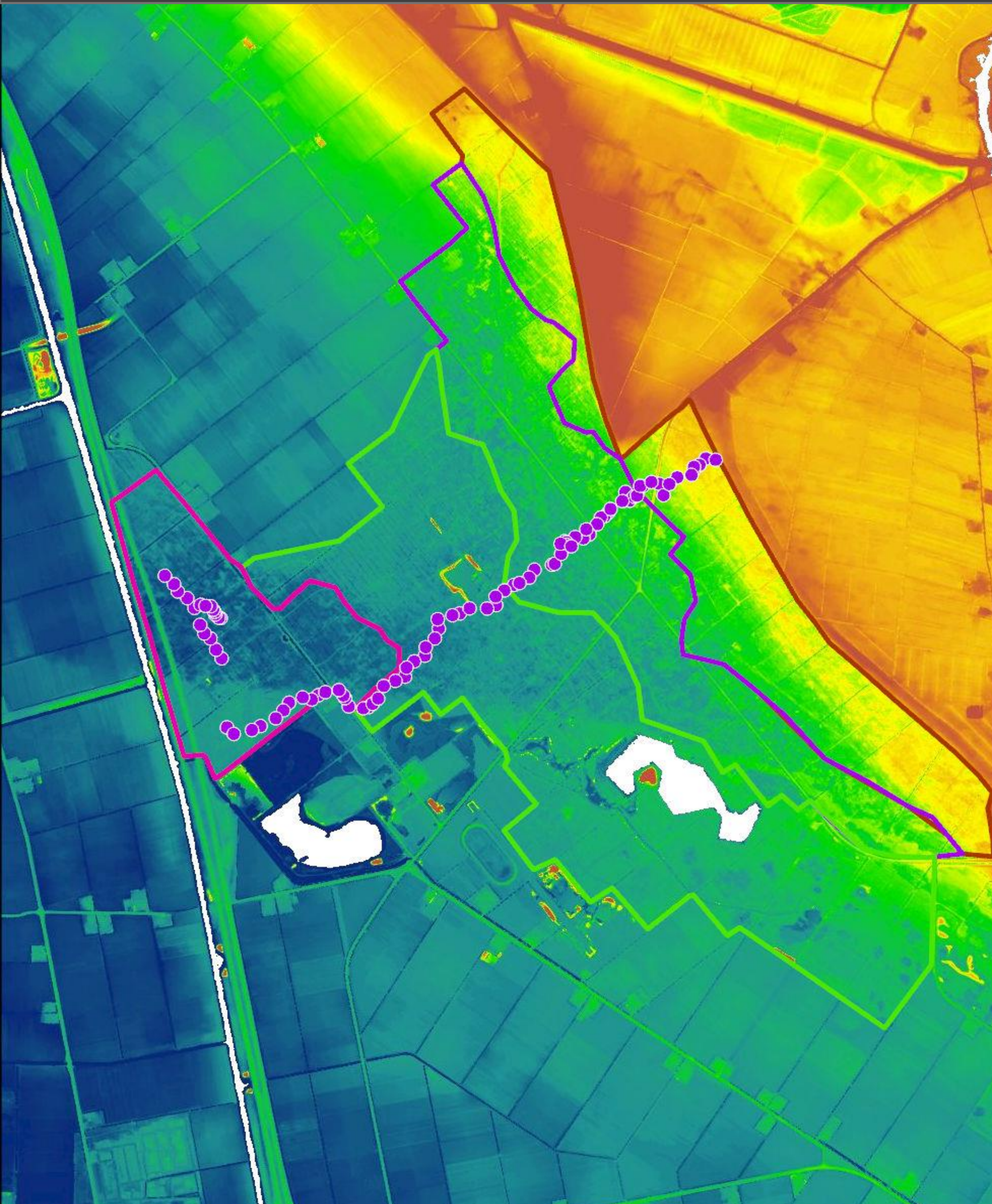
Preservation states of drowned landscapes in the former Zuiderzee

Henk-Jan Geurts



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MSc thesis

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Figure in front contains fieldwork coring locations and preservation zones based on these corings, plotted on LIDAR imagery (AHN).

Preface

During my Bachelor archaeology at Hogeschool Saxion in Deventer I received a question from a fellow student asking me, how is it possible that a drowned landscape with a dike lies 3 metres below sea level? This question intrigued me and during my master Earth, Surface and Water at Utrecht University I tried using my newly obtained knowledge to answer this question. However, all answers that were formulated were wrong in the end. Having no answer sometimes frustrates and it led to the decision that I used that question as my thesis subject. During preparation of the master's thesis other questions arose. Why are some drowned landscapes completely gone and why are some drowned landscapes in good preservation states? These two questions eventually led to what this master's thesis is now when you read it. While it seems that the thesis has strayed away from its initial question it actually answers more than only why a drowned landscape with a dike is situated 3 metres below sea level (sub-case study area Uitdam).

When writing this master's thesis, it sometimes was hard, it was oftentimes frustrating and sometimes I didn't want to do anything at all. Although it might seem I disliked writing this thesis I actually enjoyed it. Sometimes multiple things just coincide and that was the case during the global Covid pandemic that was occurring during writing of this master's thesis. While it might seem strange, the pandemic made writing this thesis even more fun than I would have without it.

During the duration of this master's thesis, I received help from several people and I would like to thank them for that. First, I would like to thank my supervisor Kim Cohen for his advice and feedback I have received during this thesis. I also would like to thank Yftinus Van Popta for his help and the discussions we held about the Kuinderbos. During fieldwork I received help from Damon Oogink, Louis Bruijn and Kirsten Pollé and I would like to thank them for that. Regarding fieldwork I would also thank Harco Bergman for receiving permission to perform fieldwork. Lastly, I would like to thank everyone that helped during my thesis and especially, Renee Hageman, Joey O'Deill, Kirsten Pollé and Damon Oogink.

I hope you, as reader have as much fun reading this master's thesis as I have had while writing it.

Henk-Jan Geurts

Deventer, June 9, 2021.

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Abstract

The Zuiderzee has been a dynamic environment from the Middle Ages onward which caused erosion and land loss until its closing off by the Afsluitdijk in 1932. Relics of land loss, drowned landscapes, have been found in different preservation states within the Zuiderzee area. This thesis research is focussed on variables and processes that led to different preservation states of drowned landscapes within the Zuiderzee. Aim of this research is to determine different variables and processes that led to different preservation states. Determining variables and processes that led to different preservation states of drowned landscapes will also lead to a further thorough understanding on different preservation states.

A suite of methodologies has been used including literature study, new data collecting fieldwork and a data analysis at a series of scales. The literature study was grouped into macro, meso and micro scales. On macro level the Holocene geological development, past human interaction and their consequences and leftovers within the landscape have been researched for the Zuiderzee area as a whole. Meso scale mostly concerned literature review of three specific regions: the Noordoostpolder area (between Schokland and Kuinre), the southwestern Zuiderzee area (between Amsterdam and Hoorn, including 'Gouwzee' and 'Hoornse Hop') and the Northwestern Zuiderzee area (between Noord-Holland and Friesland (Zuiderzee-Vlie connection)). Micro scale specific sites (3 sub-cases) have been chosen for further thorough research, analyses and comparison of different preservation states of drowned landscapes. Sub-case sites were: Kuinderbos in the Noordoostpolder, and Uitdam and Etersheim in the Southwestern Zuiderzee. Fieldwork has been performed using a coring transect perpendicular to the former Zuiderzee coast within the Kuinderbos. Data obtained from fieldwork consists of 93 individual corings that have been combined into soil profiles of different scales. Data analysis comprised several phases; the first phase is analyses of existing data with fieldwork coring data. The second phase of data analysis was to compare available information of three-case study areas together to determine differences in variables and process that led to different preservation states.

Analysis of fieldwork data led to a zonation of different preservation states of drowned landscapes within the Kuinderbos, revealing a stepped decrease of preservation in seaward direction. This zonation was then plotted on LiDAR imagery (AHN3) of the reclaimed polder to relate them to visible morphology. Locations with poor preservation states had a lower surface elevation which was caused by erosion after drowning from the Middle Ages onward. This led to the understanding that erosion depth, distance to shore and depth of drowned landscape are the main drivers for preservation states of drowned Medieval landscapes. Comparison of this correlation with other sub-case studies verified the relation between these three variables. A first try in quantification led to the distance of roughly 1.2 to 2.2 kilometres in which preservation of Medieval landscapes decreases over distance until it is fully diminished. This correlation helps with further understanding of drowned landscapes and to connect landscape preservation to processes and variables in the past and vice versa. It could also help in gaining a further understanding of prospective drowned landscapes.

1 Introduction

1.1 Topic and Research objective

xWithin the Zuiderzee drowned landscapes are present that differ in state of preservation owing to processes that varied temporal and regional. This research is about these different preservation states of drowned landscapes around the Zuiderzee and the variables and processes that led to different preservation states. To attribute all the different preservation states of landscapes to dynamics of the Zuiderzee would rule out any existing connections between the similarities and differences in preservation states. Some of these examples are: (geo)morphology, long-term geological processes and human interactions with these landscapes. Creating connections between preservation states of drowned landscapes in the Zuiderzee allows for a better understanding of underlying variables and processes.

Peatland reclamations started from the Middle Ages (450-1500) onwards around the Zuiderzee region, at first in small scale around the 8th century CE and large scale beginning from the 10th century CE (De Bont, 2008; Barends *et al.,* 2010; Borger & Kluiving, 2017). When these land reclamations began, the waterbody within the Zuiderzee area was still called Aelmere and later 'Almere' and had a freshwater environment. Onwards in time salinity and other marine influences began to slowly increase, with large storm events as a catalyst to this change. Due to an increase in influence of the sea (increase in erosivity) and influences of human activity (compaction and oxidation) susceptibility to landscape drowning increased which led to large scale erosion during the 11th and 12th century in which the Aelmere began to become a sea, the Zuiderzee (Van Popta, 2020, p.63). Large-scale erosion continued until the 17th century CE in which the sea coast began to stabilize (Van Popta, 2020, p.64) and changed from regional to local land loss. Land loss, erosion and human impact through compaction and oxidation of peat are already investigated quite well (e.g., Hoeksema, 2007; De Bont, 2008; Van Popta 2020). However, a link with this information to current preservation states of these drowned landscapes is still missing. An example of this is the lack of knowledge on cause of depth of drowned sub-case study areas in comparison to still dry land located next to these drowned landscapes (Pollé, 2019).

Land loss in the Zuiderzee region was not exclusive to medieval times: erosion also affected Mesolithic, Neolithic and Bronze Age landscapes (e.g., Ten Anscher, 2012; Waldus *et al.,* 2019) which drowned and preserved due to marked sea-level rise. In this thesis, such earlier drowning is considered part of the geological background. It is used to compare the degree of preservation of medieval landscape against, but not studied specifically.

1.1.1 What is a drowned landscape?

It is important to clearly define the term drowned landscape as used in this thesis early on. The term drowned landscape at first reading may suggests that it is an intact landscape found beneath water. However, in context of the Zuiderzee history the term is often used for former landscapes, that may have fully disappeared when it was replaced by open water. In such a view even fully eroded and vanished land still counts as being a drowned landscape. Differentiation between non-preserved and preserved parts of drowned landscapes between lost land surface and sunk land surface, and between eroded land and submerged land, is important to describe drowned landscape situations properly and to formulate and answer specific research questions. A further differentiation has been made for preserved landscapes. Differentiation has been made as the current preservation term used in archaeology states, that there has to be an *in-situ* context of the landscape or archaeological site to call it preserved.

Within the Zuiderzee region preservation is oftentimes without *in situ* context although that does not mean that no preservation exists. To fully gain an understanding on differences in preservation states, a differentiation between primary and secondary preservation has been made. Primary preservation, is preservation of a landscape with intact *in situ* context such as dikes, intact soil layers and remnants of houses. Secondary preservation, is preservation in which *in-situ* context is missing although remnants of the landscape allow reconstruction of the *in-situ* context. Examples of secondary preservation are archaeological finds present in erosive channels and compacted peat layers or eroded compact peat that might indicate the location of an eroded dike.

Reference water level
A further matter to consider in definitions, is the reference water level as it is a measure to quantify whether a landscape surface has drowned and sunk, or was calved and eroded. In tidal contexts, a preserved landscape is drowned when it is underwater during mean high-water level. Once land floods daily, human land use becomes very ephemeral. Land will be (mostly) abandoned causing it to be a drowned landscape with limited human interaction and disturbances to alter its preservation state. In the Zuiderzee, during mean low or mean water levels such a landscape could still be (partly) visible due to low tidal ranges of just 8 cm near Lemmer and only 55 cm near Enkhuizen at full and new moon (Gleuns, 1866, p.11).

1.2 Research questions

Research questions were formulated to differentiate between different aspects of different preservation states of drowned landscapes within the Zuiderzee. Where the main research question was split into subquestions and afterwards differentiated between scales. This offers better insight into different topics that form the main research question.

Main research question

What influences the preservation of drowned landscapes in the former Zuiderzee?

Macro, whole research area

1. What caused drowned landscapes surfaces to preserve within the Zuiderzee?
   - 1.1. Does preservation differ regionally and temporally?
   - 1.2. Does preservation have a common cause between regions and time periods?
   - 1.3. Did the mode of human land use (prior to drowning) affect the preservation of the drowned landscapes surfaces?
   - 1.4. Does the preservation of drowned Medieval landscape surfaces differ from the drowned landscape subsurface?

Meso, case study areas

2. Which variables are relevant to characterise a higher susceptibility to drowning of a landscape within the Zuiderzee?
   - 2.1. Does the drowning susceptibility change over time?
   - 2.2. Did human activity change the height of the landscape surface which increased drowning susceptibility?
3. Which variables are relevant to characterise degree of subsidence (vertical lowering) of drowned landscapes (former surfaces) in the Zuiderzee?
4. Which variables are relevant to characterise degree of degradation of alteration of former surfaces in drowned landscapes in the Zuiderzee?

Micro, sub-case study areas

5. What type of landscapes are drowned in the different sub-case study areas?
6. What is the thickness and composition of the Holocene sequence below drowned surfaces?
   - 6.1. Is there a relationship between the age of a landscape and the onset of drowning?
7. What is the preservation of landscapes in the sub-case study areas?
   - 7.1. Which variables are relevant to characterise a degree of degradation due to reclamation on drowned landscapes in the sub-case study areas?

2 Approach and Method

In this thesis different approaches and methods were used. The research exists mainly of a literature study complemented by fieldwork and a data analysis. Different approaches and methods are used at different scales and differs in information sources that are used.

2.1 Literature study

Most of this research was done using literature in Macro, Meso and Micro scales. At each different scale appropriate information sources were used. At macro scale literature was used to give a broad explanation of the research area. Micro scale information sources that were used mostly exists of earth scientific and archaeological fieldwork and reports resulting from implementation of the Valetta 1992 agreement in the Netherlands ('Malta' practice).

During literature study, literature was reviewed in Macro, Meso and Micro order. After completion of fieldwork and data analysis, literature was reviewed in Micro, Meso and Macro order. At the first approach a top-down view was created while at the second approach new insights at small scale were compared with existing knowledge at broader scales.

Macro

At macro level, information sources were used that give a broad overview of the topic and the research area as a whole. Examples are: Schilstra (1974); De Bont (2008); Barends *et al.* (2010); Vos (2015). Information that was used at this scale for writing of this master's thesis varies from the global Holocene geological developments to past human interaction, their consequences and leftovers in the current landscapes.

Meso

Local and regional studies were used to gain further insights in specific areas of the Zuiderzee, notably the case study areas (Figure 1). The Noordoostpolder, Southwestern Zuiderzee and Northwestern Zuiderzee were chosen for their different positions within the Zuiderzee. Different locations also represent differences in development through time and their differences in preservation states. Meso scale literature mainly includes regional research that combines local data into its regional perspective. Examples of these literature sources are: De Bont (2008); Ten Anscher (2012); Bartels (2014); Van Popta (2020).

Micro

At micro scale, information sources are used for local differences that are visible in the sub-case study areas. Sub-case study areas are specific areas within the Noordoostpolder ('Kuinderbos') and the southwestern Zuiderzee ('Uitdam' and 'Etersheim') – (Figure 1). Especially for Kuinderbos and Uitdam enough data exists to allow for geographical inter-comparison. The third meso-region, between Noord-Holland and Friesland, has no sub-case study areas as no demonstrated sites documented in sufficient detail were available here.

Regarding the three sub-case study areas, the Kuinderbos, Etersheim and Uitdam, most literature used for these research areas consists of archaeological research and archaeological reports. The literature used forms the basis for the following comparison: the differences and similarities of preservation between the different sub-case study areas. Examples of these literature sources are: Waldus (2010a, 2010b); Van Popta (2017, 2019, 2020); Pollé (2019).

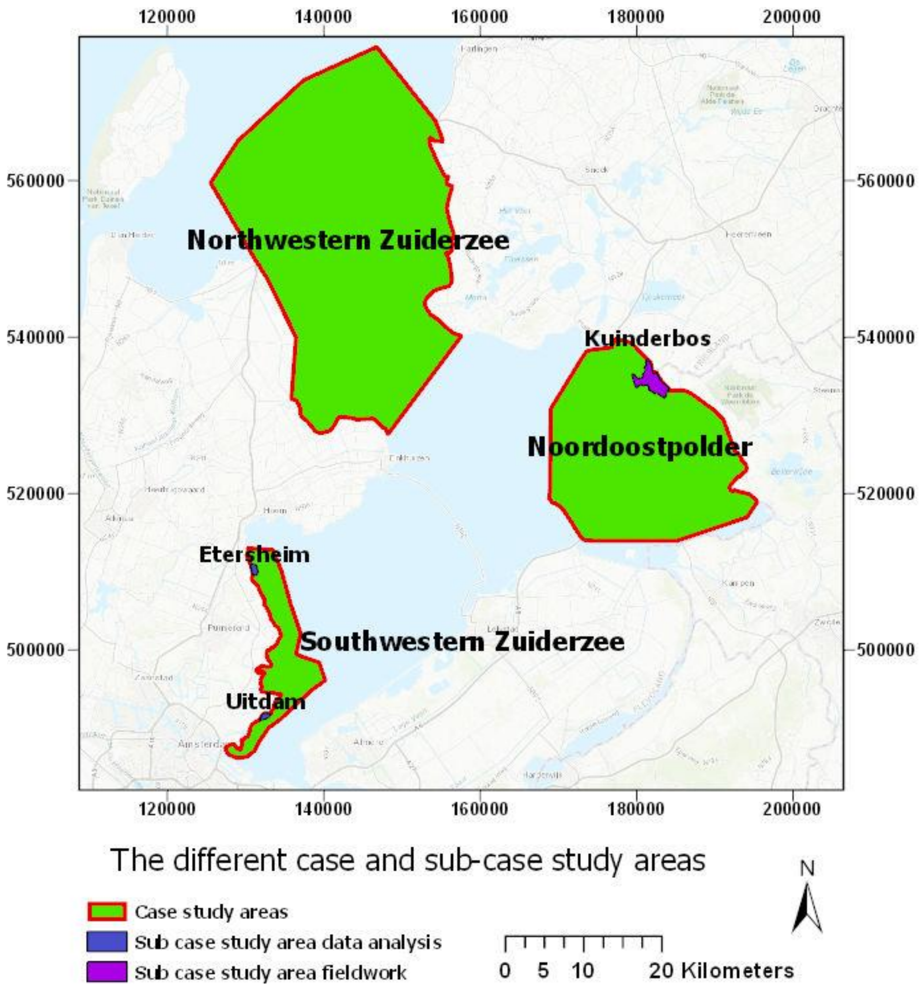

Figure 1: Different case and sub-case study areas within the thesis.

2.2 Fieldwork

Fieldwork was performed in one coring transect perpendicular to the former coast into the former sea, thus also perpendicular to the different landscapes. The dataset comprised of 93 individual corings contains data of the Holocene and a small part of the Pleistocene sequence of this area. Along the coring transect three different enclosed coring grids were placed to explain observed morphological features. After fieldwork all corings were analysed as one profile and also as several smaller profiles to explain observed morphological phenomenon. Data from the corings was then combined with visible morphology obtained by observing LIDAR imagery (AHN 3) to produce a map of different preservation zones. This map of preservation zones based on visible morphology allows for a better comparison between different sub-case study areas. Local differences between these sub-case study areas will then become more visible. Fieldwork methodologies and results are written down in the Appendix, the most promising fieldwork results are presented within the results of the thesis.

2.3 Data analysis

Data analysis was used during the sub-case study of the Kuinderbos and inter-comparison of these results with other (sub-)case study areas. Data analysis is comprised of two separate phases of which the first is an analysis between existing data of the Kuinderbos and fieldwork data, which was acquired during fieldwork of this research. The first phase analysis is mainly located at the end of the Appendix of which the main results are located in chapter '5.2.1 Kuinderbos'. The second phase is a comparison of the results from the analysis with other sub-case study areas. Results of the second phase data analysis are located in sub-case areas chapters 5.2.1 to 5.2.3.

Data analysis first phase (existing data and fieldwork Kuinderbos)

In the first phase of data analysis, fieldwork data and its profiles were analysed together with lidar images (AHN) and datasets of Van Popta (2017) and the soil map of Wiggers (1955). Similarities and differences between these data sets were then used to further specify preservation zones within the Kuinderbos. Moreover, these datasets were also used to extrapolate preservation zones onto the whole Kuinderbos using visible morphology.

Data analysis second phase (cross-comparison three sub-cases)

Within the second phase of the data analysis results of sub-case studies were made comparable, if possible, with available data. Within this comparison different preservation zones of the sub-case study area were estimated. These preservation zones show a relation between preservation of drowned landscapes, distance to shore, depth of a landscape and depth of erosion.

The preservation zones, morphology and possible structures were analysed and compared between the different sub-case study areas. Comparison of morphology and structures is based on shape, width, height, length of individual elements and position of these elements within the different preservation zones. The results led to local and regional differences and similarities in processes that led to drowning and (non)preservation of drowned landscapes. This approach is also used as a tool to improve the amount of information gathered from literature on preservation states of drowned landscapes. These results only hold for the edges of the Zuiderzee as available information sources had almost no information regarding landscape preservation further within the Zuiderzee.

3 General development of the Zuiderzee in the youngest millennia

3.1 Geological Setting

The Zuiderzee was a former inland sea located in the Netherlands, figure 2. The Zuiderzee existed until 1932, when a dam separated it from the Wadden Sea and transformed it into a lake. People living in the Zuiderzee area were depending on the dynamic environment, but the Zuiderzee also threatened livelihood of these people. This can be observed through the shifting of towns more land inward (Van Popta, 2017, p.12) and large-scale erosion that has happened along shores of the Zuiderzee (Hoeksema, 2007, p.116; Van Popta *et al*., 2020, p.45-48).

A large part of the Netherlands is a sedimentary basin in which long-term subsidence occurs caused by tectonic movement. Other factors such as sediment loading, compaction of deep earth layers and isostatic movements cause subsidence in which the delta of the Netherlands and thus also the Zuiderzee could form (e.g., van Balen *et al*., 2005; Vos, 2015; Stouthamer, Cohen & Hoek, 2015).

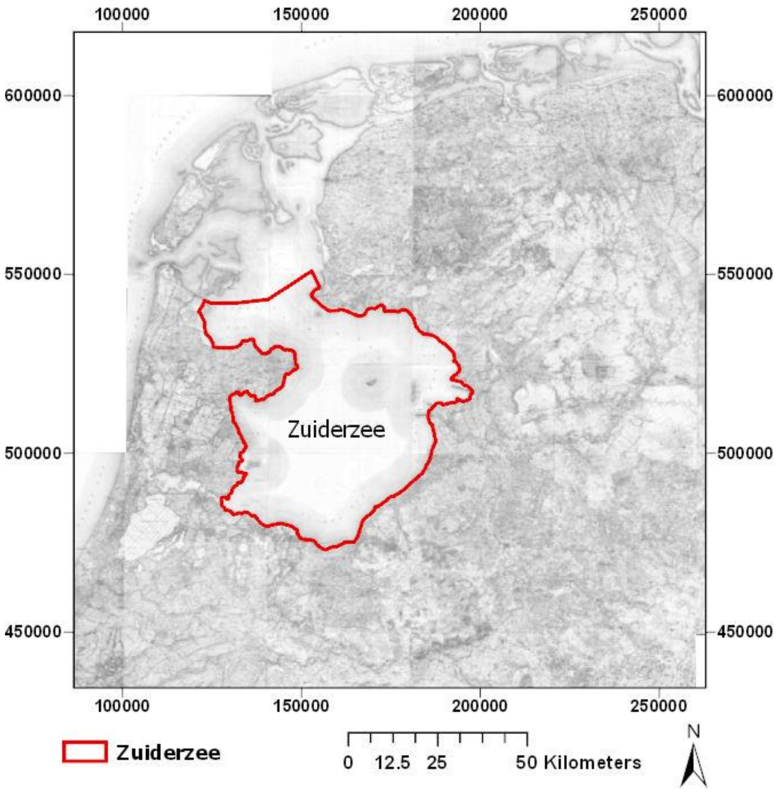

Figure 2: The Zuiderzee region highlighted on a topographic military map of 1850.

3.1.1 Holocene

Prehistoric time periods

At the onset of the Holocene (11,700 years ago) relative sea level rise accelerated due to increased glacier melting, collapse of the forebulge and the resulting glacio-isostatic movement. A forebulge is an uplifted area in front of a depressed area caused by loading of lithosphere by for example large icesheets. Rapid relative sea level rise led to fast transgression of the shoreline (Vermeersen *et al.*, 2018). During this period the North Sea was expanding land inwards causing formation of lagoon sediments in large parts of the Zuiderzee. Reconstructions of Vos (2015) show between 5500 BCE (figure 3) and 3850 (figure 4) a beginning of shoreline stabilisation after a fast transgression period. Relative sea-level rise was greatly reduced due to complete melting of the Laurentide ice sheet (Clark *et al.*, 2012).

Figure 3: Reconstruction of the NW part of Netherlands around 5500 BCE (Vos, 2015).

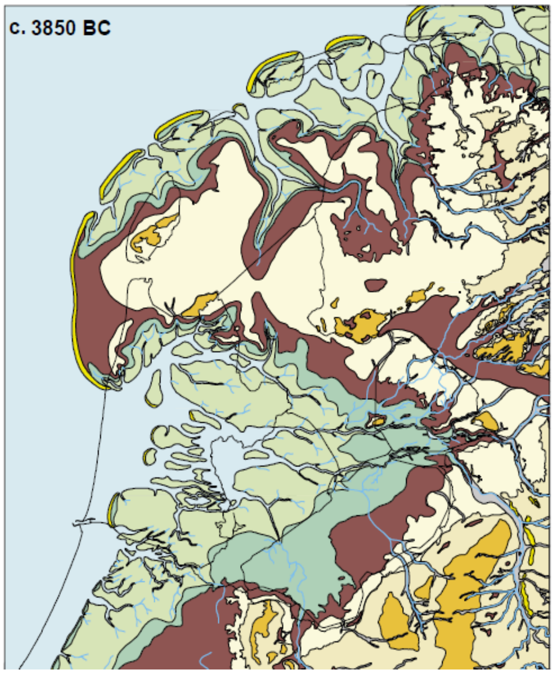

Figure 4: Reconstruction of the NW part of the Netherlands around 3850 BCE (Vos, 2015).

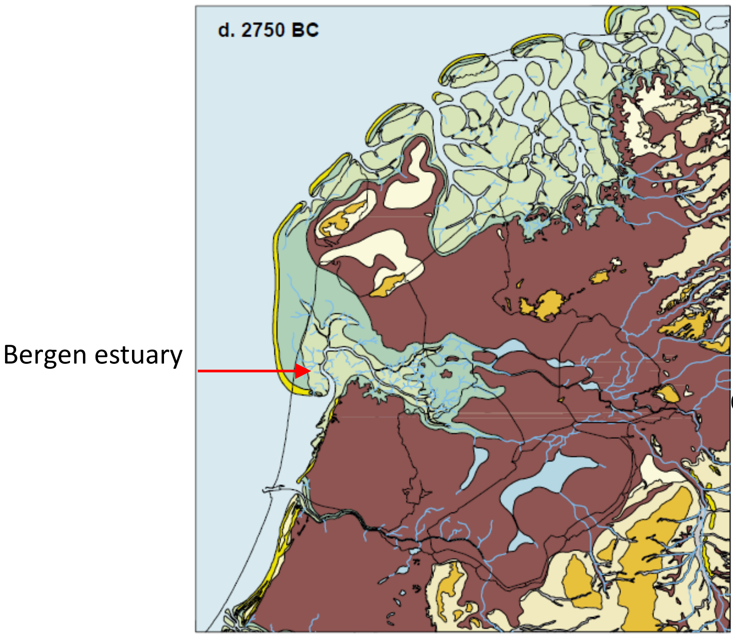

Figure 5: Reconstruction of the NW part of Netherlands around 2750 BCE (Vos, 2015).

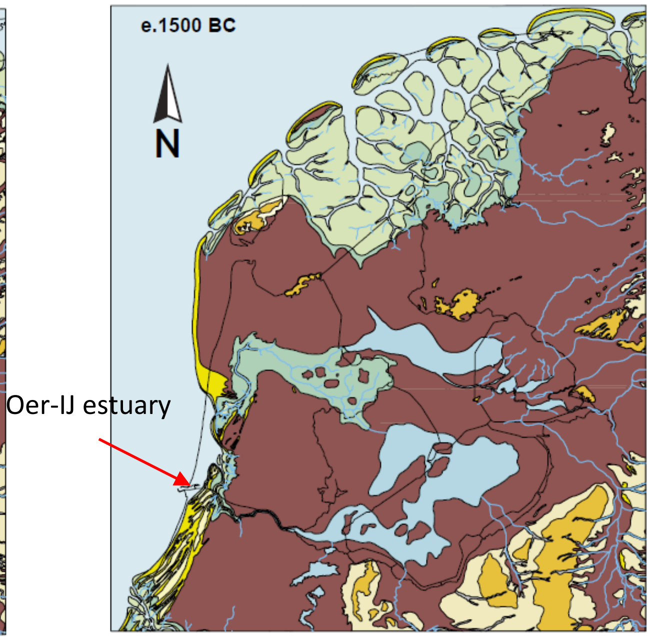

Figure 6: Reconstruction of the NW part of Netherlands around 1500 BCE (Vos, 2015).

