovered in 1997 and researched in 2002 and 2007.118 After 2002, it was decided that this site should be left unprotected, as a reference or benchmark for the other wrecks in the area.

In 2003, the site consisted of a large wreck section, 25 metres long by 8 metres wide, surrounded by loose wreck parts. There was a strong erosion gully on the south side of the wreck. By 2004, the site was only 5 metres wide. The length remained the same, but a large ridge, which was at least 50 metres long, was forming to the east. From 2004, the deep erosion gully levelled

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111 Brenk & Manders 2012, 39 and 2014. Erosion and sedimentation patterns are distilled from the subsequent multibeam data collected on site.


114 Gregory & Manders (eds) 2016.

115 Gregory & Manders (eds) 2016.


117 Brenk & Manders 2014, 41.

118 See also Vos 2012, 267–278.
out. This was still the case in 2006, but in the southwest some strong erosion pits seemed to be undermining the ship construction. In 2008, and 2009, the site was still as large as in 2004, but the seabed around it had flattened out further.

In general, the wreck appears to be slowly disappearing, probably because it is failing apart. Evidence of this can also be found in the multibeam data. While in 2003 the height difference between the wreck and the surrounding seabed was still approximately 1.40 metres, in 2009 the wreck was protruding above the seabed by only 10 cm. In 2013, these loose parts and the wreck mound had almost completely disappeared. The whole area had flattened out, and most of the objects above the seabed (causing eddy currents) had disappeared.119

The historical and more recent data show that from 1852 onwards the wreck would have eroded gradually, and since its discovery in 1997 this process of erosion accelerated, deepening the site by 6 metres in total (Fig. 3.19 A, B).120

**BZN 12**

The Burgzand Noord 12 (BZN 12) wreck, a seventeenth-century merchantman with a heavy cargo of bricks,121 was recorded with multibeam for the first time in October 2012. After three years of monitoring (December 2013, 2014 and 2015), little difference in seabed morphology could be seen (Fig. 3.20).122

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119 Brenk & Manders 2014, 42.
120 Brenk & Manders 2014, 43.
121 Vos 2012, 281–287.
122 Brenk & Manders 2014, 44.
BZN 13
The Burgzand Noord 13 (BZN 13) wreck, a seventeenth-century shipwreck (board) was recorded for the first time in 2012. The multibeam recording from December 2013 showed that the gully to the north of the site had sanded in. This process had continued in 2014 and the area was flattening out. The resolution of 2015 was lower than the other multibeam recordings, but seemed to show the same flattening out of the surrounding area (Fig. 3.21).

BZN 14
The Burgzand Noord 14 (BZN 14) wreck, a seventeenth-century armed merchantman, was recorded in 2012 for the first time. The recordings from December 2013, October 2014 and December 2015 show that the northern part of the area around the wreck site had deepened considerably (Fig. 3.22).

BZN 15
The Burgzand Noord 15 (BZN 15) wreck site was first assessed in 1999. It consisted of partly disarticulated ship parts and cargo. The most protruding element was a cargo of iron rods. The wreck was dated to the seventeenth century, and was recorded with multibeam for the first time in October 2012. A comparison with the recordings in 2013 and 2014 revealed various long objects (one even as long as 4 metres) to the south of the earlier recorded iron rods. The area itself is deepening, which is also apparent in the recording from 2015 (although the resolution of this recording is considerably lower than those made previously) (Fig. 3.23).

BZN 16
The first multibeam recording of the Burgzand Noord 16 (BZN 16) wreck (a seventeenth/eighteenth-century shipwreck) area was made in 2011. Wooden wreck parts were reported by government archaeologists in 2002. In the 2011 recording, however, no evidence of any shipwreck was found in a radius of 50 metres from the reported location. This may be because the location was not accurately recorded or the wreck parts had eroded and washed away. The latter is a plausible explanation as the area had deepened by 2 metres since the first report of a wreck (Fig. 3.24).

BZN 17
The Burgzand Noord 17 (BZN 17) wreck was discovered in 2009 and was recorded with multibeam for the first time in 2011. The wreck parts cover an area of 25 by 15 metres. Between 2011 and

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123 Brenk & Manders 2014, 45.
125 Brenk & Manders 2014, 46.
127 Brenk & Manders 2014, 47.
128 Brenk & Manders 2014, 48, 49.
Analyses based on the multibeam animation made of the BZN 18 wreck from the period 2004–2015.

Brenk & Manders 2014, 50.

Opdebeeck 2015.

Report on BZN 18 dive action by the author. Internal reporting RCE.

2012, almost no changes were visible. In 2013, a structure of more than 5 metres long had become visible on the south side of the wreck. During a quick survey in 2014, done by the RCE, this turned out to be a board of a ship. It also became immediately obvious that heavy airlifting had occurred on the site, assumed to have been done by local diving groups. This site disturbance is clearly visible in the multibeam sonar data of 2014. Large holes have appeared in the centre of the wreck site. A further investigation was carried out in 2015 to look into the possibilities of physically protecting the site and this was done in 2016 (Fig. 3.25 A, B, C).

**BZN 18**

Analyses of the multibeam sonar from 2009 revealed a new shipwreck (BZN 18) 40 metres from the BZN 3 wreck. Prior to this, no clear structures had been visible. Dive research in 2013 revealed it to be a wreck approximately 25 metres long. Not much else is known about the site, except that it had already been severely attacked by *Teredo navalis*. Since 1850, the area has deepened by approximately 6 metres. It is striking that shortly after the appearance of the wreck at the seabed surface in 2009, a deep erosion pit quickly developed to the east side. In 2013, the pit reached its maximum depth of 3 metres. Subsequently, the scour pit was filled and completely levelled out in 2015.

During a dive survey in 2013, the height difference between the wreck and the east side was already more than 2 metres. This, however, had disappeared in 2015, when the area around the wreck flattened out (Fig. 3.26 A, B).
3.4 Some conclusions about the seabed morphology

The Western Wadden Sea is a dynamic area, and this constitutes a major threat to the in-situ preservation of the wreck sites described above, as well as a potential threat to other, as yet unknown sites. The mobile Holocene layer is changing in thickness regularly, consequently covering and exposing shipwrecks. On a larger scale, we see that the currents and wave actions have an influence on the morphology of the seabed. Gullies, tidal channels and former sandbanks change place and course, opening up new areas which threaten the cultural heritage. These areas are the Burgzand, Vogelzand, Scheer, Texelstroom and Scheurrik.

There are also more stable areas: roughly the area between Vogelzwin and Vaarwater naar de Cocksdorp, and parts of the Lütjenswaard, Zuidoostrik and Balgzand. Historical research has shown these to be generally stable for a long time. Research on sedimentation and erosion in the greater Western Wadden Sea has shown that sedimentation is the general trend in the area. However, mainly due to the building of the Afsluitdijk in 1932, there is no stability as yet, and it may take another century before the entire area is stable once again.

The dynamics of sedimentation and erosion due to currents and waves at the site level of some of the wrecks in the Burgzand area have also been investigated, finding that, each year, the morphology around the monitored shipwrecks changes. The obstruction of the wreck itself causes local eddy currents that can cause scour and erosion pits in and around the site. The in-situ stabilization methods have worked to create a more stable environment. The tendency, however, is that the Texelstroom is moving southwards over the Burgzand area, which in some places will cause strong erosion patterns. Nevertheless, due to its continuous movement, some wreck sites in the northern part of the area are again in the process of sedimentation.

3.5 Biological threats

3.5.1 Introduction

Archaeological sites are not only subject to mechanical deterioration, there is also a biological threat, with wood being especially vulnerable to attack. The effects of biological attack can vary.

