Adapting to the sea

Nieuwhof, Annet ; Bakker, Marco; Knol, Egge; de Langen, Gilles; Nicolay, Johan; Postma, Daniël; Schepers, Mans; Varwijk, Theunis; Vos, Peter C.

Published in:
Ocean & Coastal Management

DOI:
10.1016/j.ocecoaman.2019.02.014

Adapting to the sea: human habitation in the coastal area of the northern Netherlands before medieval dike building

Ocean & Coastal Management 2019

doi.org/10.1016/j.ocecoaman.2019.02.014

A. Nieuwhof[1]; M. Bakker[1]; E. Knol[2]; G.J. de Langen[1,3]; J.A.W. Nicolay[1]; D. Postma[1]; M. Schepers[1,5]; T.W. Varwijk[1]; P.C. Vos[1,4].

Email Annet Nieuwhof
a.nieuwhof@rug.nl
ORCID 0000-0002-7944-0900

1 Terp Research Group, Groningen Institute of Archaeology, University of Groningen, Poststraat 6, 9712 ER Groningen, The Netherlands
2 Groningen Museum, PO Box s 90, 9700 ME Groningen, The Netherlands
3 Province of Fryslân, PO Box 20120, 8900 HM Leeuwarden, The Netherlands
4 Deltares, PO Box 85467, 3508 AL Utrecht, The Netherlands
5 Present address: Centre for Landscape Studies, University of Groningen, PO Box 716, 9700 AS Groningen, The Netherlands

Artificial dwelling mounds; flooding; Iron Age; Middle Ages; peat reclamation; salt marsh habitation; sea-level rise; Wadden Sea.

Funding
Our research was funded by the University of Groningen; the Province of Fryslân; the Province of Groningen; the Groningen Museum; the project *Terpen- en Wierdenland* of the Dutch *Waddenfonds*; and the Netherlands Organisation for Scientific Research (NWO) (project numbers 315-60-114 and 275-61-005).

Abstract
Before medieval dike building, the coastal area of the northern Netherlands was a wide, regularly inundated salt-marsh area. Despite the dynamic natural conditions, the area was inhabited already in the Iron Age. The inhabitants adapted to this marine environment by living on artificial dwelling mounds, so-called terps. Terp habitation was a highly successful way of life for over 1500 years, and may be re-introduced as a useful strategy for present and future communities in low-lying coastal regions that are facing accelerated sea-level rise. This already has been recommended in several reports, but detailed knowledge of the technology of terp habitation is usually lacking. The aim of this paper is to present nearly two decades of archaeological research in the coastal region of the northern Netherlands, in order to inform the current debate on the possibilities of adapting to the effects of climate change in low-lying coastal areas. It presents the multi-disciplinary methods of

this research and its results, supplying details of terp construction and other strategies such as the construction of low summer dikes that are still useful today. The results and discussion of the presented research also make it possible to describe the conditions that must be met to make terp habitation possible. Terp habitation could have continued, were it not for the considerable subsidence of inland areas due to peat reclamation. That made the entire coastal area increasingly vulnerable to the sea. In response to this threat, dike building began in the 11th or 12th century, but these increasingly higher dikes decreased the water storage capacity and caused impoundment of seawater during storm surges. Moreover, accretion through sedimentation was halted from then on. Unlike terp habitation, the construction of high dikes therefore cannot be considered a sustainable solution for living in low-lying coastal areas in the long term.

1. Introduction

Climate change and the associated rising sea level that is foreseen for the near future challenge the resilience of communities in low-lying coastal countries. More frequent and higher inundations will affect such communities and threaten their continued existence (Wong et al., 2014). Yet, frequently flooded coastal areas are attractive for human habitation because of their openness and fertility. That was already the case in prehistory, as demonstrated by the habitation history of our research area, the coastal region of the Wadden Sea in the northern Netherlands. Despite regular inundations, this area was colonized around 650 BC, and it soon became a densely populated region (Bazelmans et al., 2012). Prior to medieval dike building, the inhabitants coped with frequent flooding by building their houses on artificial dwelling mounds, so-called *terps*.[1]

1.1 History of research

The way of live of these early inhabitants is the subject of terp archaeology. Systematic archaeological research in this area started in the early 20th century, especially with the work of Albert van Giffen (e.g. 1910, 1936), who had a lively interest in sea-level rise and landscape development and their effects on the region's habitation history. His work set the tone for future terp research. In the second part of the 20th century, attention shifted almost entirely to archaeobotanical and archaeozoological research, exploring the ways in which humans had exploited the natural environment (Knol, 1983; Prummel, 1993; Van Zeist, 1974). A series of agricultural experiments in the unprotected salt marsh showed that several crops could successfully be grown there (Bottema et al., 1980; Van Zeist et al., 1976; in Germany: Körber-Grohne, 1967).

Many important insights date from the early phase of research. The terp dwellers had colonized the salt marsh area while it was still inundated regularly. They had to deal with a moderate rate of sea-level rise, estimated by Van Giffen (1933) on the basis of sedimentation rates at ca 3-4 cm per century. It became evident that habitation on terps, specifically, made living in this extreme landscape possible. An important discovery also was that prehistoric houses were not simple huts, as was previously assumed for northwestern Europe, but 3-aisled farmhouses with in-built byres for livestock, in addition to living quarters (Van Giffen 1931). The importance of livestock to the regional economy was furthermore underwritten by archaeozoological evidence. The later agricultural experiments showed that arable farming was also possible in this area. Inferred from similarities between excavated terps, early terp archaeology produced a general, though unilateral and static reconstruction of terp habitation. The dynamics of coastal habitation and the variety of terps, however, were systematically overlooked.

[1] Singular *terp* (Dutch/Frisian), Dutch plural *terpen*. The English plural *terps* is used here.

Archaeological terp research was rekindled in the 1990's, when new research questions arose, now primarily aimed at socio-political developments in the past. At the same time, the relationship between human habitation and the developing landscape became an even more important focal point than it was before (Besteman et al., 1999; De Langen 1992; Knol 1993; Taayke 1996). The 1990's projects were the incentive to many new research projects and excavations that have been carried out since 2000, gradually revealing more and more details of human habitation in this coastal fringe before medieval dike building began. These projects cast new light on the adaptive strategies of the coastal communities, evidencing that early adaptation not only entailed responding to nature-induced challenges, but also intervening pro-actively. The inhabitants thus had a much stronger influence on the landscape than was previously realized. Moreover, this renewed academic paradigm is contrary to the view that terp habitation equated to simple, static farming communities, living isolated lives in a marginal landscape; rather, this region is to be regarded as part of a maritime cultural landscape, which offered ample opportunities for interregional social exchange.

1.2 Geographical distribution

The terp region *sensu stricto* is located in the former salt-marsh regions and clay-covered peat regions of the northern and (to a lesser extent) western Netherlands, and of north-western Germany and southern Denmark (fig. 1). This paper will focus on the northern Netherlands because it combines the results of the authors' research projects in this area. The regional habitation history is relatively well-known since it is based on a large dataset, comprising excavation data as well as datable finds that were uncovered during large-scale commercial extraction of fertile terp soil in this region between c. 1840 and 1940.

The German and Danish coastal regions and the western Netherlands differ from the above research area in various ways. Firstly, these parts of the terp region did not go through a destructive phase of commercial quarrying; although this has been beneficial to the preservation of a unique cultural heritage, the lack of resultant 'commercial' finds means that the habitation history of these regions is less well known, as the many undated terps in Figure 1 show. The oldest salt-marsh settlements along the German coast were probably only established centuries after those in the northern Netherlands, in the 1st rather than the 7th century BC. In Denmark, the salt marshes themselves are thought to be a fairly recent development, only allowing the earliest terps here to be raised in the late Middle Ages (Bazelmans et al., 2012). Nevertheless, several large-scale excavations have shown that terp habitation in this wider Wadden Sea area was highly similar to what is described in this article, with respect to physical terp structure, associated material culture and contemporary economy (Bantelmann, 1975; Haarnagel 1979).

Terp habitation in the regions of the western Netherlands occurred only on a small scale; early terps in this area did not develop into the large dwelling mounds that we know from the northern coastal area. Despite obvious similarities in the Holocene development of the southern North-Sea coastal areas, there are considerable differences between underlying geological characteristics of the western Netherlands on the one hand, and the northern Netherlands and northwestern Germany on the other hand. A large part of the western Netherlands is sheltered by a coastal barrier dune system, whereas the more northerly coastal areas of the Netherlands and Germany were an open salt marsh landscape, an intertidal area of the Wadden Sea, prior to the large-scale medieval dike building.

Up until the late-medieval periods, terp habitation continued to be used as an adaptive strategy in regularly flooded areas throughout the Low Countries. Early-medieval terps are found in the coastal area of Belgium (Tys, 2002), and late-medieval terps are found in low-lying peat areas as well as alluvial flood plains in the Netherlands; they were part of an *amphibious culture* as Van Dam (2012) calls it. There is no evidence of terp habitation, however, in geologically analogous areas in the United Kingdom, such as the Fenlands or the Severn estuary (Loveluck and Tys, 2006; Rippon 2000).

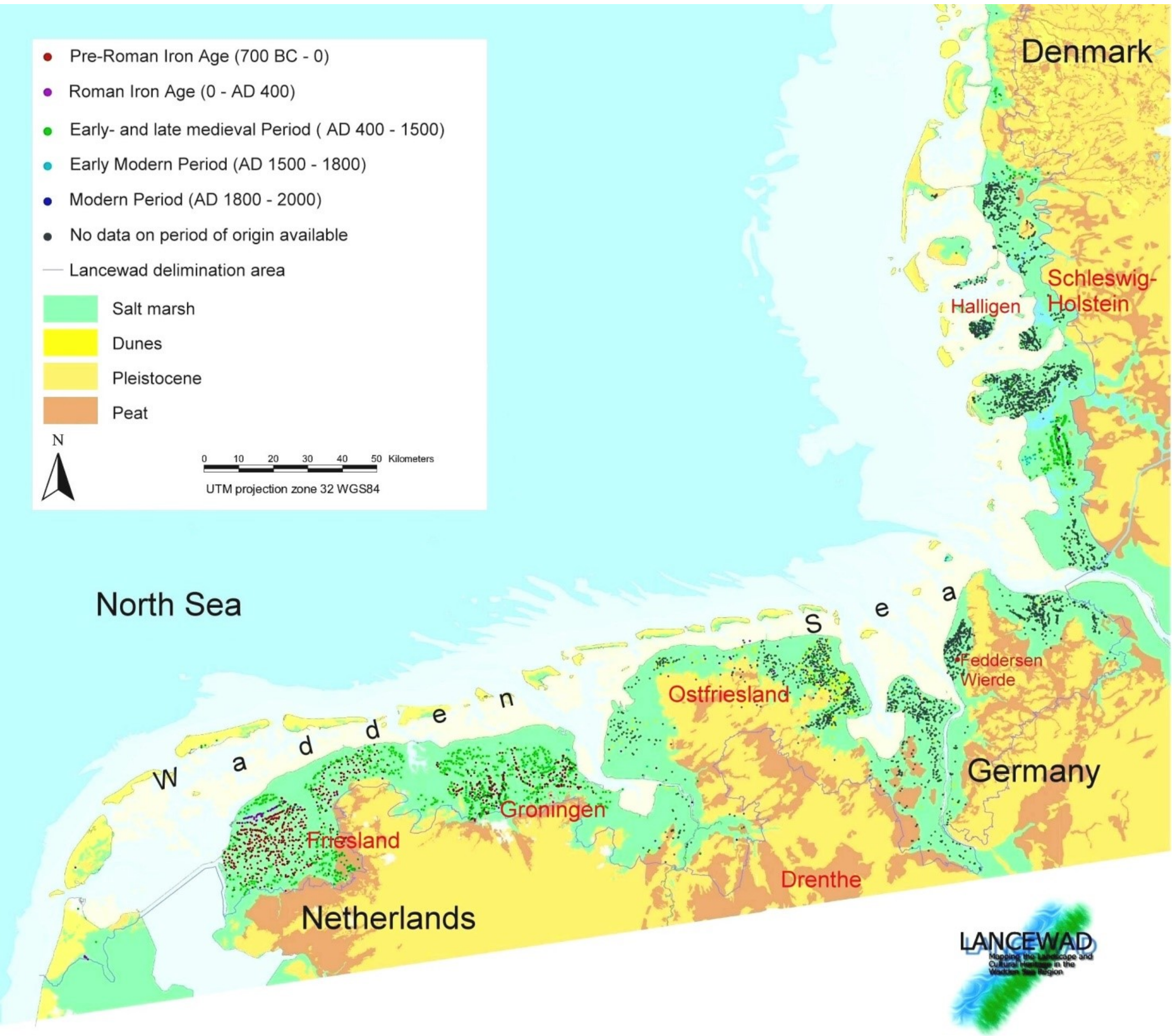

Fig. 1 The Wadden Sea region along the coast of the northern Netherlands, northwestern Germany and southwestern Denmark, with in the salt marsh areas thousands of terps, of different ages (dots, see legend). Dates give an indication but are not accurate. Map: after Vollmer et al., 2001 © Common Wadden Sea Secretariat.

