Tidal River Development

The Interreg IVB North Sea Region Programme

Shallow water areas in North Sea estuaries - Changing patterns and sizes of habitats influenced by human activities in the Elbe, Humber, Scheldt and Weser

23rd March 2013

by

Kay Hamer[1], Nick Cutts[5], Johanna Knüppel[2], Nick Liedtke[1], Sue Manson[3], Jürgen Schröter[1], Frederic Roose[4] and Wouter Vandenbruwaene[4]

1: Department of Earth Sciences FB 5, University of Bremen, P.O.Box 330440, D 28334 Bremen, Germany

2: Hamburg Port Authority (HPA), D- 20457 Hamburg, Germany

3: Environment Agency, Albion Mills, Willerby, Hull, UK

4: Flemish Government, Department Mobility and Public Works, Antwerp, Belgium

5: Institute of Estuarine & Coastal Studies (IECS), University of Hull, UK

Disclaimer

The authors are solely responsible for the content of this report. Material included herein does not represent the opinion of the European Community, and the European Community is not responsible for any use that might be made of it

This report should be cited as follows:

Hamer K., Cutts N., Knüppel, J., Liedtke N., Manson S., Roose, F., Schröter J. and W. Vandenbruwaene (2013): Shallow water areas in North Sea estuaries - changing patterns and sizes of habitats influenced by human activities in the Elbe, Humber, Scheldt and Weser. 41 pages and Annex (73 pages). TIDE- Report, financed within Interreg IVB. Hamburg.

Project part-financed by the European Union (European Regional Development Fund)

The Interreg IVB North Sea Region Programme

Table of Content page

1 Introduction

The TIDE- project (Tidal River Development) aims at developing strategies for an integrated and sustainable future management of the estuaries of the North Sea region, considering the requirements of existing uses and, additionally, the requirements of European environmental law, especially the Water Framework Directive (WFD; 2000/60/EC) as well as the Birds (BD; 79/409/EEC) and Habitats (HD; 92/43/EEC) Directives.

Different administrative and scientific institutions from the estuaries of the Elbe, Humber, Scheldt and Weser rivers are project partners of TIDE. Tidally influenced river basins are home to a number of highly regarded and protected nature and landscape features. Major parts of the TIDE estuaries belong to the European Natura 2000 network. On the other hand, centres of economic interest have developed along the estuaries. In addition to well-known ports like Antwerp, Bremen, Hamburg or Hull, uses such as industries, shipping, tourism, fisheries and agriculture are important economic factors in the TIDE-estuaries. These diverse uses in the estuaries make it a challenge to balance all interests, it is necessary to develop effective and sustainable estuary management strategies.

1.1 Hydromorphology influencing habitat patterns – Results from HARBASINS

Estuaries try to balance hydraulic energy by adapting geomorphology, naturally. Within the last centuries, mankind intervened changing the geomorphology from time to time in addition to natural processes. As a result, hydraulic “reactions” of the rivers like changes in velocities, new patterns of erosion and sedimentation can be observed.

This report sums up anthropogenic changes in the respective TIDE estuaries such as embankment, land reclamation, cut-off tributaries, straightening the river bed, fairway deepening and sand mining. In more detail it focuses on the change of habitat patterns over time by looking at their spatial appearance within the estuary at different times.

This topic had been investigated by several former projects, most recently within the Interreg IIIB project **Ha**rmonised **R**iver **Basin** **S**trategies North Sea (HARBASINS 2008). One aim of HARBASINS project was to enhance compatibility of WFD (2000/60/EC) and coastal management in the North Sea Region. Decrees to be considered were Marine Strategy Directive MSD (2008/56/EC), Wild Bird (79/409/EEC) and Habitats Directive BHD (92/43/EEC), ICZM, Trilateral Wadden Sea Conference (TWSC) and OSPAR.

A focus of HARBASINS was the ecosystem services approach (Costanza et al. 1997) which considered the whole entity of nature in different time and spatial scales. A quantification of ecosystem services should support a more holistic understanding of the estuaries and allow a better comparison of environmental assets with social and economic aspects.

As a result, HARBASINS reached a common understanding of ecology in estuary management, but methods to monitor, measure and evaluate ecosystem services were still lacking or needed harmonization. Additionally, the sectoral responsibility in environmental management hampered the consideration and implementation of ecosystem service approach. HARBASINS recommended to bridge the gaps by financing projects in that field on a European level and offered to function as a network of experts. So the European funded TIDE-project can be seen as a direct successor of HARBASINS.

Additionally, HARBASINS recommended to look at and to evaluate historical and present states of estuarine topography in order to quantify habitat changes such as the spatial development of sub-, inter- and supratidal. Within the frame of HARBASINS this was carried out for the Humber, the Scheldt, the Ems and the Weser (Elsebach et al 2007).

Within TIDE again the consideration of ecosystem services is in the focus of interest. In addition to the results of HARBASINS, the TIDE project investigates results from the Elbe estuary and compares it with the estuaries mentioned above. Additionally, the habitat patterns are distinguished in more detail. The consideration of zones defined by salinity along the rivers and currents allow a higher resolution in distinguishing habitats. Related to HARBASINS, the consideration of the Elbe estuary and the more detailed habitat differentiation of TIDE is of added value in order to consider ecosystem services on the scale of estuary.

1.2 Aim and outline of the TIDE report on shallow water areas

It is the aim of this TIDE-report

- to get an overview on human activities which might have influenced the estuaries, especially regarding the morphology of the river, its hydrodynamic characteristics and the development of habitats and their distribution and appearance in the estuary
- to collect data about the changes in habitat distribution within time
- to calculate the extension and appearance of those habitats for different time steps in the estuaries and differentiated in different salinity zones
- to discuss those findings based on the comparison of the North Sea estuaries

In chapter 2 links among anthropogenic and natural processes influencing the habitat distribution patterns are described, after the terms sustainability, ecosystem services and habitat are introduced. Additionally, an overview about the relevance of hydrology on morphology is given and the impact of human activities on both, hydrology and morphology, is described.

In chapter 3 the habitat types, the methods how areas of habitats in the estuaries were calculated and the data base are described.

The comparison of the calculated areas for habitats in different time steps and salinity zones are displayed in chapter 4.

Chapter 5 discusses specific aspects of the observed development and concludes in chapter 6.

After an index of references, for every estuary maps of habitat patterns, an overview on human activities and data about surface sizes can be found in the annex.

2 Background: Sustainability as part of management and habitats in North Sea Estuaries

Estuaries are the interfaces between open sea and fresh water, so that brackish and marine environments are in close neighbourhood. Organisms living in an estuary depend on the occurrence and extent of diverse habitats, characterized by water depth, substrate of the ground, oxygen concentration, salinity and light. These factors are directly linked to hydrology, especially currents, wave action, tides and water residence times as well as position and extent of the turbidity zone.

Naturally, in such a dynamic system the overall erosion and sedimentation are balanced. This natural balance can be interfered by external processes, either of anthropogenic or natural origin. An estuary management system should consider this web of processes in a sustainable way.

2.1 Sustainability and ecosystem services

The concept of sustainability rose when mankind became aware of limited resources and the strong links among economy, society and ecology (e.g. Meadows 1972, Munashinghe 1998) (Fig. 2-1). A sustainable development is defined as a process that ensures that today´s use of ecological resources and ecosystems provides economic growth to meet the needs of the present, but without compromising the needs of future generations.

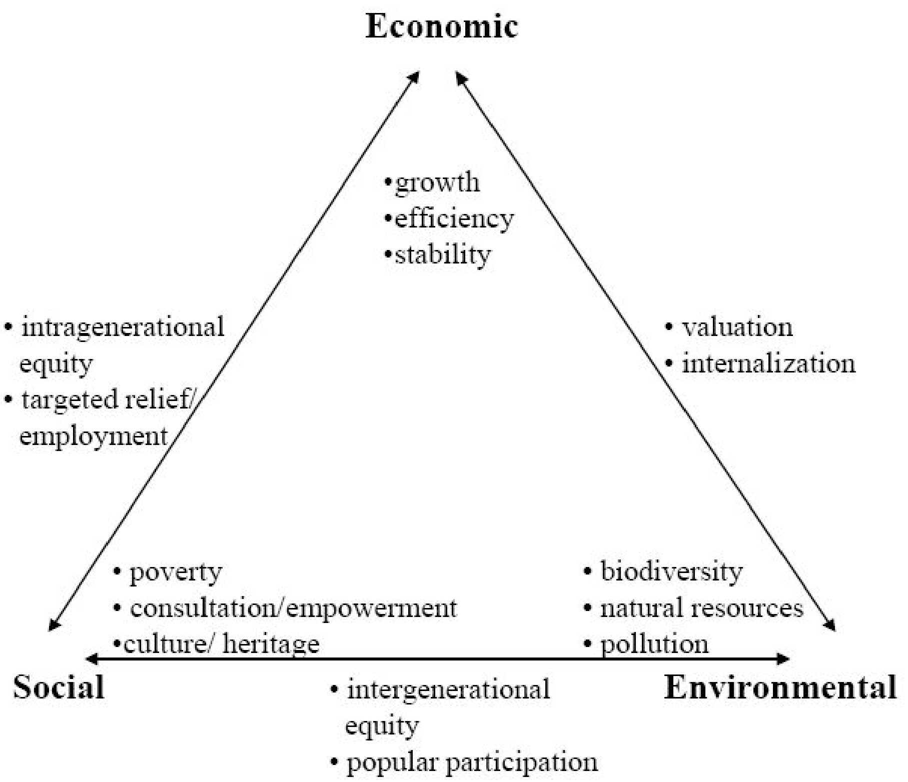


Fig. 2-1: The sustainability concept has to consider economic, environmental and social aspects (Munasinghe, 1998)

Nevertheless, due to the broadness of the concept it has been difficult to incorporate it into legal frameworks. Besides implementation into existing legislation the comparison of economy, ecology and social welfare on the scale of an estuary is complicated because such a comparison had to consider very different types of information relevant to support decision-making procedures (Costanza et al. 1997; Farber et al. 2002). How to compare environmental parameter with economic values? In order to quantify the "value" of estuaries, it should be considered that coastal and estuarine areas belong to the most productive environments. Covering an area of appr. 8% of the Earth´s surface, nearly 28% of total global primary production takes place in coastal and estuarine areas (de Jonge and Elliott, 2001).

Looking at the recently observed loss of habitats in the North Sea estuaries such as the Elbe (Schuchardt et al. 2007), the Ems (Herrling and Niemeyer 2008), the Humber and the Scheldt (Harbasins- summary report 2008) as well as the Weser (Schuchardt et al. 2007; Elsebach et al. 2007) it becomes obvious that the applied estuary management tools demand a sustainability component.

2.2 Changes in the North Sea estuaries: natural and man-made

2.2.1 Climate changes and isostatic movements after the Ice Age

Climate is a dynamic system in geological as well as historical time scales. After the last ice age, melting of glaciers and inland ice shields induced a sea level rise of 120 m and the basin of the North Sea area was flooded (Fig. 2-2). In those times the morphology of the recent coastlines developed stepwise (Streif 2004). Thinking in historical scales in Mid Europe, the so-called climatic optimum ended in 1300 AD, where the temperature laid 1-2 K above recent mean values. A later period of lower temperatures, called the "Little Ice-age", lasted until 1850. Since that time, again an increase of temperature has been measured in the middle of Europe (Schönwiese 1994).
The observed sea level showed an increase since the beginning of the measurements in the 19th century. In the German Bight the mean sea level rose approximately 25 cm since 1890 (Fig. 2-3). However, measurements demonstrate that mean high water level and mean low water level show changes to different extent; while the MHW increased in the last 100 years up to 25 cm (Fig. 2-3) the MLW increased approximately 10 cm/100 years (Fickert and Strotmann 2007; Hensen and Mulderbach 2007).
Within the mouth of an estuary, the tides at different gauges developed independly (Fig. 2-4).

Despite of an enormous data set, it is still impossible to forecast climate change. So realistic scenarios are used to simulate the development instead. As a result, these scenarios assume a temperature rises between +1.4 up to +5.8 ^{o}C and an ongoing sea level rise is anticipated between +10 cm to +90 cm for the years until 2100 in the area reaching from the Humber across the North Sea towards the German coast (IPCC 2001). For the Humber area an increase of the sea level rise rate is assumed (Environmental Agency 2011) from a recent rate at 4 mm/a up to 12 mm/a by end of the century. Additionally, the patterns of precipitation would change. Increased precipitation is to be expected in winter while a reduction for the summer period is forecasted. More heavy rain fall events are calculated. Such changes can influence the hydraulic situation in the estuaries (Atkins 2002; Schuchardt and Schirmer 2005).

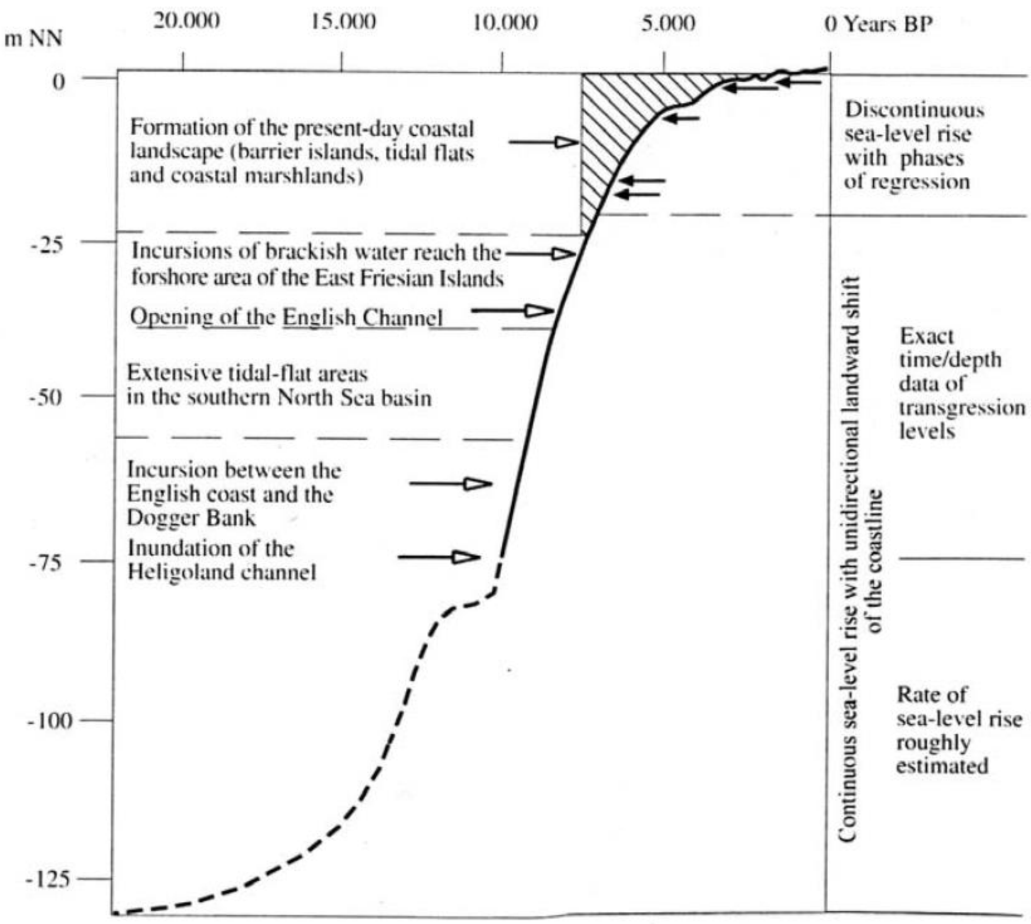


Fig. 2-2: Sea level rise in a time/depth diagram from 20,000 years BP to recent times (Streif 2004)

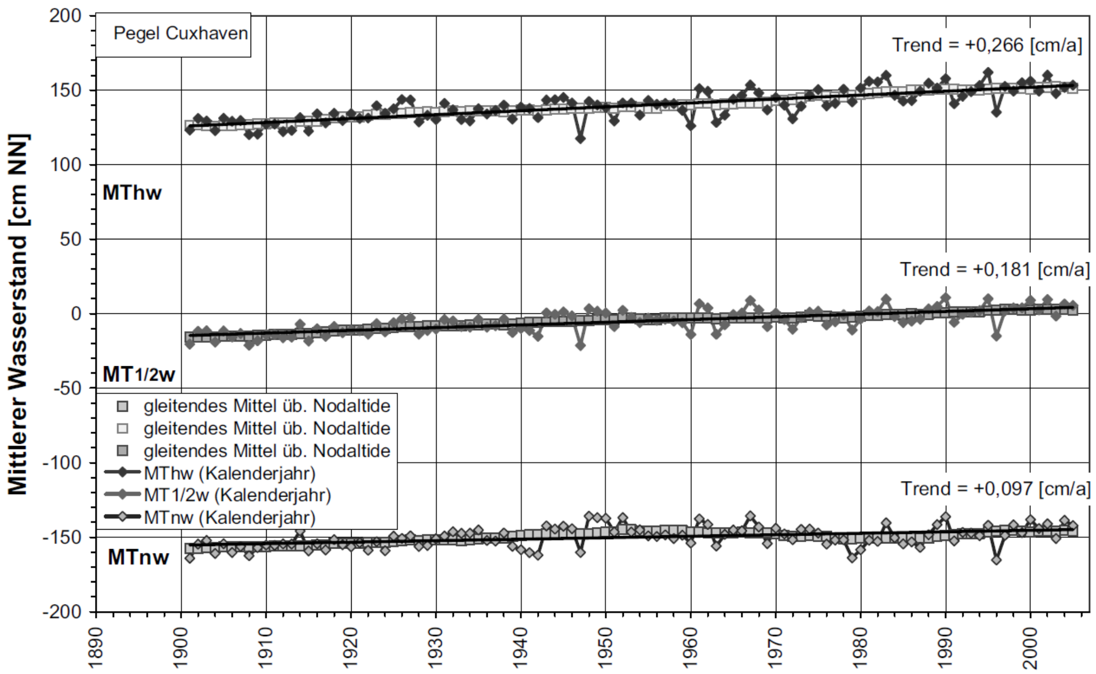


Fig. 2-3: Development of mean tidal high (MThw) and mean tidal low water (MTnw) at gauge Cuxhaven (Fickert and Strotmann 2007)

Accordingly, water residence times will change and the position of the brackish zone will move 2 km upstream (Schuchardt and Schirmer 2005) so that effects on the ecology can be expected as well.

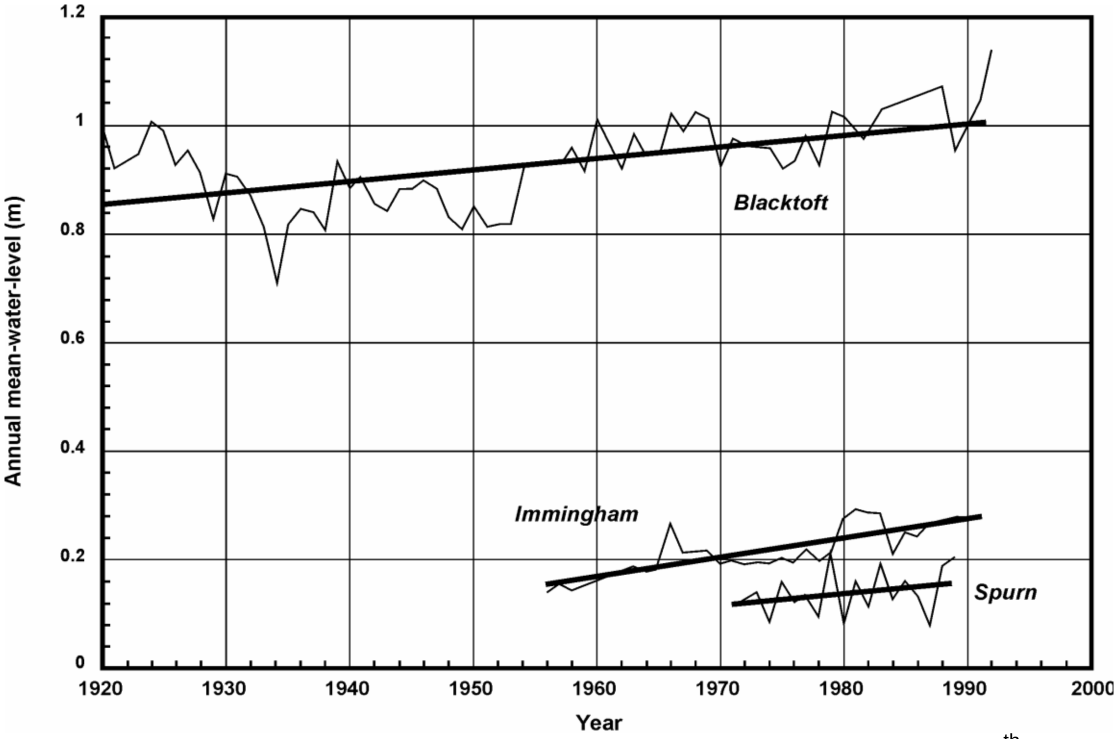


Fig. 2-4: Annual sea-level at 3 locations in the Humber during the 20th century (Atkins 2002).

Facing that situation, national and international research initiatives were started to improve understanding and quantifying the processes and developing adaption strategies. For example, the German Federal Ministry for Education and Research financed the project KLIMU which focussed on the impact of climate change in the Weser estuary (Schuchardt and Schirmer, 2005).

In addition to the direct climate related sea level rise, the North Sea estuaries are influenced by isostatic movement of the Earth´s surface. The surface is still recovering from the load of the ice masses, which covered the North Sea area during the pleistocene age. Areas covered by the ice shield such as Scandinavia rose and are still rising while areas which were not covered by ice show a subsidence. As an effect of subsidence, the sea-level is apparently rising because parts of eastern England, Belgium, The Netherlands and the German Wadden Sea Coast are sinking. Consequently, the observed sea level rises are relative to a moving reference surface (Kiden et al. 2002).

This isostatic rebound is an exponentially decreasing subsidence rate (Bungenstock 2005) which differs among regions. In the German Bight recent subsidence rates range from -5 to -7cm/100 years (Augath 1993, Shennan 1987). In Belgium and The Netherlands, a higher subsidence is observed (Kiden et al. 2002). Isostatic movements in the North Sea are obviously a contribution to the mean sea level rise of approximately 25 cm within the last century.

2.2.2 Human activity

For centuries society has modified the hydrogeomorphology of estuaries by:

- straightening and deepening the rivers
- building dykes / land claim
- protecting shorelines
- isolating/cutting-off tributaries and side channels

Over 1,000 years ago, the anthropogenic changes began with a gradual drainage of the wetlands during the pre-historic period and vast areas of flood-land have been converted to agricultural use.

In order to prevent settlements and agricultural areas from flooding, dykes were first built on the marshes. Besides protecting marshland, land claim became of increasing importance and dyke lines were constructed in intertidal areas as well. Consequently, major parts of the floodplain were separated from the river and the original inundation area was reduced (Herrling and Niemeyer 2008). The knowledge and development in wetland management increased and eased land claim like the application of warping. Warping is the process whereby tidal waters are allowed to enter an area of semi-enclosed, embanked intertidal habitat, but with the natural retreat of the waters on the ebb tide retarded for a period. The reduction in flow rate during this impoundment period allows the sediment load to settle out, and with the process repeated over a series of successive tides, there is a gradual increase in the height of the 'warped' land.

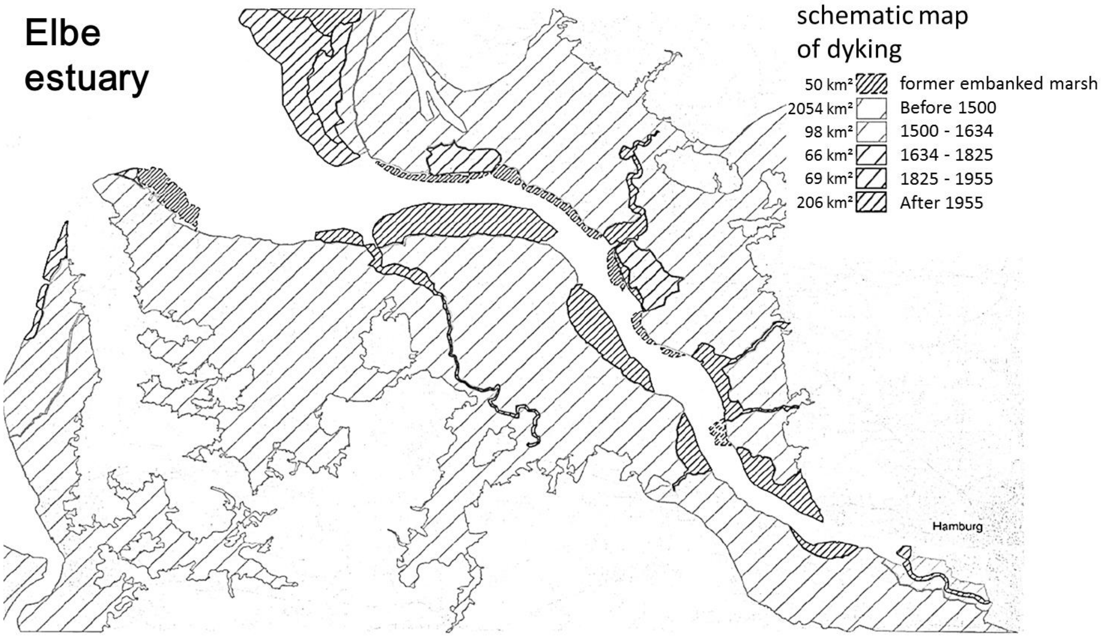


Fig. 2-5: Areas of land claim since the 15th century in the Elbe estuary (from Freitag et al. 2007)

This kind of measures led to a habitat loss in all estuaries. In the Humber and Scheldt estuaries, up to 80% of the intertidal areas has been lost in the last 300 years (HARBASINS 2008). Detailed studies including maps of historic times are available for the Humber (de Boer, 1970, Pethick, 1990; Cutts et al. 2008; Elliot et al. 2008), Ems (Herrling and Niemeyer 2008), the Weser (Elsebach et al. 2007), the Elbe (Freitag et al. 2007) (Fig. 2-5) and parts of the Scheldt (Huis 1996).

