Damaging Doggerland? The impact of offshore industrial activities on the submerged prehistoric landscapes of the Dutch North Sea.

Jong, Barteld de

Damaging Doggerland?

The impact of offshore industrial activities on the submerged prehistoric landscapes of the Dutch North Sea

Commissioned cover Illustration created by Abi Pate (including illustration p.4)

(abipate.com)

s1391410@vuw.leidenuniv.nl

Hildebrandpad 263, 2333 DG Leiden, The Netherlands

+31636068994

Damaging Doggerland?

The impact of offshore industrial activities on the submerged prehistoric landscapes of the Dutch North Sea

Barteld Anthonius de Jong (s1391410)

MA thesis (1084VTHMY)

Dr. M.R. Manders

Heritage and Museum Studies

Leiden University, Faculty of Archaeology

December 15th 2021

Final version

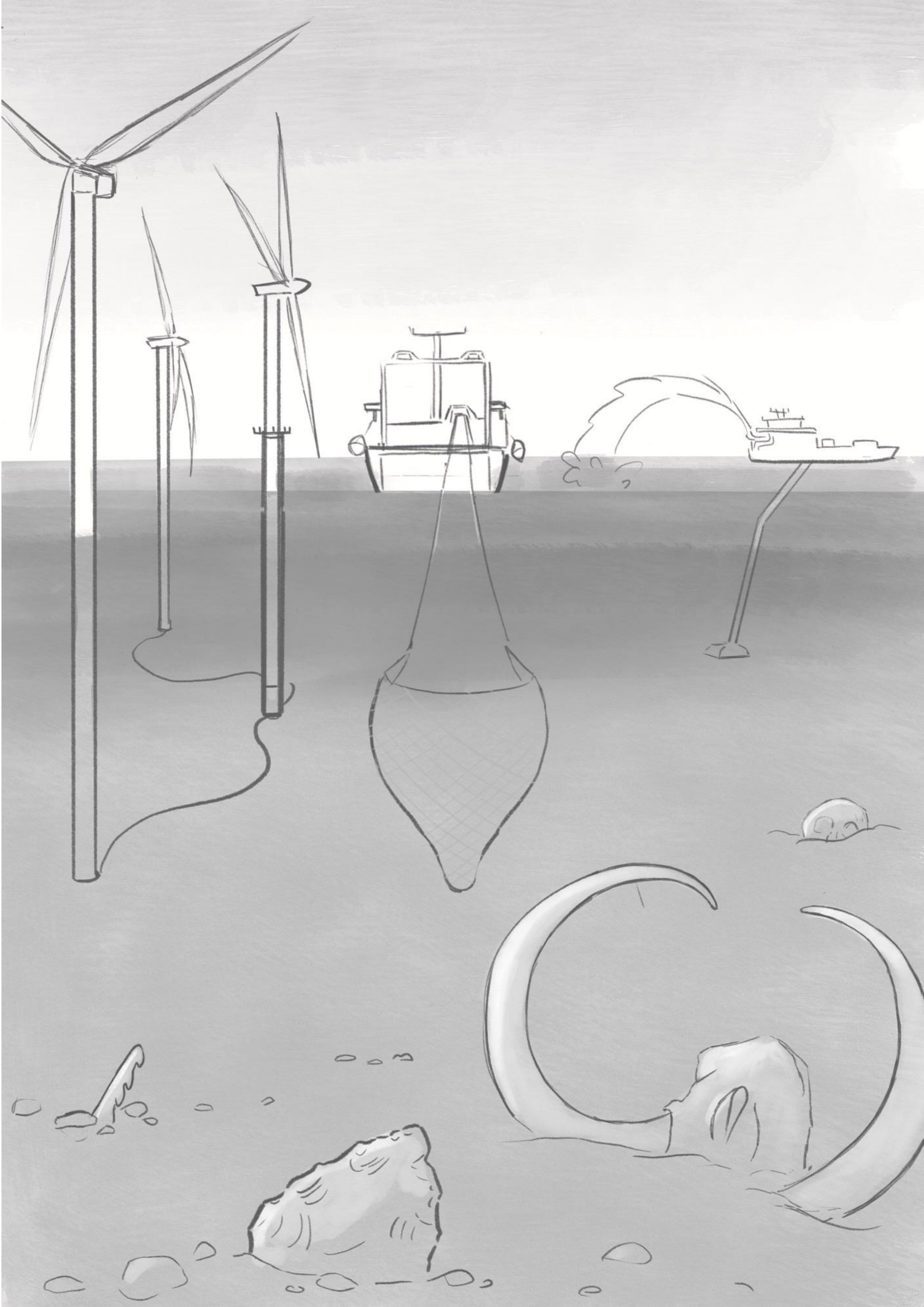


Table of Contents

Figure 1.1 – Part of a swine lower jaw I encountered walking along the beach of Noordwijk (photographed myself).

I. Introduction

Throughout the years of walking along the beach of my hometown Noordwijk I obtained a small collection of fossilised bone fragments found along the shorelines of the beach (fig. 1.1). Going to museums such as the Naturalis Biodiversity Center and speaking to people of the local natural society I learned that these bones once belonged to terrestrial mammals that used to live in the now-submerged landscapes of the North Sea. Besides the joy of being able to find fossils dating back to several thousands of years ago, the remains made me wonder what the North Sea area used to look like in prehistoric times.

Fortunately, many other people before me asked themselves the same question, which resulted in a large collection of geological, palaeontological and archaeological data gathered from the end of the 20th century to the beginning of the 21st century, obtained through several research initiatives, including the North Sea Palaeolandscape Project and SPLASHCOS (Submerged Prehistoric Archaeology and Landscapes of the Continental Shelf)(Gaffney *et al.* 2007; Bailey *et al.* 2020). The interpretation of geophysical and geotechnical data (Appendix A-B) in combination with the analysis of Holocene sea level curves led to the reconstruction of landscapes corresponding to various prehistoric periods. The reconstructed environments that date to the end of the last ice age portray the area between Great Britain and the Netherlands as a rich lowland that offered attractive environments for a variety of animals, plant species and hominin populations alike (fig. 1.2)(Cohen *et al.* 2017, 147). Nowadays this prehistoric landscape is referred to as 'Doggerland', which was introduced by Coles, who deducted it from the Doggerbank, the largest sandbank in the North Sea (Coles 2000, 393). However, after the last ice age, Doggerland was gradually lost due to progressive sea level rise, and about 8000 years ago, all of the remaining islands were flooded by the North sea, which transformed Doggerland into a prehistoric Atlantis (Bailey *et al.* 2020, 2).

Today, fragments of Doggerland can still be encountered on beaches and in fishing nets. Finds of (fossil) bone, antler, and lithic artefacts, along with my small collection, add up to an enormous amount of resurfaced prehistoric material. Taking into account the number of prehistoric remains and the vast extent of the submerged Doggerland, one can only assume that traces of its landscapes are still hidden beneath the waves. The southern North Sea is, therefore, regarded as the largest and one of the most important prehistoric research areas in the world (Roebroeks 2014, 44). While recent research develops our understanding of Doggerland, additional questions are formulated simultaneously. For me, one of these questions formed when I picked up one of the fossils on the beach. After all, why did the fossil end up in my hand, instead of being buried beneath meters of seabed sediments?

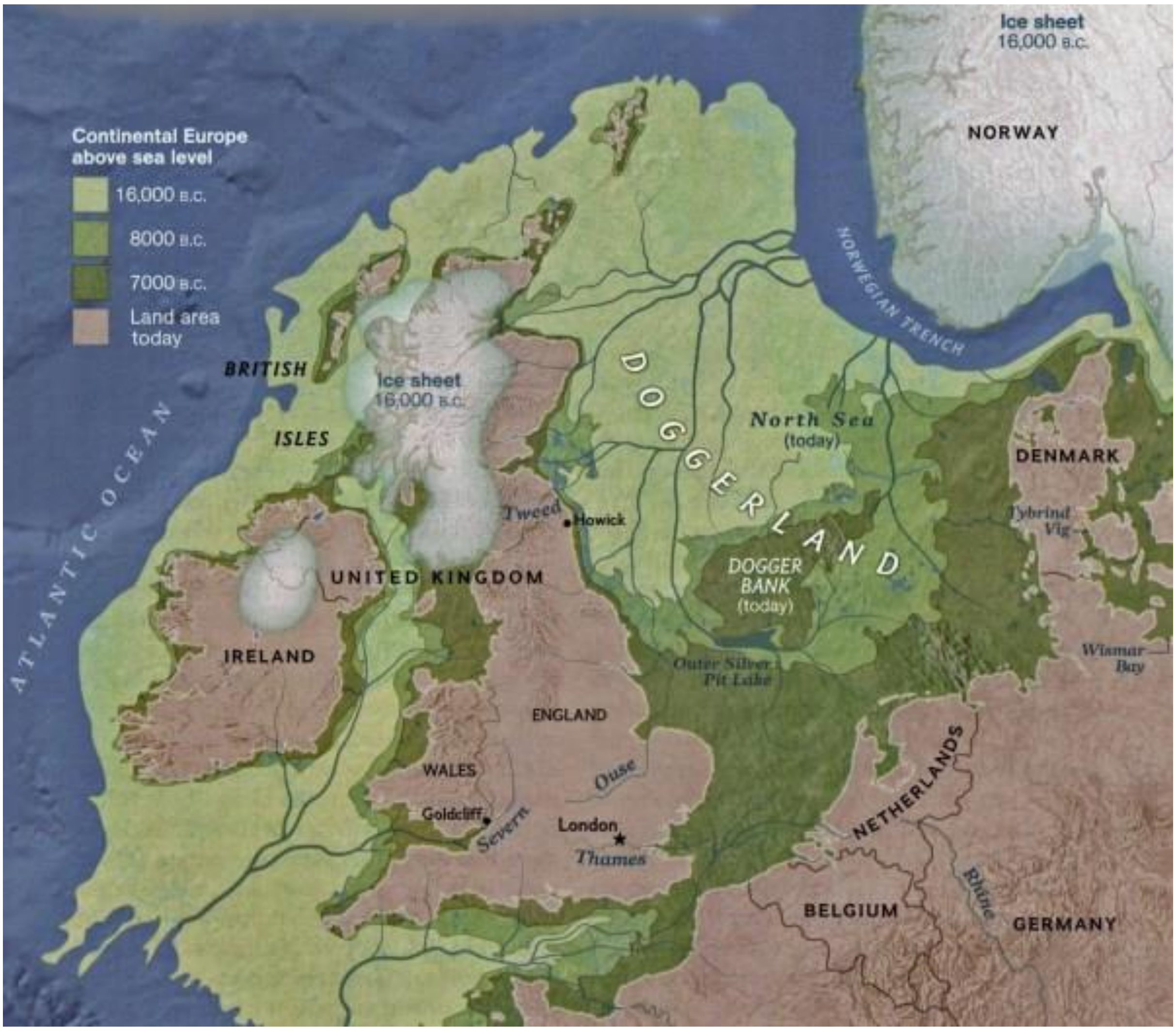


Figure 1.2 - The contours of Doggerland at the end of the Pleistocene (light green) and early Holocene (darker greens)(nationalgeographic.org).

Even though the exact origin of the fossil cannot be traced, it is generally assumed that these finds derive from submerged prehistoric deposits located further offshore (Peeters *et al.* 2019, 16). In the case of my beach finds, the fact that prehistoric fossil and lithic remains end up on Dutch beaches is most likely related to the process of sand extraction and the subsequent distribution of the material for beach nourishments or large-scale land reclamation projects (*e.g. Maasvlakte I & II*). This practice has been going on for half a century and resulted in large numbers of fossil fragments and occasional prehistoric artefacts being encountered on the supplemented and artificial beaches of the Netherlands (Peeters *et al.* 2019, 16). Unfortunately, such offshore activities also form a significant threat to the preserved prehistoric landscapes buried beneath the seabed: The large number of encountered prehistoric remains is only a fraction of the number of prehistoric objects displaced from their buried context, or even destroyed by the heavy equipment of the sand extraction industry. However, the sand extraction industry is not the only offshore industry that affects submerged prehistoric deposits. Other offshore industries that frequently damage seabed sediments include commercial fishing activities, and renewable energy developments, such as the construction of offshore wind farms (Ward 2014, 213). While some of their impacts on the submerged prehistoric deposits are visible through the encounters of prehistoric remains on supplemented beaches and in fishing nets, other impacts are invisible, as the effects of the disturbance remain below the waters of the North Sea.

Problem statement and research question

Taking these considerations into account, it can be concluded that size and type of physical impact of the seabed disturbance vary considerably. Hence there is a need for frequent assessment of the impacts of offshore activities on the submerged prehistoric deposits within the Dutch seabed. However, this need is poorly reflected in actual research as only few researchers (Ward 2014; Pater 2020; Maarleveld 2020) have attempted to tackle the issue. As a consequence, the risk for marine ecosystems is much more embedded in the minds of offshore developers than the risk for submerged prehistoric landscapes. This is evident in the Environmental Impact Assessments (EIAs), where a lot of marine ecosystems factors are weighed against offshore design alternatives, but only few words are written about the effects for prehistoric remains (Van de Bilt *et al.* 2016). Besides that, the Dutch North Sea houses three Natura 2000 reserves that protect fragile marine biotopes from excessive fishing, mining and other offshore developments, such as the construction of wind farms (rwsnatura2000.nl). Yet, no such reserves exist for the protection of submerged prehistoric deposits. Exactly this lack of interest in prehistoric remains motivates me to do research on the impact of offshore industrial activities on submerged prehistoric deposits, develop my knowledge about threats to submerged prehistoric remains and acquire means to tackle the problem professionally in the coming years. Consequently, the research question of this thesis is:

In what way do offshore industrial activities affect the submerged prehistoric deposits present within the Dutch seabed?

Research Framework

Looking into the main research question requires the explanation of certain terms used in this question, namely ‘offshore industrial activities’, ‘submerged prehistoric deposits’ and ‘the Dutch seabed. To start, the offshore industrial activities mentioned here represent the current industrial activities that take place at sea and in a way affect the seabed. These activities include fishing, oil and gas exploration, sand and aggregate extraction, dredging of shipping lanes, construction of port facilities, and offshore renewable energy (wind farms, tidal and wave energy)(Bailey *et al.* 2020, 197). To research all of the offshore industrial activities would be taking several years and therefore would

Figure 1.3 - Maritime zones in the Dutch part of the North Sea. The study area includes the Territorial Sea, the Contiguous Zone and the Exclusive Economic Zone (english.defensie.nl).

not be feasible for a master's thesis. This is why I selected three offshore activities, each of which will be analysed thoroughly. The reason why I chose each of the three offshore industries will be given at the start of chapter four. Moving on, the submerged prehistoric deposits define as an unknown extent of geological layers within the seabed that contain prehistoric remains, such as (fossil) bones, lithics, hominin remains and organic material. Besides that, it should be noted that 'prehistoric' here entails a chronology between the last million years to approximately eight thousand years ago. This large period has been selected, because the earliest remains encountered within the North Sea basin date to about a million years ago and the end of this period indicates the time when the North Sea approached its modern extent. However, the sea level then should not be taken as a fixed boundary, since the Dutch coast remained very dynamic until the end of the Middle ages. Yet, the end of the Mesolithic is primarily selected because few Neolithic remains have been encountered thus far, assuming that these remains have either been destroyed by coastal erosion or buried beneath tens of meters of Holocene sands (Bicket and Tizzard 2015, 645). The study area is defined as the Dutch seabed and therefore includes the area from the Dutch North Sea shore to the Dutch Exclusive Economic Zone (EEZ)(fig. 1.3). The reason why I stuck with this study area is because again the entire North Sea basin would be too large to study in detail. Besides that, this study area allowed me to research both Dutch and English sources as this part of the North Sea has been studied a lot from an archaeological and geological perspective, as well as an industrial perspective. Moreover, these sources were generally readily available and most did not need special permission.

Sub-questions and Chapter guide

To answer the research question, I should first ask: *What did Doggerland look like and how did it develop throughout prehistory?* The following chapter will therefore delve into the geomorphology and prehistoric archaeology of the North Sea basin. Besides that, it is important to assess the current potential of the submerged prehistoric landscapes. After all, what remains? *Which natural processes influence the survival of submerged prehistoric remains? And what submerged prehistoric deposits have been preserved?* The third chapter, therefore, focuses on the taphonomic processes that previously affected and still affect the preservation of the prehistoric deposits situated within the seabed. Nowadays, the submerged prehistoric remains are not only affected by natural processes, but by modern-day human actions too. The fourth chapter, therefore, asks: *What kind of offshore industrial activities are capable of affecting submerged prehistoric remains? And which submerged prehistoric deposits are likely to be affected?* The chapter will assess the impacts of the offshore industrial activities on the seabed sediments and the preserved prehistoric remains within. Ultimately, as the focus in the coming decades will be on expanding the coastal replenishment activities and offshore wind generation, predictions concerning offshore developments will be made in the fifth and final chapter. Most importantly, *what kind of impact could these future developments have on the submerged prehistoric deposits within the Dutch seabed?* And *are we able to protect these remains?*

Data research

In order to answer these sub-questions I used a variety of literary and other sources. Before I started writing these sources consisted of overview works, such as 'The Archaeology of Europe's Drowned Landscapes' (Bailey *et al.* 2020) and 'North Sea Prehistory Research and Management Framework 2009/2019' (Peeters *et al.* 2009; Peeters *et al.* 2019). This way I made acquaintance with the subject of submerged prehistory, of which I previously knew a little. During this stage I was helped by a couple of experts in the field. A. Stolk is advisor for sand extraction at Rijkswaterstaat, the executive agency of the Ministry of Infrastructure and Watermanagement. Together with, Dr. B. Smit, senior researcher early Prehistory (Holocene) at the Cultural Heritage Agency of the Netherlands, they answered my many questions during e-mail contact and calls. The geological and geomorphological background studies consisted of scientific journal papers and chapters in edited volumes as well as a ground-breaking subsidised report that predicted the archaeological prehistoric potential of the Dutch North Sea (Vonhögen-Peeters *et al.* 2016). For the following chapters I studied government websites (e.g. noordzeeloket.nl), analysed archaeological reports, and included national and international treaties and legislation.

Research method

I used the large number of sources to construct a qualitative research. This kind of research consists of a sequence of components: first and foremost a theoretical background. In this thesis the second and third chapter contain this theoretical background, where I explain the geological history of the North Sea basin, introduce the prehistoric artefacts that exemplify Doggerland's human past, explain why these finds have survived until today and show which North Sea deposits likely still contain similar prehistoric remains. The following fourth chapter introduces three offshore industrial activities that each affects the seabed in a way that it threatens the state of the prehistoric deposits. I used three case studies to showcase the effects of these industries on the submerged prehistoric remains, which develops into the analysis and results of my research. Throughout my archaeological studies I learned that case studies are the most effective way to conceptualise and remember certain information, thereby effectively keeping the threat to the prehistoric deposits in the mind of the reader. The fifth and final chapter primarily contains the proposed future developments of these offshore industrial activities and is followed by predicting the coming threats to the submerged prehistoric remains. These predictions ultimately develop into a discussion on the alternatives. Through this thesis I aim to provide a topical perspective on the offshore activities that affect the prehistoric deposits within the Dutch seabed and provide an insight to the future threats to submerged Doggerland.

Figure 2.1 – Landscape reconstruction of the Mesolithic occupation (around 8750 BP) of the current Yangtzehaven at the Maasvlakte 2 (Peeters *et al.* 2014, 288).

II. The land beneath the waves

The geomorphology and archaeology of the North Sea Basin

When doing research on prehistoric societies in Western Europe, researchers often only include the material remains that have been retrieved from the most recent 'dry' landscape, a landscape they are familiar with, one that didn't change drastically for the last couple of generations. However, a large area that contains abundant fossil and artefact-bearing deposits; The North Sea Basin, is often overlooked (Cohen *et al.* 2017, 153). Ironically, this area, one that we've always associated with water, has for most part of the last million years been dry land (Roebroeks 2014, 44). To get an idea of prehistoric life in Western Europe it is therefore of vital importance to take the North Sea basin into account, as Doggerland, the now submerged part of the North Sea Basin, knew a variety of landscapes that changed over time (Hijma *et al.* 2012, 31).

In the last million years, multiple hominin species including *Homo heidelbergensis*, *Homo neanderthalensis*, *Homo sapiens* and possibly *Homo antecessor* started to colonize the north-western part of Europe (Roebroeks 2014, 45). Despite millennia of erosion, several geological deposits still contain large quantities of well-preserved archaeological and palaeontological remains dating to the time of hominin occupation (Cohen *et al.* 2017, 148). In recent decades, bits and pieces of this record have been encountered in fishing nets, dredged up, or found on sand supplemented beaches in recent decades. The archaeological analysis of these finds sheds some light on what prehistoric life in Doggerland might have been like, but generally does not provide information about the environmental setting. Therefore, this chapter addresses the following research question:

What did Doggerland look like and how did it develop throughout prehistory?

Past research undertaken by the North Sea Palaeolandscape Project (Gaffney *et al.* 2007) and physical geographers (Hijma *et al.* 2012) focused on increasing the palaeographic resolution of Doggerland through the assembly and interpretation of geological and palaeo-environmental data. Through these studies, we learned that groups of hominins were attracted by a diverse landscape consisting of hills, plains, lakes, streams of freshwater, and large populations of herbivores, predators, and fish (Cohen *et al.* 2017, 147). In addition, the analysis of strategic land-use theories and the analysis of past landscape change enable researchers to predict potential locations that likely contain remains of past human occupation (Van Heteren *et al.* 2014, 33). By doing so, prehistoric landscapes can be reconstructed, resulting in landscape interpretations such as in fig. 2.1.

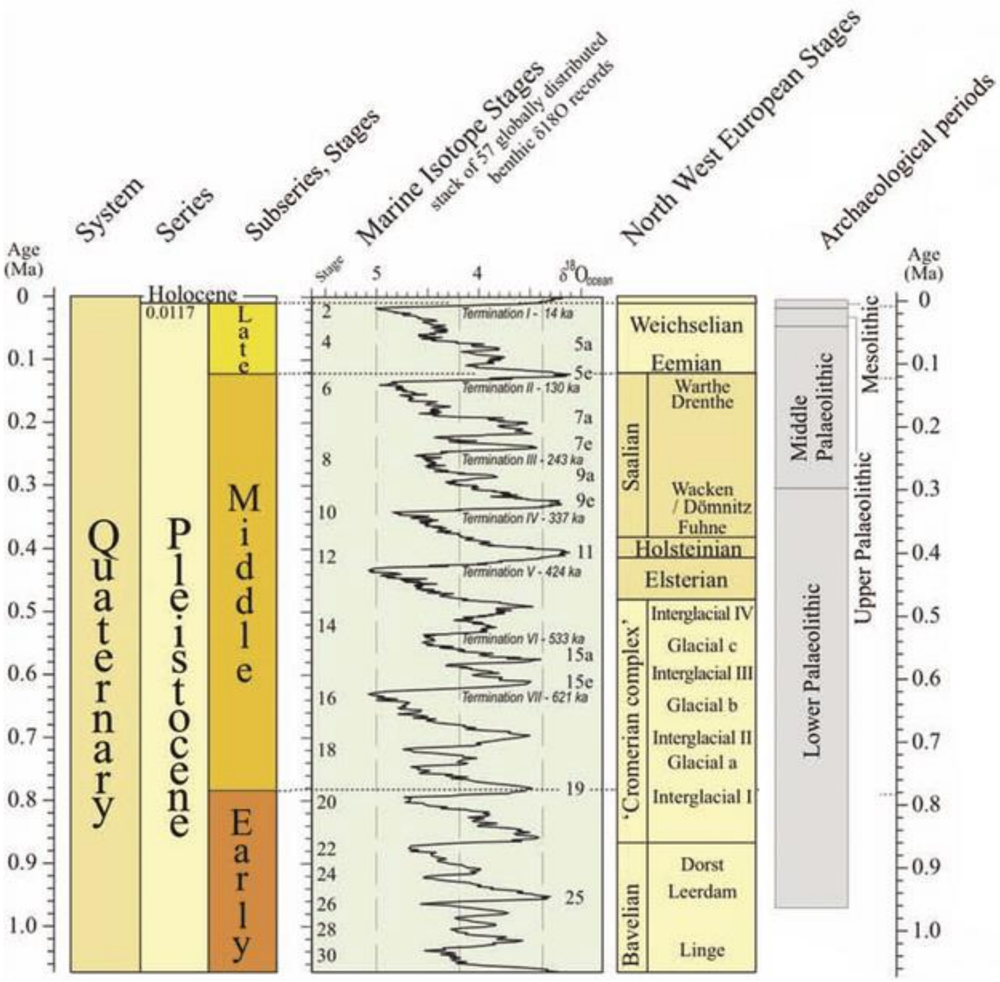


Figure 2.2 - Correlation chart for the North Sea basin for the last 1 million years, displaying the various climatic stages, archaeological periods, along with the marine isotope stages of which the left extremities highlight the colder stages (glacials) and the right extremities the warmer stages (interglacials)(after Cohen *et al.* 2017, 152).

Reconstructing prehistoric landscapes

Climate change during the Quaternary (2.58 ma to present day) is the main process behind the variable landscapes of the area now covered by the North Sea (Cohen *et al.* 2017, 154). The area has been affected by continuous sea level oscillations that were a result of alternating glacial and interglacial conditions (fig. 2.2)(Westley 2017, 136). During the glacial and interglacial periods, the basin filled-in with alternating (peri)glacial and marine deposits. In combination with their contemporaneous climate, these changing geomorphological settings characterised the habitat of the hunter-gatherer groups dwelling in the Doggerland area during the Quaternary. In the following paragraphs the general geomorphological characteristics of each period will be listed briefly, after which the associated hominin occupation will be discussed.

Early Pleistocene - 2.58 to 0.77 ma

In the course of the Early Pleistocene the area of the current Southern North Sea was a vast delta, transporting sediments from proto-‐Baltic and proto-‐Rhine-Meuse river systems to the Atlantic Ocean (Ottesen *et al.* 2018, 854). Beyond the delta, the sea remained very shallow. By then, the British island was a peninsula connected to the continent by a wide land-bridge at the Strait of Dover (fig. 2.3)(Hijma *et al.* 2012, 27). The surface of the land-bridge increased and decreased throughout the Early Pleistocene, as a result of the interaction between glacial (*i.e.* ice-age) and interglacial (warmer) periods, relating to the amount of water stored as ice (Harff *et al.* 2017, 16). Some of the earliest visible evidence of glaciation in the North Sea basin is dated to the beginning of the Pleistocene (2.6 to 1.9 ma), derived from sedimentation rates, ice-rafted debris, iceberg plough marks and glacial lineations (Ottesen *et al.* 2018, 854). Interestingly, the intensity of glaciations increased at the end of the Early Pleistocene (1.2 to 0.8 ma), spanning a longer time and increasing the surface covered by glaciers. From Scandinavia, the extent of the ice sheet reached further south but did not extend to the Southern North Sea (Hijma *et al.* 2012, 27).

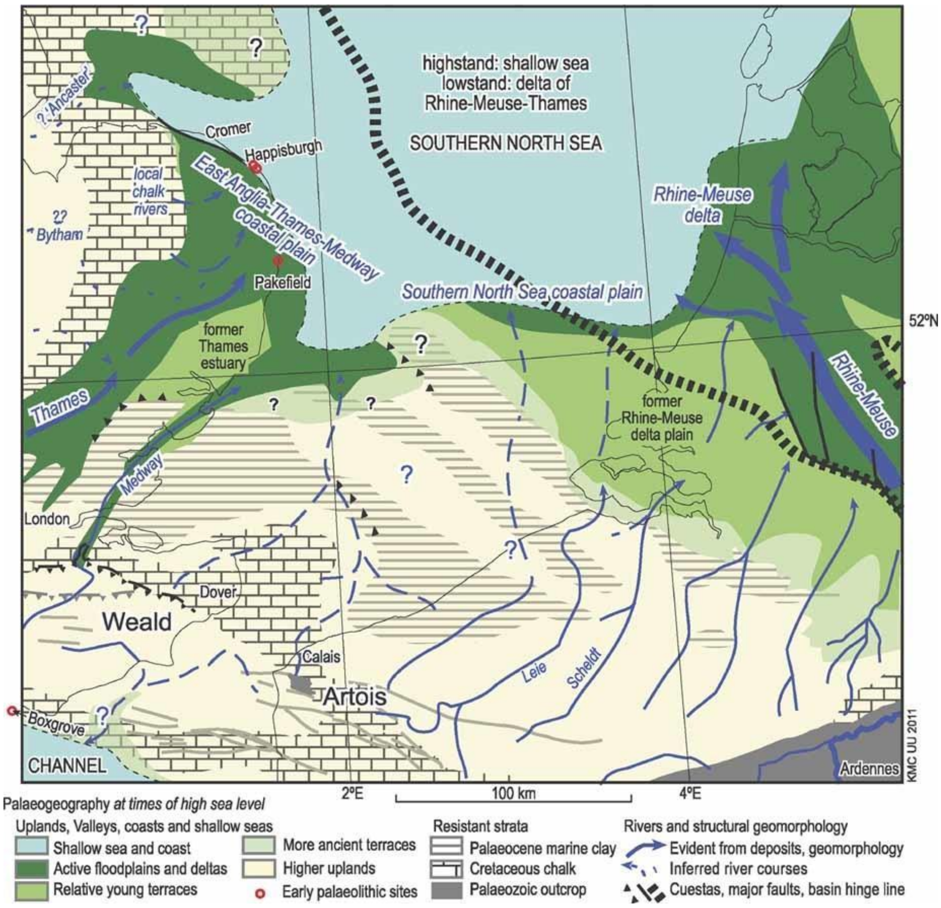


Figure 2.3 – A geographical map of the Southern North Sea during the Late Early Pleistocene and Early Middle Pleistocene at an interglacial sea level highstand, which occurred regularly between 1 ma and 0.5 ma (Hijma *et al.* 2012, 28).

Hominin occupation (Lower Palaeolithic)

Thusfar, the oldest hominin artefacts within the North Sea basin are found within the Cromer Forest Bed near *Happisburgh* (UK) and date to between 990 and 780 ka (fig. 2.3)(Parfitt *et al.* 2010, 229). This area was most likely occupied during a cool temperate period when early hominins explored the southern edge of the boreal zone, indicated by palaeobotanical research (Parfitt *et al.* 2010, 231; Roebroeks 2014, 45). Hominin footprints dating to the same period were discovered on the beach of Happisburgh in 2013. The footprints were preserved in petrified mud-flats and uncovered through erosion of the beach sediments (Ashton *et al.* 2014, 1). Interestingly, *Happisburgh* provides evidence for occupation of the North Sea basin during a relatively cool period, where no or only periodical occupation was to be expected (Parfitt *et al.* 2010, 229).

Middle Pleistocene - 770 to 130 ka

Multiple glaciations modelled the North Sea basin throughout the Middle Pleistocene (Ward 2014, 220). In contrast to the end of the early Pleistocene, sedimentary research of buried tunnel valleys suggests that several Middle Pleistocene glaciations reached the Southern North Sea basin (Van Heteren *et al.* 2014, 37). These glaciations date from the Cromerian Complex (761-563 ka), the Elsterian glacial (478-424 ka) and the Saalian glacial (191-130 ka)(Lauer and Weiss 2018, 6; Ottesen *et al.* 2020, 16). During these cold periods, the courses of the proto-Baltic, Rhine-Meuse and Thames river systems shifted to a more southerly area, forced by the ice sheet and a decrease in the rivers' discharge (Cohen *et al.* 2017, 157). At the stages of maximum glaciation, the British and the Scandinavian Ice sheets most likely merged and blocked the contemporaneous rivers from draining into the sea. Together with the meltwater from the ice sheet, the water pooled into a large proglacial lake between the ice sheet to the north and the 'land bridge' to the south (fig. 2.4)(Hijma *et al.* 2012, 28). This land bridge, located at the current Strait of Dover, was the remains of the Weald Artois chalk range formed during the Oligocene and Miocene (25 to 15 ma) and was subsequently shaped by episodes of erosion. Around 160 ka, the pressure of the proglacial water and the discharge from the Thames and Rhine systems forced streams to go across the land-bridge, which eventually created a large river valley cutting off the British peninsula from the European mainland (Cohen *et al.* 2017, 159). Alternatively, during interglacials, warmer periods of more than 10 ky, such as the Cromerian interglacials (761-563 ka) and the Holsteinian interglacial (424-374 ka), the ice sheets regressed and the sea level rose (fig. 2.4)(Van Heteren *et al.* 2014, 38). As for the interglacial drainage systems, without the pressure of an ice-sheet, the Rhine-Meuse-, Thames-, and Baltic river mouths shifted to a more northerly position (Hijma *et al.* 2012, 27).