After 4000 BCE, relative sea level rise slows down (Van De Plassche *et al.,* 2005, p.89; Vermeersen *et al.,* 2018) which resulted in a slowing down of transgression that turns into regression in reconstructions of 2750 BCE onwards (Vos, 2015, p.83). From 2750 BCE (figure 5) onwards large areas of the Zuiderzee began to be covered with peat together with development of the first lakes within the Zuiderzee (Vos, 2015, p.62). Large parts of the Zuiderzee drained during this time period at the Bergen estuary. Peat growth in the Zuiderzee area continued from 2750 BCE to 1500 BCE (figure 6). During this time period the Bergen estuary began to close which led to a decrease in drainage of the Zuiderzee area into the Bergen estuary. During closure of the Bergen estuary another estuary, the Oer-IJ estuary began to drain the Zuiderzee area. It is assumed that the lakes within the Zuiderzee area gradually increased in size in this time period. In the southern part of the Zuiderzee large lakes already began to connect due to wave action driven lake side erosion. Between 1500 BCE and 500 BCE (figure 7) the lakes (Flevo lakes) increased further in size due to wave action. The Bergen estuary closed off at this time, which meant more fresh water was held up in coastal plains, stimulating peat growth. Such peats began to encroach inland tidal sediments of the former Bergen estuary. Due to formation of mesotrophic and oligotrophic peat small peat rivers began to form. However, Vos (2015) also notes that formation of these peat rivers is generally not known on local or regional level, thus a simplification of these brook systems was made (Vos, 2015, p.63). Around 500 BCE the northern lake formed a connection with the Wadden Sea allowing discharge into the Wadden Sea. This is explained by the fact that closure of the Bergen estuary in the Iron age led to no discharge to sea. The southern lake however still drained through the Oer-IJ estuary.

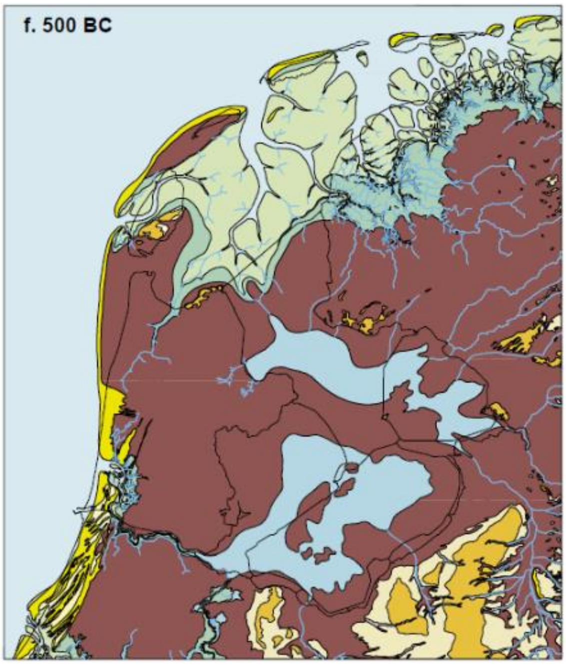

Figure 7: Reconstruction of the NW part of Netherlands around 500 BCE (Vos, 2015).

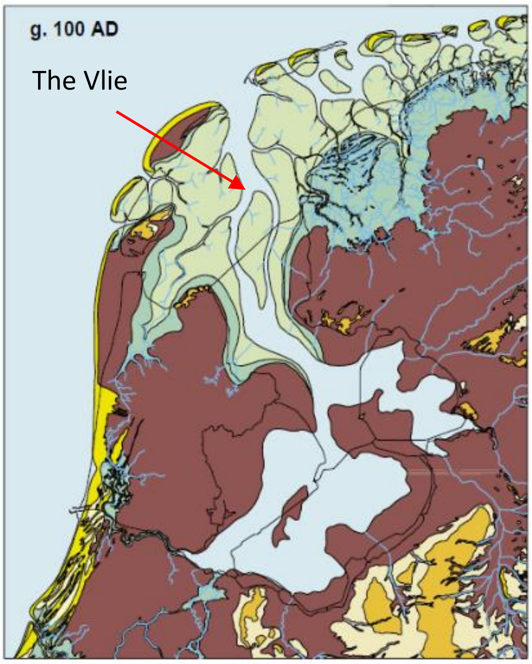

Figure 8: Reconstruction of the NW part of Netherlands around 100 CE (Vos, 2015).

Iron Age and Roman period

Between 500 BCE and 100 CE the Oer-IJ estuary lost its discharge function which led to silting up of the tidal area. (Vos 2015, p.VII). Around the same time a connection between the Northern and Southern lakes began to exist, this lake is also called lake Flevo. This connection caused possible discharge into sea for the whole Zuiderzee area. Closing of the Oer-IJ would stop almost all discharge of lake Flevo to sea. However, closure of the Oer-IJ estuary is linked to discharge of the lake to the North Sea through the Vlie. One theory about this is that water levels within the lake continuously rose and eventually broke through to connect with the Vlie (Vos 2015, p.65). A connection with the sea would increase salt water intrusion, tidal range and erosion due to storms. Erosion on the sides of this lagoon is still happening.

Roman Period and early Middle Ages

Between 100 (figure 8) and 800 CE (figure 9) an opening through the Vlie began to develop even more. Development of the Vlie would means that influence of the North Sea through tide, salt water intrusion and erosion would increase in the lagoon. Although the increase in influence of the North Sea was still relatively small. This can be explained by the name of 'Aelmere', which is a reference to stagnant water (Borger & Kluiving, 2017, p.37). Large scale peat growth is indicated by developing natural drainage systems in peatlands surrounding the Zuiderzee region. In the eastern part of the lagoon the Gelderse IJssel began to increase its influence which is indicated by presence of clay deposits. Around 800 CE first peat reclamations in and near the Zuiderzee region took place (e.g., Barends *et al*., 2010, p.64).

Middle Ages

Between 800 and 1500 CE (figure 10) water inlets within the Wadden Sea began to change. Where in the past it was mainly the Vlie tidal inlet, now a second main tidal inlet came into existence: the Marsdiep. From the 14th and 15th century onwards the Marsdiep began to develop into a major inlet system (Vos, 2015, p.66). Development of the Marsdiep caused the Vlie inlet to decrease in size and also in importance regarding to the Zuiderzee. During this development most of the land loss was still occurring in surrounding peat lands. At this moment in time the Gelderse IJssel began to develop a delta. Many peatlands were reclaimed during this time period for agricultural use. Inland more peat was dredged which created large lakes. These lakes expanded due to erosion of the lake sides which would later on threaten water safety. Around the 12th century CE and onward large-scale erosion took place within the Zuiderzee region. The Aelmere lake gradually changed into a sea over time and was called the Zuiderzee after the All Saints Flood ('*Allerheiligenvloed*') in approximately 1170 CE (Van Popta 2020, p.63).

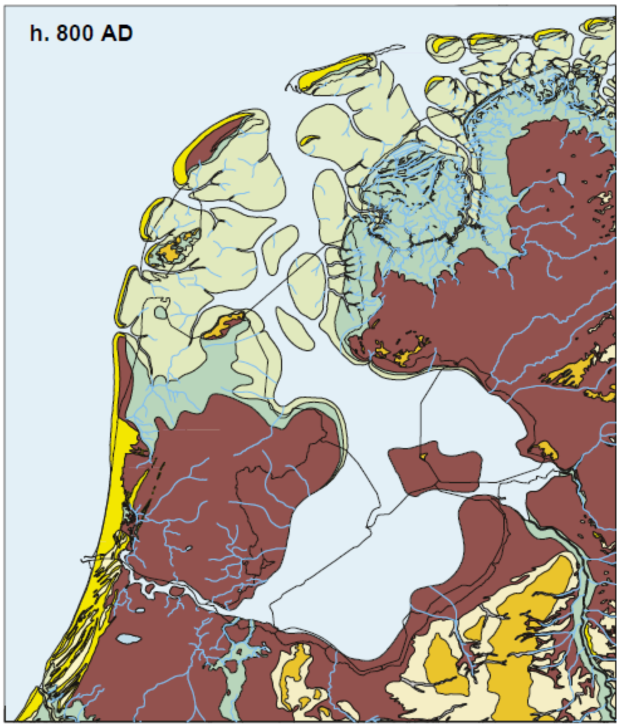

Figure 9: Reconstruction of the NW part of Netherlands around 800 CE (Vos, 2015).

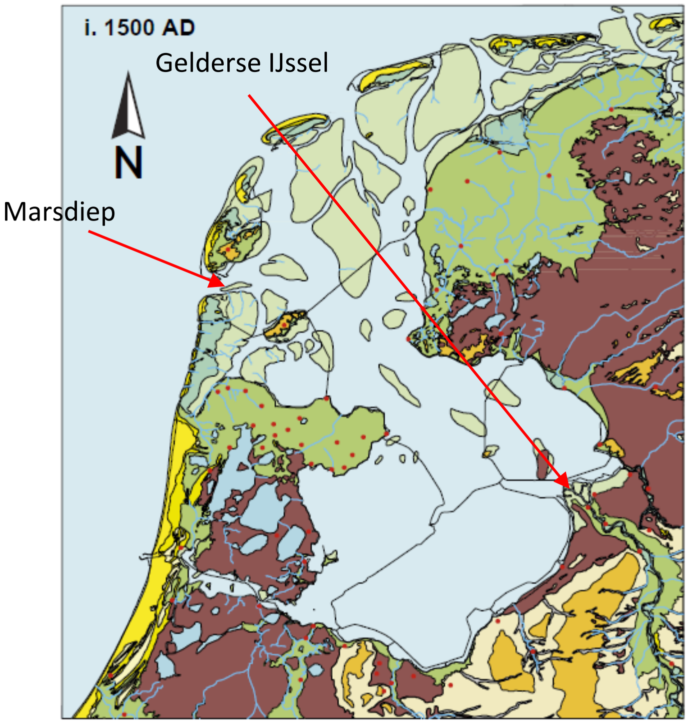

Figure 10: Reconstruction of the NW part of Netherlands around 1500 CE (Vos, 2015).

Early Modern and Late Modern periods

Between 1500 and 1850 CE (figure 11) land loss was mostly controlled by building of embankments around the Zuiderzee. Apart from building embankments, land was also reclaimed from inland lakes, small areas in the Zuiderzee and some parts of the Wadden Sea (Haagsma, 2015).

Between 1850 and 2000 CE (figure 12) large human interventions took place in the Zuiderzee. Due to the large embankment length needed to protect the Zuiderzee area from flooding, it was decided to build the Afsluitdijk ('closure dam') and was finished in 1932. Building of the Afsluitdijk reduced the, amount of sea worthy dikes needed to protect inland areas, reduced maintenance costs of the total sea defences and increased water safety for the whole Zuiderzee area. After building of the Afsluitdijk large polders were made, examples are: the Wieringermeerpolder, Noordoostpolder and the Flevopolders. With building of the Afsluitdijk (and the later Houtribdijk and ring dikes of the new reclaimed polders) influence of the sea through salt water intrusion and tide was completely terminated and threats of erosion very much decreased.

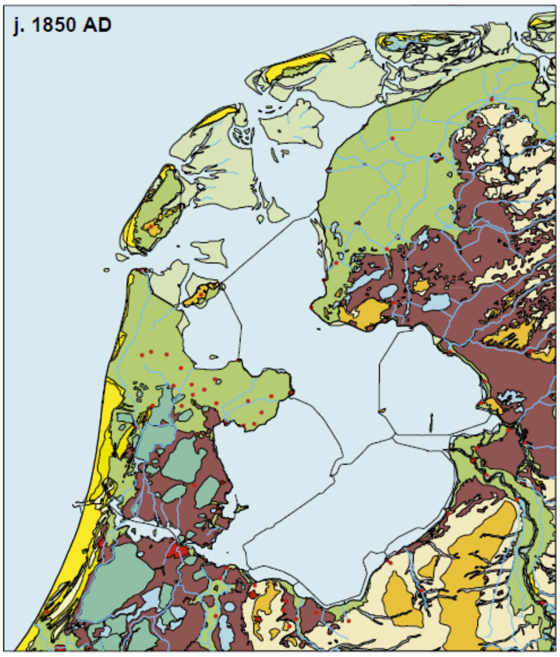

Figure 11: Reconstruction of the upper part of Netherlands around 1850 CE (Vos, 2015).

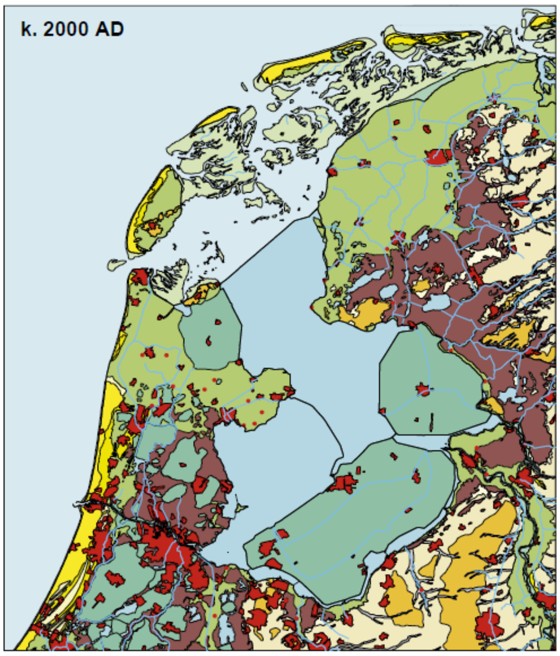

Figure 12: Reconstruction of the upper part of Netherlands around 2000 CE (Vos, 2015).

3.2 Human interactions with the Zuiderzee

From Prehistoric time periods onward, human interaction with the landscape already existed. Although the amount of influence people had on the landscape differs temporally. In this thesis the focus is mainly on the Middle Ages and later time periods because most changes to the Zuiderzee region happened in this period. It is however necessary to gain a global understanding of influence of humans on landscapes prior of the Middle Ages, because interactions of humans and the landscape already shaped the landscape which was found and utilized during large peat reclamations.

3.2.1 impact of human actions over time

Temporal changes of human induced variables and processes are mostly caused: by the timescale of a process, socio-economic value of a landscape, technological improvements and changing landscape uses. Temporal changes of these variables will be separated into archaeological time periods used in the Netherlands.

Prehistory

The time periods Palaeolithic, Mesolithic, Neolithic as well as the Bronze age and Iron age are combined together. This has been done because of: the different preserved drowned/buried landscape and the relative low influence of human activity on drowning, burial and preservation of drowned landscapes. In Prehistoric time periods, creation of drowned buried landscape was mostly characterised by long-term natural process in contrast with the Middle Ages, industrial period and the Modern period (see further in this chapter). This difference is mostly caused by limited impact on environment, low population density, minimal needs and wants, nature-oriented values and environmental knowledge and monitoring (Sponsel, 2001, p.399). Impact of humans on landscapes increases especially from the Neolithic age onward (Ten Anscher, 2012). However, short-term human interactions and their influences are still smaller than long-term processes operating in the Zuiderzee area. Examples are: sea level rise, isostatic movement and neotectonics with timescales of hundreds and thousands of years or more. Processes that operate over hundreds and thousands of years have less influence in time periods such as the Middle Ages (450-1500 CE) in comparison to for example the Neolithic (2000-4900 BCE). Agriculture and peat burning already existed from the Neolithic onwards (Ten Anscher, 2012). However, their regional influence on landscape formation was overruled by long-term natural processes. This causes long-term natural processes to characterise Prehistorical time periods.

A low degree of landscape impact does not mean that there was no impact. Evidence of peat burning near Schokland and Urk shows that in the Bronze age human impact on landscapes already took place. It is however, unclear how large impact of local burning of reed and sedge vegetation on regional drowning processes have been. Furthermore, the scale of burning this vegetation for creation of heather is not clear (Ten Anscher, 2012, p.534). Burning of vegetation might slow down peat growth, but hindered peat growth for a few years is still insignificant to peat growth of hundreds of years after this period of vegetation burning.

Roman time period

In literature not much is known of settlements during the Roman period (15 BCE to 450 CE) in or near the Zuiderzee area. Although human activity took place in for example the Oer-IJ (Borger & Kluiving, 2017, p.42-49) and the coastal area of Friesland (Gerrets, 2010) it is not known to what extend human activity changed landscapes and to what extend they influenced preservation of drowned landscape within the Zuiderzee area. Although the lack of indications of human impact on the landscape and its morphology in the Roman Period it is still expected to have increased compared to earlier time periods. Although the expected increase of impact, natural processes are still expected to be dominant over human processes on a regional scale.

The reason for relatively small human influences on landscapes during the Roman Period can be linked to progressive closing of the Oer-IJ system from 400 BCE onwards (see above; Vos, 2015). As that was the main discharge to sea for the lake system Aelmere. Closing of the Oer-IJ led to a decrease in water discharge that led to raising water levels in the Flevo lakes and thus also raised water levels in the surrounding area of the lakes and rivers feeding the lake. Such wetter conditions may explain apparent reduced human activity in the Zuiderzee region (Borger & Kluiving, 2017).

Middle Ages
In the Middle Ages higher susceptibility for drowning is regarded to mainly be caused by large scale human land reclamations. Although increased Storm activity has also been mentioned to contribute in an increase of land loss (Pierik *et al*., 2017; Van Popta, 2020). Land reclamations were sometimes also accompanied by peat digging. Early indications of peat reclamations are the name '-more' of drowned towns in the western part of the Wadden Sea (De Bont, 2008, p.143-144; Barends *et al.,* 2010, p.64). According to Borger & Kluiving (2017), large reclamations in the Middle Ages could only have happened if water levels in the Aelmere decreased after the increase that happened in the Roman time period. This would create dryer conditions in the Zuiderzee which makes reclamation easier and more productive. Large-scale peat reclamations happened on a regional scale throughout the Zuiderzee region. Due to the regional and drastic nature of the changes such as consolidation and oxidation, human processes and variables would overrule natural processes and variables in terms of influence on the state of preservation of drowned landscapes.

4 Factors influencing landscape drowning and preservation

4.1 Human interactions with the landscape and their variables and processes

Human activity in areas around the former Zuiderzee did alter the height of landscape surfaces (De Bont, 2008). Due to human land use and structures the height of landscapes was altered in such a way that it became lower, or higher (e.g., Wiggers, 1955, p.180; Schilstra, 1974, p.21; De Bont, 2008; Van den Biggelaar, 2014, p.189-190). In general, the trend was that human interaction lowered landscapes.

4.1.1 Peat reclamations

Physical susceptibility factors of peatlands
Fen peat is mostly enriched with nutrients from groundwater and surface water (Van Zijverden & De Moor, 2014, p.77). Peat formed in lower areas is generally speaking flat (De Bont, 2008, p.226) and formed in fresh to brackish water. Fen peat is fed by surface and groundwater which causes it to be flat, when peatlands increase in height the type of peat will change. Height of fen peats is considered between 50 cm to 150 cm above NAP ('*Nieuw Amsterdams Peil*', Dutch ordnance system) and estimated by (Erkens *et al.*, 2016, p.256), when looking at (De Bont, 2008, p.98) a slightly lower estimate can be found. However, De Bont (2008) differentiates three types of peat while Erkens *et al.* (2016) only differentiates between two types of peat which causes a higher estimate into more developed peat of 1 metre above mean sea level. For the sake of this research the maximum height of fen peat will be held at a maximum of 1 metre above mean sea level at the start of peat reclamation. One metre above mean sea level peat develops more height differences which could be of significant importance when looking at past peat landscapes. Within the research area peatlands are mostly evolved into bog peats with fen peat at the borders of the Flevo lakes and Aelmere in a natural situation (Wiggers, 1955; De Bont, 2008). Bog peat is mostly dominant at the sub-case study areas as these areas were situated more inland in more developed peatlands before reclamation.

When peat grows in height it also changes in composition. Peat can only grow when certain plants are present such as *Sphagnum*. These plant species store water which creates a wet environment that forces other plant species out of the area and allows for peatlands to grow into a bog peat. Due to the height growth the water that feeds the peat changes in composition which causes the peat to change in composition.

Differences in physical susceptibility of peat is also caused by distance to the Zuiderzee and height of peat. If a peatland is closer to the erosive environment of the Zuiderzee the more likely it is to be eroded although human intervention in the form of sea defences lowers susceptibility. Susceptibility from in the form of surface elevation is mainly due to height difference from 1 to 2-4 metre between fen peat, transitional peat and bog peat. Over time, drowning susceptibility of transitional and bog peat increases faster than fen peat. This increase in susceptibility can be explained by differences in composition which are mainly caused by the composition of water that feeds the corresponding peatlands. Groundwater that feeds fen peat is richer in minerals then rain water that feeds transitional and bog peat. Moreover, fen peat in and around the Aelmere (Zuiderzee region) is located at low lying areas where nutrients and sediments from the lake/lagoon could increase mineral component of fen peats. Transitional and bog peat are partly to completely fed by rainwater which causes these peat types to have a significant smaller amount of clastic material in comparison with fen peat.

Methods of reclamation

Early peat reclamation can be dated back to 800 BCE in the North of the Netherlands (Barends *et al*., 2010, p.64). The earliest historical evidence of peat reclamation is around the 8th century CE near Texel in the Western part of the Wadden Sea (De Bont, 2008, p.43; Barends *et al*., 2010, p.64;). Between the 10th and the 14th century peat reclamations became more widespread and the scale increased in which land was reclaimed (Barends *et al*., 2010, p.65-66).

At the beginning of reclamation, ditches were dug mostly perpendicular to natural peat rivers, to drain topsoil peat which allowed agricultural practices. After water drainage the soil was dry enough to sustain loading of either farm animals or heavy agricultural tools. However, waterlogged conditions within the peat changed into oxidation conditions that causes organic material in peat to react with oxygen within the pores resulting in peat oxidation. Drainage induced lowering of the groundwater table caused subsoil peat to consolidate due to removal of water pressure. Causing topsoil peat to oxidise due to aerobic conditions leading to overall vertical shrinkage of peat volume and dropped surface elevations (Erkens *et al.,* 2016, p.559). Peat shrinkage process is largely irreversible and causes permanent land subsidence (Locher & Bakker, 1987, p.254). After subsidence, waterlogged conditions will return and renewed drainage measures have to be taken to continue agricultural land use. Such measures can include deepening of ditches, (peat) rivers and/or to extend ditches further into new peat areas (De Bont, 2008; Barends *et al.*, 2010, p.66).

Natural height differences between fen peat and more developed peatlands had to be considered when reclaiming these lands. In relief rich peat, reclamations began at the flanks of the peat bog causing collapse and increasingly wet conditions. Resulting in reclamation of areas further into the bog. When reclamation of a peat bog was finished, relief in the peat was completely diminished due to compaction caused by water removal and oxidation of peat (De Bont, 2014). When the agricultural landscape was flat oxidation did not stop. To keep land dry enough the groundwater level is lowered which starts the process of compaction and oxidation again. In this case it is a negative feedback cycle which continuous until all peat is oxidised and the top layer of the ground is consolidated. Flood risk in such a landscape will only continue to rise while land is sinking due to land use.

4.1.2 Mining peat as fuel stock

Mining peat for fuel purposes has been done large scale and on small scale in and around the Zuiderzee area (Barends *et al*., 2010). Large- and small-scale mining of peat influences drowning susceptibility of landscapes. Moreover, it is also the intensity and method used that depicts how much influence peat mining has on drowning susceptibility of a landscape. Small-scale peat digging is associated with the need of fuel of one or few households. Such peat demands can be fulfilled with relatively small amounts of peat as can be seen on figure 13. Peat diggings (at least 3 in figure 13) have been found on a drowned meadow near Urk (Wiggers, 1955, p.180). These holes are 2 to 4 metre long and 1 to 2 metre in width. Small peat digging causes mostly small holes within the landscape.

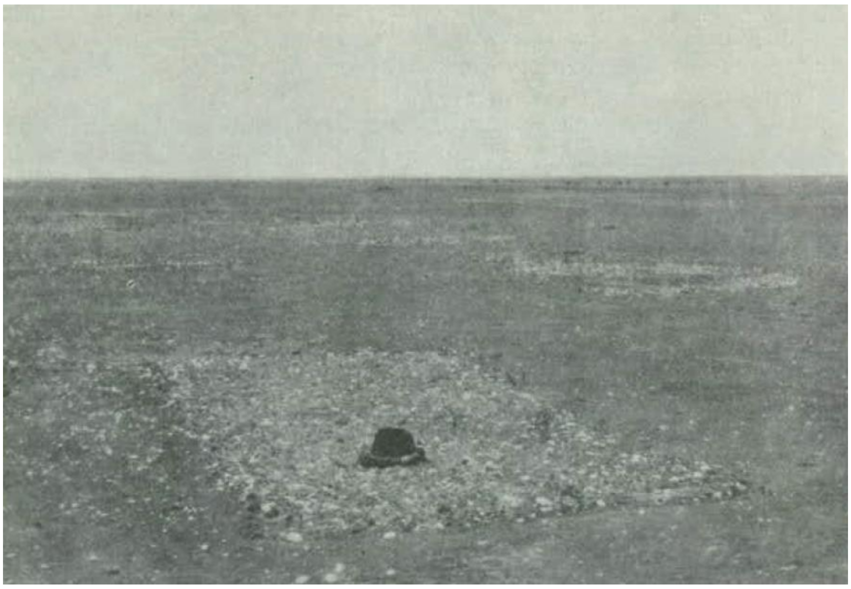

Figure 13: In the foreground a rectangular hole is visible which had been dug for peat mining (Wiggers, 1955, p.180).

Large scale peat digging

Figure 14 shows the result of large-scale peat digging for fuel. Most of the peat was first used for agriculture, however due to compaction and oxidation these grounds became too wet for agriculture. Sometimes a peatland was reclaimed and peat was dug out for fuel from the beginning. When a peatland became to wet the only other use of this land was to dig up remaining peat to sell it as fuel. This development was strengthened by an increasing fuel demand in the Western part of the Netherlands (Barends *et al.,* 2010, p.84). Increasing fuel demands led to an increasing scale in which peat was dug for fuel. After large-scale peat digging without dredge bracket (‘*baggerbeugel’*) water would remain in the middle of an agricultural land with small pieces of land at the sides still existing. Since the 15th century CE, the dredge bracket made it possible to dredge remaining peat out of shallow waters (Barends *et al*., 2010, p.81). During storm events remaining land between different peat diggings eroded which resulted in a large lake, figure 14 gives a clear indication of this erosion. These lakes were originally situated far from the Zuiderzee coast. Erosion resulted in a decrease of land between the Zuiderzee and these lakes which made the lake shore more susceptible for erosion. This led to increased damages caused by flooding near the lakes in storm events. Beulake is an example of a town that drowned due to erosion from storm events after a dike breach in such a lake (Stokvis, 2020).

Figure 14: An example of large-scale peat digging in the Weerribben-Wieden as visible on Google Earth. On the western side of the lake is the island on which Beulake Is situated. At the borders of the lake the abrupt end of agricultural land clearly shows the result of erosion caused by wind generated waves.

Decrease in susceptibility to drowning

In areas around the former Zuiderzee such as Uitdam, Schokland and Kampen it is known that human occupation and land use was associated with clay deposition on top of peats (e.g., Van den Biggelaar *et al*., 2014, p.189-190). De Bont (2008) presents 3 different peat models of which the clay on peat model represents the situation that occurred within the Zuiderzee. Due to land reclamations for agriculture, peat began to compact and oxidise. Subsidence would have led to an increasing influence of the Zuiderzee on these agricultural areas. Increasing sea influence results in a layer of clay on top of peat. To prevent further flooding, damage and possible loss of land, dikes were constructed. Around the Zuiderzee two types of dikes can be recognised.

1) A dike that floods over every winter, clay is deposited every year.
2) A dike that keeps land dry the whole year; clay is only deposited during breaches.

The amount of clay that could be trapped differs in space. In Biggelaar *et al.* (2014) it is shown that on the island of Schokland the thickness of clay layers differs in thickness between thicker layers in the south of approximately 3.2 metres and thinner layers in the north of approximately 1.9 metre. Distance to the coast and distance to the IJssel estuary are probably the most prominent causes of this difference in thickness. Stouthamer, Cohen & Hoek (2015) also shows that there is another reason for clay on peat that is caused by oxidisation. To further explain this, it is important to know what the composition of peat is defined according to the Dutch NEN-EN-ISO 14688-2:2018 definition as 35% to 100% organic material with a mud percentage of around 0 to 30% (Van Zijverden, 2014, p.184). What has been mapped as peats according to this definition, can be mainly organic material but in most cases also contains a small amount of clastic material. This applies in particular to eutrophic fen peats that formed in vicinity of rivers, brooks and inland parts of tidal creeks. This means that a small amount of clay will remain when all organic material oxidises which could also cause (a part of) a small clay layer on top of peat.

Due to human land use after reclamation on peaty soils the height of the landscape subsided. Dikes were necessary to keep land from drowning. These dikes were small ridges made out of local sediments that in some cases flooded during winter (Van den Biggelaar *et al.,* 2014, p.189-190). Flooding in winter allowed nutrient rich sediments such as clay to enter agricultural areas which ensured high fertility. It also allowed for these landscapes to either drown more slowly or prevent drowning. In Schokland for example a sequence up to 1.7 metre of lagoonal clays was formed atop of earlier clay sediments behind a dike (Van den Biggelaar *et al*., 2014, p.188-189). Although the dike ensured a supply of clay it still only delayed 'drowning' of Schokland from the 17^{th} century CE onward (Van den Biggelaar, 2014). Pierik *et al.* (2017, p. 191) mentions that clastic material deposition on top of peat leads to auto-compaction of peat below it. It also mentions that auto-compaction is related to the amount of peat in the sediment and that auto-compaction has to be overruled by the sediment influx to keep it dry or reclaim it. Due to auto-compaction of peat, sediment loading prevents higher surface level elevation due to clay deposition (Pierik *et al*., 2017) in this case.

4.1.3 The role of sea defence on susceptibility to drowning

In most places in and around the Zuiderzee, dikes were made to reduce susceptibility to drowning. Reduction of susceptibility with the use of dikes changes temporal and spatial. Although a dike protects land behind it, it can also cause more harm in case of a flooding. In a natural flooding sea water would spread out over large areas. Large flood areas cause dissipation of force over a larger area and thus decreases the erosive force. A dike prevents flooding in these areas to protect it with human assets from the sea. This also forces water vertically during a flood instead of horizontally (Vos, 2015, p.87/88). If a dike breaks or is overtopped, all of the stored energy in the water storage area in front of the dike will force its way into the area behind the dike. This water force is large enough to create a lake and dissipates after passing through this dike due to an increasing flooding area.