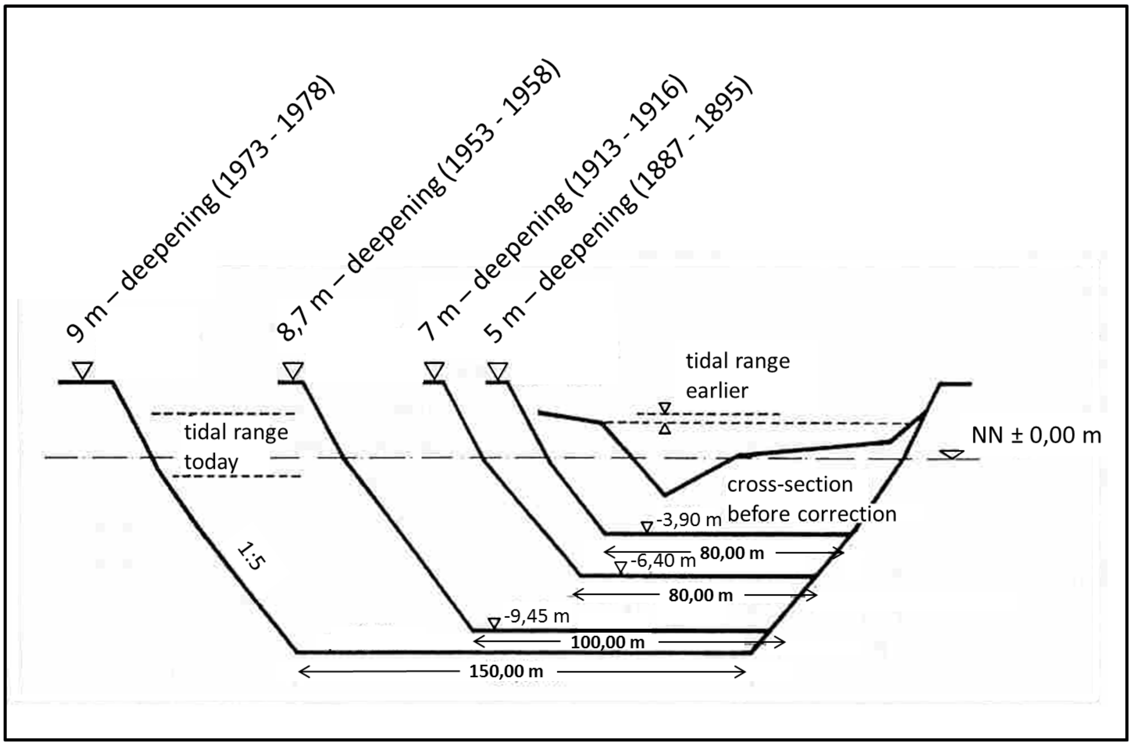


Fig. 2-6: Cross-section of the river bed at Weser km 11 (from Wetzel 1987). Downstream from km 41 a depth of 11,9 m is available and in the Outer Weser the navigational channel provides a depth of 12,5 m; and a further deepening to 13.5 m is planned.

Historically, cities and their harbours very often developed in the upstream part of the estuaries which resulted in a high impact of the demands of trading and harbours on the estuaries natural characteristics. The trading vessels became larger and needed more water depth, which in the end led to increased dredging activities, waterway construction and harbour development. Further port facilities such as Bremerhaven at the Weser were created in 1827 and the river fairways were deepened a number of times (Fig. 2-6 and -7). As supporting measures, groynes and bank reinforcements were built and maintenance dredging has been carried out. These human interferences (inventory of human impact in all estuaries see Annex A1-3) developed the rivers into their recent shape.

Additionally, the mean high water and mean low water level show opposite trends which had further hydraulic consequences (Fig. 2-8).

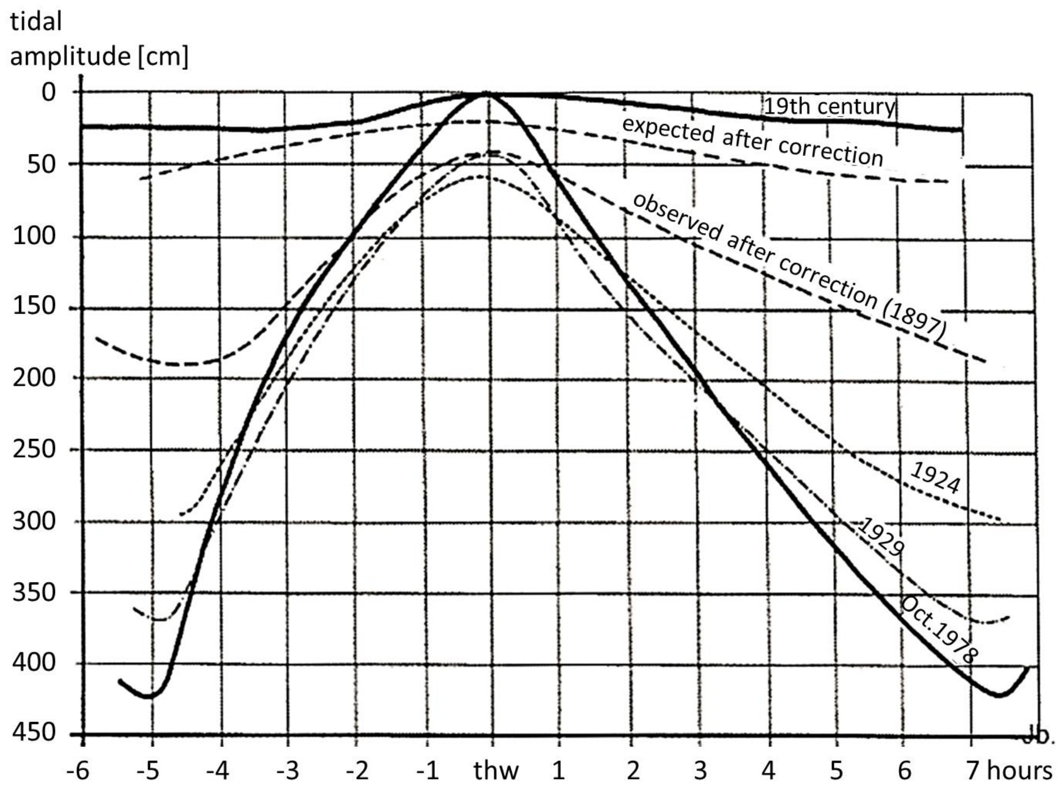


Fig. 2-7: Change of tidal amplitude in the Weser estuary at Bremen City. In the course of deepening projects from the late 19th century on the tidal range increased from few dm up to 4,2 m.

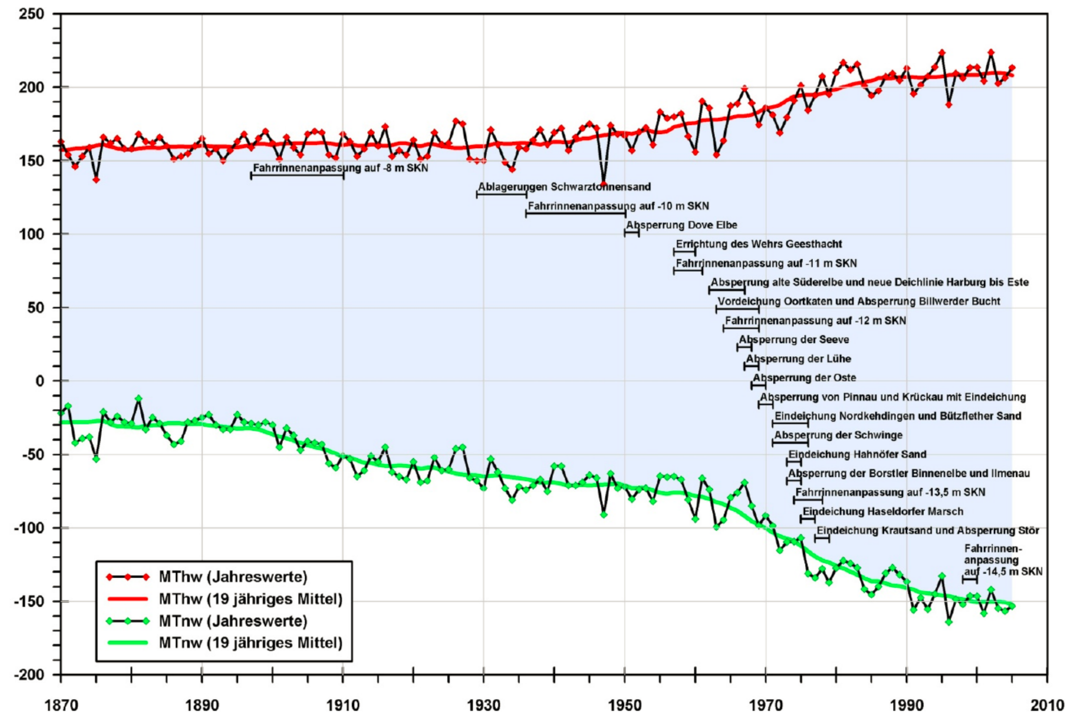


Fig. 2-8: Increase of the tidal amplitude in the Elbe estuary at the gauge at Hamburg St. Pauli. In the course of deepening projects, cutting off tributaries and dyke constructions the tidal range increased from 2 up to 3,6 m.

2.3 Hydro- and morphodynamics controlling habitats

The investigated North Sea estuaries are characterized by tidal ranges between 3 and 6 m. While Elbe, Scheldt and Weser can be classified as mesotidal, the Humber shows macrodidal characteristics (van Rijn et al. 2011). Further relevant factors are the convergence from the mouth in upstream direction and the friction at the bottom of the riverbed, depending on the given geological substrates. A balance between the friction and the converging shape of an estuary is determining whether the tidal range is amplified or damped.

Naturally, along a riverbed the tidal waves are reflected at the substrates of the riverbed, later on damped due to friction leading to a reduction of the tidal range until zero.

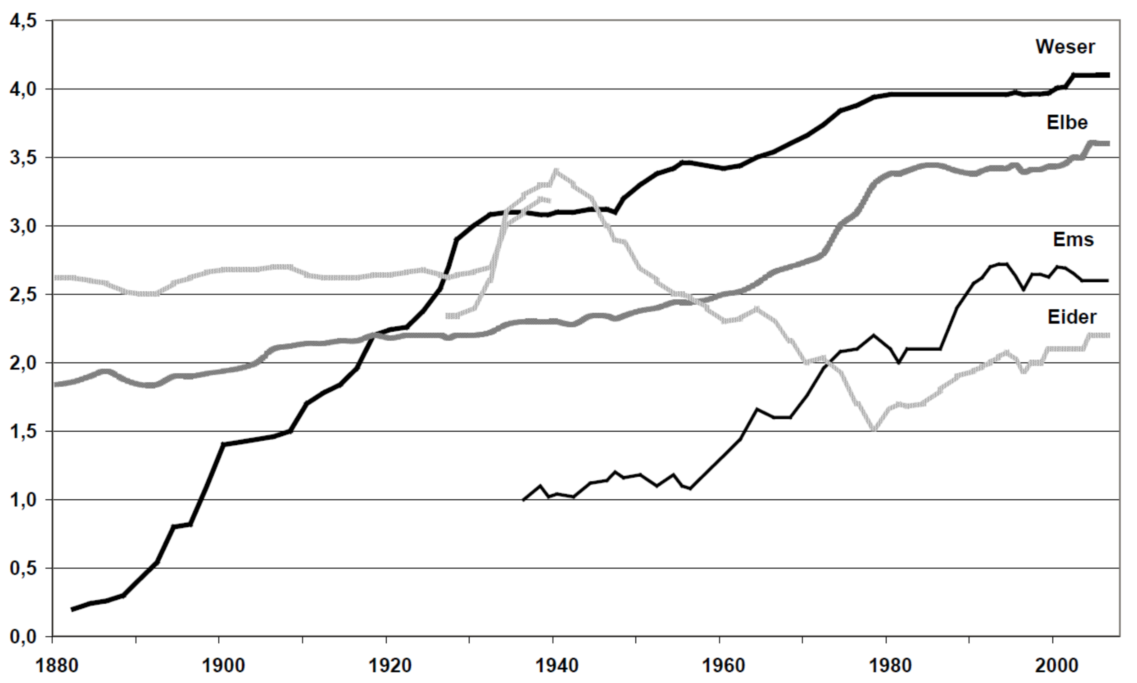


Fig. 2-9: Changes in tidal range between 1880 and 2005 in the Eider (gauges Tönning and Friedrichstadt), Elbe (gauge Hamburg St. Pauli), Weser (gauge Bremen Oslebshausen) and Ems (gauge Herbrum) (5-year running mean) (from Schuchardt et al. 2007)

The development of tidal ranges at different locations in the estuaries (Fig. 2-9) reflects the influence of natural processes and human activities on the characteristics of the tidal wave and consequently hydrodynamics and morphology. Due to straightening and deepening the rivers the tidal wave to reaches upstream regions easier and faster. Tidal damping is hindered and amplification of the tidal wave occurs. In some cases the tidal wave reaches the artificial border of the estuary without damping like in the Weser, which of course is the shortest of the four investigated estuaries. Further measures such as shoreline protection and building dykes stabilized the artificial river bed even more (Herrling & Niemeyer, 2008).

Recently all four estuaries show an amplification of the tidal amplitude in landward direction (e.g. van Rijn et al. 2011). The Humber and Scheldt show an amplification upstream from the mouth. It results in a maximum range of tidal amplitude at km 100 from the mouth of the Scheldt (Fig. 2-10) and at the Humberbridge in the Humber, respectively.

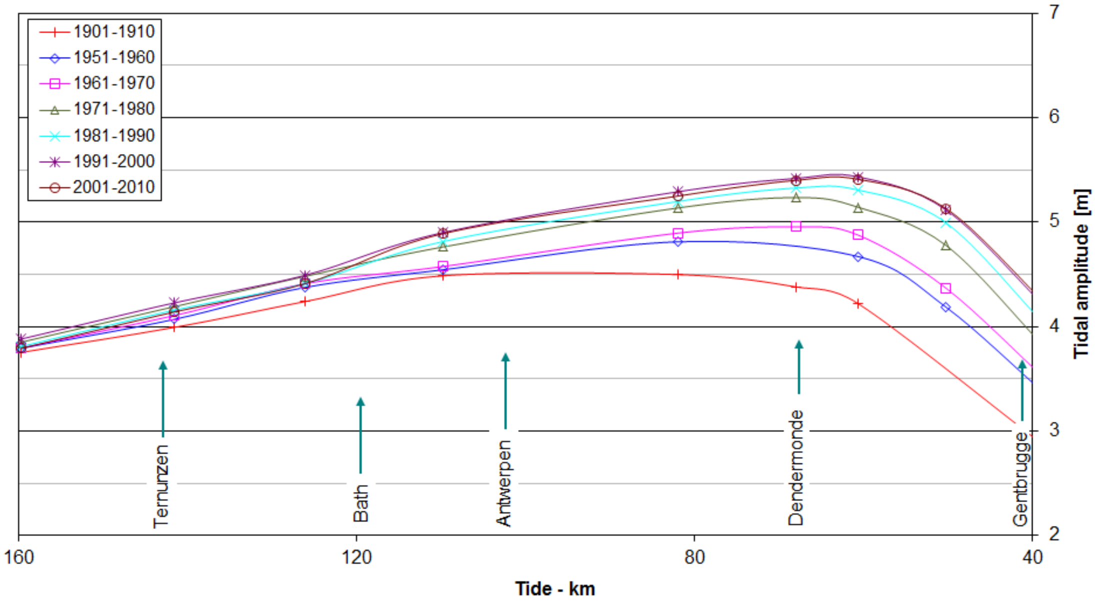


Fig. 2-10: Tidal amplitude along the thalweg of the Scheldt estuary for different times in the 19th and 20th century

Upstream the Humberbridge in the Humber damping takes place, which is observed on a very short distance due to rapidly decreasing water depth. The Elbe shows a damping at the mouth, but further upstream an amplification (Fig. 2-11).

In the Weser, the tidal range increases due to constant depth in the main fairways until the weirs at the landward end of the estuary are reached. Here reflection from the weir at the end of the estuary is of importance (Fig. 5-1).

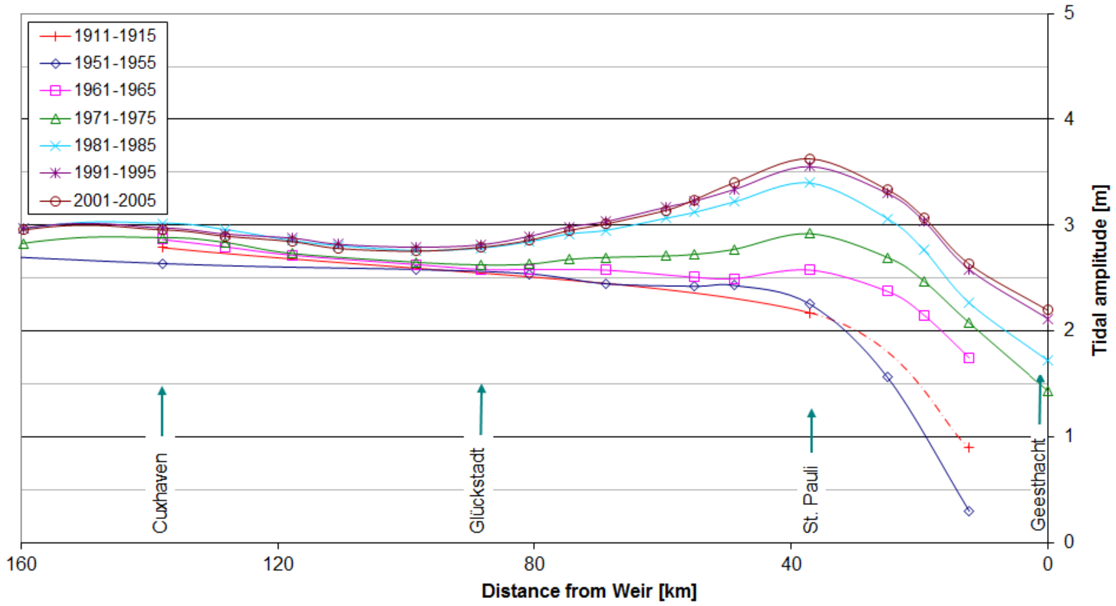


Fig. 2-11: Comparing tidal range along the Elbe in the 20th century

The increase of tidal range in the North Sea estuaries can be observed since the 19th century (Figs. 2-9,-10 and -11 and Fig. 5-1).

2.4 Habitats

For classification of environmental areas, the terms “biotope” and “habitat” are used, often synonymously, however, habitat describes the environmental characteristics in which organisms live. In addition, biotopes consider the respective community of species living there. Since this study focuses on abiotic factors, whereas information about the biological communities in the past is missing, only the term habitat is applied here.

In order to compare the habitat status of the different estuaries in the North Sea Region, preferably, one common typology system should be applied. HARBASINS (2008) compared two main groups of classification. The first group contains the EUNIS classification (Davies et al. 2004) and the Marine Habitat Classification for Britain and Ireland (Connor et al. 2004) while the second one is based on classification systems that are used in The Netherlands and Belgium. While EUNIS and Marine Habitat Classifications are largely based on the actual occurrence of species in a habitat, the others focus on physical characteristics. In the end, both approaches consider the same available information in a different hierarchical order.

Consequently, if mapping of the actual habitat status is the main aim, then the EUNIS or Marine Habitat classification type may be preferred. However, if habitat changes during historic times should be described, then an approach focussing on physical characteristics is more appropriate, because information about biotic condition in the past are not available in a resolution good enough to compare them with recent patterns.

To cope with that problem, Elsebach et al. (2007) distinguished habitats within the HARBASINS -project for which the respective information could be gained from maps, recent and historical ones. The authors described tidal environments as subtidal, intertidal and supratidal habitats according to their height in relation to mean low and mean high water. Deep and shallow water zones are categories of the subtidal habitats and siltation zones and marshes build supratidal areas (see Fig. 2-1).

Wildlife in these intertidal areas is adapted to local flood duration. Subtidal habitats give shelter to animals and plants which can cope with being permanently flooded or are able to swim and can cope with different current velocities. Organisms which are unable to bear high currents, however, need permanent flooding, are found in the adjacent shallow water zones. Close to the shore the marshes can be found. Between tidal habitats and marshes, the siltation zone is described as a transition zone by some authors (Herrling & Niemeyer, 2008; König and Wittig 2005).

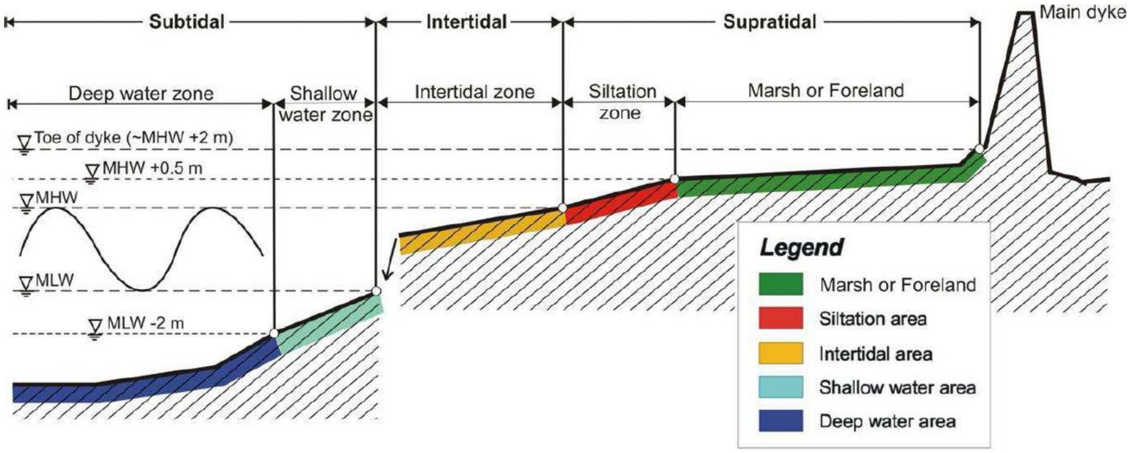


Fig. 2-12: habitat classification of the littoral (taken from Elsebach et al. 2007) applied in HARBASINS (2008)

In TIDE this classification scheme was applied in a slightly modified way (see chapter 3) and extended by the additional differentiation of high and low energy habitats. High and low energy habitats are defined by the same water depth, however, velocity, wave action and in consequence ground substrate can differ between different energy levels. This differentiation is of interest, because low energy habitats are known to be the most productive ones and show highest biodiversity in estuaries (Kraft et al. 1999; König and Wittig 2005).

3 Methodology and Data basis for TIDE habitat study

3.1 Time and spatial scales

TIDE analysed the evolution of the four estuaries in three time steps: (1) at the end of the 19th century/early 20th century, (2) at the mid of the 20th century and (3) in recent times. The end of the 19th century or the early 20th century was used as reference status prior to many human impacts. As described before, human activities started prior to the reference scenario, however, this study aims at a quantitative comparison. Therefore, earlier times could not be considered due to the lack of maps or data. A time step after 1950 in the middle of the 20th century was the next choice, because after the 2nd World War new ships were designed, which demanded increasing water depth.

Table 3.1 provides an overview about the exact times, which were considered for the comparison. Humber and Scheldt provided data for further time steps (see Annex).

Tab. 3-1: Times considered for calculating habitat areas

	End of 19th c./early 20th c.	Mid of 20th c.	Recent time	extra
Elbe	1900	1950	1992-95	
Humber	1910/24	1975	2008	1988 and 1993
Scheldt	1880/87 and 1930	1960/72	2000	1930
Weser	1860/87	1951/52 and 1961/62	2005-20008	

Since salinity is a key parameter determining ecosystems in estuaries, different salinity reaches were considered following the gradient of salinity in the respective estuary (Tab. 3-2). This study distinguished the respective salinity reaches considering the zonation of the rivers (Geerts et al. 2012). This approach allowed a comparison of the overall sizes of the four estuaries, the areas related to a certain salinity zone and different habitats located within these zones.

Tab. 3-2: Zonation based on the Venice system (Geerts et al. 2012)

<table>
<tr><th>Chlorinity range</th><th colspan="2">Elbe</th><th colspan="2">Weser</th><th colspan="2">Scheide</th><th>Humber</th></tr>
<tr><td rowspan="3"><300 mg Cl/L
Freshwater zones</td><td rowspan="3">0-91</td><td>0-24</td><td rowspan="3">0-44</td><td rowspan="2">0-31</td><td rowspan="3">0-58</td><td rowspan="2">0-31</td><td rowspan="3">Trent: 0-45 TIDE$_{Trent}$-km+
Ouse till confluence with
the Aire: 0-34 TIDE$_{Ouse-Humber}$-km</td></tr>
<tr><td>24-46</td></tr>
<tr><td>46-91</td><td>31-44</td><td>31-58</td></tr>
<tr><td>300-3.000mg Cl/L
Oligohaline zone</td><td colspan="2">91-118</td><td colspan="2">44-69</td><td colspan="2">58-89</td><td>Trent: 45-85
TIDE$_{Trent}$-km +
Ouse further
downstream:34-
60 TIDE$_{Ouse-Humber}$-km</td></tr>
<tr><td>3.000-11.000 mg Cl/L
mesohaline</td><td colspan="2">118-141</td><td colspan="2">69-84</td><td colspan="2">89-116</td><td>Humber: 60-93
TIDE$_{Ouse-Humber}$-km</td></tr>
<tr><td>>11.000 mg Cl/L
polyhaline</td><td colspan="2">141-171</td><td colspan="2">84-119</td><td colspan="2">116-160</td><td>Humber: 93-123
TIDE$_{Ouse-Humber}$-km</td></tr>
</table>

This zonation follows the Venice system (1959) and is based on recent data on the salinity in all estuaries. Since there are no data available describing the salinity along the whole respective estuaries in older times, the recent zonation is applied to the former time steps as well, although it is known that the salinity pattern might have been different in the past.