While specialized fungi and bacteria are able to degrade wood for example, usually by relatively slow biochemical processes, bivalves and crustaceans effectively fragment wood, thereby contributing to a much faster degradation process.

Biological attack of organic materials by wood borers, fungi and most bacteria is primarily dependent on the presence of oxygen. We can therefore make a distinction between the processes that occur above the seabed and those within the seabed. Within the seabed, the amount of oxygen is usually extremely low or even non-existent. However, sea organisms can also be the cause of seabed disturbance due to bioturbation and, therefore, introduce oxygen into deeper areas of the seabed.

Elements of a site directly exposed to the seawater, or a thicker layer of the sediment, may become aerobic and therefore subject to severe biological and chemical deterioration.

In the light of this basic knowledge about biological deterioration of archaeological wood under water, a series of European projects were designed, in which tests were conducted and the type and speed of biodeterioration were measured. This also resulted in the development of ways to monitor sites.

Between 2001 and 2004, the BZN 10 wreck was the test and sample site for the Culture 2000 MoSS project. At this protected wreck site, artificial woodblocks and a data logger to measure the environmental conditions were installed above the seabed to investigate degradation in aerobic conditions, and also in the seabed (actually on site) to investigate degradation in anaerobic conditions. In a large frame, 150 woodblocks (20 x 7 x 2.5 cm) of fresh oak (Quercus sp.) and pine (Pinus sylvestris) and archaeological wood (also oak: Quercus sp.) were exposed above the seabed (Fig. 3.27). Some of these blocks were physically protected with Terram geotextile (of different grades: 500, 1000, 2000 and 4000) and others were not (see for more on this Chapter 5). Sets of blocks were collected after 3 months and 12 months, respectively.

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133 Some of the changes in erosion and sedimentation patterns have also been caused by the Balgzand dike, which was built in 1924. See also Brench & Marders 2014, 10.
134 See, for example, Volkenborn et al. 2007.
135 See, for example, the results of the MoSS, BACPOLES, MACHU, WreckProtect and SASMAP projects.
136 See also Chapter 6.
137 See also Section 3.1.
138 Water-Watch System 2681 – subsea logger from EauxSys (UK) Ltd. In open water, it measured temperature, depth, dissolved oxygen and conductivity (which can be converted into salinity). Turbidity and sediment movements were also trialled. In the sediment, pH and redox potential were measured. Gregory 2004 (1).
139 Pine and oak were the main wood types used in European shipbuilding in the sixteenth and seventeenth centuries. The archaeological wood from the Mary Rose shipwreck (1545, Portsmouth) was provided by the Mary Rose Archaeological Services, a partner in the MoSS project.
140 The higher the grade, the more dense and less flexible the geotextile.
141 At the start of the project, wood samples were placed above the seabed for 3, 12, 24, 36 and 48 months. However, due to time restriction within the project, only the samples for 3 and 12 months were collected.
The blocks that were used to investigate the anaerobic environment were placed in the burial mound of the BZN 10 on the west side of the wreck, close to the frame for the aerobic samples. In total, 280 small blocks (5 x 2 cm, 5 x 3 cm) of fresh oak and pine were buried in open PVC tubes in the sediment (Fig. 3.28). They were collected at the same time-intervals as the aerobic woodblocks. A control material, Shirley Textile, was also placed in the sediment (Fig. 3.29). This fabric consists of 96% cellulose, which enables us to investigate the extent of attack caused by cellulose degrading bacteria and fungi.

Bacterial decay of submerged wood was also the special focus between 2002 to 2005 in the European 7th Framework financed BACPOLES project. In addition to house foundation poles and other kinds of archaeological sites, two submerged wrecks in the Wadden Sea were also chosen as test and sample sites: the BZN 3 and BZN 15.

The outcomes of these two projects form the basis of the information on biological deterioration of sites assembled in this chapter.

**3.5.2 Above the seabed**

There is a lack of natural hard substrate habitats in the oceans of the world, including Dutch waters. Therefore, when a ship sinks to the seabed, various marine invertebrates will colonize it relatively quickly, and there is strong competition among species for space.

Above the sediment, the environment is often oxygen rich. Exposed parts of a wreck are thus subject to a variety of biological deterioration processes.

Bacteria and fungi produce extracellular enzymes which destroy the material on which they grow, while crustaceans and molluscs bore into wood, which they ingest and may subsequently utilize. Additionally, there are fouling organisms, such as algae, moss animals, *Tunicata, Actiniaria,* or sea anemones, barnacles and *Mollusca,* which use the wood and also other natural and human-made materials as a substrate on which to grow. Within the BACPOLES and MoSS projects, visual observations of abundant growth of sea anemones on unstable, heavily deteriorated wooden wrecks were made. This causes the break up of ship elements, due to the greater resistance of the structure to the currents (Fig. 3.30).

Bioturbation by shells, lugworms and crabs has also been observed. The latter even ‘attack’ exposed archaeological objects (Fig. 3.31). Their effects have not been scientifically measured.

By far the most damaging of these organisms are the marine wood borers, which may cause damage to exposed shipwrecks and loss of archaeological information in an extremely short period of time. After the marine borers, the next agents of deterioration to consider are fungi and bacteria. These micro-organisms have a relatively minor part to play in the total breakdown of wood in seawater but their activity will affect its long-term preservation.

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142 Palma 2004, 7.
144 A sedentary colonial aquatic sea animal, either encrusting rocks, seaweed or other surfaces, or forming stalked fronds. Also *Polyzoa* or *Bryozoa.*

For example, the control samples taken within the MoSS project at the 12 and even 3 month intervals were thoroughly covered in barnacles, bivalves and algae.
3.5.3 Within the seabed

Usually, only the first few millimetres of the sediment is oxygenated. Bioturbation by invertebrates, wave action or other cultural and natural processes may extend this oxygenated zone downwards.\(^{147}\) The depth of the sediment does affect the amount of micro-organisms present. However, bacteria, unlike the marine borers and fungi, can survive in environments with very low oxygen concentrations, even in anaerobic or anoxic conditions.\(^{148}\) Relatively high numbers of aerobic bacteria and fungi occur in the first few centimetres of most marine sediments, but numbers are rapidly reduced in deeper sediment layers.

3.5.4 Different environments, different degradation processes

Different environments, dominated by the absence or presence of oxygen for example, trigger the biological deterioration of material on site due to the presence of different animals. Below, the most damaging species will be discussed.

Wood-boring bivalves

Wood-boring bivalves, generally called shipworms, belong to the families Teredinidae and Pholadidae (Fig. 3.32). Together they constitute the suborder Pholadina of the Eulamellibranch of the order Myoida.\(^{149}\) Shipworms are potentially the most rapid decomposers of wood structures under water. Moreover, when released into the water column they can travel long distances in a relatively short period in search of wood.\(^{150}\)

Shipworm larvae settle onto submerged wood and undergo a metamorphosis, becoming tiny juveniles that mature while living inside the wood.\(^{151}\) The entrance hole where the larvae first settle is small and only slightly enlarges during the life span of a shipworm. The organisms filter feed and obtain oxygen by pumping water in and out through their siphons. These tube-like organs are the only part of the animal that is visible outside the wood. The siphons normally extend out of the entrance holes but will be quickly retracted if disturbed. As long as a shipworm can position its siphons in an oxygenated environment, it can bore deep into a wreck lying in sediment. Shipworms need oxygen-rich water in their burrows for respiration to survive. Nevertheless, they can seal their burrows for several weeks if the surrounding conditions become unfavourable.