Functioning of sea defences is also dependent on environmental setting. When impact of a flooding is low,

the need for sea defences will be low. In this case that can be translated as water from the sea on land has to go back to sea without long influence in the form of salinisation and wet conditions. In a natural situation that will often happen around extreme high-water level. Flooding of land will then not occur regularly. This extreme high water, water elevation during maximum storm surge, was often the case during storm events in many areas around the Zuiderzee. Extreme high-water levels in the Zuiderzee region could reach a height of 2 to 5 metres (De Gans & Bernink, 2005, p.124).

Evidence for non-occurrence of flooding is interpreted as the existence of bog peat and transitional peat. If flooding occurred regularly then these peats would evolve into a fen peat because of increasingly nutrient enrichment to the peat. Figure 15 is a schematic reconstruction of the natural environment of the Zuiderzee based on fieldwork data and Vos, (2015, p.32). Within figure 15 the peat sequence is clearly made visible and also shows the high susceptibility to drowning when it is reclaimed.

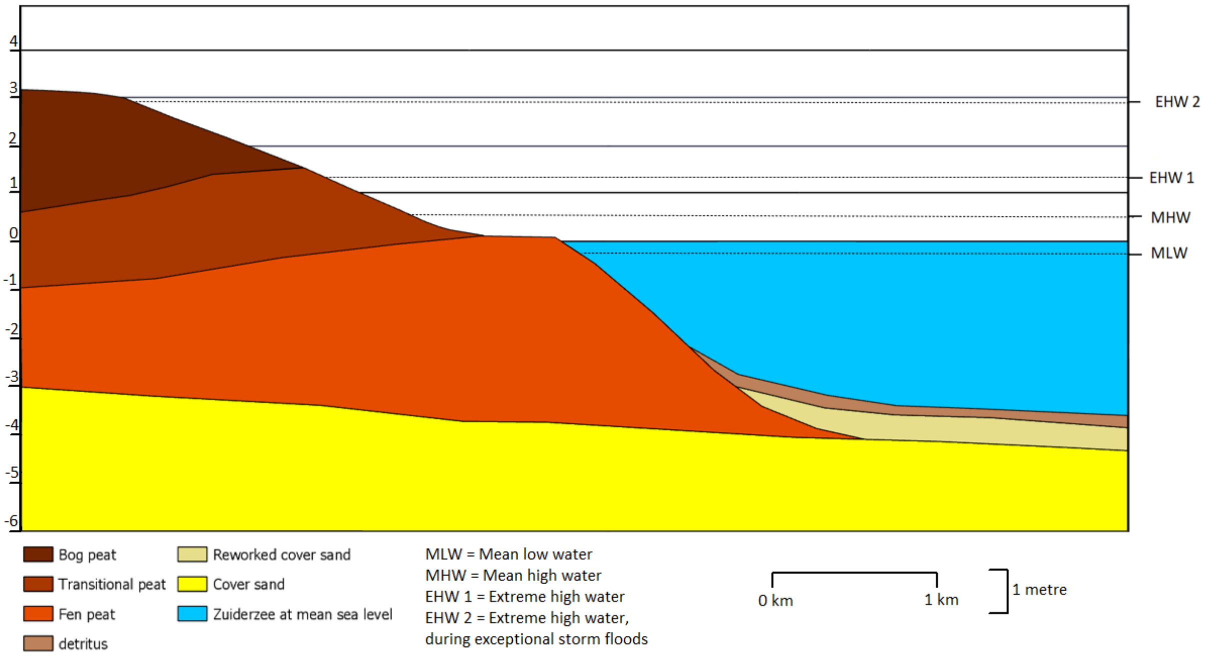

Figure 15: Schematic profile of the Zuiderzee before reclamation based on the Kuinderbos fieldwork data and Vos, (2015, p.32).

Collapsing of peat due to water drainage leads to a lowering land surface which leads to higher frequency of flooding events. In general, a higher frequency of flooding means more damage to human made structure and decreasing productivity of agricultural land. However, there is a certain threshold. Above this threshold humans can adapt to the effects of flooding, below this threshold humans need to prevent flooding to prevent land loss and large amounts of economic damage. Quantifying this threshold is outside of the scope of this thesis but it is important to identify which types of water management belong to a certain point along this threshold. Identifying different types of water management would also bring a more thorough understanding of which variables are important in an increase and decrease in susceptibility to drowning of a landscape around the Zuiderzee.

4.1.4 Adaptation to progressing land subsidence and

Due to subsidence, water drainage gradients became smaller and smaller. This means that water will have less potential gravitational energy which causes smaller flow velocities. Smaller flow velocities cause slower water flow velocities in natural water drainage systems that causing increasingly wet conditions. To adapt to smaller gradients a few steps were taken:

1) Increasing water gradient.
2) Moving to higher areas.
3) Increasing water storage.
4) Changing land use.
5) Draining areas at limited low tide only.

The first thing done in peatland and especially in peat bogs when wet conditions continued, was digging deeper trenches to lower groundwater levels to continue the existing land use type. Eventually the peat bog area becomes as low as surrounding fen peat and the water gradient became almost non-existent (De Bont, 2008, p.205). Decreasing the groundwater level using simple means such as digging deeper trenches is now increasingly hard to even impossible. Increasingly wet conditions force a change in land use type. In most cases agricultural use changes from crop production to livestock farming. Livestock farming is possible in places with a relative higher groundwater level than with crop production. This results in a slowing down of subsidence because smaller amounts of peat are prone to consolidation, shrinkage and oxidation. In case of the low laying peatlands drainage is hindered due to small difference between surface elevation and mean sea level. At high sea level peatlands can often not be drained anymore. A lack of drainage will cause wetter conditions which hinder livestock farming production. To prevent wetter conditions water storage in agricultural areas had to be increased. Oftentimes storage capacity was increased by widening or increasing the number of ditches (De Bont, 2008, p.256). Increased water storage would then mitigate seasonal wetter conditions caused by a lack of drainage (De Bont, 2008; Barends *et al.,* 2010).

When looking back at figure 15 it can be observed that higher peat areas can't drain at sea during extreme sea level during exceptional storms. Over time this will increase high sea water level and even mean sea level or below. Adaptation to flooding is increasingly difficult as water can only be drained at certain intervals between mean water level and high-water level or even only at mean low water level. For this research the boundary between adaptation and prevention will be laid around mean high-water level that is reached during high tide (Vos 2015, p.32). In the Zuiderzee region the tidal range is small ranging between 64 to 8 cm at full and new moon (Gleuns, 1866, p.11). This is caused by a negative resonance effect caused within the Zuiderzee (Vos, 2015, p.42). If no prevention took place, an area could flood daily and thus only adaptation is no longer adequate to prevent flooding. However, in late stages of adaptation prevention of flooding with the use of sea defence already took place. At this time adaptation still happened and prevention of flooding was to prevent non-regular flooding/high water events. End of the adaptation phase can be laid when the whole of the Zuiderzee coast was more or less closed by dikes. Closing of the dikes around the whole Zuiderzee would mean that on a regional scale within the Zuiderzee region flooding events would happen regularly enough to build a dike. Around the Zuiderzee the stage of adaptation ended between 1100 and 1300 CE (TeBrake, 2002, p.487). This estimate has a large temporal difference; however, it shows that the adaptation phase ended probably earlier at early reclaimed places near economic centres (Barends *et al.,* 2010). Places that were farther away from economic centres were reclaimed at a later moment in time and thus caused the adaptation phase to end later. This means that the (South)western Zuiderzee has been reclaimed earlier than areas in the Eastern Zuiderzee (Jongmans *et al.,* 2018, p.565).

4.1.5 Prevention of flooding

The prevention phase against flooding is mainly defined by the need of dikes to block regular flooding. Adaptation to a changing environment is not enough and active protection is needed for further land use to happen. In the Zuiderzee region, beginning of prevention of flooding phase begins when the adaptation phase ends, although they can briefly coexist. The prevention phase goes on until present, which means that it did not stop after completion of the closure dam in 1932, although direct marine flooding threats have been reduced. The need to prevent flooding and protect surrounding areas of the Zuiderzee/IJsselmeer still persists.

When analysing the prevention of flooding phase then the following criteria can be used to measure whether or not the prevention phase already takes place:

1) Dikes are needed to prevent flooding.
2) Building of dams and sluices are needed to block seawater.
3) Water can only be drained with human effort.

Around the Zuiderzee susceptibility to drowning of a landscape cannot be fully explained by processes that lowered or heightened the soil or water level. In some cases, a sea defence in the form of a dike was abandoned to build a new dike further in land (Van Rooijen, 2017). This phenomenon cannot be explained by physical processes but also has to be explained from a more socio-economic point of view. The following factors can be used to differentiate between sea defence around the Zuiderzee regionally and temporally.

1) Technique used,
2) Management of sea defences,
    a. Distribution of costs,
    b. Costs versus available budget.

First indications of primitive dikes within the Zuiderzee were found dating at the twelfth century CE (Middle Ages) (De Bruin & Aten, 2004, p.8). In 1129 CE people began to organize payments and maintenance of the *Omringdijk* (Schilstra, 1974, p.26). In 1250 CE West-Friesland was completely embanked (De Bruin & Aten, 2004, p.6). This regional embankment is probably an indication of the need of embankment of the Zuiderzee from the eleventh/twelfth century onwards. These first dikes were small ridges that could not resist wave action and thus needed land in front to break the waves. This way the dike could prevent flooding of land while having the least amount of risk of eroding.

Erosion of land in front of the dike happened on the short term due to the fact that most of this land was already low lying due to subsidence and by the fact that the surface often consisted of peat. Peat is mostly made out of water and organic material, which means that after erosion most water will be in sea and most or all organic material will be oxidised. Disappearance of peat due to oxidation causes an increase in accommodation space. De Bruin & Aten (2004, p.18) note that in the 16th century CE near Schellinkhout (West-Friesland) a land with the size of 30/40 *morgen* or around 27/36 hectares of land eroded in the timescale of years. An exact number of years are not noted but it is possible that the timescale can be as small as a decade. Erosion of land happened so quickly that even protection by a retaining wall was rendered useless and thus land was given up (De Bruin & Aten, 2004, p.18). Not all drowned land in front of a dike was eroded. Near Uitdam a landscape with a dike was still preserved and after drowning at least partially used as land to break the waves (Pollé, 2019, p.70). The sub-case study of Uitdam will be further specified in chapter 5.2.2 Uitdam. Usage of already subsided land after dike breaching in front of a dike accelerated the drowning process of these landscapes versus a natural situation. Although usage of retaining walls slowed down the rate of drowning processes and subsequent erosion. Changes in environment to a more erosive Zuiderzee coincides and was also (partly) caused by the change from natural to an anthropogenic situation. Changes in erosivity of the Zuiderzee makes it more difficult to measure whether or not human intervention slowed down the process of drowning using measurements such as early dikes and retaining walls. However, the position of the dike and the land behind it, did affect the ingression extent and thus drowning of these landscapes (Pierik *et al*., 2017). It is however likely that retaining walls slowed down erosion but that erosion still caused an increase in susceptibility of drowning due to land subsidence.

A reduction of susceptibility to drowning can be placed at the moment in time when technological advancement made it possible to have dikes that could withstand the erosional sea force without sacrificing land in front of it. In such a situation almost, no land drowned because of protective measures. Susceptibility to drowning of land was nullified as long as protective measures hold and are maintained.

As technology improves the amount of counter measures to prevent land loss and landscape drowning increases over time. Temporal increases of natural factors such as storm events and increasing erosivity of the Zuiderzee decreases the amount of possible measures that can be taken to prevent land loss and subsequent landscape drowning. Due to the practice of using land in front of the dike caused an ingressing sea due to continuing erosion. Even allowing for parts of towns to drown, see sub-case area of Etersheim. A hinterland behind dikes that became smaller and smaller becomes increasingly less resilient to fund damage caused by storms. To mitigate land loss the type of dike changed. Instead of land in front breaking wave action, it were wooden poles together with seagrass and reed (Schilstra, 1974, p.26-27). Figure 16 is an example of a dike that is reinforced with a belt of seagrass on the sea side where wooden poles hold the seagrass together. This seagrass belt absorbed incoming wave power while the dike behind kept the water out. Erosive forces were thus kept away from the dike. It also resulted in subsequent erosion of the sea grass layer and wooden poles (Schilstra, 1974, p.46). Not all dikes were strengthened with seagrass, reed and wooden poles. In some areas erosion of land in front of the dike was at a slower rate or it was still possible to sacrifice land. It could also be that transition to a different dike type was too expensive.

Figure 16: A reconstruction of a revetment with seagrass and wooden poles in front of the dike to absorb wave action (Ceinturion, 2008, September 1).

After 1731 CE the type of dike needed to change again. This time, change was caused by the introduction of an exotic species, the *Teredo navalis* or the 'shipworm'. These worms were attached to cargo ships and only lives in a salt water environment. Its main source of food is wood. Due to the introduction of the shipworm large amounts of wood within dikes were damaged. Large scale damages on dikes around the Zuiderzee occurred. Dikes would become increasingly unstable due to damage of its wooden frame (Schilstra, 1974, p.61-63). To mitigate this problem many dikes were now strengthened (riveted) with stones on the outside. Stone were dumped in front of the dike to become a heap that could reduce wave action against the dike. It proved to be expensive to dump stone in front of a dike so heavy stones were laid on top of a slope on the sea side of the dike to dissipate incoming wave power. This practice significantly reduced the amount of stone needed to reinforce the dikes (Schilstra, 1974, p.89). Switching from wood to stone was an expensive and slow process which increased susceptibility for land to drown. When finished susceptibility to drowning steeply decreased.

4.1.6 Role of structures

Some structures are meant to protect landscapes, such as sluices and dikes. The function of a structure is mostly known in its original function. Influence of drowned structures on preservation of a drowned landscape is still poorly understood as only a begin and end situation of the results can be found. In many settlements in the Zuiderzee area such as Veenhuizen and Etersheim structures above ground are eroded at the landscape surface.

The role of structures, mainly dikes is more known at the onset of drowning. Drowning in a landscape with dikes can only begin when a dike breach is not repaired and sea water not drained. At the place of breaching of the dike the sea can enter the hinterland. A dike breach is mainly accompanied by erosive forces caused by its momentum and gained momentum from moving downward as land behind a dike is lower than water at the top of a dike. In not drowned areas erosive forces resulting after dike breaching mainly results in a scour hole ('*kolk'* or '*wiel'*) which is an essentially round lake that can be many metres deep. In a drowned landscape it often results in an erosion channel. In Etersheim an erosion/tidal channel was developed and afterwards filled with muds (Waldus, 2020; Pierik *et al.,* 2017). Based on corings from Dinoloket an erosion channel is also expected at and around the dike breach of sub-case study of Uitdam. Filling of these channels with mud would mean that the depression was filled in an environment in which low flow velocities occurred. Deposition of this clay shows that after drowning of this landscape, flow velocities were slower than at the onset of erosion. The role of the dike in this situation is that it created a setting in which flooding of its hinterland would be increasingly erosive.

Location of dike breaches at the onset of drowning defines the location of formed erosion/tidal channels. Water could still not pass-through parts of the standing dike and forces it to go through existing breaches. Preservation of drowned landscape is lower at locations of dike breaching and locations of an erosion channel. An erosion channel however also has a great potential to trap and store eroded parts of the landscape. Debris and archaeological artifacts that come from the landscape surface fall into the depression that afterwards was filled with clay. In time surfaces around the erosion channel eroded even further because sediment input into the Zuiderzee is not enough to completely cover the landscape in thick sediment deposits. Erosion is on one side removing landscape remnants and decreasing landscape preservation. While on the other hand erosion partly increases preservation of certain landscape elements as happened in Etersheim (Waldus, 2020).

4.2 Natural processes and variables

Distinction between natural processes and human induced processes can be made with different criteria. Within this thesis distinction between natural processes and human induced processes is defined as: whether or not direct human interaction caused a certain process to happen. A human induced process also has to be aimed at the results of the occurring process. In this view compaction can be interpreted as being a natural response to an increase in water drainage of peatlands.

4.2.1 Erosion

The Zuiderzee region experienced large scale erosion especially between the 12th and the 17th century CE (Van Popta, 2020). When looking at coastal erosion than natural causes are grouped into three groups: storm events and their erosion, erosion due to wind generated waves and tidal action, hydraulic action and abrasion. Abrasion and hydraulic action are differentiated from erosion caused by wave and tidal action because abrasion causes erosion vertically while wind generated waves and tidal action causes erosion horizontally. In a natural situation abrasion and hydraulic action happen during tidal action and wind generated wave erosion.

Wind generated waves

Wind generated waves are generated by the transfer of energy from wind to water that causes vertical displacement of the surface of a water body (Davidson-Arnott, 2010, p.52). Wind generated waves flow in the same direction as the wind direction as these waves are fed by the wind. Wind generated waves are mostly controlled by: the wind speed, duration of the wind event and distance over which the wind blows over water (fetch length) (Davidson-Arnott, 2010, p.66). This also means that morphology of the Zuiderzee depending on fetch length either increases or decreases. Southwestern winds can generate larger waves than eastern winds as fetch length is larger in a southwestern direction in comparison to the eastern direction. The longer fetch length from northwest to northeast in the Zuiderzee can thus also be explained by the fact that the dominant wind direction in The Netherlands comes from the southwest (Pierik *et al.,* 2017). A part of the momentum of the wind generated waves in the Zuiderzee will be broken at the coastline, sea defences or measures to prevent erosion. This sort of wave breaking will result in an energy transfer from water to land or measures which results in erosion. Coastal morphology in which a wave breaks changes together with wind strength as wind pushes water in the wind direction which leads to differences in surface water elevation. Figure 17 Shows water level differences caused by wind generated waves in a lake or lagoon that represents the Zuiderzee (Davidson-Arnott, 2010, p.39). Characteristics of wind generated waves tend to increase significantly during storm events that oftentimes are accompanied by high wind velocities and thus also increases erosivity of these waves. An example of the effects of a storm event in the Zuiderzee region are the height difference in water level which could increase up to 2-5 metres and decrease with several metres (De Gans & Bernink, 2005, p.124).

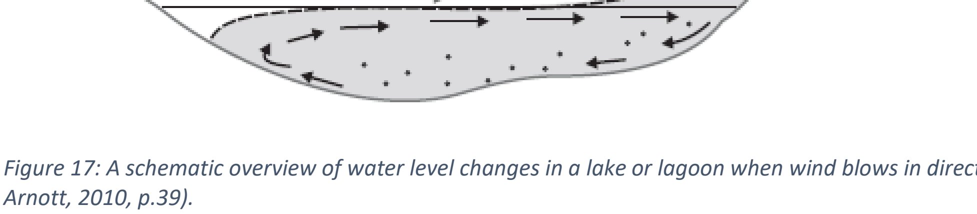

Figure 17: A schematic overview of water level changes in a lake or lagoon when wind blows in direction u (Davidson-Arnott, 2010, p.39).

Tidal waves
Erosive forces in tidal waves tend to have the same effect in terms of erosion as wind generated waves. Differences between tidal waves and wind generated waves in the Zuiderzee are mainly caused by their difference in occurrencez, tidal range, difference between high and low tide within the Zuiderzee region. The shape of the Zuiderzee causes sea water to enter and leave at the same location (between Noord-Holland and Friesland). In other words, this shape caused a reduction in force of incoming tidal waves as it was hindered by a reflected tidal wave (Vos, 2015, 42). Tidal waves did have a contribution to erosion but it was limited within the Zuiderzee. A combination of both high tide and wind generated waves (storm event) had the most potential to drown a landscape because of the increased elevated water height can more easily overtop a dike.

Hydraulic action and abrasion
Figure 18 shows wave orbital motion in water of shallow and intermediate depth that can be witnessed within the Zuiderzee region. Figure 18 also shows large shear forces that occur in waters of shallow and intermediate depth water. This shear force pushes at sediments which results in shear stress. Erosion only occurs when shear forces are larger than the erodibility of the seabed sediment. Ability of water to cause erosion through motion is called hydraulic action. Water will contain a certain amount of sediments after erosion, the water column with sediments that causes erosion through motion is called abrasion. In literature regarding the Zuiderzee within the Noordoostpolder describes erosional processes as abrasion (Wiggers, 1955). This means that a part of the capacity of water to carry sediments is already used (carrying capacity). In the Zuiderzee it is likely that especially for wind generated waves gain momentum which increases its erosivity and will cause reworking and transport of sediments in deeper part of the Zuiderzee. When waves enter increasingly shallow waters shear stress increases between water and the seabed surface. This results in lower flow velocities and a lower carrying capacity and thus in deposition of suspended sediments.

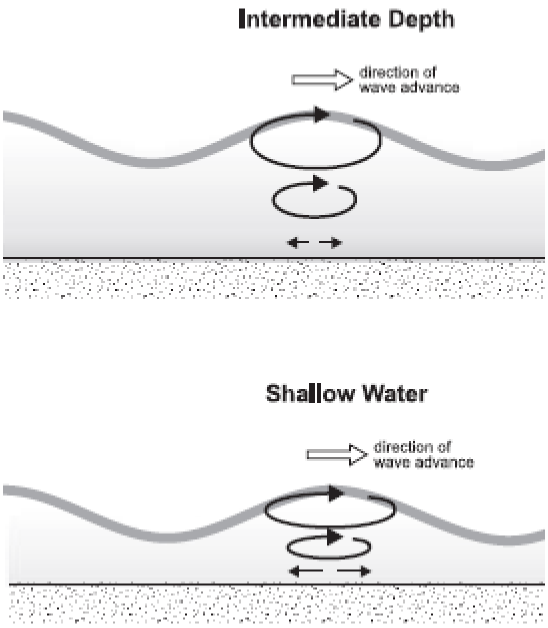

Figure 18: Orbital motion in water at intermediate depth and shallow water is visible (Davidson-Arnott, 2010, p.53.

4.2.3 Sediment

Development of the Zuiderzee region is traditionally characterized by the amount of erosion and land loss that took place which regularly led to the drowning of landscapes. In that storyline, the fact that this happened to a relatively sediment starved region is not always appreciated (Pierik *et al*., 2017). Also, the fact that the few regions that did receive reasonable sediment input (mouth of Utrecht-Vecht in Aelmere times; joint mouth of IJssel and Overijsselse Vecht in Aelmere and Zuiderzee times) suffered much less nett coastal erosion than the rest of the shores is not traditionally highlighted. Sediment influx and filling or emptying of accommodation space within this region is important to consider to explain occurrence of lost vs. preserved medieval landscapes. The amount of sediments that go into the system determines the impact of erosion because it provides resistance (cohesive sediments, material to silt up natural levees), buffer zone (waves broken over subaqueous bars of sediment) and a means of self-repair and healing of incidental storm surge scars (near points of influx, storm induced coast line set backs are temporarily only). For example, if a landscape drowns due to oxidation of peat than it can either stay drowned or be filled with sediments over time. When looking at the situation of the Zuiderzee than large-scale peat development already marks lack of clastic sediment input to fill accommodation space. At the onset of the peat reclamation compaction and oxidation causes accommodation space to slowly increase although it did not immediately lead to either ingression nor increase in sedimentation.

Erosion is mainly contributed to human processes of compaction and oxidation that accelerated already occurring erosion. From another point of view, it can be said that low sediment input in this region from the onset of the Holocene onward created the conditions for these landscapes to exist and to drown. Moreover, in this setting the amount of peat in this area forms a buffer in which clastic sediments accumulation is counteracted by auto-compaction of peat (Pierik *et al*., 2017)

Sediment cover on drowned landscapes

The amount of sediment influx also matches the conclusion of chapter 5.2.1 Kuinderbos. Sediment cover increases preservation on short term but erosion decreases long-term preservation in an ingressing sea. Although it only works in an ingressing sea that increases accommodation space faster than it can be equilibrated by sediment influx. That also means that a stop in ingression by the Zuiderzee means that sediment input is large enough to decrease accommodation space that leads to an aggrading environment. In an aggrading environment the whole landscape surface elevation is increased by a layer of sediments that also covers drowned landscapes and thus increases preservation potential of drowned landscapes. This means that distance to shore and depth of drowning of a landscape are important for its preservation. But it is also important to verify whether or not the sea continued to ingress locally and regionally. Examples of areas that are preserved when ingression stopped are all sub-case study areas described in chapter 5.2 Sub-case study areas.

4.2.2 Compaction

Compaction of soil layers around the Zuiderzee is important as for example, large-scale peat reclamations induced consolidation of peat by draining peatlands on a large scale. Within poldered areas such as the Noordoostpolder compaction can be important as groundwater levels were and are low which causes consolidation and oxidation of peat. Compaction is thus important for preservation states of drowned landscapes in different situations that can be found within the Zuiderzee area.

Compaction and oxidation due to water removal

In the Zuiderzee region sand, clay and peat are either deposited or formed. Most sediments prone to compaction in this region are either clay or peat. Both of these sediments are formed/deposited in wet conditions. Clay is deposited mainly in slow flow velocities in a sea or river. Peat is organic matter that dies and falls in wet conditions, while deposition of organic material is faster than oxidation of organic material. When water is removed from peat it consolidates and also oxidises the organic component, causing it to disappear. Initial consolidation in peat is short term while oxidation happens in a longer term and over time the effect of oxidation on surface level elevation will increase. Further aspects of oxidation will not be written down as they have been written in chapter, 4.1.1 Peat reclamations.

Ripening of clays

Clays are deposited in a wet environment and most often stay in a wet environment, especially when sedimentation of new clays continues. Conditions of clay after sedimentation differ. However, the most important condition for ripening is drier conditions. Water in the clays will be removed in dry conditions. Clay particles will move into the space of empty pores and thus causing the clay layer to compact when water is removed. Ripening will thus also decrease the thickness of a clay layer. However, most clay layers will not completely ripen due to wet conditions that continue after deposition. In these wet conditions groundwater levels tend to be high. Another factor is that in most of these areas clay deposition continuous. In this way clay will be located within the capillary zone and even within groundwater which prevents further ripening of clays. However human changes in the landscape can alter circumstances within clay layers. Building embankments will stop flooding and sedimentation clay. Agricultural practices will drain land to make it appropriate. Thus, these changes will eventually also have impact on ripening of clays. In figure 19 is a ripened clay visible under a microscope in plain polarized light (PPL). In figure 19, typical cracks in a ripened clay are visible. What is also visible is that space is created between clay particles and thus other clay particles will fill this space to increase compaction of clay layers. This will then lead to a decrease in thickness of a clay layer. Ripening is an irreversible process which means that the result cannot be undone.

Figure 19: Photo of a ripened clay in PPL (Plain Polarized Light (normal light)).

Compaction due to weight

Compaction due to weight has little effect on a landscape itself such as deep ground layer compaction due to sediment layers on top of it. However, compaction due to weight has an influence on preservation states of landscape elements that represent drowned landscapes and sometimes has a role in drowning although it is not big. The best-known example are dike remnants in the Noordoostpolder and Uitdam (Wiggers, 1955; Pollé, 2019). In Uitdam the dike is still visible on top of the surface but also in the sub-surface. While in the Noordoostpolder many dikes have been eroded on the surface and sub-surface. After dike construction weight of the dike increases effective pressure in the soil which causes soil particles moving into the pores and thus compaction (Verruijt, 2001, p.26-31). Beneath a dike compact layers of peat or clay are visible and were also used as indicators of dike locations (Wiggers 1955, p.176). A compact layer of peat can thus be part of a secondary preserved landscape in which distinct landscape features are gone, but traces remain that give indications of its original context before erosion.

Another type of compaction due to weight is auto-compaction due to clastic material deposition on for example peat. In the ingression model of Pierik *et al.* (2017) multiple steps are shown from drowning to reclamation. The first step is net drowning and maturation in which peatlands play a large role. The second phase is net infilling of drowned landscapes which is in the Zuiderzee the still most occurring phase. As already stated in this chapter, the Zuiderzee has a low sediment influx. However, large amounts of peat serve as a buffer which prevents infilling and thus preventing land reclamation from the sea. This buffer is as large as the possible auto-compaction that occurs due to the weight of overlying sediment which is also dependent on the thickness of underlying peat layers (Pierik *et al*., 2017).

5 Case studies

5.1 Regional scale

As mentioned, and showed earlier there are three different case study areas that have a different location, different development through time and regional differences in preservation states of drowned landscapes within the Zuiderzee. Within distribution of these areas the southern part of the Zuiderzee is underrepresented as not enough information was available on drowned landscapes from the Middle Ages onward. Available information from the southern region of the Zuiderzee is still used but then mainly for the macro scale to explain events throughout the Zuiderzee area.

Medieval landscape case study areas are:

1) Noordoostpolder.
2) Southwestern Zuiderzee, roughly from Hoorn to Amsterdam.
3) Northwestern Zuiderzee, the area between Noord-Holland and Friesland.

5.1.1 Noordoostpolder

The Noordoostpolder is located in the northeast of the Zuiderzee. Reclamation began soon after closing of the Zuiderzee by the Afsluitdijk (1932). Most of the polder was ditch-dewatered, and soils were made to ripen as fast as possible, for example by planting reed, all to accommodate agricultural production. Most land in the Noordoostpolder was and is used for agricultural use.

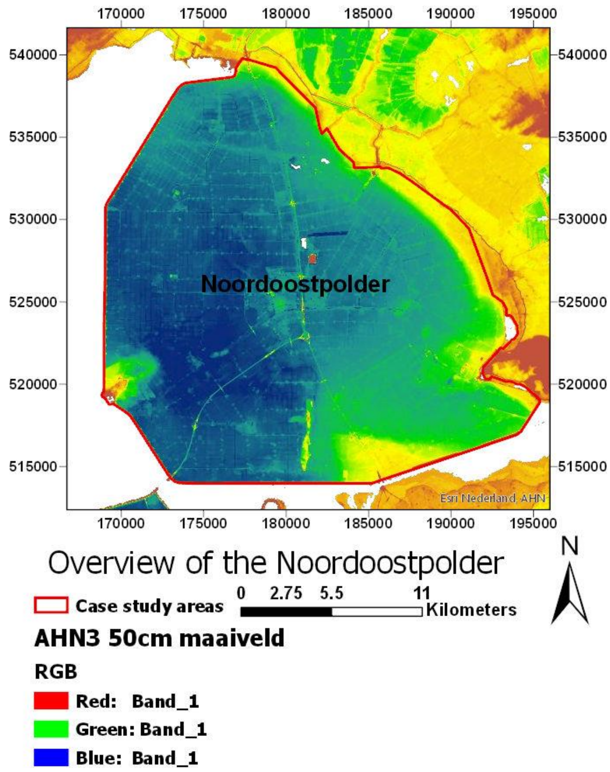

Figure 20: Overview of the Noordoostpolder location.