The Wadden Sea region is not the only part of the world where artificial dwelling mounds were the loci of settlement in frequently inundated areas. Raised fields and residential mounds were common in inundated parts of pre-Columbian Amazonia. Raised fields also occurred in the coastal swamps of Suriname and the Guyanas, during a period of considerable marine influence. At least eight residential mounds, built in phases from marine and estuarine clays and identified as terps by Dutch researchers, were identified in the coastal area of western Suriname and eastern Guyana. Radiocarbon dates are largely from the 1st millennium AD, but habitation may have lasted until European times (Rostain 2010; Versteeg 1980; Werkhoven and Versteeg, 1980).

Artificial dwelling mounds are also found in other landscapes, for instance when houses are being rebuilt over and over again on the same spot for centuries, on the accumulated remains of previous houses and waste. Examples are the middle-eastern *tells* (Wilkinson, 2003), or the raised farmhouses and settlements of northern Norway and northern Jutland (*byhoje*; Martens 2016). The platform mounds of native American societies in the south of the USA had ceremonial, public and other functions, but do not seem to have been located in inundated areas (Kassabaum, 2018). Although there are similarities in their physical structure and overall appearance, the Scandinavian and North American dwelling mounds cannot be considered true terps. The term *terp* only applies to dwelling mounds that are intentionally constructed as an adaptive strategy to living in a regularly inundated area.

1.3 Aim

Over the past few years, the reintroduction of habitation on small or large terps in low-lying coastal areas that are facing sea-level rise has been advocated in several publications (e.g. Braakhekke et al., 2008; Metz and Van den Heuvel, 2012). Future developing projects that take these recommendations at heart might benefit from detailed knowledge of coastal habitation in the past, but archaeology and coastal management are separate worlds. Moreover, many of the projects that have been carried out in the terp region since 2000 are published only in Dutch. Consequently, this research is not easily accessible to an international audience, and rather invisible even to Dutch audiences outside the world of archaeology.

Answering the appeals to the archaeological community made by authors such as Van de Noort (2011, 2013) or Rockman (2012), that is to inform current debate on climate change and its consequences, this synthesising paper sets out the contribution our research could make. We believe that the adaptive pathways of the ancient communities in our research area are of interest to present and future coastal communities living in coastal landscapes and facing similar problems to those that terp dwellers dealt with in the past.

This article's initial aim is to outline the methods and results of our research in the terp region, with a focus on the adaptive strategies previously developed to survive, if not flourish in this originally extreme natural environment. Some of these strategies were successful, but others produced significantly adverse long-term effects. It will subsequently be discussed whether the ancient technologies that proved successful, could inspire the building of resilient communities where similar environmental situations exist in the present, and what conditions must be met. Of equal importance are the conditions that must be met to avoid potential negative outcomes, since the mistakes made in the past may be avoided if we accept them as lessons for the future.

2. Methods

The synthesis that is provided in this paper is based on different types of research, belonging to different stages in terp archaeology. Firstly, the large-scale destruction of terps during the period of commercial extraction of terp soil produced, as a side-effect, many human-made objects and animal bones. These finds, which nowadays form the core collections of the northern Dutch provincial museums, not only evidence the technology and economy of the terp dwellers, but also serve to date past events, on the basis of their well-studied typological development in combination with radiocarbon dating. These finds, originating from over a thousand quarried terps, thus provide a basic framework of the habitation history of the terp region (Knol, 1993; Miedema, 1983; Taayke, 1996).

Secondly, academic excavations are a major source of information. Although none of the terps in the Netherlands have been excavated in their entirety, even partial excavations have unearthed so many finds and soil features that post-excavation analyses and publication require many years and staff resources to complete. Illustrative of the scale of such excavations is the one directed by Van Giffen in the terp of Ezinge, between 1923 and 1934. This remains the largest terp excavation ever undertaken in the Netherlands, even though only ca. 10% of this 5.5 m high terp of 16 ha was excavated. Van Giffen published some summarizing articles (Van Giffen 1931, 1936), but never came to full publication of what had been recorded in the 22 superimposed excavation levels. Only now, with the aid of digital means, full analyis has become feasible (Nieuwhof, 2013, 2014, 2015). Ezinge is important for various reasons: the long period of habitation, from 500 BC until the present day, and the large number of excavated houses, which make it possible to study the developing lay-out and history of a terp settlement. For a fuller picture, Ezinge can be compared to the Feddersen Wierde in Germany (Haarnagel, 1979), which has been excavated completely (see fig. 1), and was shown to have been inhabited from the 1st century BC to the 5th century AD. Because of the high demand on resources and time that is associated with excavating even parts of terps, this method is usually avoided, except where large infrastructural development render this unavoidable (Dijkstra and Nicolay, 2008; Tuinstra et al., 2011).

Fig. 2 Excavation in a terp near the village of Anjum, province of Friesland, in 2006. To the left: the long, cleaned escarpment of the terp remainder (on which barley is grown). Plastic is used to cover the section outside working hours, to prevent dehydration. Photo © University of Groningen, Groningen Institute of Archaeology.

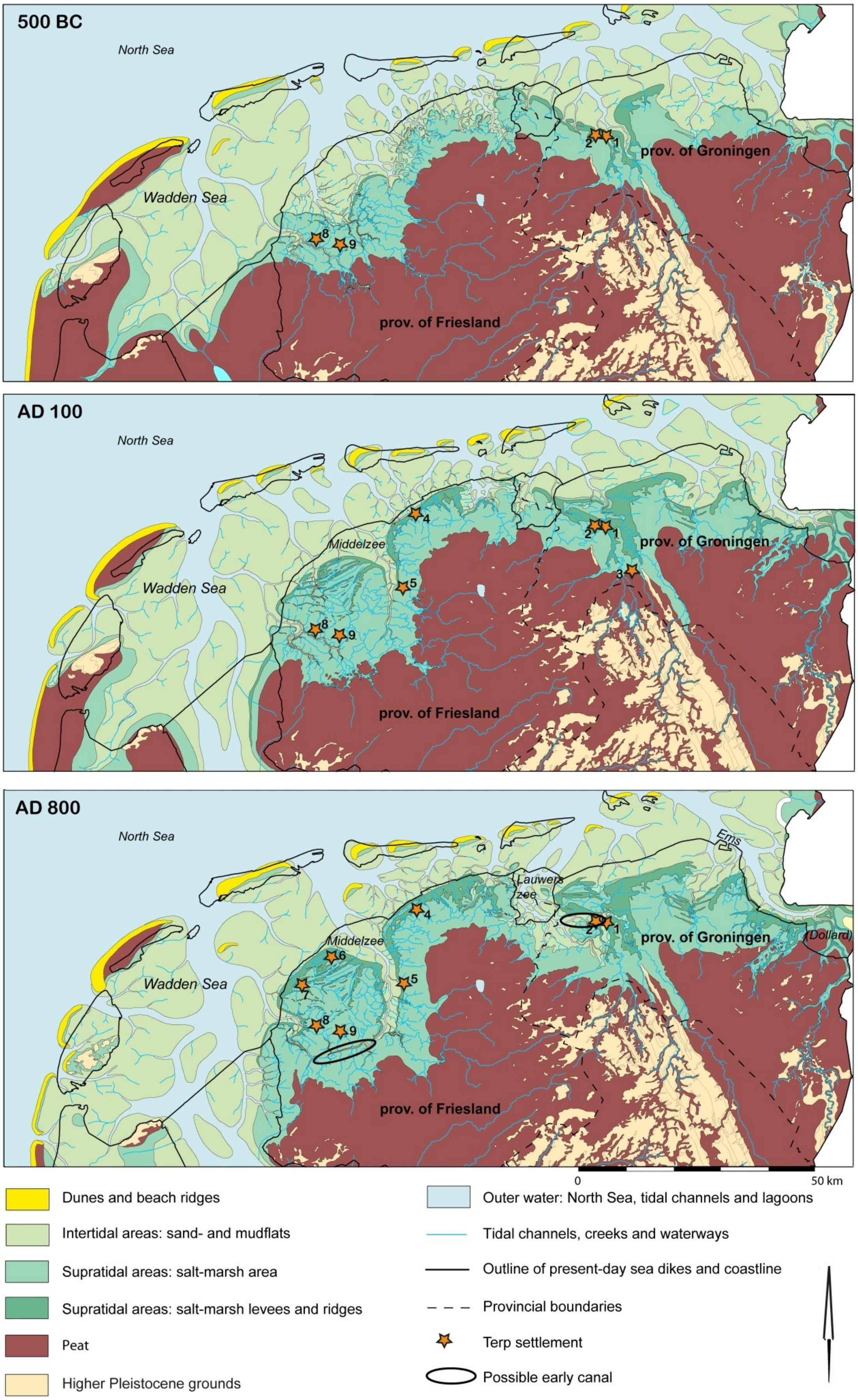

Fig. 3 Palaeogeographical maps, 500 BC, AD 100 and AD 800, with locations mentioned in the text and in captions. Two early canals are indicated, but there may be others. 1: Ezinge; 2: Englum;3: Paddepoel; 4: Hogebeintum; 5: Leeuwarden; 6: Firdgum; 7: Wijnaldum; 8: Lollum; 9: Wommels. Maps: P.C. Vos and S. de Vries, Deltares.

Since the 1990's, a more efficient type of excavation has become common (Nicolay, 2015). It makes use of the escarpements and terp *soles* (the deepest parts) that often remained after partial commercial quarrying of terps. The excavation of these 'exploitation scars' provide a quick but reliable indication of the site's general development, without significant loss of surviving archaeological remains. Most terp excavations of the last decades have applied this method (Bakker and Varwijk, 2016; Nicolay, 2010; Nicolay and De Langen, 2015; Nieuwhof, 2008; Nieuwhof et al., 2006; Vos and Varwijk, 2017; Varwijk and De Langen, 2018). Escarpments are easily stripped of vegetation with a mechanical excavator, resulting in long sections that reveal the chronology and structure of a terp (fig. 2). The terp *soles* are also easily exposed by mechanical means, showing those features that were dug in from above, such as postholes, drainage ditches and water wells. This efficient method is always combined with wet screening of soil samples for archaeobotanical and archaeo-zoological evidence and systematic metal detection across each excavation level, as well as targeted geological and mico-morphological research (Huisman, 2015; Knol and Vos, 2018; Nieuwhof and Vos, 2018; Vos, 1999, 2015; Vos and Gerrets, 2005; Vos and Knol, 2015). Natural layers under the terp are easily accessible by deepening selected sections of the excavation trenches and through coring in a wider area to provide additional information on the settlements' surrounding landscapes. Combined archaeological and geological research have resulted in a detailed understanding of the past relationships between these landscapes and local human habitation. The spatial relationship has been expressed in a series of palaeo-geographical maps, which show the expansion (and localised contraction) of the northern Dutch salt marshes over time, which is reflected in the contemporary spread of terps (fig. 3). These maps are regularly updated when new excavations provide more details on how this region's landscape developed.