The major factors influencing colonization by marine borers, including shipworms, are temperature, salinity, depth and the dissolved oxygen content of the water.\(^{152}\) Adult species of the *Teredo navalis* are tolerant of waters with a minimum temperature as low as \(-1.4\) °C and as high as \(30\) °C. They are, however, most active between \(15\) °C and \(25\) °C. They start spawning at \(11\) °C and the larvae are active between \(7.5\) °C and \(30\) °C. Metamorphosis of the larvae is possible above \(12\) °C. This means that for the reproduction and development of a healthy population, \(11\) °C is the minimum for at least some period of time each year. Larvae need \(1\) °C more to develop into adult *Teredo*, at least also for some period of time each year. This is certainly the case for the Wadden Sea.

In addition, normal boring activities of adults occur in salinities from 7 to 9 PSU.\(^{153}\) Salinity less than 4–6 PSU are lethal. Reproduction is possible above 8–9 PSU. Adults remain active between 7–45 PSU and larvae from 6–31 PSU, while 5 PSU or lower is lethal to the larvae.\(^{154}\) Active shipworm has been detected from 0 to almost 30 metres.\(^{155}\) Although probably a very important parameter, not much work has been done on the oxygen tolerance of the shipworm. However, the minimum tolerance levels are estimated to be less than 1 mg oxygen per litre within 24 hours for larvae and 1 month for adults.\(^{156}\) A healthy condition consists of an oxygen level of more than 4 mg/litre (Fig. 3.33).\(^{157}\)

Currents are important in relation to the animal’s capacity to

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\(^{146}\) They may be responsible for making the wood soft by destroying the inner cell structures. This again makes the wood vulnerable to mechanical deterioration.

\(^{147}\) Helmholtz Centre for Ocean Research Kiel (GEOMAR) 2014.

\(^{148}\) For example, sulphur-reducing bacteria. See, for example, Muyzer & Stams 2008.

\(^{149}\) Turner 1966.


\(^{151}\) See also Nair & Saraswathy 1971.

\(^{152}\) WreckProtect guideline: Manders (ed.) 2011. Sometimes other figures are mentioned: For temperature: *Teredo navalis* individuals can survive in water temperatures as high as \(30\) °C, although growth may cease above \(25\) °C. Minimum reproductive temperature is reported as approximately \(11–15\) °C. The species has recently been reported in the Weser Estuary, northern Germany, where winter water temperatures of \(0.7\) °C were recorded (http://www.srs.niue.edu/rispec/Teredo_nava-

\(^{153}\) Manders (ed.) 2011.


\(^{155}\) Manders (ed.) 2011. 19.

\(^{156}\) NEMESIS (http://invasions.si.edu/nemesis/CH-ECO.jsp?Species_name=Teredo + navalis, accessed 29-01-2017).

\(^{157}\) Helmholtz Centre for Ocean Research Kiel (GEOMAR) 2014.
travel. Adults can spread in driftwood. Larvae are free-swimmers and can do so for between 2 to 4 weeks, after which they must find wood substrate to colonize.\textsuperscript{158}

In Teredinidae, the nearly hemispherical shells cover only the anterior part of the animal, and a thin calcareous layer deposited on the walls of the burrows protects the rest of the worm-like body. Species in this family also have two associated calcified structures at the posterior end called the pallets. These are used to close the small hole connecting the burrow to the external environment.\textsuperscript{159}

The average length of an individual Teredo navalis is approximately 20 cm,\textsuperscript{160} while those in tropical waters may reach 50 cm.\textsuperscript{161} Shipworm individuals typically live for 1–3 years. After settling, they bore into the wood and seldom along the wood surface. The mollusc digs approximately 1 cm wide burrows up to 0.6–1 m long.\textsuperscript{162} It avoids joints and knots and turns around when it reaches the end of the timber. The wood on the outside looks almost intact except for the entrance holes. The damage is therefore not always easy to detect by eye, especially under water.

Despite extensive internal damage, a wreck that has been attacked by shipworm of the family Teredinidae may remain intact for a long time after infestation because the burrows of these shipworms are lined with calcium. This supporting structure helps to hold the piece of wood together, although the material strength is severely reduced. Such infested wood is very fragile and may easily break upon impact with other objects such as fishing nets, divers, anchor lines or moving debris on the seabed (Fig. 3.34).

The infestation and consequently devastating effect of the shipworm on submerged wooden structures has been a problem in the Netherlands for a long time. Early severe infestations are historically recorded in 1730–1733, 1770, 1827 and 1858–1859.\textsuperscript{163} The 1730s infestation may have been the most disastrous, causing great concern among the Dutch. The attack also destroyed most dikes, embankments and sluice gates. Before 1730, there is no mention of such a plague; however, the shipworm was known as early as the 1720s, when it is already mentioned in texts.\textsuperscript{164}

The major threat posed by this creature concerns the fact that the Netherlands heavily depends on its sea defence measures (Fig. 3.35). The causes of the attack in 1730, 1731 and 1732 thus had to be found. At the time, 82 men were sentenced to death for alleged homosexuality, which had supposedly caused the attack by the shipworm.\textsuperscript{165} In addition, the Teredo led to the first
Heritage act in the Netherlands in 1734, due to the fact that dolmen (hunebedden) were being removed and used to defend the coast in the north of the Netherlands, rather than the wooden defences that were being attacked by shipworm.¹⁶⁶

Shipworm has also posed an enormous threat to wooden ships in the past. During his fourth voyage in 1502, Columbus experienced the devastating effect they could have on the hulls of ships. Near Panama, two of his ships, the Gallega and Vizcaina, were lost due to shipworm damage.¹⁶⁷ The VOC also repeatedly mentioned attacks on their ships in tropical waters.¹⁶⁸ Although it is also often thought that the Teredo is an invasive species, pre-Christian era Greek and Roman sources and fossil finds in the UK and Belgium suggest the organism was present in Europe as early as the Eocene.¹⁶⁹ The significant problems arising after 1730 in the Netherlands may have been due to more favourable conditions for the reproduction and survival of shipworm, thus causing an explosion of the population.

Shipworm has caused problems with wooden structures – including shipwrecks – in many parts of the world. As seen above, this is no different for the Netherlands and the Wadden Sea.

Until recently, the Baltic Sea was free of Teredo navalis. This is one of the major reasons why the Baltic Sea contains so many extremely well-preserved shipwrecks. However, over the past few years Teredo navalis and its destructive effect on wooden shipwrecks and harbour installations have been recorded in Denmark and Germany, ranging from the entrance to the Baltic Sea to the German state of Mecklenburg-Vorpommern.¹⁷⁰ This is probably due to the introduction of more saline seawater from the North Sea into the Baltic Sea and possibly also due to an increase in water temperature due to climate change.¹⁷¹ Research in the WreckProtect project revealed that although there is a real threat in the southern part of the Baltic Sea, large areas to the north will not be infested in the near future (Fig. 3.36).¹⁷² In the 1960s, the Oostvoornsemeer (a lake) in the Netherlands was formed by closing off the Brielse Maas from the sea. Subsequently, it was used for sand extraction for the extension of the Rotterdam harbour. In the process, the lake was deepened by 20 to 45 metres. During these dredging activities, several historical shipwrecks emerged from the seabed.¹⁷³ These, however, remained in a very good condition due to the fact that the original salt water area had desalinated. This has made the Oostvoornsemeer unique and a popular dive spot (Fig. 3.37).¹⁷⁴

¹⁶⁸ See, for example, Duivenvoorde 2008, 330–355.
¹⁶⁹ See also Borges et al. 2014; Palma & Santhakumaran 214, 5.
¹⁷⁰ Gjelstrup Björðahl & Gregory (eds) 2011.
¹⁷² Manders (ed.) 2011, 39.
¹⁷³ Breuk & Muis 2014.
In 2008, it was decided to reverse this desalinization process to improve the water quality and to make the area a unique brackish water lake. This meant salinizing the lake again. The advice of the RCE was to keep the salinity lower than 8 ppt. Unfortunately – probably due to a miscommunication – the salinity was finally set to a Chloride level of 8 ppt. This, however, results in a salinity level of 14 ppt, way above the minimum levels. Subsequently, archaeological research executed in 2012 revealed an attack by shipworm. This was the start of intensive research to investigate the presence of shipworm, its spread and influence on the shipwrecks in this area.