Figure 20 shows an overview of the Noordoostpolder plotted on the AHN which also shows the contrast between the polder and former sea coast. In this part of the Zuiderzee fresh water influence was relatively large when considering the whole of the Zuiderzee. A relatively large fresh water influence was caused by the rivers IJssel, Vecht and Tjonger which all had their estuaries around this part of the Zuiderzee. Fluctuations in salinity in this area has a clear correlation with the amount of discharge from these rivers of which the IJssel is the largest (Wiggers, 1955, p.117).

As noted earlier, the Holocene development of the Noordoostpolder is characterised by a transgression due to relative sea level rise. After that, slowed down relative sea level rise allowed for large scale peat formation in the Noordoostpolder. Peat formation in the south, south-western and western areas of the Noordoostpolder began in the Mesolithic/Atlantic and ended in the Subboreal/Neolithic (Ten Anscher, 2012). After the ending of peat formation, a layer of subaquatic sediments was found which correlate to formation and expansion of lakes within the peat area (Wiggers, 1955). In the northern part of the Zuiderzee peat formation began locally at the onset of the Holocene (Preboreal) and ended in Late Medieval period (Wiggers 1955, p.45). In the Northern part and eastern part of the Noordoostpolder peat formation began with fen peat during the Late-Neolithic period with still some mixed deciduous forest areas. At the onset of the Bronze age most of the north and eastern part of the Noordoostpolder have become bog peat areas (Ten Anscher, 2012).

In the south and western parts of the Noordoostpolder, peat growth continued in the Atlantic as reed peat due to influence of brackish and nutrient rich waters. When brackish environment ceased peat formation continued in most of the Noordoostpolder in the form of transitional peat or bog peat. Expansion of the lakes in the Bronze age led to gyttja and dy formation which was partly formed due to erosion of existing peat at the shoreline and partly by new peat formation (Wiggers, 1955, p.65-81). Erosion of peatland became more widespread due to the connection with the Vlie and thus the North Sea from the Roman Period onward.

Within the Noordoostpolder multiple settlements were formed on stable areas such Urk, Veenhuizen, Emmeloord, Marknesse and Nagele (Van Popta, 2020). The areas of Urk and Emmeloord (Schokland) were (partly) protected by erosion resistant moraines. Erosion resistant areas formed islands on which settlements could continue until they eventually drowned. Over time only Urk would remain and all other settlements were either abandoned or destroyed.

5.1.2 Southwestern Zuiderzee

The Southwestern part of the Zuiderzee (between Hoorn and Amsterdam) contains different types of drowned landscapes. These are represented in the sub-case study group with the drowned landscape of Uitdam and drowned settlement of Etersheim. Other dike relics were found between Warder and Edam and near the Bleijckmeer polder (Van den Brenk & Van Lil, 2016). These dike relics and drowned town of Etersheim are evidence of regional phased ingression due to dike breaches and replacement.

This area had the earlier large peat reclamations of the Zuiderzee area dating around the 10th century CE or before (De Bont, 2008; Barends *et al.,* 2010). Due to oxidation and collapse of the peat bogs coastal protection was needed from the 12th century CE onwards (Bartels, 2014, p.100). First dikes in this region could not handle storm events and made use of land in front the dike, see chapter 4.1.3/4.1.4 Adaptation and prevention of flooding. When a dike breached, drowned land formed new land in front of the dike, this cycle continued until almost reaching the current coastline. Dike relics known in this case study area (Van den Brenk & Van Lil, 2016) and the drowned town of Etersheim are both related to this practice. Subsequent drowning of more and more land also causes a denser distribution of drowned landscapes near the current shore of the Markermeer.

The different position with the Noordoostpolder also causes a change in sediments that mostly consists of smaller sized sediments as eroded peat, clay and silt. Differences in sediment types available also created differences in use after landscape drowning, see chapter 5.2.2 Uitdam.

5.1.3 Northwestern Zuiderzee

Not much is known about the first-millennium CE drowned landscape conditions of the Northwestern Zuiderzee (the area between Noord-Holland and Friesland). Some mentions of town names have been found in literature (e.g., De Bont, 2008; Barends *et al.,* 2010) but evidence about preserved drowned landscapes on a regional scale is lacking. Within this region it is expected that erosion is more severe than in other areas as water moves through this area to reach the Zuiderzee during tidal movement and storm events. That said, indications of drowned landscapes are still found in the form of line structures that were interpreted as structures related to peat mining. Moreover, secondary archaeological finds such as a part of a sarcophage, bricks and tuff were found 1 kilometre from the shore of Stavoren which indicates the location of a monastery (Zandstra, 2010).

Correlation of distance to shore and erosion depth tends to be the same although erosion depth is lower located at -6 to -8 metre NAP. An example of this correlation is shown in the research conducted by Zandstra (2010). In this research, line structures have been recognised as possible relics of peat mining. These line structures have been found at approximately 1 kilometre from the shore of Stavoren which is considerably farther offshore than ditches found in the Kuinderbos. The timing at which the Zuiderzee is connected to the North Sea is still debated. This also means that the development through time of this area is still unsure and hard to clarify due to large erosive forces moving through, causing gaps in the sedimentary record.

5.2 Sub-case areas

5.2.1 Kuinderbos

The Kuinderbos is a 20th century reforested area in the north of the Noordoostpolder. After reclamation of the Noordoostpolder, the ditch-dewatered and soil-ripened parcels of Kuinderbos were planted with trees instead of being used as an agricultural area (Van Popta, 2019, p.5-6). The decision to plant a forest prevented destructive land use practices such as ploughing that destroys the geological and archaeological context. Lack of destructive land use makes it a good location for research aimed at drowned landscapes.

Within the Kuinderbos remnants of a drowned late Medieval settlement called Veenhuizen were discovered in 2017 as they are visible on LIDAR imagery. For centuries, the settlement of Veenhuizen had been moved away from the sea which resulted in multiple abandonments. The first Veenhuizen mention was in the 13th century and a second mention of Veenhuizen dates to the 16th century (Van Popta, 2020, 68). In the 17th century the current coastline was more or less reached and both Veenhuizen towns have been drowned (Van Popta, 2020, p.30). One of the possible locations of Veenhuizen is thus located in the Kuinderbos (Van Popta, 2019). After discovery of settlement traces, archaeological research consisting of corings and trial trenches was conducted. Figure 22 shows the general location of the Kuinderbos within the Noordoostpolder. The Kuinderbos area has a size of 11km^2 with a surface elevation that differs between -1 and -4 metre NAP. Surrounding non-drowned landscapes near the Kuinderbos have a surface elevation of 0.10 and -0.3 metre NAP. In most cases height differences between drowned and non-drowned are between 0.5 and 1 metre.

Geological fieldwork that is part of this research was performed in the Kuinderbos, consisting of 93 corings. Locations of these corings are shown in figure 21. Fieldwork was performed to gain better insights on landscape preservation states from the shore into sea. For practical details and reporting of methods and basic results of the fieldwork see Appendix 1. This paragraph highlights most important findings.

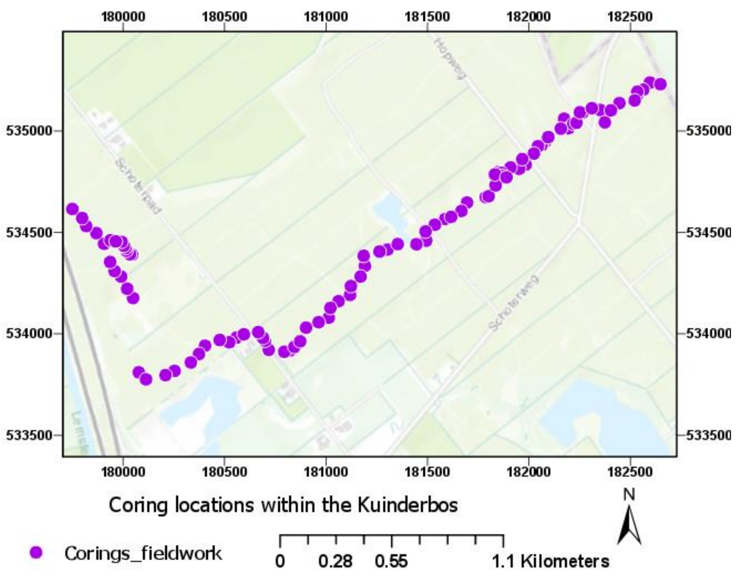

Figure 21: Coring locations within the Kuinderbos plotted on topographic map.

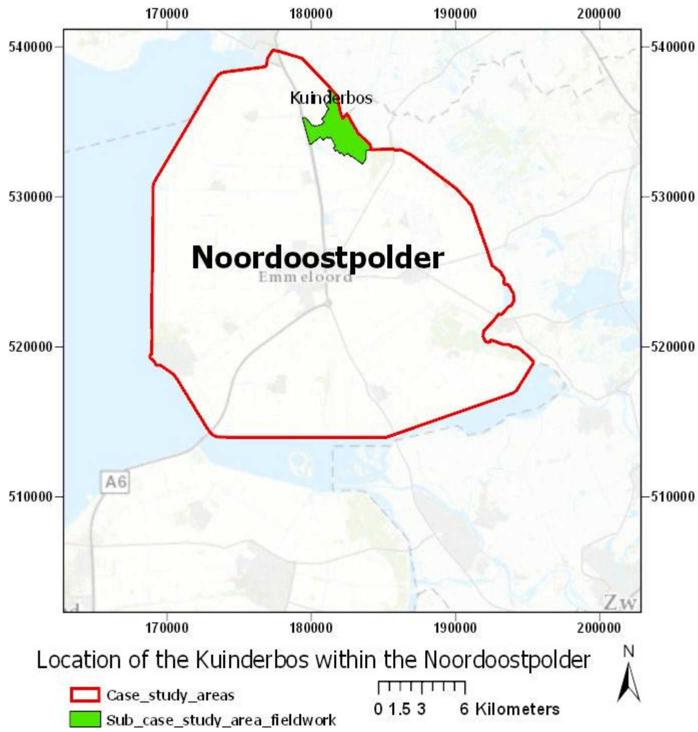

Figure 22: Location of the Kuinderbos plotted on a topographic map within the Noordoostpolder.

Type of drowned landscape
The type of medieval cultivated landscape that is projected to have existed in the Kuinderbos is that of a small village/concentration of farms surrounded by peat reclamations (Van Popta, 2020). The type of settlement/farms and type of peat reclamations are not fully known. Based on composition of the substrate, and especially types of peat (indications during fieldwork executed for this thesis), it was possible to give some indication on the type of landscape that was originally reclaimed. Composition of peat is important because it formed subtle height differences which could lead to different forms of peat reclamations and different occupation phases in the area. Based on coring observations it is highly likely that the Kuinderbos area just prior to medieval reclamations contained peat bogs. When considering the reclamation model from De Bont (2008), it can be stated that peat reclamation was done in phases along the collapsing peat. Peat reclamations in this area can be placed into a larger context in which other peat areas also were reclaimed. Examples of this are located near Schokland and in the Kuinre peninsula (Van Popta, 2020).

After the 20th century CE reclamation works, the polder was drained which led to compaction and oxidation of peat, see dataset comparison with the Wiggers 1955 dataset in the Appendix. In turn this led to relief inversion in which areas with peat would become increasingly lower than its more clastic surroundings. Relief inversion is visible in multiple parts of the forest and around remnants of Veenhuizen. These higher areas in the remnants of Veenhuizen are probably ditches that contain a clay infilling that is less prone to subsidence. In figure 23 ditches are visible as higher (yellow and red) while lower areas are visible as lower (green).

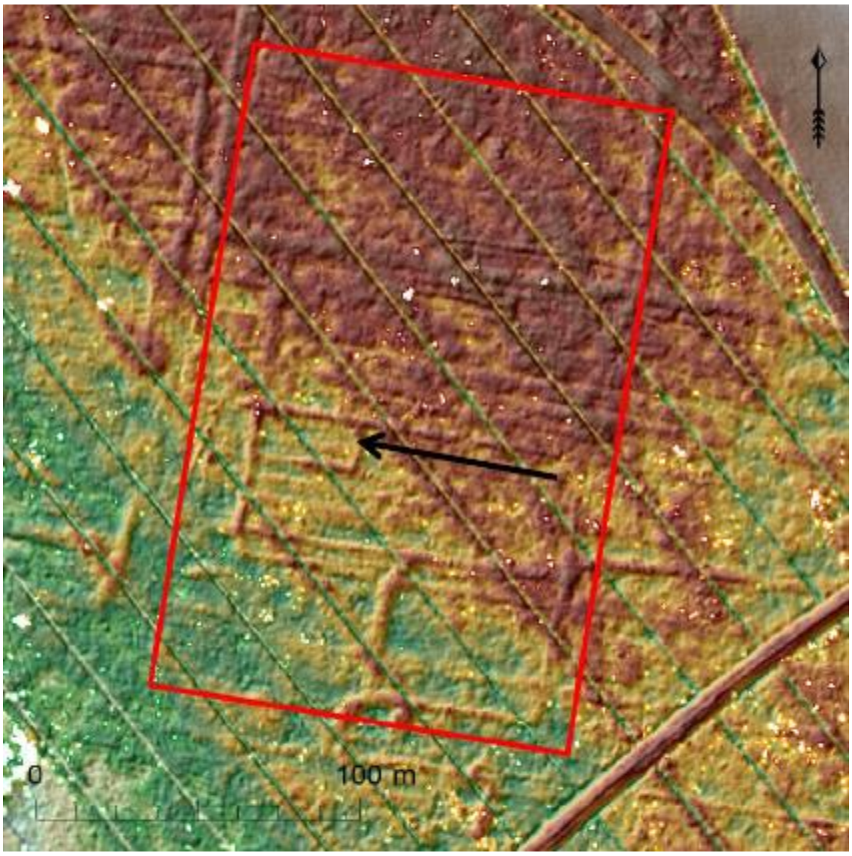

Figure 23: Ditches made visible with usage of LIDAR imagery (AHN) (Van Popta, 2019, p.19).

Sediment composition of the ditches also tells us about the landscape. During fieldwork one type of clay was recognised within the ditches, while Van Popta (2017) in trial trenches recognised 2 types of clay. One type of clay is brown grey with jarosite spots and the other is blue grey. In the Appendix a more thorough explanation is given. Brown grey clay can be identified as clay that was deposited when the landscape was not drowned and was also found in thin layers next to the ditches. This shows that flooding of the area had already happened before overall drowning of the landscape.

Presumable phases of drowning
Figure 24 shows different indications for step-wise ingression and drowning recognised in a cross-section. How this was resolved from coring information, is explained in the Appendix. Within this image are: a nearby dike indication (blue line), possible dike location (striped blue line), the Medieval landscape extend visible in the corings (all corings left of the red line), sediment accumulations that indicate a pause in ingression (red dotted line) and locations with certain sediment types and thickness that indicate a stillstand in ingression (red striped line, 2 km away from the 18^{th}-20^{th} century CE shore line of the Zuiderzee).

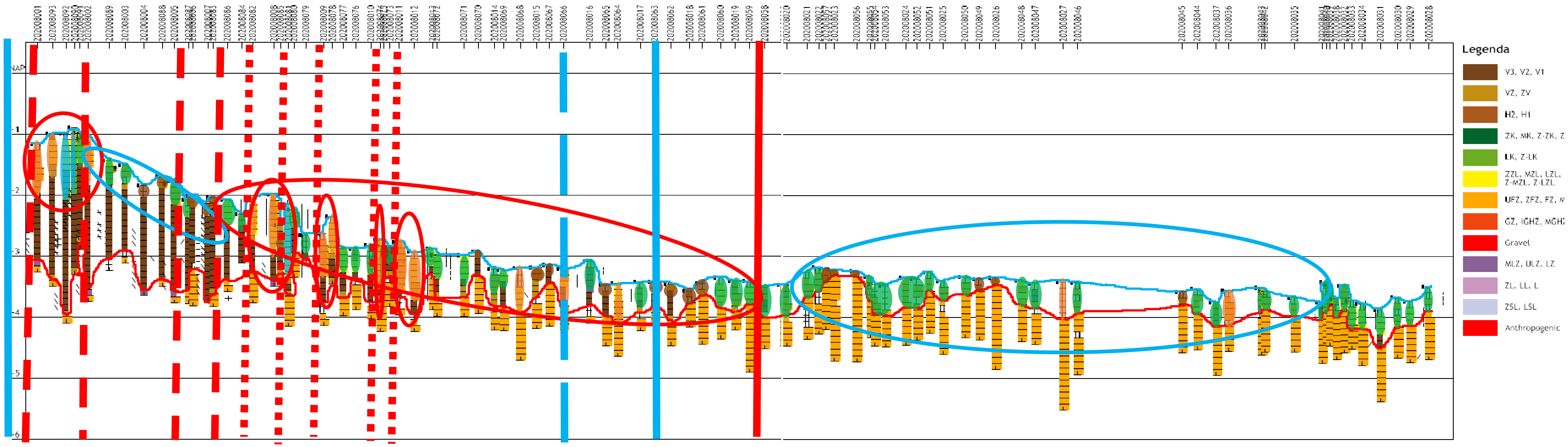

Figure 24: Locations of temporal stops in ingression of the landscape are visible through dotted and striped lines. Vertical lines indicate maximum extend of medieval landscapes within the Kuinderbos. Left = onshore (East). Right = offshore (West).

Thickness and composition of the Holocene sequence

Differences of thickness and composition of the Holocene sequence are present within the Kuinderbos. In the western area of the fieldwork grid the Holocene sequence exists of lagoonal sediments on top of cover sands. While going to the centre of the grid the Holocene thickness varies in areas with only lagoonal sediments on top of cover sand to areas with lagoonal sediments on top of peat (succession to bog peat) on top of cover sand. At the former shore around the location of former ditches of Veenhuizen, the Holocene deposits reach their maximum thickness which consists of lagoonal sediments on top of a peat succession of 1 to 2 metres on top of cover sand. The Zuiderzee mud has an overall thickness between 10-50 cm and peat thickness increases from 10 cm in the southwest to 30-50 cm in the middle to 1-2 metres near the former shore. Overall thickness of the Holocene sequence would then be 10-50 cm in the west to 50-100 cm in the middle to 1 to 3 metres near the former shore.

Preservation states of landscapes in the Kuinderbos

Preservation states of landscapes within the Kuinderbos have been assessed from 93 corings. During analysis of corings some characteristics showed similarities in their Holocene sequences and were grouped together, which led to the creation of four different preservation zones. The preservation zones are visible in figure 25. These zones show an indication on primary and secondary preservation of landscapes (see chapter 1.1.1 for landscape preservation definitions). Each of the zones is characterised by a degree of preservation of the peat sequence and soil horizons on the top of the cover sands. The zones show that preservation decreases when distance from shore increases. After placing the zones in the profile, the zone borders were plotted onto GIS to look for similarities in morphology and preservation zones. After creation of preservation zones, a GIS analysis with LIDAR imagery (AHN) was used to plot preservation zones on differences in morphology found within the Kuinderbos. Using this approach outside of the Kuinderbos in the Noordoostpolder proved to be too difficult as most morphology is destroyed by ploughing in agricultural areas.

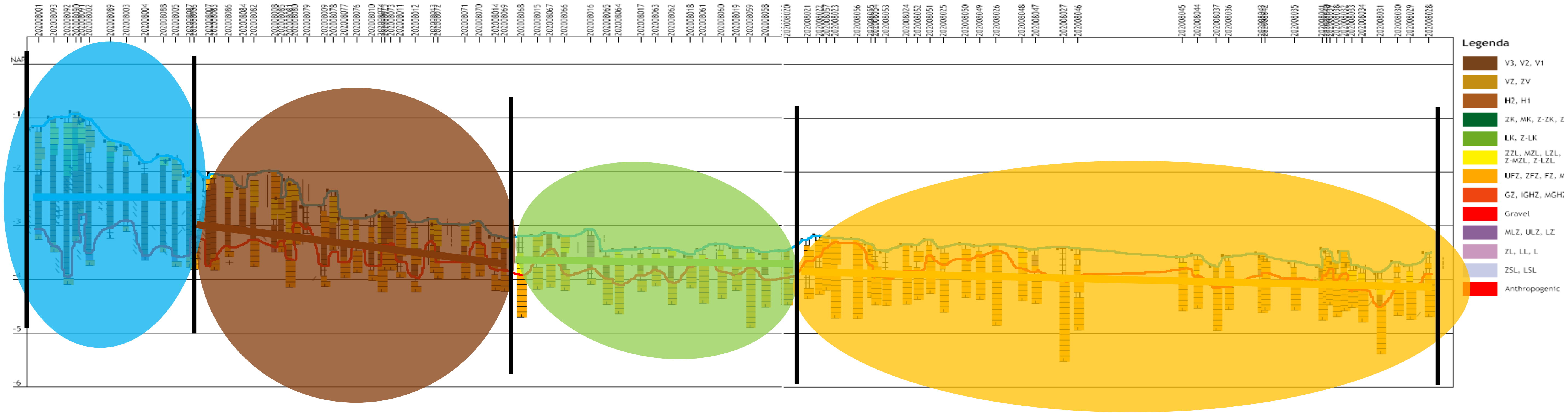

Figure 25: Preservation zones according to coring observations. Blue is the zone of preserved medieval and prehistoric drowned landscapes, brown is possible preserved medieval and preserved prehistoric drowned landscapes, green is possible preserved prehistoric drowned landscapes and yellow is no to a very low chance of a preserved drowned landscape. The black line indicates the border between the preservation zones.

GIS analyses

GIS is used to extrapolate the zones obtained in the coring profile onto areas of the Kuinderbos that have no coring data. This GIS approach also serves as a test to determine whether or not zonation remains the same when combining visible morphology with the coring data. Similarities in the morphology are then used to expand the preservation zones throughout the Kuinderbos to obtain more insights on the size and shape of these zones. Combining the fieldwork corings with the zones led to a further understanding of the formation of these morphologies and their role on the preservation within these zones. The names of the preservation zones are simplified for use in GIS in table 1.

The lower the number of the zone the higher the preservation of drowned landscapes and vice versa. Figure 26 shows an overview of different preservation zones based on visible morphology using lidar images (AHN). The area between different corings was observed to determine whether or not any morphological structures could be used for differentiation between different zones.

Categories of preservation	**Legend zone name**	**preservation Medieval landscape**	**preservation Prehistoric landscape**
Primary and secondary preserved prehistoric and medieval drowned landscapes.	Zone 1	+	++
Primary and secondary prehistoric and secondary and possible primary medieval preserved drowned landscapes.	Zone 2	+/-	+
Partly preserved primary and secondary prehistoric and partly preserved secondary drowned medieval landscape.	Zone 3	-	+/-
Low preservation of drowned prehistoric and medieval landscape.	Zone 4	--	-

Table 1: Zone name conversion table.

Different morphologies of the preservation zones

Figure 27 shows visible morphology in zone 1. It mostly consists of preserved landscape elements such as ditches, while the surroundings are relatively flat. Zone 1 is mostly located near the shore where relatively less erosion in time and depth took place than in other areas which causes high preservation and still visible landscape elements. Figure 28 shows visible morphology in zone 2. The morphology is mainly based on small mounds that have a height difference of between 60 to 20 cm in comparison with their surroundings. Size and height gradually decrease in seaward direction. These mounds are most likely caused by relief inversion as higher areas contain more clastic lagoonal sediments and small amounts of peat. Lower areas contain smaller amounts of clastic lagoonal sediments and higher amounts of peat that oxidated after creation of the polder.

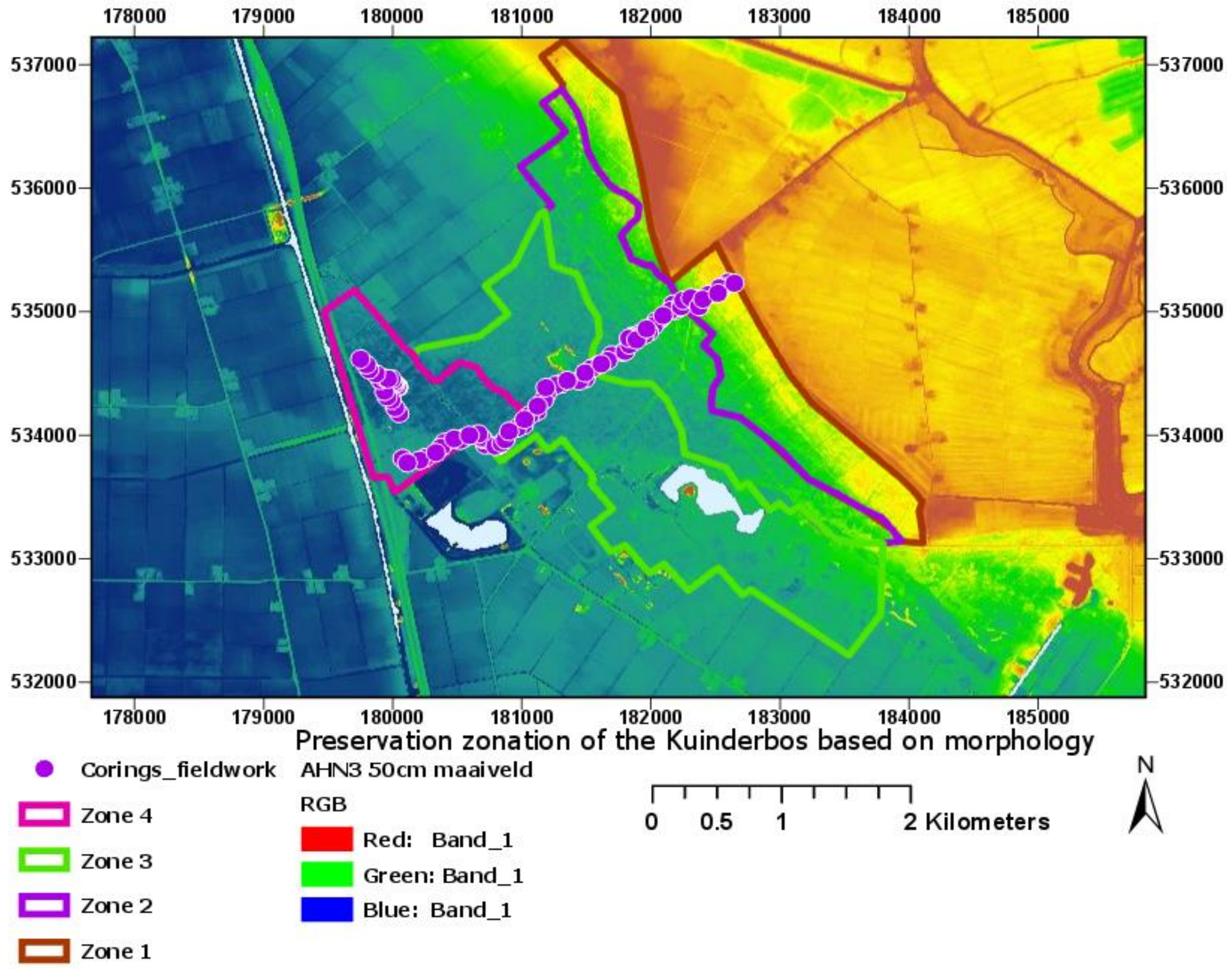

Figure 26: Different preservation zones based on visible morphology as visible in LIDAR imagery within the Kuinderbos.

Figure 29 shows visible morphology in zone 3. Zone 3 is a zone with no clear recognisable morphology and contains overlaps with zone 2 and zone 4. The different kinds of morphology can be traced back to the preservation grades in this zone. In some areas preservation is rather lacking and, in some areas, a secondary medieval drowned landscape and primary and secondary prehistoric drowned landscape are still preserved. Figure 30 shows visible morphology in zone 4. The morphology is mostly line shaped; higher line shaped elements tend to curve more while the lower line elements are straighter. The morphological structures are not the drainage channels as they go through all older morphology. A brief scan through the surroundings in the Noordoostpolder of zone 4 using AHN did not show any other examples of this kind of small-scale morphology in the region.

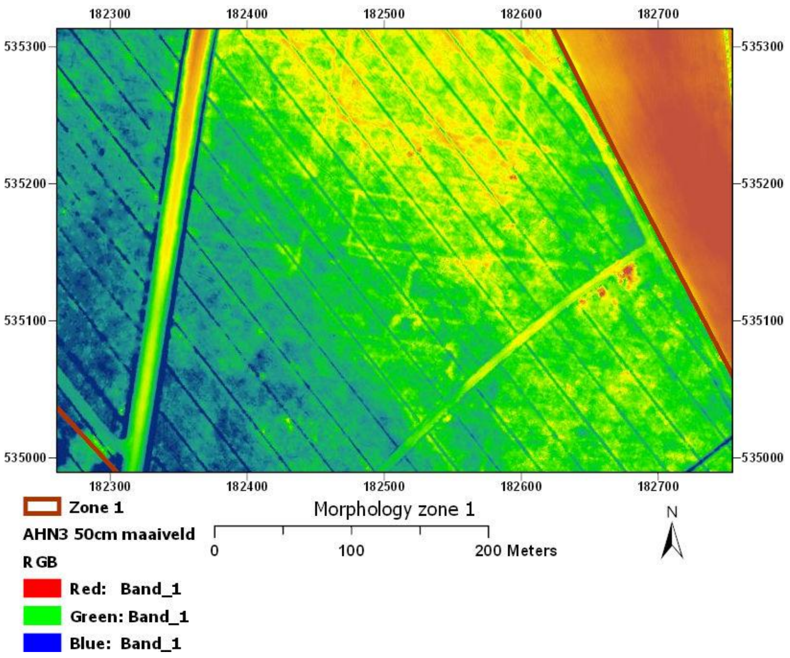

Figure 27: Visible morphology of zone 1.