3.2 Definition of habitats

While the salinity gradient is crucial for the development of biotopes along the estuary, the amplitude of the tide is important for a differentiation of habitats in lateral direction crossing the river bed. Therefore, more levels were considered with respect to the mean sea level compared to earlier projects (e.g. Elsebach et al. 2008). The habitats can be grouped into habitats below MLWL, between MLWL and mean high water level (MHWL) and above MHWL. In this study the zones are called sub-, inter- and supratidal areas, synonymously intertidal areas are named tidal flats and supratidal areas can be called marshes instead (Tab. 3-3).

The following more detailed habitat-types are distinguished within this study:

Subtidal habitats 1-6

1 and 2: Deep water habitat: below MLWL – 5m along the main channel (fairway (high energy habitat 1) or in anabranches and other structures (low-energy habitat 2)

3 and 4: Slope habitat (high/low energy): below MLWL – 2m and above MLWL –5m along the main channel (fairway-high energy habitat 3) or in anabranches and other structures (low energy habitat 4)

5 and 6 Shallow water habitat: between mean low water level (MLWL) and MLWL – 2m along the main channel (fairway- high energy habitat 5) or in anabranches and other structures (low energy habitat 6)

Intertidal habitats:

7 and 8:Tidal flat habitat: between MLWL and mean high water level (MHWL) along the main channel (high energy habitat 7) or in anabranches and similar structures (low energy habitat 8)

Supratidal or supralitoral habitats

9: Marsh habitat: above MHWL without summerdyke (i.e. the dyke is lower than storm surge water levels)

10: Summer polder: above MHWL protected by a summer dyke (dyke lower than storm surge water levels)

11: Stagnant waters in the foreland: above MHWL as part of the marsh habitats.

The information needed to determine the “stagnant water – habitat” and the “Summer polder – habitat” are only available for the recent decade.

Tab 3-3: Overview on the applied habitat classification

<table>
<tr><th>Depth</th><th>Classification acc. to Elsebach et al. 2008</th><th>Further classification</th><th colspan="2">Habitat types</th></tr>
<tr><td rowspan="2">> MHWL</td><td rowspan="2">supratidal</td><td rowspan="2">marsh</td><td>stagnant water</td><td>summer polder</td></tr>
<tr><td colspan="2">marsh</td></tr>
<tr><td rowspan="2"><MHWL
>MLWL</td><td rowspan="2">intertidal</td><td rowspan="2">tidal flats</td><td colspan="2">tidal flat</td></tr>
<tr><td>high energy</td><td>low energy</td></tr>
<tr><td rowspan="6">< MLWL</td><td rowspan="6">subtidal</td><td rowspan="6">subtidal</td><td colspan="2">Shallow (<MLWL to -2m)</td></tr>
<tr><td>high energy</td><td>low energy</td></tr>
<tr><td colspan="2">Slope (-2m to -5m <MLWL)</td></tr>
<tr><td>high energy</td><td>low energy</td></tr>
<tr><td colspan="2">Deep (more than -5m <MLWL)</td></tr>
<tr><td>high energy</td><td>low energy</td></tr>
</table>

3.3 Data basis

All estuaries collected data from various sources.

In general, based on geo-referenced maps for the times steps of interest, these maps were digitized and polygon areas were created for the intertidal, supratidal and subtidal habitats of the salinity zones. These polygons were split by using a polygon shape containing the information of the salinity zones in order to reach the final zonation of the habitat.

Among others, ESRI's ArcGIS version 10.0 was applied as GIS tool.

One aim of this study was to improve the quantification of changing environmental functions starting with a reference status against which changes are measured. It would have been good to have a reference status prior to human impact. But that is impossible due to the availability of data. For example, the Humber Estuary has been heavily modified by human activities for over 2,000 years. It is estimated that half of its intertidal area has been lost due to land claim for agricultural and industrial developments over this period. Its shape has also changed over time, initially through gradual drainage of land around the estuary head, with more substantial modifications in the main estuary since the 17th century. Channel shape within the estuary and its tributaries has also been modified for flood defence purposes and to improve the navigation access.

The most marked changes to the morphology of the Humber occurred in the middle and outer Humber system during the 19th Century, particularly in the region of Sunk Island. Changes to the morphology of the estuary from *c*. 1725 to present are shown in Fig. 3-1 with the scale of the Sunk Island land claim clearly evident, habitat loss in the middle and outer estuary over the last two hundred years being around 10 times that seen in the inner estuary.

So, TIDE improved the quantification of areal changes, but is limited by data restrictions, especially with historic data prior to the reference scenario. However, the collected data, maps and shape files provide a tool, to use the data as a reference for any effects of future measures in the estuaries of Elbe, Humber, Scheldt and Weser. Using these data it is possible to better assess changes in the four estuaries.

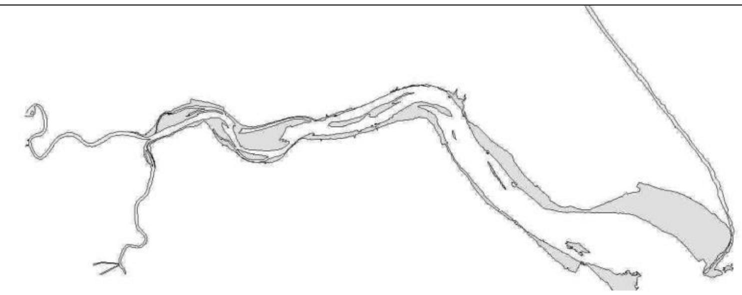
	a) Humber Estuary, *c*. 1725 Note Sunk Island is an 'island' in the outer Humber. However, the inner estuary looks broadly similar to the current morphology (C).
	b) Humber Estuary *c*. 1850 Note Sunk Island is now part of the terrestrial north bank of the estuary. The inner estuary remains largely unchanged and similar to (C). However, Read's Island has yet to be created off the south bank, east of Winteringham and Broomfleet Island joined to the north bank, west of Brough.
	c) Humber Estuary Present Apart from differences in mapping techniques, the general morphology of the estuary resembles that of the mid 19th Century (B).

Fig. 3-1: Humber Estuary morphology 1725, 1850 & present (Elliott *et al*. 2008).

So, TIDE improved the quantification of areal changes, but is limited by data restrictions, especially with historic data prior to the reference scenario. However, the collected data, maps and shape files provide a tool, to use the data as a reference for any effects of future measures in the estuaries of Elbe, Humber, Scheldt and Weser. Using these data it is possible to better assess changes in the four estuaries.

4 Results

It is the scope of this study to show estuarine habitat patterns at different times, to display trends and to compare the patterns between the four TIDE estuaries. The habitat patterns are based on data and maps, however, not for every time step or zone, detailed information covering all habitats types could be provided. It can be emphasized, that the situation of the recent time step is documented for almost all habitats as described in Tab. 3-3.

The habitat patterns and their links to hydromorphology are discussed by Vandenbruwaene et al. (2013) in detail. For the reference scenario prior to human intervention on morphology and the situation in the middle of the 20th century, deep water, slope and shallow water habitats are not considered separately in every estaury, however, they are comprised as subtidal areas. In the same way marshes (in sensu stricto), summer polder and stagnant water areas are treated as marsh in a broader sense or as supratidal if data were lacking (see Tab. 3-3). All data are listed in the annex, partly with specific information considering the respective estuary.

4.1 Evolution of areas in different salinity zones

Table 4-1 and fig. 4-1 allow an overview on the development of the areas belonging to different salinity zones estuaries at three time steps: (1) at the end of 19th century/early 20th century, (2) at the middle of the 20th century, and (3) in recent times.

There are different subzones available for some salinity reaches which are displayed in the annex.

The overall sizes of Elbe, Sea Scheldt and Weser show decreases in a range between 4 % up to more than 30 %, whereas the Humber estuary seems to remain quite stable since the 19th century. The overall size of the outer Humber was greatly reduced during the 18th and 19th century through land-claim for agriculture and port developments, with the changes to the freshwater and oligohaline habitats of the Humber having occurred some time before this (e.g. from pre-history onwards with gradual draining of the Humber headwaters wetlands).

The loss of areas is mostly located in the inner estuaries of all rivers. The impact decreases downstream towards the estuary´s mouth. In the Elbe and the Weser a third part of the freshwater habitats is lost while more than half of the freshwater habitats of the Sea Scheldt disappeared. The oligohaline and mesohaline zones show less diminishing in size, however, in the same order of magnitude (Fig. 4-1).

Tab. 4-1: Areas (ha) of zones in Tide- estuaries

	End of 19th c./early 20th c.	mid 20th century	recent	%-change
Elbe				
freshwater	10.481	8.982	6.886	-34,3
oligohaline	15.286	15.686	9.553	-37,5
mesohaline	47.376	37.910	38.905	-17,9
polyhaline	28.802	27.842	28.828	0,1
Σ Elbe zones	101.945	90.420	84.172	-17,4
Humber				
mesohaline	8704	8578	8585	-1,4
polyhaline	19719	19552	19631	-0,4
Σ Humber zones[1]	28422	28130	28216	-0,7
Sea Scheldt [2]				
freshwater	3.297	1.829	1.460	-55,7
oligohaline	1.282	1.175	997	-22,2
mesohaline	2.937	2.609	2.413	-17,8
Σ Sea Scheldt zones [2]	7.516	5.613	4.870	-35,2
Weser				
freshwater	5.943	3.761	3.912	-34,2
oligohaline	6.211	4.494	4.524	-27,2
mesohaline	11.014	10.386	9.990	-9,3
polyhaline	82.121	82.404	82.288	0,2
Σ Weser Zones	105.290	101.044	100.714	-4,3

1: The Humber estuary applies a zonation scheme, not focusing on salinity alone (see Annex)

2: Here only the Sea Scheldt without polyhaline and part of the mesohaline zone of the Western Scheldt´s estuary are considered. Accordingly, the data do not represent the overall estuary which would cover an area of appr. 35,000 ha

In the outer parts of the estuaries the nett balance of polyhaline habitats seem to be balanced, however, these overall balances integrate loss and gain of habitats in different places of the dynamic estuaries (Tab. 4-1).

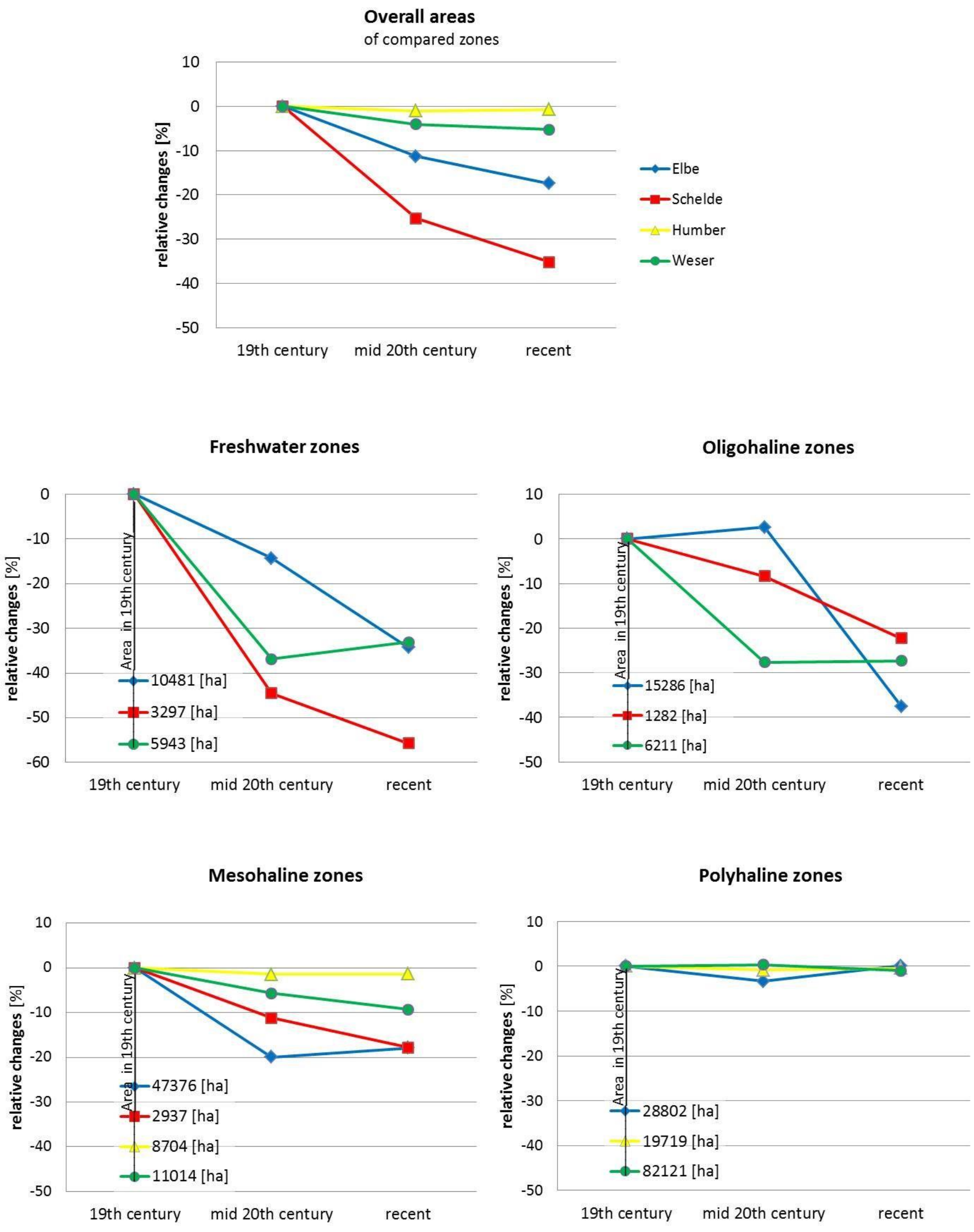


Fig. 4-1: Areal changes (%) of different salinity zones within the TIDE-estuaries in relation to areas at the end of the 19th century. The Elbe, Sea Scheldt and Weser show the highest losses of areas in the inner zones (freshwater and oligohaline), and closer to the mouth (mesohaline) less areas diminished. Note that the initial area of the zones is displayed in ha. The polyhaline areas are not displayed because the changes are below 1%. The freshwater and oligohaline zone of the Humber did not change within the last century in a way that can be displayed in this graph. There are more detailed zones considering currents, salinity and location distinguished in further TIDE-reports (Vandenbruwaene et al. 2013 and Annex this study)

4.2 Evolution of habitat distribution

The distribution patterns of habitat types are quite different among the four estuaries, as far as the proportion of marsh (supratidal) and tidal flats (intertidal) is concerned. This might be an effect of the relation of the sizes of polyhaline zones to the other zones. The bigger the polyhaline zone is, the more any changes of habitat patterns in the other smaller zones are hidden:

Tab. 4-2: Development of habitat types from 19th century until recent times

Habitat	End of 19th c./early 20th	mid 20th cent	recent	Difference 19th –rec. %	ha
Elbe					
deep water	33442	35632	33423	0	-19
Shallow water	12359	10283	8870	-28	-3489
tidal flat	34300	25771	33000	-4	-1300
Marsh	21843	18736	8882	-59	-12961
Σ Elbe	101944	90422	84175	-17	-17769
Humber					
Subtidal	17394	17206	16298	-6	-1096
tidal flat	10142	10291	11078	9	936
Marsh	887	632	840	-5	-46
Σ Humber	28422	28130	28216	-1	-206
Sea Scheldt					
Deep water	1659	1635	2074	25	416
Slope	1012	968	823	-19	-189
Shallow water	676	638	432	-36	-244
tidal flat	929	889	824	-11	-105
Marsh	1470	1021	682	-54	-788
summer polder	1720	398	0	-100	-1720
stagnant water	51	64	-		
Σ Sea Scheldt[1]	7516	5613	4834	-36	-2682
Weser					
deep water		26202	24294		
Slope	56917	15924	16618	-5	-2825
Shallow water		10869	13176		
tidal flat	40764	43255	40322	-1	-442
Marsh	7609	4793	3834		
summer polder			2391	-17	-1303
stagnant water			81		
Σ Weser	105289	101044	100716	-4,5	-4574

1: Here only the Sea Scheldt without polyhaline and part of the mesohaline zone of the Western Scheldt´s estuary are considered due to data availability. So data do not represent the overall estuary which would cover an area of c 35,000 ha

In the Humber and Weser less than 6 % of the habitat areas are marshes, while Elbe and Sea Scheldt have 11-15% of the marsh areas. Subtidal habitats cover 50-58% of the overall area in every estuary. Looking at the development of the respective habitat patterns with time, the Humber shows a stable fractionation among marsh, tidal flats and subtidal areas. The development of the habitat pattern of the Weser is comparable to that of the Humber (fig. 4-2), however, the overall area of the Weser estuary decreased, mainly due to a loss of marsh and subtidal habitats. The loss of approx. 1300 ha supratidal has to distinguish marsh and summerpolder areas. The total loss of marsh is appr. 3,000 ha which sums up to a relative loss of 49% of the former extent of the marshes in the 19th century (tab. 4-2).

The habitat pattern in the Elbe estuary is characterized by a relative increase of subtidal habitats, mainly due to a strong relative reduction of marshes from 21 % in the 19th century to 11 % recently. However, looking at absolute areas in ha, all habitat type areas in the Elbe decrease. The absolute decrease of the marsh areas in ha from approx 22,000 ha to nearly 8,900 ha is the most remarkable change.

The considered parts of the Scheldt, the Sea Scheldt, are characterized by an increasing percentage of subtidal areas from 60 to 70%. In the Sea Scheldt this increase is mainly based on the increase of deep water habitats whereas slope and shallow water habitats decrease. The marsh areas decreased by more than 50% from approx. 1,400 ha to less than 700 ha in recent times.

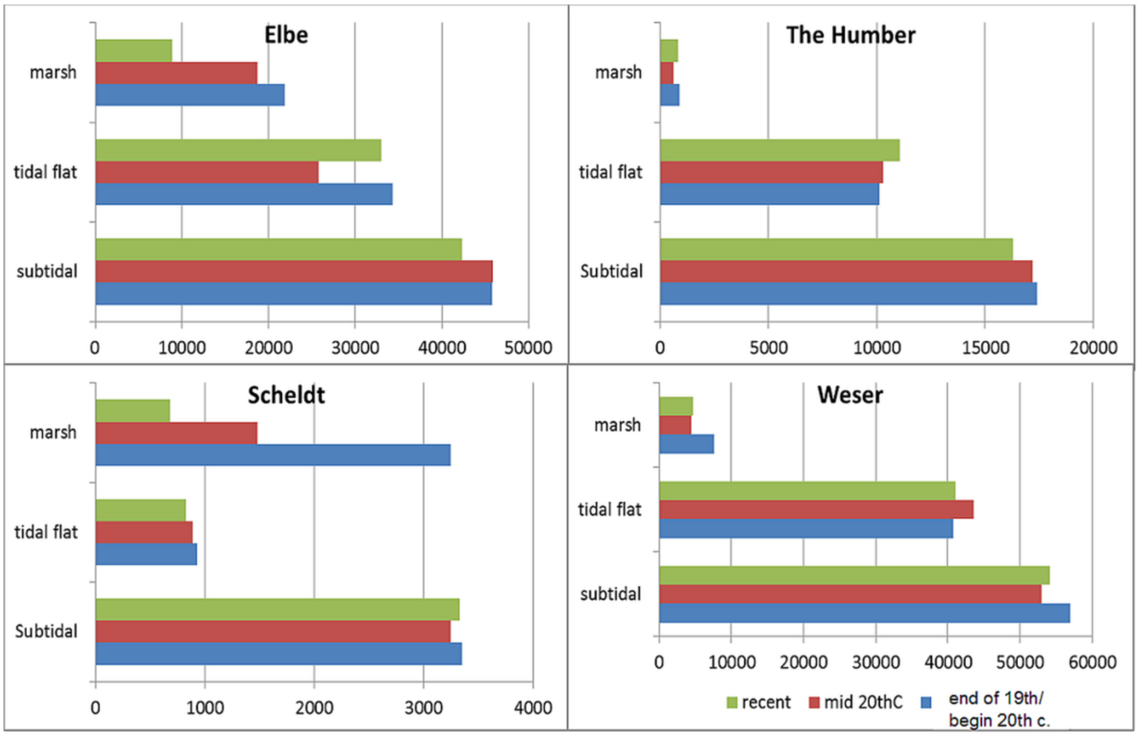


Fig. 4-2: Development of habitat distribution in estuaries vs time

It has to be pointed out, that for this comparison the Sea Scheldt with freshwater, oligohaline and parts of the mesohaline zones of the overall Scheldt estuary are considered due to the limited availability of data in the zones of the Westerscheldt for the time steps prior to mid of 20th century.

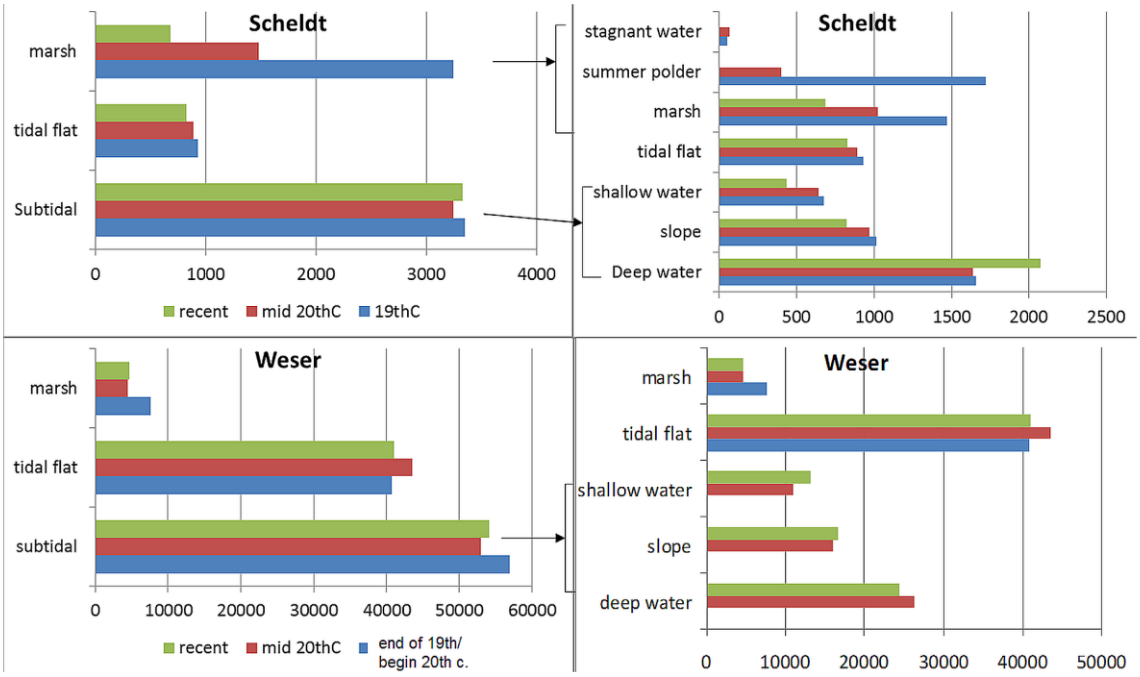


Fig. 4-3: Detailed habitat patterns in the Sea Scheldt and in the Weser

In the Sea Scheldt it was possible to distinguish different subtidal zones such as shallow, slope and deep water habitats. While the subtidal area in the Sea Scheldt along the considered zones seemed to remain quite stable it becomes obvious that there is an increase of deep water habitats to the disadvantage of slope and shallow water areas.

4.3 Evolution of habitat patterns in freshwater and oligohaline zones

The highest loss of habitats is observed in the freshwater and oligohaline zones of the estuaries (Tab. 4-1). In the Elbe, the Sea Scheldt and the Weser between 33 and 50% of the overall freshwater area disappeared. Therefore it would be of interest to investigate the habitat distribution in those zones respectively (Tab. 4-3).

Within their freshwater area the Elbe shows an increase of 780 ha deep water zones, and a loss of 3,500 ha marshes and 1,180 ha shallow water during the last century.

The freshwater zones of the Weser are characterized by a habitat loss since the end of the 19th century, mostly due to less marsh area (-35% = -1088 ha) and tidal flats (-37% = -253 ha) despite an increase of deep water (+36% = 213 ha) areas. Slope and shallow water decreased in a comparable high extent (-75 % and – 46 %).

The freshwater areas of the Sea Scheldt show a slight increase of deep water (+116 ha) which is overcompensated by the complete loss of summer polders and nearly 20% of the marsh area, summing up to a loss of more than 1,700 ha.