In July 2014, wood samples taken from 7 sites indicated that 6 had been attacked by the shipworm Teredo navalis (Fig. 3.38). Only at the deepest site, at 35 to 40 metres and 8 °C, were no living Teredo found. Investigation of the environment showed that here temperature and depth seem to be the limiting factors. Although the maximum depth at which Teredo has been found to date is a little below 30 metres, there is as yet no hard evidence to suggest why it should not be present at greater depths. The site, therefore, still has to be monitored for colonization by shipworm.

Shipworm is thus probably the most damaging sea organism on wooden shipwrecks and other submerged wooden structures. One Teredo navalis can eat away a 20 cm piece of wood in one year. Wood samples investigated in the MoSS project removed from the water after 3 months already showed the early stages of infestation by wood borers identified as Teredo navalis. This was much worse in unprotected woodblocks after 12 months, which had been heavily attacked. Pine samples placed on site for 12 months showed different levels of attack, while the oak samples were generally less attacked. The difference in oak and pine is interesting if we think of the sacrificial layer of pine wood planks that shipbuilders used to add to ships that were going to the tropics. Was the choice only based on the price of the wood or were they well aware of the fact that pine is more susceptible to attack? The continuous damage in the past, but also today, is enormous and the costs of repair or replacement of harbour structures are high.

Crustaceans

In contrast to shipworms that penetrate the wood, wood-eating crustaceans mainly gnaw and burrow on the surface. The species causing the most problems are members of the genera Limnoria, Sphaeroma and Chelura. These crustaceans are collectively called ‘gribbles’ (Fig. 3.39). In areas with very little tidal movement, wood attacked by gribbles often develops an hourglass-shaped appearance because the predominant attacks occur close to the mean seawater level. However, gribbles also degrade wood in deeper waters. In the family Limnoriidae, cellulose is degraded during passage through the gut. Members of the family Sphaeromatidae, which does not ingest wood, break down the wood mechanically and also cause enormous damage.

The effect of Limnoria lignorum is generally less destructive than that of Teredo navalis, but over an extended period of time, wood strength can be compromised and important archaeological information may be lost, especially because it attacks the surface

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175 Ruiter 2012.
176 Coenen & Houkes 2014.
177 There was recent attack, with live Teredo navalis found in almost all the wrecks that were sampled, except for DVM 12 (see below). An old Teredo attack was also identified. A significant attack may also have occurred between the closure of the first Brielse dam in the 1950s and the dam that closed off the Oostvoornsemeer from the sea. Before that time, fresh river water may have had an influence on the relatively well-preserved state of many of the wrecks.
178 Ruiter 2012.
179 Coenen & Houkes 2014.
180 Paalvast 2014.
181 Appelqvist 2011, 62.
183 This depends on the different geotextiles that were used to protect the control samples.
185 Appelqvist 2011, 57.
of the wood. Gribble requires an aerobic and saline environment with and attack was observed on aerobic wood samples in the Wadden Sea.

Micro-organisms

Specialized fungi and bacteria degrade wood in all types of aquatic environments. The fungi belong mainly to the group of Ascomycetes and Fungi imperfecti, and form what is known as soft-rot decay. Using filamentous growth, hyphae penetrate into the wood structure and utilize the wood components (cellulose, hemicelluloses and lignin) in enzymatic processes. Soft-rot decay results in a loss of cell-wall material in the outermost surface layer of the wood, as the fungi are dependent on access to higher levels of dissolved oxygen from the water. For most marine fungi, levels of less than 0.30 ml/litre (approximately 0.5mg/litre) have been reported to prevent their growth. Wood from sluice doors is, for example, often subject to fungi attack. Brown-rot are also extremely destructive to wood. However, in low-oxygen to near anaerobic conditions, only bacterial degradation can be found. Two types of bacteria have been recognized as the main wood degraders, namely erosion and tunnelling bacteria. Although wood degradation by erosion bacteria was reported in the 1980s, little was known about their taxonomy and growth because for a long time they had not been successfully isolated or cultivated in pure cultures. Some studies were done in the BACPOLES project. Tunnelling bacteria are active in seawater conditions but require higher concentrations of oxygen for activity. They can especially be found in the outer layers of non-buried wood, whereas erosion bacteria are able to degrade wood under near anaerobic conditions, including interior parts of the wood. For archaeological wood, information on the behaviour of erosion bacteria and on the damage they may do to archaeological wood in situ is of prime importance for the management and protection of archaeological sites, since they may often be the only degraders left in the environment.

A strong smell of hydrogen sulphide was the first indication that bacterial decay had occurred in wood from the wrecks in the Wadden Sea. This odour was noticed, for example, when the Terram geotextile and the sediment were removed from the woodblocks (pine and oak) sampled from the BZN 10 wreck. The smell was also noticed from the wood samples dug up from the anaerobic sediment on that same site and from samples taken in the BACPOLES project from wrecks BZN 3 and 15. The wood showed similarity. This preliminary research must be continued in the future.

Bacteria degrade waterlogged wood more slowly than fungi. However, in low-oxygen to near anaerobic conditions, only bacterial degradation can be found. Two types of bacteria have been recognized as the main wood degraders, namely erosion and tunnelling bacteria. Although wood degradation by erosion bacteria was reported in the 1980s, little was known about their taxonomy and growth because for a long time they had not been successfully isolated or cultivated in pure cultures. Some studies were done in the BACPOLES project. Tunnelling bacteria are active in seawater conditions but require higher concentrations of oxygen for activity. They can especially be found in the outer layers of non-buried wood, whereas erosion bacteria are able to degrade wood under near anaerobic conditions, including interior parts of the wood. For archaeological wood, information on the behaviour of erosion bacteria and on the damage they may do to archaeological wood in situ is of prime importance for the management and protection of archaeological sites, since they may often be the only degraders left in the environment.

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proved to be very soft and spongy in some areas. The presence of erosion bacteria attack was confirmed by microscopic research.\textsuperscript{205} The woodblocks that were buried in the sediment of the BZN 10 shipwreck showed a distinctive degradation pattern from bacteria in oak and pine samples after 12 months on site. This bacterial degradation had also been detected in the Shirley Textile (cotton) samples that were removed after 3 months on site.\textsuperscript{206}

Of the archaeological wood from BZN 3, sampled in the BACPOLES project, four pine samples were fully degraded by bacteria. Half of the total number of samples were severely degraded while, in the other half, a gradient from moderate to weak was visible. Active erosion bacteria were detected in two of the four samples. The two archaeological planks from the BZN 15 site, also sampled in the BACPOLES project were also fully and severely degraded by bacteria. Active erosion bacteria were detected in both.\textsuperscript{207}

Both the pine and oak samples were degraded. This degradation was already visible on samples left on site for 3 months. The samples were all infested by erosion bacteria, with non-degraded tissue in the wood being rare. Sapwood, if present, was always severely degraded. It also seems that the dimension of the timber is negatively correlated with the degree of degradation, and\textsuperscript{208} this seems to have more influence than the age of the wood. The oak shipwreck (archaeological) timber from the BZN 3 and 15 sites only consisted of sawn heartwood, but in all pieces a gradient in the degree of degradation was still found (severe to moderate). In a comparison with terrestrial sites in the BACPOLES project, with fresh water soil conditions, the sawn timber from the wreck sites showed relatively less degradation, despite their also relatively small dimensions.\textsuperscript{209} A comparison of samples from the BZN 10 wreck with other wrecks that were investigated in the same way during the MoSS project – the Vrouw Maria and Darsser Cog (in brackish to almost fresh water conditions) – also showed less degradation for the Burgzand wreck (saline).\textsuperscript{210} This decrease in the extent of bacterial degradation of wood may be caused by the toxic effects of high concentrations of hydrogen sulphide produced by sulphate-reducing bacteria present in organic-rich marine sediments.\textsuperscript{211}

Apparently, these factors affect the speed of degradation to such an extent that the effect of age (and therefore the exposure time) is minimal. Temperature also seems to be important, the higher it is, the more degradation, because it affects the growth of micro-organisms.