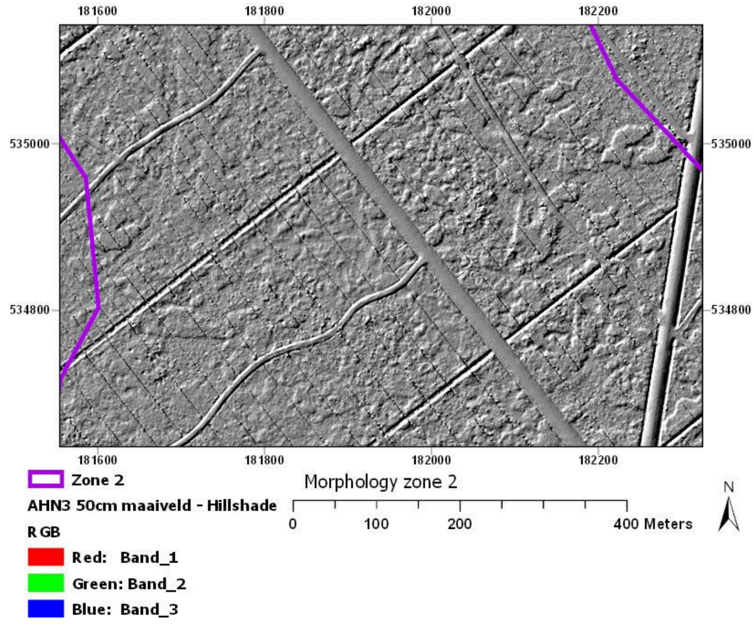

Figure 28: Visible morphology of zone 2.

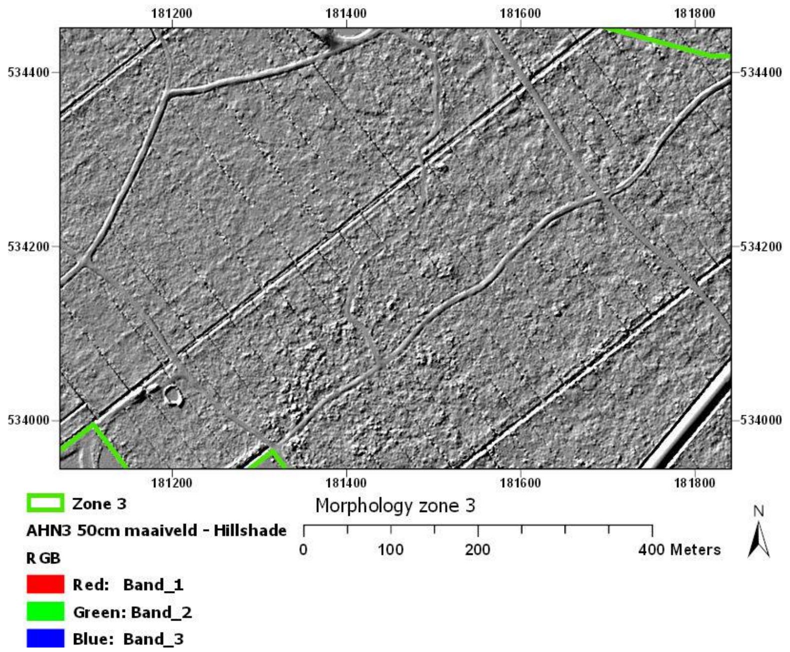

Figure 29: Visible morphology of zone 3.

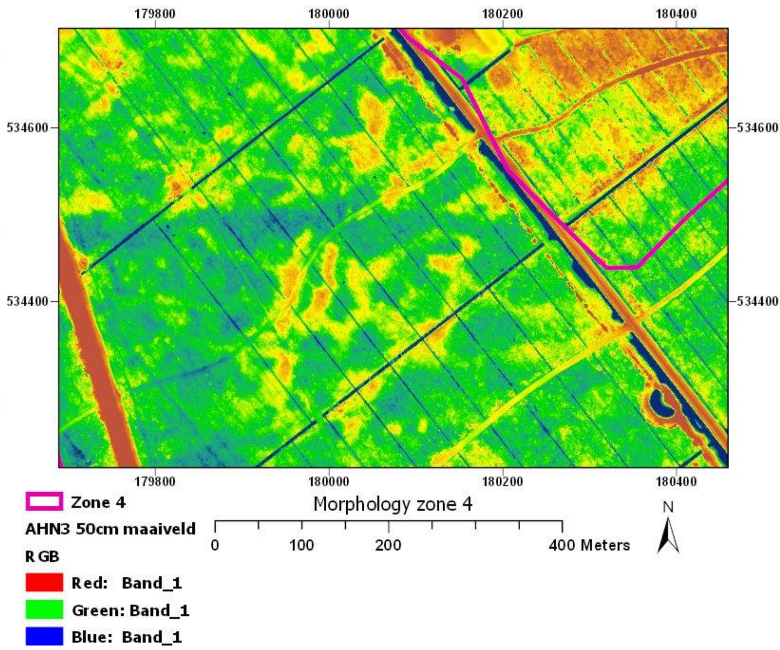

Figure 30: Visible morphology of zone 4.

Comparison prehistoric and medieval landscapes Kuinderbos

During fieldwork in the Kuinderbos, drowned landscapes from two different time periods were observed. The first landscape is the Medieval landscape which is positioned high in the soil sequence on peat which makes this landscape prone to erosive forces in the Zuiderzee and also to oxidation of its context due to current low groundwater levels. The second landscape that is identified is a prehistoric landscape on top of the cover sand in which a podzol had formed. This landscape is different because it consists of clastic material and also because of a different cause of drowning. The prehistoric landscapes slowly drowned due to raising groundwater levels which created wetter conditions in which peat formation took place. This form of long-term drowning has an aggregating effect which buries the landscape instead of eroding. The landscape surface is also more likely to be preserved due to this 'indirect long-term drowning'. When looking at preservation of these two landscapes than preservation potential of the Prehistoric landscapes are higher than the area's Medieval landscapes. The lower vertical position of Prehistoric landscape within the Zuiderzee region makes it less vulnerable to erosion, changes in land use and other disturbances. However, the higher preservation potential of Prehistoric landscapes does not mean that the landscape is preserved as observed in preservation zone 4.

Conclusion Kuinderbos

Combination of fieldwork and existing (recent) research led to new insights into variables which contribute to observed preservation states. Due to the coring transect being a line from shore into the 'sea' most stages of preservation were observed. Based on observations, fieldwork data and visible morphology, 4 different conservation zones were created.

Strong relations between different variables and preservation of different preservation zones have been found. In the short-term white sand layers indicates higher flow velocities and a possible erosive phase at the onset of drowning that could have eroded the landscape surface. Important variables regarding states of preservation on the long-term is the depth of a drowned landscape and erosion depth that is controlled by the distance to shore. When looking between both short and long-term, the process of vertical erosion caused by ingression of the Zuiderzee can be interpreted as a preserving as well as an erosion process. Sediments that are removed from earlier drowned landscapes, cover landscapes, drowned at a later moment. Thus, it will lead to an increase in preservation potential on long-midterm.

5.2.2 Uitdam

The sub-case study area of Uitdam has a size of 0.48 km^2 which is situated offshore in front of the present Markermeerdijk (Figure 31, based on bathymetric survey). This is smaller compared to the 3.9 km^2 of zones 1+2 of the Kuinderbos area in the previous section. This area of former peatland most probably did not contain a settlement. It likely was agricultural land, but nothing has been proven about land use of this landscape.

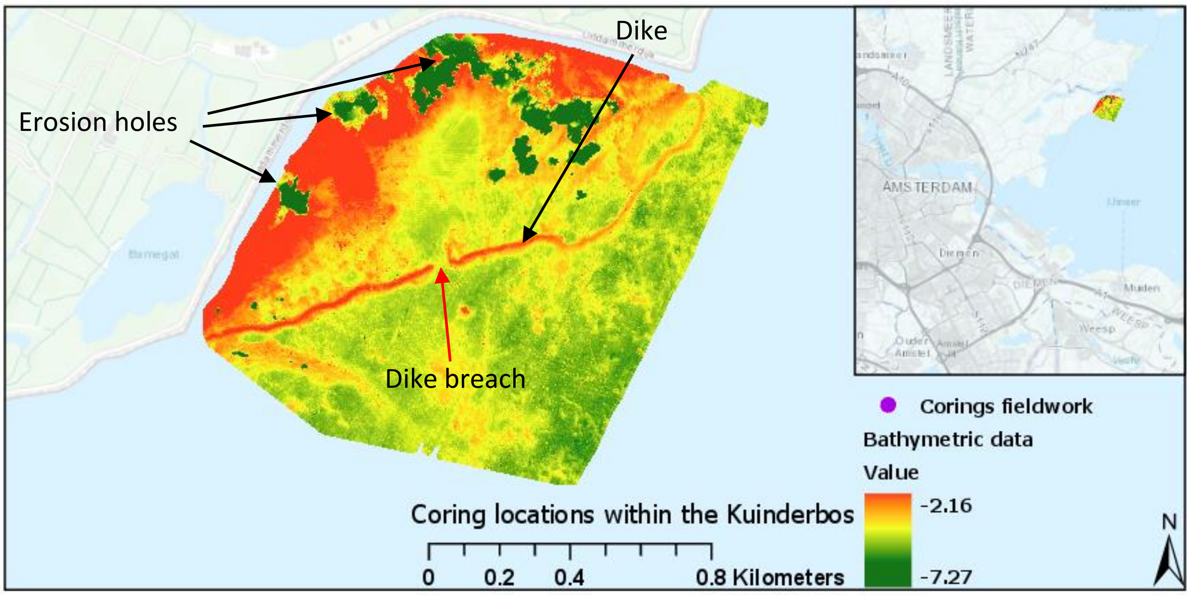

Figure 31: Height elevation map of the sub-case study area Uitdam, plotted on bathymetric data from Boskalis.

Type of landscape that has been drowned

In the case of Uitdam, the drowned landscape is probably an agricultural area, as it appears to have been protected by an earlier dike, still visible as a ridge that is approximately 30 cm higher than its surroundings. The dike appears to have been breached around the middle and there are multiple holes in the surface of the Markermeer between the former and the current dike. These holes are either caused by mining or erosion after of the landscape. The holes are mainly spatially distributed near the current dike which makes mining purposes and possibly used for strengthening the current dike likely. Activities such as mining are likely due to findings of bone and a glass bottle at the surface of one of these holes (Pollé, 2019, p.91-94). Wooden plank and pole constructions situated in one of these erosion holes are most likely used after drowning, possibly to accumulate sediment for land creation (Waldus & Muis, 2017). Other landscape uses that determines the type of landscape could not be identified.

Thickness and composition of the Holocene sequence

The Holocene sequence is derived from data available in Dinoloket. The Holocene sequence in this area goes from cover sand (Boxtel Formation) to a small band of peat with a maximum around 20 cm to none existent (Nieuwkoop Formation, Basel Peat layer). The peat is covered by clay, silt and sandy lagoonal deposits, between 2.5 metres up to 7 metres (Waalwijk Formation, Wormer Member). Then peat Formation starts again on top of lagoonal deposits with a thickness between 0.5 metre and 3 metres (Nieuwkoop Formation, Holland Peat Member) which is covered by lagoonal sediments mainly consisting of clay with a thickness of 20 cm up to 1.3 metre (Naaldwijk Formation, Walcheren Member). The Holocene deposit is overall approximately 12 metres thick.

The landscape preservation
In this area multiple researches had been concluded, most of them were focussed on general preservation of an archaeological site (Van den Brenk & Van Lil, 2016; Waldus & Muis, 2017; Pollé, 2019). A preserved archaeological site would mean a preserved landscape. However, a thorough coring or digging strategy to proof preservation of a complete landscape is missing. Pollé (2019) dug a trial trench into the dike and noted a very good preservation of the dike but not necessarily the context around it. Figure 32 shows a profile made with corings available in Dinoloket.

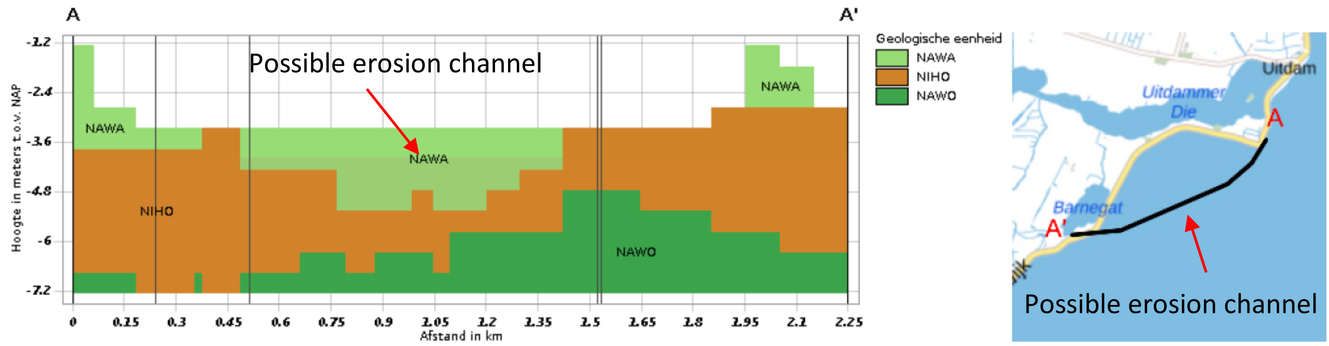

Figure 32: On the left is a profile at roughly the location of the dike, on the right the location of the profile is visible (Dinoloket).

When looking at this profile the values NAWA, NIHO and NAWO are important. NAWO means Naaldwijk Formation Wormer Member which means lagoonal sediments that were deposited in a situation with not a completely closed seashore. NIHO means Nieuwkoop Formation, Holland Peat Member which means peat formed on top of lagoonal sediments and in this case also partly covered with new lagoonal sediments. NAWA means Naaldwijk Formation, Walcheren Member which means lagoonal sediments deposited on a coastal plain (Van Zijverden & de Moor, 2014, p.34-35). In this profile the erosion channel near the dike breach is clearly visible.

In profiles made from shore to sea, a similar sequence and zonation can be observed within the Kuinderbos (despite the much greater thickness of the Holocene sequence at Uitdam). In both cases thickness of the upper peat bed gradually decreases with an increasing distance cross-shore. When using the preservation model made in the Kuinderbos it can be stated that the landscape between the current and drowned dike has a good preservation. An exception has to be made for the possible erosion channel near the dike breach where the medieval landscape is not primarily preserved but most probably secondary preserved. Sediments overlying peat mostly consist of silt and clay while peat in the Kuinderbos is mostly covered with silt and sand. When looking at available data in Dinoloket it is visible that clay deposits on top of peat mainly flattened existing relief at the surface level and that clay accumulation happened at the shores of the Zuiderzee. Thickness of the peat layer in Dinoloket data has a high variation which is comparable to the thickness differences in figure 32.

Great variation in thickness of peat is an indication of an erosive phase in this area that is followed by a more aggradation phase in which clay flattens the surface level. At least some of the difference in peat thickness are directly related to the onset of drowning at and near the dike breach. Presence of peat also indicates that the landscape of peat reclamation is at least preserved at the sub-surface level. The preservation state of this sub-case study is in line with the preservation model of the Kuinderbos and an implementation of this model on this case-study area is given in figure 33.

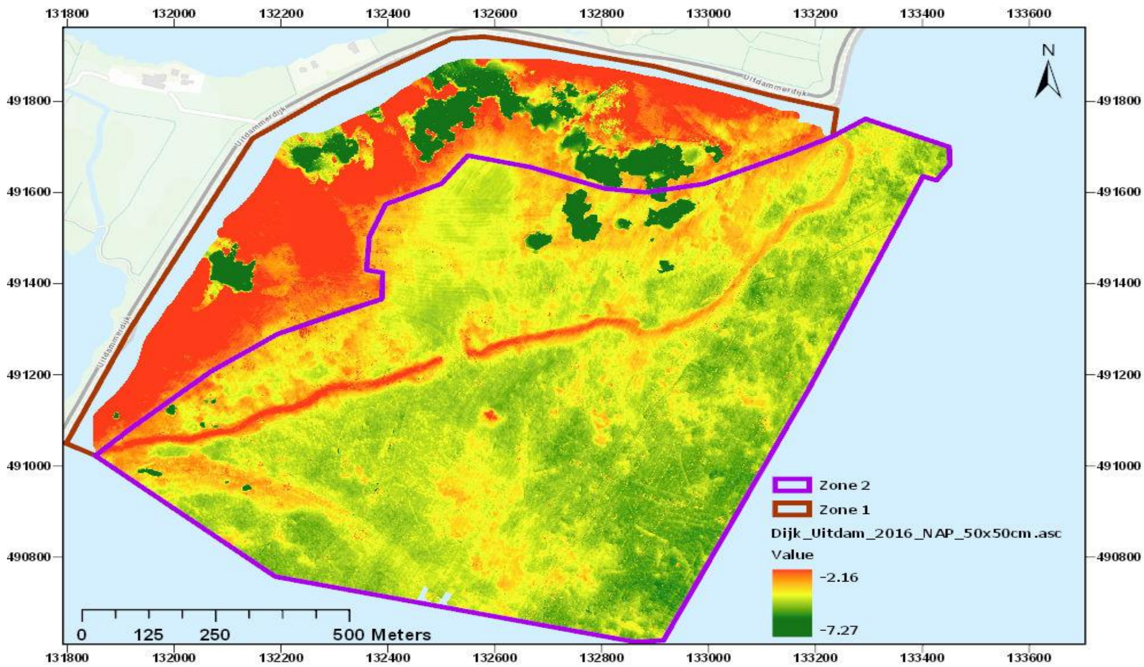

Figure 33: DEM using bathymetric data with plotted preservation zones in Uitdam, plotted on bathymetric data obtained from Boskalis.

Height differences with dry land next to the drowned landscape

The current drowned landscape has a surface elevation of around -3 and -3.2 metre NAP while on the other side of the Markermeerdijk, polder land situated has a surface elevation of around -1.2 and -1.6 metre NAP. The landscape drowned approximately between the 13th century and the 15th century CE. Height differences between the drowned landscape and non-drowned landscape are roughly 1.5 metre, although the landscape that wasn't drowned continued to have subsidence between drowning date and present.

Although the difference between non-drowned and drowned exists it is also important to know how the sub-case study area of Uitdam lies -3 metres NAP. Sea level at the time of drowning was roughly 20 cm lower than present (Meijles *et al*., 2018, p.906). When tidal range is taken into account for the area near Uitdam a tidal range of 34 cm in Edam, 25 cm in Monnickendam and 36 cm in Amsterdam were measured (Gleuns, 1866, p.11). Taking a rough estimate of the data results in a maximum of 30 cm tidal range of which +10 cm NAP at high tide and -20 cm NAP at low tide can be reconstructed (Gleuns, 1866, p.11). When assuming that land could only be drained at low tide the height difference with sea level will decrease from 3/3.2 metre to 2.6/2.8 metre. In this estimate are also not ripened muds in which it is not clear whether or not some of the clay has been ripened. Ripened clay would be an indication for dry conditions and thus clay that could be deposited during the use of the landscape prior to drowning.

The drowned dike in Uitdam has been dated from 1100 to 1500 CE and the drowned landscape in which it is a part of has been dated from 1300 to 1500 CE (Pollé, 2019, 74-100). Latest date of the landscape and dike corresponds to the earliest mentions found of windmills for polder creation from the 15th century CE onwards (Kingma, 2009; Barends *et al.,* 2010, p.71;). This is a logical development as the first land reclamation using large windmills in the Netherlands took place in the 16th century CE. Most reclaimed land areas in the 16th and 17th century were located relatively near the casus of Uitdam (Schultz, 1995, p.3). The location and the outer most date of the drowned landscape might make it possible that an artificial drainage such as a windmill existed that drained the sub-case study area. It has to be noted that more historical evidence of polders is available the younger they are. Using the dating of Pollé it can also be said that the 15th/16th century transition is the uttermost date of the dike breach and inland rerouted repair.

Although the question arises whether or not it is feasible for a polder to exist when the current dike is 30 cm above surface level together with no evidence as of yet to prove the existing of a physical drainage system. Figure 34 shows the profile of a digging performed in the dike by Pollé (2019) in which it is not clear whether or not the natural surface at the bottom has been reached after 70 cm of digging. It has to be noted that the upper 10 cm consists of lagoonal sediments. It occurs that a possible earlier phase of the dike, that is significantly smaller, can be noticed at the lower right part of the profile. This means that the dike could have been at least 60 cm or higher and over the course of 600 years collapsed into the sub-surface. When combining the height and width of 20 to 30 metres (Pollé, 2019, p.14) it could be possible that the dike was even higher. However, Huizer (2019, p. 13) notes that the dike found in the corings was only 55 cm deep and suggests that the horizontal layering is likely due to erosion removing the top of this dike. This also makes likely for this dike to protect an area that was artificially pumped with a surface level beneath low water level. It has to be noted that it is still not sure whether or not this dike completely reached the surface although it is likely with the presented data.

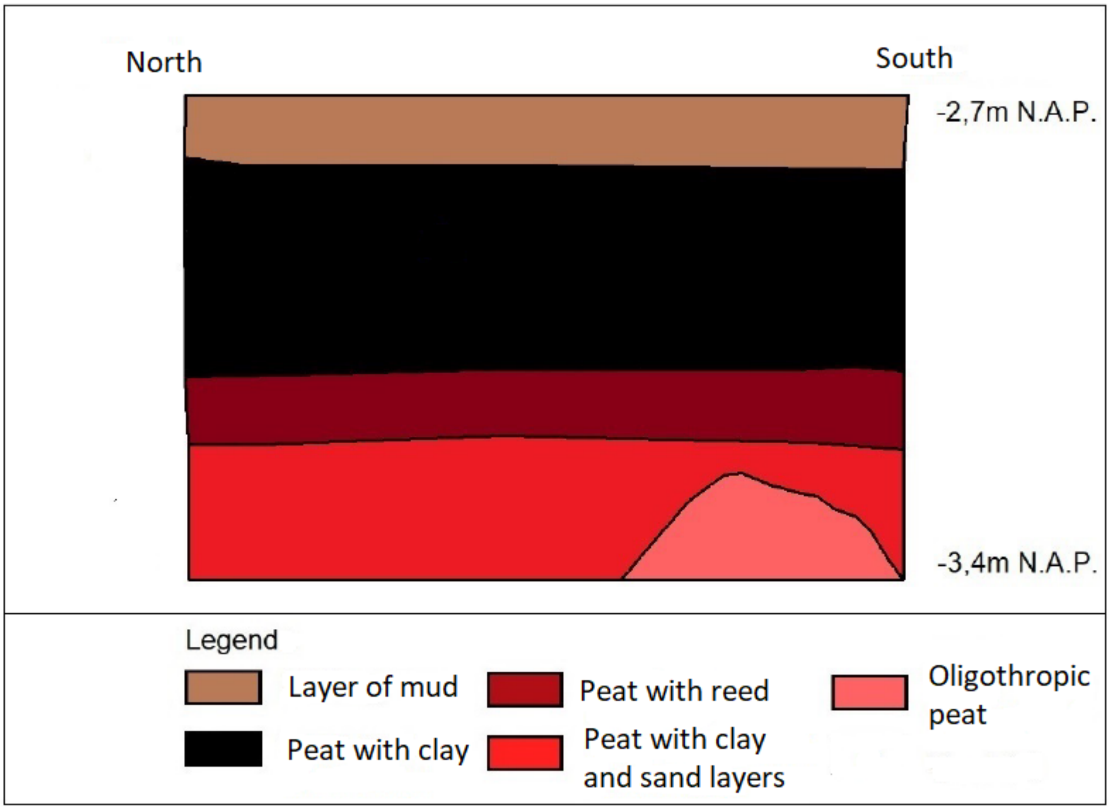

Figure 34: Profile of the dike in Uitdam, in the lower right is a possible older dike phase (Pollé, 2019, p.80).

5.2.3 Etersheim

Etersheim is a hamlet located next to the Markermeer in the East of North-Holland, the location of Etersheim is shown in figure 35. The town of Etersheim is located near the '*sarcofaag'* (sarcophagus).

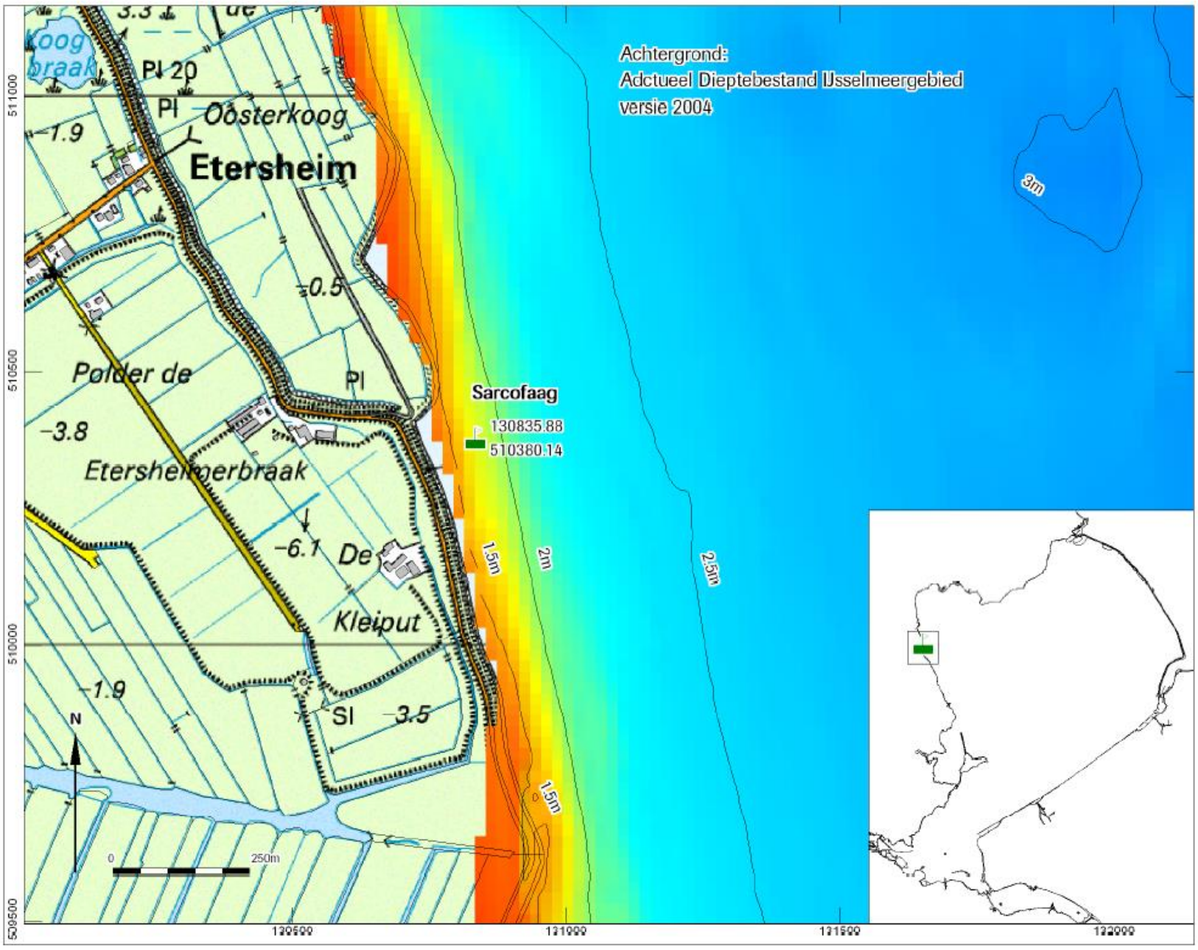

Figure 35: Location of the sarcophage at the coast of the Zuiderzee, the sarcophage is located within Etersheim (Waldus, 2010, p.6).

What type of landscape drowned?

The type of landscape that can be expected is a town surrounded by peat reclamations. The type of town and type of peat reclamations are not known. However, it is possible to make a guess on the type of landscape based on literature and composition of the Holocene sequence and especially the composition of peat. The composition of peat is the most important factor because it formed subtle height differences which led to different forms of peat reclamations and different phases of occupation within the area.

What is the thickness and composition of the Holocene sequence?
Dinoloket data is used for an overview of the thickness and composition of the Holocene sequence in and around the sub-case study area. At the base of the Holocene sequence is cover sand of the Boxtel Formation. On top of the Boxtel Formation is the basal peat layer with a general thickness of 50 cm which is covered by the Naaldwijk Formation, Wormer Member, Velsen layer which are lacustrine sediments with a thickness up to 1 metre if present. Lacustrine deposits are followed by the Naaldwijk Formation, Wormer Member which are lagoonal sediments formed in a not closed coastal system with a thickness around 13 metres. The top of the sequence exists of peat from the Nieuwkoop Formation, Hollandveen Member which is peat formed on top of lagoonal sediments with a thickness up to 3 metres if it is present. At some places peat is covered by lagoonal sediments of the Naaldwijk Formation, Walcheren Member which are sediments deposited by the Zuiderzee with a thickness up to 60 cm if present.

What is the landscape preservation?
An erosive channel was found around and throughout the archaeological site of Etersheim (Waldus, in prep). One possibility is that it formed at onset of drowning in for example a storm surge. However, it is also very likely that ditches or channels drained water from the landscape to the sea and changed through time due to influence from erosive forces in the Zuiderzee. If these drainages drain into the sea than it is likely that the drainage forms a weak spot in the sea defence in which water from the Zuiderzee could enter. This way a ditch or channel could be shaped into an erosive channel or inlet for sea water. During fieldwork (Waldus, in prep) performed by ADC Maritiem, the area of Etersheim was sampled with a core and later partly excavated in the summer of 2020. Purpose of this sampling was to find and sample the erosive channel. However, it also became visible in the cores that the top layer of peat and thus also the landscape surface was eroded. Deep(er) soil features and other characteristics of a landscape may still be present in the sub-surface which could still be preserved outside of the erosion channel. However, erosive channels and possible ditches are locations where artifacts are washed into. Artifacts can help in assessing the age and possible use of this landscape.

5.3 sub-case study inter-comparison

What type of landscapes are drowned in the different sub-case study areas?
At the sub-case study area of the Kuinderbos the type of landscape that is expected is a town surrounded by peat reclamations. Visible and verified elements in this landscape consist of ditches found using surface elevation models. A line structure that is similar to the dike in Uitdam is found although it is not verified. In Uitdam the landscape that is drowned is uncertain but likely to be used as agricultural land. Within the landscape a dike is visible that has an elevation of 30 cm. Within the dike is a breach and a possible erosive channel at the dike breach visible in coring data from Dinoloket. Other elements are holes that are most likely caused by mining and wooden structures that had a possible function to improve sediment accumulation. Landscape of Etersheim consists of a drowned settlement of which most remnants are eroded into an erosive channel.