The peat and marine, clay-covered peat zones bordering the coastal salt marsh were colonized from the Iron Age onwards and again in the High and Late Medieval period, both times through populations expanding outwards from the coastal terp region. Similar strategies as were used in the salt marshes of the terp region (draining the land with ditches, living on artificial mounds) were applied by the colonists of the peat and clay-covered peat areas, albeit with different and unforeseen consequences that effected parts of the salt marsh area as well. To investigate the habitation of the peat areas, settlements of these colonists (small house terps) have been excavated and contemporary reclamations mapped on the basis of historical maps and documentary research, aerial photography and Lidar mapping (*Actueel Hoogtebestand Nederland*) as well as geological investigations (Bakker, 2015, 2016; Bakker et al., 2018; Bakker and De Langen, 2017; De Langen, 1992; 2011; Nicolay, 2018; Vos and Bakker, 2017). The study of the processes that are associated with medieval dike building and habitation history combine excavations with geological and historical research (De Langen and Mol, 2016, 2018; Knol, 2013; Nicolay et al., 2018a, b; Vos and Knol, 2013).

Thirdly, terp archaeology is a form of wetland archaeology, which often demonstrates excellent preservation conditions for organic remains in terps (e.g. bone, wood, subfossil seeds and fruits). Palaeo-botanical and palaeo-zoological analyses have been part of archaeological research in this area for many decades, providing insights in regional palaeoecology and economy, and in the relationship between nature and culture (Beijerinck, 1929-1931; Bottema-MacGillavry, 2008; Nieuwhof, 2006; Nieuwhof and Woldring, 2008; Nieuwhof and Schepers, 2016; Prummel, 2001; 2018; Prummel & Heinrich 2005; Schepers et al., 2013; Schepers, 2016; Van Zeist 1974).

Fourthly, the analysis of material culture (e.g. houses, pottery, metal ware etc.), and of animal and human remains, has not only resulted in a corpus of knowledge about economy, technology and daily life, but also, combined with anthropological theory and a contextual approach, to insights into less tangible features of human existence, such as social change, ritual practice and interregional contacts (Knol, 2011; Nicolay, 2014, 2017; Nieuwhof, 2015; Nieuwhof and Nicolay, 2018).

Terp archaeology is a strongly interdisciplinary line of research, as will be clear from the above. The data collected from a wide geographical area, with a significant time depth and across many fields of research, together produce a high-resolution image of the past.

3. Results

3.1 Landscape formation

Throughout the Holocene, the Netherlands have been dealing with a relative sea-level rise that has multiple causes: global warming and melting of the ice sheets after the Ice Age during the first part of the Holocene, starting c. 11,700 years ago; tectonic movements, the effect of which is negligible in this context; and isostatic subsidence that came with melting of the ice sheets on Scandinavia. In the first millennia of the Holocene, sea-level rise amounted to 0.8-1 m/century, causing the submersion of a large part of the North Sea basin (Peeters et al., 2009). Glacial isostatic adjustments caused a relative sea-level rise that was less severe but continues until today, amounting to 0.05-0.10 m/century over the major part of the last 3000 years (Vos and Van Kesteren, 2000; Meijles et al., 2018). Relative sea-level rise has accelerated to 0.15-0.20 m/century since 1850, probably due to global warming and regionally also to human-induced subsidence (De Mulder et al., 2003; Vos and Van Kesteren, 2000; Wahl et al., 2013).

From around 5000 BC, when the coastline had reached its approximate present location, the postglacial sea-level rise had decreased enough to be surpassed by the net heightening through sedimentation (Beets and Van der Spek, 2000). The Wadden Sea then came into existence as an intertidal area behind a series of barrier islands and salt marshes developed in the former alluvial valleys, which had now become tidal basins. As the barrier islands gradually shifted towards the mainland, the tidal range in the tidal basins increased and deposits became sandier (Vos and Van Kesteren, 2000). From around 1500 BC, relatively sandy salt-marsh ridges or levees developed along the seaward margins of the coast, often several hundred metres wide and many kilometres long. This natural process of salt-marsh formation thus occurred thanks to sea-level rise in combination with a relatively sandy sediment supply that was sufficient to outpace sea-level rise. The majority of this sediment was redeposited from eroding Pleistocene headlands and the shallow North Sea bed; it was transported to the coast by tidal currents and wave action (Beets et al., 1994).

With the Holocene sea-level rise, drainage deteriorated and inland water tables rose, causing peat formation. Along the coast, this basal peat layer either eroded, or was covered with clastic sediment as the sea level rose further. In those areas where marine sedimentation overtook the process of peat formation, clay-covered peat lands formed. Peat areas with a thin clay cover were silted over in relatively recent times; such areas mark the boundary between a very wide coastal salt-marsh area and the vast peat areas (bogs and fens) inland (fig. 3).

The accretion of sediment resulted in rapid seaward expansion of the salt marshes in the tidal basins of around 5-10 metres per year during the first millennium BC (Vos and Gerrets, 2005; Nieuwhof and Vos, 2018). and a significant increase in height. Vegetation helped to trap sediment. Low salt marshes, inundated 50-200 days per year, developed into middle marshes, inundated up to 50 days per year, and then into high marshes, inundated only during extremely high tides. As the elevation of the salt marsh and the distance to the sea increased, the frequency of inundations decreased.

3.2 Occupation of the salt marshes

Habitation of the salt-marsh area began around 650 BC (Taayke, 1996). It was this vast area's potential for grazing livestock that must have been attractive to the early colonists (Van Zeist, 1974; Van Gijn and Waterbolk, 1984), not in the least due to the fact that the sediments deposited during recurring floods resulted in a very fertile soil (Cnossen, 1980). The very first colonists settled on high levees along salt marsh creeks; they built their houses directly on the salt marsh surface, at least during the initial phases of salt marsh occupation. This assumption of earlier terp research was confirmed by recent terp research in early-phase terps such as Lollum-Saksenoord (Vos and Varwijk, 2017) and Wommels-Stapert (Varwijk and De Langen, 2018). That situation of terpless salt marsh occupation, however, did not last long. Whether the early settlers had underestimated the level of exceptional storm surges, or whether storm surges in general became more frequent and severe in that period is unknown, but they soon started to raise their immediate living areas. Moreover, excavations of the last two decades and reassessment of older excavations have shown that later generations of settlers not necessarily chose the highest parts of the salt marsh, but rather salt-marsh ridges near the coast that had just silted up to the level of a middle marsh (Vos and Gerrets, 2005; Vos, 2015).

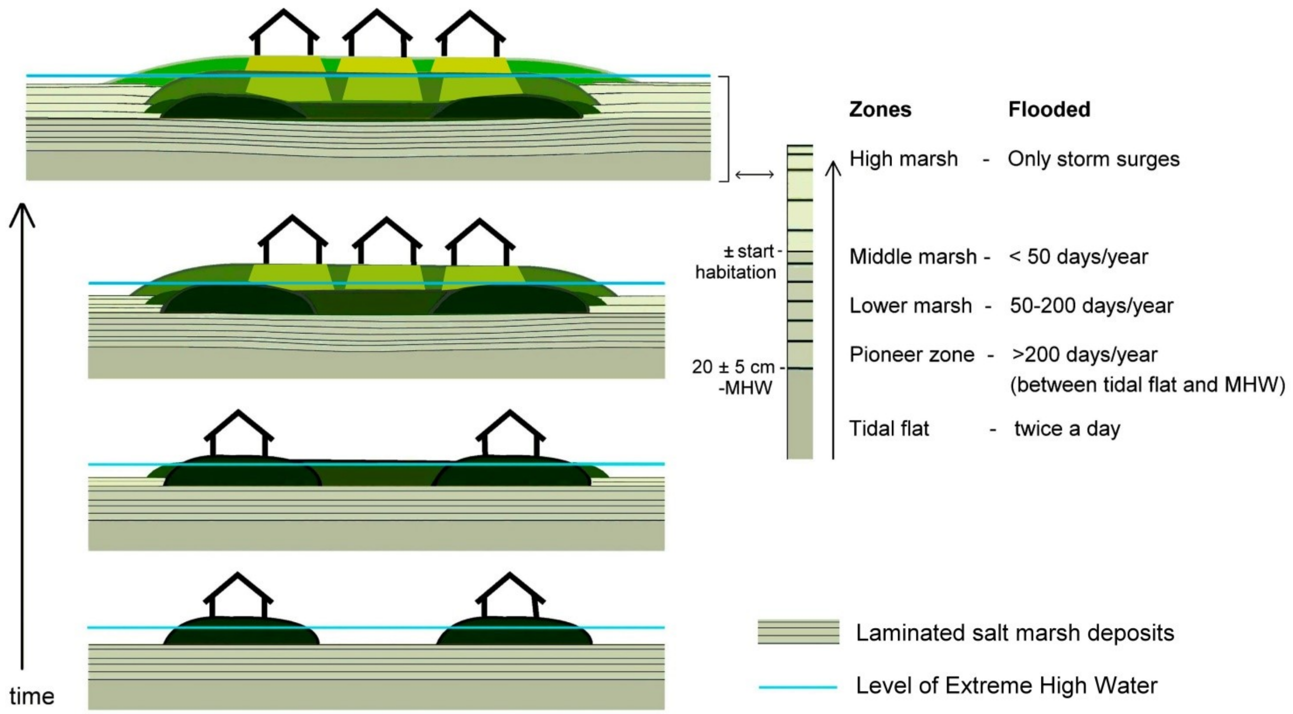

Fig. 4 Schematic cross section through different phases of a developing terp, starting on a salt marsh ridge at the level of a low middle marsh. Flooding and sedimentation continue during habitation, at a diminishing rate. Not to scale. Drawing A. Nieuwhof.

Occupation of the frequently flooded middle salt marsh was not possible without taking precautions. From the start, these settlers built their farmhouses with built-in byres on artificial platforms, so-called house terps (fig. 4). All excavations in which house platforms were uncovered show that these platforms were only slightly larger than the houses that were built on top of them, and only 0.40-1 metre high, just above the level of what must have been the highest expected level of floods (e.g. Dijksta and Nicolay, 2008; Gerrets and De Koning, 1999; Jongma, 2008; Nicolay, 2010; Varwijk and De Langen, 2018). Natural sediment layers that were deposited during floods are often found against the sides of platforms, but usually not on top of them; that indicates that this height was indeed sufficient. Due to the huge water storage capacity of the salt marsh area, extreme high water did not reach higher. Still, storm surges must have been frightful events, as the house terps turned into small islands during inundations. After the storms had passed, seawater drained from the land very quickly, via the many creeks. Terp excavations show that digging ditches in the salt marsh was common practice from the beginning of the area's occupation; these ditches were connected to natural creeks and thus further improved drainage.