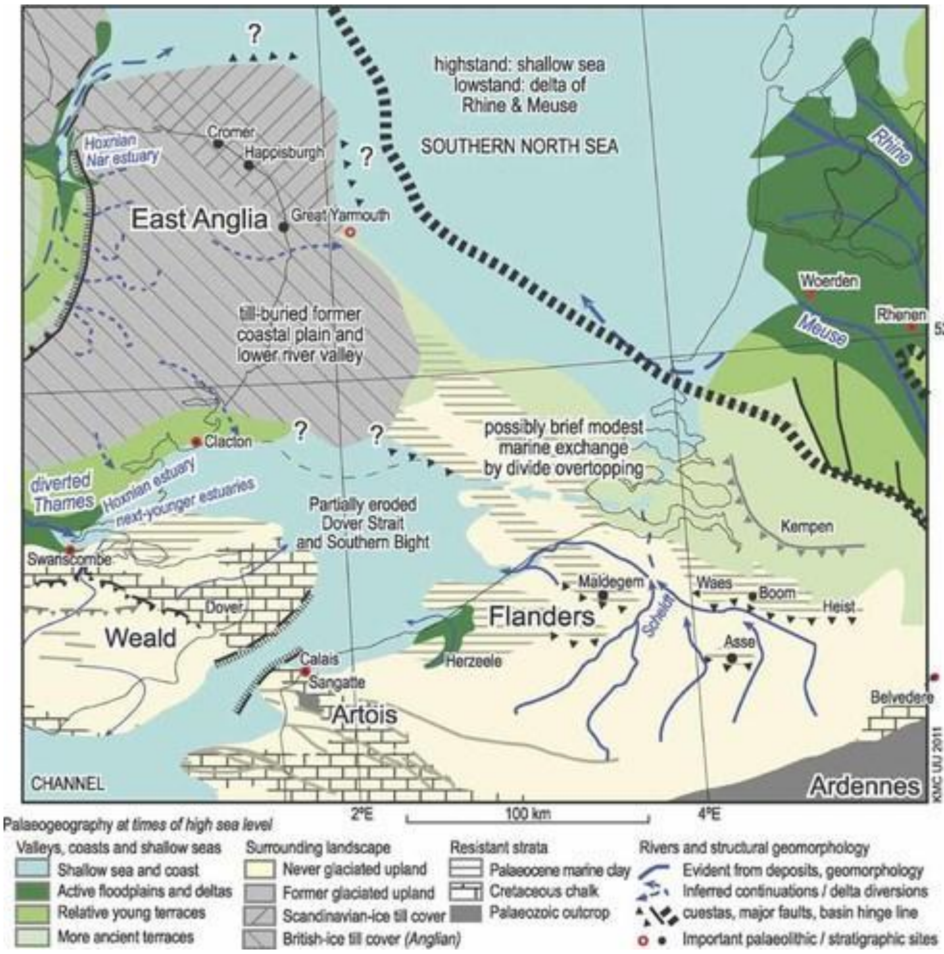


Figure 2.4 - The presumed geomorphological setting of the Southern North Sea basin during the Late Middle Pleistocene at an interglacial sea level highstand, between 400 and 150 ka (Hijma *et al.* 2012, 29).

Hominin occupation (Lower and Middle Palaeolithic)

Throughout the Middle Pleistocene, several groups of early hominins began to colonise Doggerland. Artefacts from these groups derive from current coastal sites in the United Kingdom, including *Pakefield* (750-680 ka) and *Clacton-on-sea* (400 ka)(Parfitt *et al.* 2005, 1011; Ashton 2016, 43). Additionally, in recent years some locations within the North Sea yielded Middle Pleistocene artefacts and hominin fossils (Cohen *et al.* 2017, 169). One of the most important discoveries is find of 75 Palaeolithic artefacts at the SBV Flushing wharf in 2008 (fig. 2.5). Lithics, including 33 hand axesaxes dating to the Saalian glacial, were sorted from stockpiles of gravel originating from an offshore aggregate extraction area near East Anglia (*Area 240*)(Tizzard *et al.* 2011, 66). Another rare find is a Neanderthal eye-brow ridge encountered in the sieving debris of a shell extraction company in 2001. The skull fragment was found among the shells coming from the *Zeeland ridges*, accompanied by Middle Palaeolithic (300-40 ka) Levallois tools and is therefore likely to originate from the same period (fig. 2.5)(Hublin *et al.* 2009, 779). These finds made clear that especially neanderthals have resided in the North Sea basin for a significant amount of time.

Figure 2.5 – The two important archaeological finds from the Middle Pleistocene from the North Sea seabed. Left: One of the 33 Palaeolithic hand axes (wessexarch.co.uk). Right: The Neanderthal eye-brow ridge (omroepwest.nl).

Late Pleistocene - 130-11,7 ka

The Late Pleistocene consists of the last interglacial and the last glacial until the present day. During the Eemian interglacial (130-114 ka), the North Sea had a size similar to its modern extent. Besides that, the land-bridge at the strait of Dover had been breached, making the British landmass into an island (Cohen *et al.* 2017, 159). The Rhine and Meuse river system separated from a singular system into two separate systems and extended into a large delta plain situated at the current Brown Bank (Hijma *et al.* 2012, 30). Towards the last glacial, called the Weichselian glacial (114-14 ka), the sea level dropped considerably again reaching close to one hundred meters below the current sea level (Cohen *et al.* 2017, 160). In combination with the growing British and Scandinavian ice-sheets this had the effect that the Meuse and Rhine rivers were pushed south again and drained into the large Axial channel that ran through the Dover Strait into the Atlantic Ocean (fig. 2.6)(Hijma *et al.* 2012, 32; Cohen *et al.* 2017, 161). During this Last Glacial, a large part of the southern North Sea basin was covered by a scatter of (subglacial) streams and (proglacial) lakes that painted the landscape together with valleys and ridges (Laban and van der Meer 2011, 255). The ice sheets expanded until the end of the Last Glacial Maximum (20-18 ka), which was the coolest period within the Weichselian glacial. Afterwards temperatures increased rapidly. Eventually, two short climatic shifts: The Bølling–Allerød interstadial (4.7-12.9 ka) and the Younger Dryas stadial (2.9-11.7 ka). An interstadial is a warmer period within a glacial and a stadial is a colder period within a glacial. They marked the end of this last glacial and the beginning of a new geological epoch, the Holocene (Ward 2014, 222).

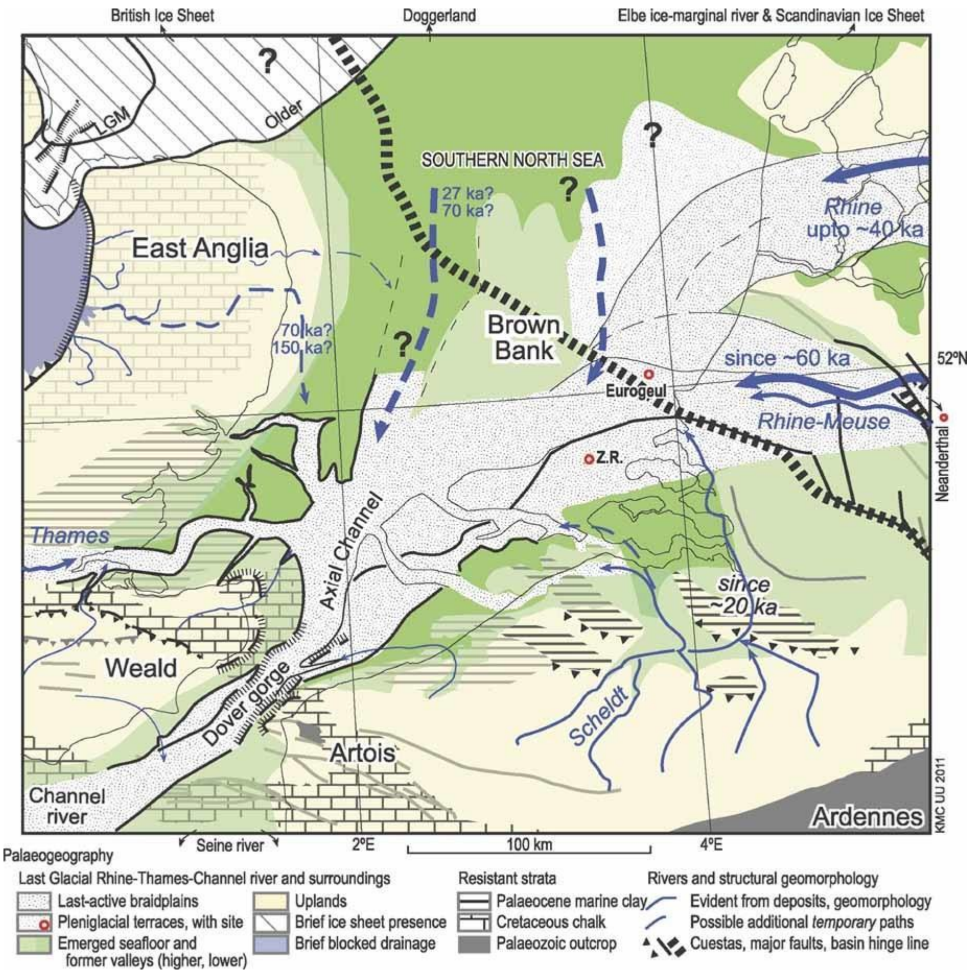


Figure 2.6 - The presumed geological setting of the Southern North Sea basin during the LGM in the Late Pleistocene at a glacial sea level low stand, between 20-18 ka (Hijma *et al.* 2012, 32).

Hominin occupation (Middle and Upper Palaeolithic)

During the Weichselian glacial, Neanderthal groups may have profited from proglacial floodplains and valleys hunting large Pleistocene mammals such as mammoth, reindeer, and woolly rhinoceros, as demonstrated by isotope studies and in-situ animal fossils (Weyrich *et al.* 2017, 358). Upon deglaciation, the glacial features, such as tunnel valleys and ice-pushed ridges developed into freshwater bodies and small hills that provided possibilities for campsites and ambush hunting grounds (Van Heteren *et al.* 2014, 37). Known artefacts that Neanderthal groups left behind consist primarily of lithics, such as hand axes, flakes, and blades (Peeters and Amkreutz 2020, 166). Amidst finds is a prepared flake partly covered by birch tar found on the artificial *Zandmotor* beach in 2016 (fig. 2.7). Carbondating indicated that the birch tar was made 50 ka, which provides evidence for the Neanderthals' ability to produce tools through a complex operational chain (Niekus *et al.* 2019, 22081). Throughout the Last Glacial Maximum, most of North-western Europe became inhospitable due to the harshening climatic conditions, and as a result some human groups may have moved to warmer regions (Roebroeks 2014, 48). Towards the end of the Pleistocene modern human groups repopulated the extensive periglacial plains of the North Sea basin. Upper Palaeolithic groups, such as the Magdalenian, Creswellian, Hamburgian, Federmesser, and Ahrensburgian groups most likely inhabited a large part of Doggerland (Peeters and Momber 2014, 56). Such groups exploited terrestrial and aquatic resources and lived discontinuously in small camps as well as larger dwellings (Peeters and Momber 2014, 57). One of the few archaeological remains attributed to these Upper Palaeolithic groups is a decorated bison bone that resurfaced after a fishing trip near the *Brown Bank* (fig. 2.7). It displays geometric lines carved into the bone and represents one of the earliest Objects of art (Amkreutz *et al.* 2018, 32).

Figure 2.7 - A prepared flint flake (left) partly covered by birch tar, found on the beach of Monster (rmo.nl) and the decorated bison bone encountered in the net of a fishing vessel (right)(rmo.nl).

Holocene - 11.7 ka – present

Throughout the Holocene the drowning of the Pleistocene landscape happened gradually, continuously 'gaining ground' in the course of the past twelve thousand years. After the Weald-Artois land bridge was breached again (ca. 9.5 ka), the sea level rose faster and flooded the basin from both the north and the south (fig. 2.8)(Cohen *et al.* 2017, 163). Peat deposits are an important proxy for indicating ancient shorelines and thus past sea level changes. A peat layer is formed when plants and other organisms that grow and live in the sheltered salt marches eventually die and stack up and do not degrade due to the anaerobic environment (Nichols 2009, 207). The peats that formed during the end of the Pleistocene and the Holocene can be radiocarbon dated, which consequently provides a chronology of coastal transgression (Cohen *et al.* 2017, 167). Radiocarbon dates from these so-called Basal peats (*i.e.* the peats formed at the beginning of the Holocene) show that since the breach of the Dover Strait, most of the Pleistocene landscape within the basin was flooded, including the largest island now known as the Doggerbank (8-7.5 ka)(Harff *et al.* 2017, 28). Additional elements that could have altered the sea level are tectonics, including glacio-isostatic adjustments, These alterations occur when land rises (rebound) after the glaciers retreat and land sinks when it was not burdened by the weight of ice. The last sinking islands left in the North Sea basin could have drowned during superimposed events, such as the Storegga event (ca. 8.1 ka). Here an enormous landslide at the coast of Norway triggered a series of tsunamis powerful enough to engulf parts of the Dutch Coast (Cohen *et al.* 2017, 164).

Hominin occupation (Mesolithic)

As the plains, rivers, lakes, and marshes submerged, the human groups that inhabited these landscapes were forced to leave their coastal settlements and establish one someplace else (Van Heteren *et al.* 2014, 38). Whether they preferred the higher local areas, settled near the shore again, or moved vast distances into the hinterland is an interesting topic for further research. Yet, it can be said that Mesolithic groups, generally speaking, lived in large groups and often near freshwater bodies (Van Heteren *et al.* 2014, 39). This is demonstrated by *Bouldnor Cliff* (Momber *et al.* 2012) and *Rotterdam Yangtze Harbour* (Boon *et al.* 2015) two submerged Mesolithic sites that were close to a river, a lake, and the sea (Peeters and Momber 2014, 59). Artefacts found at sites such as *Hardixveld-Polderweg* and *Rotterdam-Beverwaard* include bone harpoons, netting, flint utensils, hearths, and construction wood for houses. Combined with zoological and palaeoecological data, they indicate a rather sedentary lifestyle profiting from marine and lacustrine resources (Peeters and Momber 2014, 63).

Figure 2.8 – Reconstructed map of the North Sea around 10 ka, showing a slowly disappearing Doggerland (Amkreutz *et al*. 2021, 37).

Conclusion

The previous pages demonstrate that the North Sea basin is an important area concerning research of prehistoric groups that inhabited European Pleistocene and Holocene landscapes. Nonetheless, it remains a difficult research area, since it is a land beneath the waves. Fortunately, the use of existing and recent palaeogeographic and palaeoenvironmental data provides us with a way to see through the waves and uncover a great number of different prehistoric landscapes. Besides that, analysing archaeological finds, encountered in fishing nets, dredged up or found on sand supplemented beaches, include (fossil) bone, lithics, antler, and botanic finds, provides us with a basic understanding of what life was like in prehistoric times. Yet, we must bear in mind that the known submerged prehistoric archaeological record is only the tip of the iceberg, which could lead us to making inaccurate assumptions about prehistoric life. The analysis of preservation could, therefore, show us what can still be expected to have survived from prehistory and possibly give a clue about what is still missing.

Figure 3.1 – Buckets of Pleistocene faunal remains collected by fishermen off the coast of the Dutch North Sea (Amkreutz 2021, 24).

III. What remains?

Loss and preservation of submerged prehistoric landscapes

Just as with terrestrial archaeology, where it is hard to tell what still is present underneath the surface, it is equally hard if not harder to predict what survived below the seabed. One can only assume, due to the prehistoric remains that have been discovered already, and taking into account the enormous area of the North Sea basin, that there are many traces of prehistoric societies still hidden in the deep. The fact that certain geological deposits within the North Sea basin have good preservation qualities is demonstrated by the many accidental finds of (fossil) mammal bones, antlers, and lithics encountered on the beaches and in fishing nets (fig. 3.1)(Peeters and Amkreutz 2020, 170). However, an important note to this is that the deposits, from which these finds derive, have recently been exposed due to marine erosion (Bailey *et al.* 2020, 195). This means that even though a couple of artefacts from these deposits are discovered, a lot of them will be separated from their context and subjected to destructive hydrodynamic processes (Bailey *et al.* 2020, 18). Even though it is yet impossible to determine the extent of the submerged prehistoric deposits that have survived until today, this chapter attempts to provide part of the picture answering the following questions:

- *Which natural processes influence the survival of submerged prehistoric remains*? And;
- What submerged prehistoric deposits *have been preserved?*

In order to find answers, the chapter focusses on taphonomy, which is the post-depositional natural alteration of objects and sediments. Taphonomy depends on a variety of factors that reworked sediments before the landscape subsided (terrestrial phase), during the drowning of the landscape (transgressional phase), and during exposure on the seabed (Submerged phase)(Flemming *et al.* 2017, 4). The change in environment could have been a matter of years, but could also have taken decades, centuries, or millennia, affecting the degree of the erosional and sedimentation processes and subsequently the state of preservation. Moreover, the fact that some of the Pleistocene deposits could have experienced multiple marine and terrestrial stages should be taken into account (Cohen *et al.* 2017, 154). Therefore, understanding the depositional context provides the bedrock for predicting the location and preservation of archaeological finds, sites, and landscapes in the contexts where they are set (Ward 2014, 213). The chapter is divided into sections about the terrestrial, transgressional, and submerged phases, and the physical consequences for the prehistoric deposits as a result of the associated natural processes.

Before submersion

During the terrestrial phase, the landscape is affected by glacial and interglacial conditions that destruct the former landscape and construct a new landscape. At the time of a glacial period, due to a decreasing sea level, the landscape expanded and large rivers and glaciers moved with great force through the North Sea basin. Severe erosion, caused by the movement of glaciers, the ever-blowing wind and the mass of streams and rivers, disintegrated large chunks of the former Pleistocene landscape (Cohen *et al.* 2017, 171). As a result, one can state that much of the earlier terrestrial landscape had been altered beyond recognition (Flemming *et al.* 2017, 2). On the other hand, parts of the prehistoric landscape might be buried and preserved locally. For instance, the inner slow-moving bend of a low-energy meandering river is likely to preserve lithic material due to the steady deposition of fine-grained river sediments (Macklin 1999, 527). Other examples are events such as landslides and floods that result from either thawing permafrost (landslides) or a sudden increase in water volume (floods)(Nichols 2009, 110). These instantaneous events cover surfaces quickly with a layer of sediments, increasing the chances of preservation. Events such as landslides and floods are progressively more common at either greater distances from a glaciated landscape, during interstadials (short warmer periods within a glacial period) or towards the end of a glacial period. These favourable conditions for preservation were beneficial for hominin and early modern human presence and this luckily coincided with a better preservational setting.

During the Elsterian and Saalian glaciations, the North Sea landscape was shaped by the erosional force of the Rhine and Meuse river systems. As a consequence, Early and Middle Pleistocene sedimentary records have been either poorly preserved or not preserved at all. The few prehistoric deposits that did preserve show irregular and patchy distribution patterns (Hijma *et al.* 2012, 34). This means that archaeological remains from hominin species that preceded the Neanderthals and (early) modern humans, have rarely been preserved and might only derive from ex-situ environments (Hijma *et al.* 2012, 34). In contrast to the Early and Middle Pleistocene, the Late Pleistocene deposits have a more favourable rate of preservation. For instance, the Brown Bank member (a sub-layer within the Eem Formation), dating to the Early Weichselian, relates to clay sediments deposited by a large lowland delta of the early Rhine and Meuse. These deposits are great for the preservation of artefacts, as the clay provides an oxygen-depleted environment, enhancing the preservation of organic artefacts (Hijma *et al.* 2012, 35). Yet, even within deposits such as the Brown Bank member, the preservation depends on the degree of erosion by the previous and following glacial processes, that in this area would only preserve the deeper parts in the landscape, where streams deposited sediments at a constant rate (Vonhögen-Peeters *et al.* 2016, 19).

Nowadays, a large number of glacial and interglacial features are still preserved and visible on the seabed (fig. 3.2)(Van Heteren *et al.* 2014, 36). These include till features (glacial deposits), such as kames (mounds of aggregated till), and moraines (ice-pushed ridges), and erosional features, including tunnel valleys (sub-glacier meltwater valleys) and iceberg plough marks (impact of iceberg keels on pro-glacial lake sediments)(Nichols 2009, 108). Examples of interglacial features are tidal ridges (sediment accumulations next to tidal channels) and beach barriers (sand barriers constructed by wave-action)(fig. 3.3)(Nichols 2009, 210). Both of the depositional and erosional features might have provided for attractive areas in later prehistoric periods: Large tunnel valleys are likely to have formed fresh-water lakes during warmer times and ice-pushed ridges and mounds would become good vantage points, both of which are perfect for later prehistoric use (Cohen *et al.* 2017, 166).

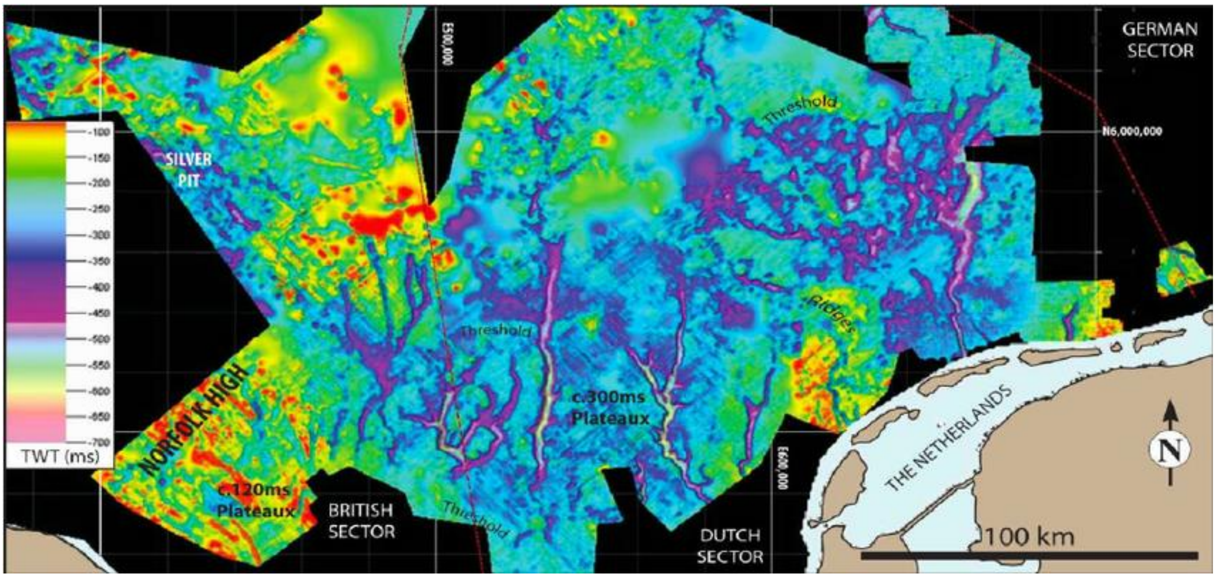


Fig. 3.2 – Map of preserved glacial features in the northern part of the Dutch North Sea, showing a number of large tunnel valleys (purple and white), dating to the Saalian or older glaciations (Moreau *et al*. 2012, 105).

During submersion

The transgressional phase is characterized by sediments being affected by natural processes associated with brackish and near-marine environments, as a consequence of rising sea level. As this happened numerous times during the Early and Middle Pleistocene, most of these deposits have either not survived or were buried at great depths (Hijma *et al.* 2012, 34). On the other hand, the prehistoric coastal landscapes dating to the end of the Pleistocene and the first half of the Holocene have largely been preserved. The preservation of these landscapes can be attributed to both a relatively rapid sea-level rise and the fact that currently there hasn't been a significant climatic shift yet (Van Heteren *et al.* 2014, 38). At the beginning of the Holocene, the rapid sea level rise was accompanied by increased sediment aggradation, which covered the coastal area swiftly and preserved soils better than during a sea level rise at a slower pace, when tidal scouring intensifies (Cohen *et al.* 2017, 167). Additionally, areas adjacent to the active channel systems presented conditions to form rather stable coastal systems, such as mudflats and salt marshes (fig. 3.3).

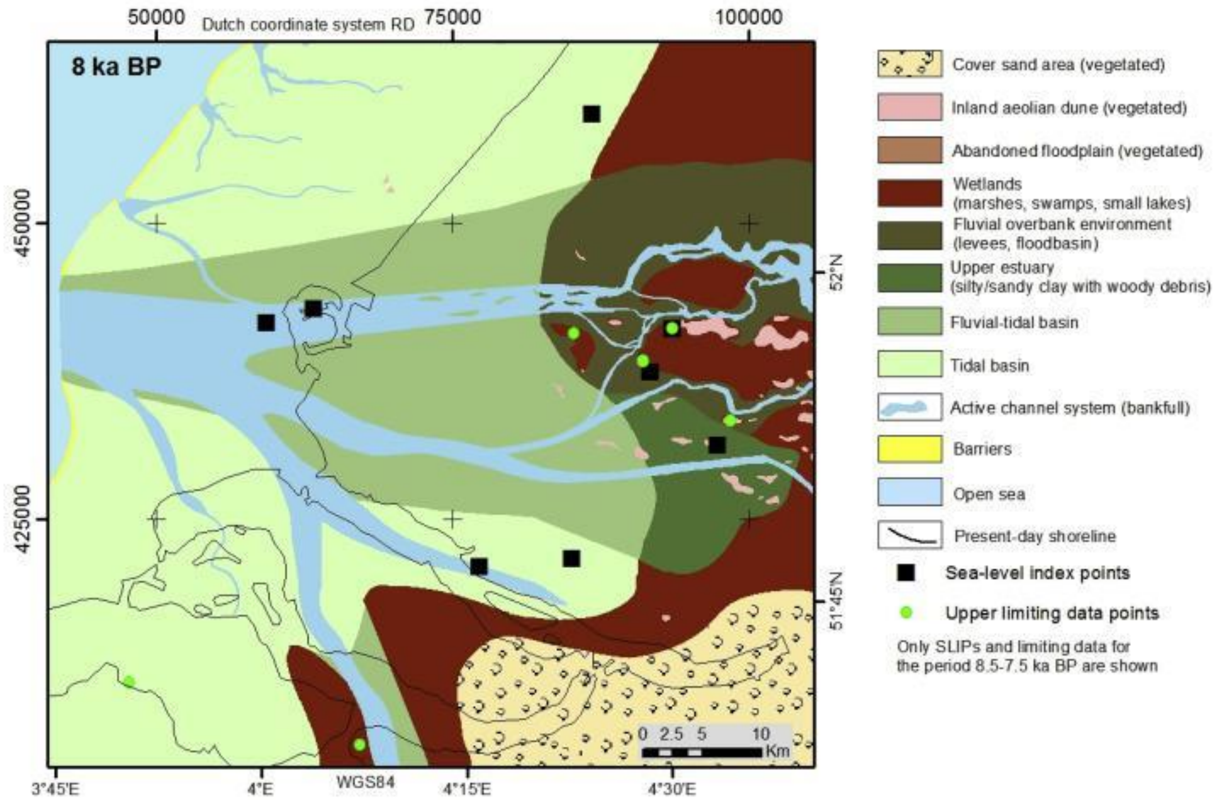


Figure 3.3 - A palaeogeographical map of Zuid-Holland showing the coastal environments at 8 ka BP (Hijma and Cohen 2019, 72).

These prehistoric salt marshes are preserved as basal peat deposits and can still be encountered along the sandbanks of the Southern North Sea (Ward 2014, 223). The deposits do not only hold palaeoenvironmental indicators, as the anaerobic peat preserves organic material perfectly, but might also contain archaeological artefacts associated with the prehistoric peoples that at the time of submersion lived in the vicinity of the sea. These artefacts, encountered by trawling fishing vessels or found on Dutch and UK beaches, consist of Late Pleistocene and early Holocene inorganic material, including flint and fossilized bone, and organic material, such as antler, bone, and wooden artefacts (Firth 2013a, 792). Geophysical research around the Brown Bank and on the artefacts encountered on the fishing vessels indicates that at least part of a prehistoric inhabited coastal landscape survived (Ward and Larcombe 2008, 75). Other locations within the North Sea Basin, where similar patches of basal peat have been preserved, might therefore be of great value for further research to Upper Palaeolithic and Mesolithic societies and their relation to the sea.

After submersion

After submersion, or the inundated phase, hydrodynamic conditions affect the submerged prehistoric deposits present on top or underneath the seafloor. These hydrodynamic conditions shape the seabed using sediments lying on the seabed and the influx of sediments from the major river systems (Harff *et al.* 2017, 27). In general, sediments are transported by tides, currents, and wind-driven waves. The tides that flow anticlockwise around amphidromic points (not being influenced by tides) are the dominant factor in the distribution of sediments (Cohen *et al.* 2017, 151). Besides that, the tidal flows instigate the migration of sand waves. These seabed features typically range between a couple of meters to ten meters in height and have wavelengths in the order of hundreds of meters. They migrate along the general direction of the tidal currents with speeds up to five to ten meters per year (fig. 3.4)(Boon *et al.* 2018, 36). Generally, the sand wave migration is considered to be the most threatening seabed shaping process to both submerged prehistoric deposits and offshore industrial structures alike (Terp Paulsen *et al.* 2016, 8). In addition to the impact of tidal currents, wind-driven swells have an increasing influence on the movement of sediments in the vicinity of the coast, sweeping up sand and distributing it someplace else (Van der Molen 2002, 2759). The result is a constantly changing topography of the seabed that has been going on since the moment the land was inundated.

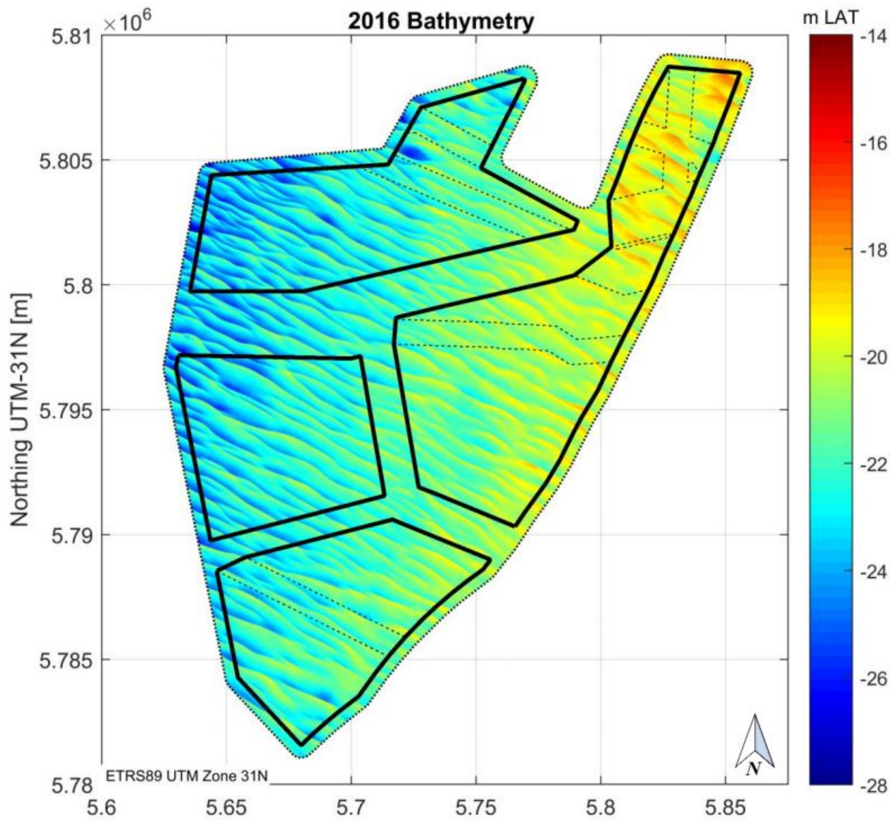


Figure 3.4 – Bathymetric map of the *Hollandse Kust Zuid* wind farm site, displaying a large number of north-east moving sand waves (Terp Paulsen 2016, 6).

As a consequence, prehistoric remains situated near or at the top of the seabed are at risk of being affected by these hydrodynamic processes. Here, the distinction between covered and exposed is essential for the preservation of the submerged prehistoric landscapes, since exposure increases the detrimental effects of mechanical, biological, and chemical processes (Flemming *et al.* 2017, 2; Manders 2017, 83). For instance, at the seabed surface, prehistoric remains could be damaged by the force of shifting sand and eventually be removed from their layered deposits to the bottom of a sand wave. Even though these erosive processes only affect the top centimetres of the seabed, in the space of a thousand years, they'll have a significant effect on the seabed morphology, especially during storm surges, when the suspension of sediments increases. On the other hand, storm surges could reshape the seabed morphology in a way that previous eroding surfaces experience a renewed accumulation of sediments (Bailey *et al.* 2020, 19). Hydrodynamic mechanisms are therefore crucial elements that either protect or expose geological deposits within the seabed.

Another threat that might damage or displace prehistoric deposits is the disappearance of eelgrass (*Zostera noltii and Z. Marina*). In sheltered marine environments, the eelgrass protects submerged prehistoric landscapes by strengthening the topsoil of the seabed. However, when the grass disappears as a result of disease, changing water quality, or industrial activities, the seabed sediments will be increasingly exposed to erosion, chemical and biological threats (Reise and Kohlus 2008, 78). For instance, exposed Mesolithic wooden artefacts are threatened by wood-boring bivalves and crustaceans, such as the shipworm (*Teredo navalis L.*), that fragmentarily consume wooden objects (Manders 2017, 83). Besides this, chemical threats, resulting from changing oxygen levels or warming of sea temperatures, might degrade wooden artefacts too. For instance, bacterial activity on fragments of wood could form particles of the mineral Pyrite, which considerably lowers the pH scale and consequentially damages the cellular structure of wood (Manders 2017, 91).

Preserved prehistoric deposits

Understanding the geological stratification of the Dutch seabed is key when searching for the context of the paleontological and archaeological objects that have been recovered from the North Sea. Yet, as the Dutch North sea spans an area of 57.000 km^2 (clo.nl), it is nearly impossible to get a detailed stratigraphic picture of the entire surface of the seabed (Van Heteren *et al.* 2014, 36). Besides that, the density of geological data from the North Sea is much lower compared to data from land surfaces (dinoloket.nl). Moreover, only in the last couple of decades, the geophysical and geotechnical data sets have been made available by the hydrocarbon industry for research to the geological history of the North Sea basin (Van Heteren *et al.* 2014, 32). Despite this, an attempt has been made by Vonhögen-Peeters *et al.* to model the prehistoric potential of the Dutch North Sea substrate

(Vonhögen-Peeters *et al.* 2016). They have described the Holocene and Pleistocene geological formations present up to 30 meters below the seabed surface and analysed their potential of having preserved prehistoric material, using existing lithostratigraphic data obtained through geophysical and geotechnical surveys executed for the offshore mining industry (fig. 3.5). Afterwards, they identified deposits that could contain in-situ or minimally disturbed archaeological contexts and plot them on a map of the Dutch North sea (Vonhögen-Peeters *et al.* 2016, 3). In this part of the chapter, their data is used to list the geological formations present below the seabed and describe their potential for preserving prehistoric archaeology (fig. 3.6).