Tab. 4-4: Evolution of freshwater zones

	End of 19th c./early 20th	mid 20th cent	recent	Change [%] 19th –rec.	Change [ha]
Elbe					
deep water	3059	4116	3837	25	778
shallow water	1964	1111	786	-60	-1178
tidal flat	860	753	1149	34	289
marsh	4599	3003	1116	-76	-3483
Σ Elbe	10482	8983	6888	-34	-3594
Sea Scheldt					
deep water	148	135	264	78	116
slope	402	360	336	-16	-66
shallow water	254	228	156	-39	-99
tidal flat	277	281	250	-10	-28
marsh	525	347	438	-17	-87
summer polder	1640	326	0	-100	-1640
stagnant water	50	66	0	-100	-50
Σ Sea Scheldt	3296	1743	1443	-56	-1853
Weser					
deep water	589	696	802	36	213
slope	844	392	455	-46	-389
shallow water	680	193	170	-75	-510
tidal flat	689	594	436	-37	-253
marsh	3141	1886	2053	-35	-1088
Σ Weser	5943	3761	3912	-34	-2031

In the oligohaline zones the Sea Scheldt shows again an increase of deep water, however, a complete loss of summer polders and over 60% of the marsh area.

The respective oligohaline zone of the Elbe estuary is dominated by an decrease of 2/3 of the marshes accompanied by an increase of tidal flat areas. Deep and shallow water areas decreased as well.

The oligohaline realm of the Weser shows a special evolution. Here deep water zones decrease by 50% which dominates the development. Marshes are decreasing while further habitat types show increases.

Tab. 4-5: Evolution of oligohaline zones

	end of 19th c./early 20th	mid 20th cent	recent	Change [%] 19th –rec.	Change [ha]
Elbe					
deep water	5151	4745	4270	-17	-881
shallow water	1059	1462	848	-20	-211
tidal flat	1044	1126	1832	75	788
marsh	8032	8353	2603	-68	-5429
Σ Elbe	15286	15686	9553	-38	-5733
Scheldt					
deep water	451	450	505	12	55
slope	183	195	167	-9	-16
shallow water	136	119	75	-45	-61
tidal flat	193	165	155	-20	-38
marsh	241	173	94	-61	-147
summer polder	79	73	0	-100	-79
Σ Scheldt	1282	1175	997	-22	-285
Weser					
deep water	2503	1128	1223	-51	-1281
slope	302	513	393	30	90
shallow water	267	380	293	10	26
tidal flat	802	1007	865	8	63
marsh	2337	1466	1751	-25	-586
Σ Weser	6211	4494	4524	-27	-1687

An interestuarine comparison requires a resolution of habitat patterns that allows comparison of catchments of several 1,000 ha without being loss of details. However, the habitat patterns change on a scale of some ha which should be exemplified at the situation of the Rupel tributary in the Scheldt estuary.

The Rupel is a more or less straight river section without adjacent flooding zones, connecting the 2nd generation tidal tributary rivers Nete, Dijle and Zenne to the Scheldt (Fig. 4-4). The total subtidal area reduced between 1960 and 2001 because the tidal anabranch Eikenvliet was disconnected. The area of shallow water habitat decreases in favour of the slope habitat and the deep subtidal habitat.

Tidal flat habitat decreases from 69ha in 1930 to 51ha in 2001. Again an important part of this habitat loss is related to the disconnection of the Eikenvliet. A large area of salt marsh habitat and all floodland disappears (Data see annex A-62).

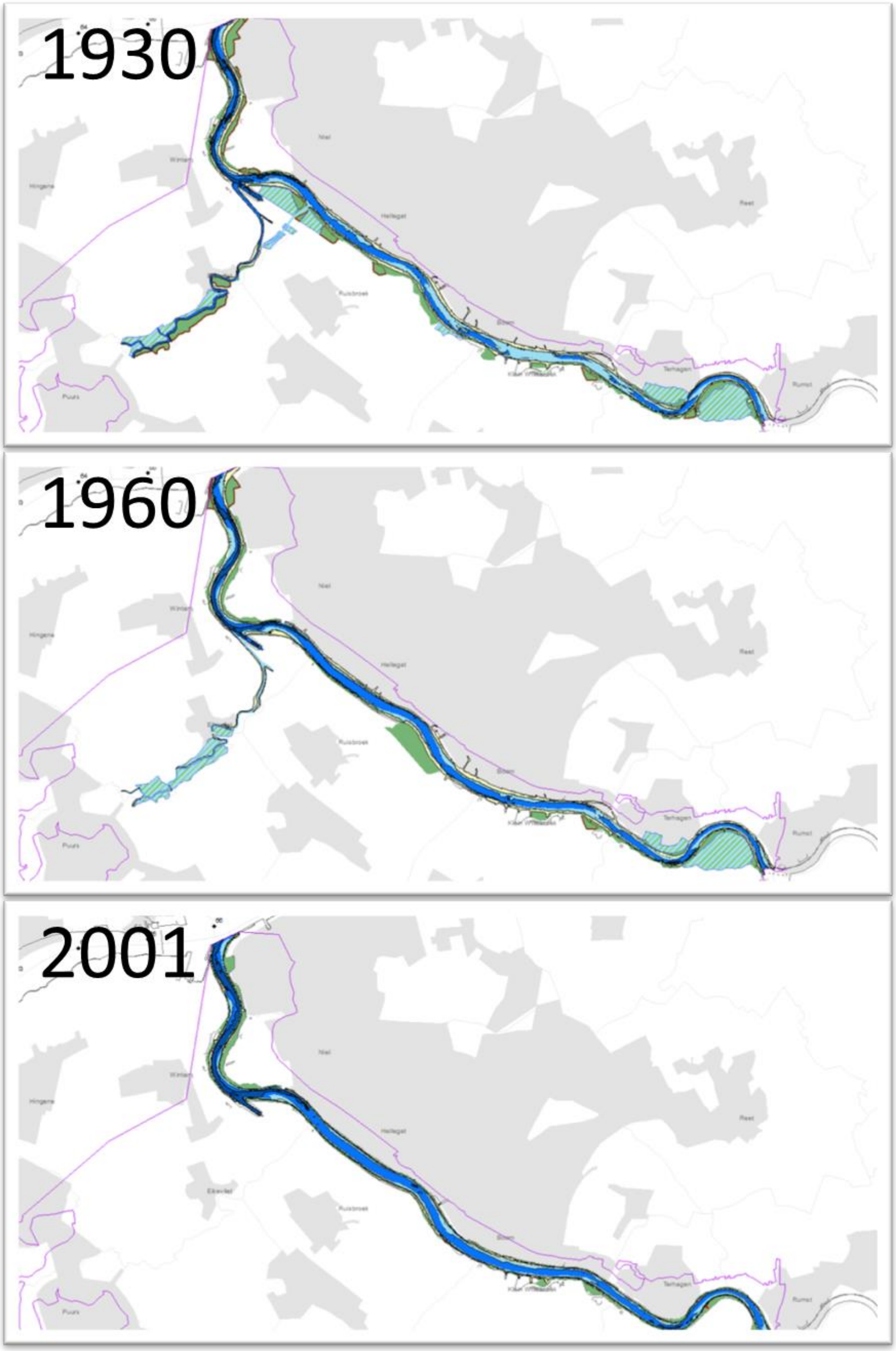


Fig. 4-4: Development of habitat patterns in the Rupel tributary (legend see Fig. 5-3)

5 Processes influencing habitat patterns

Estuaries are very dynamic systems and have changed greatly during geological time through natural events as well as anthropogenic activities. On a geological time scale, the sea level rise with approximately 120 m is a very impressive change and in the course of that transgression the recent coastline developed (Streif 2004). Another natural movement is the isostatic subsidence in the southern part auf the North Sea (Kiden et al. 2002). Combined with the global sea level rise, the North Sea level increased in a range of some dm during the last 100 years and is anticipated to increase up to +100 cm within the next century (e.g. Atkins 2002).

Rising water level combined with changing precipitation patterns, both due to climate change will influence the hydrology in the estuaries. In addition to that water level changes, e.g. in the Weser estuary an upstream shift of the brackish zone in a range of a kilometre is forecasted (Schuchardt and Schirmer 2005). These changes in the water level of about 1 cm/a can not be influenced by any estuary management except of adaptive measures such as the enhancement of dykes. Compared to these natural changes beyond the influence of the estuary management, the influence of human activities on the hydrology and morphology is remarkable. Estuarine environments have been modified and managed by mankind through human history and particularly with respect to protecting the landscape from flooding, to claim wetlands for agriculture or settlements and to allow and maintain navigation. In the course of that development the human view on the rivers changed: In addition to their natural function, estuaries became part of the human infrastructure.

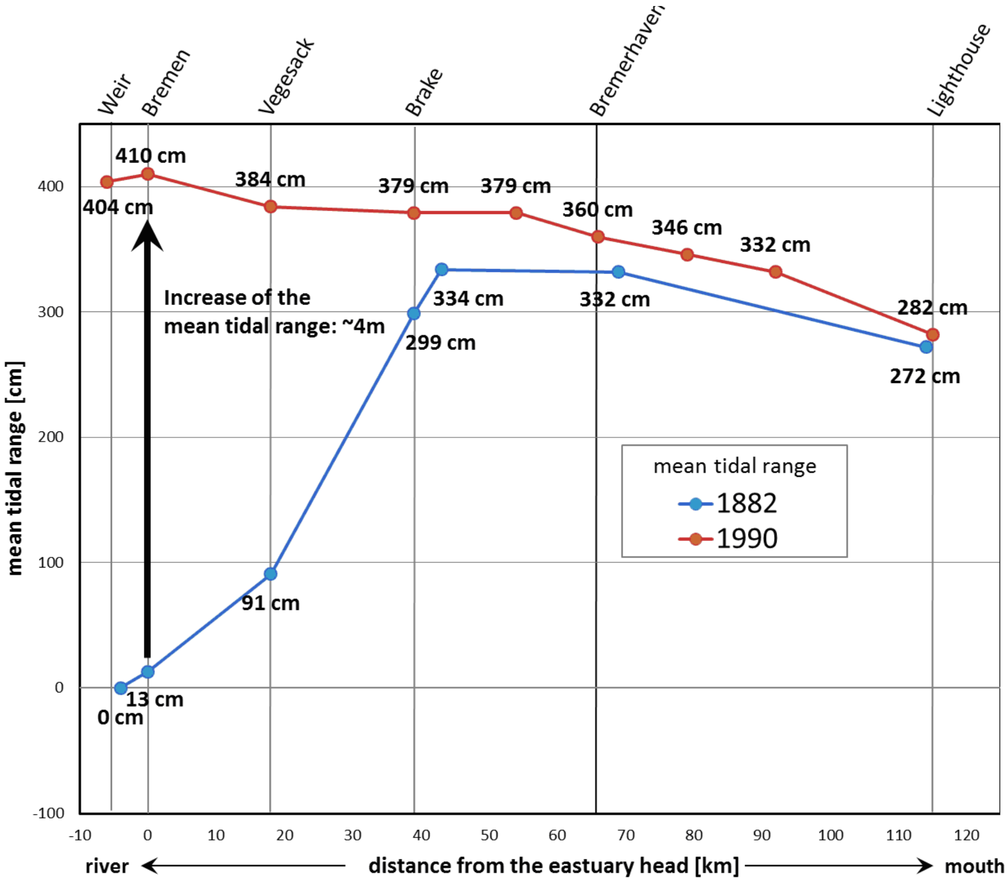


Fig. 5-1: Tidal wave development along the Weser

More than hundred years ago, the tidal influence in the inner estuaries was naturally fading out to zero. At the Weser for example in Bremen a tidal range of approximately 20 cm was measured. Recently, it is amplified up to 420 cm, which is an increase by a factor of 20 (Fig 5-1) and this effect changed habitat patterns: By the end of the 19th century the Weser was a braided stream with shallow and slope subtidal habitats in the vicinity of Harrier Sand. After straightening and deepening the river in the end of that century, the tidal amplitude rose enormously and the velocities increased as well. This effect was foreseen (Franzius and Büchel 1895) and wanted in order to reduce maintenance dredging. Further measures were carried out such as the installation of groynes to stabilize the new shorelines. Nowadays the habitats in Weser at Harrier Sand are characterized by a deep fairway and many dyked areas compared to the 19th century.

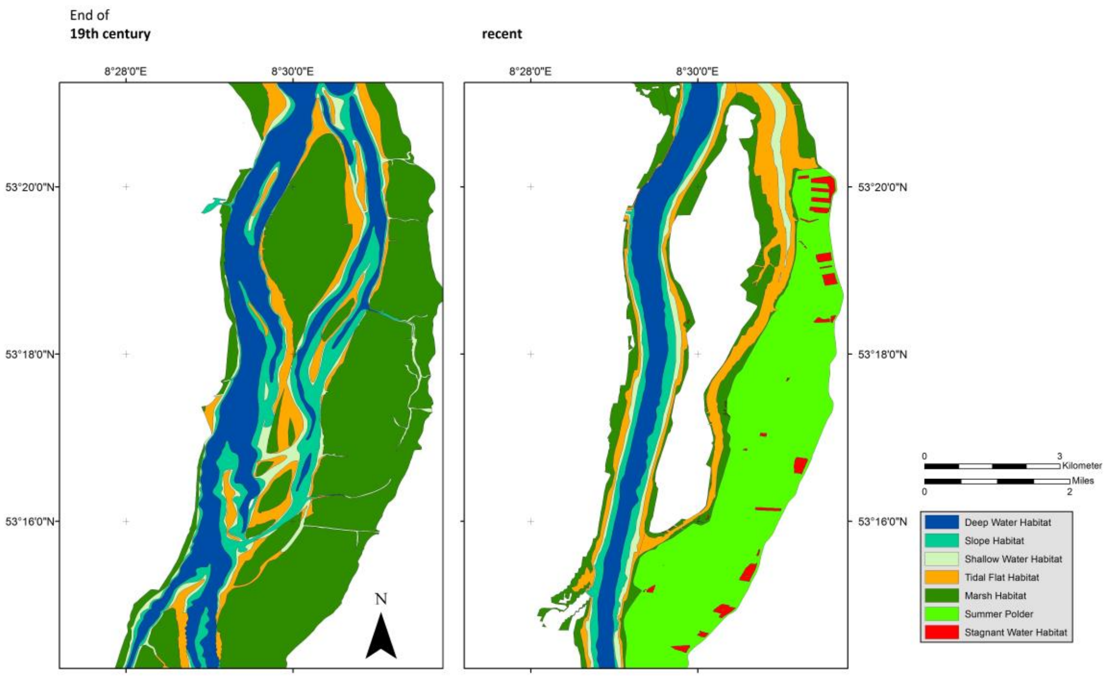


Fig. 5-2: Change of habitats in the Weser estuary at Harrier Sand. The white areas are dyked parts. Among all estuarine habitat types, only summer polders and intertidal habitats grew.

In every estuary the same catalogue of measures was applied such us construction of dykes, straightening and deepening, combined with cutting of tributaries and protecting the shorelines. In addition to the example of Harrier Sand the Durme tributary of the Scheldt shows the impact of such measures on the habitat areas (Fig. 5-3). The total subtidal area reduced because of straightening of the river. The area of tidal flat habitat nearly remained stable but the location of the tidal flat habitat shifted and summer polder areas completely disappeared. The overall Durme area of nearly 1,000 ha in the beginning of the 20th century was reduced to remaining 15% (Fig. 5-3).

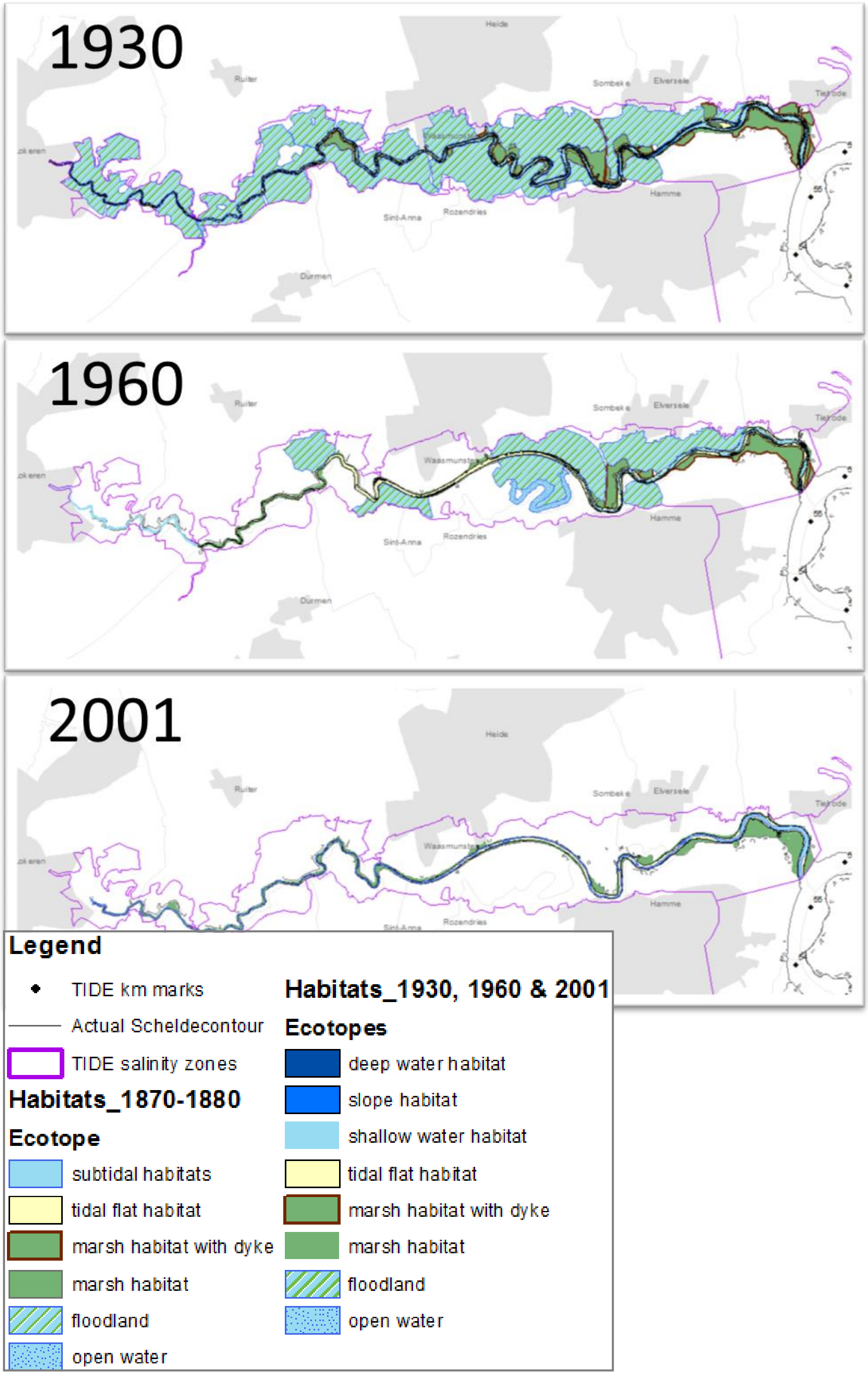

1930
1960
2001
Legend
TIDE km marks
Actual Scheldecontour
TIDE salinity zones
Habitats_1870-1880
Ecotope
subtidal habitats
tidal flat habitat
marsh habitat with dyke
marsh habitat
floodland
open water
Habitats_1930, 1960 & 2001
Ecotopes
deep water habitat
slope habitat
shallow water habitat
tidal flat habitat
marsh habitat with dyke
marsh habitat
floodland
open water

Fig. 5-3: Development of the Durme tributary

The loss of estuarine areas as well as different types of habitats can be related to several anthropogenic impacts such as dyke construction, land claim, deepening and straightening the rivers, cutting of tributaries and stabilizing the shorelines.

In general, the isolation of tributaries from the main estuary can be considered as the primary reason for loss. Dyke construction, either for land-claim or for flood protection, reduces marsh area under tidal action (Fig. 5-2 and 5-3).

Straightening and deepening led to higher current velocities and further penetration of the tides into the river catchment. To protect the catchment from those changes, higher dykes and weirs to cut off the tidal influence were constructed. These management measures further changed the hydrological characteristics, led again to higher current velocities and resulted in changes in sedimentation and erosion patterns. Subsequently new measures were required such as stabilising the new estuary beds with shoreline structures, groynes and training walls and intensified maintenance dredging (Herrling & Niemeyer 2008).

In the Elbe, the Sea Scheldt and the Weser the freshwater zones (Fig. 5-4) are characterized by an increase of deep water habitats, while shallow and slope water areas diminished. In all rivers the decrease of either marsh or summer polder shows the most remarkable loss. This had occurred in the Humber as well, however, prior to the end of the 19th century.

The evolution of the areal pattern in the oligohaline zones (Fig. 5-5) is dominated by the embanking of marsh habitats. A potential increase of subtidal habitats due to deepening the rivers can only be assumed for the Sea Scheldt. In the Elbe and the Weser that latter effects may have been confounded by straightening the rivers. Due to higher current velocities, the internal pattern of subtidal habitats shifted individually in every estuary.

This study collected no data about the patterns of organisms and functions distributed in the mapped habitats. However, less overall habitat areas without any remarkable increase of any habitat combined with higher velocities influencing turbidity and further factors describes a strong change in boundary conditions for the biotopes. Particularly the elimination of shallow water areas and secondary channels, both providing the space for the most estuarine biotopes influenced the overall biological productivity of estuaries. This observed development of diminishing space for benthic, bird and fish population can result in a decreasing biodiversity.

Fig. 5-4: Losses and gains of habitats (ha) in the freshwater zones from the end of the 19th century up to recent times

Fig. 5-5: Losses and gains of habitats (ha) in the oligohaline zones from the end of the 19th century up to recent times

6 Summary

Diverse uses in the estuaries form a challenge for balancing economic as well as environmental interests in a sustainable way. The project TIDE aimed to consider the ecosystem service approach in estuarine management. Since the services of an ecosystem are dependent on the area of habitats hosting the respective organisms of the ecosystem, it was the scope of this study to compare the change of habitat areas and patterns in the North Sea estuaries Elbe, Humber, Scheldt and Weser.

The evolution of the habitats of the four estuaries was analysed in three time steps: (1) at the end of 19th century/early 20th century, (2) at the middle of the 20th century and (3) in recent times. This approach has allowed to compare the development of the overall sizes of the estuaries, the areas related to a certain salinity zone and different habitats within these zones.

Sea charts, different types of maps and areal photos were digitized and the extensions of the respective habitat types within different salinity zones along the river were calculated applying GIS tools for the three time steps. Additionally, river specific inventories of human activities, potentially influencing the hydromorphology of the rivers were assembled.

In geological time scales, North Sea estuaries have changed as the result of climate changes after the Ice age. The melting of glaciers and inland ice shields led to a flooding of the North Sea basin due to a sea level rise of approximately 120 m. In addition, the North Sea estuaries are influenced by isostatic movement of the Earth´s surface. The surface is still recovering from the load of the ice masses, which covered the North Sea area. Areas covered by the ice shield such as Scandinavia rose and are still rising while areas which were not covered by ice show a subsidence. As an effect of subsidence, the sea-level is apparently rising because parts of eastern England, Belgium, The Netherlands and the German Wadden Coast are sinking.

Considering historic times, the estuaries have been modified by mankind with respect to protect the landscape from flooding and erosion, to claim wetlands for agriculture and settlement and to allow and maintain navigation along the fairways. In particular, navigation became more important because the settlements developed into prosperous trading places being reliant on these shipping routes.

It is notable that the estuaries generally show the highest loss of area in the inner freshwater and oligohaline zones. In the mesohaline zone less space has been lost and within polyhaline areas there was more or less a balance in the losses and gains. Across all salinity zones, the Elbe, Weser and Sea Scheldt show decreases of their overall area between 5 to more than 30 percentages. While the overall size of the Humber reduced greatly in the 18th and 19th century through land-claim for agriculture and port developments, more recently it has remained relatively stable.

In the Sea Scheldt appr. 1,850 ha respectively even more than half of the freshwater area has disappeared. In the mesohaline zone 500 ha got lost which is less than 20%.

In the Elbe 17% of the area (17,000 ha) is lost in the last century, most of it in the freshwater (-3,600 ha) and oligohaline zones (-5,700 ha) whereas the polyhaline zone remains stable.

The Weser shows a total loss of 4.5% of its area (-4,600 ha) with one third in the freshwater area (-2,000 ha) and a fourth of the oligohaline area (-1,700 ha). As well, here the area of the polyhaline zone did not change a lot. The loss of estuarine areas as well as different types of habitats can be related to several anthropogenic impacts such as building dykes and land claim, straightening and deepening the rivers, protecting shorelines and cutting-off tributaries or side channels.

These measures have partly led to higher current velocities, a further upstream penetration of the tides and tidal amplification. These changes in hydromorphological features changed the habitat patterns, decreased the overall area of the estuaries and in turn affected the ecological functioning of the estuarine environment.

7 References

Atkins, WS., (2002): Warming up the Region: The Impacts of Climate Change in the Yorkshire and Humber Region. WS Atkins report no: AK2970.068.dg.013, Epsom. pp. 109.

Augath, W. (1993): Stand und Weiterentwicklung der Höhenentwicklung der niedersächsischen Nordseeküste.– Nachrichten der niedersächsischen Vermessungs- und Katasterverwaltung 43, 78-92

BIOCONSULT (2008): Umsetzung der Wasserrahmenrichtlinie (WRRL). Maßnahmenkonzeption für 5 verschiedene Maßnahmentypen in den niedersächsischen Übergangs- und Küstengewässern im Auftrag des NLWKN Betriebsstelle Brake-Oldenburg. Die Ergebnisse der Uferkartierung liegen digital als GIS-Daten vor.