It remains difficult, however, to pinpoint the environmental conditions which optimize the decay of wood by erosion bacteria. They are active in virtually all waterlogged environments. Moreover, the low redox values encountered at these sites are typical for iron Fe-reducing and sometimes for sulphate-reducing environments that are essentially without oxygen. Until now, it was not known whether erosion bacteria have a requirement for oxygen that would be needed for lignin modification.\textsuperscript{212} However, the results indicate that erosion bacteria may be active in essentially oxygen-free environments,\textsuperscript{213} and therefore have to be considered anaerobes. It would seem that erosion bacteria have developed a method for lignin modification that works under anoxic conditions.

In addition, water flux may also be crucial for the spread of erosion bacteria.\textsuperscript{214} This means that the orientation and placement of the structural ship element or object may affect the severity of degradation by erosion bacteria.\textsuperscript{215} This is an interesting hypothesis and, although laboratory tests have been executed in the BACPOLES project, this still needs extensive research with actual field sampling before it can be confirmed.\textsuperscript{216}

If we take a look at the pH conditions of the sites, we see that they generally need to be slightly more alkaline for bacteria (pH 7 to 8) than for fungi. However, there are exceptions. Sulphur oxidizers can even be active and grow in an acid environment with a pH of less than 2.\textsuperscript{217}

Degradation by erosion bacteria, causing mass loss and associated increased water content, makes the wood extremely sensitive to abrasion, scouring, warping, cracking and even disintegration during drying out. If archaeological wood needs to be excavated, it has to be thoroughly protected during and after an excavation to prevent such damage. Excavation and recovery of large degraded wooden objects is difficult because of a massive loss of strength and, although large objects therefore need ample support before they can be lifted, it must be recognized that the supporting material may deform the wood surface locally.

Although bacterial degradation can be severe, it usually does not

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\textsuperscript{205} Nilsson & Björdahl 2008, 6–7, Palma 2004 (2), 23.
\textsuperscript{207} Klaassen et al. 2005, 80–81.
\textsuperscript{208} Nilsson & Björdahl 2008, 6–7, Palma 2004 (2), 23.
\textsuperscript{209} Husman et al. 2008, 42.
\textsuperscript{210} Husman et al. 2008, 42.
\textsuperscript{211} See, for example, the results of the Tensile Testing of buried cotton samples in the MoSS project (Wyeth 2004, 29).
\textsuperscript{212} Blanchette 2000.
\textsuperscript{213} i.e. (O2) < 10–6 M.
\textsuperscript{214} Klaassen 2008, 61–68.
\textsuperscript{215} Suggested in Klaassen (ed.) 2005, 90.
\textsuperscript{216} Klaassen 2008, 61–68.
cause as severe damage to the archaeological wood as fungal or Teredo degradation. While the latter can destroy features and sources of archaeological information, bacteria usually only damage the inner cell structure. Nonetheless, bacteriological degradation may sometimes be the only direct threat to a shipwreck, especially in areas with a lack of oxygen.  

3.5.5 Some conclusions on the biological threats

Biological deterioration of wooden shipwrecks is a continuous process. In aerobic environments, more species are active, while in less aerobic and even anaerobic or anoxic environments, erosion bacteria may still be active. However, the speed of deterioration varies. While deterioration by Teredo navalis is extremely violent and rapid, erosion bacteria work at a much slower pace. Biological attack can be accelerated by mechanical attack, such as erosion of the seabed. Water flux and the amount of organic matter in the sediment also have an influence on the deterioration of wood.

3.6 Chemical threats

As on land, several processes may occur that chemically threaten archaeological sites. On a large scale, climate change may cause pH in water to change.  

changes of current may cause different sediments or types of water to mingle and start reactions, while activities on the site may cause oxygen to react with archaeologically valuable material. Different materials and elements may react with each other. Changes in the environment due to climate change, excavation, bioturbation or more common natural changes in the seabed trigger new reactions that cause a change in the equilibrium, which is often found to a varying extent on historic sites.

Chemical processes can affect the integrity of archaeological objects. One of the most common processes is the corrosion of iron and other metals. In marine environments, this occurs in oxygen-rich environments as well as under anaerobic reducing conditions. When oxygen is present, iron corrodes to form iron oxides. Under reducing conditions, the typical corrosion products are iron mono-sulphides. Iron corrosion products can precipitate in the structure of organic materials – including wood – that are in contact with or in close proximity to the corroding iron. Iron mono-sulphides and di-sulphides such as pyrite are also formed under reducing conditions in sea floor sediments and can precipitate. Iron mono-sulphides and di-sulphides may be oxidized in the presence of oxygen. This can occur when

shipwrecks that were buried under reducing conditions within seabed sediment are exposed to oxygenated water. However, this is also a common occurrence once the organic materials are recovered from a site. These oxidation reactions produce sulphuric acid and a range of intermediate iron-sulphur species. The strong acidification that results, causes a range of degradation reactions in wood, bone and metals. The above-mentioned processes have been identified on several ships, ship fragments and artefacts recovered from the seabed, such as the Vasa, a warship in Sweden, the Mary Rose in England, the Batavia in Western Australia, the BZN 3 and 15 wrecks and the Ventjager wreck and Roompot wreck in the Netherlands.

During the study of degradation patterns, wood from the BZN 3 and 15 sites appeared to contain substantial amounts of pyrite (FeS₂). The chemical wood analyses that are available confirm that high concentrations of iron (Fe: 1.1 – 2.3 %) and sulphur (S: 0.8 – 2.4 %) occur in the wood from BZN 15. Pyrite is formed in reducing environments, where ample reducible iron, sulphate and organic matter are available. The organic matter is used by bacteria to reduce iron to form Fe²⁺ and sulphate to form bisulfide (HS⁻), which subsequently react to form sulphides. The presence of pyrite minerals has been observed under the microscope in many wood samples, but the amount of such minerals formed would be dependent on the supply of sulphate and iron. In fresh water, little sulphate is available, so pyrite will be scarce, whereas, in seawater, sulphate is present in much larger amounts. Iron may be available in the sediment and in wood in proximity to iron objects (e.g. nails, bolts, cannons and anchors), but will be in shorter supply elsewhere inside the wood.

Pyrite may cause degradation in addition to bacterial activity if burial conditions change. It is unstable in oxygenated environments and releases sulphuric acid when it comes into contact with oxygen. The acid produced by this process is detrimental to the wood because of localized low pH (lower than 3) that causes hydrolysis of cellulose. Several ships that have been recovered from the seabed – including the Vasa, the Mary Rose and the Batavia – have suffered severe damage as a result of such processes. There are some indications that wood from the marine shipwrecks in this study may also have become subject to the same damage under oxygenated conditions. Tell-tale orange-brown iron oxide precipitates were observed during microbial culturing of wood samples from the BZN 3 wreck. The presence of pyrite was...
also shown separately in one of these samples. Finally, the presence of holes made by shipworm in the wood of BZN 15 is evidence that it had been in an aerobic environment some time before sampling, and therefore under direct threat of damage by pyrite oxidation.