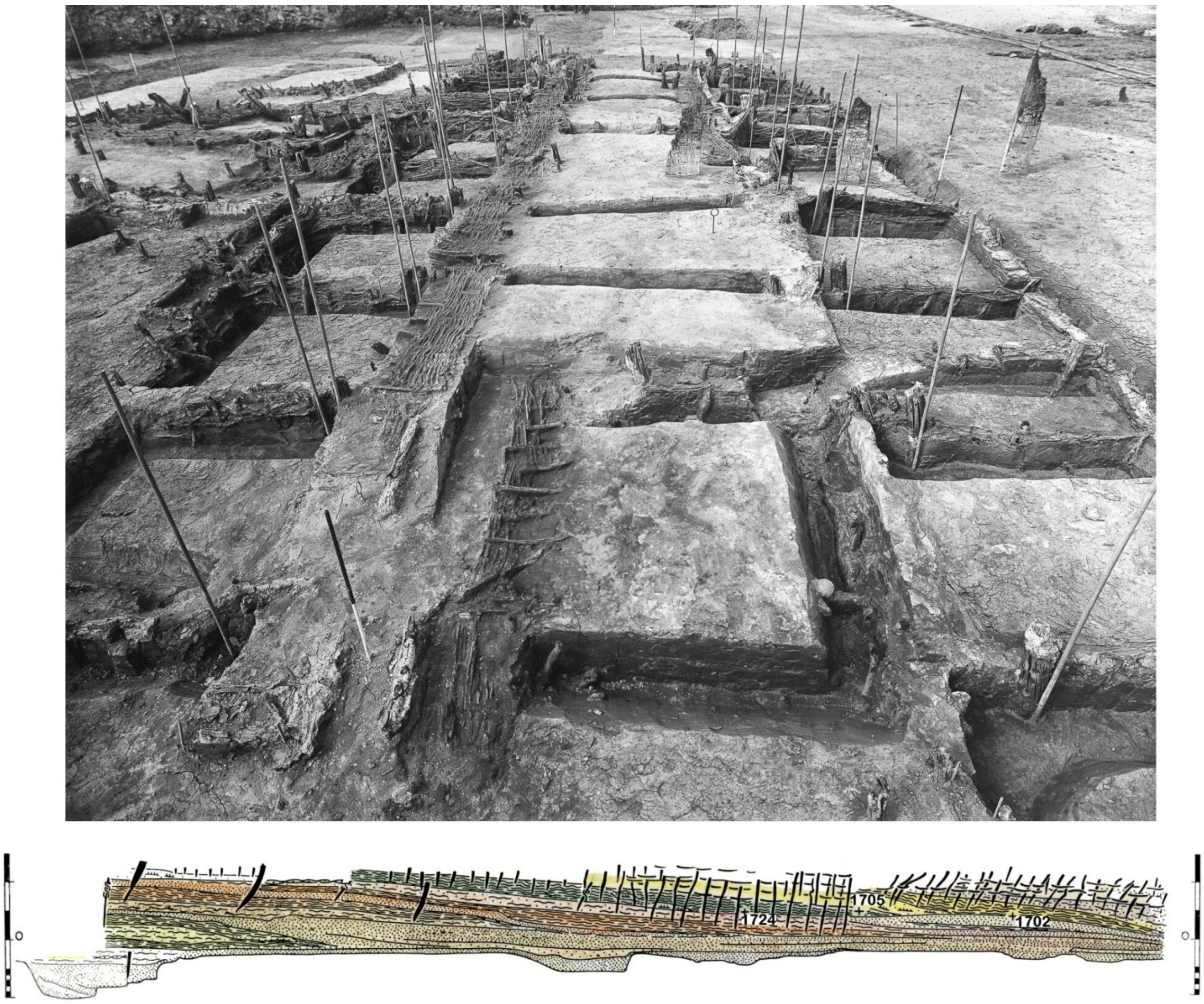

Fig. 5 A series of consecutive houses dated between the 4th and 2nd century BC on the terp of Ezinge. Top: Excavation photograph in longitudinal direction (1933), showing the remains of cattle stalls. Bottom: longitudinal section, showing stakes and poles of the consecutive house phases, with heightening layers in between. Each new house phase was further from the centre of the terp on the left. Numbers refer to finds. Photo and drawing © University of Groningen, Groningen Institute of Archaeology.

The small house terps required frequent maintenance and, since the sea level continued to rise slowly, occasionally needed to be heightened. Heightening layers were also applied over the remains of houses that had come to the end of their lifespan, providing a foundation for new farmhouses. Intentional heightening and extension layers and, to a lesser extent, dumped waste filled in the space between neighbouring platforms, thus joining these together. The process of building, demolishing and heightening was repeated again and again, with houses being rebuilt on more or less the same location for many generations (fig. 5). Over the centuries, many of the early house platforms developed into small or large village terps of several metres high, also including fields and gardens. Even in the 13th century terps were enlarged, although dike building had already started at the time. The increased surface areas were used for arable farming (De Langen and Mol, 2016).

While the terps were growing in height and in surface area, the elevation of the surrounding salt marsh also increased, due to ongoing sedimentation (fig. 4). Many terps are barely visible nowadays. These are the terps that only just kept up with the continuing relative sea-level rise; their 'soles' are hidden by younger deposits. Other terps became much higher and larger than necessary in view of safety, up to over 8 m +NAP (the terp of Hegebeintum in the province of Friesland).[2] The size of the population, which provided the necessary labour, must have played a decisive role in the final size of a terp; status may have been an additional factor, at least during the final stages when heightening was no longer an environmental necessity.

3.3 Population changes

The way of life described above was generally successful; the Iron Age population increased and new salt-marsh ridges along the northern coast were colonized, always starting with small platforms. The area was one of the most densely populated areas of that period, with around 30,000-40,000 inhabitants during the pre-Roman and Roman Iron Age, 15-20 inhabitants per km^2 (Bazelmans et al., 2012). During the 2nd and 3rd centuries AD, however, the salt-marsh area was gradually abandoned and during the 4th century AD, a diminished population inhabited only a very small number of terps. Ezinge in the province of Groningen, and possibly some terps along the Middelzee in the province of Friesland, were amongst the few terps not to be abandoned (Nieuwhof 2011, 2013, 2016).

On the Pleistocene Drenthe Plateau further inland, habitation was not interrupted in this same period, which suggests an (at least partly) environmental cause for the depopulation of the salt marshes. Marine inundations had not posed problems to communities living on terps as long as the area was well drained. However, newly developing salt-marsh areas along the coast were considerably higher than the older ones in the south, because of continuing relative sea-level rise (see Supplementary Material 1). Drainage of freshwater as well as seawater became increasingly hindered during the Roman period, turning the salt marsh into a brackish swamp that was no longer attractive to the inhabitants. These were not able to cope with these extensive drainage problems. The resultant emigration seems to have started in the lowest parts of the salt-marsh area farthest from the coast where washed-over or so-called 'frustrated terps' are found, for instance in Paddepoel, in the outskirts of the present city of Groningen (Van Es, 1970).

Abandonment may have started because of increasingly poor drainage, but it was certainly reinforced by social circumstances. Younger terps in better-drained areas, such as Wijnaldum (Gerrets and De Koning, 1999), were also abandoned, as late as around AD 325, probably due to the damage foregoing depopulation in the hinterland had caused to such settlements' socio-economic environment. The few settlements that did persist, participated in geologically more diverse networks and had stronger ties to inland areas in the south and the east, as is shown by their

[2] Dutch Ordnance Datum, approximately mean sea level.

associated material culture; these socially and economically more resilient terp settlements were therefore better equipped to deal with the increasingly challenging natural conditions (Nieuwhof, 2011, 2016).

New inhabitants arrived from the beginning of the 5th century AD (Lanting and Van der Plicht, 2010), settling first along the coast and along rivers where drainage was good. The material cultural of the immigrants strongly resembles that of coastal areas of northern Germany and southern Denmark, and it is generally accepted nowadays that they were migrants from that region, 'Anglo-Saxons', who moved to the west in this period, not only to the northern Netherlands but also to Britain (Boeles, 1951; Knol, 2011; Nicolay, 2014, 2017; Nieuwhof 2011, 2013). The new population included the small groups that had stayed behind in the terp region, and probably also people from sparsely populated inland regions who all shared a similar material culture. The new settlers resumed the old ways of the terp dwellers, gradually repopulating the abandoned terps and colonising new salt-marsh ridges. They did, however, bring with them their own traditional form of house construction, replacing the region's older custom of building with wattle and daub with turf-walled buildings (Postma, 2015). These formed the ultimate adaptation to the naturally treeless but grass-rich salt marsh environment, their construction and maintenance becoming an integral part of early-medieval terp construction (fig. 6). During the following centuries, drainage improved, probably partly owing to human interventions (see section 3.5).

3.4 The technology of adaptation

Terps and platforms are not just random heaps of earth; these would be prone to erosion and sagging. They were carefully constructed with local materials: well-rooted clay-rich salt marsh turf, consisting of laminated silty or fine-grained sandy clay; animal (mainly cattle) dung, used especially in the eastern part of Friesland and Groningen; and sometimes wattle. Animal dung in platforms and floors also served as an insulating material (Zimmermann, 1999).

Fig. 6 Experimental reconstruction of an early-medieval turf house on a turf platform in Firdgum. Photo D. Postma.

The construction of house platforms changed only slightly over time. The earliest excavated platform in Ezinge, dated around 500 BC, consisted of turves and dung in a wattle encasement (i.e. fixed formwork) surrounded with turves (fig. 7). In a somewhat later house platform, the lower section of a building's wattle wall served as a retaining wall of similar design. This close connection between the house's construction and raising its plot was clearly intentional, because the thresholds in the walls were placed in an elevated position from the beginning. Other excavated platforms in Ezinge and elsewhere consisted of carefully placed turves. Alternatively, a rectangular retaining wall was constructed entirely of turf and backfilled with more turves or dung (fig. 8). This technique was used throughout the northern coastal region and into the early-medieval period, apparently being sufficiently strong to prevent sagging.

Fig. 7 Three types of platforms from the first phases of habitation in Ezinge. 1: corner of the earliest platform in Ezinge, dated around 500 BC, consisting of turves and dung in a wattle encasement surrounded with turves (dug away for the photo). 2: consecutive house platform, early 5th century BC; the lower section of the building's wattle wall served as a retaining wall that was filled in with turves. The thresholds were placed in an elevated position when the walls were built. 3: a platform from around 400 BC, consisting of carefully placed turves. The part outside the posts of the house was dug away. Photo © University of Groningen, Groningen Institute of Archaeology.

Some platforms were surrounded by a drainage ditch (fig. 9), the soil of which would have been used to construct the platforms. Most of the platforms' mass, however, and that of later platform expansions, consisted of turves that were cut further away from the platforms. This is where the early-medieval turf houses came into their own as a sustainable vernacular type of construction; when the buildings needed maintenance or replacement, their voluminous walling material was reused to raise or expand the platforms. The surroundings of terps were speckled with turf and clay-extraction pits, some of which were kept open as drinking-water basins for livestock (Nicolay and De Langen, 2015).

In addition to terps, low summer dikes were constructed as early as the beginning of the first millennium AD. Four such dikes have been excavated in the province of Friesland (Bazelmans, 2005; Zandboer, 2010). They were made of randomly placed turves, covered with a turf outer skin. The vegetation that continued growing on this outer layer provided cohesion and prevented erosion. Since only small stretches of these dikes were excavated, we do not know whether they were circular dikes; in that case, water outlets would have been needed to prevent problems with drainage. Such outlets have not been found in the northern Netherlands, but the technology was available. Contemporary examples made of hollowed-out tree trunks with additional check valves are known from Bentumersiel on the Ems (Prison, 2009) and Vlaardingen in the province of Zuid-Holland (De Ridder, 2005), places that were within the social exchange networks of the terp dwellers of the northern Netherlands. Key to the sustainable long-term use of these early dikes, which protected parts of the landscape including arable fields, is that they were low enough to allow flooding in wintertime, thus trapping sediment and helping to raise the endiked parcels (Nieuwhof, 2006).