Bund für Umwelt und Naturschutz in Deutschland: (2006): Themenheft "Klimawandel trifft Unterweserregion - aber wie?“ Bremer Beiträge für Naturkunde und Naturschutz Band 8

Bungenstock, F (2005): Der holozäne Meeresspiegelanstieg südlich der ostfriesischen Insel Langeoog, südliche Nordsee – hochfrequente Meeresspiegelbewegungen während der letzten 6000 Jahre. 130 pages. PhD thesis University of Bonn

Connor, D.W., Allen, J.H., Golding, N., Howell, K.L., Lieberknecht, L.M., Northen, K.O. & J.B. Reker (2004): The Marine Habitat Classification for Britain and Ireland - Version 04.05. Joint Nature Conservation Committee (JNCC), Peterborough. ISBN 1 861 07561 8 (internet version) www.jncc.gov.uk/MarineHabitatClassification

Costanza, R.; dÁrge R, deGroot R, Farber S, Grasso M, Hanno B, Limburg K, Naeem S, O´Neill RV, Paruelo J, Raskin RG, Sutton P, van den Belt M (1997): The value of the world´s ecosystem services and natural capital. NATURE Vol 387, 253-260

Cutts, N.D., Murby, P. & K.L. Hemingway (2008): Habitat Loss in the Humber Estuary, UK. Institute of Estuarine & Coastal Studies (IECS), University of Hull, UK. Report produced as part of the European Interreg IIIB HARBASINS project.

Davies C.E., Moss D. & M.O. Hill, 2004. EUNIS habitat classification revised (2004): Report to European Environment Agency, European Topic Centre on Nature Protection and Biodiversity. http://eunis.eea.eu.int/upload/EUNIS_2004_report.pdf.

de Boer, G., 1970. Accretion and reclamation in the River Humber. East Yorkshire Field Studies, No. 3.

de Jonge, V.N. & Elliott, M., 2001. Eutrophication. In Steele, J., Thorpe, S. & Turekian, K. (Eds). Encyclopedia of Marine Sciences, Academic Press, London, 852-870.

Elliott, M., Hemingway, K.L., Cutts, N.D., Burdon, D., Pérez-Dominguez, R., Allen, J., Thomson, S.M., de Jonge, V.N., Breine, J., Van den Bergh, E., Stevens, M., Simoens, I., Jager, Z. & F. Twisk (2008): Estuarine Ecosystem Functioning, Restoration and Health. Institute of Estuarine & Coastal Studies (IECS), Research Institute for Nature and Forest (INBO) & Rijkswaterstaat. Report produced as part of the HARBASINS European Interreg IIIB project, 657 pp.

Elsebach, J., Kaiser, R. und Niemeyer, H.D. (2007): HARBASINS Report: Spatial Balance of Habitats in the Weser Estuary. Lower Saxony Water Management, Coastal Defence and Nature Conservation Agency – Coastal Research Station. http://tide-project.eu/downloads/Spatial_Habitat_Development_Weser_Estuary.pdf

Elsebach, J.; Kaiser, R.; Niemeyer, H.D. (2007b): Identifikation von erheblich veränderten Gewässerbereichen in der Tideweser, Untersuchungsbericht 05/2007, NLWKN- Forschungsstelle Küste, Norderney (unpublished)

Environment Agency, 2011. The Humber Environment in Focus 2011. Environment Agency, Leeds, 59 pp.

Farber, S; R. Costanza and M.A. Wilson (2002): Economic and ecological concepts for valuing ecosystem services. Ecological Economics, 41 (Special Issue: The Dynamics and Value of Ecosystem Services: Integrating Economic and Ecological Perspectives): 375-392

Fickert, M and Strotmann, T (2007): Hydrodynamische Entwicklung der Tideelbe. Pp 59-68. Coastline Reports 9 (2007), ISSN 0928-2734, ISBN 978-3-9811839-1-7

Franzius. L., Bücking, H. (1895) Die Korrektur der Unterweser. Verlag Wilhelm Engelmann, Leipzig.

Freitag, C., Hochfeld, B. and Ohle, N. (2007): Lebensraum Tideelbe. Pp 69-79 in: G. Gönnert, B. Pflüger & J.-A. Bremer (edts.): Von der Geoarchäologie über die Küstendynamik zum Küstenzonenmanagement Coastline Reports 9 (2007), ISSN 0928-2734, ISBN 978-3-9811839-1-7

Geerts, L., Wolfstein, K., Jacobs, S., van Damme, S. and Vandenbruwaene (2012): Zonation of the TIDE estuaries. 19 p. TIDE report

Harbasins (2008): Steps towards a harmonized transnational management strategy ffor coastal and transnational waters. Summary report. 48 pp download at www. Harbasins. Org

Herrling, G. & HD Niemeyer (2008): Hydro- and morphological pressures and impacts. 28 pp. Harbasins report at www.Harbasins.org)

Homeier, H. (1962): Historisches Kartenwerk 1:50 000 der niedersächsischen Küste, Jahresbericht der Forschungsstelle Küste, Band XIII (Karten Nr. 8 bis 14)

Huijs S.W.E. (1996). De ontwikkeling van de morfologie in de Westerschelde in relatie tot menselijke ingrepen 1955-1994. Universiteit Utrecht, R96-17.

Institut für Seeverkehrswirtschaft und Logistik ISL (2009): Bedeutung der Fahrrinnenanpassung für die Schifffahrt im Hamburger Hafen. 31. S

IPCC (2001): Climate change. The Scientific basis. Cambridge University Press.

Jensen, J. & C. Mudersbach (2007): Zeitliche Änderungen in den Wasserstandszeitreihen an den Deutschen Küsten. Ber. z. dt. Landeskunde Bd. 81, H. 2: 99-112.

Kiden, P., Denys, L. & Johnston, P. (2002): Late Quaternary sea-level change and isostatic and tectonic land movements along the Belgian-Dutch North Sea coast: geological data and model results.– Journal of Quaternary Science 17 (5-6), 535-546.

Kraft, D; Osterkamp, S and M. Schirmer (1999): Die ökologische Situation der Unterweser und ihrer Marsch als Ausdruck der naturräumlichen Situation und Nutzung pp. 129-152 in Schirmer and Schuchardt (eds.): Die Unterweser als Natur- Lebens- und Wirtschaftsraum. 211 pp. Bremer Beiträge zur Geographie und Raumplanung 35.

M. Munasinghi(1998): Climate change decision making. Int. J. Environment and Pollution 10 (2), pp. 188-239, 1998

Meadows D.L. (1972): The Limits of Growth. 244 pp. Universe books, New York

Pethick, J.S., 1990. The Humber Estuary. In Ellis, S. & D.R. Crowther (Eds.). Humber Perspectives: A Region through the Ages. Hull University Press, Hull.

R. Constanza, dÁrge R, deGroot R, Farber S, Grasso M, Hanno B, Limburg K, Naeem S, O´Neill RV, Paruelo J, Raskin RG, Sutton P, van den Belt M, The value of the world´s ecosystem services and natural capital. NATURE Vol 387, 253-260, 1997

Rijn, L.C. van, (2011): Comparison Hydrodynamics and Salinity of Tide estuaries: Elbe, Humber, Scheldt and Weser. TIDE Report

Schönwiese, CD (1994): Klimatologie. Uni Taschenbuch 1793, Ulmer, Stuttgart

Schuchardt B, Scholle J., Schulze S. & T. Bildstein (2007): Vergleichende Bewertung der ökologischen Situation der inneren Ästuare von Eider, Elbe, Weser und Ems. In G. Gönnert, B. Pflüger & J.-A. Bremer (Hrsg.): Geographie der Meere und Küsten Coastline Reports 9 (2007), ISSN 0928-2734

Schuchardt B. & M. Schirmer (2005): Klimawandel und Küste. Die Zukunft der Unterweserregion. 341 S., 81 Abb., Springer-Verlag Berlin Heidelberg

Shennan, I. (1987): Holocene sea-level changes in the North Sea Region.– In: TOOLEY, M. J. & SHENNAN, I. (eds.): Sea-level changes. 109-151.

Streif, H. (2004): Sedimentary record of Pleistocene and Holocene marine inundations along the North Sea coast of Lower Saxony, Germany.– Quaternary International 112, 3-28.

Vandenbruwaene, W.; Plancke, Y.; Verwaest,T.; Mostaert, F. (2013). Interestuarine comparison: Hydrogeomorphology: Hydro- and geomorphodynamics of the TIDE estuaries Scheldt, Elbe, Weser and Humber. Version 4. WL Rapporten, 770_62b. Flanders Hydraulics Research: Antwerp, Belgium

Venice system (1959). The final resolution of the symposium on the classification of brackish waters. Archo Oceanogr. Limnol., 11 (suppl): 243–248.

Wetzel, V. (1987): Der Ausbau des Weserfahrwassers von 1921 bis heute, Jahrbuch der Hafenbautechnischen Gesellschaft Hamburg, Band 42

8 Annex

8.1 Human activities along the Elbe, Humber and Weser estuary from the 19th century on

8.1.1 Activities along the Elbe

A - 1: Human activities along the Elbe estuary from the 19th century.

Activity	Construction begin	Construction end	Construction time	Total surface impoundment [ha]
Fairway deepning to 8 mKN	1897	1910	13	-
Sand nourishment Schwarztonnensand	1929	1936	7	-
Fairway deepening to 10 mKN	1936	1978	42	-
Construction Leitdamm Kugelbake	1939	1972	33	-
Cut off Dove Elbe	1950	1952	2	130
Construction of the weir Geesthacht	1957	1960	3	-
Fairway deepening to 11 mKN	1957	1961	4	-
Cut off the inner este	1959		1	-
Cut off Alte Süderelbe (closure water-level of storm surge barrier: 2,8 mNN) and new dykeline from Harburg to Este	1962	1967	5	200
Poldering Oortkaten	1963	1963	1	160
Poldering Geesthacht to Billwerder Bucht	1963	1973	10	160
Cut off Billwerder Bucht with channels (closure water-level of storm surge barrier: 3,5 mNN)	1963	1969	6	170
Fairway deepening to 12 mKN	1964	1969	5	-
Shoreface nourishment from Störleitdamm to Bütteler Hafenpriel	1964	1969	5	
Cutting off Seeve River(Schließwasserstand: 3,3 mNN)	1966	1966	1	550
Cut off Lühe (closure water-level of storm surge barrier: 2,0 mNN)	1967	1967	1	1400
Raising dam between Hanskalbsand and Neßsand to 1 m üNN by sand nourihment	1967	1968	1	-
Cut off Oste (closure water-level of storm surge barrier: 2,0 mNN)	1968	1968	1	?
Cut off Pinnau and Krückau (closure water-level of storm surge barrier: 2,5 mNN) mit Eindeichung des zwischenlieg. Vorlandes	1969	1969	1	1650
Poldering Hahnhöfer Sandes and in front of Schwinge-, Pinnau- and Krückau	1969	1974	5	3050
Cut off Schwinge and Bützflether Süderelbe (closure water-level of storm surge barrier: 2,2 mNN) and Poldering Bützflether Sand	1971	1971	1	1140
Poldering Nordkehdingen	1971	1976	5	5500
Cut off Ilmenau (closure water-level of storm surge barrier: 3,3 mNN)	1973	1973	1	650
Poldering Hahnöfer Sand and cut off Borstler Binnenelbe	1973	1974	2	560
Fairway deepening to 13,5 mKN	1974	1978	4	-
Cut off Stör (closure water-level of storm surge barrier: 2,5 mNN)	1975	1975	1	1400
Poldering Haseldorfer Marsch	1975	1977	2	2100
Poldering Krautsand	1977	1977	1	2990
Fairway deepening to 14,5 mKN	1998	2000	2	-
Backfilling Mühlenberger Loch	2002	2002	1	110

8.1.2 Activities along the Humber

A - 2: Overview of human activity and modification to the Humber, 1700 to present (various sources)

Activity	Time	Remarks
Maintenance dredging commences on the Humber	1778	
Humber Dock, Hull, opened	1807	
Steam driven dredgers commence operation	Mid 1800s	
Improvements to the River Ouse (River Ouse Act) including re-profiling of sections	Mid 1800s	
Victoria, Albert and Alexandra Docks	Late 1800s	Dredging increased with material deposited in channel on the south side
Present spoil grounds opposite Victoria and Alexandra Docks opened	1903	
13.4m t of dredged material deposited on south side of channel between Hull Middle & Skitter Sands	1899-1904	
Maintenance dredgings deposited on Burcom Sand close to existing deposit ground		
New ports constructed at Immingham(1912) and King George Dock, Hull	Early 20th Century	
Completion of training walls at the Trent Falls confluence	1935	Larger vessels could reach Goole
50 vessels engaged in dredging on the estuary	1950	
Queen Elizabeth Dock, riverside jetties at Immingham & Saltend and Immingham Bulk and Oil Terminals	Late 1960s	
Sunk Dredged Channel (SDC) capital & maintenance dredging starts	As consequence of IOT & IBT above	
Deposit ground at Bull Sand Fort commenced	Late 1960s, early 1970s	
Immingham Gas Jetty Constructed	Early 1980s	
Dredge volumes: annual in situ volume excavated due to maintenance and relocated 7.3m m^3 pa. Total of 7.2m m^3 capital dredge material. 4.6m m^3 of that being SDC.	1960-1994	
11.8m m^3 material requiring dredging	1994	
Riverside RORO Terminal, HIT & HST constructed	2000-2005	
Increase in overall maintenance dredge requirements due to HIT HST & IOH – 3m m^3 of capital dredge inc. SDC 1.2m m^3 of material dredged in 2004	1999-2006	
No requirement for Sunk Dredge Channel dredging	2007-2010	Accretion erosion cycle duration currently being investigated

8.1.3 Activities along the Weser

A - 3: Human activities along the Weser estuary from the 19th century on (Küster 1999; Schuchardt and Schirmer 2005 and www.wsa.de)

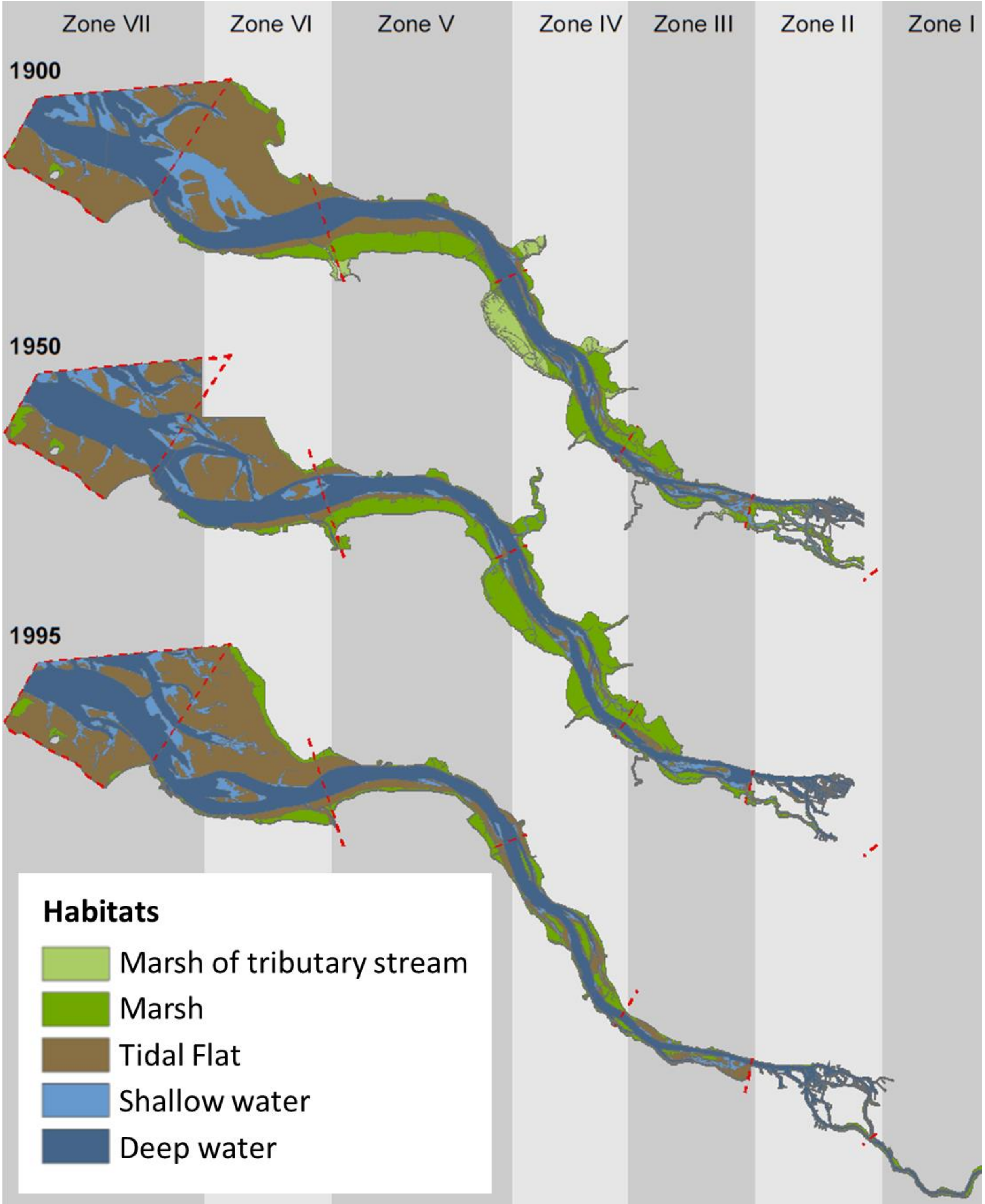
Activity	Time	Remarks
Constructing port of Bremerhaven	1827	Easier navigation compared to Bremen
Straitening the fairway in Bremen Lankenau	1883	Easier navigation in Bremen
Straitening the fairway of the Unter Weser to a depth of -5m - “Franzius correction”	1887-95	Along the whole estuary, Millions of cubic meter
Weir controlling the Geeste (tributary at Bremerhaven)	1890-92	Renewed in 1961
Deepening the fairway along the Outer Weser to -7,3 m	1891-95	Millions of cubic meter
Installation of groynes and dams at the Franzius plate	1891-95	
New harbour basins in the City of Bremen	1888-1906	Stephaniekirchhof 1888, Gröpelingen 1891, Hemelingen 1902, Shipyards 1905; Overseas Transport 1906
Weir construction in Bremen City	1906-15	Installation of a weir in Bremen city to control upstream water levels in order to allow upstream navigation and to prevent the floods to reach areas upstream of Bremen
Deepening of the fairway in the Unterweser to -7 m depth	1913-16	Millions of cubic meter
Deepening the Weser fairway to Bremen to 7 m depth	1921-24	Millions of cubic meter
Changing the fairway in the Outer Weser estuary (Fedderwarder Arm)	1922-26	Millions of cubic meter
Construction of dams at the fairways in the Outer Weser	1910-26	Robbensüdsteert and Langlütjennordsteert
Deepening the Unterweser fairway to 8 m depth	1925-29	Millions of cubic meters
Deepening the Unterweser fairway to 8,7 m depth	1953-58	Millions of cubic meters
Changing the city fairway	1953-60	Millions of cubic meters
Maintenance to compensate effects of 2. WW	1954-67	Millions of cubic meters and renewing dams in Outerweser
Construction of the container Hafen Neustädter Hafen Bremen	1960	Millions of cubic meters
Deepening the Outer Weser to -12 m depth	1969-71	Millions of cubic meters
Deepening parts of the Unter Weser (Blexer Bogen) to -10,5 m	1971	Millions of cubic meters
Deepening the Unterweser to -11 m	1973-74	Millions of cubicmeters
Floodweirs at the Lesum and the Ochtum (tributaries)	1974 and 76	Tide induced erosion in the tributaries was prevented
sand mining activities in the Unterweser ended	Until 1980	
Construction and renewing shoreline structures between Nordenham and Brake	1982-91	
Enlarging container port in Bremerhaven CT III	1987-91	
Deepening the fairway Outer Weser to -14 m	1998-99	Millions of cubic meters
Water discharge at Nordenham to cool the power plant	Since 1998	
Refilling the Überseehafen, Bremen	1999	

8.1.4 Activities along the Schelde

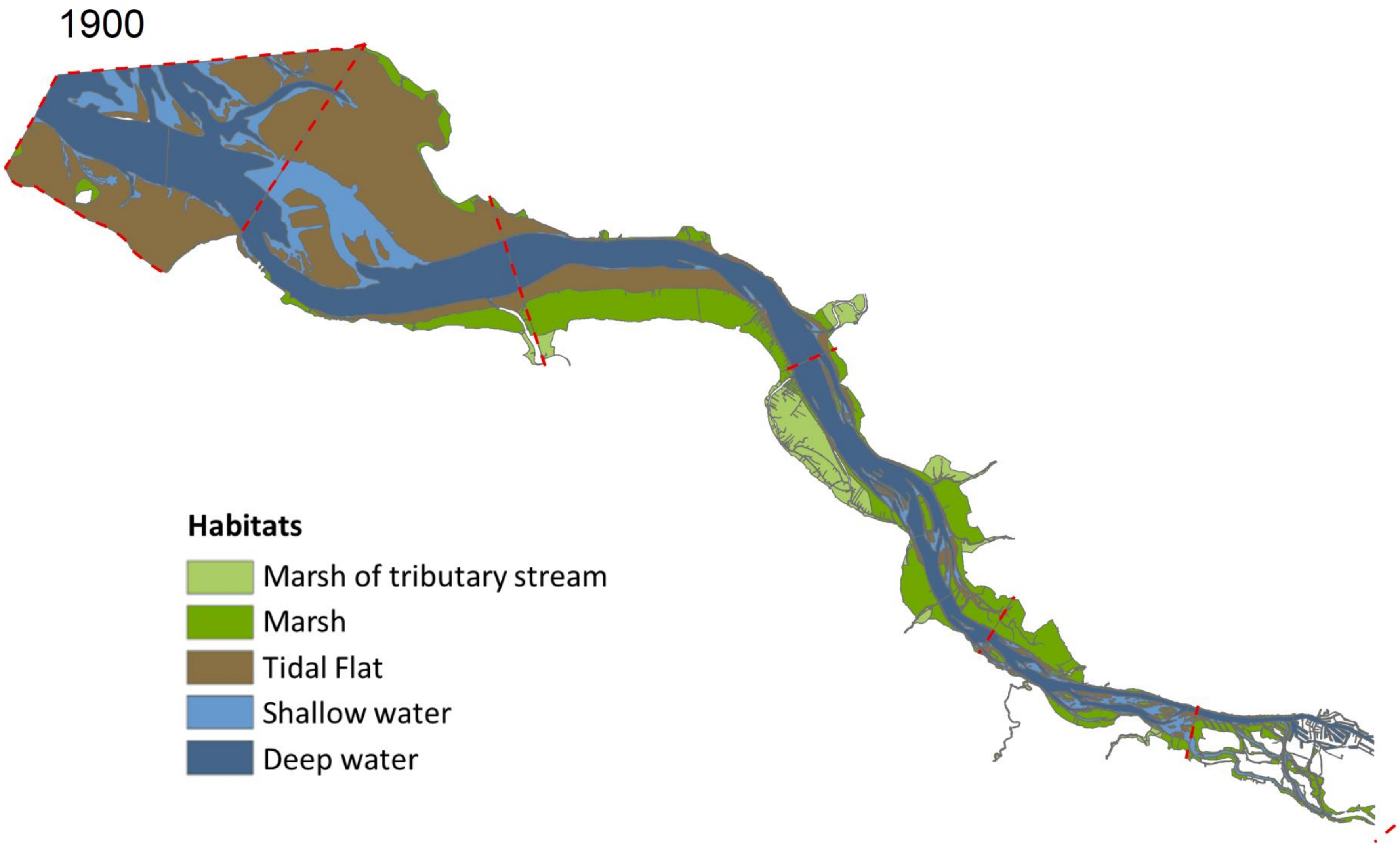
Can be found within the Annex 8.2.3.