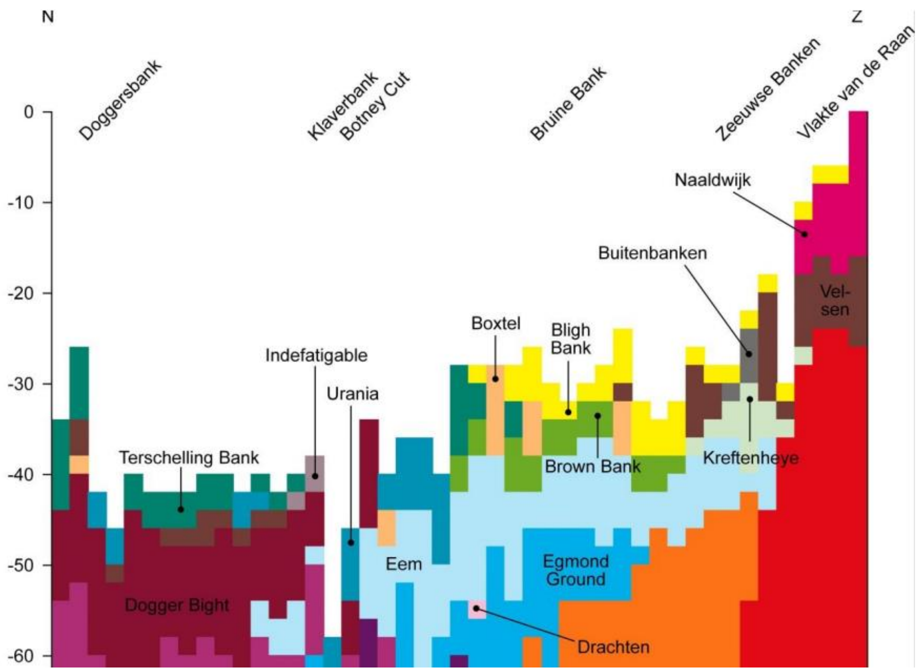


Figure 3.5 - A schematic cross-section of the Dutch North Sea, regarding the Holocene and Pleistocene geological deposits present until – 60 meters NAP (Vonhögen-Peeters *et al.* 2016, 10).

The seabed stratigraphy can be subdivided into formations deposited during the Pleistocene and formations deposited during the Holocene (fig. 3.5 and 3.6). Even though there are deposits around *Cadzand* that date before the Pleistocene, deposits older than the Middle Palaeolithic will not be mentioned here, since they are situated too deep (>30 meters) to be affected by both natural and industrial processes or do not contain archaeologically interesting deposits (*Cadzand*)(Vonhögen-Peeters *et al.* 2016, 9). The top Holocene formations, on the other hand, will be included, as there are eroding deposits that do provide Meso- and Neolithic remains, even though these remains are constantly subject to hydrodynamic processes.

Southern Bligh Formation
Geological Period:
Entire Holocene
Depth (m – seabed):
0- 10

The Southern Bligh Formation has been and is still being deposited from the beginning of the Holocene on and consists of marine sands, creating sand- ridges and waves under influence of hydrodynamic processes. Sub-units such as the Bligh Bank and Terschelling Bank members possibly contain Mesolithic or Neolithic derived artefacts.

Naaldwijk Formation
Geological Period:
Entire Holocene
Depth (m – seabed):
0- 10

The Naaldwijk Formation has been and is still being deposited from the Early Holocene on and consists of near coastal clayey sands, typical for estuarine environments. Sub-units such as the Velsen member, dated to the Mesolithic, could contain *in situ* remains and preserved flint and bone artefacts within the tidal deposits.

Nieuwkoop Formation
Geological Period:
Early to middle Holocene
Depth (m – seabed):
5 - 15

The Nieuwkoop Formation has been deposited during the early and middle Holocene and consists of a basal peat bed no more than half a meter thick. The peat bed developed due to the groundwater-table rise as a consequence of rising sea levels and could increase the preservation of terrestrial surfaces organic artefacts.

Boxtel Formation
Geological Period:
Late Pleistocene to early Holocene
Depth (m – seabed):
5 - 15

The Boxtel Formation consists of both river deposits as well as wind-blown deposits related to periglacial environments at the end of the Wechselian. Even though the formation likely preserved relict dunes (Delwijnen member), Upper Palaeolithic (*in situ*) sites will probably not be preserved due to lengthy erosional processes (Wierden member).

Dogger Bight Formation
Geological Period:
Late Pleistocene
Depth (m – seabed):
15 - 30

The Dogger Bight Formation, deposited during the Weichselian glaciation, consists of silty sands in combination with coarse sands, ascribed to the sedimentation of glaciomarine and glaciolacustrine environments. Sub-units such as the Dogger Bank member, situated in the vicinity of the Dogger Bank, preserves moraines that could indicate the presence of highly fragmented later prehistoric remains.

Kreftenheye Formation
Geological Period:
Late Pleistocene
Depth (m – seabed):
5 - 20

The Kreftenheye Formation consists of fine-to-coarse sands and gravel deposited in braided streams from the transition to until the end of the Weichselian on. The Wijchen member, that formed during the end of the glaciation, could preserve *in situ* Middle/Upper Palaeolithic remains as the top of this unit is sometimes covered by basal peat deposits (Nieuwkoop Formation).

Eem Formation
Geological Period:
Middle to Late Pleistocene
Depth (m – seabed):
10 - 40

The Eem Formation includes the coastal, tidal, and shallow marine deposits formed during the Eemian interglacial and early Weichselian glacial. The Brown Bank member, which was deposited at the beginning of the Weichselian, could have preserved in-situ or derived Middle Palaeolithic remains within the fragmented yet extensive deposits in the west of the Dutch North Sea.

Egmond Ground Fm. Geological Period: Middle Pleistocene Depth (m – seabed): 20 - >30	The Egmond Ground Formation consists of marine sediments deposited during the Holsteinian interglacial. It is highly unlikely that these deposits preserved any Early Palaeolithic remains, possibly only artefacts deriving from the beginning of the Saalian glaciation.
4.4.1. (Yarmouth Roads) Formation Geological Period: Early to Middle Pleistocene Depth (m – seabed): 10 - 40	The 4.4.1 Formation, previously known as the Yarmouth Roads Formation, consists of fine to coarse sands and gravels deposited in braided streams from the transition to until the end of the Elsterian glaciation. These deltaic deposits are situated locally near the shore of Zuid-Holland and could contain derived Early Palaeolithic remains.

Figure 3.6 - Table listing and describing the main Holocene and Pleistocene lithostratigraphic units present until 30 meters below the Dutch seabed (after Vonhögen-Peeters *et al.* 2016, 12-23).

In recent years, the geological knowledge about the Dutch seabed improved a lot thanks to new and technically upgraded geophysical and geotechnical surveys. Yet, discovering prehistoric sites within the seabed remains a challenge, since these surveys show a highly intricate patchwork of superimposed glacial and interglacial landscape elements shaped by a varying degree of erosion and sedimentation from their deposition until today (Van Heteren *et al.* 2014, 32). Still, essential finds, such as the neanderthal eyebrow ridge and bone harpoons from the *Maasvlakte II*, can be linked to the Wijchen member (eyebrow) and the Naaldwijk Formation (harpoons) and thereby say something about the quality of preservation (Johansen *et al.* 2009, 6; Kuitems *et al.* 2015, 370). Therefore, assessing the archaeological significance of these geological deposits and determining the quality of preservation, as is undertaken by Vonhögen-Peeters *et al.*, provides the basis for distinguishing geological deposits of a high archaeological potential and those of a lower potential. Their identification and validation of prehistoric deposits, lead to the creation of an indicative map for the prehistoric potential of the North Sea (fig. 3.7)(Vonhögen-Peeters *et al.* 2016, 41).

At the time of initial archaeological investigations, this map could provide an understanding of what remains could be out there, an important first step in the assessment of the offshore industrial impacts on the prehistoric submerged deposits (Peeters *et al.* 2019, 19). However, this map should not be used for archaeological heritage management decisions relating to offshore industrial activities, as the areas represent only an indication of the presence of prehistoric remains, based on hypotheses of prehistoric hominin behaviour in combination with preservation potential, and lacks the detail needed to accurately assess the archaeological potential on a smaller scale. Therefore, recent geophysical and geotechnical data should always validate the archaeologically interesting deposits displayed on the map, as these deposits and their archaeological remains could have been

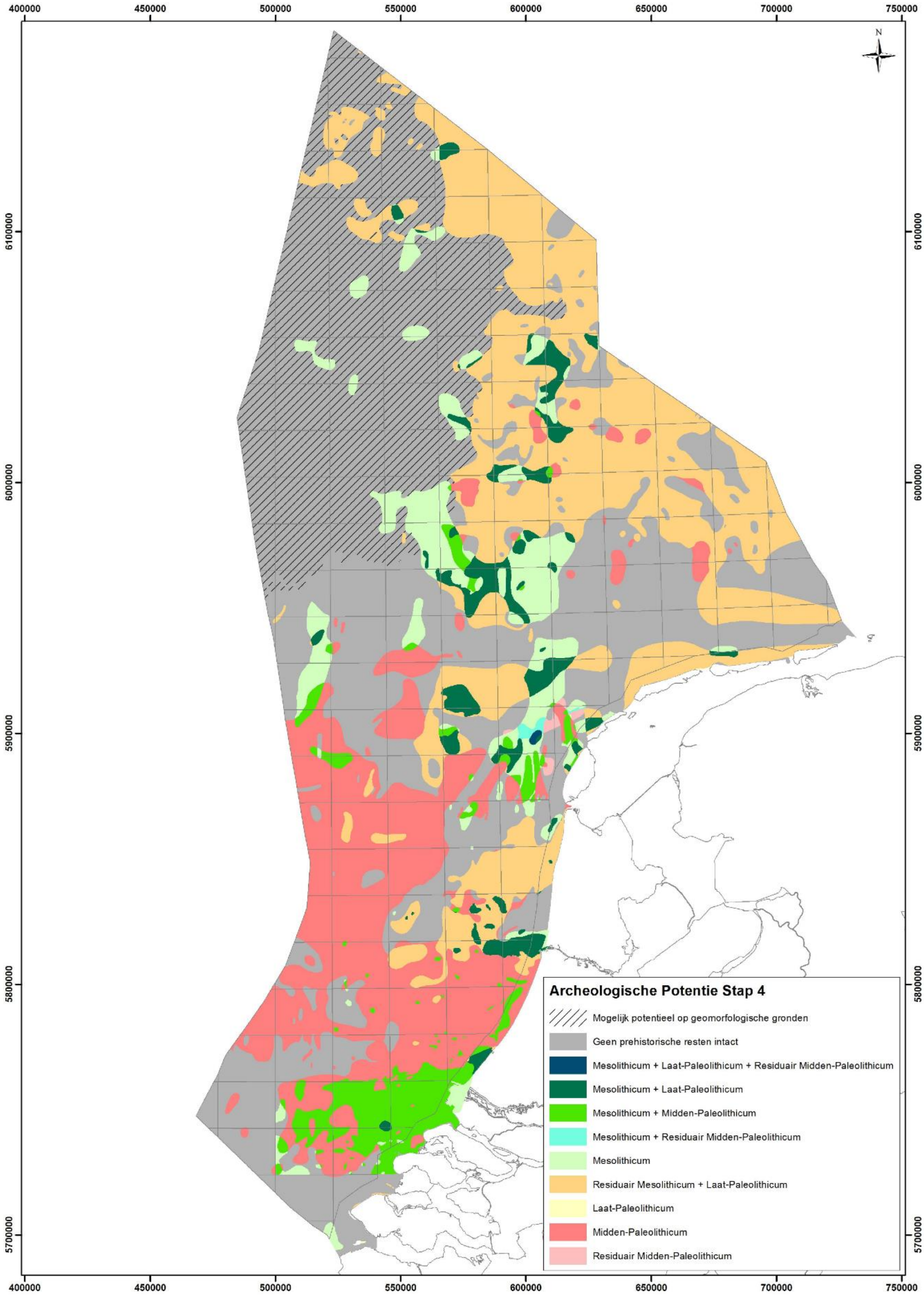


Figure 3.7 - Archaeological indicative map of the Dutch North Sea depicting areas that indicate the potential of containing preserved prehistoric remains, where the colours indicate distinctive archaeological periods or a combination of two or three periods (Vonhögen-Peeters *et al.* 2016, 41).

lost as a result of mechanical and chemical erosion. Besides that, the areas where no prehistoric remains should be, could contain prehistoric remains as erosion affects areas locally and borders between these areas are gradual (Vonhögen-Peeters et al. 2016, 41).

Conclusion

Throughout the last couple of decades, geophysical and geotechnical research developed our understanding of the geological deposits within the Dutch seabed. Stacked sediments of terrestrial, coastal, and marine deposits demonstrated that the North Sea basin has been subject to continuous sea level fluctuations, and as a consequence knew a variety of landscapes of which the deposits are now buried beneath the seabed. However, a large part of these submerged landscapes has either disappeared or is hardly recognizable, as the succession of sedimentation and erosion removed many of the former features and replaced them with new features complacent with the current climate. This palimpsest of multiple landscape generations together with the limited amount of geological data and the vast extent of the seabed, makes searching for prehistoric remains a tough job.

On the other hand, the deposits that have been preserved contain a lot of information about the Pleistocene and Holocene landscapes. For instance, there are several interesting interglacial and glacial deposits that have possibly preserved prehistoric remains, some *in situ*, but most in derived contexts. Among these deposits are fragments of (highly preservational) peat beds (Nieuwkoop Formation), deltaic environments (Naaldwijk Formation), periglacial river deposits (Wijchen member), and hills, formed as moraines or dunes (Dogger bank and Delwijnen member), all of which can be associated with prehistoric human behaviour and occasionally linked with artefacts such as bone harpoons (Naaldwijk Formation) and hominin remains such as the Neanderthal eyebrow ridge (Wijchen member). Yet, we must bear in mind that the known submerged prehistoric resources are only the tip of the iceberg and that there is a lot more data that can be recovered from the seabed.

At the same time, the prehistoric deposits are not a lasting databank: The ones that survived the trials of time and are situated in the vicinity of the seafloor are still in danger of disintegration through marine hydrodynamic mechanisms and subsequent destruction of prehistoric artefacts by biological and chemical processes. In essence, the bathymetry of the seabed causes an irregular distribution of erosion and sedimentation that exposes or covers prehistoric deposits. This leads to some of these deposits being affected by shipworm and decreasing pH levels, both of which degrade organic artefacts. Through the analysis of depositional context, taphonomic processes as well as the current hydrodynamic conditions, Holocene and Pleistocene deposits can be arranged according to a lower and higher probability of containing preserved prehistoric remains. These geo-archaeological assessments, as executed by Vonhögen-Peeters *et al.*, in combination with site-specific and up-to-date geological data would hand archaeologists the prerequisite tools for archaeological risk assessments prior to offshore industrial developments. These geo-archaeological assessments also mark the fact that offshore industrial activities form a threat to the submerged prehistoric remains. Yet, what kind of threat?

Figure 4.1 - The process of ‘rainbowing’ sand during the construction of the Sand Motor (Zandmotor) at the beach of Monster, Zuid-Holland, in 2011 (beeldbank.rws.nl).

IV. The modern human footprint

Impacts from offshore industries on the prehistoric landscapes of the Dutch North Sea

The previous chapters provide a basic understanding of the geology, geomorphology, and prehistory of the North Sea basin. In essence, beneath the top of the seabed, stacked geological deposits relating to past landscapes have still been preserved. Originating from these deposits, discoveries of prehistoric remains, such as the Neanderthal eye-brow ridge (fig. 2.4), the tar-backed flint tool (fig. 2.6), and the decorated bison bone (fig. 2.6) indicate the presence of hominins during times when large parts of the North Sea area were dry land. These deposits and archaeological finds point to the fact that a lot of information can be retrieved from the seemingly barren North Sea.

Yet, it is important to question in what way this information has been obtained, as these finds did not materialise out of thin air: Their discovery has been the result of various forms of offshore seabed exploitation. For instance, the eye-brow ridge has been found after the mining of shells, the flint tool was encountered on the replenished beach of the *Zandmotor* and the bison bone was discovered in the fishing net of a beam trawler (see Ch. 2). In essence, these finds underline the significance of the offshore industries for the research of the prehistory of the North Sea basin. Besides that, these finds are not the only benefits resulting from offshore industries, since much of our present understanding of the North Sea's prehistoric landscapes would not have been possible without the analysis of geological data acquired through geophysical and geotechnical surveys in advance of offshore activities (Bailey *et al.* 2020, 197). Essentially, without the archaeological finds and the large quantity of accessible geophysical and geotechnical data collected as a consequence of offshore industrial activities, the understanding of the prehistoric hominin occupation of North-western Europe would still have been severely limited.

However, the knife cuts both ways. For instance, one might wonder why countless numbers of prehistoric remains have been discovered in the nets of trawling vessels, along the beaches of the Dutch coast, and within stockpiles at aggregate wharves. In a way, artefact bearing deposits located at or near the surface of the seabed have been directly or indirectly impacted by offshore activities that disturbed the seabed to a certain degree. Yet, the nature of the disturbances is only little researched and therefore largely unknown. Moreover, the resurfaced prehistoric finds bear witness to the fact that many other remains have not been encountered. After all, the nets only tackle a fraction of the seabed, and really only bring up the larger Pleistocene fossil due to the mesh size of the nets. The smaller material, found at the sand replenished beaches of the Netherlands, is continuously being picked up by beach strollers and therefore must represent only a small percentage of the amount of material that is really out there (fig. 4.1). These considerations lead to this chapter's research questions:

- *What kind of offshore industrial activities are capable of affecting submerged prehistoric remains?* And
- *Which submerged prehistoric deposits are likely to be affected?*

In short, there are several offshore activities that regularly or occasionally disturb parts of the seabed. These include demersal trawl fishing, oil and gas exploration, sand and aggregate extraction, dredging of shipping lanes, construction of port facilities, and development of offshore wind farms (Bailey et al. 2020, 197). This chapter, however, will focus on only three of these offshore industries: demersal trawl fishing, sand extraction, and the development of offshore wind farms. Demersal trawl fishing and sand extraction have been selected because they are established forms of offshore activities that have been disturbing the seabed for multiple decades (Firth 2013b, 51; Salter *et al.* 2014, 152; Maarleveld 2020, 523). The development of offshore wind farms, on the other hand, is selected because it is the fastest-growing offshore industry and capable of impacting large areas of the seabed (Pater 2020, 509). This chapter is therefore divided up into three parts, each of which will list the impacts resulting from one of these offshore industries and assess the effect on the submerged prehistoric remains.

As this chapter aims to analyse the impacts of the offshore developments, the term 'impact' should be explained. Here, impact is defined as the physical alteration of a (prehistoric) deposit resulting from a development activity (Wessex Archaeology 2007, 30). The impacts of these activities can be separated into 'direct impacts' and 'indirect impacts'. A direct impact relates to an initial physical and short-term disturbance of the seabed, such as the dragging of trawling nets across the seabed, or the piling of foundations for offshore windmills. An indirect impact, on the other hand, involves a long-term disturbance of deposits at the same spot or beyond the location of the initial footprint (direct impact), including changes in hydrodynamics that lead to increased erosion and sedimentation (Wessex archaeology 2007, 9). Each part of the chapter is therefore subdivided into direct impacts and indirect impacts, and not least important, followed by a section about the positive effects of offshore activities on the prehistoric landscapes.

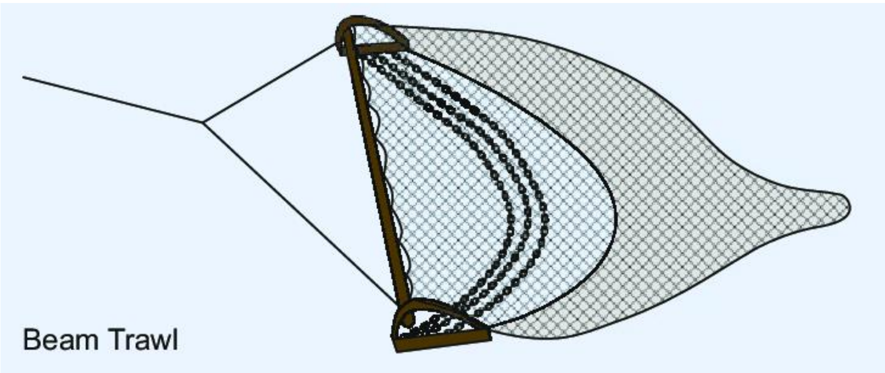
Demersal trawl fishing

Traditionally, the fishing industry is one of the threats for the submerged prehistoric remains within the North Sea seabed. This is because, in several instances, palaeontological finds and artefacts are being encountered after kilometer-long fishing stretches across the North Sea seabed (fig. 4.2)(Peeters and Amkreutz 2020, 160). Inevitably, this leads to a certain interest in the prehistoric character of the North Sea basin. However, this is not a recent interest. The interest for this specific part of the field most probably originated from incidental prehistoric finds in the early twentieth century, such as the Mesolithic Colinda point found around the Leman and Ower banks in 1931 (Gaffney *et al.* 2007, 1) and expanded in the ’70s and ’80s, when fishing vessels began to use trawling beams to tow their nets across the seabed, which caught, besides fish, a large number of Pleistocene and Holocene (fossil) bones and in fewer numbers Palaeolithic and Mesolithic artefacts (Peeters and Momber 2014, 61). As a consequence, these Pleistocene fossils instigated a long-lasting trade between fishermen, private collectors, professional palaeontologists, and archaeologists (Maarleveld 2020, 531). A trade that is still growing to this day (Peeters and Amkreutz 2020, 158). Cooperation between the groups has brought about a more systematic approach to finding Pleistocene fossils and artefacts and this resulted in some targeted fossil fishing expeditions in the vicinity of the Brown Bank, the Yarmouth Roads Formation, and the Rhine-Meuse paleo-valley channel (Cohen *et al.* 2017, 168). Much of our current knowledge concerning the prehistory of the North Sea basin derives from the analysis of the artefacts and palaeontological finds from the fishing vessels’ bycatch. On the other hand, the remains on or near the seabed could be destroyed or disassembled in this very process, either on the seafloor itself or aboard the fishing vessels, where these remains are not being recognized or valued by the fishermen (Salter *et al.* 2014, 152; Maarleveld 2020, 524).

Figure 4.2 - A fisherman shows a mammoth upper arm bone in the Texel harbour *Oudeschild* (Maarleveld 2020, 530).

Direct impacts on the seabed

One of the fishing techniques used to catch flatfish, called 'beam trawling', has especially impacted the sediments of the North Sea seafloor (Maarleveld 2020, 523). This fishing technique consists of two large nets that are trawled for kilometers across the seafloor. The nets are kept open by a steel beam that has steel tickler chains attached to it, which stir up the near-surface sediments to scare the bottom-dwelling fish into the net (fig. 4.3a)(Eigaard *et al.* 2016, 2). The width of the beam trawl itself varies between 4.5 and 12 m, relating to the power capacity of the engine. Attached to the beam are two 'shoes' that keep the net from going too deep into the seabed. The depth the tickler chains reach in the fine sands of the North Sea seabed is 4-8 cm, increasing to 15 cm when the net gets heavier as more fish are caught (Rijnsdorp *et al.* 2020, 2). Figure 4.3b shows that these trawling tracks are easily discernible with sonar equipment and clearly point to the fact that the seabed is damaged considerably during beam trawling. New techniques, such as electrical pulse fishing (further explained in chapter five), don't need heavy tickler chains and therefore prove to be much less intrusive to the seabed. The difference between the two fishing techniques amounts to 3-8 cm of sandy seabed and is clearly visible in the sonar projection (Depestele et al. 2016, 20).



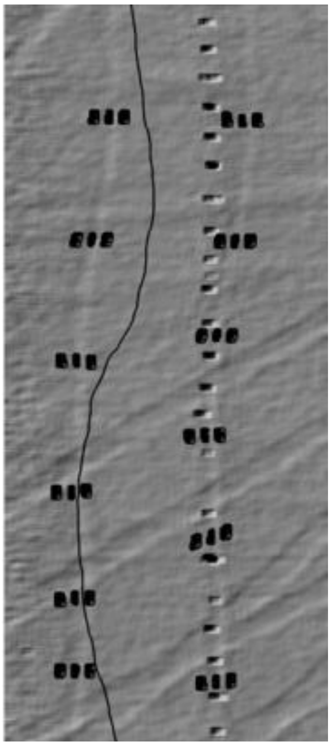


Figure 4.3 – (a) Above an Illustration of a beam trawl, used to fish on flatfish, of which usually two are deployed on each side of the fishing vessel (Maarleveld 2020, 524). (b) To the right a sonar (multibeam echosounder) visualisation of trawl tracks on the seafloor during an experiment of the effects of beam trawling and pulse trawling. The straight diagonal and parallel lines occur as a consequence of commercial tickler-beam trawling. The narrower and shallower vertical lines occur as a consequence of the experiment beam and pulse trawling. The black boxes represent the places where depth measurements were taken and the black line the trajectory of the research vessel (Depestele *et al.* 2016, 22).

Indirect impacts on the seabed

The direct impacts on the seabed caused by the kilometer-long trawling hauls also instigate indirect impacts affecting the local geology of the seabed. One of these indirect impacts is the change in hydrodynamic processes, following the figurative vacuuming of the seabed, which removes all benthic life and leaves a barren wasteland (Maarleveld 2020, 523). Moreover, the estimated recovery time of the seabed sediments after a single trawling activity is close to a year, therefore, multiple fishing trips per year in the same location disturb the seabed even more (Rijnsdorp *et al.* 2020, 1777). This might lead to persistent hydrodynamic changes eroding some parts of the seabed even deeper than the initial impact of the beam trawls. Another indirect impact due to bottom trawling is the resuspension of sediments caused by the hydrodynamic drag of the fishing gear (Rijnsdorp *et al.* 2020, 4). The suspended particles, consisting predominantly of silts, are eventually redeposited back on the seabed. This form of sedimentation affects the seabed morphology, changing hydrodynamic conditions, but also covers organic matters, such as seagrass, of which the loss leads to a decreased seabed integrity, as described in the third chapter (p.34)(Eigaard *et al.* 2016, 16; Rijnsdorp *et al.* 2020, 13). Furthermore, it is very likely that as a consequence of trawling, sediments are being piled up forming heaps of deposits on the seabed, creating artificial sand waves.

The scale of the impact

Due to the large demand for bottom-dwelling (demersal) fish, the rate at which the Dutch North Sea seabed is ploughed is problematic. According to recent (2019) numbers, there are, at least, 291 Dutch trawling vessels active in the North Sea (agrimatie.nl). The older vessels, so-called cutters, have been active for more than 20 years in the North Sea. Relatively recent numbers show that they trawl between 40 and 90% of the entire seabed at the surface level and between 25 and 80% at the subsurface level (Eigaard *et al.* 2016, 8). Since these percentages account for the entire North Sea basin, the footprint (scale of impact) on the Dutch seabed, which is among the easiest to trawl surfaces, is even as high as 93% (Eigaard *et al.* 2016, 12). These percentages correspond to the Seabed Integrity (SBI) values calculated and published by Eigaard *et al.* (fig. 4.4). However, Dutch fishermen alone aren't responsible for these high percentages. Important to know is that the Dutch territorial waters are not only accessible to Dutch fishing vessels but also fishing vessels from neighbouring countries. Each neighbouring country has an agreement with the Dutch government in what region and which species to fish. For instance, Belgian and French fishermen may fish for all species of fish, but the Belgians are allowed to fish closer to the coast. German and Danish fishermen, on the other hand, are restricted to demersal fish species and fishermen from the United Kingdom are only permitted to fish north of the Frisian islands (noordzeeloket.nl).

Impact on the prehistoric landscapes

Obviously, the beam trawling technique does not disturb fish alone, but also any object that protrudes or remains close to the seabed surface, resulting in the discovery of large fossil bones, such as shown in fig 4.2. In a way, prehistoric deposits will be filtered by the nets of the fishing vessels, as the mesh size of the net is too large to collect small (fossil) bones or lithic artefacts.

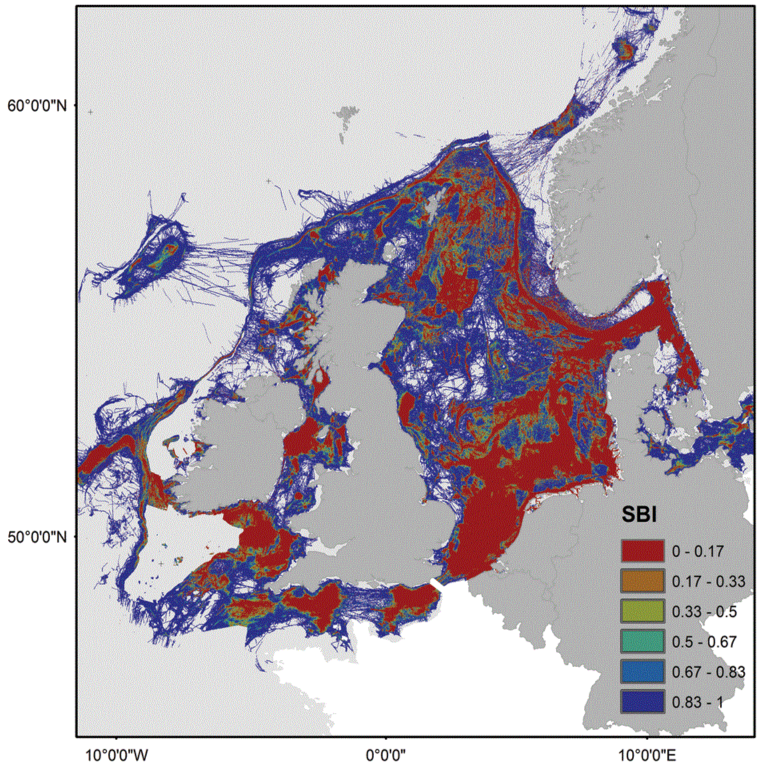


Figure 4.4 - SeaBed Integrity (SBI) values corresponding to subsurface trawling intensities (sediment abrasion ≥ 2 cm) in the Atlantic, British and North Sea. The SBI ranges between 0 (where all taxa is potentially impacted) and 1 (where none of the taxa is impacted). The light grey areas show grid cells that were untrawled (Eigaard *et al.* 2016, 13).

This of course could lead to false assumptions regarding the prehistoric biodiversity or hominin behaviour. Moreover, whether these large-scale physical disturbances touch upon the prehistoric remains buried in the seabed not only depends on the character of the disturbance but also on local stratigraphic and oceanographic conditions (i.e. the presence of preserved and shallow prehistoric deposits)(Ward 2014, 213). Since the large numbers of fossils and (in fewer cases) artefacts resurface during kilometer-long fishing hauls, it is hard to determine the exact location from which these finds derive (Peeters *et al.* 2019, 41). Yet, a good attempt is to consult with fishermen to identify zones that yielded many finds across the years (Peeters and Amkreutz 2020, 160). One of the zones is the Brown Bank area, situated far west in the Dutch North Sea territory (fig. 4.5). This area is therefore an excellent case study to illustrate the relation between the fishing industry and the submerged prehistoric landscapes.

The Brown Bank area

The Brown Bank is a ca. 35-kilometer long sand ridge, situated between the Dutch and British coast some 80 kilometres off IJmuiden. The area surrounding the Brown Bank is characterised by a great number of sand ridges, of which the Brown Bank is the tallest, with its top 16 meters below sea level, approximately 10 meters taller than the rest of the surrounding sand ridges, and having a gully measuring 40 meters deep on the eastern side of the ridge (fig. 4.5)(Missiaen *et al.* 2021, 142). The Brown Bank area most likely formed during the Late Pleistocene and was subsequently covered by Holocene deposits, as can be deducted from the lithostratigraphic units encountered during geophysical and geotechnical surveys by Missiaen *et al.* 2021. These surveys indicate that the Pleistocene deposits belong to the Yarmouth Roads Formation (Elsterian) and the Brown Bank Formation (Weichselian)(Vonhögen-Peeters *et al.* 2016, 19 & 23). Interestingly, the upper part of the Pleistocene deposits possibly does not relate to the marine Brown Bank formation, but might represent periglacial deposits from the very final part of the Weichselian (Missiaen *et al.* 2021, 148). The Holocene deposits consist of the Naaldwijk Formation, deposited during the transgressional phase in the early Holocene, and Nieuwkoop Formation, associated with the formation of a basal peat layer, both of which are covered by a thin layer of mobile seabed (Southern Bight Formation)(fig. 4.6)(Vonhögen-Peeters *et al.* 2016, 14-15).