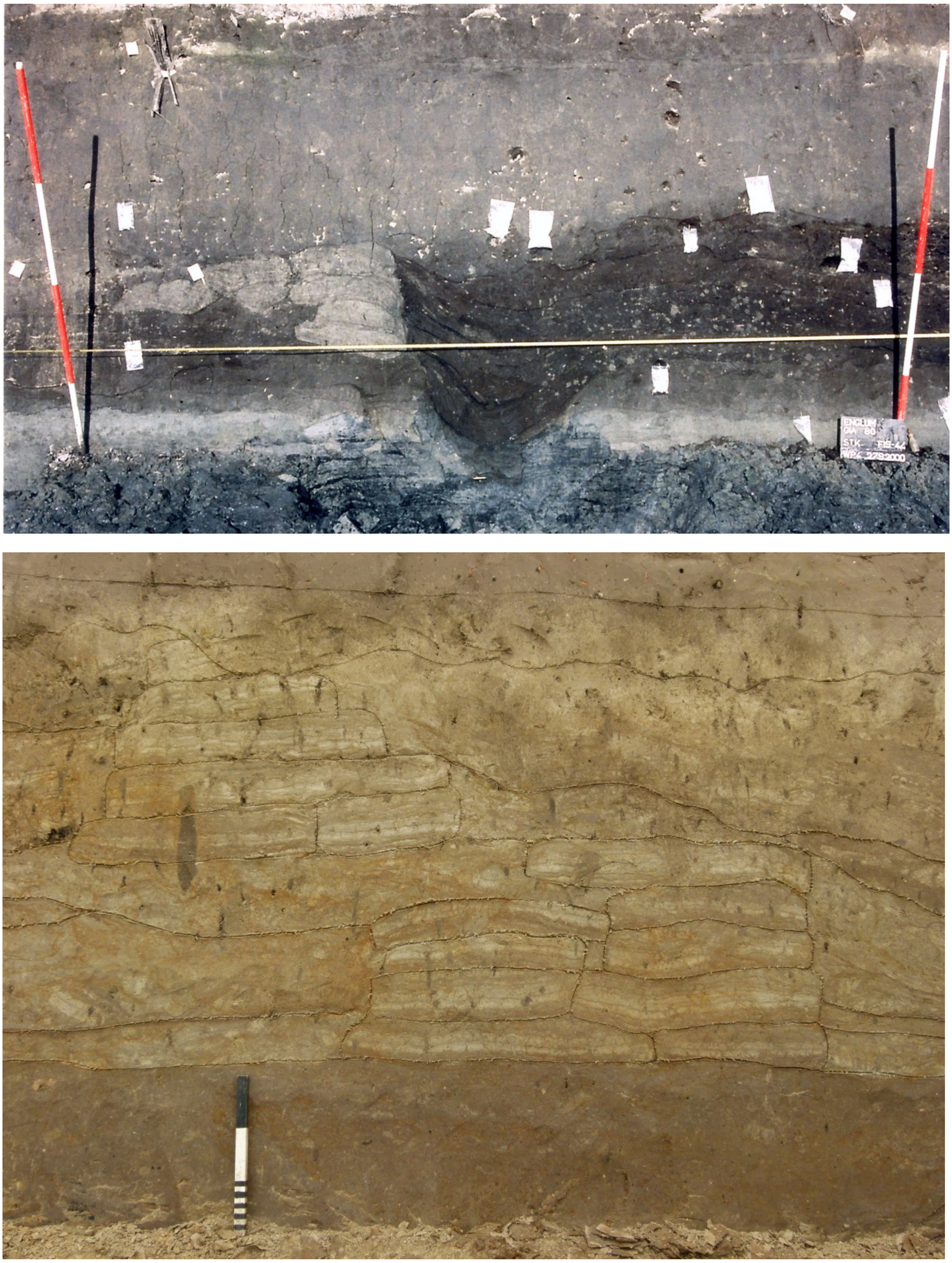

Fig. 8 Section photos of two platforms with retaining walls constructed of turf. Top: A platform from the 5th century BC in Englum. The core of the platform (left) consists mainly of dung; a later extension (right) consists entirely of dung. Bottom: A similar retaining wall of turves, from the 7th century AD, was excavated in Firdgum. The core of this platform (to the left) consists of turves. Photos © University of Groningen, Groningen Institute of Archaeology.

Fig. 9 Transection through a 2nd-century AD platform in Leeuwarden. Its core consists of turves; these are covered by thin floor layers of dung and clay, and heightening layers. The platform was surrounded by a ditch, which was dug anew after application of a heightening layer. The wooden posts are the remains of the farmhouse on this platform. Photo ADC-ArcheoProjecten.

Experiments have shown that the salt marsh was fertile and productive, not only for animal husbandry but also for arable farming, so long as inundation did not occur during the early growing season (Bottema et al., 1980; Körber-Grohne, 1967; Schepers, 2016; van Zeist et al., 1976). The salt marsh did not need to be fertilized, since winter floods brought all the necessary minerals. All animal dung available could thus be used for platforms and for fuel (Nieuwhof and Woldring, 20018; Huisman, 2015).

Long-term terp building and summer dike construction and maintenance were necessarily based on community effort and shared responsibility, which must have been embedded in social organization. During the pre-Roman Iron Age, the colonization of new salt-marsh ridges and the maintenance of terps and summer dikes were probably organized by the chosen leaders of regional communities. Cooperation rather than conflict characterized the relationships between these communities. During the Roman Iron Age, leadership may have become hereditary, and the new communities of the early Middle Ages developed into regional kingdoms with the characteristics of chiefdoms (Nieuwhof and Nicolay, 2018). In all these periods and organizational forms, every community member must have been imbued with the necessity of giving priority to terp maintenance. Land use, technology, settlement development, architecture and social organization in the salt marsh area were closely linked in this society’s approach to environmental adaptation.

3.5 Loss of land

While large parts of the coast expanded to the north into the Middle Ages, other parts eroded and gave way to marine ingressions. The loss of habitable land occurred on a particularly large scale due to large peat areas having been reclaimed and cultivated (De Langen, 2011; De Langen and Mol, 2018; Knol, 2013; Knol and Vos, 2018; Vos and Knol, 2015). Already during the 4th or 3rd century BC, seaward fringes of the peat areas were colonized (Bakker, 2016; Gerrets, 2010; Vos and Bakker, 2017). Ditches were dug in peat and clay-on-peat areas to improve drainage, unintentionally causing oxidation and therefore loss of organic material. While the natural peat surface was well above sea level, resultant subsidence and the flood water's easy access via ditches made the land vulnerable to marine erosion. Early canals, probably dating from after the 5th-century (see fig. 3, AD 800), reinforced this process (De Langen, 2011; Vos and Knol, 2015), as did early-medieval salt extraction from seawater-infused, clay-covered peat. Several tidal inlets (Middelzee, Lauwerszee) thus developed into large tidal basins in the Early Middle Ages (fig. 3), probably destroying terp settlements in the process, but on the other hand improving drainage (Knol and Vos, 2018).

3.6 Dike building: fighting against the sea

After more than 1500 years of nearly unprotected habitation in the salt marsh, dike building began in the 11th century AD, initially with low summer dikes along rivers and around fields (Knottnerus, 2013). The question *why* dike construction was started is not often asked, since to modern (Dutch) eyes it seems self-evident that dikes were the ultimate strategy in coastal regions. Yet, as we have seen, living without dikes on terps had been a successful strategy previously. The most likely reason is not that coastal areas were vulnerable to inundations (they had often been inundated in the past without causing much damage), but rather that reclaimed peat areas inland became uninhabitable because of subsidence and subsequent flooding and deteriorating drainage. Reclaimed peat-areas were among the first areas that were diked (De Langen, 2011; Knol, 2013).

The diked-in areas must have had a knock-on effect on unendiked areas, since they reduced the surface area available for flooding, pushing up water levels during high tides and storm surges. Dike building therefore was not limited to low-lying regions but eventually encompassed the entire coastal area. Over time, the low, regional dikes were heightened and combined into a long, high coastal-barrier system, which was meant to prevent inundations altogether. The inland dikes formed compartments that limited the damage of eventual dike-bursts (Van Dam, 2012). Drainage of the areas that were enclosed by dikes was provided by a fine-meshed system of ditches and canals that drained into the Wadden Sea via sluices and other water outlets in the dikes. These outlets were often of the simple but effective type that was already in use in the 1st centuries BC and AD (Knottnerus, 2013) (see section 3.4).

After the first large-scale dikes were built in the High Middle Ages, many of the terps all but lost their safety function, allowing farmsteads to move to the flanks of the terps or onto adjacent house platforms. Several such house platforms along the northern coast have been recently excavated, all of which were surrounded by newly deposited sediment layers, indicating that this newer generation of dikes had not yet achieved full flood protection (Nicolay et al. 2018a, 2018b). Many existing terps nonetheless changed use to serve mainly for agricultural purposes and were even enlarged with this objective in mind.

After dike building, reclamation of peat and clay-covered areas continued. Where thick layers of peat were present, the land kept subsiding to levels even below Mean High Water. In the western part of the province of Friesland, several large lakes came into existence due to heavy erosion.

An immediate consequence of large-scale dike building was the loss of the salt marshes' water storage capacity. Instead of floods that were relatively tranquil because they could flow over a vast salt marsh area, storm surges now impounded on the dikes. This became especially problematic along the Ems estuary in the eastern part of the province of Groningen, where the level of storm surges increased considerably after dike building. Moreover, maintenance of the dikes was hindered by conflicts between those responsible for their upkeep (De Jonge, 2009; Knottnerus, 2013). In the 15th and early 16th century, a series of catastrophic storm surges broke through these dikes, and the tidal basin of the Dollard came into existence. Terp settlements in this area were washed away (Knol, 2013; Vos and Knol, 2013).

Because of the dikes, storm surges could become far more catastrophic than before. Impoundment easily led to dike bursts. Some terps situated outside the dikes, however, remained inhabited until the 19th century, especially in the Groningen area. These did not suffer from impounding seawater and were not affected by the catastrophic floods that followed dike bursts; they were only abandoned when these salt marshes were finally reclaimed, as part of continuing artificial salt-marsh reclamation that lasted well into the 20th century (Knol, 2013; Knottnerus, 2013).

4. Discussion: past meets present

Salt marsh development depends on the subtle interplay of several factors, such as the rate of (relative) sea-level rise, the availability of sediment and its grain size, the levels of Mean and Extreme High Water, the morphology of tidal basins, and the energy in the tidal system. These natural conditions were also paramount to the possibilities for terp habitation in the Wadden Sea region:

- The rate of relative sea-level rise was moderate, and sediment supply was sufficient to outpace relative sea-level rise. Therefore, the salt marsh region increased in elevation and size.
- Tidal basins in the area allowed the rapid development of vast salt marsh areas.
- The vast salt marsh area provided an enormous storage capacity for flood water. Since water levels remained low, even during storm surges, the early terp platforms did not need to be very high and large. That made early terp building feasible.
- The vastness of the fertile salt marsh area was highly attractive to the terp dwellers as pasture land.
- The available sediment contained sufficient sand (and the energy in the system was high enough) to enable the formation of salt marsh ridges, and sufficient clay and silt to give firmness and cohesion to the salt marsh turf, which was an important condition for the usability of turves for terp building.

However, terp habitation is not necessarily confined to coastal regions with similar natural conditions. The pre-Columbian terps and raised fields of the Guyana’s, for instance, were located in an equally vast coastal plain with sandy cheniers and mudflats not unlike the terp region, but with westward shifting landscapes due to marine currents, and mangrove vegetation on the coast (Augustinus, 1980). An additional requirement for terp habitation on comparable low coastal plains elsewhere in the world is a low risk of extreme events such as hurricanes or tsunamis, unless terps are high enough to provide safety in case of such events.

As presented in Section 1.2, terp habitation can also be found in flood-prone inland, freshwater landscapes. Residential mounds and fields, combined with canals and embankments, were common in the northern part of South America in river areas (Rostain, 2010). In the Netherlands, terps are found in peat areas from the pre-Roman Iron Age onwards (Bakker, 2016; Jongma, 2009; Nicolay, 2018; Van Smeerdijk et al. 2009), and in river floodplains and along inland coasts from the late Middle Ages (Van Dam, 2012). The terps in peat areas were usually small and low, one or two-generation platforms, made of clay and peat. Due to the considerable subsidence that was caused by reclamation, house platforms in these areas were rebuilt after a short period of use, and repositioned in the direction of newly reclaimed plots.

As little as terp habitation is restricted to the Wadden Sea area, or even coastal areas of similar making, is this settlement form exclusive to long foregone periods. In the Netherlands, habitation on house terps in river floodplains has been revitalized in the Netherlands during the last decade, after a number of near-disasters in periods of extremely high water in the Dutch river area in the 1990s. The *Room for the river*-programme consists of over 30 projects that are aimed at preventing future flooding of rivers, especially by increasing the rivers' storage capacity. The Overdiepse polder in the floodplain of the river Maas, for instance, has been designated as a water storage area in case of extremely high water levels. To house the polder's farmsteads, eight large terps have been constructed, with massive cores of sand, and covered by a thick layer of clay, a total of 14.000 m^3 per terp.[3] In New South Wales in Australia, farmers in regularly flooded coastal plains are advised to build *livestock flood refuge mounds*. Detailed instructions include the application of a clay-based surface, a slight slope to improve drainage, and sowing pasture on the mound to minimize erosion (Briggs, 2009). The resulting mounds are much like the terps in the coastal are of the northern Netherlands.

The terp dwellers of the northern Netherlands not only built terps but also small summer dikes, as early as the beginning of the 1st millennium AD. Such low dikes did not block out marine influence altogether, but provided some protection from the energy of waves. They were low enough to allow flooding and sedimentation during high winter storm surges, but high enough to prevent flooding in the summer growing season. Thus, they were a valuable addition to the strategy of living on terps, and may well inform a beneficial land management strategy in present-day situations.