What is the thickness and composition of the Holocene sequences below the drowned surfaces?
In the Kuinderbos thickness and composition changes over distance from shore to sea. Near shore the Holocene thickness is between 1 to 3 metres and consists of 1 to 2 metres of peat and lagoonal sediments consisting of sand, silt and clay that differ in thickness between 20 cm and 1 metre. In most seaward direction, the Holocene sequence consists of 10 to 50 cm mostly consisting of silt and sand. Soil data of Wiggers (1955) proved that on top of silt and sand a layer of detritus was deposited with an estimated thickness of 20 cm. This layer was completely oxidised between the creation of the polder and moment of fieldwork. In the middle of the coring transect the Holocene sequence has a sediment thickness of 50 to 100 cm consisting of 30-50 cm detritus and 10 to 50 cm of lagoonal sediments consisting of sand, silt and peat.

The Holocene sequence in Uitdam has an approximate thickness of 12 metres. The sequence starts with a small Basal Peat layer with a thickness of up to 20 cm. On top of the Basal Peat is a layer of lagoonal deposits with a thickness between 2.5 metre and 7 metre consisting of silt, sand and clay. Lagoonal sediments are covered with a layer of peat with a thickness varying between 0.5 and 3 metres. This peat layer is than covered by lagoonal deposits with a thickness between 20 cm and 1.3 metre.

In Etersheim the Holocene sequence has an approximate thickness of 17 metres. The sequence starts with a layer of Basal peat on top of cover sand with a general thickness of 50 cm. The Basal Peat layer is covered by lacustrine sediments with a thickness of up to 1 metre if present. Lacustrine deposits are covered by lagoonal deposits formed in a non-closed sea shore with a thickness around 13 metres. Lagoonal deposits are covered by peat with a thickness of up to 3 metres when present. Peat is at some place covered by lagoonal sediments from the Zuiderzee with a thickness of up to 60 cm when present.

Relationship between age of landscape and onset of drowning
Age of a landscape and the onset of drowning do have a relationship but that is mainly linked to subsidence caused by oxidation that increases over time until a threshold of maximum drainage was reached. Drowning would then still only happen if technological advancement and socio-economic development of a region were insufficient to keep land dry. A direct relationship between age and drowning of a landscape cannot be found.

What is the preservation of the landscapes in the sub-case study areas?
Landscape preservation in the sub-case study areas was mainly explored using preservation zones created for the Kuinderbos and testing them on Uitdam. For Etersheim lack of data prevented use of this approach. However, using available data of Dinoloket still showed a similar relation of landscape preservation found in the Kuinderbos and Uitdam. Although it can be said that preservation in Etersheim is mostly likely worse than found in Uitdam and Kuinderbos. The lower preservation state is most likely caused by lack of a complete sediment cover that protects the landscape from further erosion. It seems that the relationship between distance to shore and preservation also holds for Etersheim but that the best preservation state is worse than in other case study areas. The preservation state of Uitdam is estimated to be in zone 1 and 2 except for mining locations and expected erosive channel. In the Kuinderbos a good preservation is observed near shore that slowly worsens over distance into sea. Zone 3 in the Kuinderbos shows the highest variance in observed preservation of drowned landscape although it is in general worsen than in zone 2. Within the Kuinderbos preserved landscape elements consist of mostly ditches with possibilities for dike structures.

Comparison with Kuinderbos
Only zone 1 and 2 are identified and compared with Uitdam and compared with the Kuinderbos. This is most likely due to the limited distance from shore which is visible in bathymetric data. Preservation zones of both sub-case study areas match in both morphology and lateral distance from shore. The biggest difference are large holes which are presumably used for clay or peat mining. This shows a difference in land use after drowning, influence of available sediments on land use and differences in socio-economic situation caused land use difference between the Kuinderbos and Uitdam after drowning of the landscapes.

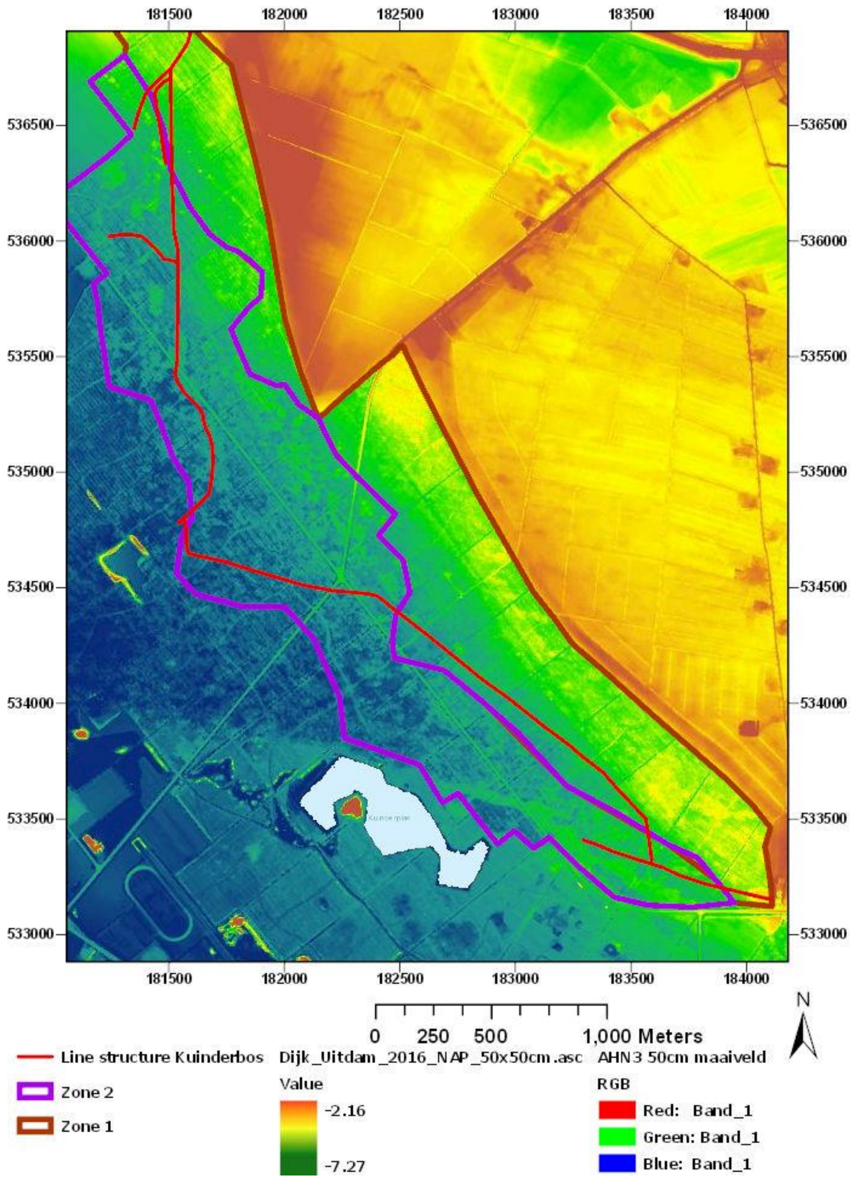

Figure 36: Line structure Kuinderbos plotted on preservation zones in Kuinderbos.

Normally zone 1 is a zone with high preservation potential, however the primary preservation of the peat reclamation landscape is gone at the location of these holes. In another way these holes are also part of a newer overlying landscape in which mining and erosion are prominent. Morphology between zone 2 of the Kuinderbos and Uitdam differs, although it is possibly caused by different sedimentological conditions, different geomorphology and difference between a polder and a still submerged landscape. In Uitdam a dike is situated in zone 2 and in comparison, to the Kuinderbos a similar looking structure can be observed. It is not known whether or not this structure is an actual dike or something build during or after creation of the Noordoostpolder. Figure 36 shows the line structure in the Kuinderbos. The line structure in the Kuinderbos is 10-15 metre wide, 40-80 cm high and 5.4 kilometre long which is longer, but also smaller than the dike in Uitdam. Both dikes are mostly positioned in zone 2 where it corresponds with the high expected preservation state.

Comparison with Etersheim, Uitdam and the Kuinderbos
Most of the finds of Etersheim are in close proximity to shore which is in line with other sub-case study areas. Differences with Etersheim in comparison to the sub-case study areas is that Etersheim is a drowned settlement. Due to the lack of information and details it is hard to compare the preservation state with other sub-case study areas. Although the erosion channel and secondary preserved archaeological finds are within the scope of the preservation prediction based on distance to shore and height of the landscape. Preservation of the Etersheim sub-case study area is fully in line with the Kuinderbos and Uitdam area. Although further in detail differences and similarities cannot be explained in further detail.

Preservation zones within the sub-case study comparison
Within this research non-preservation, primary preservation and secondary preservation of drowned landscapes and their causes have been summed up and proven using an approach of literature study, fieldwork and data analysis. The main result is the preservation zonation created using fieldwork data (Kuinderbos) and comparison to other data available for that case. These zones have been compared with available morphology to look if a preservation state is reflected by visible morphology on lidar imagery (AHN). Combining morphology with coring data proved to be a means for comparison with the Uitdam bathymetric data although there were many uncertainties regarding morphology and their corresponding zones. Zone 3 is for example recognised by the lack of distinctive morphology which makes it difficult to identify in other sub-case study areas. Moreover, zone 2 and zone 4 have no clearly defined boundary based on either size or height of the morphology and causes overlap with zone 3. Further comparison with sites and a deeper understanding of the morphology linked to preservation states may improve the zonation model for further archaeological research.

Correlation to predict preservation states

For the Kuinderbos sub-case, coring data was able to reveal four zones with different preservation states at increasing distance from shore, relative depth of a landscape and erosion depth. Dinoloket data was then used to verify the theory at other parts of the Zuiderzee including the sub-case study areas. After verification a quantification was tried to look whether or not a specific distance can be attributed to a certain preservation zone for other areas within the Zuiderzee. Comparing data of Dinoloket and the Kuinderbos the same development in decrease of peat thickness is witnessed throughout the Zuiderzee region. When applying the Kuinderbos zones to this data, it matches sites with shallower cover sands better than sites with a similar Holocene sequence as Uitdam. This approach does not hold for all areas but distances acquired from the Kuinderbos sub-case study area can give a first indication on preservation. Zone 1 seems to holds until roughly 400 meters into the sea, while zone 2 holds until roughly 1200 to 1300 meters into the sea, and zone 3 holds unto roughly 2100 to 2200 meters. The only thing that can be stated for zone 4 is that it roughly starts at roughly 2100 and 2200 meters, however the end of this zone cannot be further specified due to a lack of any specific data.

The correlation to predict preservation states is influenced by several factors such as, sediment influx, measures taken to prevent erosion and drowning of landscapes, further ingressions after drowning of a specific site, erosion, storm events, technological advancements and socio-economic situation at a certain time and place. When these and possible other causes and influences on drowning of landscapes are linked to each other a model can be created in which preservation of current and future drowned landscapes may be predicted. Using such a prediction may enhance *in situ* landscape preservation of drowned landscapes in line with the treaty of Valetta and current *in situ* practices within the commercial archaeology. This will allow for more information gain in the future on these landscapes of which still a lot is unknown.

6 Discussion

Usage of macro, meso and micro scales

Within the research an approach of different scales, macro, meso and micro was used. Both macro and micro have been researched in detail while the meso scale lacks detail. Lack of detail in the meso scale is mainly caused by data availability on chosen regions and overlaps with both macro and micro scale. Although the meso scale lacks in detail it still proved to be essential for a complete understanding of preservation states of drowned landscapes within the Zuiderzee area.

What caused drowned landscapes to preserve along the Zuiderzee?

Data of the sub-case study areas show that preserved Medieval landscapes within the Zuiderzee have a position close to the shoreline in common. Usage of obtained fieldwork data in the Kuinderbos shows an increase in erosion depth and a decrease in preservation state as distance to shore increases. This leads to the correlation in which the distance to shore, erosion depth and the depth of the landscape are the most important factors in preservation of Medieval landscapes. Comparison between the different sub-case study areas shows that landscape preservation differs regionally and locally due to human interaction with the landscape. The drowned landscape in Uitdam has possibly a better preservation than the eroded town of Etersheim. The 'Veenhuizen' lost settlement in Kuinderbos most likely has a preservation grade between that of Uitdam and Etersheim. With the available data obtained in chapter 4 and chapter 5, it is not sure whether or not human land use prior to drowning caused a better preservation of the drowned landscape. What can be said is that human land use caused large scale erosion and land loss (see chapter 4.1) which resulted in the erosion of drowned landscapes as their distance to sea increased.

Within the observed drowned landscapes of the Kuinderbos there is a difference between the preservation state of the landscape surface and the landscape sub-surface. In corings performed during fieldwork an erosive sand layer marks the onset of drowning caused by storm events. This kind of short-term drowning creates an environment in which the landscape surface most likely erodes while the sub-surface can be intact. The difference is mostly caused by its difference in position within the sequence. The landscape surface is located at the top of the sequence and more prone to erosion than the sub-surface layer which is farther away from erosive processes then the surface. Comparison between prehistoric and Medieval landscapes observed in corings of the Kuinderbos proves that the landscape surface of a prehistoric landscape tends to be preserved better. Higher preservation of prehistoric landscape surfaces is caused by the difference in drowning which is caused by a slow transition to wetter conditions that buries the landscape surface and thus increases its preservation potential (see chapter 3.2.1).

Which variables are relevant to characterise a higher susceptibility to drowning of a drowned landscape in the Zuiderzee?

From literature study it is clear that within the Zuiderzee region, susceptibility to drowning of a landscape was mainly human induced. Peat reclamation caused subsidence which increased erosion speed as there was less sediment to erode, see chapter 4.1.1. Moreover, an increase in erosion also increased the size of the Zuiderzee and thus also the fetch length of waves that could cause waves to be more erosive over time (Davidson-Arnott, 2010). Human induced subsidence was limited to technological and socio-economic possibilities (Sponsel, 2001; Schilstra, 1974).

Technological advances allowed for deeper drainage and thus lower surface elevations even below mean low sea level. Socio-economic value of a landscape could also determine whether or not a landscape was worth defending. If the sea defence became too expensive than it was sometimes possible to abandon land and maintain a less expensive sea defence more land inward. With the use of sea defences, susceptibility to drowning overall decreased. However, if land did flood after a dike breach than it was more likely to be abandoned because of a low surface elevation, see chapters, 4.1.3 to 4.1.6.

When further exploring susceptibility of drowning over time than it can be said that mainly around the Middle Ages susceptibility increased as distance from landscape to sea decreased, see chapter 4.1.5 (Schilstra, 1974). Prehistorical landscapes within the Zuiderzee were also susceptible to drowning but it mostly led to adaptation and abandonment (Ten Anscher, 2012). It has to be noted that drowning of prehistoric landscapes was different than Medieval landscapes. The difference is mostly caused by a slow increase in wetter conditions in prehistoric times versus sudden event-based drowning and erosion in the Middle Ages, see chapter, 3.2.

Which variables are relevant to characterise a degree of subsidence of drowned landscapes in the Zuiderzee?
Oxidation and compaction of peat mostly causes subsidence of landscapes. In most of the landscapes that is still the case however it also has to be linked to local capabilities to decrease surface elevation, see chapter 5.2.2. In Uitdam for example the hypothesis created in the sub-case study suggests an artificial drainage that allows surface elevation to be as low as -3 metres NAP. In landscapes within the Kuinderbos a higher elevation was found of around -1 metre NAP which either means a difference in technological possibilities or a difference in socio-economic possibilities.

Which variables are relevant to characterise the degree of degradation of alteration of former surfaces in drowned landscapes in the Zuiderzee?
Degree of degradation of alteration of former surfaces can be split into variables that alter the former surface while it is drowned and variables that alter the surface when it is situated in a polder. Erosion, reworking, sedimentation and human interaction are the most important for altering underwater drowned surfaces, see chapters 4.1 and 4.2. Erosion causes landscapes to disappear but also allows for secondary preservation of the landscape (e.g., Waldus, 2020). Reworking changes mostly the stratigraphy in which these landscapes are found and recognised. Sedimentation within the Zuiderzee region flattens the existing relief and relief caused by erosion, an example of this is sub-case study area Uitdam. Sediments increase preservation potential of low-lying areas of the landscape (e.g., Van Popta, 2019). Human interaction in for example Uitdam most likely caused large mining holes (Waldus & Muis, 2017; Pollé, 2019) which increased degradation of the landscape.

Within the Noordoostpolder landscape surfaces are altered by ploughing (Van Popta, 2020), relief inversion and peat oxidation, see also closed coring grids in the Appendix. Ploughing after creation of the polder altered most of the drowned landscape surfaces within the Noordoostpolder as large quantities of land are used for agriculture (Van Popta, 2020). Fieldwork results show that Low groundwater levels allow for peat oxidation, relief inversion and thus degradation of preserved Medieval landscape surfaces. Relief inversion takes mostly place if there are differences in types of sediments and in the Kuinderbos it is marked by difference between clastic and non-clastic material (peat), see datasets comparison within the Appendix. Peat oxidation that results in relief inversion degrades landscape surfaces at present times while it also allowed for the discovery of these landscapes (Van Popta, 2019).

What influences the preservation of drowned landscapes in the former Zuiderzee?
Preservation of drowned landscapes is influenced by different variables that changes temporal and lateral. The largest influences on preservation are distance to shore, depth of a landscape and erosion depth, as observed within the Kuinderbos. Timing of drowning is overruled by distance to shore as sediment influx in the region was insufficient to prevent erosion when a landscape is located further from shore. This also shows that ingressions, erosion of land in front of the dike and abandonment of dikes was of great influence to drowned landscape preservation as this causes an increase in distance to shore. The distance to shore correlation is based on coring data from the Kuinderbos fieldwork that shows a lower land elevation as distance to shore increases. Dinoloket shows a similar elevation and distance to shore relation in other parts of the Zuiderzee.

Distance to shore is thus a large controlling factor although it is also shown in the Kuinderbos coring data that depth of a landscape in the Holocene sequence and erosion depth are important. This shows that other drowned landscapes such as prehistoric landscape have a higher preservation potential due to overlying sediments that prevents erosion of these landscapes. Moreover, indications of aggregating phases visible in Uitdam and the Kuinderbos show that stability of the shoreline increases overall preservation of landscapes. Decrease in land loss diminishes the increase in accommodation space which is more likely to be filled with sediments, see chapter 4.2.3 and Pierik *et al.* (2017). If the increase in accommodation space is the same or smaller than the influx of sediments than landscape preservation potential increases due to a sediment layer covering it.

7 Conclusion

Aim of this research was to try to explain the preservation states of drowned landscapes within the Zuiderzee with their differences and similarities. To explain different phenomena that led to a drowned landscape and its subsequent erosion or preservation, an approach of zooming in from macro to micro and zooming out from micro to macro was used. Within this approach, data obtained from macro and meso helped with defining a correlation on the micro scale combined with fieldwork data. Within this correlation a clear relation was found between distance to shore, erosion depth, depth of drowned landscape within the sedimentation sequence and preservation of the landscape. This approach or concept was then used to create preservation zones which are defined by morphology and the differences visible within the Holocene sequence of the Kuinderbos. Important variables within this sequence are thickness of peat, succession within the peat, thickness of overall Holocene sediments and thickness and composition of the Zuiderzee sediments. Results of the preservation correlation and the following preservation zonation have been clearly defined due to a few reasons. First of all, due to the 50 meter coring resolution allowing for an in depth detail of the composition of different drowned landscapes within the Kuinderbos area. Second of all due to the approach of zooming in from macro to meso to micro and then zooming out from micro to meso to macro which allowed testing of the preservation correlation and preservation zonation on different spatial and temporal scales. This allowed for further specification and quantification for application to the whole research area instead of only the coring transect within the Kuinderbos or only the sub-case study areas. Last of all, the meso and macro publications and data sources as Dinoloket have sufficient detailed information to allow for application of micro results onto meso and macro results.

Within the application of the preservation correlation there are several reasons as to why the results are as clear as they are. First of all, the preservation correlation is based on multiple detailed datasets such as Wiggers, (1955), Van Popta, (2017), LIDAR imagery (AHN) and fieldwork data from this research. This allowed for a thorough investigation and identification of preservation zones and causes of preservation. Second of all, overall identification of variables that influence the preservation correlation of, distance to shore, depth of a landscape and erosion depth allowed for a more precise in depth model. These influencing factors are: long-term conditions (neotectonics and glacial isostatic movement), human land use practices, taken protective measures against drowning, sediment influx, failure of protection against drowning, scale of human interaction with the landscape and increase in natural erosional forces over time (storms and wind generated waves).

Results of the preservation states of drowned landscapes within the centre of the Zuiderzee are not quite clear. The first reason for this is the limited extend into the Zuiderzee of the sub-case study areas which is at most 4.5 kilometres. The second reason is that islands and former islands within the Zuiderzee have not been studied in this research. This raises uncertainty to whether or not the preservation correlation with preservation states includes islands and former islands. The reason is that currently very little research has been done on the landscape preservation states away from the coast within the Zuiderzee.

Results of both Etersheim and Northwestern Zuiderzee area lack detailed description and thus lack results on landscape preservation states. This is foremost caused by the lack of literature. In case of Etersheim it is due to a lack of access to available data and in case of the Northwestern Zuiderzee it was caused by the lack of data. The last reason for a lack in detail is the large scope of this research within the available time span. This led to choices which caused a less in-depth investigation of the cases of Etersheim and Northwestern Zuiderzee.

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Appendix

Fieldwork

This appendix reports detailed fieldwork results collected from the Kuinderbos case area in the North of the Noordoostpolder. Figure 37 shows the coring transect location. Results of fieldwork are split into sections in which the first part is analyses of acquired data and the second part consists of a data analysis of the fieldwork dataset with datasets of Van Popta (2017, 2018) and Wiggers (1955). The dataset of van Popta will be mainly used to compare results and also forms an addition to the north-eastern corings of the fieldwork to gain a further understanding of drowned medieval landscape preservation in the Zuiderzee. Wiggers (1955) is already used in comparison and will not be further explained in this part.

Material used to plan cross-section

The following information sources were used to decide on positioning of the coring transect:

1) AHN 3 (elevation map of the Netherland, hillshaded and coloured visualisations).
2) National soil map, scale 1:50,000 published by BRO.
3) Coring and ditch data from Veenhuizen obtained by Van Popta in 2017.
4) Topographic map dataset obtained via ArcGIS Pro.
5) National geomorphological map, scale 1:50,000 published by BRO.
6) Dinoloket, geological dataset consisting of corings published by TNO.

AHN 3 with hillshade and coloured relief were used to gain a thorough understanding of the terrain which is made visible through height differences. Height differences also give indications on (geo)morphology and anthropogenic influences in the area. The national soil map was used to gain an indication of soil sequences, figure 38 contains the coring transect with corings of week 1. This was then also used to look for boundaries where corings could be placed on to gain a further understanding on changes within these boundaries. Coring data and trial trench data of medieval ditches found using AHN from Van Popta (2017) were used for comparison and verification of the eastern part of the coring transect. For comparison most corings were placed outside of the ditches and an enclosed grid was placed on a series of ditches. The coring transect was located as close to a path as possible in case the GPS stopped working due to dense forest vegetation so that analogue position checks would also be feasible. During fieldwork the GPS could be used at all times and had an error margin between 3 to 10 metres. After creating the coring transect, the national geomorphological map was used to look whether or not something was missed. However, most areas correspond to the national soil map and thus the coring transect was also in position when comparing it to the location of map units in the national geomorphological map. At last, Dinoloket is used to look at the depth of Pleistocene cover sands to get an indication of the required coring depth.

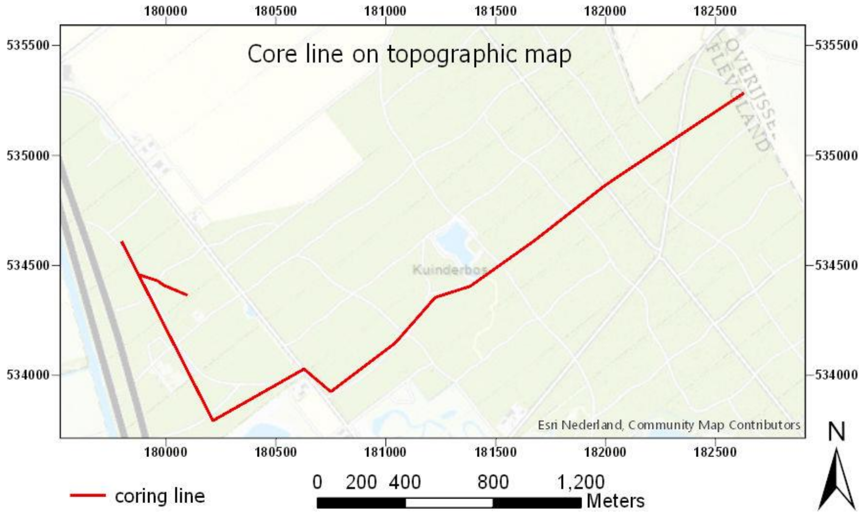

Figure 37: Coring transect in the Kuinderbos on a topographic map.

In the first week of fieldwork, corings were performed with a distance of between 150 and 180 metres, with the aim to cover the full transect and obtain corings from all units on the soil map and geomorphological map. This gave a first indication on recognisable landscape features and contrasts in preservation of former land and peat surfaces along the transect. In a second week of coring these were further investigated.

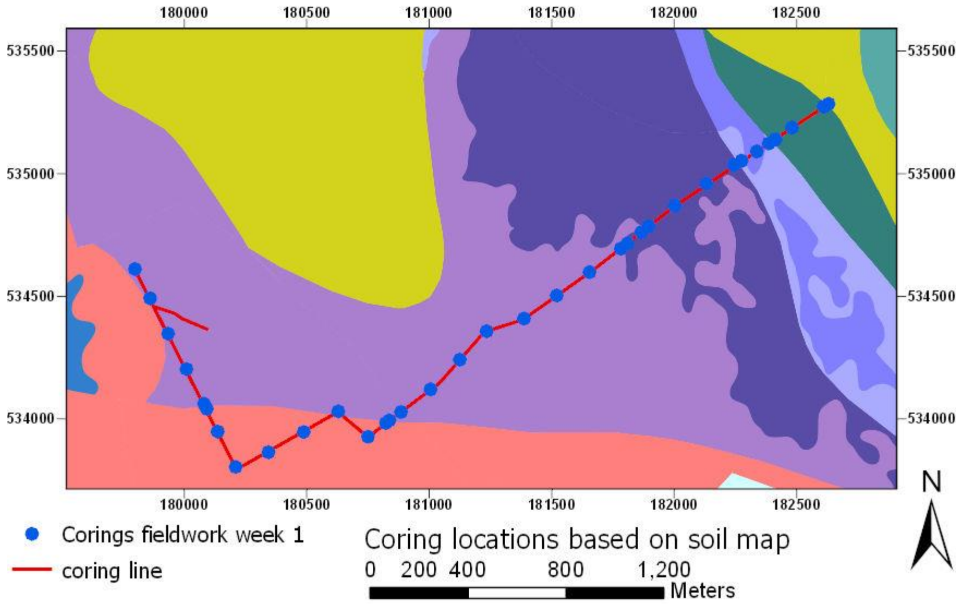

Figure 38: Corings of fieldwork week 1 are overlain on top of the soil map.

Corings for fieldwork aimed to upgrade the corings spacing of the transect to 50 metres. New boreholes thus were placed between the corings of week 1. Furthermore, a more enclosed grid was used at three different locations based on height differences observed using LIDAR imagery. Corings were placed on high and low locations to investigate what is causing differences in height. In figure 39, location of the enclosed grids along the coring transect are visible. Two of the enclosed grids (left and right) were thought out according to height differences on the AHN and the middle-enclosed grid was created during fieldwork according to a height difference observation in the field. Figures 40,41 and 42 show the locations of corings made during fieldwork per different enclosed grid.

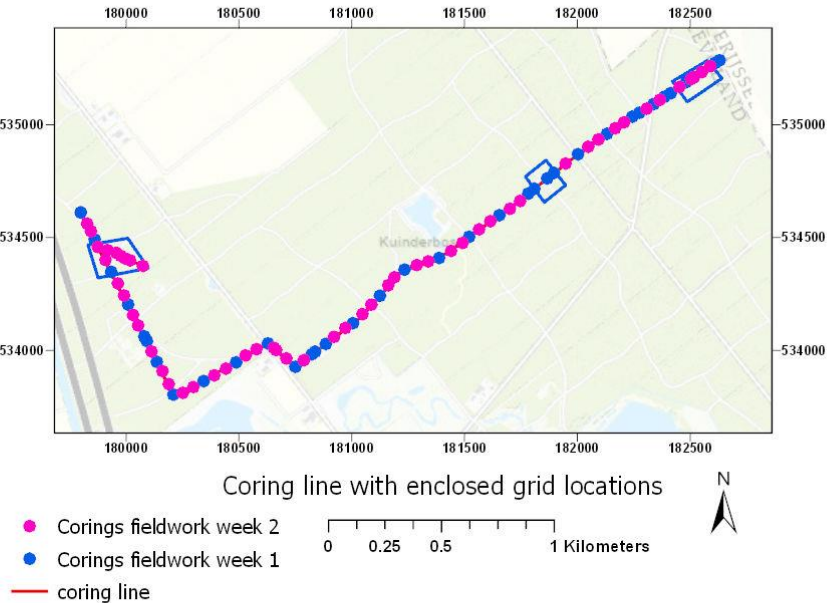

Figure 39: Coring transect including all coring and enclosed coring locations zones.

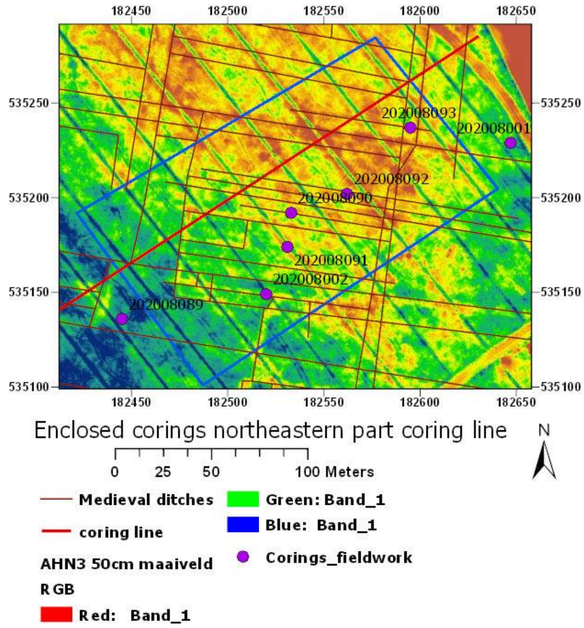

Figure 40: Enclosed corings in the northeastern part of the coring transect plotted on medieval ditch remnants and LIDAR imagery.