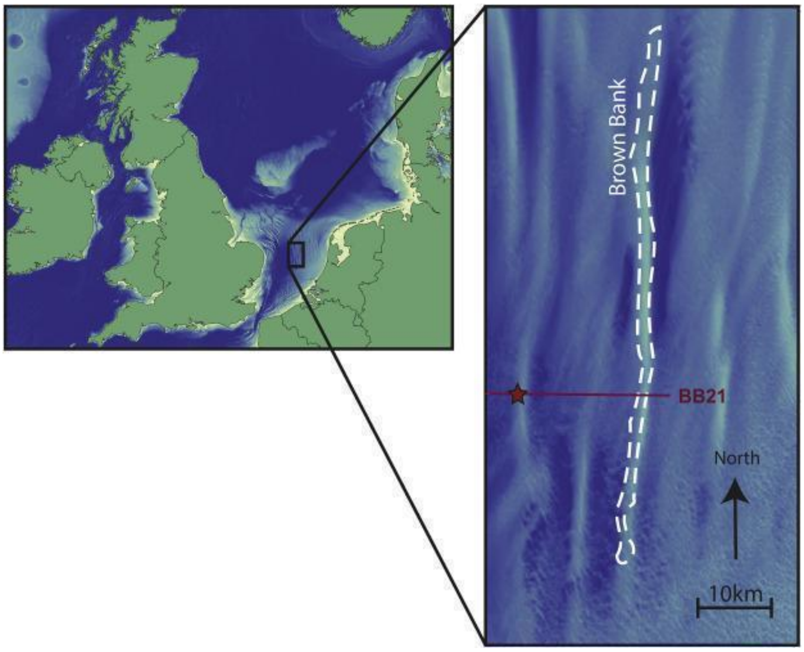


Figure 4.5 - the location of the Brown bank in the North Sea, the red line and star represent the localities of the acoustic and geotechnical survey completed by Missiaen *et al.* (Missiaen *et al.* 2021, 142).

What is clear from the acoustic survey is that especially the slopes of the sand ridges are influenced by erosion. The mobile seabed, as well as the different formations buried underneath, are in erosional contact with each other (Missiaen *et al.* 2021, 145). This means that the early Holocene deposits and the Late Pleistocene deposits are at risk of being exposed on the seabed. Furthermore, as there is only a thin layer of mobile seabed sediments covering these deposits, it is likely that these areas will be affected by current fishing methods, notably, by beam trawling. This has already been proven by the large number of fossils and archaeological objects deriving from this area, which resulted in a great variety of archaeological finds throughout the last decades. These include predominantly Mesolithic worked bone and antler tools such as shafthole picks, axes, adzes, but also lithic artefacts (Peeters and Amkreutz 2020, 160). Additionally, these finds are often accompanied by lumps of peat, containing reeds, pieces of wood, and bone, each perfectly preserved. The presence of peat implies the existence of salt marsh deposits belonging to the Nieuwkoop Formation that demonstrate not only the high potential of preservation for Mesolithic organic artefacts, but also the preservation of Upper Palaeolithic in-situ remains (Missiaen *et al.* 2021, 147). One of the most famous finds coming from the Brown Bank area, the already mentioned decorated bison bone, attributed to the Upper Palaeolithic Federmesser culture, is an example of the latter (Amkreutz *et al.* 2018, 22). Yet, this also means that not only Holocene deposits are situated close to the seabed surface, but Late Pleistocene deposits too, and therefore they could be affected by frequent trawling activities. On the other hand, the fossils and prehistoric artefacts most likely derive from the gullies next to the sand ridges, which indicates that they are not coming from an in-situ environment, but rather from an accumulation of derived material at the bottom of the gullies (Missiaen *et al.* 2021, 113). However, despite the lack of a contextual value, the artefacts themselves still hold a number of scientific values, relating to the study of isotopes, dating techniques, comparative morphology studies, mass spectronomy, and ancient DNA research (Missiaen *et al.* 2021, 141). Therefore, the analysis of the paleontological and archaeological finds encountered during fishing trips in the vicinity of the Brown Bank is very important for the reconstruction of the early Holocene and Late Pleistocene landscapes.

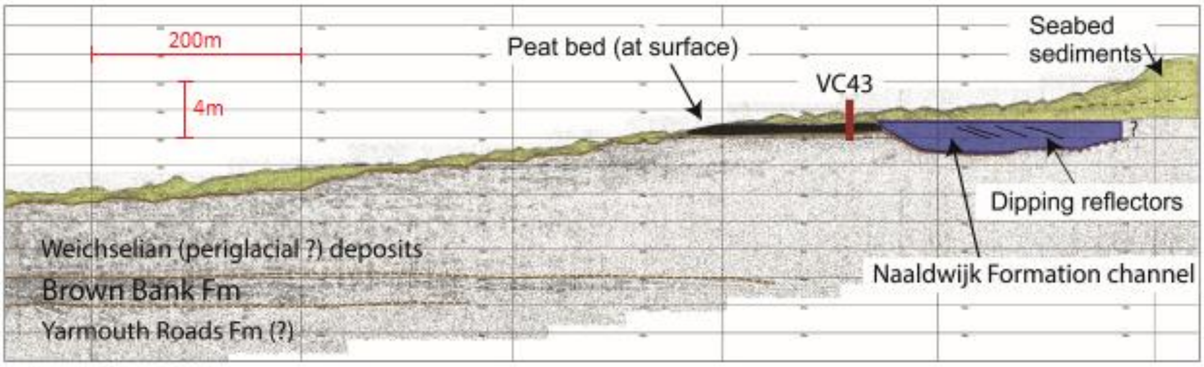


Fig 4.6 - Coloured cross-section of the lithostratigraphic units, showing the top part of the brown bank (right) and its western slope (left), recorded with a parametric echosounder during the acoustic survey (sub bottom profiling) of Missiaen *et al.* 2021 (Missiaen *et al.* 2021, 145).

Potential benefits for the prehistoric landscapes

Even though much of the prehistoric remains could be damaged or moved during the fishing hauls of trawling vessels, the finds that are retrieved are of major scientific significance, since they are the scarce tangible evidence for prehistoric occupation of Doggerland coming from this rather inaccessible environment (Maarleveld 2020, 532). Often these finds are being recognized by attentive fishermen that regularly have their own collection of predominantly Pleistocene fossils, either for the sake of collecting or to sell them to interested parties. These fishermen prove to be an asset to the scientific community since they know a lot about the offshore environment and have a real interest in prehistoric paleontological and archaeological remains, which could lead to them sharing their finds and possibly being partners in research initiatives (Maarleveld 2020, 533). A great example is the publication of the find of the decorated bison bone, where fishermen Albert Hoekman and Klaas Post recount their first encounter with the artefact (Amkreutz *et al.* 2018, 43).

Conclusion

Until today, fishing grounds such as the Brown Bank area built a repertoire of providing fossils and archaeological objects that originate from submerged early Holocene and late Pleistocene deposits, eroding at the slopes of the large sand ridges. Although it is clear that current fishing methods affect this environment to a certain extent, due to the resurfacing of these remains, it is unclear whether these prehistoric objects derive from an in-situ or derived context. A better understanding of the seabed stratigraphy and the oceanographic conditions affecting these deposits provides the bedrock for contextualizing archaeological finds, encountered during fishing hauls, and predicting the location of preserved submerged prehistoric landscapes. Yet, in the meantime the use of the beam trawls further threatens the submerged prehistoric deposits, especially in frequently trawled areas, where local oceanographic conditions could further damage these remains.

Figure 4.7 - Spatial representation of the sand extraction reserve area (shades of green) and areas reserved for other offshore industries (noordzeeloket.nl).

Sand and aggregate extraction

The North Sea seabed is a well-known depository of sand, gravel, and shells, each of which can be used in a variety of ways. Of these surface minerals, sand is extracted the most. The large amount of extracted sand is a result of the demand in replenishment sand needed for coastal reinforcements and sand needed for the production of concrete and foundation (Ministry of Infrastructure and the Environment and Ministry of Economic Affairs 2015, 44). Sand extraction from the seabed is generally preferred over sand extraction on land. This is due to the availability of the supply and the smaller effect on the offshore physical and social environment, compared to the onshore environment (noordzeeloket.nl). Among the countries connected by the North Sea, the largest amount of offshore sand is removed by the Netherlands (Ministry of Infrastructure and the Environment and Ministry of Economic Affairs 2015, 44). The extraction on Dutch territory adds up to about 25 million m^3 every year, with an equal division of replenishment sand (+/- 12 million m^3) and fill sand (+/- 13 million m^3). However, this amount excludes major coastal replenishment projects and harbor extensions, such as the Zandmotor (+/-21.5 million m^3) and the Maasvlakte 2 (+/- 180 million m^3)(noordzeeloket.nl). Bordering countries, including Great Britain and Belgium, extract significantly less. Their combined sand extraction (per year) amounts to about half of the volume removed on Dutch territory (GB: 8,5 million m^3; BE: 3,5 million m^3)(The Crown Estate licences 2019, 12; Federale Overheidsdienst Economie 2020, 20).

To cope with the demand in replenishment and construction sand, the Dutch government designated a zone between the established NAP -20m isobath and the border of the territorial sea (12 nmi) along the entire length of the coastline, to be used as sand extraction zone (fig. 4.7) (noordzeeloket.nl). In this roughly 6 nmi wide zone the sand extraction is given priority over other offshore industries, such as the fossil and renewable energy industry (Ministry of Infrastructure and the Environment and Ministry of Economic Affairs 2015, 89). The landward boundary (established NAP -20m isobath) of the zone was selected for reasons of ecology and safety since extracting sand from the coastal sand buffer would harm the coastal defence. The seaward border, on the other hand, is set along the border of the territorial sea and while it could be extended, it is for the offshore dredging companies more profitable to obtain the sand closest to the shore, in light of transportation costs (Haasnoot *et al.* 2018, 35).

The scale of gravel and shell extraction, on the other hand, is much smaller compared to sand extraction. For instance, extraction of shells is limited to a quota of 165.000m³ per year, as the amount of shells removed is not allowed to surpass its natural accretion (Van Duin *et al.* 2017, 30). Regarding gravel extraction, the scale of extraction is even smaller, as hard substrates currently cover only 1% of the Dutch seabed (Ministry of Infrastructure and the Environment and Ministry of Economic Affairs 2012, 30). For this reason and due to financial considerations, the import of gravel, as well as the extraction of gravel from the Meuse and Rhine, is generally preferred over offshore mining.

Direct impacts on the seabed

During a sand extraction operation, a dredging company deploys a trailing suction hopper dredger to withdraw sand from the seabed. A trailing suction hopper dredger extracts sand from the seabed using a draghead and a large suction hose to pump the extracted mineral into its hold (fig. 4.8). This typical method of sand extraction creates 2 to 3 meter wide and 0.5 meter deep furrows, each extending for several kilometers in length or concentrated in a specific area (Cooper and Brew 2013, 75). The draghead is about a meter in diameter and allows the collection of very fine-grained to very coarse-grained material (vanoord.nl). On the other hand, the objects in the seabed that are of a greater diameter than the draghead and suction hose, are occasionally forced deeper into the sediment matrix, resulting in a physical disturbance of the stratigraphic units, which eventually leads to the formation of lag deposits (Kuitems *et al.* 2015, 387).

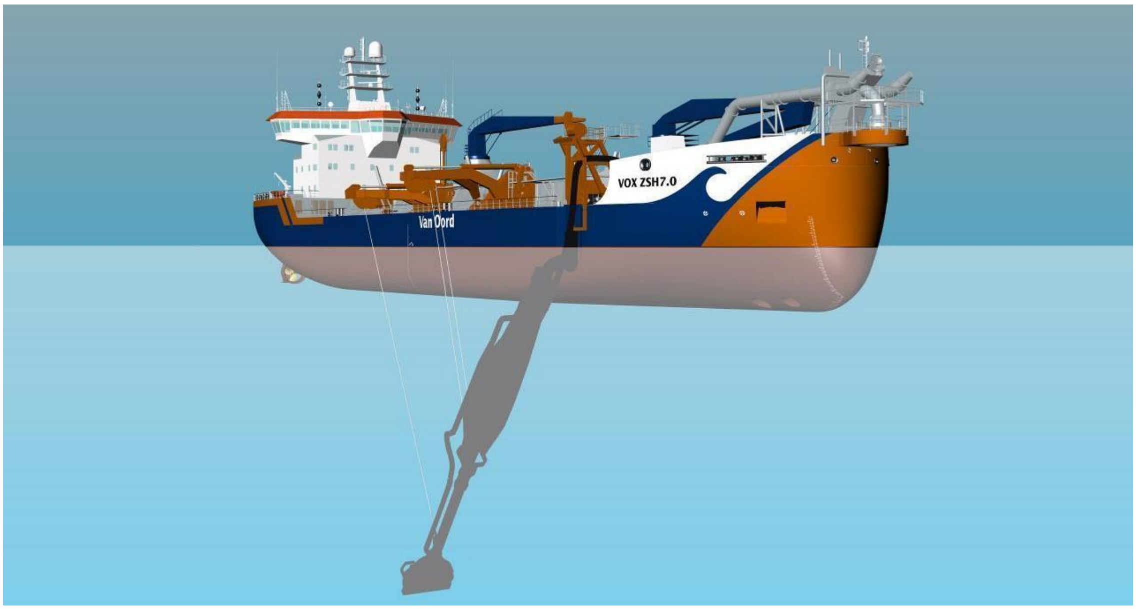


Figure 4.8 - Illustration of one of Van Oord’s newest trailing suction hopper dredgers (vanoord.nl).

After extraction, the sand is transported to its destination. The sand to be used for construction and infrastructure is transported to the wharves, where it is loaded from the quay onto the stockpile using scraping buckets or bucket wheels to distribute the sand on the conveyor belts (Newell 2013, 20). For coastal reinforcements, the hold can be emptied in four different ways. The sand is either released close to the coastline by opening the hatches to the hold, transported by floating pipes to the discharge area itself, pumped back through the suction hose and draghead, or showered into the sea in a process called rainbowing (fig. 4.1)(vanoord.nl). Sometimes, shell and other aggregates are similarly collected by specialist trailer suction hopper dredgers too, but more often smaller clamshell or scallop dredges to obtain the coarse aggregates (Newell 2013, 43).

Indirect impacts on the seabed

While the above-mentioned direct impacts on the seabed have been caused by the equipment used during the process of sand extraction, the indirect impacts extend beyond the initial footprint of the extraction and continue to affect the seabed afterwards. For instance, the changes in bathymetry, brought about by the suction hoses of the dredger, can reshape the existing wave, tide, and sediment regimes, which generates increased erosion and sedimentation in a much larger area than the designated extraction zone (Cooper and Brew 2013, 78). This process can pose a threat to the prehistoric artefacts in the vicinity of the extraction area by increasing the chance of exposure that subsequently leads to degradation or disturbance of the object. In addition to the changes in bathymetry, the transportation of the extracted sands create another indirect impact: As a consequence of the release of water, that accompanied the sediments into the hull of the ship, columns of cloudy water, called ‘density plumes’, are formed that continue to accumulate until arrival to the final destination (fig. 4.9)(Cooper and Brew 2013, 78; Van Duin *et al.* 2017, 61).

Figure 4.9 – Release of excess water from the hold during the extraction process, which leads to the formation of density plumes (iadc-dredging.com).

The suspended particulate matter is eventually redeposited on the seabed, although the exact location depends on the grain size of the sediments; coarse material sinks almost instantly, whereas fine-grained sediments will blanket the seabed up to 20 kilometres from the sand extraction site (Spearman 2015, 261).

Impact on submerged prehistoric landscapes

During the process of sand extraction, transportation, and suppletion, the seabed is significantly affected and as a consequence, the submerged prehistoric landscape is likely to be impacted as well. Yet, the submerged prehistoric landscapes can only be affected when the sand extraction activities reach stratigraphic levels containing prehistoric remains (Ward 2014, 213). To shed light on the effect of the sand extraction activities on these deposits, a case study will be made of the port construction of the *Maasvlakte II*, where a lot of dredged sand was needed for the construction of the new port, posing a significant threat to submerged prehistoric remains.

Maasvlakte II

From 2008 to 2013, a large-scale expansion of the port of Rotterdam called *Maasvlakte II* was constructed. In order to facilitate a larger number of container ships, new land was created in addition to the earlier realized *Maasvlakte I*, increasing the size of the port by 2000 hectares. For the land reclamation, an enormous quantity of 180 million m³ of sand was extracted from the seabed approximately 10 kilometers off the coast of Hoek van Holland (Kuitems *et al.* 2015, 355). The extracted sand was dredged from two sand extraction pits within a designated sand extraction zone located on the southern side of the *Eurogeul*, the direct shipping route to the port of Rotterdam (fig. 4.10).

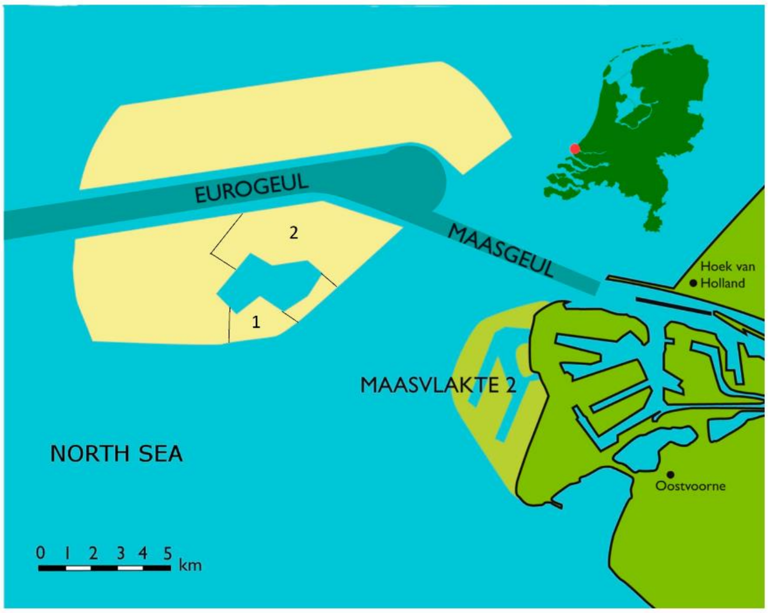


Figure 4.10 - Location of the sand extraction zone (pale yellow) and the two sand extraction pits (1 and 2) that were used to obtain sediments to construct the Maasvlakte II port expansion (after Mol *et al.* 2018, 2; Kuitems *et al.* 2015, 358).

The two pits were dug out using trailing suction hopper dredgers that continuously withdrew sediments until approximately 10m of sand was obtained from the first pit and 20 meters of sand was extracted from the second pit, deepening the seabed to -30m (pit 1) and -40m (pit 2) NAP (fig. 4.10). Afterwards, the sediments were transported to their destination and re-deposited on the site through floatable pipelines and the process of rainbowing (Kuitems *et al.* 2015, 358). As a result of these sand extraction procedures, Palaeolithic and Mesolithic submerged landscapes were threatened, this is demonstrated by both earlier discoveries of artefacts and palaeoenvironmental information (e.g. animal fossils and peat) during fishing and dredging activities around the Eurogeul, as well as artefacts found on the beaches of both the earlier constructed Maasvlakte and later Maasvlakte II itself (Manders *et al.* 2008, 21; Kuitems *et al.* 2015, 391).

To understand where these finds came from and assess the impact of the sand extraction on these prehistoric remains, an extensive geo-archaeological project was carried out, which included geophysical and geotechnical research, as well as targeted fishing trips and systematic surveying of the artificial beach by both manual and mechanical (Mega Beach Cleaner) beachcombing (Peeters and Amkreutz 2020, 163). The geotechnical surveys described the lithostratigraphic units present in the research area: Holocene deposits include the Southern Bight Formation and the Naaldwijk Formation. The Pleistocene deposits buried beneath consist of several different members of the Kreftenheye Formation and the Urk Formation (fig. 4.11)(Busschers *et al.* 2013, 9-13).

Lithostratigraphic Unit	***Base of the deposit (m – NAP)***	***Prehistoric Period***	***Possible prehistoric remains***
Southern Bight Fm.	*26-29*	*Mesolithic and later*	*Derived (re)worked flint, bone, and wooden artifacts*
Naaldwijk Fm.	*28 – 30*	*Mesolithic and Upper Palaeolithic*	*Derived (re)worked flint, bone, and wooden artifacts, possible in situ sites*
Kreftenheye Fm. (Wijchen member)	*27,5 - 31*	*Mesolithic and Upper Palaeolithic*	*Derived (re)worked flint, bone artifacts, possible in situ sites*
Kreftenheye Fm.	*28 – 42*	*Middle Palaeolithic*	*Derived (re)worked flint, bone artifacts*
Urk Fm.	*>47*	*Middle to Lower Palaeolithic*	*Derived (re)worked flint, bone artifacts*

Figure 4.11 - Defined lithostratigraphic units within the sand extraction zone (after Busschers *et al.* 2013, 14; Kuitems *et al.* 2015, 370; Vonhögen-Peeters *et al.* 2016).

Figure 4.11 shows the lithostratigraphic units within the sand extraction zone defined during the geotechnical survey. However, as it was impossible to cover the entire research area, it is possible that some units or sub-members could have been missed. For instance, peat block clusters identified during the geophysical research and subsequently hauled by the trawling survey indicate the presence of a transitional zone between two different deposits. Besides that, it marks the preservation potential of the units directly beneath the peat bed (Wiersma and Mesdag 2013, 12). Moreover, they also suggest a favourable environment for human occupation, especially during the Mesolithic (Vonhögen-Peeters *et al.* 2016, 16).

The geophysical and geotechnical research of the sand pits were executed shortly after the sand extraction had been completed. Due to this timing, the boreholes could penetrate deeper into the seabed than usual, as there were no recent Holocene deposits in the way (fig. 4.12)(Busschers *et al.* 2013, 5). This provided the perfect opportunity to assess the impact of the trailing suction hopper dredgers on the seabed sediments. These studies concluded that the Southern Bight, Naaldwijk, and Kreftenheye formations, had been disturbed considerably. This was indicated by the fact that the WNW facing sand waves pattern was disrupted at the slope of the pit. Furthermore, the bottom of the pits showed an irregular accumulation of sediment heaps, resulting from either drag head impacts or slope processes (Kuitems *et al.* 2015, 369). On the other hand, the disturbance caused by the sand extraction activities predominantly takes place at the top of these sedimentary deposits, which makes the identification of the lithostratigraphic units possible (Busschers *et al.* 2013, 8).

Artefacts that were present in the top layers of these deposits, such as stone, bone, and wooden artefacts, could have been displaced and mixed into the volume of dredged sand in the hull of the ship, which led to the loss of relationship between the artefacts and their initial context (Missiaen *et al.* 2016, 16). Even disseminated artefacts (displaced before the intervention of sand extraction) were at risk of losing valuable information. Although they did not lose their in-situ context, they might still lose the link to the derived sediments, which can be an important proxy to establish the original context (Firth 2013b, 51). On the other hand, as mentioned at the direct impacts, objects too large to fit through the draghead (e.g. large Pleistocene fossils) could have been forced down through deeper deposits. This may have led to damage to the object itself, damage to other artefacts, and mixing of deposits, resulting in loss of contextual information (Kuitems *et al.* 2015, 387). After extraction, prehistoric artefacts, including worked bone and wood, were at risk of being damaged during storage and subsequent transportation of the extracted mineral. This is the case when the dredged sediments were loaded into the hold since the erosional forces of the moving sand stir the artefacts in between the coarser material and the finer material that separate during the process of deposition in the hold of the dredging vessel (Newell 2013, 19). Finally, during the coastal reinforcements, the artefacts that were present in the matrix could have been damaged when transported through the pipes that distribute the sand at the construction area. Organic artifacts along with lithic material could be damaged or even shattered through the force at which the matrix is coming out of the pipeline. Although this is suspected, no academic evidence has been provided yet.

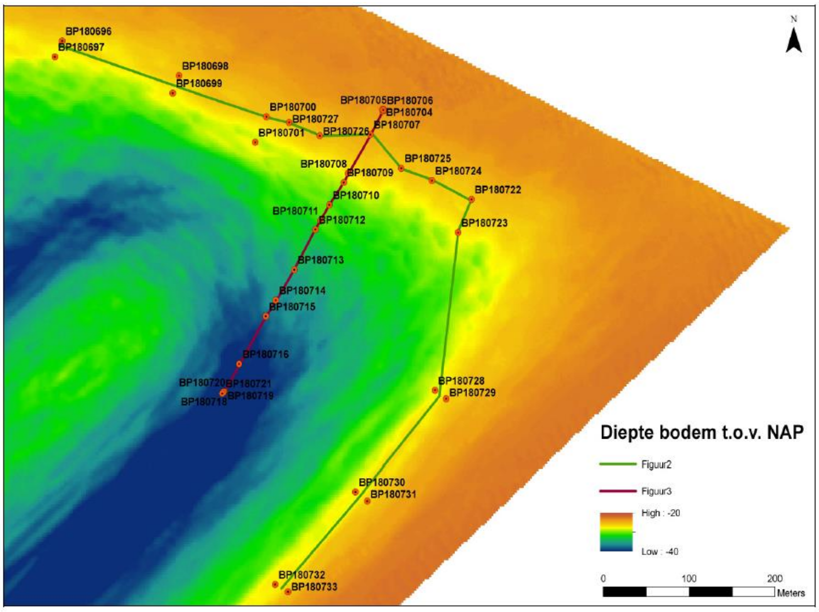


Figure 4.12 - Bathymetric map showing the seabed disturbance as a consequence of the sand extraction activities and displaying the locations of the boreholes executed during the geotechnical survey afterwards (Busschers *et al.* 2013, 4).

Impacts shell and aggregate extraction

The impact of the shell and aggregate extraction is far less extensive compared to the impact from the sand extraction. As shells are extracted closer to the shore; seawards in waters deeper than -5m NAP (noordzeeloket.nl). With this proximity to the coast, the effect on the submerged prehistoric landscape is most likely restricted to the near-shore Mesolithic remains, deposited at the time of the youngest coastal transgressions (Newell 2013, 43). Even so, these potential archaeological deposits are expected to be covered by a thick recent mobile seabed and are therefore not prone to disturbance. Besides that, the scale of impact is minimal in comparison to the sand extraction.

Potential benefits for the submerged prehistoric landscapes

Even though a large number of prehistoric remains will be moved or destroyed during the sand extraction process, the finds that have been encountered during the beach-combing project or afterwards by people visiting the beach of Maasvlakte II, are of major scientific significance, since they are scarce tangible evidence of prehistoric occupation coming from this rather inaccessible environment (Maarleveld 2020, 532). Besides that, the dredging contractor provided a list of all the locations where the suction hopper dredgers extracted the sand and where they deposited it, thereby making it possible to retrace the origin of some of the artefacts found on the beach (Kuitems *et al.* 2015, 387). In combination with the development of a website called 'oervonstchecker', where this information is assembled, a beach-stroller can upload a picture of his/her encountered artefact or fossil and add the location where it was found, to be provided with a determination and a crude date by either an archaeological or zoological specialist (oervondstchecker.nl). Moreover, with both small- and large-scale sand extraction projects, a series of detailed, geophysical, and geotechnical surveys provide data to complete a piece of the geomorphological puzzle of the North Sea basin. This data is available for archaeologists to interpret and conduct future research on (Pater 2020, 514). Besides that, there are benefits as a result of the (in)direct impacts, that initially might have disturbed prehistoric deposits: Although the sand extraction pit will increase the rate of erosion in some parts of the seabed, conversely, it will also aid prehistoric deposits by covering them at an increased rate of sedimentation.

Conclusion

Each year, large quantities of sand are extracted from the Dutch seabed. Employing trailing suction hopper dredgers, the mineral is systematically dredged from seabed sediments within a designated sand extraction zone, where sand extraction is given priority over other offshore industries. Yet, this designated zone, situated between the established NAP -20m isobath and the border of the territorial sea, crosses areas of the seabed that contain archaeologically interesting deposits. The fact that these prehistoric deposits are at risk, is demonstrated by the enormous quantities of archaeological finds encountered by beach-strollers and the public visiting the newly formed beaches of the *Maasvlakte II* and the *Zandmotor.* The prehistoric sediments have been subject to the direct impacts of the sand extraction, including the voyage through the drag heads and suction pipes, into the holds of the extraction vessels and subsequently deposited on the beaches, through similar pipes and the process of rainbowing. The question whether the finds within these sediments are being damaged during the process of sand extraction and suppletion remains largely unanswered, but certainly, the original context has been disturbed significantly. Furthermore, indirect impacts, such as erosion induced by the changes in bathymetry, could expose prehistoric deposits even further and increase chances of impact by other offshore industries, notably demersal trawl fishing. On the other hand, additional research on the prehistoric landscapes, as a consequence of the sand extraction activities, increases our understanding of the prehistoric periods. Besides that, according to my own experience, it is exciting and educational to discover fossils and artefacts on the artificial and replenished beaches of the Netherlands. After all, more people come into contact with prehistoric remains and this increases the public value of our prehistoric environment.

Offshore wind industry

In early 2016, 28 member states of the European Union signed the United Nations Climate Agreement of Paris 2015. This agreement was developed as a response to the findings of the Intergovernmental Panel on Climate Change (IPCC), which stated that if global warming is limited to a temperature rise of 2 degrees (preferably 1.5 degrees) Celsius, consequences will be severe but manageable (IPCC.ch). As a result, 196 countries (including 28 EU member states) agreed to follow the advice of the IPCC and signed the Paris Climate Agreement in 2015, in order to 'keep the increase in the global average temperature to well below 2°C above pre-industrial levels and pursue efforts to limit the temperature increase to 1.5°C' (United Nations 2015, 3 (Art. 2(a)). To achieve this goal, the EU member states set a target to cut 40% of the greenhouse gas emissions in relation to 1990 and develop at least a 32% share for renewable energy by 2030 (ec.europa.eu). Keeping true to these ambitions and even raising the stakes, the Klimaatwet (Climate Law), signed by the Dutch government, is set to reduce the CO^2 emissions to 49% of the CO^2 emissions in 1990, by 2030 and reach a reduction of 95% by 2050 (Raad van State 2020, Art. 2(2)).

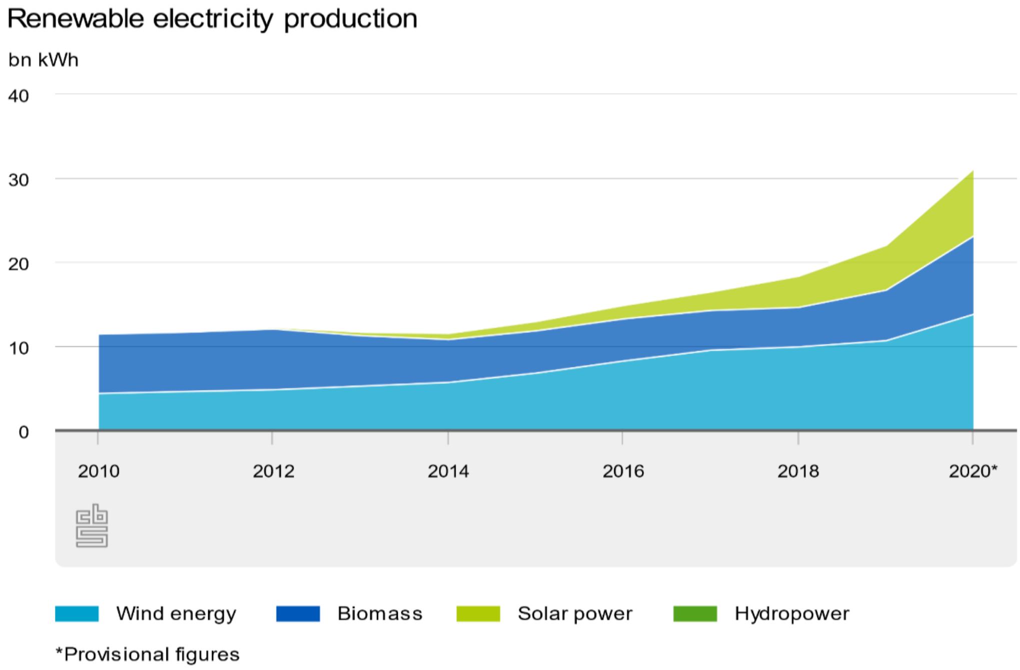


Figure 4.13 - A decade of developments in renewable electricity production, measured in power capacity (cbs.nl).

The provision of energy plays a pivotal part in a sustainable future. Therefore, the Dutch government wants that by 2030 at least 27% of all used energy in the Netherlands will be coming from renewable and sustainable sources. Progressing to 2050, the supply of energy should become emission-free (rijksoverheid.nl). For renewable energy, wind power has become the main (45%) source in the Netherlands in the past decade (fig. 4.13)(cbs.nl). Newly constructed wind farms join the traditional windmills to become a quintessential part of the Dutch landscape. In recent years, the demand for new wind farm areas has increased a lot and because there is a limit in space for large-scale wind farms on Dutch soil, a solution was found in the North Sea.

The North Sea is an excellent area for the production of wind energy for a couple of reasons: First of all, the wind at sea blows faster and more consistently offshore than onshore. This is due to the lack of obstacles the wind has to pass. Second, the depth of the seabed varies between 20 and 30 meters, which doesn't complicate the construction of the numerous wind turbine foundations. Last, the windfarms are in the vicinity of the ports of Rotterdam and IJmuiden and proximity to other large industrial areas, where energy can be supplied straight to the large industrial consumers (rijksoverheid.nl). Therefore, Offshore renewable wind energy can play a significant role in the transition to a sustainable future of energy production. However, it is not possible to fill the entire North Sea with wind farms. Even though the sea seems like a vast and empty space, it is one of the busiest shipping lanes in the world. Therefore, according to the Dutch government, the combination of both onshore and offshore wind power generation is the right path towards a sustainable future.

To date, six offshore wind farms are in operation (fig. 4.14). The first one to be put to use was Egmond aan Zee (OWEZ) in 2007. The 36 3-megawatts (MW) wind turbines are located six nautical miles (nmi) off the coast of Egmond and Zee and jointly they generate a power capacity of 108 MW. In 2008, the second offshore wind farm was opened: The Prinses Amalia windpark (120 MW). Luchterduinen (129 MW) was opened in 2015. The fourth and fifth wind farms, the Buitengaats and Zee-Energie, jointly called the Gemini wind farm (600 MW), were opened in 2017. Recently, the largest and most impressive wind farm was put into use: The windfarm Borssele (1502 MW)(fig. 4.14). Every following windfarm constructed better developed wind turbines, increasing in height from 120m to 200m, and increasing in generated power from 2 MW to 9.5 MW. Combined, the 462 wind turbines generate an amount of nearly 2.5 gigawatt (GW), which translates to ten Terawatt-hours (TWh) per year, enough to supply nearly 2.8 million homes in the Netherlands (rijksoverheid.nl; windopzee.nl; noordzeeloket.nl).