Summer dikes were also the first dikes to be made when large-scale dike building began in the Netherlands in the late Middle Ages. That is why the farmsteads that moved from the terps in this period were still built on house platforms. Further development, however, led to the high, defensive structures that we now know as dikes, designed to keep the sea out under any circumstance. This absolute exclusion of marine influence has come at a price: not only did the impoundment of seawater lead to much more destructive inundations than ever before, high dikes also halted further sedimentation. Meanwhile, sea-level rise and land subsidence as a result of drainage and subsequent oxidisation of the (sub)soil, have continued or even accelerated; many endiked areas are now below sea level, their dikes in need of ever-increasing raising. Obviously, when the medieval dike builders abandoned their cooperation with the sea and started following a more offensive strategy, they could not foresee their fight evolving into a battle that cannot be won in the end.

A similar downward spiral set in with peat reclamation and dehydration. We already mentioned the human-induced erosion of the Lauwerszee and the Middelzee, but similar processes occur elsewhere. At the coast of Schleswig-Holstein, the Halligen are another eroding salt marsh area, which cover an older peat landscape that has been severely affected by peat extraction for salt and fuel. The Halligen consist of salt marsh islands, where terp habitation began in the 8th century AD (Bauer et al., 2001). The islands are protected nowadays by summer dikes, which slow down the

[3] www.ruimtevoorderivier.nl (consulted 1st February 2019).

process of erosion and partly prevent flooding. During high storm surges, seawater covers the Halligen, leaving only the upper parts of the terps free.

The combined effect of human-induced subsidence and dike-building is even more threatening. That was the case in the Dollard area, as described in Section 3.6. Another eroded terp region is located north of present-day Ostfriesland in Lower Saxony. Here, parts of the salt marsh fringe were eroded in the late Middle Ages as a result of higher levels of Extreme High Water after the start of dike building, combined with subsidence after reclamation and salt extraction from salt-containing peat in the subsoil (Niederhofer, 2016). Building of high dikes in combination with reclamation and extraction of peat, are clearly human interventions which in hindsight have disadvantageous outcomes: the reclamation and/or extraction of peat land causing subsidence, and dike building, which diminished the water storage capacity of the salt marsh outside the diked areas, and caused impoundment of flooding water.

Subsidence caused by human-induced dehydration of low-lying peat areas, however, has not come to a standstill. Inhabited, drained peat areas, of which there are many in the northern and western Netherlands, will keep subsiding until the Pleistocene subsoil has been reached. In the province of Groningen, some such low-lying parts have recently been turned into lakes or wetlands (*Blauwe Stad* and *De Onlanden*, see Supplementary Material 1), to create more storage capacity in the case of new inland flooding. Other, similar areas also are in danger of becoming uninhabitable. However, peat reclamation is not the only cause of subsidence. Gas and salt extraction are additional, modern causes of subsidence. Continued drainage of low-lying peat areas (Lof et al., 2017), as well as salt and gas extraction, not to mention the effects of global warming, do not spell good for the Holocene clay and peat areas in the long term. A more integrated, eco-system based coastal defence is called for (De Jonge, 2009; Reise, 2017; Temmerman et al., 2013), possibly even without dikes (Borsje et al., 2017).

5. Conclusions

The Dutch are widely known as fighters against the sea. However, their offensive or at least overly defensive approach is a relatively recent development. Prior to large-scale medieval dike building, the inhabitants of the salt-marsh area of the northern Netherlands successfully adapted to the sea by living on terps, working together with nature rather than aiming to ban its influence on the land altogether. High dikes and terps testify to very different mind sets.

Living behind dikes of ever-increasing height, does not seem to be a sustainable strategy for low-lying coastal areas in the long term. Terp archaeology of the last decades has shown that the inhabitants of the salt marsh region of the northern Netherlands were more daring and pro-active than previously realized. Their settlement strategy, habitation on terps, eventually combined with low summer dikes, may provide a solution for future areas and communities that are facing regular flooding and sea-level rise all over the world, provided that a number of basic conditions are considered:

- A vast floodplain is required, over which flood water can flow out rather than rise.
- The water must supply sufficient sediment to allow accretion, and thereby keep pace with sea-level rise.
- To prevent impoundment, the floodplain should not be bordered by high dikes or long, natural obstructions.

- The area should be well-drained by creeks, combined with ditches if necessary, provided that the subsoil does not contain peat layers that would be negatively affected by this drainage.
- The minimum height of small or large terps depends on the maximum level of Extreme High Water that can be expected in an area.
- Building and maintenance of terps ideally uses local or at least easily available materials (e.g. turf, raw clay, unfired bricks), to be sustainable in the long run.
- Available sediment or other materials must permit building of firm platforms that withstand erosion and sagging.
- Areas where hurricanes or tsunami's may occur are not ideal for terp (or other) habitation, unless terps are sufficiently high and erosion-resistant.
- The degree of social organization must be high enough to permit planning and organization of terp construction and maintenance, but low enough to make the inhabitants feel responsible and involved. Bottom-up initiatives with input of expert knowledge and outside help may be expected to have better results than top-down approaches.
- If sediment is available (requiring erosion elsewhere), low dikes may serve as sediment traps, also providing opportunities for arable farming without the need of fertilizing; accretion may partly make up for sea-level rise.

The interventions of the coastal population of the past, however, did not all have a positive result; some had very adverse, unforeseen effects, which can be equally informative for developing new terp habitation strategies. Cultivation and drainage of peat areas led to subsidence and to severe erosion already at an early stage. The lesson to be learnt here is that any form of land use that causes low-lying coastal areas land to subside, should be avoided, especially in times of increasing sea-level rise such as we are facing now. Although this may seem as an insight that speaks for itself, it is not acknowledged by all parties responsible for drainage of peat areas, or for gas and salt extraction in the Netherlands. This problem shows that we have become accustomed to living behind dikes to the degree that the landscape does not play a decisive role in the perception of the inhabitants, industry and policymakers anymore, as it undoubtedly did in the past.

As the habitation history of the northern Netherlands over the past 2650 years demonstrates, natural circumstances and technological adaptations are not the only factors that determine the possibilities for living in low-lying coastal areas. Long-term terp building and summer dike construction and maintenance are necessarily based on community effort and shared responsibility, which must be embedded in social organization. The success of living in these areas is determined by the interplay of natural, socio-economic, political and cultural factors. Only when these factors all work together, may it be possible to adapt to the changing circumstances that are caused by current and future sea-level rise.

References

1. Augustinus, P.G.E.F., 1980. Actial development of the chenier coast of Suriname (South America). SEDIMENT GEOL 26, 91-113. https://doi: 10.1016/0037-0738(80)90007-X
2. Bakker, M., 2015. Eerste bevindingen van de terpopgraving Sneek-Harinxmaland. Van Wierden en Terpen. Mededelingen van de Vereniging voor Terpenonderzoek 20, 5-9.
3. Bakker, M., 2016. Leeuwarden-Bullepolder 2015: bewoning op het hoogveen in de Midden-IJzertijd. Paleo-aktueel 27, 41-47.
4. Bakker, M. & de Langen, G., 2017. Opgraving Wartena-Noord (GIA-131): onderzoek aan een huisterp en een oud verkavelingspatroon in het Friese klei-op-veengebied tussen Warten en

Warstiens (= Grondsporen 28). Groningen Institute for Archaeology, University of Groningen, Groningen. http://hdl.handle.net/11370/280503d6-7764-4fe9-8aed-252539da3915

5. Bakker, M., Varwijk, Th., 2016. Een verhaal over trends en continuïteit: aardewerkonderzoek nieuwe stijl toegepast op het aardewerk van Jelsum, in: Nieuwhof, A. (Ed.), Van Wierhuizen tot Achlum. Honderd jaar archeologisch onderzoek in terpen en wierden. Vereniging voor Terpenonderzoek, Groningen, pp. 181-206.
6. Bakker, M., de Langen, G., Sibma, T. 2018. Opgraving Sneek-Harinxmaland. Van vlaknederzetting in een veengebied tot afgetopte terp onder een kleipakket (Grondsporen 36). Groningen Institute for Archaeology, University of Groningen, Groningen.
7. Bantelmann, A., 1975. Elisenhof: die Ergebnisse der Ausgrabung der frühgeschichtlichen Marschensiedlung beim Elisenhof in Eiderstedt 1957/58 und 1961/64. Bd. 1: Die frühgeschichtliche Marschensiedlung beim Elisenhof in Eiderstedt: Landschaftgeschichte und Baubefunde. Lang, Bern.
8. Bauer, E., Fischer, L., Kühn, H.J., Maluck, M., Meier, D., 2001. The Schleswig-Holstein Wadden Sea Region. Wadden Sea Ecosystem 12, 119-157.
9. Bazelmans, J., 2005. Die Wurten von Dongjum-Heringa, Peins-Oost und Wijnaldum-Tjitsma: kleinmaßstäblicher Deichbau in ur- und frügeschichtlicher Zeit des nördlichen Westergo, in: Fansa, M. (Ed.), Kulturlandschaft Marsch. Natur-Geschichte-Gegenwart. Landesmuseum für Natur und Mensch, Oldenburg, pp. 68-84.
10. Bazelmans, J., Meier, D., Nieuwhof, A., Spek, T., Vos, P., 2012. Understanding the cultural historical value of the Wadden Sea region. The co-evolution of environment and society in the Wadden Sea area in the Holocene up until early modern times (11,700 BC-1800 AD): An outline. OCEAN COAST MANAGE 68, 114-126. https://doi:10.1016/j.ocecoaman.2012.05.014.
11. Beets, D.J., van der Spek, A.J.F., van der Valk, L., 1994. Holocene ontwikkeling van de Nederlandse kust, Rijks Geologische Dienst, Haarlem.
12. Beets, D.J., van der Spek, A.J.F., 2000. The Holocene evolution of the barrier and the back-barrier basins of Belgium and the Netherlands as a function of late Weichselian morphology, relative sea-level rise and sediment supply. GEOL MIJNBOUW-N J G 79, 3-6.
13. Beijerinck, W., 1929-1931. De subfossiele plantenresten in de terpen van Friesland en Groningen. I: vruchten, zaden en bloemen. II: diatomeeën-schalen; III: overige macro- en microscopische resten, Fonds landbouw export bureau 1916-1918, Wageningen.
14. Besteman, J.C., Bos, J.M., Gerrets, D.A., Heidinga, H.A., de Koning, J., 1999. The excavations at Wijnaldum. Reports on Frisia in Roman and Medieval times, Volume I. Balkema, Rotterdam/Brookfield.
15. Boeles, P.C.J.A., 1951. Friesland tot de elfde eeuw. Zijn vóór- en vroege geschiedenis, second ed. Martinus Nijhoff, 's-Gravenhage.
16. Borsje, B., Folmer, E., Hartman, S., Mehnen, N., Schepers, M., 2017. Ditching dikes! Waddenzee zonder dijken/Life without dikes? Noorderbreedte 41, 3-5.
17. Bottema-MacGillavry, J.N., 2008. Hout, in: Nieuwhof, A. (Ed.), De Leege Wier van Englum. Archeologisch onderzoek in het Reitdiepgebied, Vereniging voor Terpenonderzoek, Groningen, pp. 177-186.
18. Bottema, S., van Hoorn, T.C., Woldring, H., Gremmen, W.H.E., 1980. An agricultural experiment in the unprotected salt marsh. Part II. Palaeohistoria 22, 128-140.
19. Braakhekke, W., van Winden, A., Litjens, G., Berkhuysen, A., 2008. Hoogtij voor Laag Nederland. Werken met de natuur voor een veilige en mooie delta. Wereld Natuur Fonds, Zeist.
20. Briggs, G., 2009. Livestock flood refuge mounds (= Rural development guidelines, Primefact 961). State of New South Wales. https://www.dpi.nsw.gov.au/climate-and-emergencies/emergency/community/before-an-emergency/refuge-mounds