### 3.6.1 Some conclusions on the chemical threats

Different materials and elements may cause chemical reactions when they are combined. This also occurs in and on the seabed. Changes in the environment trigger new reactions that cause a change in the equilibrium that is often found to a varying extent on historic sites.

The most well-known chemical deterioration process is that of corrosion. This is also active in the Wadden Sea, especially with iron in high-oxygen and saline areas. This is the case for objects surfacing the seabed. In low-oxygen conditions, for example in the sediment, the process of corrosion is much less, but may exist, especially under the influence of biological attack by bacteria. This form of corrosion may cause significant problems when wood is salvaged and needs to be conserved. The results of this process have been noted in large conservation projects such as that of the Vasa and the Mary Rose.

### 3.7 Human threats

Human threats to underwater cultural heritage (UCH) may be considerable. Human activity can either affect underwater cultural heritage directly or indirectly. An obvious and much debated problem is treasure hunting. This is a direct threat to underwater cultural heritage, as are other forms of commercial salvaging and even opportunistic souvenir hunting by recreational divers. However, while such activities are a severe threat regarding perceptions and opinions of underwater cultural heritage and its preservation in situ, they probably only pose a small direct threat to UCH in general, especially when compared to the multiple other human-induced threats. Other human interventions may very well have much larger effects, sometimes direct, sometimes indirect. One only need consider the debates on the effects of trawling on underwater cultural heritage.

It will be impossible to discuss all forms of human activity that directly or indirectly, immediately or eventually threaten our underwater cultural heritage. Below, I will discuss some examples in relation to the Western Wadden Sea area:

1. Looting, commercial salvaging and souvenir hunting
2. Fishing
3. Dredging and development works
4. Archaeology
5. Perception of significance

### 3.7.1 Looting, commercial salvaging and souvenir hunting

The primary aim of commercial salvaging is to make money and not to learn more about the past. It is as simple as it is logical, otherwise it would not be commercial salvaging. This fundamental difference leads to – among other issues – different selection criteria and different working methods and techniques, aiming to make profits for a few and not for the benefit of all. Treasure hunting has the aim to – as the name suggests – find valuable treasure. It is usually triggered by the assumed economic value of the archaeological finds. In relation to shipwrecks, these treasures are often associated with precious metals and stones. This hunt for objects of economic value usually leads to commercial salvaging, which has often attracted much attention from the media and thereby sent a different message to the public than that preferred by cultural heritage managers.

However, it is not always easy to make an immediate distinction between treasure hunting, looting and souvenir hunting. They represent a sliding scale. An obvious and clear example of large-scale commercial salvaging on a historic shipwreck in the Netherlands is the HMS Lutine (1799). The various activities concerning the salvage of wreck materials have a 200 year history, beginning right after the disaster. This case, therefore, is interesting in the sense that, over the years, salvaging on a site changes from the removal of contemporary objects to compensate the owners of the ship, or for reuse, to commercial salvaging related to cultural heritage and that which aims to salvage a wreck’s scrap or economic value.

The salvage of still useful materials has a long tradition. In the Wadden Sea, examples of contemporary salvaging have been archaeologically identified on the Scheurrak SO1 wreck (end of the sixteenth century) and the Buytsenorg (1753) (Fig. 3.40). Important archaeological finds, such as the Vasa (1628),

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226 Fors 2005.
227 Huismann 2005, 199.
228 Grenier et al. 2006, x–xi. The UNESCO Convention for the Protection of the Underwater Cultural Heritage (Paris, 2001), for example, is still very much focused on the fight against treasure hunting.
232 The only part of the portside of the ship that has survived was investigated, removed and conserved. It shows clear axe marks on the frames. The portside was that part of the ship still surfacing the low water mark and must have been cut away to provide access to the ship. Manders 2003 (2), 326.
233 Braven et al. 2003, 53.
The information is often untrustworthy because there are different incentives. Money making is the biggest driver, not curiosity. Time is money and the story is a selling point. Objects may illustrate what we already know or they may be deliberately or even unintentionally connected to a wreck because the story has to be enhanced or a shipwreck needs to be identified.

The Kerwood sank in 1919 after it hit a mine. Its copper and lead value and the profits made by salvaging them marked the founding of the salvaging company, Friendship BV, from Terschelling. (http://wrakkenmuseum.nl/kerwood, accessed 29-01-2017). The HMS Aboukir, HMS Cressy and HMS Hogue sank in 1914 after being torpedoed by a German submarine. More than 1400 lost their lives. The wrecks have been salvaged for scrap metal (http://www.worldwar1.co.uk/cressy.htm, accessed 29-01-2017).

Some sites are salvaged purely for their material value. The difference from the above is that here – for the actors involved – the story of the ship is never important and sometimes it is found to be better to remain silent about where the material comes from. Dutch examples of scrap metal salvaging are the Kerwood (1919) and the three British warships, the HMS Aboukir, HMS Cressy and HMS Hogue (1914). In the Wadden Sea, bricks, were salvaged for cannons immediately after sinking. The HMS Lutine had a cargo of gold on board for the Hamburg stock exchange when it sank between Terschelling and Vlieland in 1799, and since then mystery has surrounded the wreckage and its cargo. The first official salvage attempt occurred as early as January 1800 and unofficially, there may have been many more attempts. There are stories of fishermen who attempted to find the gold from the Lutine and there are some indications that these attempts may have been successful one night in October 1799, but this cannot be confirmed. In recent years, research has been conducted on site to gain an understanding of what really happened during that night in October 1799. New plans are being developed.

Commercial salvaging is directed towards making money. The shipwrecks are a resource, a mine exploited to make that money (Fig. 3.41). However, historical and archaeological research may play a role in the process of commercial salvaging, by locating the site of investigation, or by confirming or enhancing stories about a site and in so doing raising the market value of the objects concerned. People are usually more prone to pay higher prices for objects with a context or story. Therefore contextualizing a site may be well important in the commercial exploitation of a site. Although money can be made through the commercial salvaging of shipwrecks, this revenue model is – especially with respect to cultural heritage sites – very doubtful and often fails.

The most significant problem with commercial salvaging may not be the direct disturbance of any particular archaeological site, but how it affects the way people look at – especially – shipwrecks, with a focus on commercial value, which may eventually have an effect on the public perception of the entire underwater resource. This may be much more problematic than any one site being destroyed. Working on wrecks, telling their stories and removing great artefacts does appeal to the general public. However, the real context of the artefacts is often forgotten and the story lacks any scientific basis, with the information or knowledge gained minimal and/or untrustworthy.
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leather and tropical hardwood are also known to have been salvaged on a smaller scale, all for reuse. It can be safely assumed that objects have been removed from all shipwrecks discovered in the Wadden Sea. It is not always bad intentions that initiated such activity. Some of the wrecks are perceived to have been ‘saved’ from being washed away by currents, after having been exposed by the ongoing erosion of the seabed. Other objects have been dug out, with severe damage to the site as a consequence. Some of these objects find their way to auction houses or websites; others will end up in someone’s garage or on their mantelpiece. The looting or souvenir hunting can be so extreme that entire sites are plundered, or at least damaged in such a way that their value can be compromised to a large extent. Objects taken from wreck sites are often removed without considering the context. The loss of context means an object also loses much of its value. Taking objects from wrecks is not merely something done for financial reasons or to have a souvenir to remember the past. It also concerns the issue of ownership of a site or may at least be an expression of or deliberate evidence that a diver has been there. This territoriality can occur on a private or group level. This intrinsic claim of ownership has a long tradition along the Dutch Wadden Sea coast and may explain the hesitance of people from the Dutch Wadden Islands to report their finds or involve the national government in shipwreck management in the Wadden Sea. Undermining the in-situ protection of shipwrecks such as the BZN 3 may thus be seen as a local response to activities undertaken by the central authorities; in other words, a warning not to interfere with their history and past, which is claimed to be the exclusive right of the inhabitants themselves.