The industries' footprint

The offshore wind farms operational today and the planned wind farms of the future jointly cover a significant part of the Dutch North Sea. As is evident from assessing the prehistoric potential map (fig. 3.7), many of the current and future wind farm sites cut across areas containing potential Palaeolithic and Mesolithic remains. These remains within the seabed will be impacted to a certain extent during the process of installing, maintaining, and decommissioning the large number of wind turbines offshore. However, even though the areas seem vast, the actual impact on the seabed is limited to localized and relatively thin penetrations of the seabed (Peeters *et al.* 2019, 26).

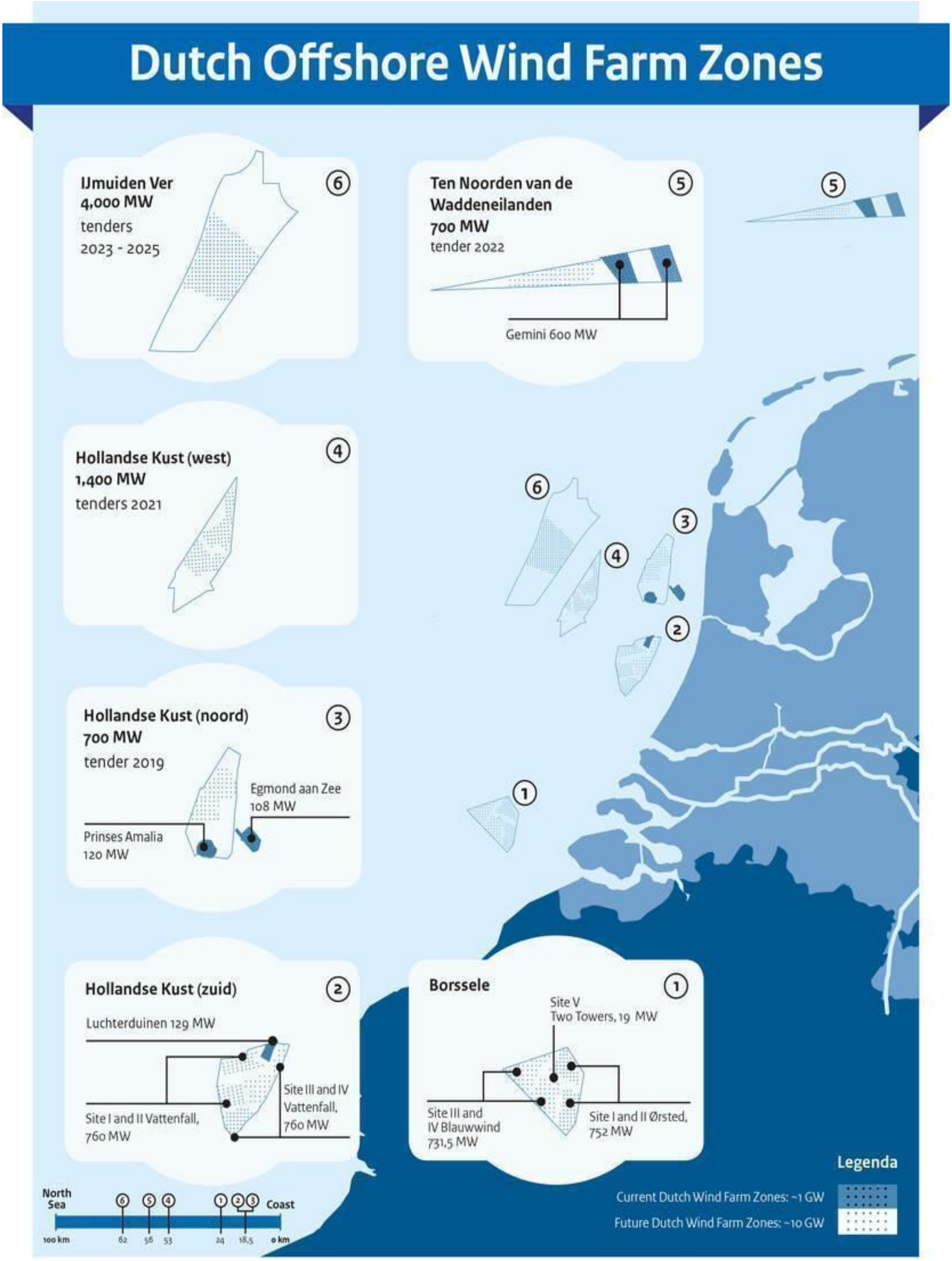


Figure 4.14 - Road map for the development of offshore wind farms, including currently operational wind farms, provided by the Dutch government (government.nl).

To gain insight into the extent of direct impact caused by the offshore wind farm industry on the seabed, it is imperative to understand the operations taking place during the construction, maintenance, and decommissioning of the wind farms. Only then, one will acquire a complete picture of the industries' footprint on the seabed. However, the offshore wind industry is a highly innovative industry; new turbine designs and additional construction procedures are incorporated swiftly. These innovations and their impact on the submerged prehistoric landscape will be discussed in the following chapter. Even so, it is possible to gather a basic understanding of offshore turbine installation by giving a short description of the installation process in its most basic form. The subsequent steps describe the general offshore installation process concerning the direct impacts on the seabed. They, therefore, do not represent a complete installation process. These are generally the last big steps taken after years of lobbying, research, tendering, components production, and other preparations:

1. **Site prospecting** includes the collection of site-specific environmental data through a geophysical and geotechnical survey (Department of Energy and Climate Change 2016, xvii).
2. **Site clearing** includes the detection of obstructions situated within the site that if necessary will be cleared from the site, for instance, Unexploded Ordnance (UXO) and removal of old cables and pipelines (Department of Energy and Climate Change 2016, xvii).
3. **Installation of meteorological (Met) mast(s)** includes the placement and piling of the mast, using a monopile construction, executed by a specialized jack-up vessel (BVG 2019, 26). The monopile foundation measures between 4-7 diameter and reaches a depth of 20-30 meter (geminiwindpark.nl).
4. **Seabed preparation before the foundation** includes placing scour protection in the form of a layer of rocks that surrounds the foundations (fig. 4.15)(BVG 2019, 70). A flexible fallpipe vessel (transformed bulk carrier ship) deposits the layer of rocks, creating a large rock pad measuring 30 diameter and penetrating the seabed to a depth of approximately 1,5 meter (geminiwindpark.nl).
5. **Installation of export power cables** includes the trenching and subsequent burial of high voltage cables (220 kV) connecting an offshore substation to an onshore substation (BVG 2019, 58). The export cables should be buried at a depth where local hydrodynamics cannot reach, typically between 1-4 meter (BVG 2019, 90). The task at hand is completed by specialized cable laying vessels assisted by a Remotely Operated Vehicle (ROV) that digs a 2-3 meter wide trench and buries the cable simultaneously (fig. 4.15)(geminiwindpark.nl; BVG 2019, 94).
6. **Installation of Offshore High Voltage Station(s)(OHVS)** includes placing substation(s) in the middle of the designated wind farm grid, where it can aggregate the electricity generated by the wind turbines. At the OHVS the power is increased to match the export cables' capacity and then transferred to the shore (BVG 2019, 72). OHVS typically got a jacket foundation, secured by four poles puncturing 20-30 meter into the seabed (Augustyn *et al.* 2017, 4327)

7. **Installation of the monopile foundations and transition pieces** includes the placement and piling of steel monopiles into the scour protected seabed, using the cranes and piling equipment from a specializes jack-up vessel, after which the transition piece is placed on top of the monopile (see fig. 3.14)(BVG 2019, 82). The monopile is hollow with diameters ranging between 7-10 meter (10 meter for the largest wind turbines) and it penetrates the seabed to a depth of 30-40 meter (BVG 2019, 90; geminiwindpark.nl).
8. **Placement of scour protection** following the construction of the foundation includes another layer of rocks placed alongside the monopile itself (BVG 2019, 71). This layer of rocks does not extend more than a couple of meters from the monopile.
9. **Installation of array cables** connecting all the wind turbines in the grid to the offshore high voltage station(s), completed by specialized cable laying vessels assisted by a remotely operated vehicle (ROV)(BVG 2019, 61/94). The ROV trenches and buries the cables at a depth between 1-2 meter below the mudline (geminiwindpark.nl).
10. **Installation of the tower, nacelle, rotor hub, and blades** includes the placement of each of these components on the transition piece from a specialized jack-up vessel (BVG 2019, 97). A specialized vessel, such as the Van Oord's Aeolus, has four jack-up legs measuring 81 meter in length and 4.5 meter in diameter (fig. 4.15)(Van Oord 2018, 2).

figure 4.15 - Illustration of seabed preparation (left), monopile piling (middle), and cable laying (right) (geminiwindpark.nl).

Direct impacts

Assessing this list of procedures, the construction of an offshore wind farm is likely to affect a large part of the seabed, taking into account the number of turbines that need to be installed. Besides that, for each part of the process, the nature of seabed disturbance is variable. For instance, the trenching of export and array cables penetrates the seabed only rather shallowly (1-4 meter), while the piling of monopile foundations locally penetrates the seabed to between 30-40 meter below the mudline (BVG 2019, 90; geminiwindpark.nl). On the other hand, a much larger part of the seabed is affected by the burial of these cables in contrast to the piling of monopiles. To assist, the table in fig.

4.16 provides a general overview of the projected direct impacts in meters depth and in affected area (calculated using the dimension of length (l), width (w), and radius (r)) occurring during the installation of wind farms. Besides that, a distinction is made between primary direct impacts, where the primary footprint of an activity coincides wholly or partly with the seabed substrate, and secondary direct impacts, that occur from activities directly related to the development process, but are not intended as such (Wessex Archaeology 2007, 9).

Primary seabed impact	**Depth footprint (m – seabed)**	**Area footprint (m^2)** (Either $A = l \times w$ or $A = \pi r^2$)
Site prospecting (vibrocore sampling) (BVG 2019, 26; vliz.be)	5 - 10	0.0079 (r = 0.05 m)
Site clearing (removal obstructions)	unknown	unknown
Installation Met mast (monopile foundation) (BVG 2019, 26)	20 - 30	12.6 – 28.3 (r = 2 to 3.5 m)
Seabed preparation (scour protection) (BVG 2019, 70; geminiwindpark.nl)	1.5	706.2 (r = 15 m)
Trenching and burial export cable (by ROV) (BVG 2019, 90; geminiwindpark.nl)	1 - 4	2 - 3 m wide (area depends on distance)
Installation OHVS (jacket foundation) (Augustyn *et al.* 2017, 4327; BVG 2019, 86)	20 - 30	0.79 – 1.18 (r = 0.5 to 0.75)
Installation monopiles (by jack-up vessel) (BVG 2019, 90; geminiwindpark.nl)	30 - 40	38.5 – 78.5 (r = 3.5 to 5)
Installation array cables (by ROV) (geminiwindpark.nl)	1 - 2	1 m wide (area depends on distance)
Secondary seabed impact		
Impact Jack-Up vessel legs (Van Oord 2018, 2)	1 - 10	15.9 (r = 2,25)
Impact anchors of construction and maintenance vessels (Department of Energy and Climate Change 2016, 12)	unknown	unknown
Future decommissioning of Turbine foundations (BVG 2019, 122)	unknown	unknown

Figure 4.16 – Table containing the nature of impact (footprint) of each of the seabed impacting procedures, undertaken during the construction of offshore wind turbines, visualized in the depth of impact and the area of seabed affected.

Indirect impacts

Direct impacts, however, are not the only kind of impact on the seabed caused by the offshore wind industry. The process of installing turbines and the structures itself also bring about indirect impacts on the seabed. These indirect impacts extend beyond the initial footprint of the offshore wind industry and have, unlike the direct impacts, a continuous effect on the seabed (Wessex Archaeology 2007, 9). In the marine environment, this generally implies a change in hydrodynamics, increased erosion, and sedimentation of deposits in the direct surrounding of the newly installed structures. Specifically for the offshore wind industry activities, the indirect impacts include seabed scour around the foundations of installations and the suspension and deposition of sediments in the direct vicinity of the constructions (Ward 2014, 228; Boon *et al.* 2018, 34). Seabed scour is local erosion of the sediments around an installation secured to the seabed (monopiles, jackets, and cables) created by the acceleration of the currents around these installations (fig. 4.17)(flow-offshore.nl). Local scour can reach depths of 2 meter in the direct surrounding of the foundation and cause shallow erosion (max a couple of decimetres) extending up to 80 meter from a single pile (Clark *et al.* 2014, 11).

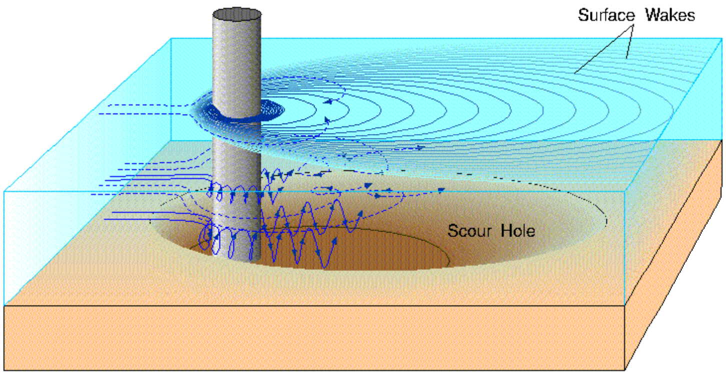


Figure 4.17 – Illustration of local scouring around a monopile. Scouring (erosion) results from changes in current velocity caused by obstructions on the seafloor. Around a monopole the current accelerates, creating a so-called eddy current, which leads to increased erosion right behind the monopole, extending into a scour hole (flow-offshore.nl).

Besides the local scour, the installation of monopiles can significantly influence the bed shear stress, which is the parallel stress caused by the flow of water acting on the seabed sediments. Eddy currents, stronger currents around spherical objects, consequently create scour holes and stir up sediments that otherwise would have remained on the seabed, so-called suspended particulate matter (SPM)(Boon *et al.* 2018, 34). As the sediments keep on moving through an entire field of monopole foundations, they form turbid wakes (plumes of SPM), clearly discernible from space (Boon *et al.* 2018, 34). A good example of this is an article published by Vanhellemont and Ruddick, where 30 – 150 meter wide and several kilometer-long plumes were reported in the wake of the London Array Offshore Wind Farm, recorded by the Landsat 8 satellite (fig. 4.18)(Vanhellemont and Ruddick 2014, 105). This phenomenon unfortunately does not seem exclusive to the UK. Even though the turbid wakes from the London Array wind farm originate from an area with relatively high SPM presence, plumes were also visible around lower SPM presence in Belgian waters and it may be possible that these turbid wakes also exist in the Dutch North Sea (Boon *et al.* 2018, 34). To test if these plumes are also present in Dutch waters I studied Sentinel 2 satellite images of an operating Dutch wind farm, which are available through the United States Geological Survey (USGS) (landsatlook.usgs.gov). In my opinion, though hardly visible in the figure, I discerned sediment plumes at the Luchterduinen OWF on the 29th of March 2021 (fig. 4.18).

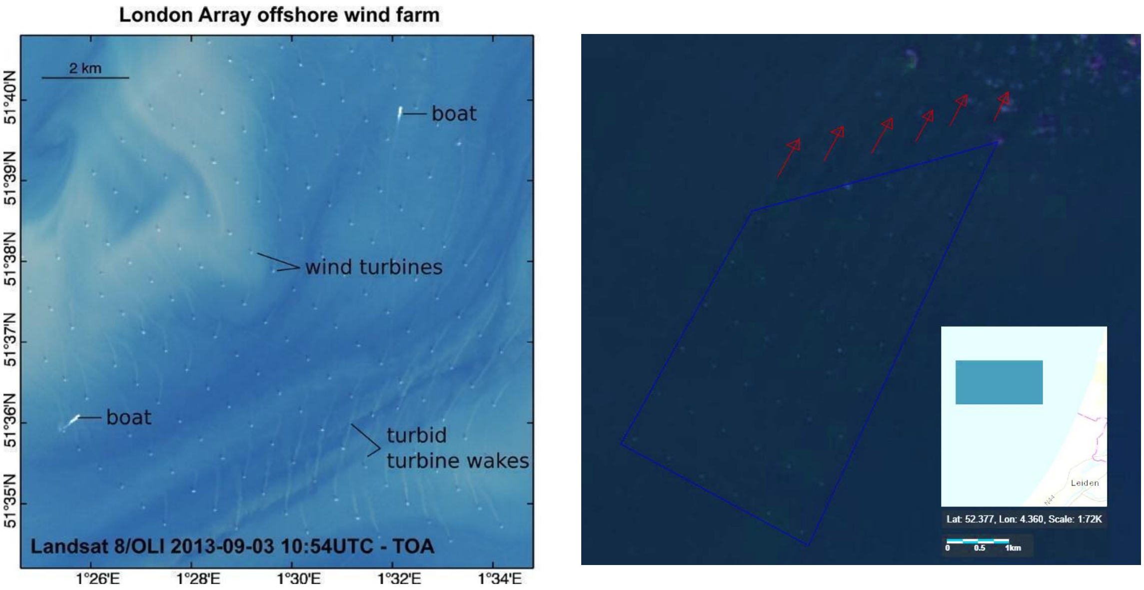


Figure 4.18 – Landsat 8 image of visible turbid wakes in the London Array wind farm (left)(Vanhellemont and Ruddick 2014, 105) and Sentinel 2 image taken of the Luchterduinen windfarm on the 29th of March 2021 (right), where slight sediment plumes can be recognized (Landlook.usgs.gov).

Impact on the prehistoric landscapes

Whether these physical disturbances touch upon the prehistoric remains buried in the seabed depends not only on the character of the disturbance but also on the presence of preserved and shallow prehistoric deposits (Ward 2014, 213). Currently, an archaeological assessment of available geophysical data is the best attempt to quantify the possible impacts on the prehistoric landscape caused by offshore wind farm developments. The authors of an archaeological assessment base their advice on the gathered information from desk-based, geophysical and geotechnical site studies, along with the information on known preserved archaeological remains coming from the seabed and their implications from recent archaeological research. Since the degree of impact on the prehistoric landscape is quintessentially site-specific, the scope of an archaeological assessment of offshore wind industry impacts can best be illustrated using a case study:

Hollandse Kust Zuid Wind Farm Zone

The Hollandse Kust Zuid Wind Farm Zone (HKZWFZ) is a collection of four wind farm sites under construction situated ten nmi off the coast of Zuid-Holland (fig 4.19)(offshorewind.rvo.nl). The total wind farm zone covers an area of 235,8 km^2 and when in operation (by 2022/2023) it will have a power capacity of 1520 MW, generated by about 140 enormous Siemens-Gamesa 11-MW wind turbines (Netherlands Enterprise Agency 2018, 15). In 2016 and 2017, the potential of prehistoric archaeological remains within the seabed geology was assessed by Periplus Archeomare using both geophysical and geotechnical data provided by Fugro Survey B.V. along with a geological desk study completed by Deltares (offshorewind.rvo.nl). The archaeological assessment has been divided into three phases; an archaeological desk study using existing data and information gathered from previous research (Phase I), an archaeological assessment of the geophysical survey results (Phase II), and an archaeological assessment of the geotechnical survey results (Phase III). Since the assessment of the geotechnical survey results is not publicly available, only the results of the archaeological assessment of the geophysical survey shall be incorporated.

Figure 4.19 - The projection of the Hollandse Kust Zuid wind farm zone on the Archaeological indicative map of the Dutch North Sea (fig. 3.7), showing that mostly Middle Palaeolithic (red) remains (if present) could be disturbed (Van Lil *et al.* 2016, 15).

The bathymetric data from the geophysical surveys show water depths ranging from 15.6 to 27.9 meters below Low Astronomical Tide (bLAT). The seabed morphology is characterized by large and medium-high sand ridges, measuring between two and six meters in height and between 200 - 1000 meters in wavelength, all the while they are migrating across the seabed in a north-easterly direction at a rate of 0.7 - 3 meters per year (Terp-Paulsen *et al.* 2016, 40 & 45). The seabed geology is characterized by several Holocene and Pleistocene deposits corresponding to different climatic and geographic conditions.

Lithostratigraphic Unit	*Vertical extent (m – seabed)*	*Prehistoric Period*	*Possible prehistoric remains*
Southern Bight Fm.	*0 - 8*	*Mesolithic*	*Derived (re)worked flint, bone, and wooden artifacts*
Kreftenheye Fm.	*8 - 28*	*Mesolithic, Upper- and Middle Palaeolithic*	*Derived (re)worked flint, bone artifacts*
Eem Fm. (Brown Bank Member)	*28 - 50*	*Middle Palaeolithic*	*Derived and in-situ (re)worked flint, bone artifacts, and (camp)sites*
Yarmouth Roads Fm.	*> 50*	*Lower Palaeolithic*	*Possible Derived and in-situ (re)worked flint, bone artifacts, and (camp)sites*

Figure 4.20 - Table containing the extent and nature of the lithostratigraphic units encountered by geophysical survey within the HKZ wind farm zone (After *Van Lil et al. 2016, 43-44 and Vonhögen-Peeters et al. 2016, 7).*

The lithostratigraphic units include the Southern Bight Formation, Naaldwijk Formation, Boxtel Formation, Kreftenheye Formation, Eem Formation, and Yarmouth Roads Formation (Van Lil *et al.* 2016, 43). In terms of human occupation, the Velsen Bed (Naaldwijk Fm.), the Wijchen layer (Kreftenheye Fm.), the Wierden and Delwijnen members (Boxtel Fm.), and the Brown Bank member (Eem Fm.) are of significant archaeological interest. That is if these layers have been preserved (fig. 4.20). However, according to the seismic data, the expected Boxtel formation has not been encountered or identified as such in the entire research area (Van Lil *et al.* 2016, 43). Besides that, the top of the Kreftenheye formation (8-28m - seabed) has been subject to such a degree of erosion that no in situ prehistoric remains, but solely individual derived remains, appear to have been preserved (Van Lil *et al.* 2016, 50). On the other hand, site I and IV of the wind farm zone contain sequences of the Brown Bank Member at a depth of between 13-22 meter. Especially in zone IV, Brown Bank Member contours reveal higher and lower parts in the palaeolandscape, inferring the presence of a lake, and therefore, a likely possibility for Middle Palaeolithic Neanderthal occupation and consequentially the preservation of in-situ remains (fig. 4.21)(Van Lil *et al.* 2016, 50). Regarding the geotechnical survey, Periplus Archeomare advises looking into the borehole samples of Site I and especially Site IV from an archaeological perspective to find proxies for Middle Palaeolithic occupation (Van Lil *et al.* 2016, 51).

Overall, as a consequence of the absence and erosion of the archaeological significant layers at the top of the seabed (0 - 13 meters - seabed), it is believed that minor seabed penetrating actions, such as the installation of cables, and the indirect impacts, including scour, would not affect potential in-situ prehistoric remains. Therefore, additional archaeological research is not deemed necessary for the upper seabed and passive archaeological supervision (on-call) should be sufficient (Van Lil *et al.* 2016, 9 & 50). On the other hand, the installation of monopiles (0 – 40m - seabed) would penetrate the Brown Bank Member in Site I and IV and could affect in-situ prehistoric remains. Assessment of the geotechnical survey will provide a clearer perspective on the possible impact and aid further management (Van Lil *et al.* 2016, 50).

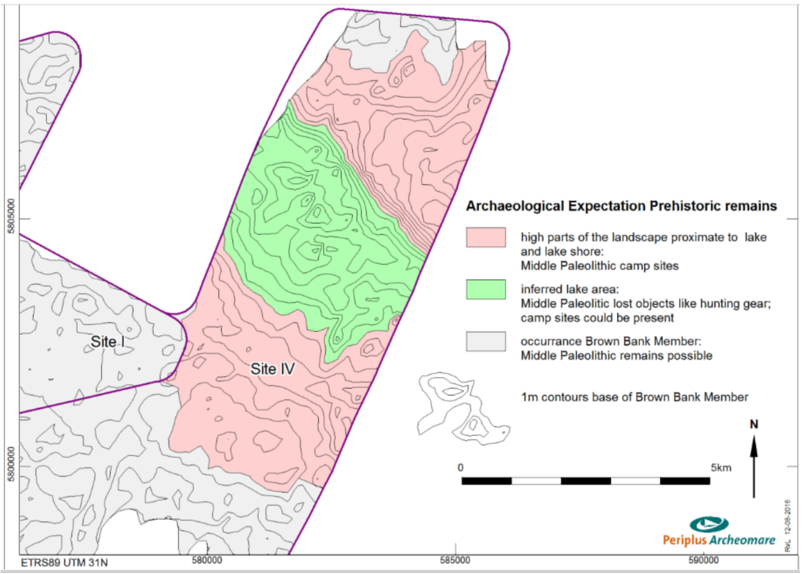


Figure 4.21 – Map of the contours of the Brown Bank Member encountered in the northern part of site IV and the expectation of Middle Palaeolithic archaeological remains projected on it (Van Lil *et al.* 2016, 50).

Potential Benefits for the prehistoric landscapes of the North Sea

While only having described the adverse impacts of offshore developments, it is equally important to stress the beneficial impacts of these developments on the submerged prehistoric landscape. A couple of positive impacts can be attributed especially to the development of offshore wind farms. For instance, with each new wind farm zone, a series of detailed, geophysical, and geotechnical surveys provide data to complete a piece of the geomorphological puzzle of the North Sea basin, which is available for archaeologists to interpret and conduct future research on (Pater 2020, 514). There are even benefits as a result of the (in)direct impacts, that initially might have disturbed prehistoric deposits: Although the placement of scour protection might damage prehistoric remains situated close to the surface of the seabed, it will also protect prehistoric deposits from scouring induced exposure and erosion (Ward 2014, 228). Besides that, the level of initial disturbance is likely to be disproportionate to the level of scour protection provided by the hard substrate. Alternatively, while scouring uncovers parts of the seabed, it might also bury prehistoric deposits at the same time. This relates to the importance of considering the 'do-nothing' scenario, where hydrodynamic conditions are examined to assess the changes to the seabed, which are expected to occur without the interference of offshore developments (Oxford Archaeology 2008, 6). Additionally, in terms of management, an advantageous side-effect of an offshore wind farm zone is that this large area is one-purpose only and therefore subject to much-reduced pressure from trawling boats and dredging vessels, which excludes (partially) the cumulative impacts from these activities on the seabed (Van der Molen *et al.* 2014, 61; Ward 2014, 227). Furthermore, as a consequence of the ever-increasing offshore developments, archaeologists are provided with an opportunity to do large-scale and fully-funded research to the submerged prehistoric landscapes, which result from the legal obligation to conduct an initial investigation and environmental impact assessments (EIA's) prior to these offshore developments (Bailey *et al.* 2020, 13).

Conclusion

To fight global warming and reach the climate goals set by the Paris Agreement, a lot more new offshore wind farms need to be developed in the future. Unfortunately, this could pose a threat to the prehistoric deposits present underneath the mobile seabed layer: As some of the industry-related activities cut deep into the seabed sediments, prehistoric deposits will likely be disturbed. Yet, the character and scale of the impacts caused by the offshore wind farm industry are far from certain. This is due to the pace of innovations within the industry, making it very hard to predict which construction methods will be used to develop wind turbines. Assessing the general wind farm construction process, the seabed deposits will most likely be disturbed by direct impacts, including the piling of monopiles and the force of the jack-up vessels legs, and indirect impacts, such as seabed scour. On the other hand, whether these physical disturbances touch upon the prehistoric remains buried in the seabed depends on the presence of preserved and shallow prehistoric deposits. Understanding the depositional context, as well as the taphonomic processes and the current hydrodynamic processes that affect these deposits, provides the foundation for predicting the actual impact of the industrial activities on the submerged prehistoric landscapes. This is illustrated by the case study, where only in some areas prehistoric deposits are at risk of being disturbed. Alternatively, it is important to keep in mind the positive effects for the prehistoric deposits and the archaeologists studying them. After all, due to the offshore wind farm developments, the archaeologists are able to conduct large-scale and fully-funded research on the submerged prehistoric landscapes, which ultimately results in a better understanding and increased appreciation of the prehistoric environment.

Conclusion

Industrial activities at the North Sea have been going on for a long time and will continue for a long time to come. The area is of great economic value for the fishing industry, commercial shipping, aggregate extraction, non-renewable and renewable energy generation. Besides that, the North sea acts as a hub connecting each of the surrounding countries through a huge network of data cables, pipelines, and shipping lanes. Because of these and many other reasons, the sea is of vital importance to our own welfare. Due to the ever-expanding demand for the products and services related to the North Sea, industrial activities are being developed non-stop. Yet, these industrial developments often include a certain degree of seabed disturbance. This chapter, therefore focused on the seabed disturbance by three of these offshore industries. First of all, it demonstrated that demersal fishing vessels directly impact the seabed using beam trawls that systematically plough through the top of the seabed. Afterwards, as a consequence of frequent trawling, the sediments experience increased erosion, resulting in additional exposure. Second, it established that within the sand extraction zone, trailing suction hopper dredgers extract several meters of sand, including many Pleistocene bones and prehistoric artefacts. The extracted sand, used for coastal replenishments as well as onshore construction, results in large pits that affect the hydrodynamic processes on the seabed. Third, it determined that offshore wind farm developments will directly impact the seabed deposits through the piling of monopiles and the force of the jack-up vessels legs, and indirect impact the sediments through the effects of seabed scour, forming around one of the many seabed installations. As a consequence, artefact bearing deposits located at or near the surface of the seabed could be directly or indirectly impacted by these offshore activities, as is demonstrated by the case study.

Countless numbers of prehistoric remains have been encountered in the nets of trawling vessels that fished around the Brown Bank, along the artificial beaches of the Maasvlakte 2 and the Zandmotor, and are waiting to be found as a result of archaeological surveys preceding the development of offshore wind farms. Each of these finds bears witness to fact that prehistoric deposits have occasionally been and will be disturbed by offshore activities. Evidently, the occurrence of prehistoric finds points to the impacts of the offshore industries. But, these impacts are not the only reason the artefacts are encountered: Their encounter is rather the result of a combination of factors: the nature and extent of impacts caused by offshore activities in combination with the exposure of prehistoric deposits, due to the erosion of sediments, resulting from local hydrodynamic processes. Therefore, whether these physical disturbances touch upon the prehistoric remains depends on the location and preservation of the prehistoric deposits. In essence, Understanding the stratigraphy of the near-surface seabed and the oceanographic conditions affecting these deposits provides the bedrock for contextualizing archaeological finds, encountered during fishing hauls and on artificial beaches, and predicting the location of preserved prehistoric landscapes.

The impact resulting from offshore activities turns out to be not all bad. Exceptional finds including the tar-backed Neanderthal flint tool, the Federmesser decorated bison bone, and the Neanderthal eye-brow ridge, prove to be important to archaeological research as they provide new insights into the behaviour of prehistoric people that lived within the North Sea Basin. However, while we learn a lot about the possibilities of these submerged landscape through the prehistoric finds we encounter and the geological data, we do not yet understand the relation between these finds and the prehistoric deposits. Unfortunately, there is currently too little context known about finds to adequately design measures to protect prehistoric hot-spots, such as the Brown Bank, the Eurogeul sand extraction locality and the northern area of the Hollandse Kust wind farm. If underwater excavation could be part of the planning in such hot-spots before large offshore projects, we could be able to uncover more about the relation between prehistoric finds and their context within the seabed.

Figure 5.1 - A crowded sea, fishing amongst a wind farm off the coast of IJmuiden (Mol *et al.* 2019, 1).

V. Offshore developments

Predicting the future offshore developments and their impact on the prehistoric landscapes of the Dutch North Sea

Throughout the first decades of the 21st century, we have seen a significant increase in the exploitation of marine resources. Especially in recent years, the Dutch North Sea has been affected by the growing needs for coastal replenishment sand and offshore renewable energy. Along with the fishing industry, fossil fuel extraction, and shipping infrastructure they make the Dutch North Sea into one of the busiest and economically most valuable stretches of sea on the planet (fig. 5.1).

At the same time, the Dutch North Sea holds an astonishing archive of multiple Pleistocene and Holocene submerged landscapes, landforms, and deposits, within which traces of prehistoric groups have been preserved. Although fragmented and influenced by destructive marine erosion, these preserved prehistoric deposits extend across large parts of the Dutch seabed. Considering that the focus in the coming decades will be on expanding the offshore developments, there will certainly be an overlap between the areas of future developments and areas containing prehistoric deposits. Several types of offshore developments, such as demersal trawl fishing, sand and aggregate extraction, and the construction of wind farms, physically impact the seabed substrate, which could in turn lead to the disturbance and possible destruction of archaeological remains. Yet, the nature of the disturbance depends on the size and degree of physical impact, which will be different for every type of seabed exploitation. Therefore, the main questions are: *What kind of impact could these future developments have on the submerged prehistoric deposits within the Dutch seabed?* And *are we able to protect these remains?*

This chapter aims to provide the most recent predictions on future offshore industrial activities and their effect on the submerged prehistoric deposits. It will be divided into a section about the predicted future developments for each of the previously described industrial activities and their implications for the submerged prehistoric deposits. The last part of the chapter focusses on the protection of the remains and highlights the global significance.