8.2 Maps and reports used for surface calculation

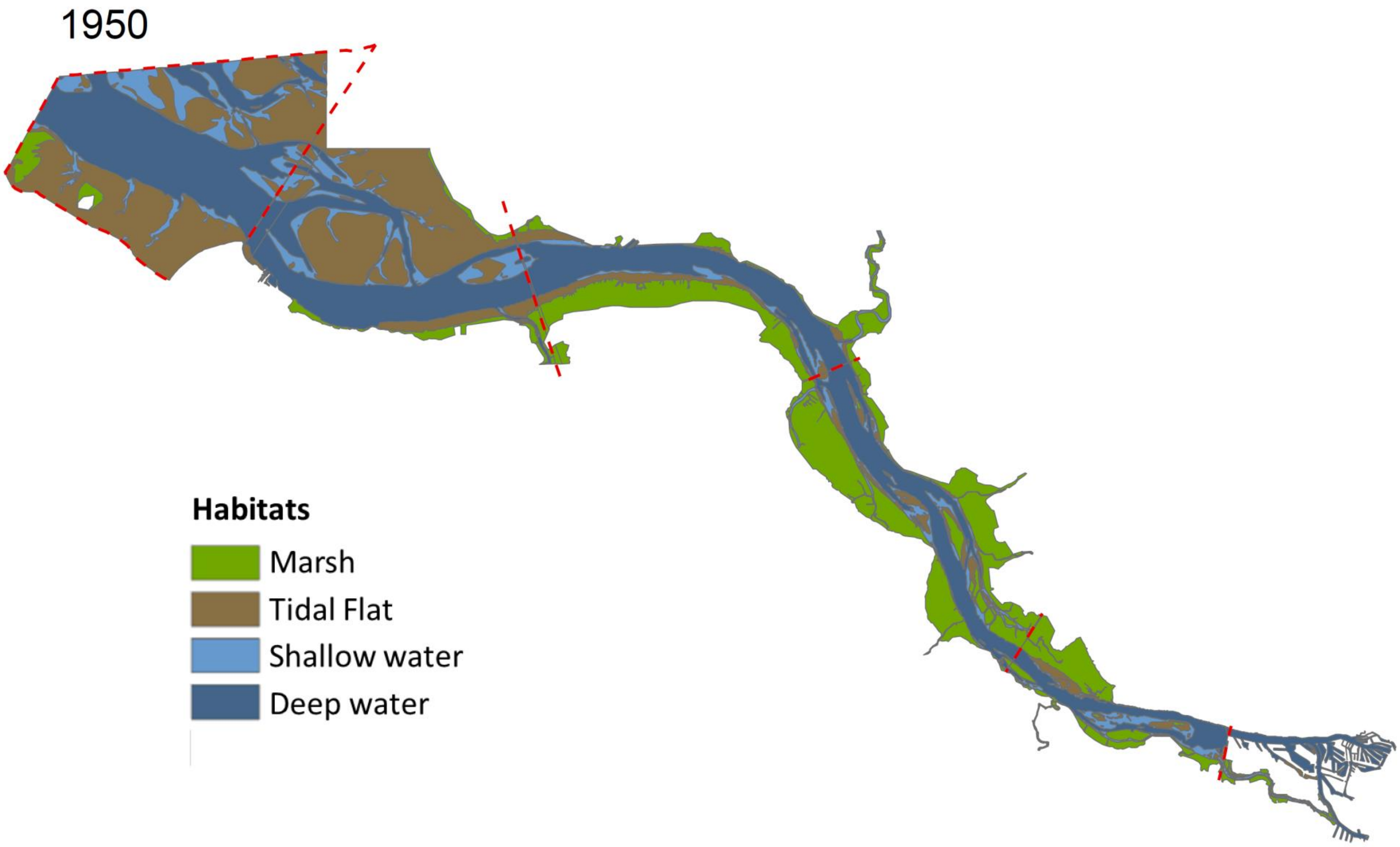
8.2.1 Elbe



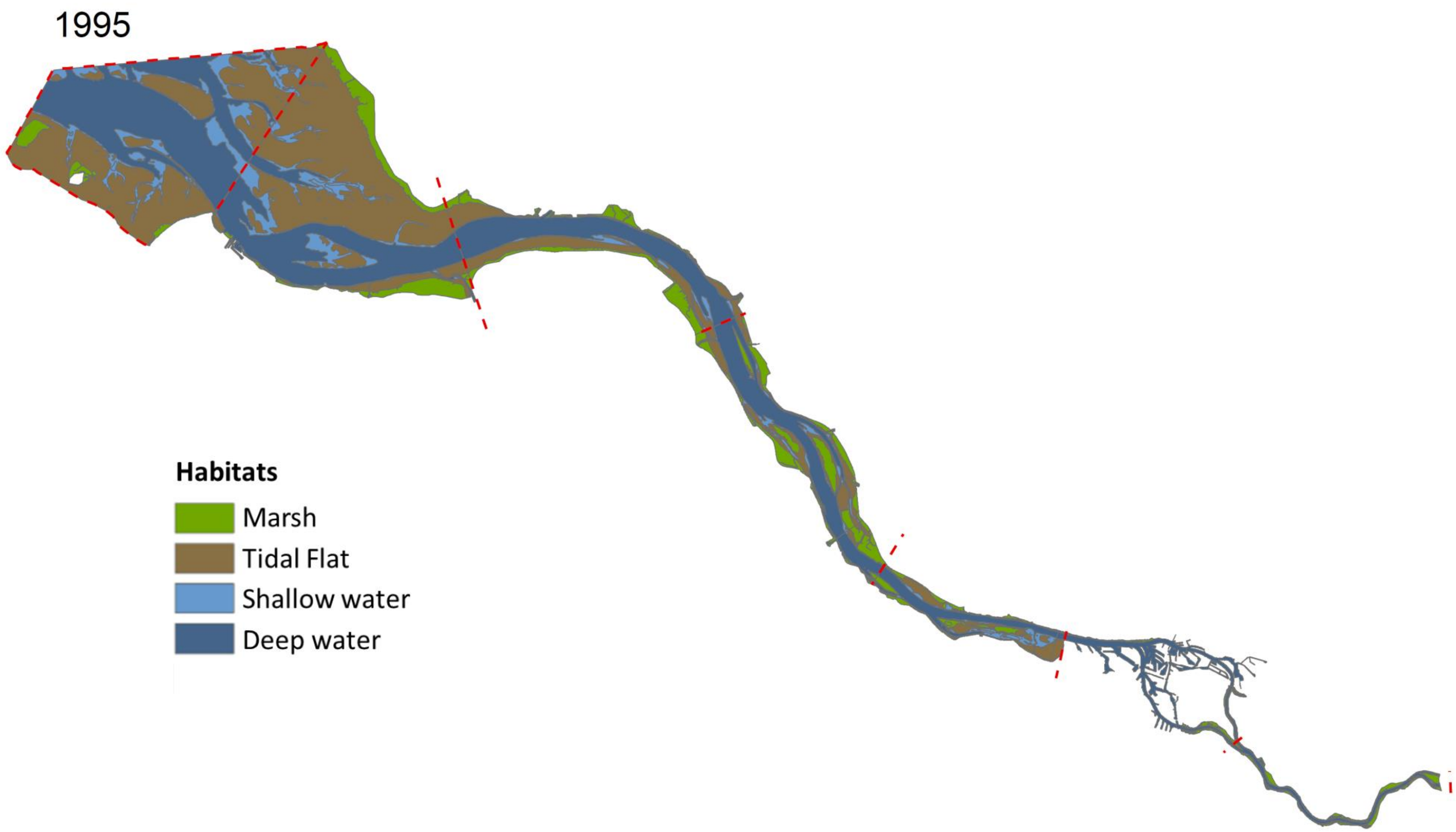
A - 4: Overview of all zones within the Elbe estuary for all applied timesteps



A - 5: Overview of the Elbe estuary in the beginning of the 20th century

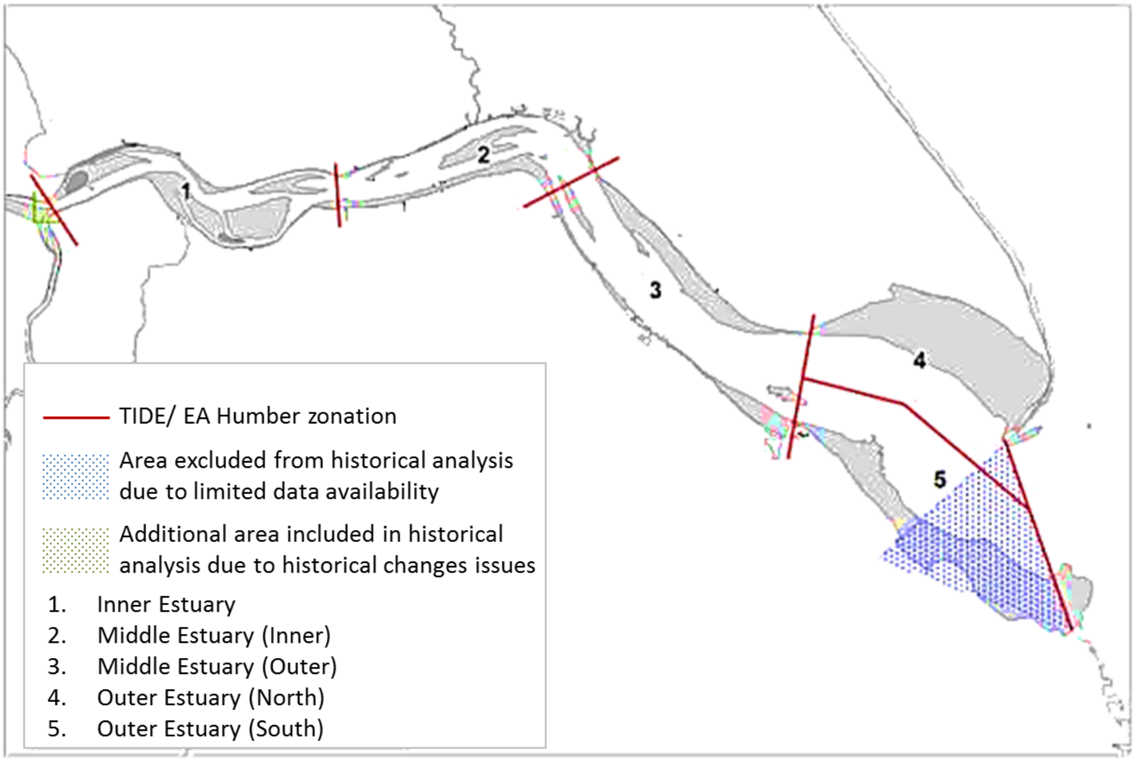


A - 6: Overview of the Elbe estuary in the mid - 20th century



A - 7: Overview of the Elbe estuary in the end of the 20th century

8.2.2 Humber

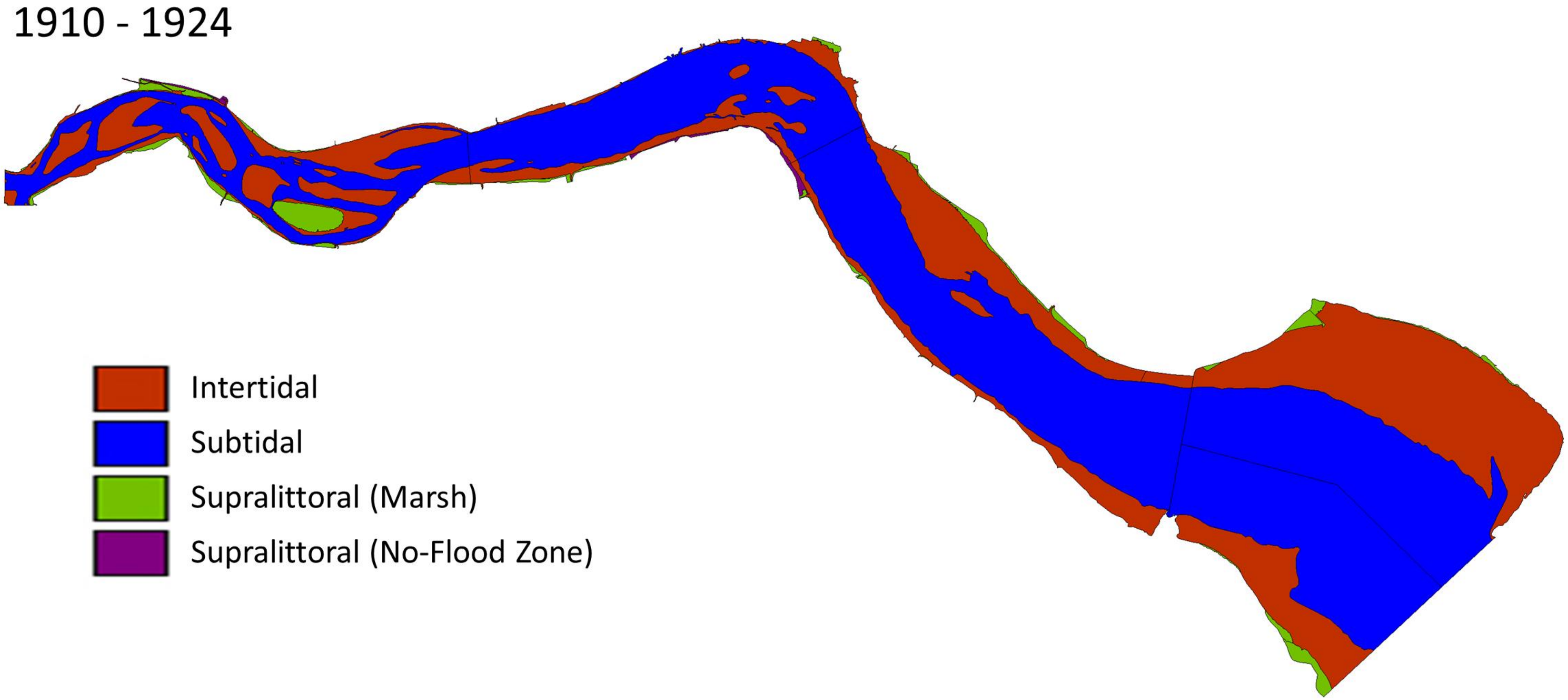


A - 8: Map showing Humber Estuary analysis sectors

Admiralty charts for the Humber from 1910/1924, 1975, 1988, 1993 & 2008 were scanned and geo-referenced. For each year, height bands of subtidal, intertidal (tidal flat), supralittoral (marsh) and supralittoral (no-flood zone) were digitised (A – 9, A – 10, A – 11, A – 12, A – 13).

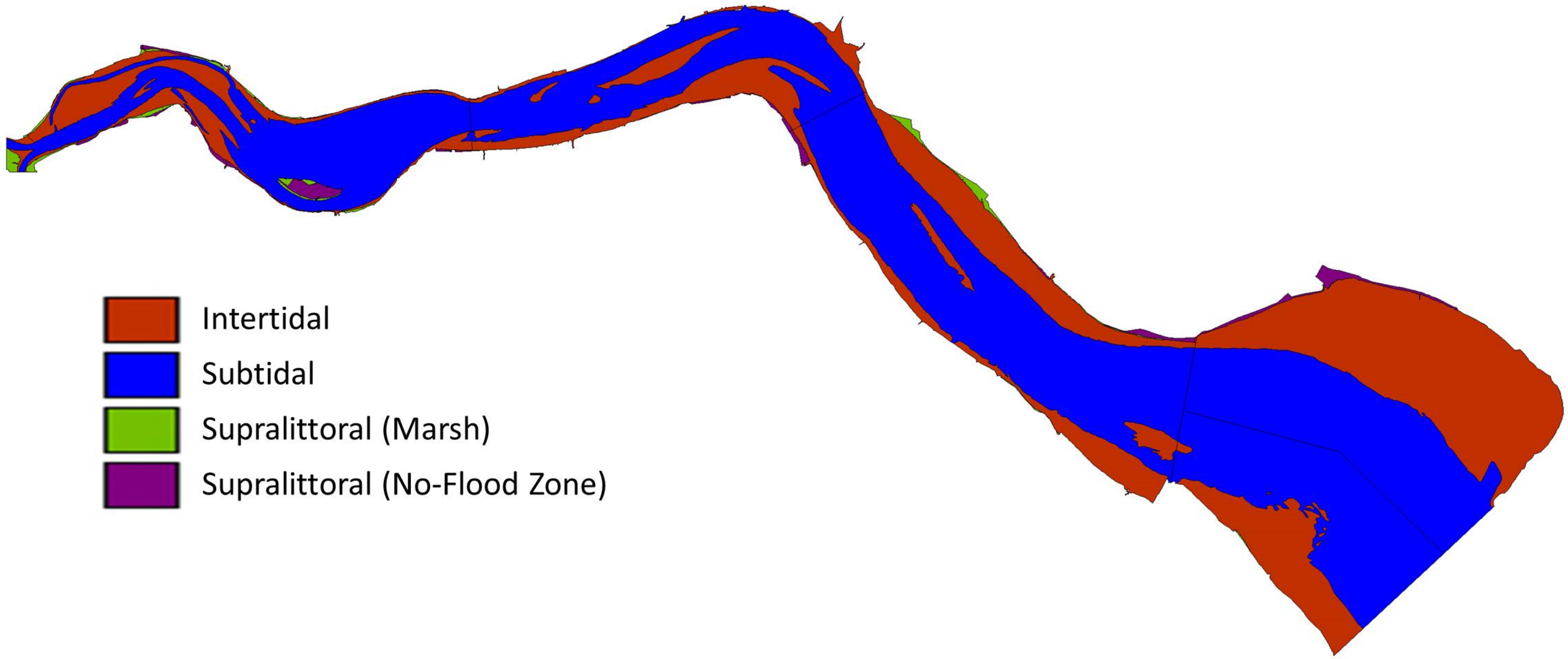
The projection used was British National Grid (BNG) which was a common projection throughout the charts used however, particularly in the older maps accuracy was compromised.

Where chart sections were missing, boundaries were interpolated using a current Ordnance survey backdrop. All areas were digitised into closed polygons and the line work was cleaned to ensure accurate representation. Areas of each height band in each section of the estuary (Figure A 8) were then calculated in hectares. However, the tidal freshwaters were excluded from the analysis due to data limitations. The Outer South zone of the Humber was similarly excluded from the analysis, due to data limitations. However, given there had been a relatively important change in the confluence of the Rivers Trent and Ouse, the extreme lower reaches of both river were included in the analysis (e.g. slightly upstream from the management boundary identified for the inner Humber for use in other work packages), this increased area shaded green in Figure.

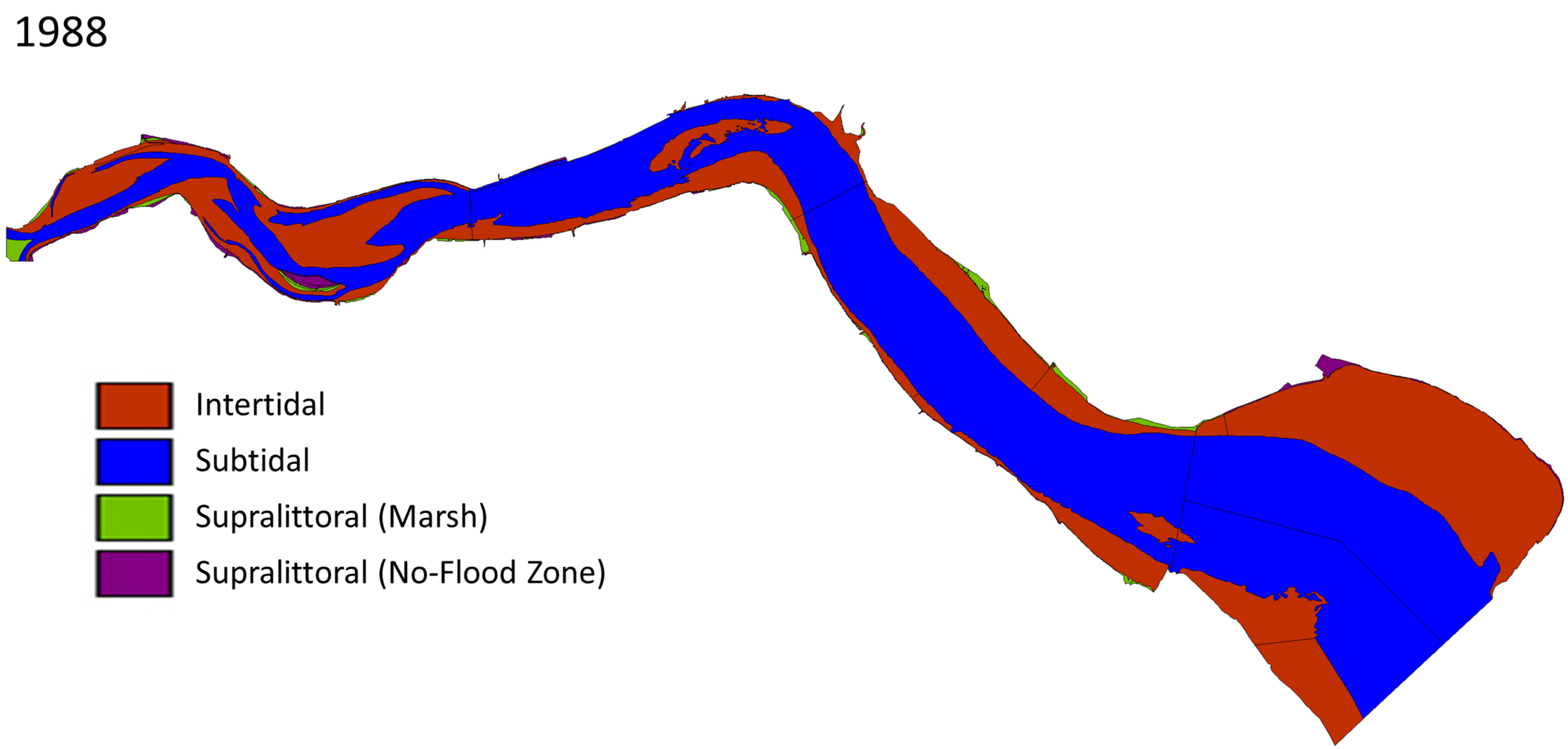


A - 9: Map of Habitat-Zonation of the Humber for 1910 - 1924

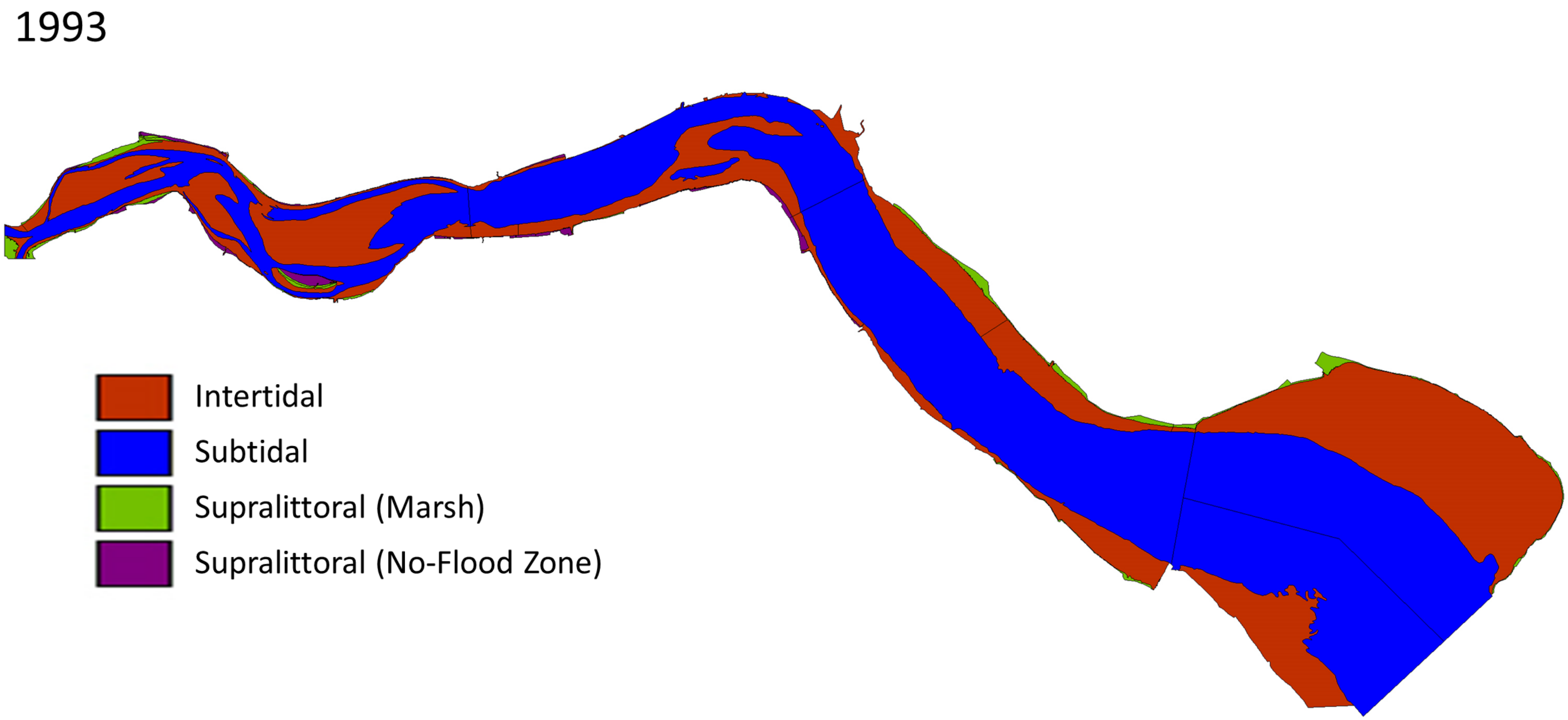
1975



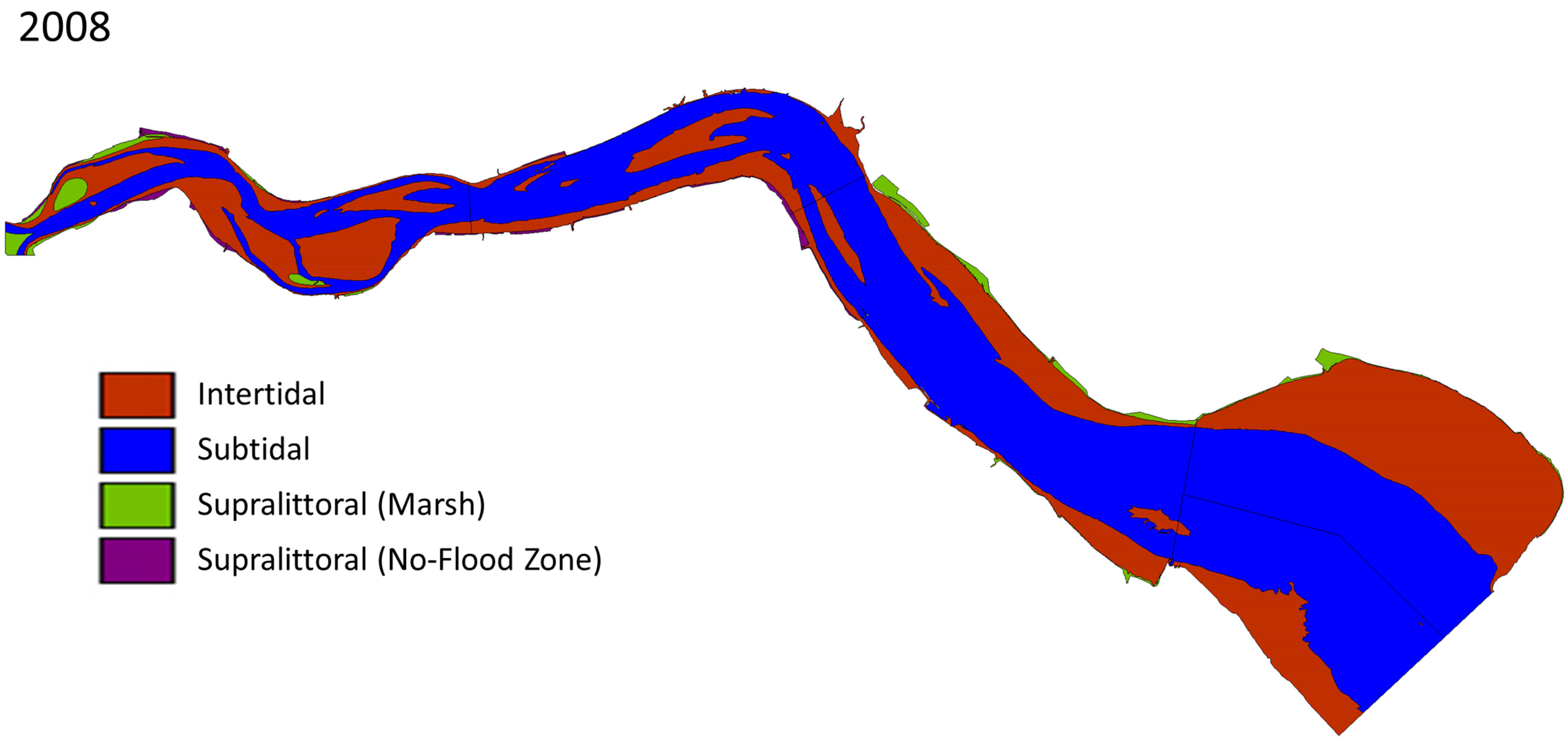
A - 10: Map of Habitat-Zonation of the Humber in 1975