Before the 2007 Monuments Law was implemented, much heritage management was indeed organized centrally. Today, municipalities are at the forefront of organizing the management of their cultural heritage. This means that there is a logical basis for this behaviour. Cultural heritage management can be decentralized and municipalities can prioritize what they protect.

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and what not. 259 Nevertheless, people are still required to report their finds 259 and intrusive activities are prohibited without an excavation permit. 257 Until the new Heritage act was implemented in July 2016, it proved very difficult to effectively enforce the law. One of the main issues was that those appealing to the law have to prove that intrusive activities have occurred on a shipwreck. The seabed is very dynamic and although excavating objects without a permit was made illegal it was not prohibited to remove finds from the seabed surface. Illegal excavation could only be proven if it was visually observed. 218 This has changed in the new Heritage act, which came into force on 1 July 2016. 255 It is now sufficient to prove that the sites are being disturbed. The removal of objects from a site is also considered to be an act of disturbance, as is cutting the protection nets. Will this simple change of wording in the new law be sufficient to preserve and disturb, as is cutting the protection nets. Will this simple change of wording in the new law be sufficient to prove that the sites are being disturbed. The new Heritage act, which came into force on 1 July 2016. See also, 261

3.7.2 Farming and fishing

Tension may arise between the use of the sea for farming and fishing and cultural heritage. The Wadden Sea has long been used as a source of food. Fish and shells are important resources. In earlier times, until the early twentieth century, seagrass (Zostera marina and noltii) grew in large fields on the seabed and was harvested for mattresses and dikes. 265 This seagrass disappeared in the Dutch Wadden Sea 262 due to disease 263 and the closing of the Afsluitdijk in 1932. Today, replanting of the species is being tested. 264 In addition to its attractiveness for sea life and water clarity, seagrass may also make the seabed less susceptible to erosion, just as the artificial seagrass on the BZN 10 site does at the moment. 265

The most important commercial shells in the Wadden Sea are the common cockle (Cerastoderma edule) and the mussel (Mytilus edulis). The mechanical fishery of common cockle in the Wadden Sea area has been fiercely debated, resulting in this form of fishery being prohibited in 2005. 266 The method of fishing was very intrusive on the top layer of the seabed and although its negative effect on the population of cockles was disputed, the method had a negative effect on the cultural heritage in the seabed. 267

The Wadden Sea is also an important area for mussels. Of all the mussels traded at the Dutch fish auction centres, 50% come from the Wadden Sea. 268 In addition, an enormous number of mussel seeds are harvested, caught and bred. The mussel fields stabilize the seabed and form a kind of natural protection against erosion of the seabed. 269 However, harvesting the mussels and mussel seeds from the seabed is harmful to the upper layer. 270 Again, this may also threaten those wrecks that are surfacing the seabed. Mussel seed capture installations (MZI) have now been designed to catch seed mussels from the water. This should be less intrusive than fishing for them from the seabed. However, MZIs may have other negative effects on the wrecks or other cultural heritage that might possibly be present in the seabed.

There are at least two ways to construct MZIs. There are floating models that are secured in place with anchors or concrete blocks on the seabed, and fixed MZIs, which are attached to poles that are driven into the seabed. The latter is most intrusive and poses a real threat to cultural heritage in the sediment. 271 For a few years, the floating version was preferred by the Cultural Heritage Agency of the Netherlands (RCE), which gave approval to operate in such a way. Unfortunately, however, in the dynamic Wadden Sea, the anchors proved not to be strong enough, and in 2014, the mussel seed farmers decided to use the fixed method (Fig. 3.42). 272 In addition to the intrusive driving of the poles into the seabed, the question of whether the fixed method also has a negative effect on erosion-sedimentation patterns on the seabed is still the subject of research. Monitoring of the areas

255 With the new Heritage act that came into force in 2016, the roles of municipalities have become even greater.
258 See, for example, the case of the Kursk, mentioned above.
262 Bos & Katwijk 2005, 18, 21.
263 See Bos & Katwijk 2005.
265 For artificial seagrass on BZN 10, see Section 3.3.
268 http://www.waddenzee.nl/Mosselvisserij.1913.0.html (accessed 2-7-2015)
269 This may also have a positive effect on the growth of natural seagrass in the Wadden Sea.
272 This has not been approved by the RCE. At the time of writing, the discussion between the RCE and the Ministry of I&M is ongoing.
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Among which, some of the most stable places, see http://www.rli.nl/publicaties/2007/advies/natuurlijk-vissen-op-de-waddenzee (accessed 29-01-2017).


In the early 2000s, the fish auction (visafslag) in Wieringen notified the RCE that a frame of an old shipwreck with a label from the AAO (Afdeling Archeologie Onderwater, the department of underwater archaeology of the Ministry of WVC, the predecessor of the RCE) was brought in by one of the trawlers. It turned out to be the BZN 10 site.

Another risk related to the use of MZIs that should be further investigated is growth in the amount of organic carbon (C) on the seabed after installation of large MZIs. This may cause more bacteriological attacks on the wooden shipwreck structures in the sediment.

A possible synergy between underwater cultural heritage and mussel cultivation has been proposed, with the idea of using in-situ preserved shipwrecks as places to install these MZIs.

In the Western Wadden Sea, several types of fishing occur. Most forms of fishery are prohibited on the tidal flats, but in other areas, which are often subject to seabed erosion and which include wrecks that are surfacing the seabed, trawling for shrimp or flatfish continues.

The trawling nets disturb the seabed directly and may become entangled in the wooden constructions of wrecks, with consequent damage to these sites. In-situ protection by covering a site with polypropylene nets mitigates against threats by trawling, as they transform the site into a sloping artificial reef which the nets pass over (see Chapter 5.2.3). New bottom-trawling methods have also decreased the impact of such nets on the seabed (Fig. 3.43). On a worldwide scale, deep sea trawling is considered to be one of the most damaging human activities with respect to underwater cultural heritage.

### 3.7.3 Dredging and development works

It is clear that although the Western Wadden Sea is part of a UNESCO World Heritage site, the system is under considerable pressure from human use and exploitation. This also has an impact on sediment dynamics. These anthropogenic pressures and influences include many different activities, such as the above-mentioned salvaging, farming and fishing (Fig. 3.44 A B C). There is also still considerable dredging occurring to maintain the waterways. These areas, however, are usually already disturbed to a certain depth and as long as those maximum depths and areas are recognized, there seems to be not much risk of additional disturbance to existing cultural heritage sites. However, harbours must be accessible to ships whose sizes are ever-increasing. This increases the pressure to dredge deeper channels, with consequences for hidden cultural heritage resources. Moreover, the introduction of larger ships may lead to the disturbance of the seabed and the introduction of more oxygen into the water locally, due to propeller movement.

As we know, the closure of the former Zuiderzee by the Afsluitdijk in 1932 and also the Lauwerszee in 1968, changed the dynamics of the Wadden Sea; for example, the tidal amplitude and fine sediment dynamics were affected. The system is still finding a new equilibrium, with substantial morphological changes as a result.