Demersal trawl fishing

Since the beginning of the 21st century, the rate at which the North Sea seabed is ploughed through is decreasing. The search for fuel cost reduction by fishermen led to the gradual replacement of the heavy consuming beam trawl by a more hovering kind of ground tackle, such as otter boards and SumWing beams (Maarleveld 2020, 532). Electrical pulse ticklers took over from the steel tickler chains. This fishing method uses small electrical pulses to efficiently scare the flatfish into the hovering nets (fig. 5.2). In contrast to the steel tickler chains, the electrical ticklers cause less drag and therefore less fuel is consumed, which is beneficial to the fishermen as well as the upcoming climate goals (International Council for the Exploration of the Sea 2020, 1). Besides that, some fishermen even changed the trawling fishing method to fly shooting, seines, and rigging, all of which are significantly less harmful to the benthic (seabed) ecosystem (Min. of Infrastructure and the Environment 2012, 46). Due to these technological and strategic developments, the seabed integrity increased. However, despite these developments, from July 2021 on, the Council of the EU banned the use of electrical pulse equipment for fishing in the North Sea. The EU put the ban in place to 'minimise the impacts of fishing gear on marine ecosystems' (Council of the European Union 2019/1241, Art. 7(b)). Yet, this assumption is disputed. The International Council for the Exploration of the Sea (ICES) recently released advice about the subject, describing that, opposed to beam trawling, electrical pulse fishing 'reduces the disturbance of the seafloor and impact on the benthic ecosystem', which is backed by the research of Rijnsdorp *et al.* (International Council for the Exploration of the Sea 2020, 1; Rijnsdorp *et al.* 2020, 11). By forcing fishermen to resort back to a more destructive fishing methods, the ban contradicts the aim of protecting the marine ecosystems, leading to a renewed threat to the seabed integrity (Maarleveld 2020, 532).

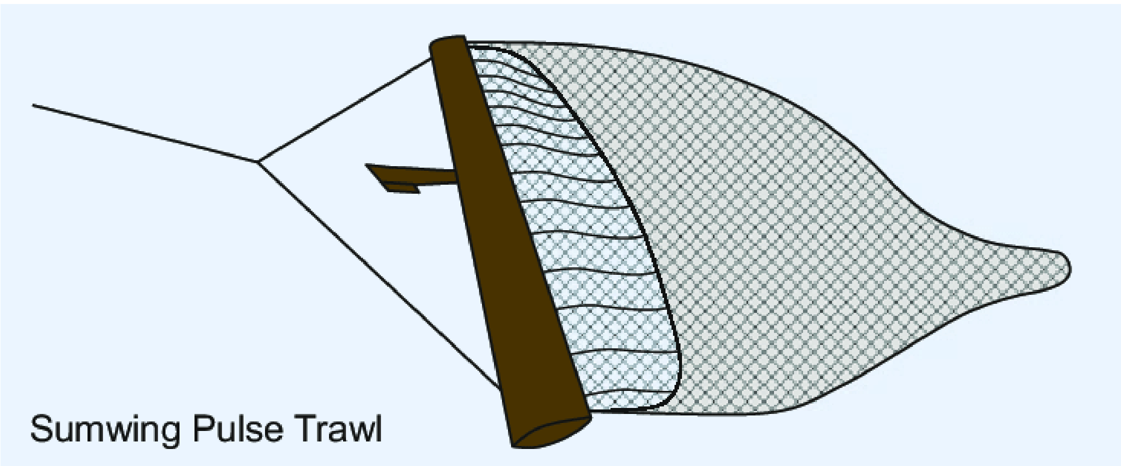


Figure 5.2 - Illustration of a Sumwing Pulse trawl. Whereas steal chains of the beam trawl impact the seabed throughout the entire length of the beam, the electrical pulse ticklers affect a significantly smaller area (Maarleveld 2020, 524).

Another recent development affects the fishermen working under the Dutch flag. The Agreement for the North Sea (Het Akkoord voor de Noordzee), delivered in June 2020, contains agreements between the Dutch government and the various North Sea stakeholders about the sustainable use of the Dutch North Sea in the next 10 years (Van Nieuwenhuizen Wijbenga 2020). Respecting the promises made during The Paris Agreement in 2015, the focus of this agreement lies on energy transition, creating more room for the development of offshore wind farms and, as a consequence, reducing the size of fishing grounds. Taking the renewable energy developments into account, as well as the developments in shipping and expansion of the Natura 2000 (European protection of natural areas), the loss of fishing grounds for demersal fisheries adds up to 13,7% in 2023 and 15% in 2030 (Overlegorgaan Fysieke Leefomgeving 2020, 23). Therefore, in order to be sustainable in the future, the Dutch fishing fleet is encouraged to be reduced and innovated. As compensation, the government has set up a transition fund that provides 45 million euros as a subsidy for the development and application of sustainable fishing equipment and 74 million to mitigate the costs for fishermen that leave their profession as a result of The Agreement for the North Sea (Overlegorgaan Fysieke Leefomgeving 2020, 7).

To top the storm the fishermen are already in, the new Brexit deal directs that 25% of the EU fishing rights in United Kingdom territorial waters will be transferred to UK fishermen in the coming five years, after which fish quota negotiations continue (Council of the European Union 2020, 899). Until the UK left the European Union, European fishermen (Non-UK) used to fish the majority of the quota in UK waters, and even though foreign fishermen will still be able to fish in UK territory for the next five years, it means that these lost quota have to be fished elsewhere (bbc.com). In this light, the change predicts an increased pressure on the left-over demersal fishing grounds in the rest of the North Sea Basin, especially in the Dutch territorial waters. Yet, several of the affected countries could decrease the fish quota for UK fishing vessels in their own waters, thereby mitigating the changes a little.

Impact on the submerged prehistoric deposits

The abovementioned developments demonstrate that the demersal fishing industry is changing rapidly. As a consequence, its impact on the submerged prehistoric deposits is changing too. For instance, the initial replacement of the heavy fuel-consuming beam trawl by a more hovering kind of ground tackle, such as otter boards and Sumwing beams led to the decrease of seabed disturbance, which lead to an estimated 95% reduction of prehistoric bones and artefacts resurfacing (Peeters *et al.* 2019, 40). Was it not for the ban on the use electrical pulse equipment, the number of prehistoric encounters was predicted to decrease even further in the following years. Alternatively, the ban will force some of the fishermen to resort back to more seabed destructive fishing methods, including the traditional beam trawl, which increases the disturbance of prehistoric deposits situated close to the seafloor. However, the threat to the submerged prehistoric landscapes still depends on the local stratigraphic context of the seabed and the hydrodynamic processes affecting it. Yet, vulnerable areas, like the Brown Bank, might become Natura 2000 reserves in the future, as these often gradient areas are important for the biodiversity of the benthic ecosystems and will therefore be shielded from the destructive force of the beam trawls. This way prehistoric deposits there could at least be partly protected from industry-related physical impact. However, will this be enough? Fishermen are apparently willing to change to less harmful and more cost saving fishing methods. Line fishing, seining and otter boards seem like good alternatives, but are they? Line fishing, most likely does not reach the target amount and is very labour intensive, and otter trawls are excellent for round fish swimming a little above the seabed, but do not catch enough flatfish. Perhaps, seining, especially a Danish seine, is the best contestant, as the weighted seine ropes rest on the seabed, whilst pulling in the net (fig. 5.3)(afma.gov.au). Yet, with all the traffic on the North Sea, a stagnant fishing vessel might be a problem.

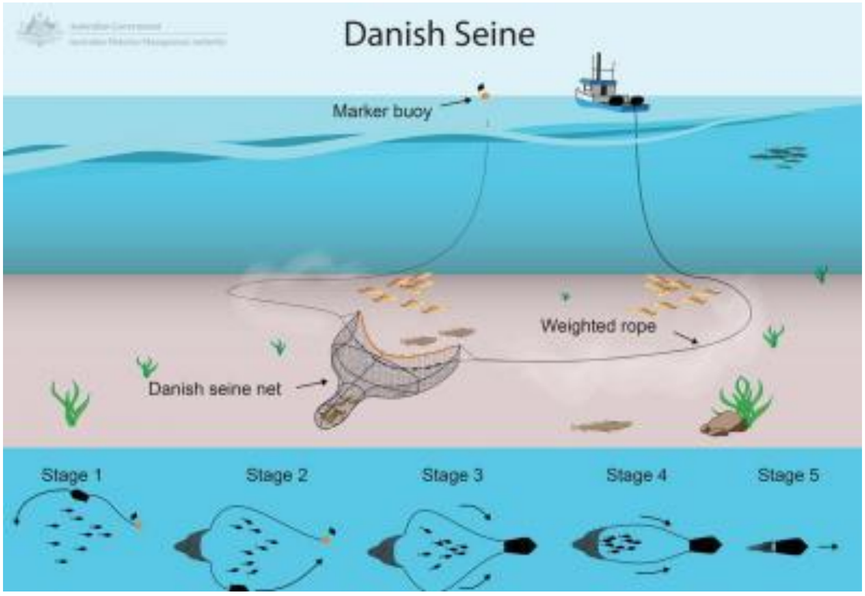


Figure 5.3 – Schematic illustration of the Danish Seine fishing method (afma.gov.au).

Sand and aggregate extraction

The sand and aggregate extraction, in contrast to the demersal fishing industry, is increasing every year. To protect the people living in coastal regions from ever-increasing sea levels caused by climate change, the Dutch government will have to increase the amount of sand extracted for coastal replenishment. According to the Intergovernmental Panel on Climate Change, the sea level rise will increase from 2 mm/year nowadays, to 14mm/year in 2050 and up to 60mm/year in 2100, which translates to a sea level rise of 1m throughout the next century (Haasnoot *et al.* 2018, 4). The quantity of sand extracted from the Dutch seabed currently amounts up to 12 million m^3 each year. However, in the worst-case scenario, the amount of sand for replenishment, has to be raised to 50 million m^3 by 2050 and up to 240 million m^3 by 2100 (Haasnoot *et al.* 2018, 33). As a consequence, successful coastal replenishment projects, such as the Zandmotor experiment, where 21,5 million m^3 of sand was extracted and deposited in a small area, will have to be repeated up to eleven times over to keep the beaches as they are today. Inevitably, this means that the number of sand pits within the designated sand extraction zone will have to be expanded, which creates problems when other offshore industrial activities are growing too. This could lead to new areas within the North sea to be designated as sand extraction zones (fig. 5.4). This means that the increase in demand for coastal replenishment sand in the future will cause additional disturbance of the seabed sediments.

Figure 5.4 - Possible extra sand extraction zones (set of grey shaded areas) besides the currently reserved area (white), taking into account the present and future use of the maritime space by other offshore industries (Haasnoot *et al.* 2018, 37).

As mentioned in chapter four, the disturbance of the seabed sediments by trailing suction hopper dredgers varies from a couple of meters depth for annual coastal replenishment to 20m below the seabed surface for large-scale port construction and coastal suppletion projects. In advance of each new sand extraction project, different sand extraction scenarios are weighed through an environmental impact assessment, which weighs the impact of the proposed activities on the benthic ecosystem as well as on other impacted industries and environments (noordzeeloket.nl). Specifically for the integrity of the local benthic ecosystem, containing the disturbance within a small area is preferred. This is because small but deep sand pits disturb less of the seabed surface than larger shallower sandpits, as the benthic ecosystem extends across the entire seabed (noordzeeloket.nl). Therefore, it is safe to assume that future sand extraction pits will likewise cover a small area, but bring about significant changes to the seabed morphology. Besides that, large-scale sand extraction projects will likely be preferred over small-scale sand extractions, as the lower frequency between extraction will provide the time needed for the recovery of the seabed (Haasnoot *et al.* 2018, 37).

Moreover, the designated sand extraction zone cannot be used to the fullest extent. Within the zone, there are a lot of obstructions that have to be avoided during the sand extraction process. These obstructions, include munition deposits, musselbanks, protected ecosystems, historical and archaeological objects, such as shipwrecks, fishing industry waste, and a large number of cables and pipelines (noordzeeloket.nl). To avoid collision between these obstructions and the suction pipes of the suction hopper dredgers, the Regional Miningplan North Sea 2 (Regionaal Ontgrondingenplan Noordzee 2) devised a set of distancing standards related to the nature of the obstructions. For example, there needs to be a distance of 1200m between sand pits and seal nesting grounds, a buffer of 500m on either side of gas- and pipelines, and a radius of 100m around archaeological objects (Van Duin *et al.* 2012, 42). These exclusion zones, decrease the amount of available sand for extraction, which could lead to increased pressure on certain parts of the seabed, regardless of the fact that they might contain preserved prehistoric remains.

On the other hand, the extraction of sands that aggregated within the previously used sandpits, is a smart solution to obtain the right kind of sand, without having to search for new sand extraction pits. Besides the economic advantage, this re-use of already exploited sand extraction pits, along with the use of dredged sands from shipping lanes and port basins, will decrease the disturbance of intact parts of the seabed sediments and lead to a smaller impact on the benthic ecosystem (Planteijdt 2007, 29).

Impact on the submerged prehistoric deposits

Nowadays, countless prehistoric fossil and archaeological remains are encountered on the beaches along the Dutch coast. These finds remind us of times when the North Sea basin wasn't fully submerged and bear witness to the fact that an unknown number of prehistoric deposits have still been preserved beneath the seabed. The fact that these prehistoric remains are predominantly found on newly constructed artificial beaches, such as the Maasvlakte II and the Zandmoter, demonstrates that sand extraction activities touch upon prehistoric deposits situated within the designated sand extraction zones. With the increase in demand for sand replenishment, new sand extraction pits will likely be exploited in the future, which increases the threat to submerged prehistoric deposits and doubtlessly leads to the loss of context for many prehistoric artefacts.

Regarding the future developments of the sand extraction industry, the construction of relatively deeper (but smaller) sand pits, opposed to shallower more extensive ones, will pose both beneficial as well as disadvantageous effects for the submerged prehistoric deposits. On the one hand, as a smaller area of the seabed surface will be affected, a smaller part of the better preserved more recent prehistoric (Mesolithic and Upper Palaeolithic) deposits will be impacted. On the other hand, deep sand extraction (up to 20m below the seafloor) will reach earlier prehistoric deposits (Upper and Middle Palaeolithic remains) that would not have been reached during shallow extraction (Van Duin *et al.* 2012, 250). Besides that, a deeper sand extraction pit could also cause increased erosion of prehistoric deposits situated at or close to the slope, due to a change in hydrodynamic conditions called sand starvation (zandhonger). In any case, as every depositional context is different, geophysical and geotechnical research prior to the sand extraction will determine which strategy is best.

Furthermore, the re-use of already exploited sand extraction pits, along with the use of dredged sands from shipping lanes and port basins, will decrease the disturbance of additional preserved prehistoric deposits (Planteijdt 2007, 29). Likewise, the exclusion zones (100m buffer), while possibly unable to cover the entire preserved prehistoric site, could provide some protection from the impacts of sand extraction, especially since the exclusion zones of other obstructions might shelter the deposits too. The cooperation between offshore dredging companies, ports, and archaeological heritage institutions, however, remains a factor of importance and concern. While cooperation between the dredging company PUMA, that executed sand extraction for the Maasvlakte II, the Port of Rotterdam, and the Dutch Cultural Heritage agency was exemplary, this is hardly the standard. Often the access of heritage officials to oversee the different stages of sand extraction is denied, as it is perceived that archaeological finds might bring unwanted additional costs or stop the process entirely (Peeters *et al.* 2019, 40).

For the submerged prehistoric resource, a change in coastal protection method is highly unlikely, as North Sea sand is more plentiful than anywhere else in the Netherlands, more accessible than anywhere else, and has little transportation costs. Besides that, the thick recent Holocene sand buffer (close to the shore) is inaccessible, due to the fact that it already protects the coast against sea level rise. Hence, it seems like sand extraction and coastal replenishment will remain necessary for as long the sea will rise. Therefore, the implications for the submerged prehistoric remains will have to be dealt with In the future. A clear set of rules and earlier incorporation of archaeological risk could prevent miscommunication and improve cooperation between offshore mining companies, archaeological researchers and the (local) government.

Offshore wind industry

To reach the goals of The Paris Climate Agreement, a lot more offshore wind farms need to be realized. Therefore, the Dutch government, energy providers, and many stakeholders of the Energy sector signed The (Dutch) Climate Agreement (Het Klimaatakkoord) in 2019. In this piece all parties agreed to limit carbon emissions and increase the production of renewable energy (rijksoverheid.nl). For offshore wind energy specifically, while the sector already progresses to a capacity of 4,5 GW by 2023 as a consequence of The Energy Agreement for Sustainable Growth (Het Energieakkoord voor duurzame groei) of 2013, the parties shook on raising capacity to 11,5 GW by 2030 (Energieakkoord voor duurzame groei 2013, 32; rijksoverheid.nl). This power capacity translates to roughly 1100 offshore wind turbines by the year 2030, generating 49 TWh per year and powering 40% of the Dutch energy use (windopzee.nl). As we need to generate 1 GW per year until 2030, several future offshore windfarms are currently being developed. The roadmap of figure 4.14 (p. 64) depicts five new offshore windfarms besides the ones in use right now:

'Hollandse Kust Zuid' (two 760 MW windfarms), located 10 nmi off the coast of Zuid-Holland, will start providing energy in 2022/2023, 'Hollandse Kust Noord' (700 MW) will likely do so in 2024, 'Hollandse Kust West' (two lots of 700 MW) will open between 2025 and 2027, 'Ten Noorden van de Waddeneilanden' (700 MW), located next the Gemini windfarms, will be put into use in 2027 and 'IJmuiden Ver' (two 2 GW windfarm lots), situated the furthest off the coast at 29 nmi of IJmuiden, will open just before 2030 (rijksoverheid.nl). Plans have been made to continue the renewable offshore windfarm path with 'NorthH2', a huge windfarm situated somewhere north of the Dutch barrier islands, which will provide 4 GW by 2030 and will be extended into a 10 GW windfarm area by 2040 (shell.nl). If successful, this huge project and subsequent projects will bring the Netherlands a step closer towards the goal of a capacity of 60 GW by 2050, with which the country will generate the second-highest amount of offshore wind energy in Europe, only with the United Kingdom producing more (80 GW)(Freeman *et al.* 2019, 53).

With the proposed production capacity of 60 GW by 2050, there will be some moments when the offer of electricity generated from offshore wind farms will exceed the demand of the Dutch population, especially when the wind is blowing intensively. In such instances, the surplus of energy could be stored as hydrogen and subsequently transported to the shore, to be used when the demand exceeds the offer. In order to produce hydrogen, the electricity generated by the wind turbine is used to instigate the process of electrolysis, during which a current runs through water, splitting it into oxygen and hydrogen molecules (Hooft Graafland and Blokdijk 2021, 12). The production of clean hydrogen (from renewable energy) will likely play a pivotal role in the energy transition, as wind turbines consisting of an integrated electrolyser have recently been developed.

Additionally, plans have been drawn to convert disused oil and gas platforms into offshore electrolysis stations as well as constructing artificial islands amidst the many offshore wind farms that would be used as hydrogen production and distribution hubs (fig. 5.5)(Hooft Graafland and Blokdijk 2021, 12).

Figure 5.5 – Impression of an offshore electrolysis station (tractebel-engie.com).

In response to the increasing demand for bigger and more effective wind turbines, new wind turbine designs are being developed every day, making the offshore wind industry a highly innovative industry (tno.nl). For instance, the most recent 11 MW offshore wind turbines, reaching approximately 250m in height, need to be supported by super strong foundations that anchor and stabilize the wind turbine in any marine environment (siemensgamesa.com). Until today, the most widely used offshore wind turbine foundation type is the monopile, which performs well in the shallow water of the Dutch North Sea. Currently, the largest one, called the XL monopile, measures 10m in diameter. Yet, as the size of the wind turbines is expanding, the largest turbines would soon require even larger monopiles (tno.nl). Besides that, different types of offshore turbine support structures are being developed as well. These include gravity base, tripod, and jacket foundations, each of which could be installed in water depths of up to 50m below sea level (see fig. 4.5)(Wu *et al.* 2019, 380). Floating turbine support structures could be developed to such an extent that they might be preferred in specific marine environments or they might become a cost-effective alternative to the monopile, as the large costs of offshore monopile installation are still a significant problem. However, for water depths greater than 50m, floating turbine support structures are generally more cost-effective than foundations embedded into the seabed. Even though the Dutch seabed does not reach depths of more than 40m, these floating foundations have the potential to be exploited in water depths of up to 300m, which could significantly increase the potential area for offshore wind energy developments throughout the world (fig. 5.5)(Bailey *et al.* 2014, 9).

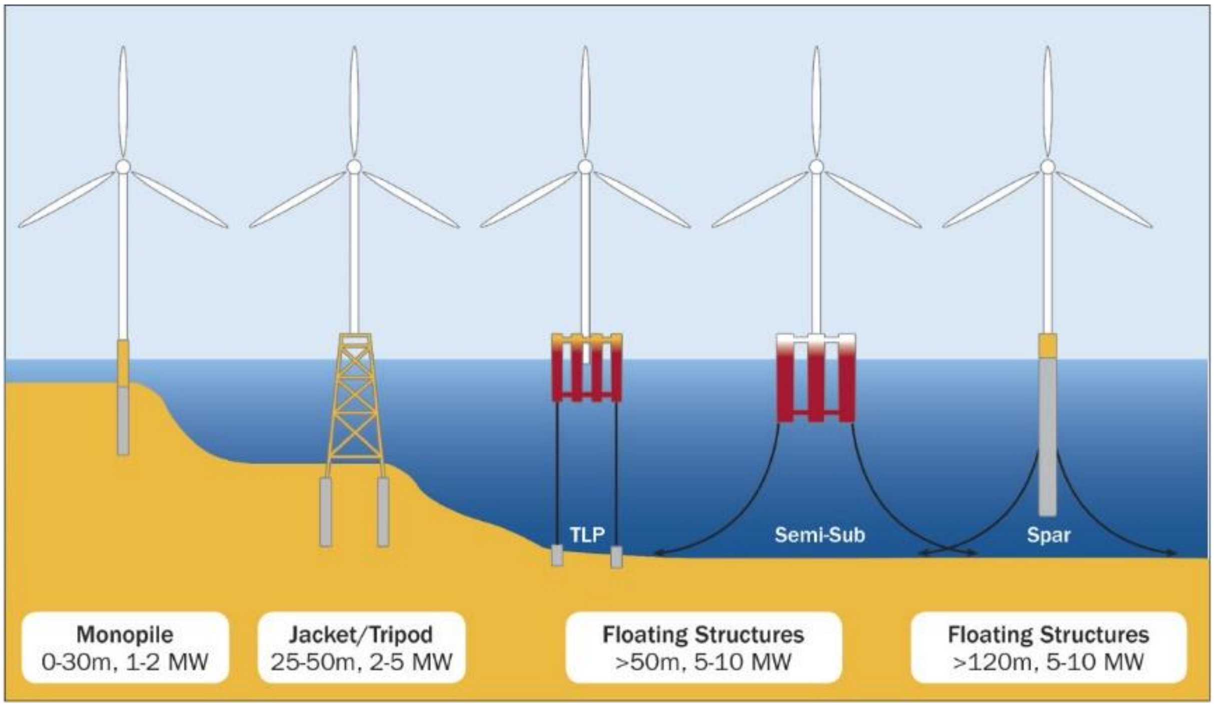


Figure 5.6 - Foundation types of currently used or developed offshore wind turbines foundations. Note to this is that the depth and power capacity were calculated in 2014 and therefore do not correspond with current design limitations (Bailey *et al.* 2014, 9).

Impact on the submerged prehistoric deposits

To meet the goals of The Paris Climate Agreement and The Climate Agreement, the Dutch government envisages large-scale expansion of the offshore wind industry (Salter *et al.* 2014, 153). Unfortunately, this could pose a threat to the prehistoric deposits present within the seabed sediments. As some of the industry-related activities cut deep into the seabed sediments, prehistoric deposits will likely be disturbed.

However, could other renewable energy sources perhaps become so efficient that offshore wind farms are able to descale and thereby limit the impact of offshore turbine construction? Of course, solar energy, biomass and onshore windpower provide for a lot of GW already. Yet, each of these energy sources have limitations (not excluding offshore wind energy). For instance, solar energy is not reliable when cloudy, takes up large amount of space and materials needed are scarce and can pollute (conserve-energy-future.com). Biomass is often not entirely clean, and needs a lot of space for a single plant (syntechbioenergy.com). Finally, onshore wind farms have only a limited amount of space. Forntunately, new renewable energy sources keep on being developed. Promising techniques are Blue Energy (osmosis). Osmosis generates energy through the interaction between positively and negatively charged sweet and salt water. A single energy plant, located especially near river delta's and estuaries, is now able to generate around 200 MW and therefore has huge potential for the future (olino.org). Yet, as the Dutch government put most of its money on the development of offshore wind farms already, the future generations will see a lot of wind turbines on the horizon.

But, the nature and extent of the future impacts caused by the offshore wind industry are far from certain. This is for instance the case regarding the hydrogen production and distribution hubs. On the one hand, the re-use of oil and gas platforms will prevent constructing platforms from scratch, and therefore limit further disturbance of submerged prehistoric deposits. On the other hand, the construction of artificial islands would involve major sand extraction and suppletion, which poses a significant threat for both Mesolithic as Palaeolithic submerged remains. Accordingly, taking these considerations into account and weighing them against other possible environmental impacts of such proposed developments, might move the involved authority to decide to go with a less destructive design. As there are many different project designs it is impossible to predict the impact of wind-powered hydrogen production on the submerged prehistoric deposits already. This will have to be researched when the hydrogen plans are described in detail.

Just as with the plan for offshore hydrogen production, the sheer pace of technological innovations within the construction designs of wind turbines, followed by the development of a large variety of support structures, make it difficult to anticipate the impact of installing turbine foundations on the submerged prehistoric deposits. Currently, the most cost-effective and therefore most commonly used turbine support structure is the monopile, and it will likely remain so in the near future. Therefore, the piling of large numbers of monopiles by specialized jack-up vessels will be a considerable threat to preserved prehistoric deposits for at least the foreseeable future. However, other seabed fastenings, such as the gravity base, tripod, and jacket, might be used to a greater extent than today and could have entirely different physical impacts on the submerged prehistoric deposits. Tripods and jackets are piled into the seabed in a similar way to monopiles, albeit with poles smaller in diameter, but greater in number (3 or 4 for every turbine), and generate a similar disturbance of seabed deposits to monopiles, including piling of monopoles, the force of jack-up vessels legs, and indirect impacts, such as seabed scour. In contrast, gravity-based support structures are heavy structures (often concrete) that are sunk onto the seabed directly, without the need for additional fastening, and therefore generate no physical impact from piling and jack-up vessels. Yet, they could certainly affect the prehistoric deposits situated close to the seabed surface, as the sediments will be greatly compressed resulting from the force of the concrete block (tno.nl).

Floating support structures, on the other hand, might provide a solution for decreasing the industries' impact on the submerged prehistoric deposits. As these foundations are solely anchored to the seabed using several mooring lines, they could significantly decrease the physical impact of the offshore wind industry on the seabed sediments (tno.nl). However, in the shallow Dutch part of the North Sea, they are currently not cost-effective enough to compete with the most common types of offshore foundations (Ghigo *et al.* 2020, 2). Despite this fact, the development of floating offshore wind farms could in the future be encouraged by the government, since, in design, they additionally offer greater benefits for the seabed's ecosystem opposed to the fixed-seabed foundations (Ghigo *et al.* 2020, 2).

All in all, these innovations demonstrate that the offshore wind industry will certainly look very different years from now, especially when wind turbines are being developed on a vertical axis too (fig 5.7)(tno.nl). It is therefore important that these developments are being assessed constantly in terms of understanding how change within the offshore wind industry, such as new turbine foundation designs, might alter its physical impact on the seabed sediments (Pater 2020, 518).

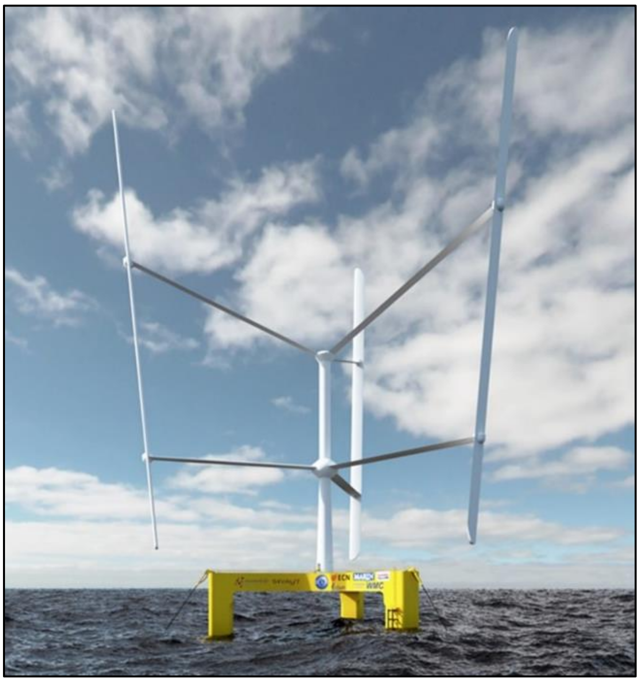


Figure 5.7 - An artist impression of an offshore vertical axis wind turbine (VAWT) supported by a semi-submersible foundation (tno.nl).

Room for Prehistory?

Obviously, the future is uncertain. However, a few things are clear; offshore industrial activities will increase and its installations, vessels and projects will only get bigger. As demonstrated in the previous chapters, this will increasingly threaten the submerged prehistoric remains within the Dutch seabed. Yet, are we able to protect the submerged prehistoric remains? Could we provide for in-situ preservation when fighting Climate Change demands loads of sand to support the coast and tens of thousands of wind turbines? Is the prehistoric interest able to outweigh other marine interests? If not, in what way can we make sure that data and archaeological objects can be collected, examined and stored? Clearly, these questions ask for solutions. But, where do we find these?

Currently, prehistoric remains within the Dutch seabed are protected by Dutch legislation. This includes a variety of laws and policies of which the 'Heritage Act (Erfgoedwet)', the 'Earth Removal Act (Ontgrondingenwet)', the 'Water Act (Waterwet)', the 'Mining Act (Mijnbouwwet)' and the 'Environmental Protection Act (Wet milieubeheer)' are the most important (Cultural Heritage Agency 2014, 2). Regarding the submerged prehistoric remains, the acts strive to contain as much of it within the seabed; an in-situ approach so to speak. They obligate a duty to report prehistoric finds, ensure that the cultural interest is weighed during offshore developments and guarantee that Environmental Impact Assessments (EIA) describe the effects of proposed offshore industrial activities on prehistoric sites and their context. Finally, when these archaeological investigations have been completed, the costs will be charged to the offshore developers (Noordzeeloket.nl). In practice, this means that prior to industrial activities aimed at the Dutch seabed, archaeological investigations will be carried out, in the shape of Archaeological Impact Assessments (AIA), which are usually deducted from geophysical and geotechnical surveys. After these assessments, in case there is a chance of archaeological remains, an archaeologist will be either on call or accompany the offshore undertaking (Van Lil *et al.* 2016, 51). However, as the Dutch North Sea, including the seabed, is cut into several maritime zones (fig. 1.3), the Heritage Act does not apply to the Exclusive Economic Zone, which implicates that submerged prehistoric interests will not outweigh industrial interests. Yet, clear cultural heritage sites (predominantly wrecks) will get a clearance of a 100m radius, after they have been examined through an AIA (Cultural Heritage Agency 2014, 3).

But, despite their advantages, these protective measures are not enough. The legislation merely provides a blanket protection, as it only applies to larger prehistoric remains and geological anomalies and forgets about important contextual information, such as environmental proxies including pollen and seeds, and archaeological proxies, like flint fragments and charcoal. Besides that, geophysical surveys are by far not accurate enough to get detailed images of the deeper parts of the seabed, which do get disturbed by the piling of wind turbines. Geotechnical surveys could also easily miss out on a lot of data, as the sediment core samples are far too small to cover the entire survey area. Documented chance finds are a welcome change, but always lose their contextual information. Yet, while so little is known about the submerged prehistoric remains and the current research methods do not suffice, it is easy to blame the protective measures. Perhaps we should look to other directions? Maybe researching the Dutch seabed before major developments are taking place is the way forward? This way an improved version of the archaeological indicative map (fig. 3.7) could be created, which should lead to faster archaeological assessments prior to offshore activities. However, funding such a large-scale research will be very expensive and could turn out to be only a slight advantage to our current situation. Yet, research from abroad shows promising results.

In 2002, the Aggregate Levy Sustainability Fund (ALSF) was introduced in the United Kingdom as a fund to 'tackle a wide range of problems in areas affected by aggregate extraction'. Marine cultural heritage was one of these areas, which resulted in a large number of researches studying the submerged landscapes of the British North Sea and the impact of aggregate extraction on them (archaeologydataservice.ac.uk). Renowned projects followed, including the North Sea Palaeolandscapes Project (NSPP), which mapped more than 23,000 km^2 of early Holocene land surfaces on the North Sea seabed (fig. 5.8) and the project Seabed Prehistory: Site Evaluation Techniques (Area 240), which funded archaeological research following the discovery of the handaxes from aggregate licence Area 240 (p. 22)(Fitch *et al.* 2007, 116; Tizzard et al. 2011, 73).