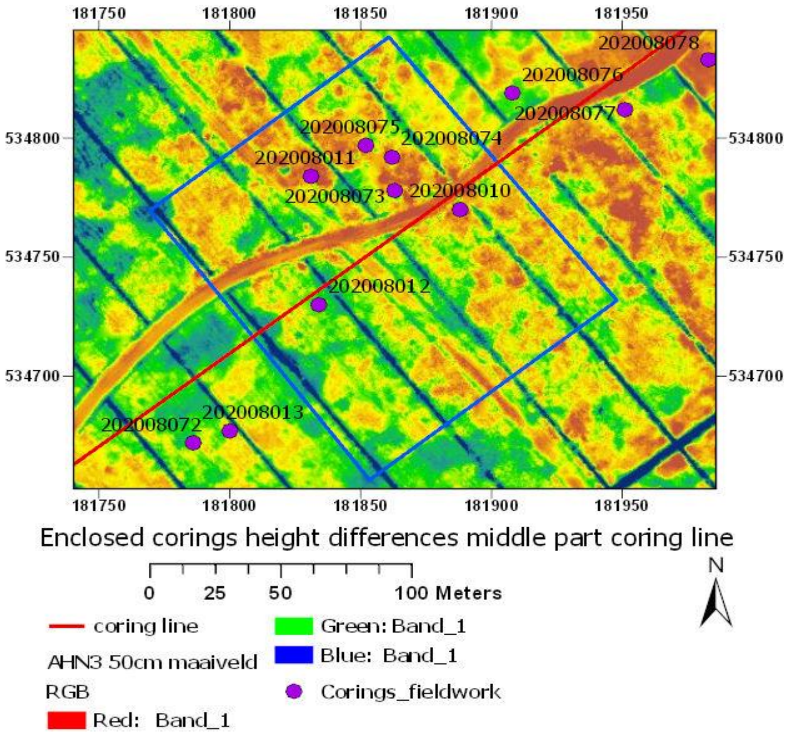

Figure 41: Enclosed corings based on height differences observed during fieldwork.

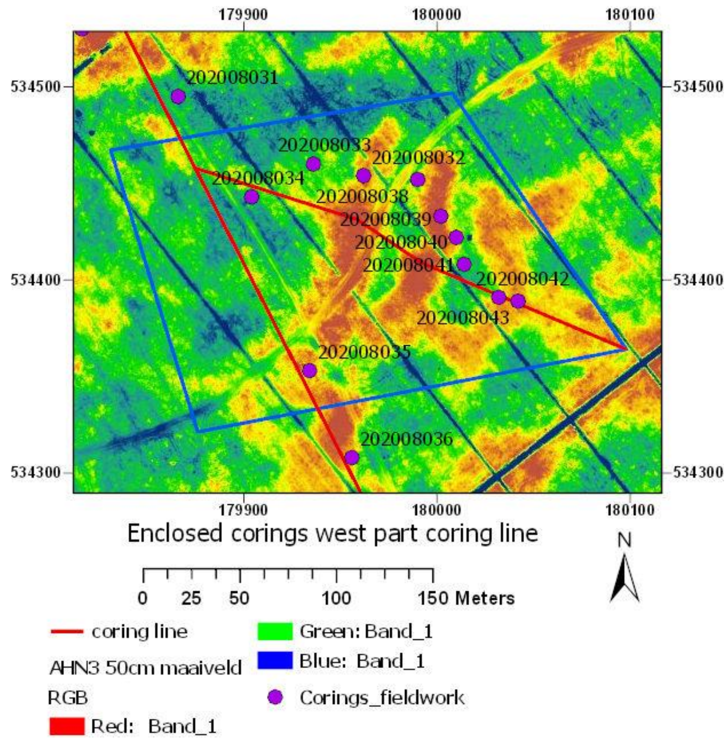

Figure 42: Enclosed corings plotted over height differences and an unknown morphological structure visible on LIDAR imagery.

During fieldwork it was difficult to place corings on the exact locations as planned before fieldwork. Especially the planned borehole locations on top of medieval ditches were difficult to place due to dense forest vegetation. Moreover, field observations and insights during coring caused the coring plans to be changed during fieldwork to obtain better results. The following variables caused the field corings to differ from the planned grid:

1) Dense vegetation made it sometimes impossible to core at a certain location. However, coring near obstructed location was always possible.
2) Unforeseen structures at coring location such as a ditch.
3) Unforeseen shooting zone which forbade trespassing and thus prevented coring within its locations (southwestern part of the coring transect).
4) On field observations and insights had to be tested using more corings than planned at certain locations such as the enclosed coring grid in the middle of the coring transect.

Multiple reasons existed to split off the results of week 1 and week 2 and afterwards combining them again:

1) The gap between the fieldwork weeks was used to analyse week 1 for better insights that led to better decision making on week 2 for possible changes in the planned corings.
2) Due to new insights in week 2 the insights of week 1 had to be reviewed and revised to prevent wrong conclusions.
3) Insights of week 1 and week 2 were sometimes contradicting each other and thus both results had to be reviewed for possible causes.

After all data was reviewed and revised everything was analysed together. All corings are visualised in figure 43 with legend and determinations in Dutch. In table 2 a conversion from Dutch codes used during fieldwork (B&S 2001) to USDA is made (Cohen, Hijma and Törnqvist, version 1.5).

Cross-section results: observations

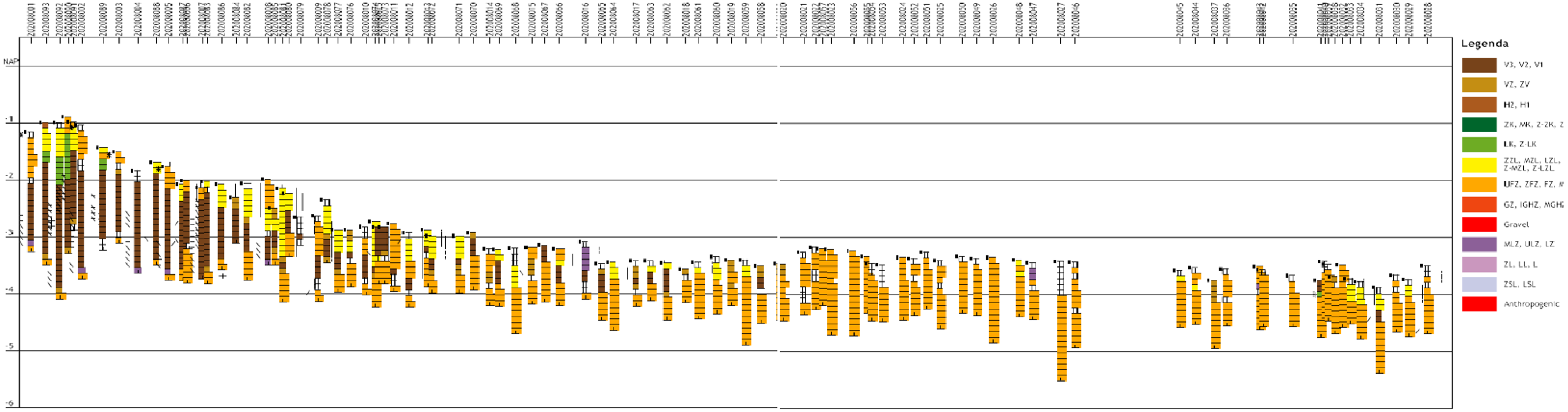

Figure 43: All 93 corings made during fieldwork with -NAP values on Y-axis and the distance between corings and their individual numbers on the X-axis.

B&S 2001 codes	Description Dutch	USDA codes	Description English
ILZ	Zwak lemig zand	LS	Loamy Sand
Z-LK	Zandige lichte klei	SCL	Sandy Clay Loam
MZL	Matig lichte zavel	SiL	Loam
ZZL	Zware zavel	SiL	Clay Loam
LK	Lichte klei	SiCL	Silty Clay Loam
ZV	Zandig veen	SP	Sandy Peat
H0	Iets humeus	M0	Little Humic
H1	Humeus	M1	Humic
H2	Sterk Humeus	M2	Very Humic
V1	Venige klei	M	Muck
V2	Kleiig veen	PM	Peat Muck
V3	Veen	P	Peat

Table 2: Conversion of the Dutch code and their meaning to USDA and their meaning in English.

Figure 44 shows the height differences between left (north-eastern part of the coring transect) and right (southwestern part of the coring transect). In this trend the ground level lowers with roughly 1.5 metres while cover sand is slightly more stable with a height difference of roughly 80 cm. Height differences between left and right are partly caused by the remaining succession of peat on the left while it diminishes sea inwards (right). Relief in the cover sands can be explained by paleo relief and long-term subsidence processes which is due to its age. Cover sand dates roughly to the Weichselian (MIS 2) and has an approximate age of the length of the Holocene which is roughly 11,700 years.

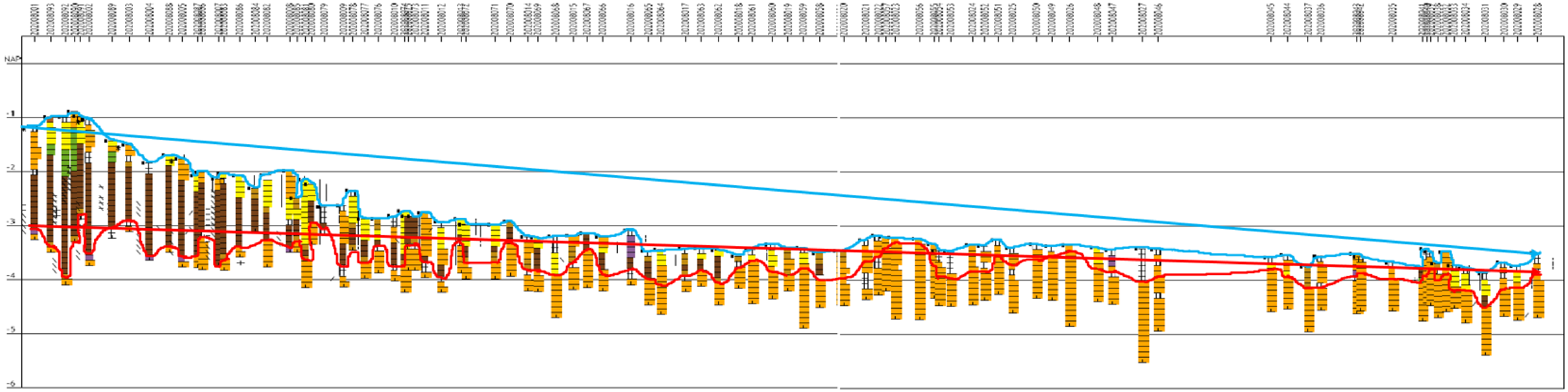

Figure 44: Trend in surface height (blue) and cover sand heigh (red) plotted on -NAP heights. Blue shows ground level locations and its trend while red shows cover sand locations and its trend.

Figure 45 shows a relation on the amount of clastic (blue) and organic sediment (brown) visible in individual corings. In corings on the left a large part of the sequence consists out of organic sediments. While the right part of the figure consists of mainly clastic sediments. It can then be stated that a relationship exists between the trend of lower ground level and a decrease in organic sediments in the sequences.

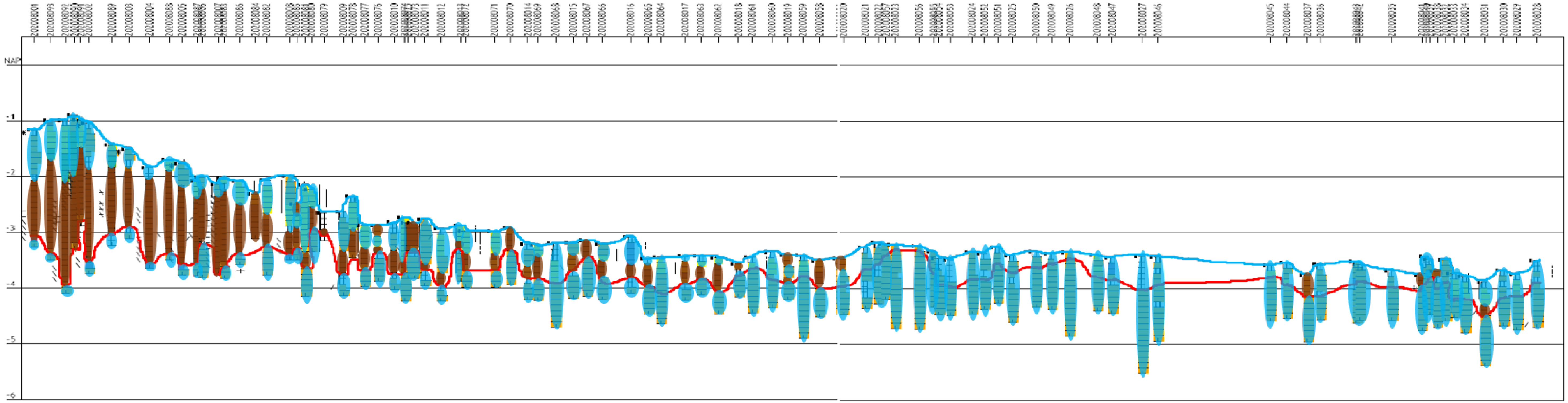

Figure 45: The amount of clastic sediments in a coring in blue and amount of organic sediments in brown.

Figure 46 shows whether or not relief was influenced by paleo relief. Red zones (areas were paleo relief influences relief) tend to become bigger as the amount of organic sediments decreases in the corings. While blue zones (areas where paleo relief has none to a little influence on relief) are not increasing nor decreasing. The relationship between the size of the red zones and the amount of organic sediments can mainly be explained by the fact that paleo relief has a decreasing influence on relief as it is buried by more sediments. It is also shown that a large amount of peat does not completely rule out influence of paleo relief on present relief. Influence of paleo relief on existing relief will only increase in especially the left part of the image due to present low groundwater levels leading to oxidation of peat. A relationship between thickness of the peat and influence of paleo relief on relief is not visible as relief is influenced in zones with high amounts of organic sediments and in zones with less to none organic sediments. A direct relationship can thus not be made however, there is still a relationship visible between the amount of organic sediments and influence of paleo relief on morphology.

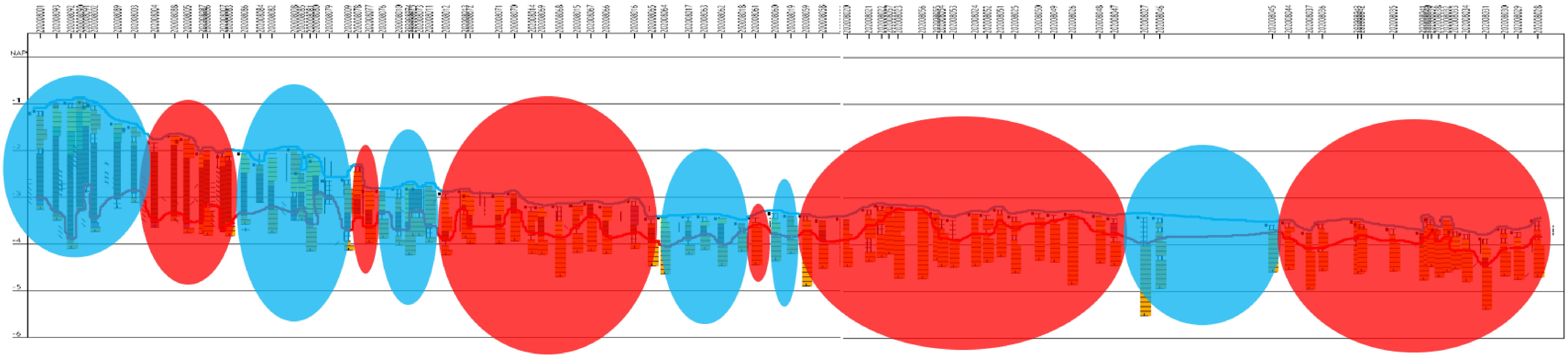

Figure 46: Red zones are areas where paleo relief has influence on relief while blue zones indicate areas where no to almost no influence of paleo relief on relief is visible.

Figure 47 shows different preservation zones that could be made according to observations in corings from fieldwork in combination with research from Van Popta (2017). Preservation of landscapes are determined by certain features that give an indication of preservation in a coring. Preservation of a landscape in cover sand is more easily observed than in a medieval peatland landscape. Differences between the preservation observation is mainly caused by difference in clastic and organic nature of sediments. Cover sands are older sediments which were prone to soil formation and through time a podzol could form. An intact podzol with an A-horizon or an intact succession from A-horizon to peat due to gradual drowning would mean a preserved or an almost complete preservation of a drowned landscape. With an A and or B horizon in a podzol it is possible to state that the landscape is mostly gone and only deep soil features of landscapes structures can partly survive. Peat reclamations cause peat oxidation and any feature in the sub-soil that could be a marker would be either eroded by the sea or oxidised by present or past oxidation. In peat it is only possible to find indications of preservation when looking at destructive phases in the sequence and link that to a past landscape. Oxidation due to peatland drainage led to relative enrichment of clastic materials on the surface that increases in thickness as oxidation continuous through time. A clastic layer can form from oxidation of metres of peat because peat exists of 2% to 15% clastic material (Stouthamer, Cohen & Hoek, 2015, p.240). Clastic layers on top of peat that could be attributed to oxidation have not been found in fieldwork corings nor in fieldwork data of Van Popta (2017). Two reasons for this are that peat has reached bog peat or transitional peat succession (Wiggers, 1955) which fed wholly or partly on rainwater and erosion at the onset of drowning. Feeding on rainwater causes a low amount of clastic materials of between 1% to 2% in bog peat (Stouthamer, Cohen & Hoek, 2015, p.240) and thus will also create a small layer of clastic material even if 1 to 3 metres of peat oxidises. Looking for oxidation locations to determine past reclamation is not possible due to still occurring oxidation. Relative compaction of peat gives indication for three different processes, compaction due to structures, erosion and deposition of peat and consolidation of peat due to water drainage. Places with a highly compacted peat are indicators for past structures such as dikes (Wiggers, 1955, p.175-176). Marine erosion and deposition led to a peat layer that is less compacted than peat layers in its original context, these peat layers were in fieldwork characterised by shell fragments. Consolidation due to water drainage led to compact peat layers, compact layers of peat were also found near the top of peat in the northeast although it was not sure whether this was compaction due to past or present processes. In the northeastern corings a clay layer was found on top of the peat; this clay layer is also an indicator for preservation of the medieval landscape. Clay indicates an environment with low flow velocities which most likely indicates a depression in the drowned medieval landscape or flooding of the medieval landscape before drowning. Van Popta (2017) linked clay to ditches that were dug to drain peat reclamations and documented a thin clay layer outside the ditches. A most probable explanation for clay deposition in the ditches is that after drowning the depression that was formed by ditches created an environment with low flow velocities where clay could be deposited until the depression was entirely filled in. Infilling of these depressions led to shallow water condition, higher flow velocities and thus coarser sediments that lie on top of clay. An explanation for clay next to the ditch is flooding of the area while it was land. Water would flow back into sea but clastic material within water would be left behind on land.

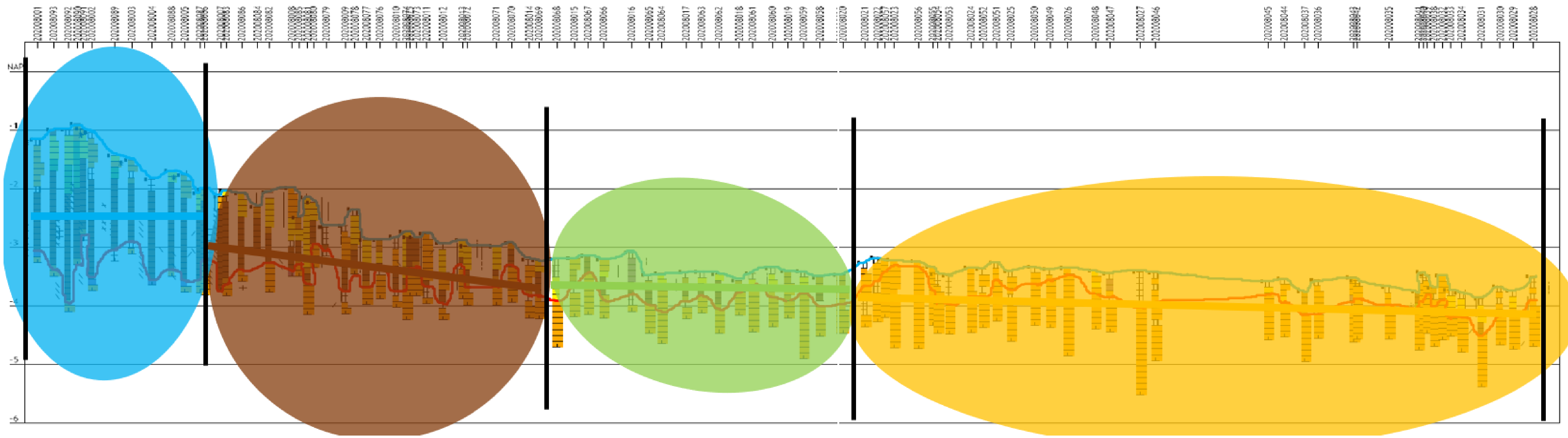

Figure 47: Preservation zones with a clear distinguish between zone boundaries with a black line. Inside the zones a line of the same colour is used to indicate the length of the zones also in other figures.

In figure 48 there is a strong relationship between the thickness of the Holocene sequence and preservation of certain landscape types. The blue zone of primary and secondary preserved prehistoric and medieval drowned landscapes has the thickest Holocene sequence of around 1.5 metres. The brown zone with primary and secondary prehistoric and possible primary and secondary medieval preserved landscapes has a Holocene thickness between 60 cm to 1.5 metre. The Holocene thickness of the green zone of a partly preserved primary prehistoric and partly preserved secondary medieval landscape becomes thinner to a value between 30 cm to 1 metre. The yellow zone has the thinnest Holocene sequence and the lowest preservation of drowned landscapes with a Holocene thickness mostly smaller than 1 metre. Figure 49 shows different classifications of peat. It also shows that in areas with more peat a general higher preservation of prehistoric and medieval drowned landscape. On the left side of figure 49 where most of the peat is intact a succession to peat bog is visible. To the right, peat successions are still visible that go to transitional peat or fen peat. Classification of peat in this case is not based on the plant remains because of a lack of knowledge to classify plant remains in peat. Instead, it is classified on the amount of clastic material that can be observed in the field. V1 is peat with high amounts of clastic material. V2 is peat muck and it contains less clastic material than V1. V3 is muck and contains most organic material. In the peat succession from fen to bog the amount of clastic material decreases due to the changing origin of water that feeds peat. This means that V3 is an indication of bog peat moreover when it is oxidised and relatively enriched by clastic materials due to oxidation. Most peat in the corings was (partly) oxidised thus relatively enriched with clastic materials. This peat succession gives a minimum of peat succession due to oxidisation in past and present and due to erosion by the Zuiderzee. A strong relation between the Holocene thickness and visible peat succession to bog peat is visible. Moreover, an intact peat succession is an important indication of preservation of a drowned medieval landscape as it is located on top of peat. Places with no to a thin layer of peat indicates a lack of preservation of a medieval landscape.

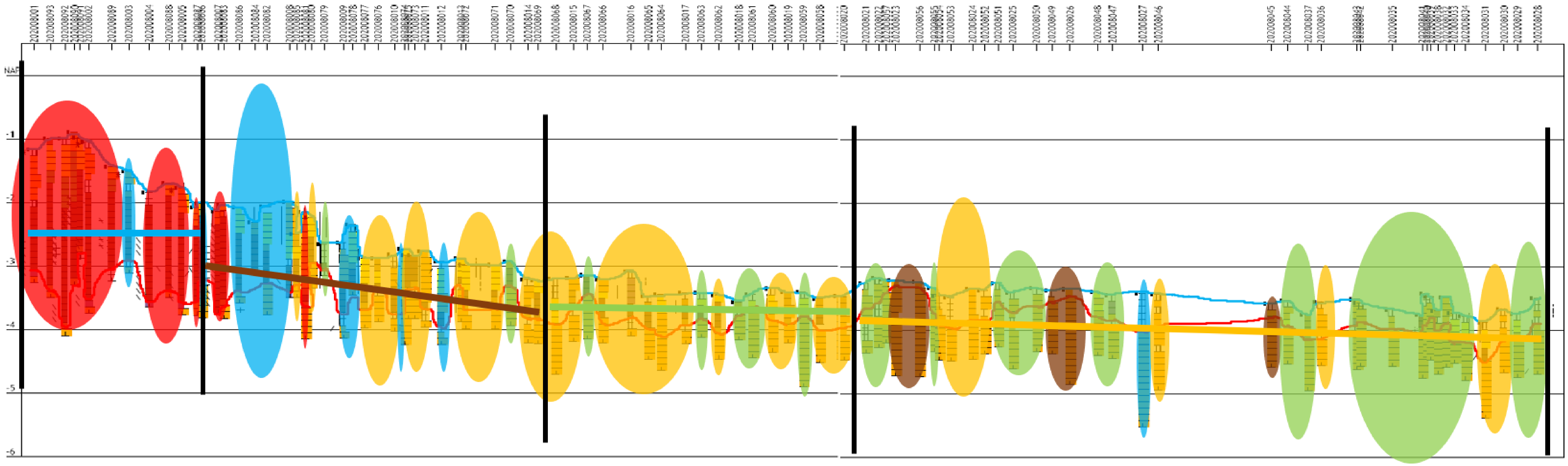

Figure 48: Thickness of the Holocene sequence and width of different preservation zones. Red means a thickness of at least 1.5 metre, Blue means a thickness of 1.1 metre till 1.5 metre, Yellow/orange means 60 cm to 1 metre, green means 30 cm to 50 cm and brown means 20 cm or thinner

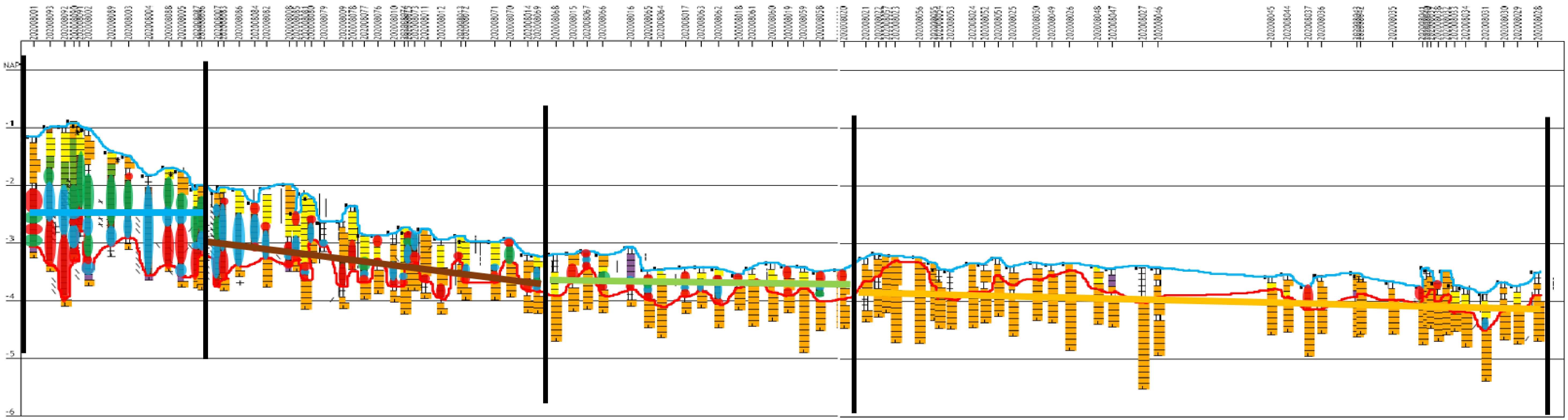

Figure 49: Succession of peat. Green means V3, peat. Blue means V2, peat muck. Red means V1, muck.

Figure 50 shows thickness of lagoonal sediments from the Zuiderzee. Within the profile larger circles are clusters of roughly the same sediment that indicate ingression periods and their relative location within the ingression period compared to the water level. Coarse material can be found close to the water surface as flow velocities and the sediment capacity increases. Finer material is mostly found in locations with lower flow velocities and thus a lower sediment capacity. Smaller red circles in figure 50 indicate relative thick sediment deposits compared to corings next to it. Colours within the circles indicate thickness of lagoonal sediments. Blue is a thickness between 1.1 to 1.5 metre, orange/yellow is a thickness between 60 cm to 1 metre, green is a thickness between 30 cm and 50 cm, brown is a thickness of 20 cm or smaller. Large blue circles indicate a zone with relative coarse sand and reflect an area that was relatively close to the water surface. The large red circle indicates an area with mainly silts that indicate an area with deeper waters and thus an area that drowned quickly. This ingression could be linked to a large ingression period in the 12th century in the Zuiderzee area although exact dating has yet to prove it. Smaller circles in the large circle to the right are locations of thick lagoonal sediments that indicate a temporary stop of the ingressive period in which sediments could accumulate in front of the dike. The red circle to the left is an area that has a thinner peat sequence and a thicker lagoonal sequence that is evidence for prolonged periods of oxidation and/or prolonged periods of sedimentation. The time of sedimentation was started from the 17th century CE onwards (Van Popta, 2019, p.37) when this area was completely drowned and stable coastline caused sediment accumulation in the smaller red circle to the left.