A - 11: Map of Habitat-Zonation of the Humber in 1988



A - 12: Map of Habitat-Zonation of the Humber in 1993

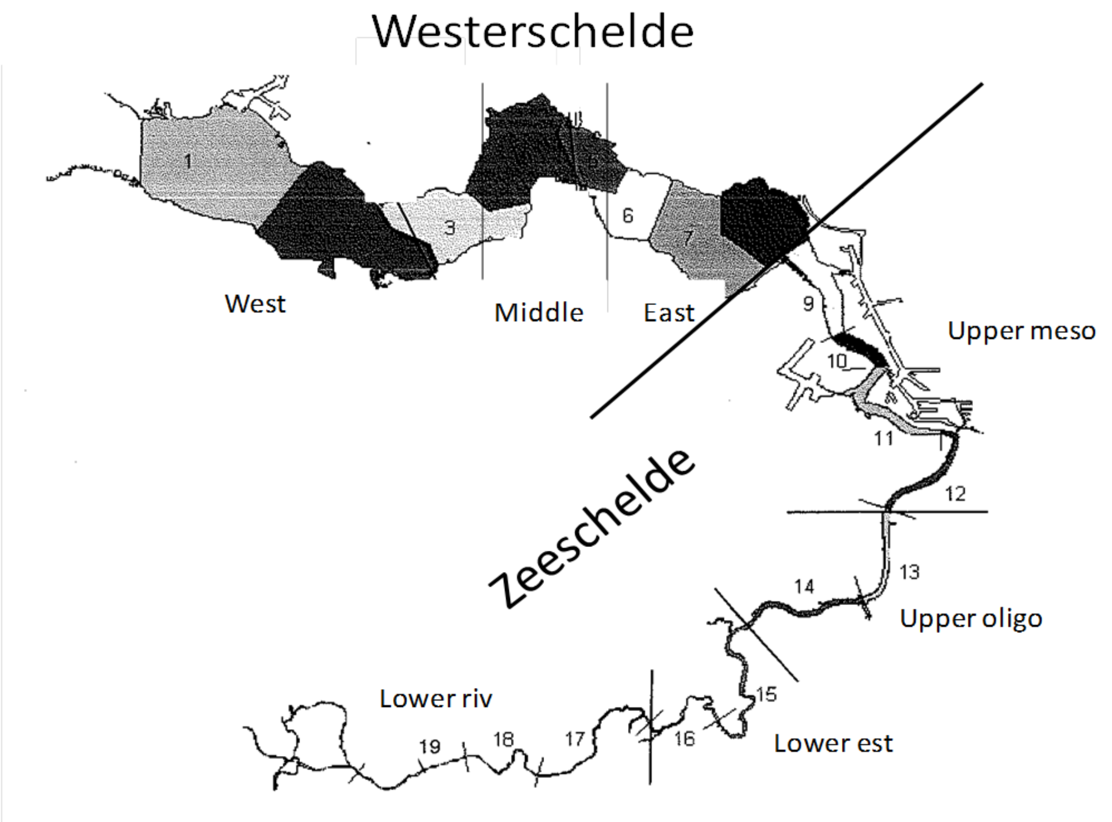


A - 13: Map of Habitat-Zonation of the Humber in 2008

8.2.3 Scheldt

Both, Flanders and the Netherlands have compiled several physiotope maps as part of the integrated monitoring program and joint reporting effort. The physiotope maps contain areas of similar abiotic conditions (depth, hydrodynamic conditions, inundation time, sediment composition). All types of prevailing physiotopes are classified into a hierarchical scheme.

Physiotope maps of the Beneden-Zeeschelde (Flanders) are compiled by the Institute for Nature and Forest Research (INBO) and cover TIDE zones 1 to 4 and part of TIDE zone 5. Physiotope maps of the Westerschelde (the Netherlands) are compiled by Rijkswaterstaat (RWS) and cover the remaining part of TIDE zone 5 and TIDE zone 6 (A – 14).



A - 14: Schelde zonation scheme according to the Venice-System

Additional to what is collected in this report, more useful information on the evolution of habitats can be derived from literature. Conclusions relevant for TIDE can be mentioned as a qualitative description or quantitative information in other zones than the TIDE salinity zones and in other habitat classifications.

A - 15: Data availability along the Scheldt for different time steps

TIDE - zone	Source	MAP 1900	MAP 1950	MAP 2000
1	INBO	Available	Available	Available
2				
3				
4				
5-1				
5-2	RWS	Not available	Areas are mentioned in literature	Available
6				

Because of different availability of data sources, differences in between the maps occur:

- The 1870-1880 map has been derived from aerial photographs and/or topographic maps and does not allow further distinction of the subtidal habitats.
- The 1930 map is derived from bathymetric data and from aerial photographs and/or topographic maps.
- The 1960 and 2001 maps are derived from bathymetric data, hence no information on the supratidal habitats is available.

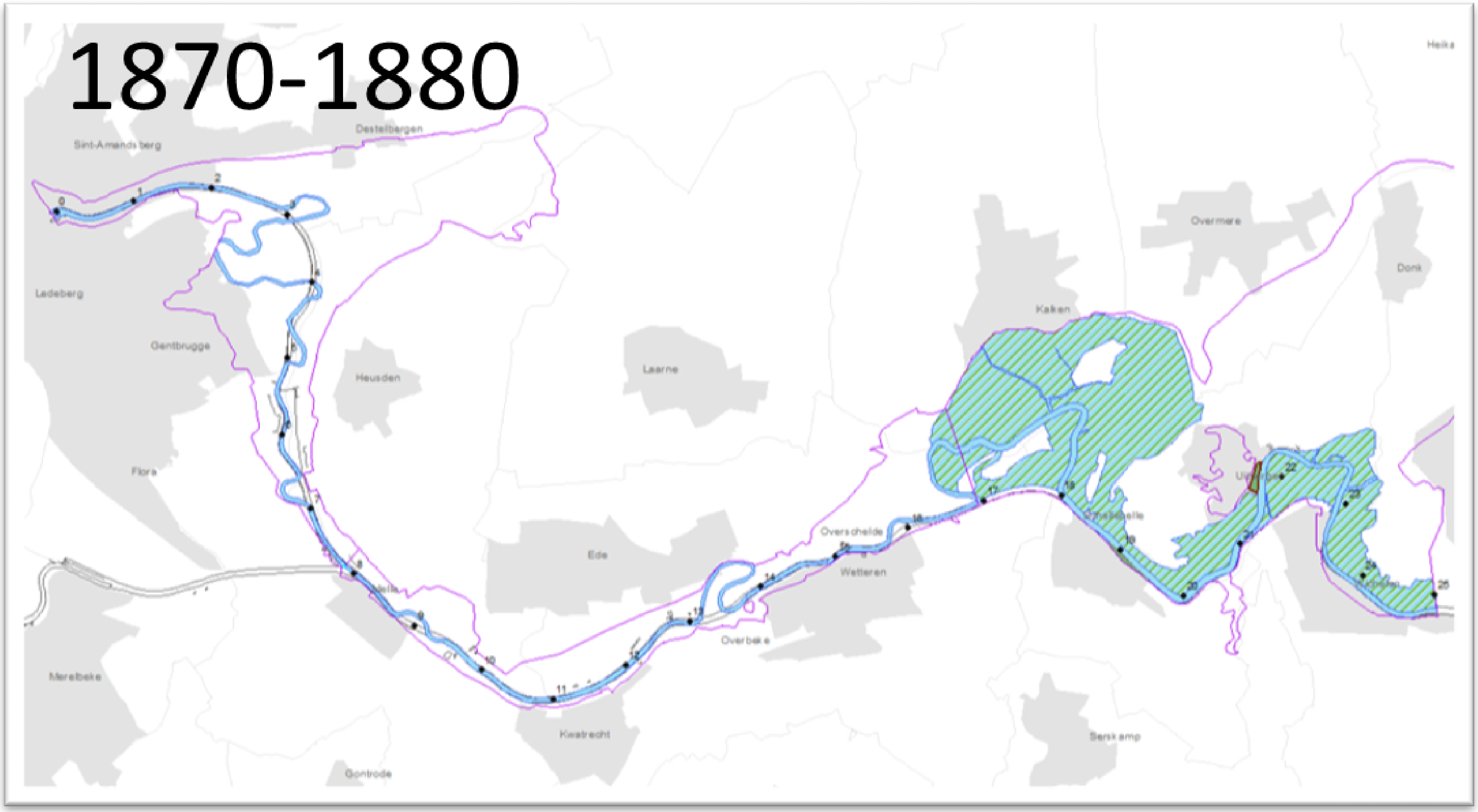
Because of lack of information of historical current velocities and since the Zeeschelde is a meandering tidal river with a single channel, all subtidal and intertidal habitats of the Zeeschelde are classified as high energy habitats.

8.2.3.1 TIDE zone 1 - Fresh water zone 1

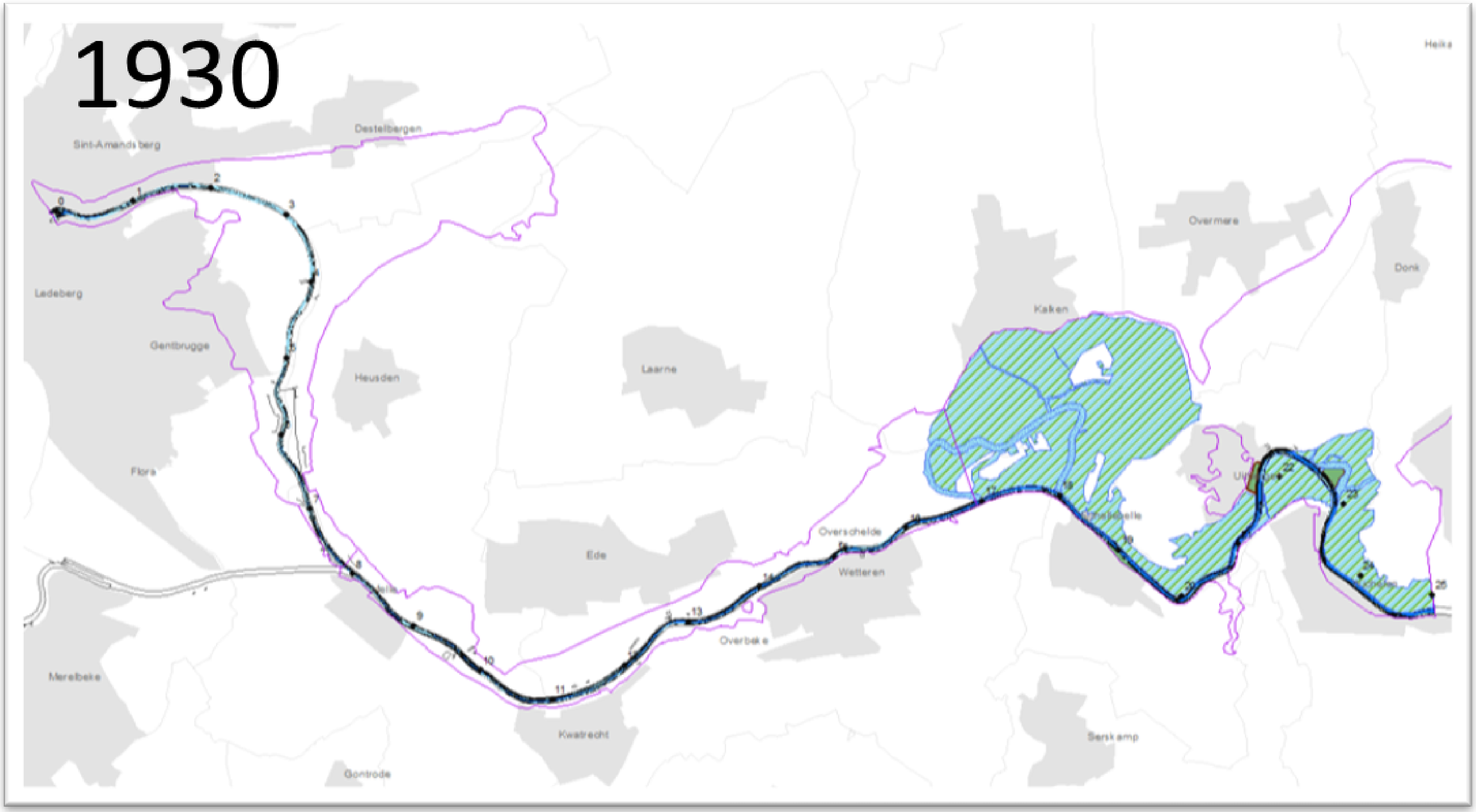
TIDE zone 1 stretches from the upstream weir at Gentbrugge to Wichelen. Table A - 20 gives the habitat areas [ha] for TIDE zone 1. The extent of the 1960 map does not cover the whole subtidal and intertidal area. The total area of considered habitats of the 1960 and 2001 map are equal although their different extent.

The upstream weir at Gentbrugge became disfunctional in 1969 when a lock was completed near Merelbeke in the 'Ringvaart' around Ghent, allowing inland ships to sail around Ghent and connecting the Schelde estuary in Melle to the upstream Schelde and Leie catchments, to the inland channel to Bruges and Ostende and to the Channel Ghent-Terneuzen.

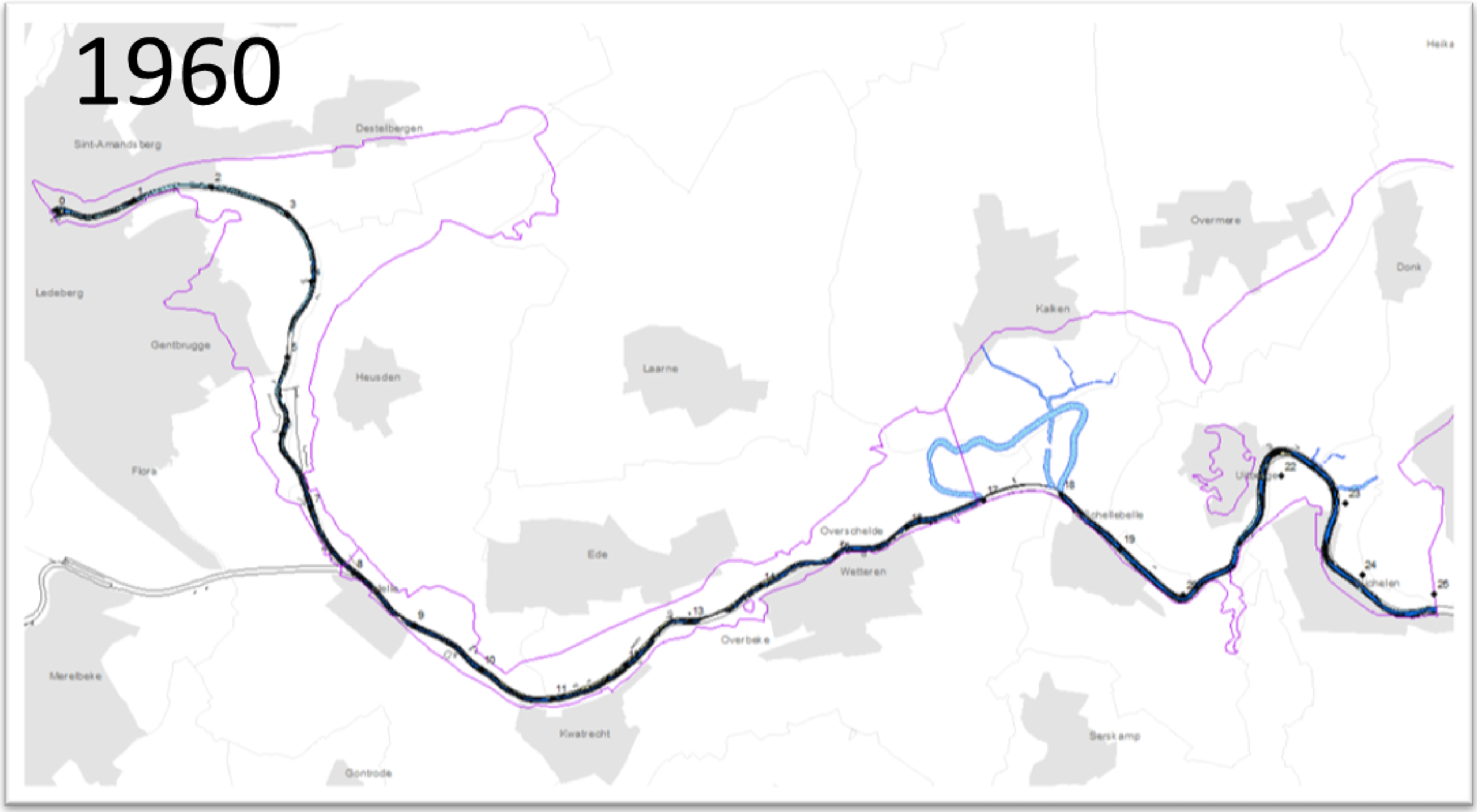
The connection at the weir of Merelbeke cut off the fresh water discharge from former stretch Gentbrugge-Melle, causing this stretch to shoal up steadily. Consequently the subtidal and intertidal habitats of this stretch are classified as high energy habitats in 1870-1880, 1930 and 1960 and as low energy habitats in 2001.



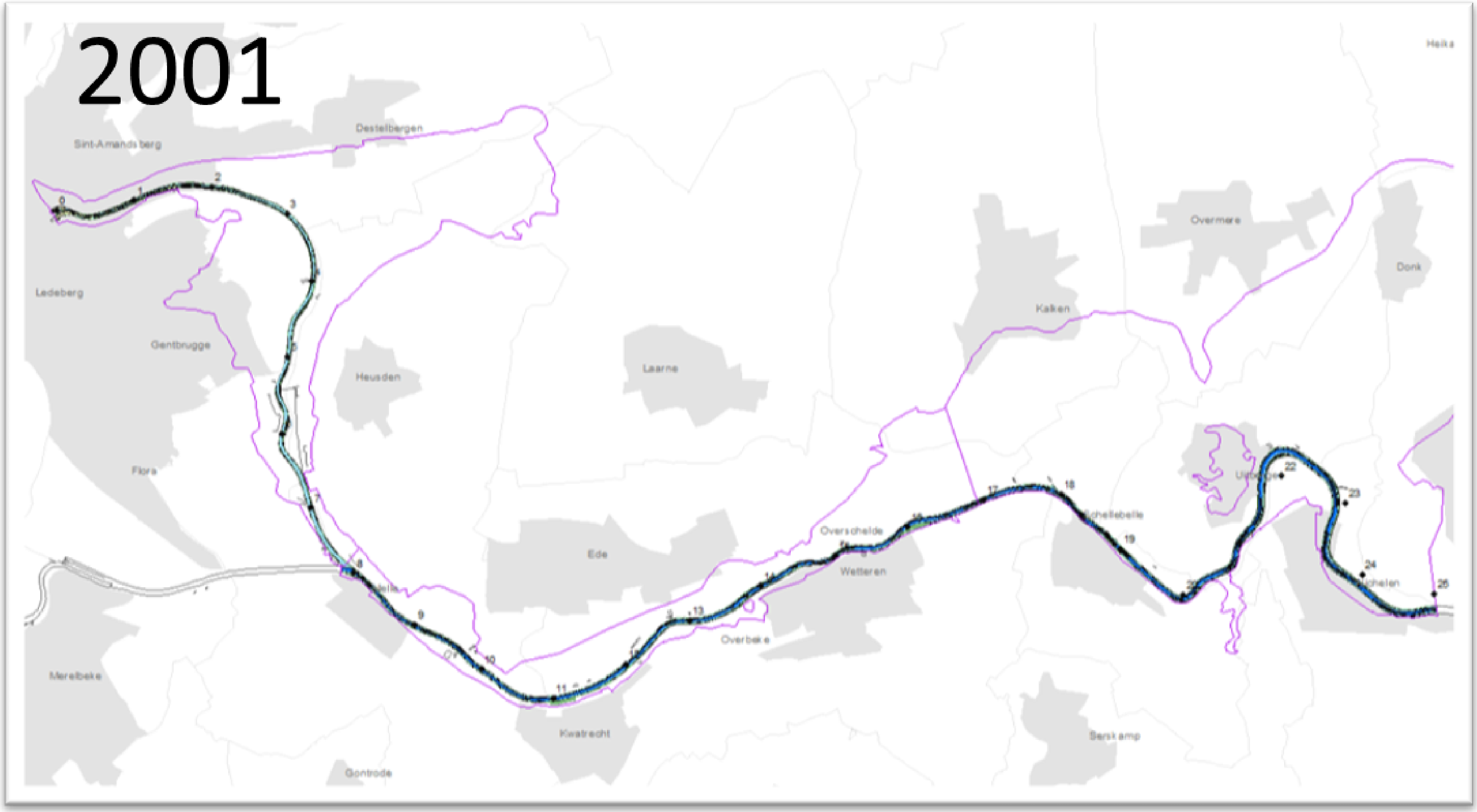
A - 16: Map showing the TIDE – zone 1 (Freshwater zone 1) in the Schelde at 1870 - 1880



A - 17: Map showing the TIDE – zone 1 (Freshwater zone 1) in the Schelde in 1930



A - 18: Map showing the TIDE – zone 1 (Freshwater zone 1) in the Schelde in 1960



A - 19: Map showing the TIDE – zone 1 (Freshwater zone 1) in the Schelde in 2001

A - 20: Overview of areal distribution within the TIDE zone 1

	TIDE habitat	1880	1930		1960		2001	
Subtidal	1 deep subtidal habitat (high energy)	192	129	2	111	1	115	9
	2 deep subtidal habitat (low energy)							0
	3 slope habitat (high energy)			73		68		68
	4 slope habitat (low energy)							0
	5 shallow water habitat (high energy)			53		42		21
	6 shallow water habitat (low energy)							17
Intertidal	7 Tidal flat habitat (high energy)	0	15	15	34	34	34	16
	8 Tidal flat habitat (low energy)							18
Suprati-dal	9 Salt marsh habitat	5		10		0		37
	10 Summer polder	731		736		0		0
	11 Stagnant water in foreland	7		45		41		0
	Total area	**935**	**934**		**186**		**186**	

Subtidal habitats

The total subtidal area reduced because of straightening of the river (cutting off meanders). Although the shorter river stretch, the deep subtidal habitats increased since 1960, the moderately deep subtidal habitat remained constant and the shallow water habitat decreased.

Intertidal and supratidal habitats

The tidal flat habitat increases between 1880 and 1960, probably because of the increasing tidal amplitude. Since the 1960 map is incompletely covered, interpretation of the results of the 1960 map is not possible.

A huge area (more than 730 ha) of summer polders is present until 1930. Later the construction of a winter dyke allowed agriculture and this area is only flooded occasionally.

Stagnant water is present in river branches that were cut off from the tidal river. In zone 1 these cut-off river branches are typically surrounded by summer polders. The area of stagnant water increases from 7 ha in 1880 up to 45 ha in 1930 and 41 ha in 1960 due to river engineering. After 1960 these stagnant water disappear because of poldering.

8.2.3.2 TIDE zone 2 - Fresh water zone 2

TIDE zone 2 stretches from Wichelen to Baasrode. Table A - 21 gives the habitat areas (ha) for TIDE zone 2.