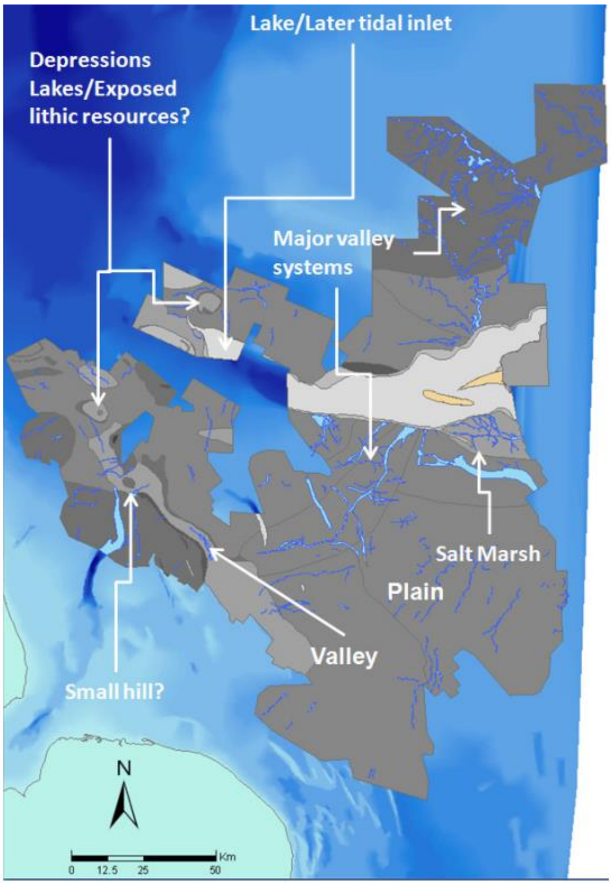


Figure 5.8 - The extent of the North Sea Palaeolandscapes Project and showing significant topographic features in the study area (Fitch *et al.* 2007, 117).

These and other ALSF funded projects showed that large-scale palaeolandscape research was possible and more than that, that offshore industries, such as the Aggregate Levy, are open to collaborations. Fortunately, the Netherlands and the UK are not the only countries experimenting with prehistoric marine heritage management. Countries all around Europe are investigating their submerged remains too. SPLASHCOS, or Submerged Prehistoric Archaeology and Landscapes of the Continental Shelf, was another great initiative at the beginning of this millennium. Funded by COST, a European mechanism that supports academic action, SPLASHCOS provided 20 million euros of grants to archaeologists, marine scientists, museum staff and heritage agencies from around 25 countries, including Israel, the Ukraine, and the Russian Federation between 2009 and 2014 (Bailey *et al.* 2020, xii). However, though submerged prehistoric research is blooming in most (wealthier) countries, only few research groups write about the importance of impact assessments and natural threats to the submerged prehistoric deposits. Hotspots are countries around North Sea, the USA, Canada and Australia. Even though these countries are environmentally, culturally and economically different, they do have some offshore industries and a submerged prehistoric landscape in common (fig 5.9).

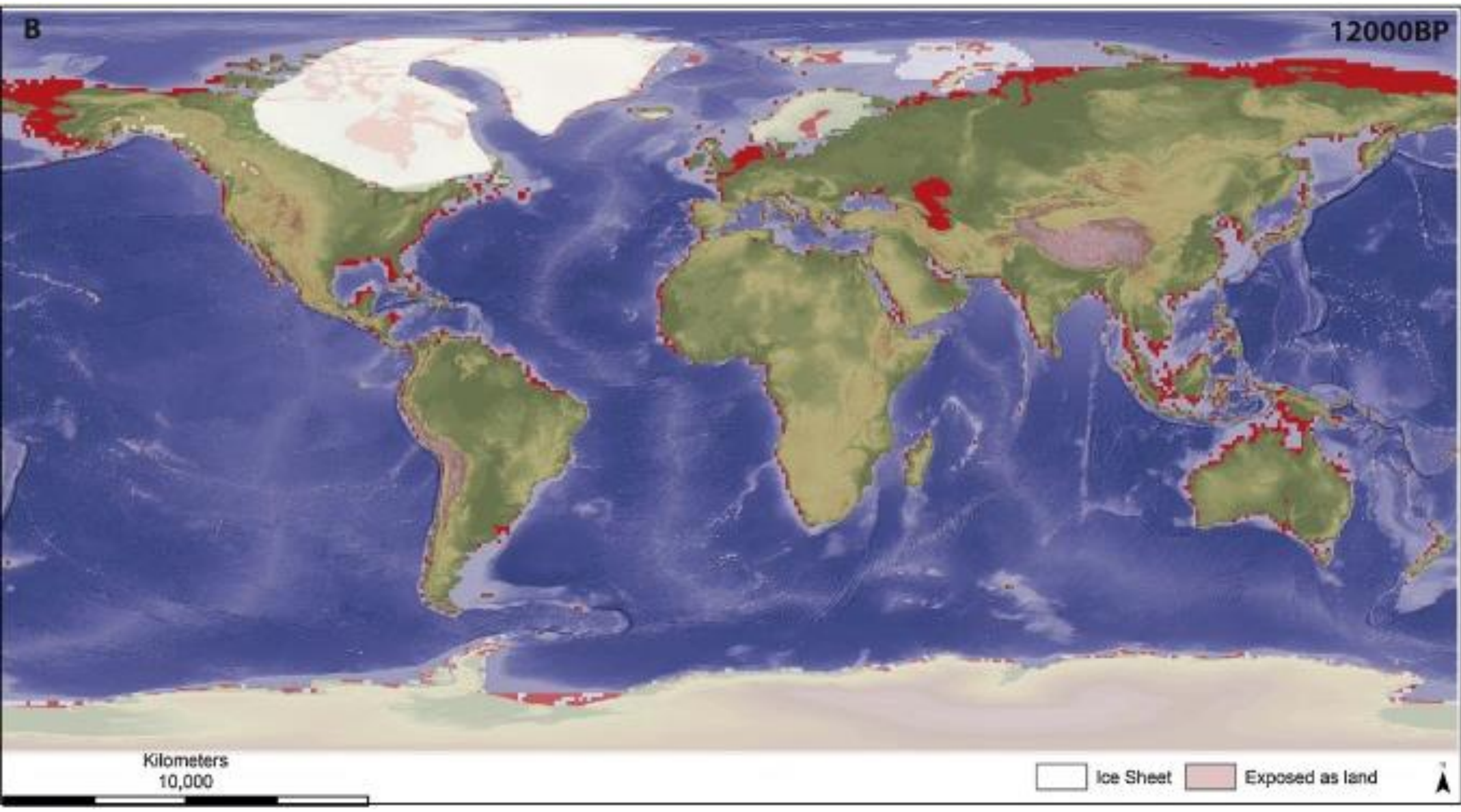


Figure 5.9 - Map of the world displaying ice extents and regions of the continental shelf exposed as land around 12 ka (Sturt *et al.* 2018, 656).

Take, for instance, The USA. Looking at the map, you'll notice that most of the American coast was extended by several kilometers twelve thousand years ago. Remains from these now submerged landscapes have recently been retrieved from fishing nets and dredging installations and include faunal remains of mammoth and mastodon. Along with the discovery of an in-situ archaic human (7200 years old) burial, they make these preserved prehistoric deposits equally interesting for further research (Sturt *et al.* 2018, 669). On the other hand, severe modification of the seabed has been attributed to trawling and dredging activities for shrimp and scallops. Also, large amounts of oil rigs and pipelines cover the seafloor in the Gulf, though the focus has recently shifted to offshore wind energy. Yet, while the US Federal Government is obligating regulations regarding pre-disturbance surveys in offshore industrial activities, and both geophysical and geotechnical techniques are being improved, more effort should be put in transporting these methods and techniques to other shores in the US (Evans *et al.* 2009, 46; Sturt *et al.* 2018, 669).

What this shows us is that seabed disturbance, affecting prehistoric deposits, is not a regional issue, but and international problem. Looking at the map again, also marks another point. The red areas represent the land that has been lost. However, they also represent the amount of land that could be lost due to sea level rise, as a result of climate change (fig 5.9). Clearly, a lot of measures need to be taken in order to mitigate the impact of this rise, measures that will certainly continue affecting the submerged prehistoric deposits. While the hydrodynamic changes (in erosion and sedimentation), due to climate change, should surely also be taken into account.

Can we still protect the submerged prehistoric resource? Or should we only count on incidental ex-situ finds from the beach and fishing trips and learn to accept that one cannot obtain the geological and archaeological data we are used to on shore (Peeters and Amkreutz 2020, 172). Because, until now, the only concrete in-situ submerged prehistoric site discovered has been the Yangtze Harbour Mesolithic site (Moree *et al.* 2015). Still, through the ex-situ finds we no longer can ignore the existence of preserved prehistoric remains within the seabed. Therefore, the challenge is now to push for additional legal safeguarding of this prehistoric heritage, despite the fact that we still cannot determine the origin of the finds with certainty. Additional legal safeguarding could come in the form of an UNESCO treaty the Netherlands signed in 2001; the Convention on the Protection of the Underwater Cultural Heritage (UCH). The treaty, currently ratified by 69 state parties, provides protection of underwater cultural heritage through giving the state the power to allow forbid any activities aimed at UCH within the territorial and contiguous zone and coordinate these activities together with other state parties in the exclusive economic zone (unesco.org). However, the Netherlands did not ratify this treaty yet, assuming that the large amount of offshore activities are the main reason why. Giving significance to the UCH, through rare finds and additional geological research, will prove vital in order for the treaty to be ratified. Otherwise, Doggerland will eventually go down.

Conclusion

In recent years, the scale and intensity of offshore developments in the Dutch North sea expanded incredibly. Demands for marine resources have increased tremendously, especially in the sectors of sand extraction and renewable energy, as climate change, including sea level rise, requires constant action. Obviously, the North Sea has an enormous economic value, since fishing, sand replenishment, and offshore wind farms provide us with food, protection and renewable energy. In the near future, the expansion of these offshore developments will doubtlessly be accompanied by new types of seabed exploitation, fuelled by improvements in offshore technologies. Yet, its prehistoric value will likely decrease, resulting from the disturbance of submerged prehistoric deposits related to the very same fishing, sand extraction, and offshore wind industries. While the actual character of and extent of future seabed exploitation is far from certain, some predictions and early-stage developments have crudely shaped their contours.

For the demersal fishing industry, the future will be characterized by decreasing fishing areas, due to foreign political decisions and the preference for other offshore industrial activities in most parts of the Dutch North sea. The loss of fishing grounds accompanied by the search for fuel-cost reduction will lead to more hovering fishing nets, which means less seabed disturbance and therefore a limited impact on the submerged prehistoric deposits. However, the ban on the seabed-friendly pulse fishing method, put in place by the European Parliament, will increase the seabed disturbance and therefore interrupt the progression of the demersal fishing industry towards having a negligible impact on the prehistoric remains beneath the seabed surface.

The future developments of the sand extraction industry, on the other hand, will be characterized by the increase in demand for coastal replenishment sand, as a consequence of sea-level rise, and additional demand in sand for construction. As new seabed areas within the sand extraction zone will be exploited in the future, the construction of relatively deep (but small in area) sandpits, will result in additional disturbance of both Palaeolithic as Mesolithic submerged remains, looking at the scale of impact from previous sand extraction activities. However, the re-use of already exploited sand extraction pits along with the protection provided by exclusion zones could provide some protection from the impacts of sand extraction on preserved prehistoric deposits.

Furthermore, to limit future negative effects of climate change, the 21st century is likely to bring the transition from fossil fuel production to a large-scale expansion of generating renewable energy, principally offshore wind farms. However, despite the positive green developments, the expansion could be accompanied by increased disturbance of submerged prehistoric deposits, as a result of direct seabed impacts, such as the piling of foundations, and indirect effects, like obstruction related seabed scour. Yet, the nature and extent of the future impacts caused by the offshore wind farm industry are far from certain. On the one hand, the disturbance of seabed sediments could increase through the construction of hydrogen hubs, in the form of artificial islands, and the continuous use of monopiles. On the other hand, the impact on the seabed sediments could significantly be reduced through the reuse of offshore oil and gas rigs for hydrogen production and the transition from fixed sea-bed foundations to floating support structures. However, is the current prehistoric heritage management enough? Funded large-scale projects abroad, such as the ALSF have sky-lifted research to submerged prehistoric landscapes and could very well help to protect sites similar to Area 240 in the future.

Figure 6.1 – A woolly mammoth molar found on the beach of Maasvlakte II (newscientist.nl).

VI. Final words

Nowadays, as I walk along the beach of Noordwijk, I keep on looking at the shorelines hoping to find a piece of Doggerland. When picking up a fossil bone, my mind begins to wonder. What could it be? Could I connect this find to a specific part of an animal? And which animal? Or is it just one of the many indeterminable pieces? Although my collection of fossil bones is expanding, one day, I hope to find a prehistoric artefact. It would be amazing to hold a tool made by a person that lived thousands of years ago and investigate whether this tool could tell us a story about life in Doggerland. According to me, that's what it's about. The significance of the beach find is in the things we could learn from it.

However, how much can we learn from such a find if all contextual information is lost? Researching the (original) context is the glue that pieces the individual artefacts together and could create a story with a beginning and an end. Yet, where to find the context? Will we be able to find it? Or do we have to create it ourselves? Fortunately, over the years, Doggerland has revealed a lot of its prehistory already. Thanks to the work of many pioneering research groups the prehistoric landscapes of Doggerland and its occupants can be pieced together partly. They researched important finds, such as the Neanderthal eyebrow ridge, the tar-backed flint tool, and the decorated bison fossil, and examined extensive geophysical and geotechnical data, obtained through recent geological expeditions and existing data provided by offshore industries. Stacked sediments of terrestrial, coastal and marine deposits reveal that Doggerland has been subject to continuous sea level oscillations, and as a consequence knew a variety of landscapes and seascapes. Prehistoric groups that inhabited these Pleistocene and Holocene landscapes profited from what these environments had to offer, until the moment they were steadily replaced by the rising sea levels. Taking into account the number of remains these prehistoric groups would have left behind, and the vast extent of the Doggerland, spanning across a large part of the current North sea, one can imagine that many undiscovered remains are still hidden beneath the waves, demonstrating the significance of Doggerland.

However, this significance depends on the state of preservation of the prehistoric deposits. After all, what remains of these vast and intricate landscapes? Are the fossil and occasional lithic finds the only remnants, or is there more material to be expected? First of all, we need to take into account the complex landscape evolution of the North Sea basin, which experienced varying successions of marine, lacustrine, fluvial and glacial sedimentation and erosion. This change between sedimentation and erosion created an array of palimpsests (erasing past landscape elements and constructing new ones within). Besides that, from the moment the area was submerged, until today, the seabed surface has been shaped by continuous marine erosion and sedimentation induced by hydrodynamic processes, such as tidal currents and wave action. As a consequence, there is still a lot of uncertainty regarding the prehistoric significance of submerged Doggerland. On top of that, these prehistoric deposits are still in danger of destruction, as current marine hydrodynamic mechanisms and subsequent biological and chemical alterations repeat the process, which continues to create palimpsests.

Besides these natural threats, offshore industrial activities, such as bottom trawling, sand extraction, and the construction of wind farms pose a significant threat to the submerged prehistoric remains too. Especially the use of heavy trawling gear, the creation of sandpits, and the piling of monopoles, cut deep into the seabed sediments, and could easily displace, damage and/or destroy prehistoric deposits residing close to the seabed surface. Additionally, these offshore industrial activities invoke indirect impacts resulting from the alteration of seabed sediments. For instance, frequent trawling activities might flatten the seabed surface, which, over time, leads to a snowball effect that increases erosion of the seabed sediments. Moreover, beam trawling at spots where the mobile seabed layer is thin, such as the Brown Bank, will lead to increased disturbance of prehistoric deposits, as demonstrated by the large number of Pleistocene fossils that already resurfaced in the fishing nets. On the other hand, the activities related to the sand extraction and construction of wind farms will have different indirect effects. Instead of a general increased erosion, the erosion is of a more localised nature, as especially the slopes of the sandpits will be eroding severely. Concerning the offshore wind industry, the monopiles used to support the wind turbines will lead to scouring holes on the leeward side of the pole, uncovering adjacent seabed.

Yet, whether these direct and indirect disturbances touch upon the prehistoric remains buried in the seabed depends on the presence of preserved and shallow prehistoric deposits. Therefore, understanding the site-specific depositional context, as well as the taphonomic processes and the current hydrodynamic processes that affect these deposits, provides the foundation for predicting the actual impact of the industrial activities on the submerged prehistoric landscapes. Even though this is a mammoth task already, the future will doubtlessly provide for ever-increasing challenges related to the development of these offshore industries. While the impact of bottom trawling remains present for now, due to the ban on electrical pulse gear, the search for more fuel-efficient trawling gear will change the industries’ impact. On the other hand, the impact of the coastal replenishments and the development of offshore wind farms will certainly increase, considering that the focus in the coming decades will be on expanding the coastal replenishment and the transition to renewable energy resources will steer towards increasing the megawatts generated offshore. It is therefore likely that there will be significant overlap between the proposed areas of future developments and areas containing prehistoric remains. Whether this means that the submerged prehistoric deposits will be affected to a greater extent than today is yet far from certain, as the pace of innovations within the offshore industries is incredible. For instance, floatable wind turbine support structures could eventually replace the monopiles, and the re-use of sandpits, along with the protection provided by exclusion zones, could provide some protection from the impacts of these industries on the preserved prehistoric deposits within the Dutch seabed.

To conclude, the future of Doggerland is far from certain. Archaeologists and heritage workers see the value of this area for the knowledge we can obtain through academic research. Yet, not everyone recognises this value. Certainly when we're fighting climate change at the same time. They do not see the harm in minimizing the effort to protect the submerged prehistoric remains in-situ and wait to see what we will pick up from the beach. Yet, prior to offshore developments small-scale research on the submerged prehistoric landscapes of the North Sea is currently possible and this ultimately results in a better understanding of the prehistoric environment. This does not create the context that we hope to find, but along with international research initiatives, public participation from the beaches, media attention from spectacular finds and new museum exhibitions (rmo.nl), it does increase appreciation for the submerged prehistoric heritage. Whether this appreciation will result in additional protection for the submerged prehistoric remains, depends on tough lobbying by heritage workers, backed up by research of Doggerland and the threats it faces. But, to quote famous ocean explorer Jacques Yves Cousteau: 'People will protect what they love' (Berger Kaye and Cousteau 2010, 10). Unfortunately, due to ongoing offshore activities, time is running out, and though we have only recently discovered Doggerland, we should already determine what to do with it.

Abstract

Today, large amounts of Pleistocene fossils and prehistoric artefacts are encountered in the nets of bottom trawling fishing vessels and found on beaches along the Dutch coast. Interestingly, these finds do not derive from the current mainland but originate from a prehistoric land currently submerged beneath the North Sea. This land, known to us as 'Doggerland', extended across major parts of the North Sea during times when the sea level was more than 50 meters lower than today. The area consisted of diverse landscapes that ranged from tundra plains, during the glacial periods, to forested areas and coastal swamps, during warmer interglacial periods. These prehistoric landscapes were home to a large number of animal and plant species, and consequentially offered attractive environments for prehistoric hunter-gatherer groups.

The fact that remains from Doggerland are encountered today demonstrates that at least parts of these prehistoric landscapes have been preserved beneath the seabed. However, at the same time, the finds indicate that the submerged prehistoric remains are being disturbed and displaced from their original or derived context. The disturbance can be attributed to offshore industrial activities, such as the fishing industry and sand extraction activities. Through their exploitation of the seabed, a large amount of fossil bones and artefacts resurface in the fishing nets and on sand suppleted beaches along the Dutch coast. Besides that, considering that certain offshore industrial activities will expand in response to the renewable energy transition and the ever-rising sea level, major parts of Doggerland are likely to be lost in the future. On the other hand, the nature and extent of the offshore industrial disturbances in relation to the submerged prehistoric remains are far from certain. This applies to today and the future especially. The following thesis, therefore, investigates the impacts of trawling activities, sand extraction and offshore wind generation on the seabed sediments, taking into account the depositional context, taphonomic processes as well as the current hydrodynamic conditions that have altered these deposits already.

Acknowledgements

I would like to thank all the people that have supported me throughout the entire length of this thesis. Especially, I would like to thank Martijn Manders for being patient and guiding me through the process, Ad Stolk and Bjørn Smit for answering all my questions and checking my thesis using their expertise, Jelle Moree and Daniel Bökenkamp for being great friend with constructive feedback, and my family and friends for being patient and the welcome distraction.

References

Literature

Amkreutz, L., Verpoorte, A., Waters-Rist, A., Niekus, M., Van Heekeren, V., Van der Merwe, A., Van der Plicht, H., Glimmerveen, J., Stapert, D. and L. Johansen, 2018. What lies beneath . . . Late Glacial human occupation of the submerged North Sea landscape. *Antiquity, 92*(361), 22-37. https://doi.org/10.15184/aqy.2017.195.

Amkreutz, L., Verpoorte, A., Waters-Rist, A., Niekus, M., Van Heekeren, V., Van der Merwe, A., Van der Plicht, H., Glimmerveen, J., Stapert, D. en L. Johansen, 2018. IJstijdjagers op de bodem van de Noordzee: Zeldzame aanwijzingen voor de Laat-glaciale menselijke bewoning van het Noordzeelandschap. *Cranium* 35(1), 41-45.

Amkreutz, L.W.S.W., Cohen, K.M., Hijma, M.P. en O. Odé, 2021. Verdrinkend land in kaart, in L.W.S.W. Amkreutz and S. Van der Vaart-Verschoof, *Doggerland: Verdwenen wereld in de Noordzee*. Leiden (NL): Sidestone Press, 33-37.

Ashton, N.M., Lewis, S.G., De Groote, I., Duffy, S.M., Bates, M., Bates, R., Hoare, P., Lewis, M., Parfitt, S.A., Peglar, S., Williams, C. and C. Stringer, 2014. Hominin Footprints from Early Pleistocene Deposits at Happisburgh, UK. *PLoS ONE* 9(2), 1-13. https://doi.org/10.1371/journal.pone.0088329.

Ashton, N.M., 2016. The human occupation of Britain during the Hoxnian Interglacial. *Quaternary International* 409, 41-53. https://doi.org/10.1016/j.quaint.2015.11.055.

Augustyn, D., Nielsen, M.B. and R.R. Pedersen, 2017. 17.04: Design of offshore wind turbine jacket foundations: On the influence of subsequent modifications on fatigue performance. *Ce/papers 1(2-3), Eurosteel 2017*, 4323-4332. https://doi-org/10.1002/cepa.491.

Bailey, G., Galanidou, N., Peeters, H., Jöns, H. and M. Mennenga, 2020. The Archaeology of Europe's Drowned Landscapes: Introduction and Overview, in G. Bailey, N. Galanidou, H. Peeters, H. Jöns and M. Mennenga (eds), *The Archaeology of Europe's Drowned Landscapes*. Cham (CH): Springer Coastal Research Library 35, 1-23. https://doi.org/10.1007/978-3-030-37367-2_1.

Bailey, G., Momber, G., Bell, M., Tizzard, L., Hardy, K., Bicket, A., Tidbury, L., Benjamin, J. and A. Hale, 2020. Great Britain: The Intertidal and Underwater Archaeology of Britain's Submerged Landscapes, in G. Bailey, N. Galanidou, H. Peeters, H. Jöns and M. Mennenga (eds), *The Archaeology of Europe's Drowned Landscapes*. Cham (CH): Springer Coastal Research Library 35, 189-219. https://doi.org/10.1007/978-3-030-37367-2_10.

Berger Kaye, C. and P. Cousteau, 2010. *Going Blue: A Teen Guide to Saving Our Oceans & Waterways*. Minneapolis (USA): Free Spirit Publishing.

Bicket, A. and L. Tizzard, 2015. A review of the submerged prehistory and palaeolandscapes of the British Isles. *Proceedings of the Geologists' Association* 126, 643-663. https://doi.org/10.1016/j.pgeola.2015.08.009.

Boon, J.J., Peeters, J.H.M., Brinkhuizen, D.C., Cohen, K.M., Kooistra, L.I., Kubiak-Martens, L., Moree, J.M., Niekus, M.J.L.Th., Schiltmans, D.E.A., Verbaas, A., Verbruggen, F., Vos P.C. en J.T. Zeiler, 2015. Twenty meters deep! The Mesolithic period at the Yangtze Harbour site - Rotterdam Maasvlakte, the Netherlands, Early Holocene landscape development and habitation, in J.M. Moree and M.M. Sier (eds), *Interdisciplinary Archaeological Research Programme Maasvlakte 2, Rotterdam*. Rotterdam (NL): BOORrapporten 566, 7-350.

Boon, A.R., Caires, S., Wijnant, I.L., Zijl, F., Schouten, J.J., Muis, S., van Kessel, T., van Duren, L. en T. van Kooten, 2018. Assessment of system effects of large-scale implementation of offshore wind in the southern North Sea. *Deltares rapport 11202792-002*. Deltares, Delft.

Busschers, F., Westerhoff, W. en S. van Heteren, 2013. Het stratigrafische raamwerk voor de geologische opbouw van het zandwingebied Maasvlakte 2. *Rapport 1 van het geo-archeologisch en paleontologisch onderzoek zandwingebied en buitencontour Maasvlakte 2*. TNO, Utrecht.

BVG, 2019. Guide to an offshore wind farm: Updated and extended. *Report BVG Associates*. BVG Associates, Swindon.

Clark, S., Schroeder, F. and B. Bashek, 2014. The influence of large offshore wind farms on the North Sea and Baltic Sea - a comprehensive literature review. *HZG report 2014-6*. Helmholtz-Zentrum Geesthacht, Geesthacht.

Cohen, K.M., Westley K., Erkens G., Hijma, M.P. and H.J.T. Weerts, 2017. The North Sea, in N.C. Flemming, J. Harff, D. Moura, A. Burgess and G.N. Bailey (eds), *Submerged Landscapes of the European Continental Shelf: Quaternary Paleoenvironments*. Hoboken (USA): John Wiley & Sons, Ltd., 147-186. https://doi.org/10.1002/9781118927823.ch7.

Coles, B.J., 1998. Doggerland: a Speculative Survey. *Proceedings of the Prehistoric Society* 64, 45-81. https://doi.org/10.1017/S0079497X00002176.

Cooper, N.J. and D.S. Brew, 2013. Impacts on the physical environment, in R. Newell and T. Woodcock (eds), *Aggregate Dredging and the Marine Environment: An overview of recent research and current industry practice*. London (UK): The Crown Estate, 68-87.

Council of the European Union, 2019. Regulation (EU) 2019/1241 of the European Parliament and of the Council of 20 June 2019 on the conservation of fisheries resources and the protection of marine ecosystems through technical measures, amending Council Regulations (EC) No 1967/2006, (EC) No 1224/2009 and Regulations (EU) No 1380/2013, (EU) 2016/1139, (EU) 2018/973, (EU) 2019/472 and (EU) 2019/1022 of the European Parliament and of the Council, and repealing Council Regulations (EC) No 894/97, (EC) No 850/98, (EC) No 2549/2000, (EC) No 254/2002, (EC) No 812/2004 and (EC) No 2187/2005. European Parliament, Council of the European Union, Brussels. http://data.europa.eu/eli/reg/2019/1241/oj, accessed on 13/07/2021.

Council of the European Union, 2020. Trade and cooperation agreement between the European Union and the European Atomic Energy Community, of the one part, and the United Kingdom of Great Britain and Northern Ireland, of the other part. *Free Trade Agreement*, Brussels and London.

Cultural Heritage Agency of the Netherlands, 2014. Legislation underwater surfaces (Wetgeving waterbodems). *Brochure archaeological implications*. Cultural Heritage Agency of the Netherlands, Amersfoort.

Department of Energy and Climate Change, 2016. UK Offshore Energy Strategic Environmental Assessment: Future Leasing/Licensing for Offshore Renewable Energy, Offshore Oil & Gas, Hydrocarbon Gas and Carbon Dioxide Storage and Associated Infrastructure. *Department for Business, Energy & Industrial Strategy*, London. https://www.gov.uk/government/consultations/uk-offshore-energy-strategic-environmental-assessment-3-oesea3.

Depestele, J., Ivanovic, A., Esmaelli, M., Polet, H., Roche, M., Summerbell, K., Teal, L.R., Vanelslander, B. and F. O'Neill, 2016. Measuring and assessing the physical impact of beam trawling. *ICES Journal of Marine Science* 73(1), 15-26. https://doi.org/10.1093/icesjms/fsv056.

Eigaard, O.R., Bastardie, F., Hintzen, N.T., Buhl-Mortensen, L., Buhl-Mortensen, P., Catarino, R. Dinesen, G.E., Egekvist, J., Fock, H.O., Geitner, K., Gerritsen, H.D., Marín González, M., Jonsson, P., Kavadas, S., Laffargue, P., Lundy, M., Gonzalez-Mirelis, G., Rasmus Nielsen, J., Papadopoulou, N., Posen, P.E., Pulcinella, J., Russo, T., Sala, A., Silva, C., Smith, C.J., Vanelslander, B. and A.D. Rijnsdorp, 2016. The footprint of bottom trawling in European waters: distribution, intensity, and seabed integrity. *ICES Journal of Marine Science* 74(3), 847–865. https://doi.org/10.1093/icesjms/fsw194.

Evans, A.M., Firth, A. and M. Staniforth, 2009. Old and New Threats to Submerged Cultural Landscapes: Fishing, Farming and Energy Development. *Conservation and Management of Archaeological Sites* 11(1), 43-53. https://doi.org/10.1179/135050309X12508566208407.

Federale Overheidsdienst Economie, 2020. *Zand- en grindwinning in het Belgische deel van de Noordzee*. Brochure Federale Overheidsdienst Economie K.M.O., Middenstand en Energie, Brussel.

Flemming, N.C., Harff, J., Moura, D., Burgess, A. and G.N. Bailey, 2017. Introduction: Prehistoric Remains on the Continental Shelf — Why do Sites and Landscapes Survive Inundation?, in N.C. Flemming, J. Harff, D. Moura, A. Burgess and G.N. Bailey (eds), *Submerged Landscapes of the European Continental Shelf.* Hoboken (USA): John Wiley & Sons, Ltd., 1-10. https://doi.org/10.1002/9781118927823.ch1.

Firth, A.J., 2013a. Submerged Prehistory in the North Sea, in B. Ford, D.L. Hamilton and A. Catsambis (eds), *The Oxford Handbook of Maritime Archaeology*. New York (USA): Oxford University Press, 786-809. https://doi.org/10.1093/oxfordhb/9780199336005.013.0034.

Firth, A.J., 2013b. Marine Archaeology, in R.C. Newell and T.A. Woodcock, (eds), *Aggregate Dredging and the Marine Environment: an overview of recent research and current industry practice*. London (UK): The Crown Estate, 44-66.

Fitch, S., Gaffney, V.L. and K. Thomson, 2007. Heritage Management and the North Sea Palaeolandscapes Project, in V.L. Gaffney and K. Thomson (eds), *Mapping Doggerland: the Mesolithic Landscapes of the Southern North Sea.* Oxford (GB): Archaeopress, 105-129.

Freeman, K., Frost, C., Hundleby, G., Roberts, A., Valpy, B., Holttinen, H., Ramírez, L., Pineda, I. and C. Walsh, 2019. Our energy, our future: How offshore wind will help Europe go carbon-neutral. *Report BVG associates*. BVG Associates, Swindon.

Gaffney, V.L., Thomson, K. and S. Fitch, 2007. *Mapping Doggerland: The Mesolithic landscapes of the Southern North Sea*. Oxford (GB): Archaeopress.

Ghigo, A., Cottura, L., Caradonna, R., Bracco, G. and G. Mattiazzo, 2020. Platform Optimization and Cost Analysis in a Floating Offshore Wind Farm. *Journal of Marine Science and Engineering 8*(11), 835. https://doi.org/10.3390/jmse8110835.

Haasnoot, M., Bouwer, L., Diermanse, F., Kwadijk, J., van der Spek, A., Oude Essink, G., Delsman, J., Weiler, O., Mens, M., ter Maat, J., Huismans, Y., Sloff, K. en E. Mosselman, 2018. Mogelijke gevolgen van versnelde zeespiegelstijging voor het Deltaprogramma: Een verkenning. *Deltares rapport 11202230-005-0002.* Deltares, Delft.

Harff, J., Flemming, N.C., Groh, A., Hünicke, B., Lericolais, G., Meschede, M., Rosentau, A., Sakellariou, D., Uścinowicz, S., Zhang, W. and E. Zorita, 2017. Sea level and Climate, in N.C. Flemming, J. Harff, D. Moura, A. Burgess and G.N. Bailey (eds), *Submerged Landscapes of the European Continental Shelf.* Hoboken (USA): John Wiley & Sons, Ltd, 11-49. https://doi.org/10.1002/9781118927823.ch2.

Hijma, M.P. and K.M. Cohen, 2019. Holocene sea-level database for the Rhine-Meuse Delta, The Netherlands: Implications for the pre-8.2 ka sea-level jump. *Quaternary Science Reviews* 214, 68-86. https://doi.org/10.1016/j.quascirev.2019.05.001.

Hijma, M.P., Cohen, K.M., Roebroeks, W., Westerhoff, W.E. and F.S. Busschers, 2012. Pleistocene Rhine–Thames landscapes: geological background for hominin occupation of the southern North Sea region. *Journal of Quaternary Science* 27(1), 17-39. https://doi.org/10.1002/jqs.1549.

Hooft Graafland, C. and R. Blokdijk, 2021. Hydrogen Techonology Guide: Excelling in Hydrogen, Dutch technology for a climate-neutral world. *Joint report Netherlands Enterprise Agency and FME*. Netherlands Enterprise Agency (RVO), Utrecht.

Hublin, J.J., Weston, W., Gunz P., Richards M., Roebroeks, W., Glimmerveen J. and L. Anthonis, 2009. Out of the North Sea: the Zeeland Ridges Neandertal. *Journal of Human Evolution* 57, 777-785. https://doi.org/10.1016/j.jhevol.2009.09.001.