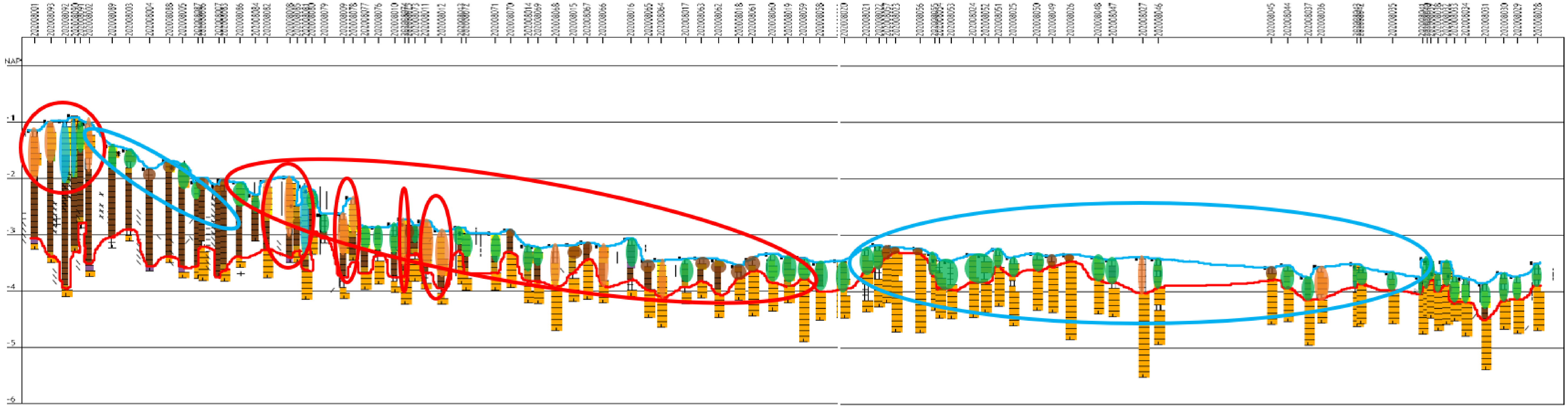

Figure 50: Thickness of lagoonal sediments. In the large circles it shows groups of the same sediments and smaller circles within the large circle indicates a location with a thicker lagoonal deposit compared to its surrounding corings.

Cross-section results: interpretative

Figure 51 shows the locations of prolonged periods of stillstand within the ingressive periods in this landscape. The red line indicates the beginning of the Medieval landscape based on the onset of a fast ingressive period indicated by the large red circle. The blue line indicates a coring with eroded highly compacted peat that gives an indication of previous compaction. Figure 52 shows erosion development of dike remnants. In case of the blue line, it is around phase E of figure 51 in which only eroded remnants of a nearby compacted peat feature are visible. At the striped blue line is a still intact compacted peat feature present that indicates a possible dike location. Red dotted lines are temporary pauses within the fast ingression period in which sedimentation accumulated in front of the coast. Two red striped lines next to the fast ingression period are locations where a sequence of sand and silt in lateral direction is found. Sand is linked to low water depths and can mean drowning of protective land in front of the dike while silt indicates a greater water depth. Difference in this water depth could be caused by oxidation of peat that created a lower area. The coring next to the silt is sand again which indicates a low water depth again which could be caused by still existing height differences in the peat. Two striped lines to the left also indicate two stillstands in the ingression. The one most to the left roughly represents the current coastline although its location should be more to the left. All these areas are indicative for possible dike/coast locations although future research has to prove whether or not these locations are actual indications of either dikes or stillstands in ingression.

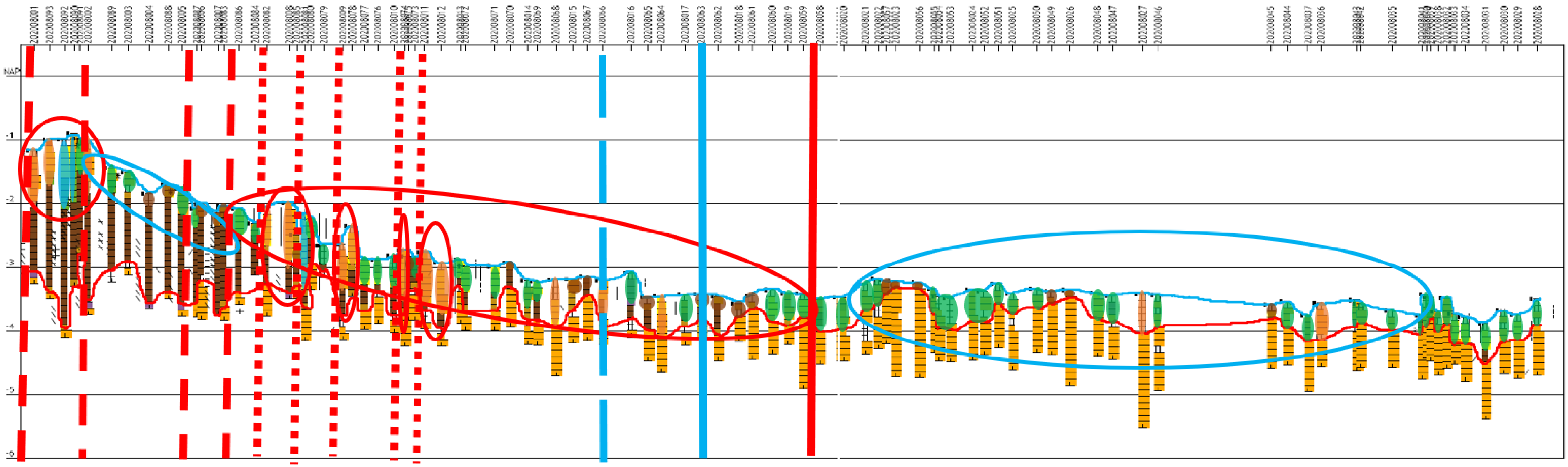

Figure 51: Locations of temporal stops in ingression of the landscape are visible through dotted and striped lines. Vertical lines indicate maximum extend of medieval landscapes in the Kuinderbos.

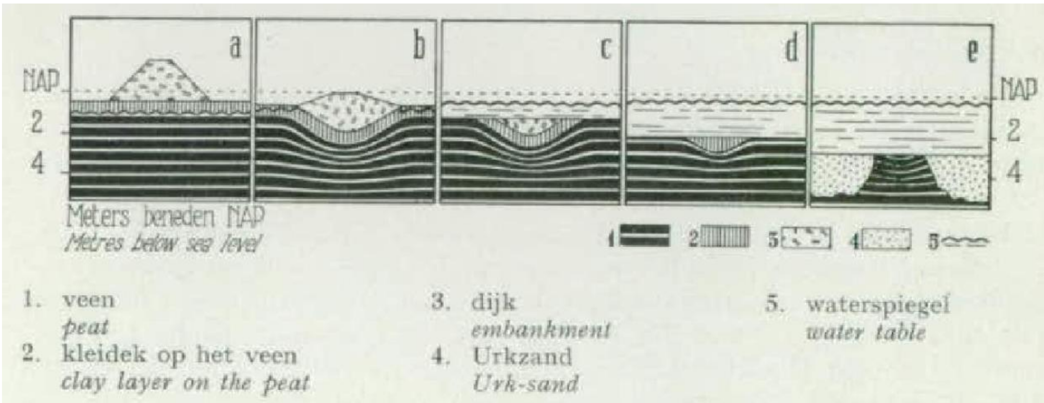

Figure 52: Development of erosion of dike remnants in the Zuiderzee (Wiggers 1955, p.176).

In multiple corings a small layer of white sand was found within the sequence. The source of white sand is found in two corings (corings 49 and 50) where it is found in its original position. Figure 53 shows locations of the white sand sources in a red circle and locations with a blue circle are corings with a layer of white sand. To gain a further understanding of this phenomena black lines are places on the vertical position of white sand within the corings. It can be stated that the vertical position of white sand within the Holocene sequence is different. On the right of the black vertical line white sand is in between the Zuiderzee sediments. While on the left of the black vertical line white sand is located on top of the drowned surface. Erosion and deposition of white sand took place after drowning on the right side of the vertical line. On the left side deposition of white sand equals onset of drowning. As white sand is slightly coarser than cover sands and can be explained as deposition of a storm event that caused drowning of a part of the landscape. Corings further to the left of coring 76 (east) do not contain any white sand which could be explained as the sea could not carry the white sand further east (left in the figure) from its source. When combining white sand data with ingression data above an interpretation can be made stating that the medieval drowned area can be placed more to the west (right), at the location of the vertical black line. Most white sand depositions on the landscape are placed further to the right (west) in the ingression area as indications of sea defence are more located to the left (east). This is caused by the fact that the source of white sand is located in the right (West) and that sand could not travel throughout the whole profile due to its particle size.

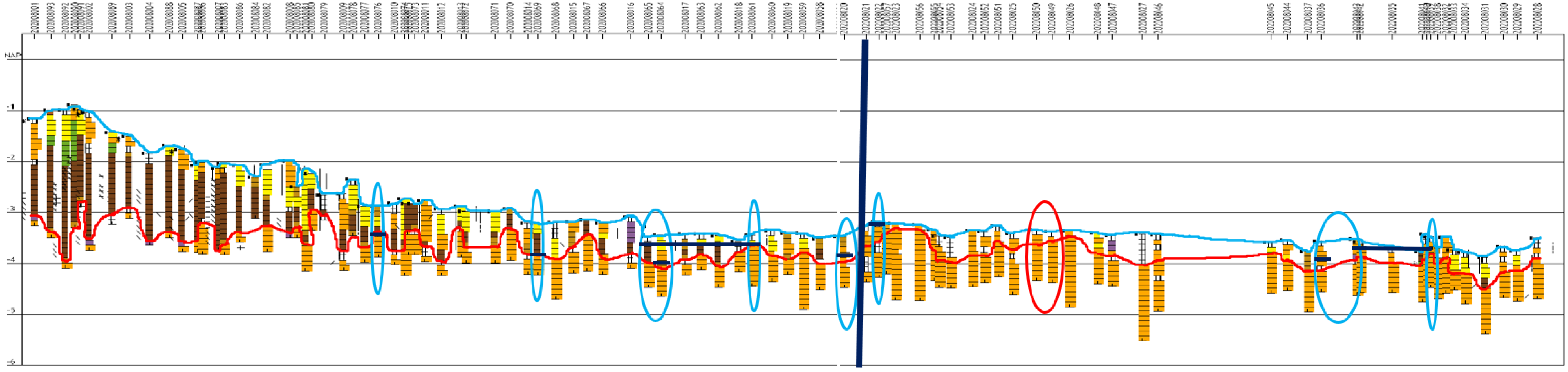

Figure 53: Blue circles indicate eroded white sand deposited elsewhere while red circle indicates the white sand source. Horizontal black lines indicate the location of the sand layer and the vertical black line indicates a change in location of the white sand position in a coring.

Using data on white sand deposits within corings it is possible to say that due to sea ingression the erosion location migrates more land inwards with an ingressing sea and thus possibly slowly moving away from the white sand source. Within the profile the lowest depths are around -3 to -4 metres NAP (Dutch ordnance datum). that means abrasion stopped at this height and that new sediments could be deposited and eroded again/reworked. When looking at the profile it can be said that a relation between preservation and thickness of Holocene sediments and lateral distance to the coast is rather strong. At a certain distance from the coastline abrasion created a maximum depth of around -3 to -4 metres NAP while water depth decreases as distance to coast decreases. However, this decrease is not linear as it happens more stepwise. It also works the other way around as distance to shore increases water depth of not maximum abrasion depth will increase until it reaches local maximum abrasion depth. That means that preservation of drowned landscapes decreases as distance from shoreline increases until a certain point related to depth of the landscape and maximum reach of abrasion. Then another important variable for preservation would be depth of a landscape which can then be explained as: landscape depth ≥ maximum abrasion/erosion depth = persevered, while: landscape depth ≤ maximum abrasion/erosion depth = not preserved. If the component lateral distance to shore is introduced than it will become distance to shore is large, abrasion depth is maximal and chance of preservation of drowned landscapes will be minimal. If lateral distance to shore is minimal then abrasion depth will be minimal then preservation of drowned landscapes will be maximal.

Detailed investigations and comparison with Wiggers (1955) dataset

During coring a relief difference was visible and thus an enclosed coring grid was used to explain the height differences, the corings made on the morphology are visible in figure 54. In figure 55 the profile of the enclosed core grid is visible. A small height difference was observed between coring 73,74 and 75 of which 74 is the highest and 73 and 75 are lower. A direct cause to the height differences is the difference in clastic sediments in coring 74 and peat in corings 73 and 75 at the top of the coring. In corings 73 and 75 the thicker peat layer near the surface is more prone to oxidation which causes relief inversion. The difference in composition at the top is also shown in figure 55 in which coring 74 is marked as an indication of a temporary stillstand in the fast ingression period.

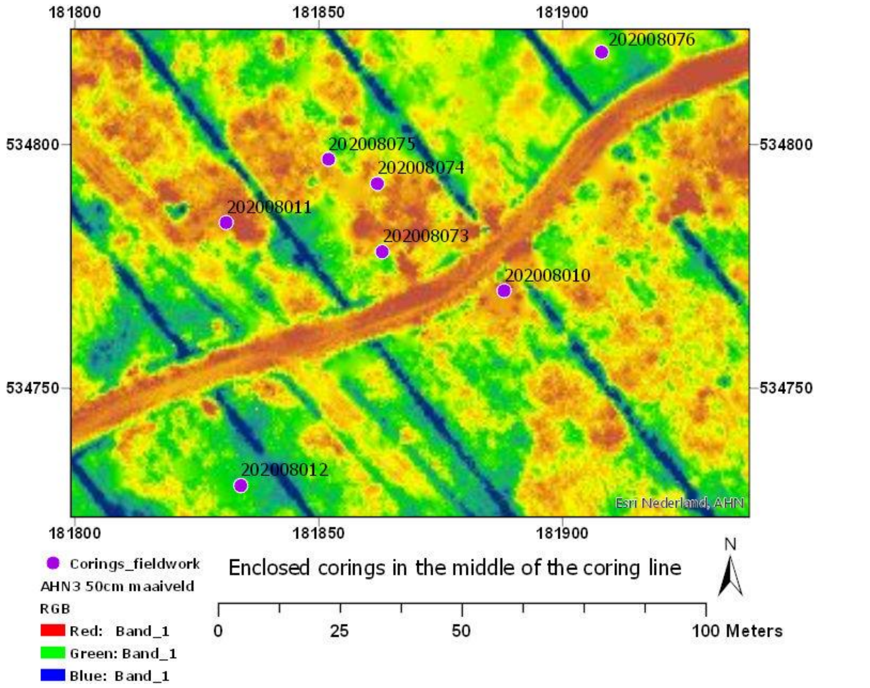

Figure 54: Enclosed coring grid on height differences in the middle of the coring transect.

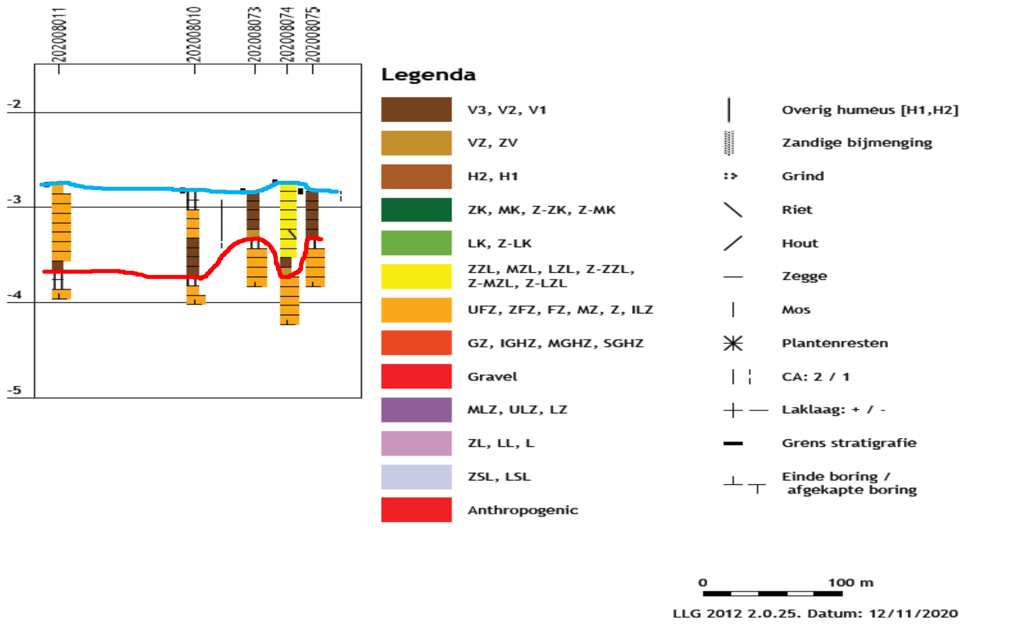

Figure 55: Profile of the enclosed grid in which the blue line indicates the ground level and the red line shows cover sand height.

Figure 56 shows the soil profile at the enclosed coring location and its surrounding. The soil profile shows an incision of Zuiderzee sediments (Zu) in the peat (mV), in this incision humic silts are deposited by the Zuiderzee. Another observation is that incisions in the peat by the Zuiderzee are common over small distances in which alternation of shallow and deep incision occurs. These incisions are visible in figure 56. All indications of a stagnation in ingression based on Zuiderzee sediment thickness in corings 84 till 72 are located in incision locations. A relation between stagnation of ingression and incision can be made as either an erosive event or prolonged periods of peat erosion at the same location. Some incisions in different profiles can be linked together although it is difficult to link them purely by shape in the profiles as the shapes tend to differ in each profile.

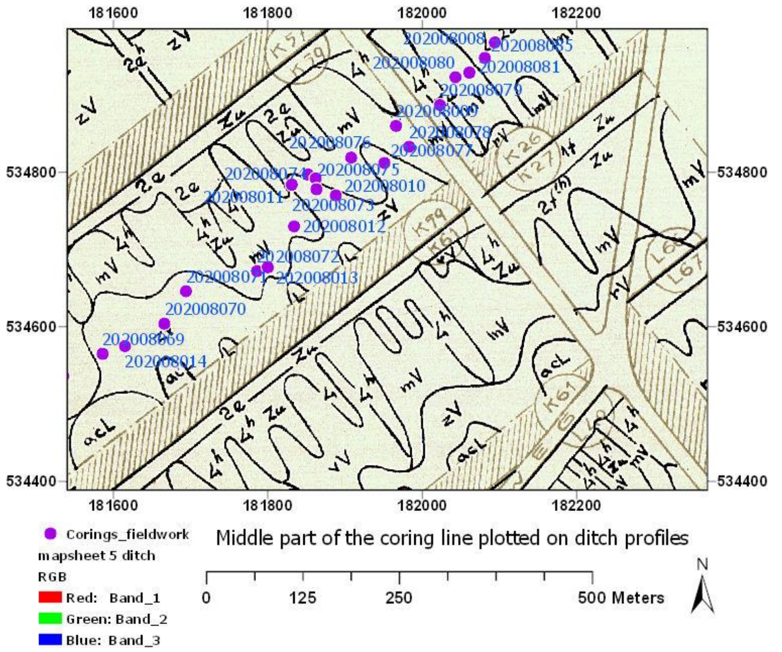

Figure 56: Coring transect in the middle part of the ditch profile overview map of Wiggers 1955.

Another enclosed grid location was located in the southwestern part of the grid visible in figure 57. In figure 58 the surface level is visible in blue while cover sand is visible in red. It shows that height differences are mainly based on the relief of cover sand. However, the shape visible in figure 57 shows that morphology on the image is not a morphology that would be expected of cover sands. Whether or not human interaction changed the already existing relief is unknown. To get a better understanding of these structures the soil map of Wiggers (1955) was reviewed and it is visible in figure 59. Profiles were made along the then fresh ditch cuts and the top of these profiles is georeferenced to the location of the ditches. The closer a coring is to a ditch the better the comparison with the soil profile can be made. Near coring 43, cover sand (acl) is getting higher after a depression. Differences in height in cover sands are also visible in ditch profiles although these profiles still indicate sedge peat (zV) above cover sands while almost no peat has been found. Disappearance of peat due to oxidation after creation of the polder made height differences in this area more visible.

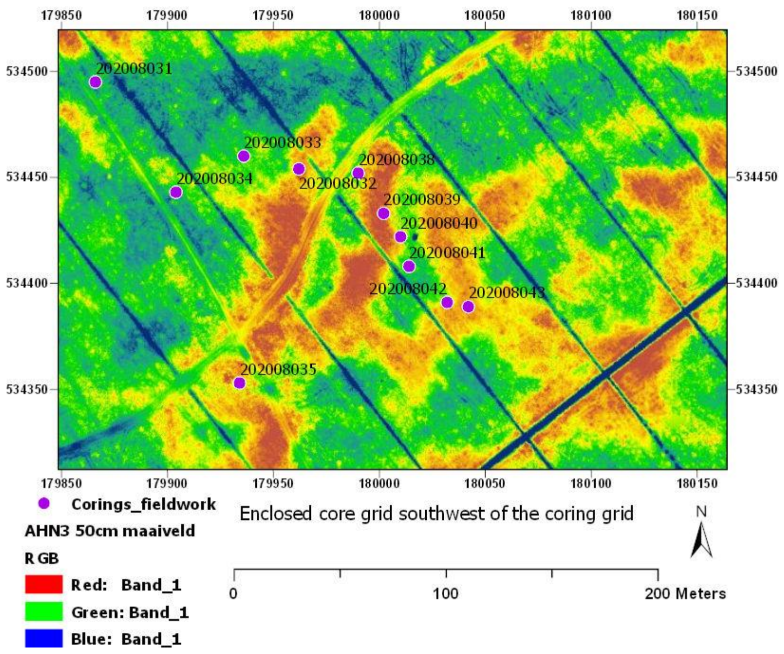

Figure 57: Corings on or near height differences in the enclosed coring grid.

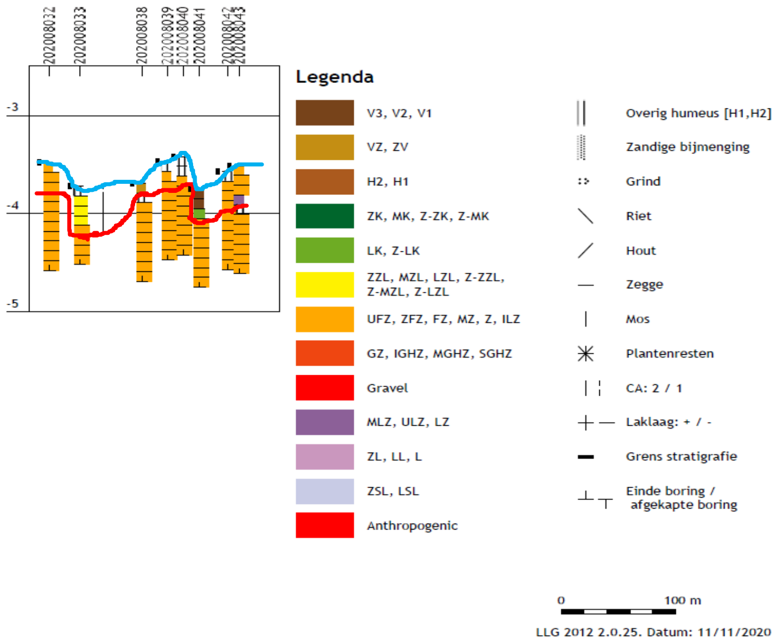

Figure 58: Profile of corings performed on visible height differences within the enclosed grid.

Figures 59 and 60 shows the soil map created by Wiggers (1955). 4//V means 10-15 cm of silts (4) and peat (V) till 25-30 cm the zV below it means sedge peat until at least 45 cm below ground level and below that cover sand (acl) is visible in the corings. Differences made between sedge peat and peat is an indication of the nature of peat in which it is not sure if the peat is still in its original context while sedge peat indicates that peat is in its original context of forming. At some locations in figure 60 the code 5/D is used which means Silts with higher clay percentages till 10-15 cm detritus till 25-30 cm below ground level. Detritus lies in the profiles on top of the sedge peat which indicates no erosion of cover sands. Thus, the soil profiles indicate that the morphological structure was already formed before peat formation as peat in its original context was found on top of cover sand in this area. In present corings almost no peat has been found due to oxidation after creation of the polder.

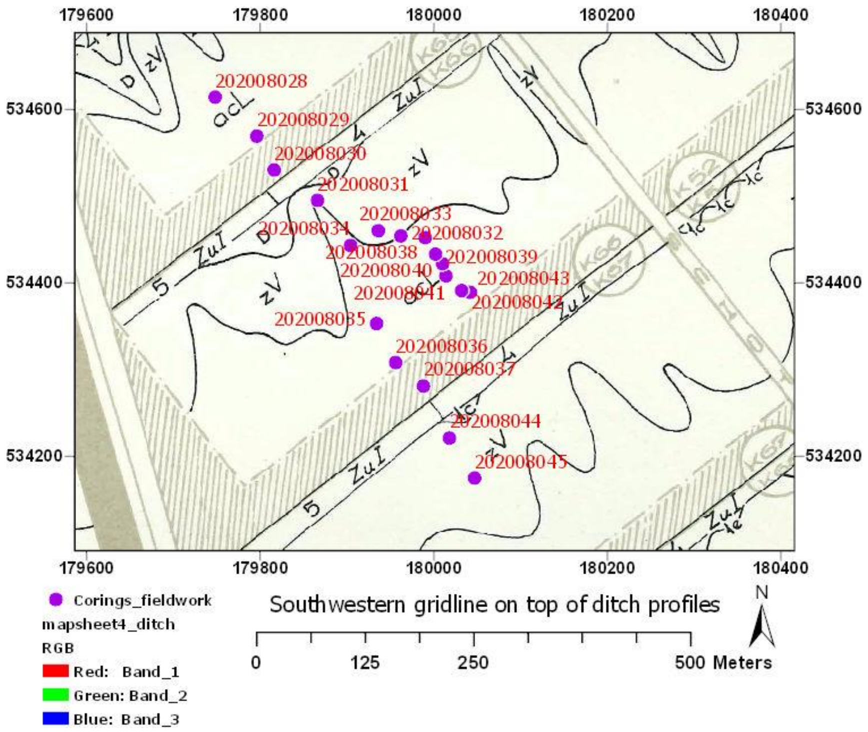

Figure 59: Southwestern part of the coring transect plotted onto ditch profiles from Wiggers 1955.

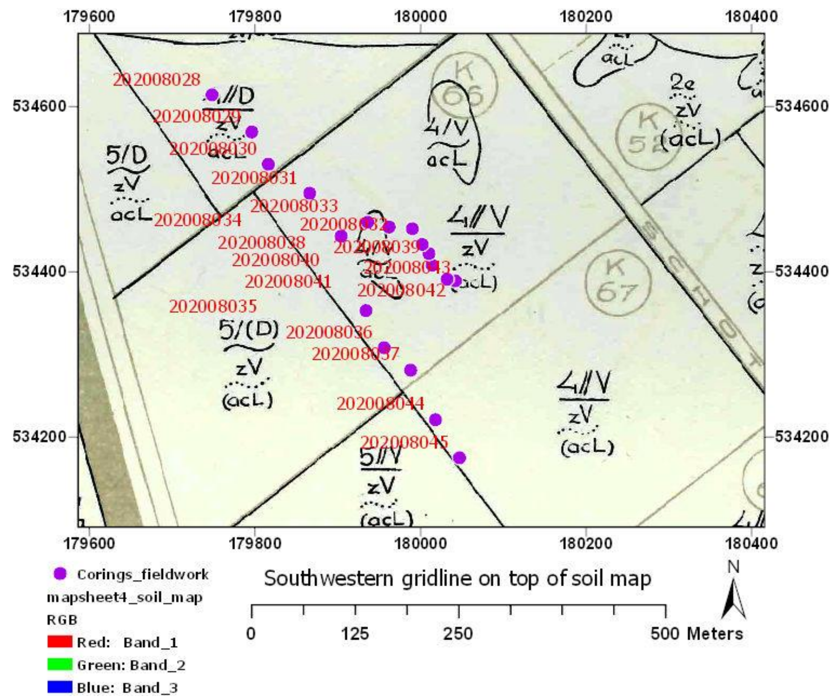

Figure 60: Coring grid on top of the soil map of Wiggers 1955.

Comparison with Van Popta datasets

When looking at the coring data it can be observed that the profile shows similarities in the structure of sediments and their successions. Within the datasets are also eight profiles. These profiles were used to get a further understanding of the corings as the stratigraphy is better visible in the profiles. During the current fieldwork only 1 type of clay was found while Van Popta recognised two types of clay within some profiles. When looking at the description of clays two sedimentary environment end-members can be identified while clays in themselves could be in transition from one end-member to the other end-member. Clay at the bottom is blue grey with reed remains while the top clay layer in the ditch is brown grey with jarosite spots. Blue grey clay is most likely deposited when the landscape was not drowned as it is positioned in the lowest part of the ditch and contains reed and has a blue grey colour. While brown grey clay is evidence of clay that is deposited in brackish/saltwater conditions and thus deposited just before drowning as the sea could flood onto the landscape and after drowning in which the ditch was a slow velocity area in which clay sedimentation could go on. Jarosite present in the brown grey clay gives an indication of the brackish/saltwater. Jarosite forms in sediments with none too little calcium carbonate when pyrite oxidises and pyrite is formed in sediments that contain iron, sulfate, organic matter and sediments needs to be in a reduction state (no oxygen) (Jongmans *et al*, 2018, p.36-37). Criteria for jarosite to form are oftentimes met in lagoonal sediments. Next to the ditches is also a much thinner clay layer present that is comparable with the brown grey clay. Whether or not clay next to the ditches was deposited before or after drowning is not known, but it is safe to assume that before complete drowning, clay was deposited after flooding of the area. That would then also mean that the lowest part of the brown grey clay was also deposited in the ditch before drowning which could indicate a more extensive use of the area and less maintenance to the ditches.

Discussion Fieldwork

During fieldwork, observations were made regarding preservation stated of different landscapes. Some observations based on peat classification were hindered by a lack of knowledge to classify peat in the field. To overcome this problem peat was classified according to its physical properties in the field. Moreover, the creation of the Noordoostpolder is a good opportunity to research drowned landscapes, although it also poses a threat to the current preservation grade. Low groundwater levels found in areas with the highest preservation grade cause further oxidation of peat and thus information loss. Reconstructions based on field corings had to be checked with observations made by Wiggers (1955) whom observed sediment sequences just after creation of the polder.

Throughout the fieldwork chapter and the fieldwork appendix are some indications about storm events and ingression phases which could not have been fully proven. They are more suggestion in which further thorough investigation has to prove whether or not ingression happened in same phases and same locations as noted in the appendix.