21. Cnossen, J., 1980. Bodem, in: Vlieger, J. (Ed.), Het Friese Landschap. Friese Pers, Leeuwarden, pp. 28-41.
22. de Jonge, V.N., 2009. From a defensive to an integrated approach, in: Reinhard, S., Folmer, H. (Eds), Water policy in the Netherlands: integrated management in a densely populated delta. Resources for the Future (RFF), Washington D.C, pp. 17-46.
23. de Langen, G.J., 1992. Middeleeuws Friesland. De economische ontwikkeling van het gewest Oostergo in de vroege en volle Middeleeuwen. Wolters-Noordhoff/Forsten, Groningen.
24. de Langen, G., 2011. De gang naar een ander landschap. De ontginning van de (klei-op-) veen-gebieden in Fryslân gedurende de late ijzertijd, Romeinse tijd en middeleeuwen (van ca. 200 v. Chr. tot ca. 1200 n. Chr.), in: Niekus, M.J.L.Th., van der Zee, S., Looijenga, T., Kiestra, F. (Eds), Gevormd en omgevormd landschap van Prehistorie tot Middeleeuwen. Drents Prehistorische Vereniging, pp. 70-97.
25. de Langen, G., Mol, H., 2016. Terpenbouw en dorpsvorming in de volle middeleeuwen, in: Nieuwhof, A. (Ed.), Van Wierhuizen tot Achlum. Honderd jaar archeologisch onderzoek in terpen en wierden. Vereniging voor Terpenonderzoek, Groningen, pp. 99-128.
26. de Langen, G., Mol, H., 2018. Een heilige in It Heidenskip. Een volmiddeleeuwse veenontginning onder de klokslag van Sint Ursula, in: Nieuwhof,A., Knol, E., Schokker, J. (Eds), Fragmenten uit de rijke wereld van de archeologie. Vereniging voor Terpenonderzoek, Groningen, pp. 173-186.
27. De Mulder, E.F.J., Geluk, M.C., Ritsema, I.L., Westerhoff, W.E., Wong, T.E., 2003. De ondergrond van Nederland, Wolters-Noordhoff, Groningen/Houten.
28. de Ridder, T., 2005. Wassermanagement in römischer Zeit: Die ältesten Deltawerke in Westeuropa, in: Fansa, M. (Ed.), Kulturlandschaft Marsch. Natur-Geschichte-Gegenwart. Landesmuseum für Natur und Mensch, Oldenburg, pp. 60-67.
29. Dijkstra, J., Nicolay, J.A.W. (Eds), 2008. Een terp op de schop. Archeologisch onderzoek op het Oldehoofsterkerkhof te Leeuwarden, ADC, Amersfoort.
30. Gerrets, D.A., 2010. Op de grens van land en water. Dynamiek van landschap en samenleving in Frisia gedurende de Romeinse tijd en de volksverhuizingstijd, Barkhuis & Groningen University Library, Groningen.
31. Gerrets, D.A., de Koning, J., 1999. Settlement development on the Wijnaldum-Tjistma terp, in: Besteman, J.C., Bos, J.M., Gerrets, D.A., Heidinga, H.A., de Koning, J. (Eds), The excavations at Wijnaldum. Reports on Frisia in Roman and Medieval times I. Balkema, Rotterdam/Brookfield, pp. 73-124.
32. Haarnagel, W., 1979. Die Grabung Feddersen Wierde. Methode, Hausbau, Siedlungs- und Wirtschaftsformen sowie Sozialstruktur, Steiner, Wiesbaden.
33. Huisman, H., 2015. Terplagen en verbrande mest onder de loep: micromorfologisch onderzoek op een terpflank, in: Nicolay, J.A.W., de Langen, G. (Eds), Graven aan de voet van de Achlumer dorpsterp. Archeologische sporen rondom een terpnederzetting. Vereniging voor Terpenonderzoek, Groningen, pp. 69-81.
34. Jongma, S., 2008. Sporen en structuren, in: Nieuwhof, A. (Ed.), De Leege Wier van Englum. Archeologisch onderzoek in het Reitdiepgebied. Vereniging voor Terpenonderzoek, Groningen, pp. 31-46.
35. Jongma, S., 2009. Terpen in het zonnige zuiden. Van Wierden en Terpen. Mededelingen van de Vereniging voor Terpenonderzoek 13, 3-4.
36. Kassabaum, M.C., 2018. Early platforms, early plazas: Exploring the precursors to Mississippian mound-and-plaza centers. J ARCHAEOL RES, online first. https://doi.org/10.1007/s10814-018-9121-y
37. Knol, E., 1983. Farming on the banks of the river Aa. The faunal remains and bone objects of Paddepoel 200 BC-250 AD. Palaeohistoria 25, 145-182.

38. Knol, E., 1993. De Noordnederlandse kustlanden in de vroege Middeleeuwen. PhD dissertation, Vrije Universiteit Amsterdam.
39. Knol, E., 2011. The first early medieval cemeteries along the northern Dutch coasts and their significance for Anglo-Saxon migration, in: Panhuysen, T.A.S.M. (Ed.), Transformations in North-Western Europe (AD 300-1000). Proceedings of the 60th Sachsensymposion 19.-23. September 2009 Maastricht. Konrad Theiss Verlag, Hannover, pp. 218-227.
40. Knol, E., 2013. Moorkolonisation und Deichbau als Ursache von Flutkatastrophen - das Beispiel der nördlichen Niederlande. Siedlungs- und Küstenforschung im südlichen Nordseegebiet 36, 157-170.
41. Knol, E., Vos, P.C., 2018. Lauwerszee, in: Nieuwhof, A., Knol, E., Schokker, J. (Eds), Fragmenten uit de rijke wereld van de archeologie. Vereniging voor Terpenonderzoek, Groningen, pp. 157-168.
42. Knottnerus, O.S., 2013. Reclamations and submerged lands in the Ems River Estuary (900-1500), in: Thoen, E., Borger, G.J., de Kraker, A.M.J., Soens, T., Tys, D., Vervaert, L., Weerts, H.J.T. (Eds), Landscapes or seascapes? The history of the coastal environment in the North Sea area reconsidered. Brepols, Turnhout, pp. 241-266. https://doi:10.1484/M.CORN.1.101555
43. Körber-Grohne, U., 1967. Geobotanische Untersuchungen auf der Feddersen Wierde. Steiner, Wiesbaden.
44. Lanting, J.N., van der Plicht, J., 2010. De ^{14}C-chronologie van de Nederlandse pre- en protohistorie VI: Romeinse tijd en Merovingische periode, deel A: historische bronnen en chronologische thema's. Palaeohistoria 51/52, 27-168.
45. Lof, M., Schenau, S., de Jong, R., Remme, R., Graveland, C., Hein, L., 2017. The SEEA EEA carbon account for the Netherlands, Statistics Netherlands/Wageningen University, Den Haag.
46. Loveluck, C., Tys, D., 2006. Coastal societies, exchange and identity along the Channel and southern North Sea shores of Europe, AD 600–1000. J MARIT ARCHAEOL 1, 140-169. https://doi:10.1007/s11457-006-9007-x
47. Martens, V.V., 2016. North Norwegian farm mounds – economic resources and landscape conditions, in: Klápštì, J. (Ed.), Agrarian technology in the medieval landscape. Brepols, Turnhout, pp. 173-183. https://doi:10.1484/M.RURALIA-EB.5.110463
48. Metz, T., van den Heuvel, M., 2012. Sweet & salt. Water and the Dutch. NAi Publishers, Rotterdam.
49. Meijles, E.W., Kiden, P., Streurman, H.J., van der Plicht, J., Vos, P.C., Gehrels, W.R., Kopp, R.E., 2018. Holocene relative mean sea-level changes in the Wadden Sea area, northern Netherlands. J QUATERNARY SCI 33, 905-923. https://doi:10.1002/jqs.3068
50. Miedema, M., 1983. Vijfentwintig eeuwen bewoning in het terpenland ten noordwesten van Groningen, PhD-dissertation Vrije Universiteit, Amsterdam.
51. Nicolay, J.A.W. (Ed.), 2010. Terpbewoning in oostelijk Friesland. Twee opgravingen in het voormalige kweldergebied van Oostergo, Barkhuis/Groningen University Library, Groningen.
52. Nicolay, J.A.W., 2014. The splendour of power. Early medieval kingship and the use of gold and silver in the southern North Sea area (5th to 7th century AD), Barkhuis Publishing and University of Groningen Library, Groningen.
53. Nicolay, J.A.W., 2015. Terp excavation in the Netherlands. In: Carver, M., Gaydarska, B., Montón-Subía, S. (Eds), Field Archaeology From Around The World. Ideas And Approaches. Springer, Cham etc., pp. 149-151.
54. Nicolay, J.A.W., 2017. Odin in Friesland. Scandinavian influences in the southern North Sea area during the Migration and early Merovingian periods, in: Valentin Eriksen, B., Abegg-

Wigg, A., Bleile, R., Ickerodt, U. (Eds), Interaktion ohne Grenzen. Beispiele archäologischer Forschungen am Beginn des 21. Jahrhunderts. Wachholtz Verlag, Schleswig, pp. 499-514.

55. Nicolay, J.A.W. (Ed.), 2018. Huisplaatsen in de Onlanden. De geschiedenis van een Drents veenweidegebied. University of Groningen/Groningen Institute of Archaeology & Barkhuis Publishing, Groningen.
56. Nicolay, J.A.W., de Langen, G. (Ed.), 2015. Graven aan de voet van de Achlumer dorpsterp. Archeologische sporen rondom een terpnederzetting, Vereniging voor Terpenonderzoek, Groningen.
57. Nicolay, J.A.W., Nieuwhof, A., Veenstra, V., Bakker, A., 2018a. Warffum: dorpswierde, boerderijplaats en Oude dijk, in: Nieuwhof, A., Nicolay, J.A.W., Wiersma, J. (Eds), De geschiedenis van terpen- en wierdenland. Een verhaal in ontwikkeling, Vereniging voor Terpenonderzoek, Groningen, pp. 197-214.
58. Nicolay, J.A.W., Pelsmaeker, S., Postma, D., Veenstra, H., 2018b. Hallum: 'nieuwe Friezen' in beeld, in: Nieuwhof, A., Nicolay, J.A.W., Wiersma, J. (Eds), De geschiedenis van terpen- en wierdenland. Een verhaal in ontwikkeling, Vereniging voor Terpenonderzoek, Groningen, pp. 149-172.
59. Niederhöfer, K., 2016. *Archäologische Fundstellen im ostfriesischen Wattenmeer - Siedlungsgeschichte einer untergegangenen Landschaft bis 1570*. Verlag Marie Leidorf, Rahden/Westf.
60. Nieuwhof, A., 2006. Changing landscape and grazing: macroremains from the terp Peins-east, province of Friesland, the Netherlands. VEG HIST ARCHAEOBOT 15, 125-136. https://doi: 10.1007/s00334-005-0011-0.
61. Nieuwhof, A. (Ed.), 2008. De leege Wier van Englum. Archeologisch onderzoek in het Reitdiepgebied, Vereniging voor Terpenonderzoek, Groningen.
62. Nieuwhof, A., 2011. Discontinuity in the Northern-Netherlands coastal area at the end of the Roman Period, in: Panhuysen, T.A.S.M. (Ed.), Transformations in North-Western Europe (AD 300-1000). Proceedings of the 60th Sachsensymposion 19.-23. September 2009 Maastricht. Konrad Theiss Verlag, Hannover, pp. 55-66.
63. Nieuwhof, A., 2013. Anglo-Saxon immigration or continuity? Ezinge and the coastal area of the northern Netherlands in the Migration Period. Journal of Archaeology in the Low Countries 5, 53-83.
64. Nieuwhof, A. (Ed.), 2014. En dan in hun geheel. De vondsten uit de opgravingen in de wierde Ezinge, Vereniging voor Terpenonderzoek, Groningen.
65. Nieuwhof, A., 2015. Eight human skulls in a dung heap and more. Ritual practice in the terp region of the northern Netherlands, 600 BC - AD 300. Barkhuis Publishing & University of Groningen Library, Groningen.
66. Nieuwhof, A., 2016. De lege vierde eeuw. Jaarverslagen van de Vereniging voor Terpenonderzoek 98, in: Nieuwhof, A. (Ed.), Van Wierhuizen tot Achlum. Honderd jaar archeologisch onderzoek in terpen en wierden. Vereniging voor Terpenonderzoek, Groningen, pp. 83-98.
67. Nieuwhof, A., Prummel, W., Vos, P.C., 2006. De wierde Wierum (provincie Groningen). Een archeologisch steilkantonderzoek, Barkhuis & Groningen University Library, Groningen.
68. Nieuwhof, A., Woldring, H., 2008. Botanische resten, in: Nieuwhof, A. (Ed.), De Leege Wier van Englum. Archeologisch onderzoek in het Reitdiepgebied. Vereniging voor Terpenonderzoek, Groningen, pp. 160-176.
69. Nieuwhof, A., Schepers, M., 2016. Living on the edge: Synanthropic salt marshes in the coastal area of the Northern Netherlands from around 600 BC. Archaeological Review from Cambridge 31, 48-74.