International Council for the Exploration of the Sea, 2020. Request of the Netherlands on the ecosystem and environmental impacts of pulse trawling for the sole (Solea solea) fishery in the North Sea. *Report of the ICES Advisory Committee* (sr.2020.03.), 1-12. https://www.ices.dk/news-and-events/news-archive/news/Pages/PulseTrawlAdvice.aspx.

Johansen, L., Niekus, M.J.L.Th. en D. Stapert, 2009. Zwarte vuur stenen uit het Midden-Paleolithicum in Nederland. *Paleo-aktueel* 20, 1-8. https://orcid.org/0000-0003-1082-8058.

Kuitems, M., Van Kolfschoten, T., De Loecker, D. and F.S. Busschers, 2015. Geoarchaeological and palaeontological research in the Maasvlakte 2 sand extraction zone and on the artificially created Maasvlakte 2 beach: a synthesis, in J.M. Moree and M.M. Sier (eds), *Interdisciplinary Archaeological Research Programme Maasvlakte 2, Rotterdam*. Rotterdam (NL): BOORrapporten 566, 351- 398.

Laban, C. and J.M. van der Meer, 2011. Chapter 20 - Pleistocene Glaciation in The Netherlands, in J. Ehlers, P.L. Gibbard and P.D. Hughes (eds), *Developments in Quaternary Science* (15). Amsterdam (NL): Elsevier, 247-260. https://doi.org/10.1016/B978-0-444-53447-7.00020-9.

Lauer, T. and M. Weiss, 2018. Timing of the Saalian- and Elsterian glacial cycles and the implications for Middle - Pleistocene hominin presence in central Europe. *Scientific Reports* 8(1), 5111-5113. https://doi.org/10.1038/s41598-018-23541-w.

Maarleveld, T.J., 2020. Beam Trawls and Bones: A Reflection on Dutch Fisheries, in G. Bailey, N. Galanidou , H. Peeters, H. Jöns and M. Mennenga (eds), *The Archaeology of Europe's Drowned Landscapes*. Cham (CH): Springer Coastal Research Library 35, 521-535. https://doi.org/10.1007/978-3-030-37367-2_27.

Macklin, M.G., 1999. Holocene river environments in prehistoric Britain: Human interaction and impact. *Journal of Quaternary Science* 14(6), 521-530. https://doi.org/10.1002/(SICI)1099-1417(199910)14:6<521::AID-JQS487>3.0.CO;2-G.

Manders, M.R., 2017. *Preserving a layered history of the Western Wadden Sea: managing an underwater cultural heritage resource*. Leiden University, Leiden (unpublished Ph.D. thesis Leiden University).

Manders, M.R., Otte-klomp, A., Peeters, J.H.M. en P. Stassen, 2008. Wetenschappelijk kader voor de archeologische monumentenzorg bij aanleg tweede Maasvlakte, Europoort-Rotterdam. *Rapportage Archeologische Monumentenzorg 169.* Rijksdienst voor archeologie, cultuurlandschap en monumenten, Amersfoort.

Ministry of Infrastructure and the Environment and Ministry of Economic Affairs, 2012. Marine Strategy for the Netherlands part of the North Sea 2012-2020, Part 1. *Policy document Ministry of Infrastructure and the Environment and Ministry of Economic Affairs*. The Ministry of Infrastructure and the Environment, The Hague.

Ministry of Infrastructure and the Environment and Ministry of Economic Affairs, 2015. *Policy Document on the North Sea 2016-2021*. The Ministry of Infrastructure and the Environment, The Hague.

Missiaen, T., Derudder, T., Rabaut, M., Van Haelst, S., Pieters, M., Lettany, R., Pirlet, H., en F. Maes, 2016. Erfgoed in zee: wat moet ik ermee? Richtlijnen voor de gebruikers van de Noordzee met betrekking tot het cultureel erfgoed onder water. Gent (BE): *VLAIO SeArch brochure*. SeArch, Gent.

Missiaen, T., Fitch, S., Harding, R., Muru, M., Fraser, A., De Clercq, M., Moreno, D.G., Versteeg, W., Busschers, F.S., van Heteren, S., Hijma, M.P., Reichart, G. and V. Gaffney, 2021. Targeting the Mesolithic: Interdisciplinary approaches to archaeological prospection in the Brown Bank area, southern North Sea. *Quaternary International* 584, 141-151. https://doi.org/10.1016/j.quaint.2020.05.004.

Mol, A. , van Oostenbrugge, H., Röckmann, C. en N. Hintzen, 2019. Wind op Zee: bepaling van de waarde van geplande windparkgebieden voor de visserij. *Wageningen Economic Research nota 2019-011*. Wageningen Economic Research, Wageningen.

Mol, D., Bijkerk, A. and J.P. Ballard, 2018. Deciduous Tusks and Small Permanent Tusks of the Woolly Mammoth, Mammuthus primigenius (Blumenbach, 1799) Found on Beaches in The Netherlands. *Quaternary* 1(7), 1-14. https://doi.org/10.3390/quat1010007.

Molen, van der, J., 2002. The influence of tides, wind and waves on the net sand transport in the North Sea. *Elsevier Continental Shelf Research* 22, 2739-2762. https://doi.org/10.1016/S0278-4343(02)00124-3.

Momber, G., Tomalin, D., Scaife, R., Satchell, J. and J. Gillespie, 2012. Mesolithic occupation at Bouldnor Cliff and the submerged prehistoric landscapes of the Solent. *CBA Research Report 164*. CBA, York.

Moreau, J., Huuse, M., Janszen, A., van der Vegt, P., Gibbard, P.L. and A. Moscariello, 2012. The glaciogenic unconformity of the southern North Sea. *Geological Society Special Publications* 368, 99-110. https://doi.org/10.1144/SP368.5.

Newell, R.C., 2013. Introduction, in R.C. Newell and T.A. Woodcock (eds), *Aggregate Dredging and the Marine Environment: An overview of recent research and current industry practice*. London (UK): The Crown Estate, 14-21.

Netherlands Enterprise Agency, 2018. Project and Site Description Hollandse Kust (zuid) Wind Farm Zone Wind Farm Sites III & IV. *Netherlands Enterprise Agency* (RVO), Utrecht. Offshorewind.rvo.nl: Project and Site Description HKZ III & IV, Version October 2018.

Nichols, G., 2009. *Sedimentology and Stratigraphy*. Chichester (UK): Wiley -Blackwell.

Niekus, M.J.L.Th., Kozowyk, P.R.B., Langejans, G.H.J., Ngan-Tillard, D., Keulen, van H., Plicht, van der J., Cohen, K.M., Wingerden, van W., Os, van B., Smit, B.I., Amkreutz, L.W.S.W, Johansen, L., Verbaas, A. and G.L. Dusseldorp, 2019. Middle Paleolithic complex technology and a Neandertal tar-backed tool from the Dutch North Sea. *Proceedings of the National Academy of Sciences* 116(44), 22081-22087. https://doi.org/10.1073/pnas.1907828116.

Ottesen, D., Batchelor, C.L., Dowdeswell, J.A. and H. Løseth, 2018. Morphology and pattern of Quaternary sedimentation in the North Sea Basin (52–62°N). *Marine and Petroleum Geology* 98, 836-859. https://doi.org/10.1016/j.marpetgeo.2018.08.022.

Ottesen, D., Stewart, M., Brönner, M. and C.L. Batchelor, 2020. Tunnel valleys of the central and northern North Sea (56°N to 62°N): Distribution and characteristics. *Marine Geology* 425, 1-19. https://doi.org/10.1016/j.margeo.2020.106199.

Overlegorgaan Fysieke Leefomgeving, 2020. Het Akkoord voor de Noordzee. *Rapport onderhandelaarsakkoord Noordzeestrategie tot en met 2030 en daarna*. 's Gravenhage (NL): Overlegorgaan Fysieke Leefomgeving. Het Akkoord voor de Noordzee juni 2020 - Overlegorgaan Fysieke Leefomgeving.

Oxford Archaeology, 2008. Guidance for Assessment of Cumulative Impacts on the Historic Environment from Offshore Renewable Energy. *COWRIE report (CIARCH-11-2006)*. COWRIE Ltd., London.

Pater, C., 2020. *Seabed Infrastructure Projects, Underwater Cultural Heritage and The Environmental Assessment Process: The UK Example*, in G. Bailey, N. Galanidou, H. Peeters, H. Jöns and M. Mennenga (eds), *The Archaeology of Europe's Drowned Landscapes*. Cham (CH): Springer Coastal Research Library 35, 509-520. https://doi.org/10.1007/978-3-030-37367-2_26.

Peeters, J.H.M. and L.W.S.W Amkreutz, 2020. The Netherlands: Probing into the Submerged Prehistoric Archaeology, Landscapes and Palaeontology of the Dutch Continental Shelf, in G. Bailey, N. Galanidou, H. Peeters, H. Jöns and M. Mennenga (eds), *The Archaeology of Europe's Drowned Landscapes*. Cham (CH): Springer Coastal Research Library 35, 157-174. https://doi.org/10.1007/978-3-030-37367-2_8.

Peeters, J.H.M., Amkreutz, L.W.S.W., Cohen K.M. and M.P. Hijma, 2019. North Sea Prehistory Research and Management Framework (NSPRMF) 2019: Retuning the research and management agenda for prehistoric landscapes and archaeology in the Dutch sector of the continental shelf. *Nederlandse Archeologische Rapporten (NAR) 63*. Cultural Heritage Agency of the Netherlands, Amersfoort.

Peeters, J.H.M. and G. Momber, 2014. The southern North Sea and the human occupation of northwest Europe after the Last Glacial Maximum. *Netherlands Journal of Geosciences (Geologie en Mijnbouw)* 93, 55-70. https://doi.org/10.1017/njg.2014.3.

Parfitt, S.A., Ashton, N.M., Lewis, S.G., Abel, R.L., Coope, G.R., Field, M.H., Gale, R., Hoare, P.G., Larkin, N.R., Lewis, M.D., Karloukovski, V., Maher, B.A., Peglar, S.M., Preece, R.C., Whittaker, J.E. and C.B. Stringer, 2010. Early Pleistocene human occupation at the edge of the boreal zone in northwest Europe. Nature 466(7303), 229-233. https://doi-org.ezproxy.leidenuniv.nl/10.1038/nature09117.

Parfitt, S.A., Barendregt, R.W., Breda, M., Candy, I., Collins, M.J., Coope, G.R., Durbidge, P., Field, M.H., Lee, J.R., Lister, A.M., Mutch, R., Penkman, K.E.H., Preece, R.C., Rose, J., Stringer, C.B., Symmons, R., Whittaker, J.E. Wymer, J.J. and A.J. Stuart, 2005. The earliest record of human activity in northern Europe. Nature 438(7070), 1008-1012. https://doi.org/10.1038/nature04227.

Planteijd, R., 2007. MER aanleg Maasvlakte 2: Bijlage Archeologie. *Rapport Havenbedrijf Rotterdam*. Havenbedrijf Rotterdam, Rotterdam. https://commissiemer.nl/docs/mer/p14/p1450/1450-159archeologie.pdf.

Raad van State, 2020. *Klimaatwet*. Den Haag: Raad van State en Staten-Generaal. https://wetten.overheid.nl/jci1.3:c:BWBR0042394&hoofdstuk=1&artikel=2&z=2020-01-01&g=2020-01-01, accessed on 26/05/2021.

Reise, K. and J. Kohlus, 2007. Seagrass recovery in the Northern Wadden Sea? *Helgol Mar Res* 62, 77-84. https://doi-org/10.1007/s10152-007-0088-1.

Rijnsdorp, A.D., Depestele, J., Eigaard, O.R., Hintzen, N.T., Ivanovic, A., Molenaar, P., and T. van Kooten, 2020. Mitigating seafloor disturbance of bottom trawl fisheries for North Sea sole Solea solea by replacing mechanical with electrical stimulation. *PloS One* 15(11), 1-17. https://doi.org/10.1371/journal.pone.0228528.

Rijnsdorp, A.D., Hiddink, J.G., van Denderen, P.D., Hintzen, N.T., Eigaard, O.R., Valanko, S., Bastardie, F., Bolam, S.G., Boulcott, P., Egekvist, J., Garcia, C., van Hoey, G., Jonsson, P., Laffargue, P., Nielsen, J.R., Piet, G.J., Sköld, M. and T. van Kooten, 2020. Different bottom trawl fisheries have a differential impact on the status of the North Sea seafloor habitats. *ICES Journal of Marine Science* 77(5), 1772-1786. https://doi-org/10.1093/icesjms/fsaa050.

Roebroeks, W., 2014. Terra incognita: The Palaeolithic record of northwest Europe and the information potential of the southern North Sea. *Netherlands Journal of Geosciences (Geologie en Mijnbouw)* 93, 43-53. https://doi.org/10.1017/njg.2014.1.

Salter, E., Murphy, P. and H. Peeters, 2014. Researching, Conserving and Managing Submerged Prehistory: National Approaches and International Collaboration, in A. Evans, J. Flatman and N. Flemming (eds), *Prehistoric Archaeology on the Continental Shelf*. New York (USA): Springer, 151-172. https://doi.org/10.1007/978-1-4614-9635-9_9.

SER, 2013. Energieakkoord voor duurzame groei. *Sociaal-Economische Raad akkoord.* https://www.rijksoverheid.nl/documenten/convenanten/2013/09/06/energieakkoord-voor-duurzame-groei, accessed on 16/11/2021.

Spearman, J., 2015. A review of the physical impacts of sediment dispersion from aggregate dredging. *Marine Pollution Bulletin* 94, 260–277. https://doi.org/10.1016/j.marpolbul.2015.01.025.

Sturt, F., Flemming, N., Carabias, D., Jöns, H. and J. Adams, 2018. The next frontiers in research on submerged prehistoric sites and landscapes on the continental shelf. *Proceedings of the Geologists' Association 129*(5), 654-683. https://doi.org/10.1016/j.pgeola.2018.04.008.

Terp-Paulsen, B., Roetert, T., Raaijmakers, T., Forzoni, A., Hoekstra, R. and P. van Steijn, 2016. Morphodynamics of Hollandse Kust (Zuid) Wind Farm Zone: Prediction of seabed level changes between 2016 and 2051. *Deltares report 1230851-000*. Deltares, Delft.

The Crown Estate Licences, 2019. *Marine aggregates, summary of statistics 2019.* The Crown Estate, London.

Tizzard, L., Baggaley, P.A. and A.J. Firth, 2011. Seabed Prehistory: Investigating palaeolandsurfaces with Palaeolithic remains from the southern North Sea, in J. Benjamin, C. Bonsall, C. Pickard and A. Fisher (eds), *Submerged Prehistory*. Oxford (GB): Oxbow Books, 65-74.

United Nations, 2015. Paris Climate Agreement: Convention on Climate Change. *21st Conference of the Parties.* United Nations, Paris. https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement, accessed on 26/05/2021.

Van de Bilt, S., Jaspers Faijer, M. and E. Arends, 2016. Environmental Impact Assessment Site I Windenergiegebied Hollandse Kust (zuid). *Pondera report 715082*. Pondera consult, Hengelo.

Van der Molen, J., Smith, H.C.M., Lepper, P., Limpenny, S. and J. Rees, 2014. Predicting the large-scale consequences of offshore wind turbine array development on a North Sea ecosystem. *Continental Shelf Research* 85, 60-72. https://doi.org/10.1016/j.csr.2014.05.018.

Van Duin, C., Vrij Peerdeman, M., Jaspers, H. en A. Bucholc, 2017. Winning suppletiezand Noordzee 2018 t/m 2027: Milieueffectrapportage. *SWECO rapport 351935.* SWECO, De Bilt.

Vanhellemont, Q. and K. Ruddick, 2014. Turbid wakes associated with offshore wind turbines observed with Landsat 8. *Remote Sensing of Environment* 145, 105-115. https://doi.org/10.1016/j.rse.2014.01.009.

Van Heteren, S., Meekes, J.A.C., Bakker, M.A.J., Gaffney, V., Fitch, S., Gearey, B.R. and B.F. Paap, 2014. Reconstructing North Sea palaeolandscapes from 3D and high-density 2D seismic data: An overview. *Netherlands Journal of Geosciences (Geologie en Mijnbouw)* 93, 31-42. https://doi.org/10.0.3.249/njg.2014.4.

Van Lil, R., van den Brenk, S. and E.A. van den Oever, 2016. Hollandse Kust (zuid): An archaeological assessment of geophysical survey results. *Periplus Archeomare Report 16A009-01.* Periplus Archeomare, Amsterdam. Offshorewind.rvo.nl: Report - Archaeological Assessment (II) - Periplus Archeomare.

Van Nieuwenhuizen Wijbenga, C., 2020. Mariene Strategie voor het Nederlandse deel van de Noordzee. 's Gravenhage (NL): *Brief van de minister van Infrastructuur en Waterstaat aan de Voorzitter van de Tweede Kamer der Staten-Generaal*. https://www.tweedekamer.nl/kamerstukken/detail?id=2020D25021.

Van Oord, 2018. Offshore installation vessel Aeolus. *Leaflet Equipment Sustainable EPC and Marine Contractors*. Van Oord, Rotterdam.

Vonhögen-Peeters, L.M., van Heteren S. en J.H.M. Peeters, 2016. Indicatief model van het archeologische potentieel van de Noordzeebodem. *Deltares rapport 1209133-000*. Deltares, Delft.

Ward, I., 2014. Depositional Context as the Foundation to Determining the Palaeolithic and Mesolithic Archaeological Potential of Offshore Wind Farm Areas in the Southern North Sea. *Conservation and Management of Archaeological Sites* 16(3), 212-235.

Ward, I. and P. Larcombe, 2008. Determining the preservation rating of submerged archaeology in the post-glacial southern North Sea: a first-order geomorphological approach. *Environmental Archaeology* 13(1), 59-83. https://doi-org/10.1179/174963108x279229.

Wessex Archaeology, 2007. Historic Environment Guidance for the Offshore Renewable Energy Sector. *COWRIE report (ARCH-11-05).* COWRIE Ltd., London.

Westley, K., 2017. The Northwest Shelf, in N.C. Flemming, J. Harff, D. Moura, A. Burgess and G.N. Bailey (eds), *Submerged Landscapes of the European Continental Shelf.* Hoboken (USA): John Wiley & Sons, Ltd, 135-145. https://doi.org/10.1002/9781118927823.ch6.

Weyrich, L.S., Duchene, S., Soubrier, J., Arriola, L., Llamas, B., Breen, J., Morris, A.G., Alt, K.W., Caramelli, D., Dresely, V., Farrell, M., Farrer, A.G., Francken, M., Gully, N., Haak, W., Hardy, K., Harvati, K., Held, P., Holmes, E.C., Kaidonis, J., Lalueza-Fox, C., de la Rasilla, M., Rosas, A., Semal, P., Soltysiak, A., Townsend, G., Usai, D., Wahl, J., Huson, D.H., Dobney, K. and A. Cooper, 2017. Neanderthal behaviour, diet, and disease inferred from ancient DNA in dental calculus. *Nature* 544(7650), 357-361. https://doi-org.ezproxy.leidenuniv.nl/10.1038/nature21674.

Wiersma, A. en C. Mesdag, 2013. Geofysisch onderzoek zandwinput Maasvlakte 2: Rapport 2 van het geo-archeologisch en paleontologisch onderzoek zandwingebied en buitencontour Maasvlakte 2. *Deltares rapport 1204969-000*. Deltares, Delft.

Wu, X., Hu, Y., Li, Y., Yang, J., Duan, L., Wang, T., Adcock, T., Jiang, Z., Gao, Z., Lin, Z., Borthwick, A. and S. Liao, 2019. Foundations of Offshore Wind Turbines: A Review. *Renewable & Sustainable Energy Reviews* 104, 379-93. https://doi.org/10.1016/j.rser.2019.01.012.

Digital sources

IN ORDER OF APPEARANCE

https://www.abipate.com/, accessed on 30/11/21.

I.

https://www.nationalgeographic.org/maps/doggerland/, accessed on 10/06/2021.

https://www.rwsnatura2000.nl/overnatura2000/default.aspx, accessed on 20/11/2021.

https://english.defensie.nl/topics/hydrography/maritime-limits-and-boundaries/netherlands-boundaries-in-the-north-sea, accessed on 20/11/2021.

https://www.noordzeeloket.nl/, accessed on 14-12-2021.

II.

https://www.wessexarch.co.uk/news/palaeolithic-flints-submerged-landscapes, accessed on 15/11/2020.

https://www.omroepwest.nl/nieuws/17192/Eerste-Neanderthaler-fossiel-gepresenteerd-in-Leiden, accessed on 15/11/2020.

https://www.rmo.nl/nieuws-pers/nieuwsberichten/neanderthalerlijm/, accessed on 15/11/2020.

https://www.rmo.nl/nieuws-pers/nieuwsberichten/oudste-mens-en-kunst-uit-noordzee/, accessed on 15/11/2020.

III.

https://www.clo.nl/indicatoren/nl124304-beschrijving-van-de-noordzee, accessed on 17/05/2021.

https://www.dinoloket.nl/ondergrondgegevensoket, accessed on 5/10/2021.

IV.

https://beeldbank.rws.nl/MediaObject/Details/Zandmotor, accessed on 21/11/2021.

https://www.agrimatie.nl/PublicatiePage.aspx?subpubID=2526&themaID=2286&indicatorID=2880&sectorID=2862, accessed on 19/05/21.

https://www.noordzeeloket.nl/en/functions-and-use/visserij/#content-start, accessed on 15/12/2020.

https://www.noordzeeloket.nl/en/functions-and-use/artikel-baseline/, accessed on 04/02/2021.

https://www.vanoord.com/en/equipment/trailing-suction-hopper-dredger/, accessed on 20/05/2021.

https://www.iadc-dredging.com/article/turbidity-limits-for-dredging/, accessed on 20/05/2021.

https://www.oervondstchecker.nl/, accessed on 25/05/2021.

https://www.ipcc.ch/sr15/chapter/spm/, accessed on 26/05/2021.

https://ec.europa.eu/clima/policies/strategies/2030_en, accessed on 26/05/2021.

https://www.cbs.nl/en-gb/news/2021/08/green-electricity-production-up-by-40-percent, accessed on 26/05/2021.

https://www.rijksoverheid.nl/onderwerpen/duurzame-energie/windenergie-op-zee, accessed on 26/05/2021.

https://windopzee.nl/onderwerpen-0/wind-zee/waar/, accessed on 26/05/2021.

https://www.noordzeeloket.nl/en/functions-and-use/offshore-wind-energy/bestaande-windparken/, accessed on 26/05/2021.

https://www.government.nl/topics/renewable-energy/offshore-wind-energy, accessed on 26/05/2021.

https://www.geminiwindpark.nl/how-does-it-work.html#boven, accessed on 24/05/2021.

http://www.vliz.be/nl/vibrocorer, accessed on 24/05/2021.

https://flow-offshore.nl/page/project-in-support-structures.html, accessed on 24/05/2021.

https://landsatlook.usgs.gov/, accessed on 24/05/2021.

https://offshorewind.rvo.nl/generalzh, accessed on 24/05/2021.

V.

https://www.bbc.com/news/52420116, accessed on 19/05/2021.

https://www.afma.gov.au/fisheries-management/methods-and-gear/danish-seine, accessed on 21/11/2021.

https://www.noordzeeloket.nl/en/functions-and-use/artikel-baseline/, accessed on 04/02/2021.

https://windopzee.nl/onderwerpen-0/wind-zee/waar/, accessed on 26/05/2021.

https://www.rijksoverheid.nl/onderwerpen/klimaatverandering/klimaatakkoord/wat-is-het-klimaatakkoord,accessed on 29/05/2021.

https://www.shell.nl/media/persberichten/2020-media-releases/grootste-groene-waterstofproject-van-europa-in-groningen.html, accessed on 29/05/2021.

https://tractebel-engie.com/en/news/2020/h2-offshore-platform-driving-the-energy-transition-forward, accessed on 29/05/2021.

https://www.tno.nl/en/focus-areas/energy-transition/roadmaps/renewable-electricity/wind-energy/support-structure-wind-turbine/design-large-monopiles/, accessed on 29/05/2021.

https://www.siemensgamesa.com/products-and-services/offshore/wind-turbine-sg-11-0-200-dd, accessed on 29/05/2021.

https://www.tno.nl/en/focus-areas/energy-transition/roadmaps/renewable-electricity/wind-energy/support-structure-wind-turbine/floating-wind-turbine/, accessed on 29/05/2021.

https://www.conserve-energy-future.com/disadvantages_solarenergy.php, accessed on 24/11/2021.

https://www.syntechbioenergy.com/blog/biomass-advantages-disadvantages, accessed on 24/11/2021.

http://www.olino.org/blog/nl/articles/2009/10/15/osmose/, accessed on 24/11/2021.

https://www.tno.nl/nl/aandachtsgebieden/energietransitie/roadmaps/hernieuwbare-elektriciteit/grootschalige-opwekking-windenergie/ondersteuningsconstructie-windturbine/drijvende-draagconstructie-vawt/, accessed on 29/05/2021.

https://www.noordzeeloket.nl/functies-gebruik/onderwater-cultureel/, accessed on 20/11/2021.

https://archaeologydataservice.ac.uk/archives/view/alsf/, accessed on 24/11/2021.

http://www.unesco.org/new/en/culture/themes/underwater-cultural-heritage/2001-convention, accessed on 25/11/2021.

VI.

https://www.newscientist.nl/nieuws/de-fossielenjager-van-maasvlakte-2/, accessed on 20/11/2021.

https://www.rmo.nl/tentoonstellingen/tijdelijke-tentoonstellingen/doggerland/, accessed on 26/11/2021.

Appendix

https://ets.wessexarch.co.uk/recs/how-we-study-the-seafloor/geophysical-survey/, accessed on 23/11/2021.

https://ets.wessexarch.co.uk/recs/how-we-study-the-seafloor/geological-methods/, accessed on 23/11/2021.

Appendix

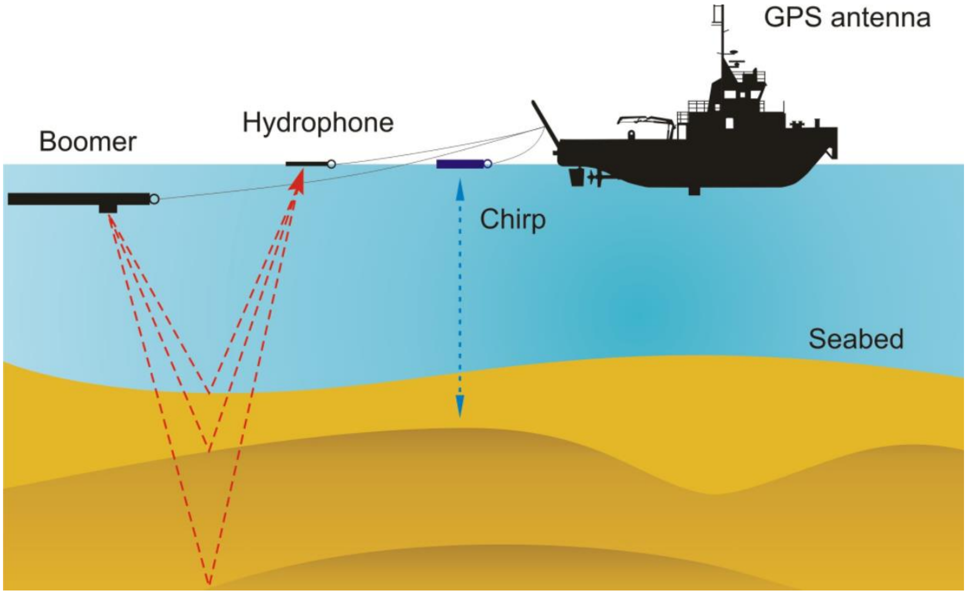


Figure A.1 – A schematic drawing of sub-bottom profiling (ets.wessexarch.co.uk).

Appendix A: Geophysical survey

A marine geophysical survey is used to see what geological strata are below the surface of the seabed. Sub-bottom profiling is one of the techniques to do this (Fig. A.1). During the profiling, a boomer or chirp, devices that create sound pulses, is towed behind a research vessel. These sound pulses penetrate the seabed and are eventually reflected back when a change in geology occurs. These so-called horizons are then received by a hydrophone, which is trailing behind the vessel as well, and mapped (ets.wessexarch.co.uk). The difference between the chirp and the boomer is that the frequency of the sound pulses. A chirp releases a high-frequency pulse, which in turn creates a detailed projection of the geological changes within the seabed. However, these sound pulses do not penetrate deep into the seabed. A boomer, on the other hand, releases a low(er)-frequency pulse and can therefore travel deeper into the seabed. Yet, it provides a less detailed picture of the seabed (ets.wessexarch.co.uk).

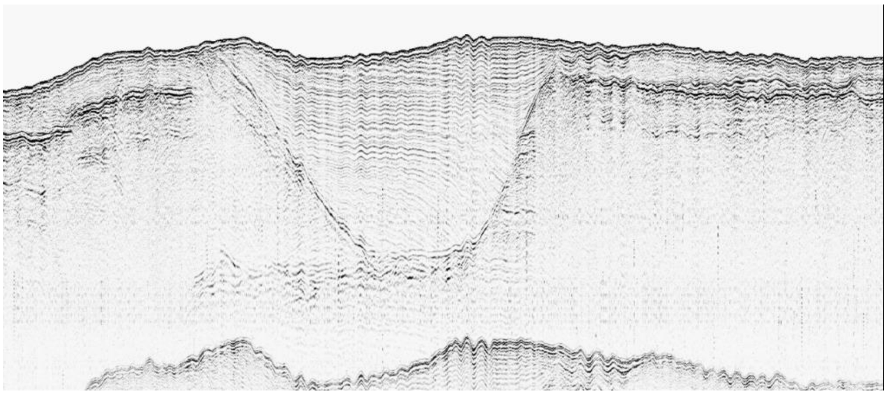


Figure A.2 - This is a projection of an infilled and submerged river channel provided by sub-bottom profiling (ets.wessexarch.co.uk).

Appendix B: Geotechnical survey

A geotechnical surveys are often executed to verify the geophysical survey results and obtain more detailed about the different sedimentary deposits within the seabed. In order to do that, a geophysicist or geo-archaeologist collects bore samples of sediments from the sites at the sea that are going to be developed. The most common technique used is taking vibrocore samples. A vibrocorer works by vibration, hence the name. It consists of a long tube (a core), a device that creates strong vibrations and pushes the core into the seabed (Fig, B.1). The core is between five and six meters long and 80-90mm in diameter (ets.wessexarch.co.uk/geological-methods). At each site the geophysicist collects two samples. One will be used for dating the geological strata using Optically Stimulated Luminescence (OSL) and one will later be taken apart to record sediment grain size, colour, type of sediment, acidity and search for other materials within the core sample, such as, shell, wood and charcoal (a possible proxy for human occupation). The core samples will consist of an unbroken record of 5 meter sediments cut into 1 meter parts (Fig. B.1). Depending on the size of the proposed industrial activity, there could be more than hundred vibrocore samples.

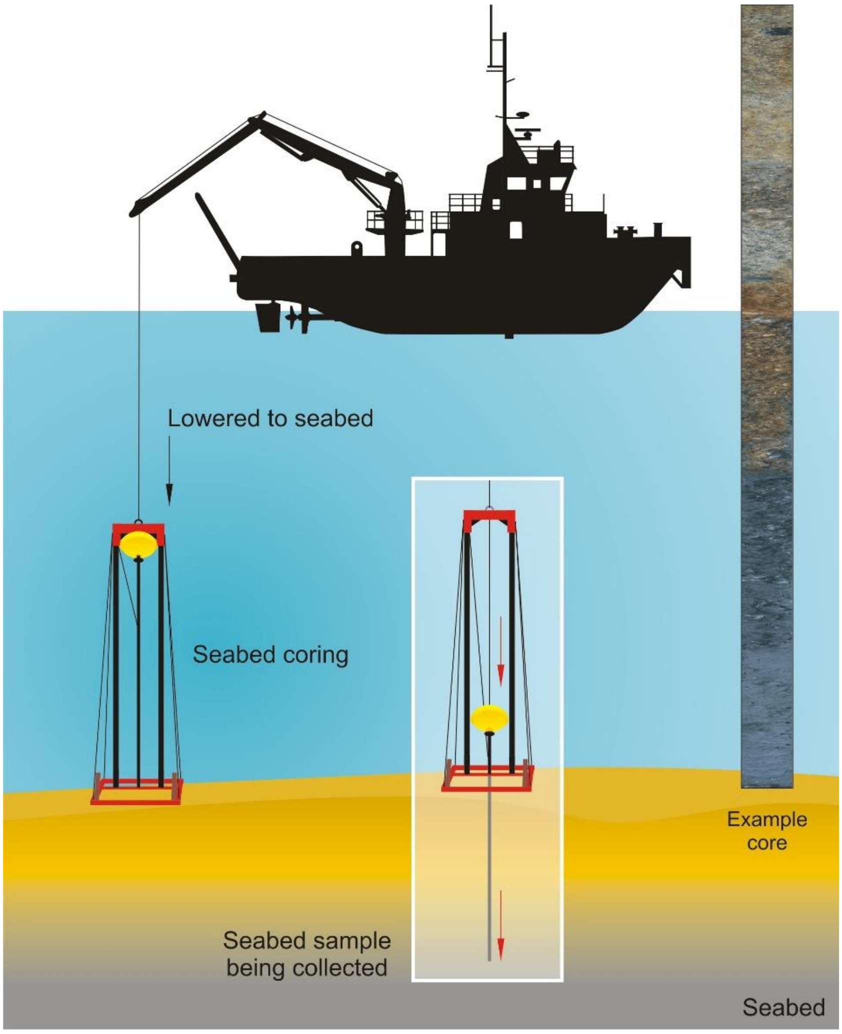


Figure B.1 - A schematic drawing of the vibrocore method and core sample (ets.wessexarch.co.uk/ geological-methods).