A similar kind of effect has occurred due to the fixing of
3.7.4 Archaeology

Archaeologists may also pose a threat to the underwater cultural heritage, especially when research is executed incorrectly, which may result in the immediate physical deterioration of the site. A direct and obvious effect is the careless movement of divers in and around a wreck. This may result in damage to or the uncovering of artefacts, but also the breaking off of structural elements of the shipwreck. The chances of something such as this occurring are particularly great when such elements are also weakened due to biological, other mechanical or chemical deterioration. However, the uncovering of a site for investigation may also be the cause of further erosion, due to the changing of local eddy currents and the scouring of, or attack by, degrading animals such as shipworm. The effects can also be negative in the longer term. Firstly, oxygen will be introduced to elements that were previously covered and bioturbation may have an effect on those layers that have been sufficiently covered before.

Secondly, poor re-burial of the site with sediment may result in the deterioration of areas that have been stable for centuries.

Another large threat that archaeologists may pose is excavating without any prior plan or research question. Requirements for responsible intrusive research have been listed in the ICOMOS charter on the protection and management of the Underwater Cultural Heritage (Sofia 1996) and the UNESCO Convention on the Protection of the Underwater Cultural Heritage (Paris 2001).

Without clear and well-founded research questions, we will not know if the excavation of a particular site is of value, and the project will certainly lack direction. Archaeology would be reduced to Lustgrabung, keeping us busy, without learning from this material source.

3.7.5 Perceptions threatening underwater cultural heritage

As the name suggests, underwater cultural heritage lies hidden under water. Out of sight may be out of mind. The Wadden Sea is not a popular sports diving place. Low visibility under water, tidal flow and better alternatives nearby (e.g. the North Sea) are three important reasons why this is the case. At present, it still remains difficult to visualize underwater shipwrecks and make them accessible to the non-diving public (See Chapter 7). Visual contact, therefore, almost exclusively remains possible by a site visit. This also directly reflects on the way local governments take up their responsibility for underwater cultural heritage management. At present, very few municipalities have included their underwater territory in heritage policy maps. This may pose a threat, since this heritage may not be taken into account in development planning.

Decentralization of cultural heritage management has the advantage that municipalities become more aware of their responsibilities for managing the whole spectrum of cultural heritage, including the underwater element, but the high costs may become an issue. Archaeological management, in general, is seen as a high financial risk, where the cost factor is of more importance than the knowledge that can be gained. In addition, although positive in the sense of more awareness and involve-

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Footnotes:
283 This process of degradation was noted at the shipwreck site of the Ranger in Port Royal (Jamaica) during the UNESCO foundation course on underwater cultural heritage, which was held in 2012 (http://www.unesco.org/new/en/culture/themes/underwater-cultural-heritage/education/capacity-building/, accessed 29-01-2017), and on the OVM 8 shipwreck in Lake Oostvoorne in the Netherlands in 2014.
284 Questions need to be answered using specific methods.
285 Lustgrabung is the German word for undertaking an excavation without any focus, in the hope of finding something special.
287 Decentralization of cultural heritage management has the advantage that municipalities become more aware of their responsibilities for managing the whole spectrum of cultural heritage, including the underwater element, but the high costs may become an issue. Archaeological management, in general, is seen as a high financial risk, where the cost factor is of more importance than the knowledge that can be gained.
288 Although big steps are being taken using new technologies for mapping the
ment, decentralization also means more power to local stakeholders with different views on how to treat cultural heritage. This requires a different role for state services and their archaeologists. They will need to change their role from being the decision-makers to becoming providers of guidance in the process of significance assessment and selection of sites.

One important aspect to overcome is the biased view on in-situ preservation. While official institutes, backed up by official laws and policies, ‘preach’ in-situ preservation as the first option, the public wants to see and feel its past. Although there is something to say for both points of view, and both can also coexist, government budgets and activities are not always in line with responsible in-situ preservation policy. For industrial parties, contractors, entrepreneurs and many municipalities, archaeology has therefore primarily become an expense issue and restrictor of development.

3.7.6 Some conclusions on human threats

The human or anthropogenic threat is potentially great. Some of the threats are direct and obvious, and their impact can easily be understood and measured. However, human activities and interventions may also affect underwater cultural heritage many years, decades or even centuries after the fact. The Wadden Sea is one of the most diked seas in the world. In addition to the building of the Afsluitdijk, this general use of dikes has led to a change in erosion—sedimentation patterns and thus the mechanical deterioration of underwater cultural heritage over a long period of time. Salvaging, farming, fishing and dredging have all had a direct effect by disturbing the seabed, as well as an effect over the long run, by causing a change in scour or erosion patterns around shipwrecks and other features. Even archaeologists may cause unintended damage due to improper handling or due to no or poor treatment of the site after exploration. Unfortunately, due to the delay in effects, it is often difficult to hold the original disturber accountable (financially or otherwise) for the degradation of underwater cultural heritage. Finally, the lack of interest in underwater cultural heritage may also lead to neglect of the resource.

3.8 General conclusions on threats

There are many processes that threaten underwater cultural heritage. Any change in the environment is generally not good, as underwater cultural heritage thrives better under stable conditions. Cultural heritage managers study ‘change over time’ and attempt to avoid or mitigate against it. The threats can generally be divided into mechanical, biological, chemical and human grounds of deterioration. All these processes are interlinked and may enhance individual effects. Erosion, especially, is a big threat in the Wadden Sea. This process is a catalyst for biological and human activities on site. The greatest biological threat is shipworm (Teredo navalis). In effect, it can destroy wood that surfaces the seabed within one year. If the site becomes anaerobic, only erosion bacteria remain active. This is an ongoing but slow process of deterioration. Treasure and souvenir hunting pose obvious threats to underwater cultural heritage; however, the use of the seabed for farming and fishing may well pose the biggest threat.

It is important to better understand the different processes of deterioration, both on site and on a larger scale, in order to find ways to mitigate against threats using the best in-situ preservation methods. Some threats may be easily identified because they have a direct and obvious effect. However, some may result in the gradual damage to the underwater cultural heritage over decades or even hundreds of years. These effects have to be taken into consideration when protecting a site in situ. One example is climate change but, on a smaller scale, there may be numerous effects of a newly built bridge, a wind farm, a dike or sand extraction on current patterns and gullies on the seabed, which may result in the erosion of newly exposed sites.

It is impossible to hold the builders of the Afsluitdijk (1932) responsible for the damage this construction causes to historic shipwrecks in the Wadden Sea, even if this is at least partly true. However, on the basis of a more sound understanding of the processes and their long-term effects, heritage management decisions may be better made. People’s perceptions are also important when aiming to better preserve underwater cultural heritage. One enormous disadvantage for underwater cultural heritage is the fact that it is generally not visible, or barely so, especially in the Wadden Sea. It is not always easy to see the advantages of having such a rich resource that can tell us about our past within one’s territorial boundaries.

While the implementation of the Treaty of Valletta has led to a growth in archaeological activities, the system leans heavily (if not completely) on the ‘disturber pays’ principle. Determining who is responsible for destroying an underwater archaeological site is not always simple, while the damage may also be due to effects continuing for decades or even centuries. Those responsible for overall management do not have the financial resources to pay for activities to preserve in situ or ex situ: all in all this means we face a complex situation of a heritage under threat. However, it

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292 Manders 2015 (2).
293 Manders 2015 (2).
294 Willems 2012, 4–5.
295 At present, there is no permanent budget available for in-situ protection and monitoring by the Cultural Heritage Agency of the Netherlands.
may be worthwhile to make the effort to continue to embrace the principle of in-situ preservation as an important part of underwater cultural heritage management. (See also Fig 1.8). It will not be easy, but as I will argue in the coming chapters, there are many reasons to at least try.