70. Nieuwhof, A., Vos, P.C., 2018. New data from terp excavations on sea-level index points and salt marsh sedimentation rates in the eastern part of the Dutch Wadden Sea. NETH J GEOSCI 97, 31-43. https://doi:10.1017/njg.2018.2.
71. Nieuwhof, A., Nicolay, N., 2018. Identiteit en samenleving: terpen en wierden in de wijde wereld, in: Nieuwhof, A., Nicolay, J.A.W., Wiersma, J. (Eds), De geschiedenis van terpen- en wierdenland. Een verhaal in ontwikkeling, Vereniging voor Terpenonderzoek, Groningen, pp. 57-84.
72. Peeters, J.H.M., Murphy, P., Flemming, N. (Eds), 2009. North Sea Prehistory Research and Management Framework (NSPRMF), RCE, Amersfoort.
73. Postma, D., 2015. Het zodenhuis van Firdgum. Middeleeuwse boerderijbouw in het Friese kustgebied tussen 400 en 1300, Terpencentrum Rijksuniversiteit Groningen, Groningen.
74. Prison, H., 2009. Von Prielen und Sielen. Ein kaiserzeitliches Siel? Archäologie in Niedersachsen 12, 127-129.
75. Prummel, W., 1993. Birds from four coastal sites in the Netherlands. ARCHAEOFAUNA 2, 97-105.
76. Prummel, W., 2001. The Significance of animals to the early medieval Frisians in the northern coastal area of the Netherlands: Archaeozoological, Iconographic, historical and literary evidence. ENVIRON ARCHAEOL 6, 73-86. https://doi:10.1179/146141001790523178
77. Prummel, W., 2018. Botten van kraanvogels (Grus grus) uit terpen en wierden, in: Nieuwhof, A., Knol, E., Schokker, J. (Eds), Fragmenten uit de rijke wereld van de archeologie, Vereniging voor Terpenonderzoek, Groningen, pp. 211-220.
78. Prummel, W., Heinrich, D., 2005. Archaeological evidence of former occurrence and changes in fishes, amphibians, birds, mammals and molluscs in the Wadden Sea area. HELGOLAND MAR RES 59, 55-70. https://doi.org/10.1007/s10152-004-0207-1
79. Reise, K., 2017. Facing the third dimension in coastal flatlands. Global sea level rise and the need for coastal transformations. GAIA 25, 89-93.
80. Rippon, S., 2000. Holding back the tides. Explaining Romano-British and early medieval reclamation around the Severn estuary, South West Britain. Stichting voor de Nederlandse Archeologie, Amsterdam.
81. Rockman, M., 2012. The necessary roles of archaeology in climate change mitigation and adaptation, in: Rockman, M., Flatman, J. (Eds), Archaeology in society: Its relevance in the modern world. Springer, New York/Dordrecht/Heidelberg/London, pp. 193-215. htps://doi:10.1007/978-1-4419-9881-1_14.
82. Rostain, S., 2010. Pre-Columbian earthworks in coastal Amazonia. Diversity 2, 331-352. https://doi:10.3390/d2030331
83. Schepers, M., 2016. Gebruiksplanten in het terpen- en wierdengebied, in: Nieuwhof, A. (Ed.), Van Wierhuizen tot Achlum. Vereniging voor Terpenonderzoek, Groningen, 141-152.
84. Schepers, M., Cappers, R.T.J., Bekker, R.M., 2013. A review of prehistoric and early historic mainland salt marsh vegetation in the northern-Netherlands based on the analysis of plant macrofossils. J COAST CONSERVAT 17, 755-773. https://doi:10.1007/s11852-013-0275-y.
85. Taayke, E., 1996. Die einheimische Keramik der nördlichen Niederlande. 600 v.Chr. bis 300 n. Chr., PhD-dissertation, University of Groningen.
86. Temmerman, S., Meire, P., Bouma, T.J., Herman, P.M.J., Ysebaert, T., de Vriend, H.J., 2013. Ecosystem-based coastal defence in the face of global change. Nature 504, 79-83. https://doi:10.1038/nature12859.
87. Tuinstra, S.J., Veldhuis, J.R., Nicolay, J.A.W., 2011. Hallum, een welvarend dorp aan de monding van de Middelzee, ARCbv, Groningen.
88. Tys, D., 2002. De inrichting van een getijdenlandschap. De problematiek van de vroegmiddeleeuwse nederzettingsstructuur en de aanwezigheid van terpen in de kustvlakte:

het voorbeeld van Leffinge (gemeente Middelkerke, prof. West-Vlaanderen). Archeologie in Vlaanderen 8, 257-279.
89. van Dam, P.J.E.M., 2012. Overstromingen en culturele aanpassingen in historisch perspectief. Water Governance 5, 10-17.
90. van de Noort, R., 2011. Conceptualising climate change archaeology. Antiquity 85, 1039-1048. https://doi:10.1017/S0003598X00068472.
91. van de Noort , R., 2013. Climate change archaeology. Building resilience from research in the world's coastal wetlands, Oxford University Press, Oxford.
92. van Es, W.A., 1970. Paddepoel, excavations of frustrated terps, 200 BC - 250 AD. Palaeohistoria 14, 187-352.
93. van Giffen, A.E., 1910. Het dalingsvraagstuk der Alluviale Noordzeekusten, in verband met bestudeering der terpen. Tijdschrift voor geschiedenis, land- en volkenkunde 25, 258-294.
94. van Giffen, A.E., 1931. Mededeeling omtrent het systematisch onderzoek, verricht in de jaren 1928, 1929 en 1930. Jaarverslagen van de Vereniging voor Terpenonderzoek 13-15, 16-46.
95. van Giffen, A.E., 1933. De terp te Ezinge. De Ingenieur 48, 313-315.
96. van Giffen, A.E., 1936. Der Warf in Ezinge, Provinz Groningen, Holland, und seine westgermanische Häuser. Germania 20, 40-47.
97. van Gijn, A.L., Waterbolk, H.T., 1984. The colonization of the salt marshes of Friesland and Groningen. The possibility of a transhumant prelude. Palaeohistoria 26, 101-122.
98. van Smeerdijk, D., Pals, J.P., van Geel, B., van Bennekom, J., 2009. Mens en landschap in middeleeuws Diemen, in: Blok, H., Krook, W., van Reenen, P. (Eds), Diemen in het land van Amstel. De Bataafsche Leeuw, Amsterdam, pp. 351-366.
99. van Zeist, W., 1974. Palaeobotanical studies of settlement sites in the coastal area of the Netherlands. Palaeohistoria 16, 223-371.
100. van Zeist, W., van Hoorn, T.C., Bottema, S., Woldring, H., 1976. An agricultural experiment in the unprotected salt marsh. Palaeohistoria 18, 111-153.
101. Varwijk, T.W., de Langen, G., 2018. Standaardrapport Terpzoolopgraving Wommels-Stapert 2014 (GIA 138). Terug na 20 jaar: Nieuw archeologisch onderzoek aan de commercieel afgegraven terp Stapert bij Wommels in het hart van Westergo (Friesland) (Grondsporen 35). Groningen Institute for Archaeology, University of Groningen, Groningen.
102. Versteeg, A.H., 1980. C-14 datings from archaeological sites in Suriname. Stichting Surinaams Museum 32, 38-53.
103. Vollmer, M., Guldberg, M., Maluck, M., Marrewijk, D., Schlicksbier, G., 2001. Landscape and cultural heritage in the Wadden Sea region – project report. Wadden Sea Ecosystem No. 12. Common Wadden Sea Secretariat, Wilhelmshaven.
104. Vos, P.C., 1999. The Subatlantic evolution of the coastal area around the Wijnaldum-Tjitsma terp, in: Besteman, J.C. , Bos, J.M., Gerrets, D.A., Heidinga, H.A., de Koning, J. (Eds), The excavations at Wijnaldum. Reports on Frisia in Roman and Medieval times. Volume I. Balkema, Rotterdam/Brookfield, pp. 33-72.
105. Vos, P.C., 2015. Origin of the Dutch landscape. Long-term landscape evolution of the Netherlands during the Holocene, described in visualized in national, regional and local palaeogeographical map series, Barkhuis, Groningen.
106. Vos, P.C., van Kesteren, W.P., 2000. The long-term evolution of intertidal mudflats in the northern Netherlands during the Holocene; natural and anthropogenic processes. CONT SHELF RES 20, 1687-1710. https://doi:10.1016/S0278-4343(00)00043-1
107. Vos, P.C., Gerrets, D.A., 2005. Archaeology: a major tool in the reconstruction of the coastal evolution of Westergo (northern Netherlands). QUATERN INT 133-134, 61-75. https://doi:10.1016/j.quaint.2004.10.008

108. Vos, P.C., Knol, E., 2013. De ontstaansgeschiedenis van het Dollardlandschap; natuurlijke en antropogene processen, in Essink, K. (Ed.), Stormvloed 1509 - Geschiedenis van de Dollard. Stichting Verdronken Geschiedenis, Groningen, pp. 31-43.
109. Vos, P.C., Knol, E., 2015. Holocene landscape reconstruction of the Wadden Sea area between Marsdiep and Weser. Explanation of the coastal evolution and visualisation of the landscape development of the northern Netherlands and Niedersachsen in five palaeogeographical maps from 500 BC to present. NETH J GEOSCI 94, 157-183. https://doi:10.1017/njg.2015.4
110. Vos P.C., Varwijk, T.W., 2017. Paleolandschappelijke opname Saksenoord (GIA 133). Uitwerking van de geologische opname in de archeologische terpopgraving Saksenoord (provincie Friesland), Deltares.
111. Vos, P.C., Bakker, M., 2017. Paleolandschappelijke opname Wartena-Noord. Uitwerking van de geologische opnamen van de terpopgraving Wartena-Noord (Provincie Friesland), Deltares.
112. Wahl, T., Haigh, I.D., Woodworth, P.L., Albrecht, F., Dillingh, D., Jensen, J., Nicholls, R.J., Weisse, R., Wöppelmann, G., 2013. Observed mean sea level changes around the North Sea coastline from 1800 to present. Earth-Science Reviews 124, 51-67. http://dx.doi.org/10.1016/j.earscirev.2013.05.003
113. Werkhoven, M.C.M., Versteeg, A.H., 1980. The vegetation of four mounds in the coastal plain of Suriname/De vegetatie van 4 terpen in de Westsurinaamse kustvlakte. Stichting Surinaams Museum 32, 8-36.
114. Wilkinson, T.J., 2003. Archaeological landscapes of the Near East, University of Arizona Press, Tucson.
115. Wong, P.P., Losada, I.J., Gattuso, J.-P., Hinkel, J., Khattabi, A., McInnes, K.L., Saito, Y., Sallenger, A., 2014. Coastal systems and low-lying areas, in: Field, C.B., Barros, V.R. et al. (Eds), Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK/New York, USA , pp. 361-409.
116. Zandboer, S. (Ed.), 2010. Wergea Terp Groot Palma. ADC-ArcheoProjecten, Amersfoort. https://doi.org/10.17026/dans-xub-yc77
117. Zimmermann, W.H., 1999. Why was cattle-stalling introduced in prehistory? The significance of byre and stable and of outwintering, in Fabech, Ch., Ringtved, J. (Eds), Settlement and landscape. Proceedings of a conference in Århus, Denmark, May 4-7 1998. Jutland Archaeological Society, Højbjerg, pp. 301-318.

Supplementary manterial 1

Adapting to the sea: human habitation in the coastal area of the northern Netherlands before medieval dike building

In: Ocean and Coastal Management

A. Nieuwhof; M. Bakker; E. Knol; G.J. de Langen; J.A.W. Nicolay; D. Postma; M. Schepers; T.W. Varwijk; P.C. Vos.
Corresponding author: A. Nieuwhof, Groningen Institute of Archaeology, University of Groningen. Email: a.nieuwhof@rug.nl

Elevation map of the northern Netherlands based on the *Actueel Hoogtebestand Nederland* (AHN), www.ahn.nl/index.html (after Knol 2013); with new lakes and storage areas in low-lying areas.