A - 21: Overview of areal distribution within the TIDE zone 2

	TIDE habitat	1880	1930		1960		2001	
Subtidal	1 deep subtidal habitat (high energy)	198	172	25	167	27	177	44
	2 deep subtidal habitat (low energy)							
	3 slope habitat (high energy)			113		93		101
	4 slope habitat (low energy)							
	5 shallow water habitat (high energy)			34		47		32
	6 shallow water habitat (low energy)							
Intertidal	7 Tidal flat habitat (high energy)	27	35	35	39	39	37	37
	8 Tidal flat habitat (low energy)							
Supratidal	9 Salt marsh habitat	114		111		96		91
	10 Summer polder	72		90		31		0
	11 Stagnant water in foreland	0		2		1		0
	Total area	**411**	**410**		**333**		**305**	

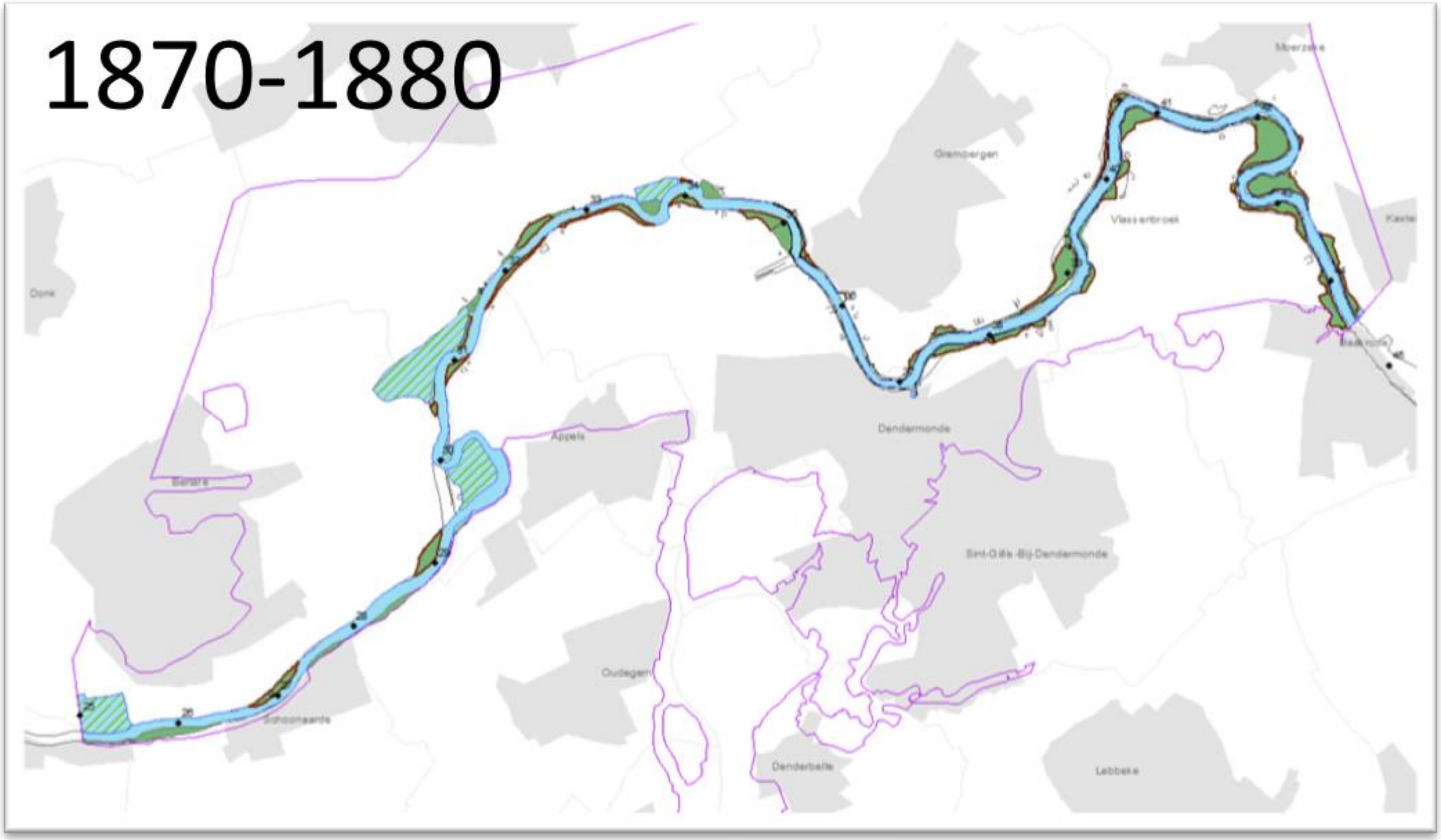
Subtidal habitats

The total subtidal area reduced because of straightening of the river (cutting off meanders). Although the shorter river stretches, the deep subtidal habitats increased since 1930. The moderately deep subtidal habitat remained constant and the shallow water habitat decreased.

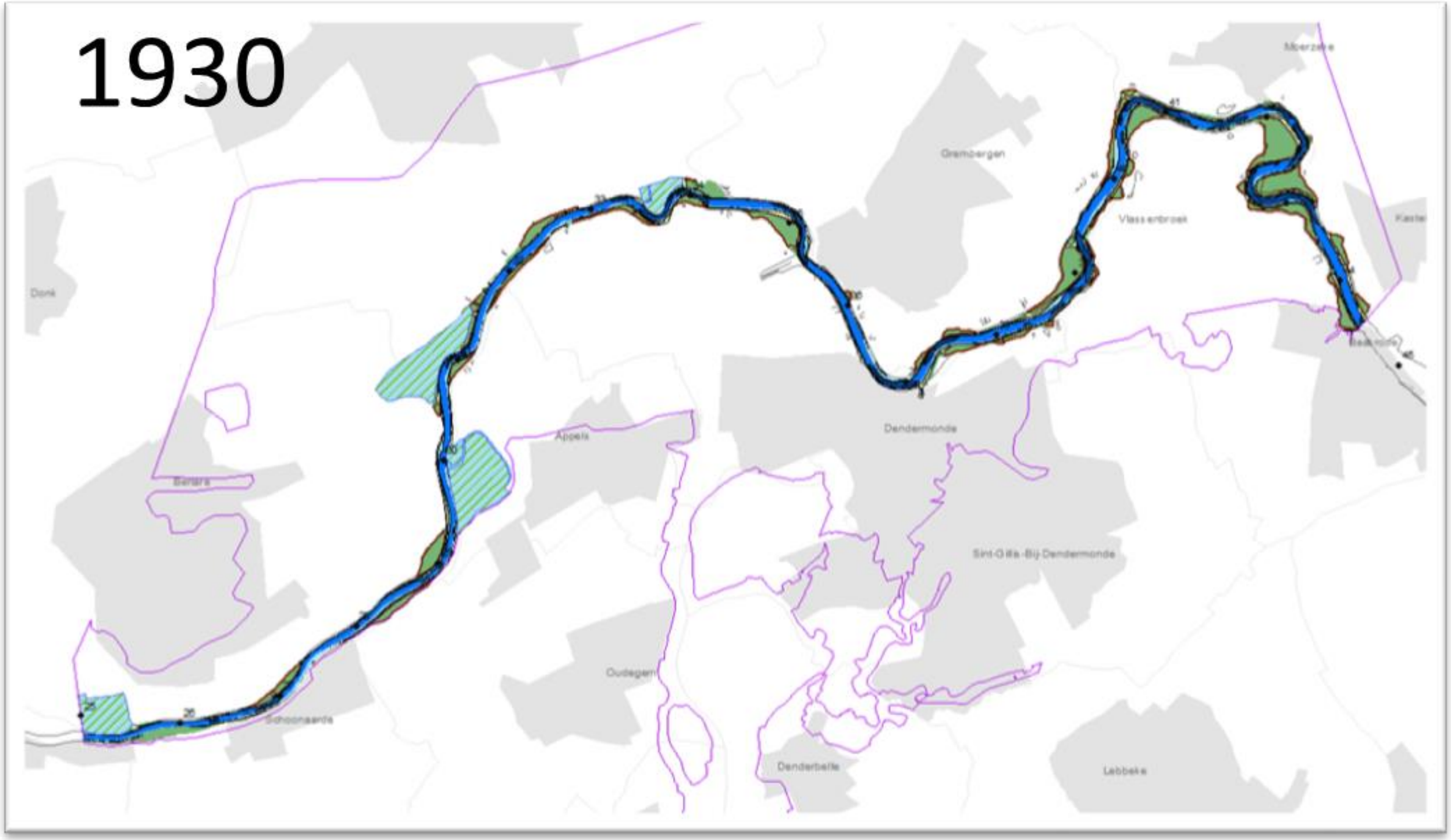
Intertidal and supratidal habitats

The area of tidal flat habitat increases and the area of marsh habitat decreases between 1880 and 1960, probably because of the increasing tidal amplitude.

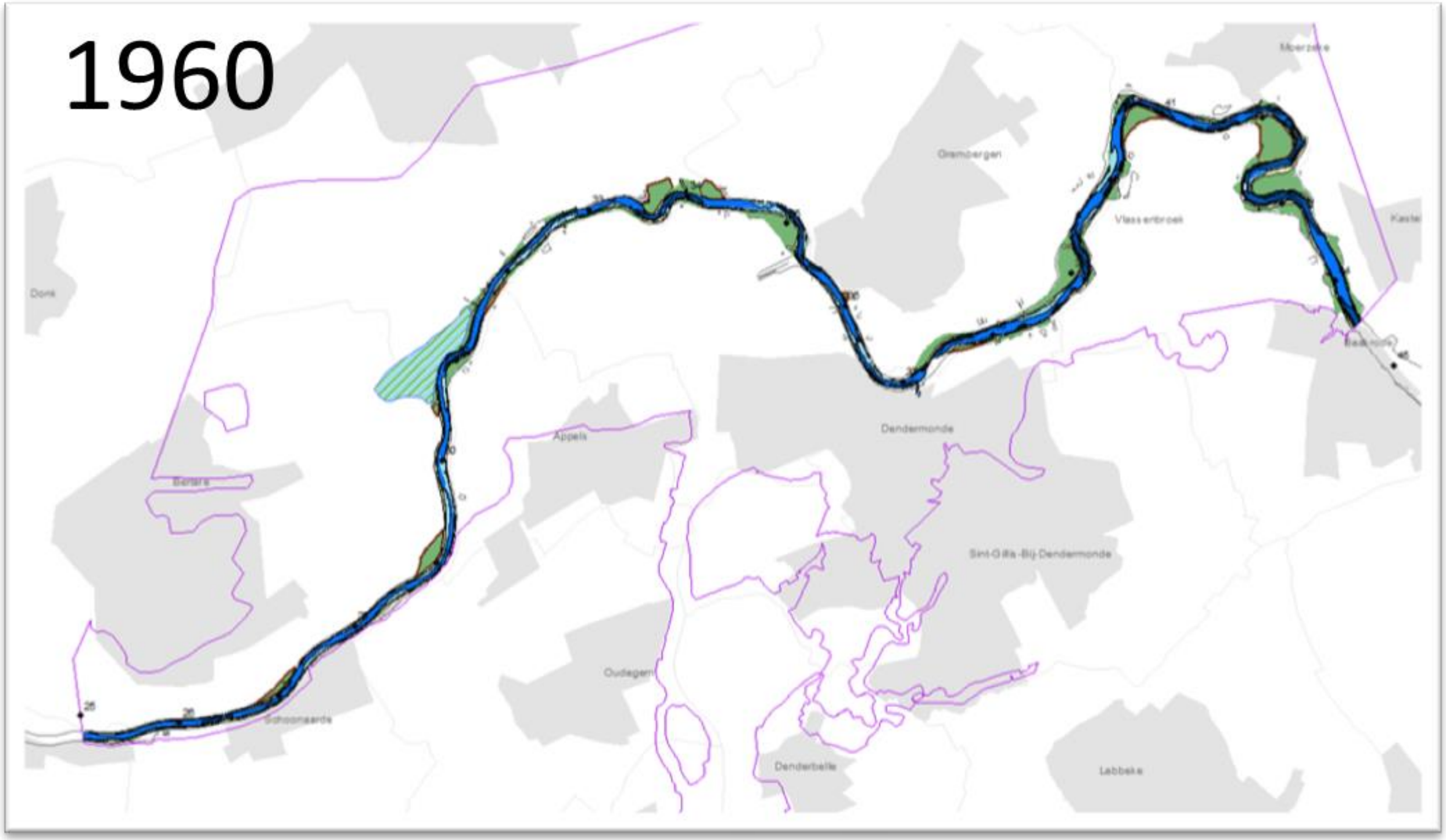
The decrease in total area of TIDE-zone 2 can be attributed to the decrease and disappearance of summer polders (‘floodland’) and stagnant water in the foreland.



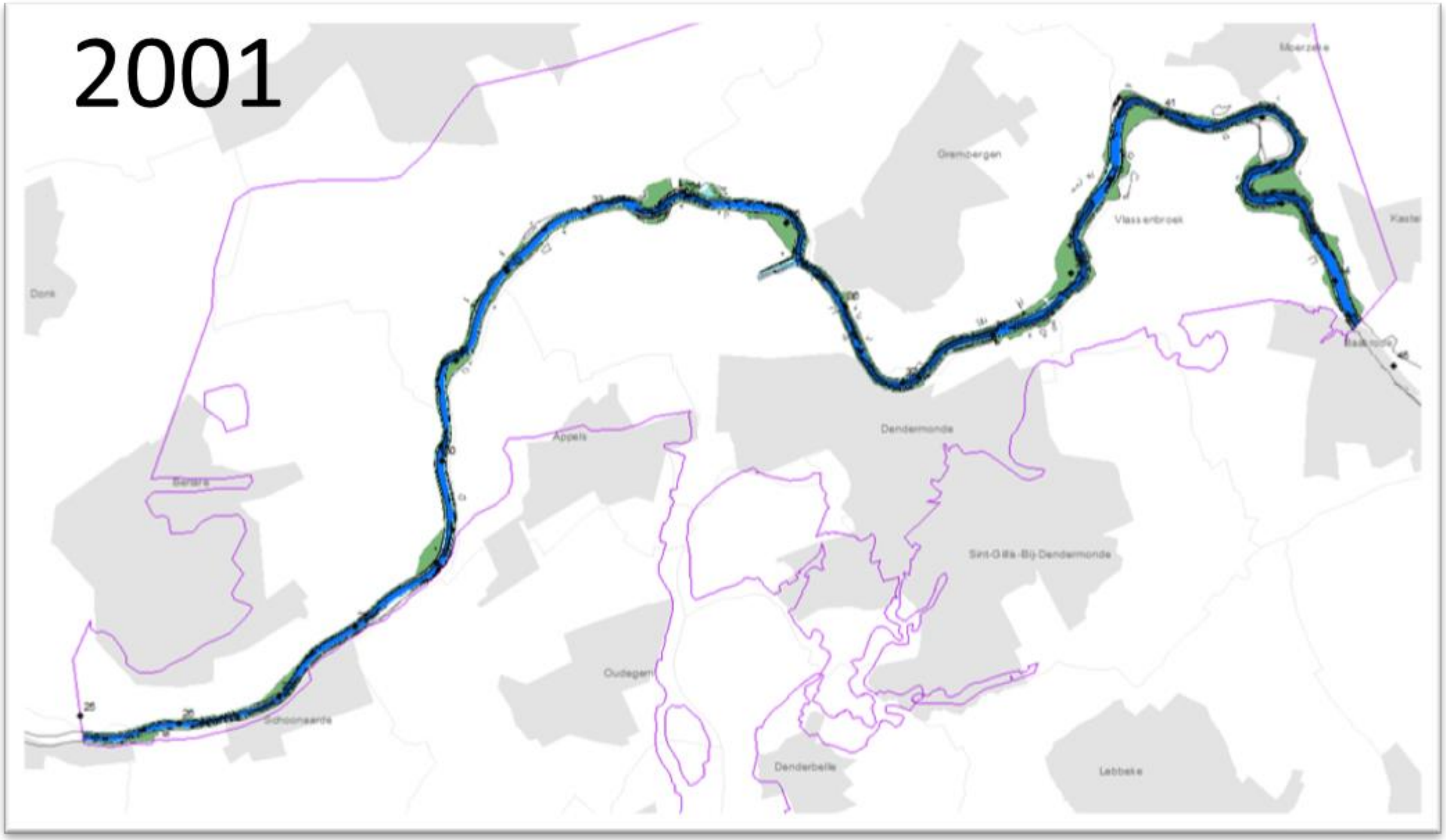
A - 22: Map showing the TIDE – zone 2 (Freshwater zone 2) in the Schelde from 1870 - 1880



A - 23: Map showing the TIDE – zone 2 (Freshwater zone 2) in the Schelde in 1930



A - 24: Map showing the TIDE – zone 2 (Freshwater zone 2) in the Schelde in 1960



- 26/114 -

A - 25: Map showing the TIDE – zone 2 (Freshwater zone 2) in the Schelde in 2001

8.2.3.3 *TIDE zone 3 without Durme - Fresh water zone 3*

TIDE zone 3 stretches from Baasrode to Rupelmonding. Table A - 26 gives the habitat areas (ha) for TIDE zone 3. This zone includes the Durme tributary for all maps except 1870-1880. The Durme is a meandering tidal river with low fresh water discharge and flooding zones adjacent. Therefore all subtidal and intertidal habitats of the Durme are classified as low energy habitats.

A - 26: Overview of areal distribution within the TIDE zone 3 (without Drume)

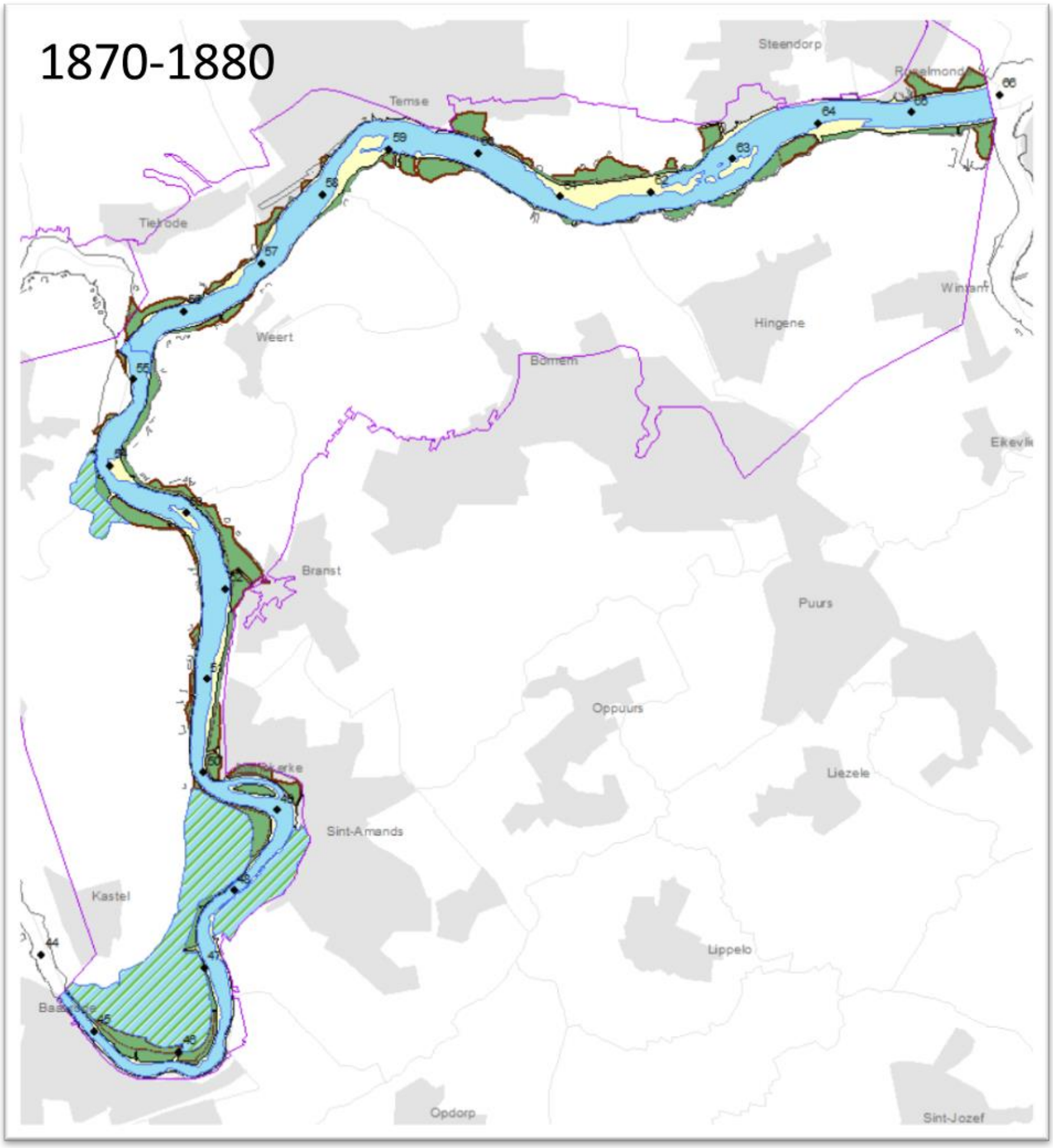
	TIDE habitat	1880	1930		1960		2001	
Subtidal	1 deep subtidal habitat (high energy)	444	429	119	408	106	454	211
	2 deep subtidal habitat (low energy)							
	3 slope habitat (high energy)			197		196		166
	4 slope habitat (low energy)							
	5 shallow water habitat (high energy)			113		106		77
	6 shallow water habitat (low energy)							
Intertidal	7 Tidal flat habitat (high energy)	157	180	180	148	148	137	137
	8 Tidal flat habitat (low energy)							
Supratidal	9 Salt marsh habitat	239		271		251		219
	10 Summer polder	243		86		4		0
	11 Stagnant water in foreland			0		0		0
	Total area	**1.083**	**967**		**811**		**811**	

Subtidal habitats

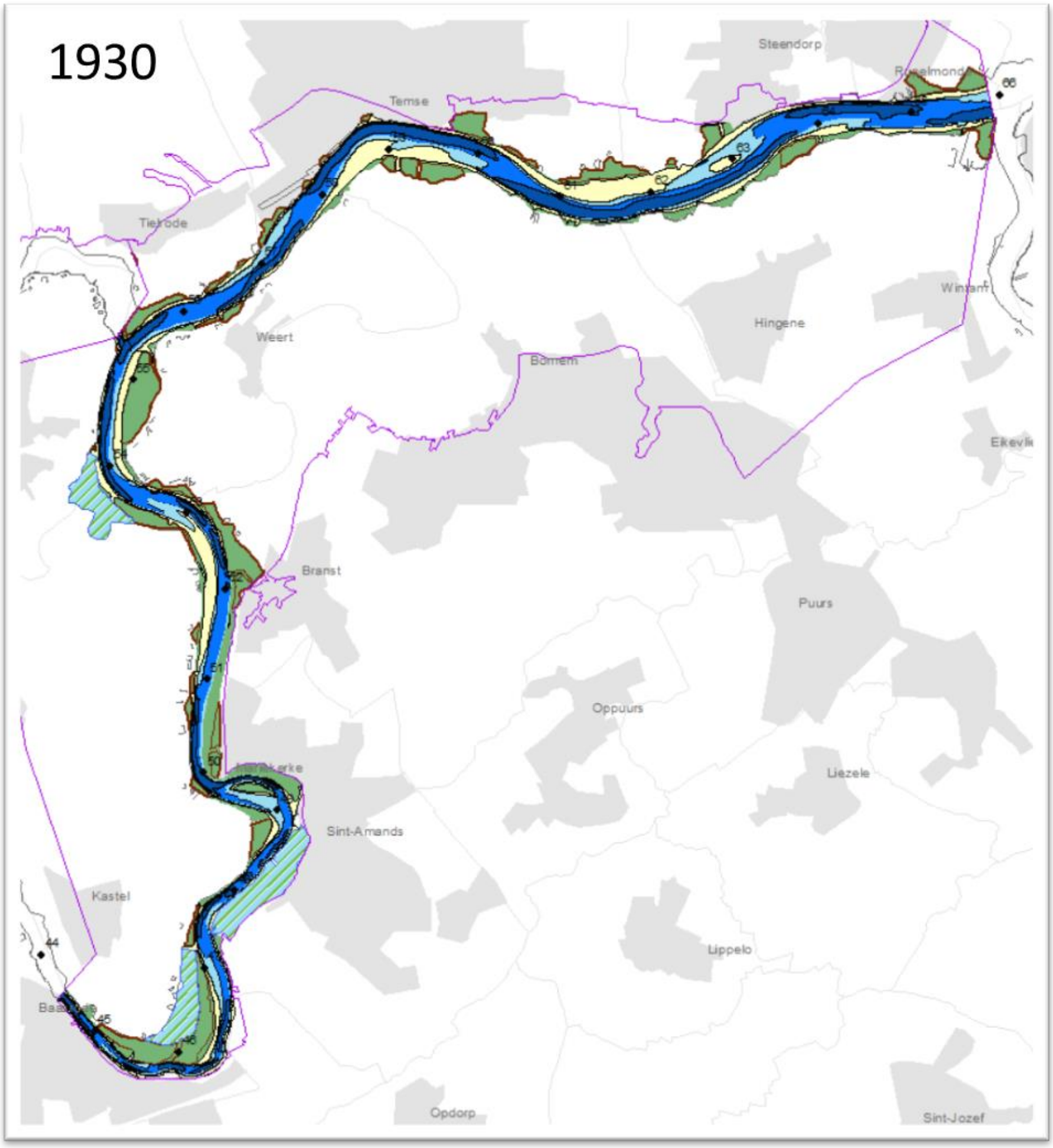
The total subtidal area reduced until 1960 and then increased again. The area of the deep subtidal habitat doubles between 1960 and 2001, while the slope habitat and the shallow water habitat decreased.

Intertidal and supratidal habitats

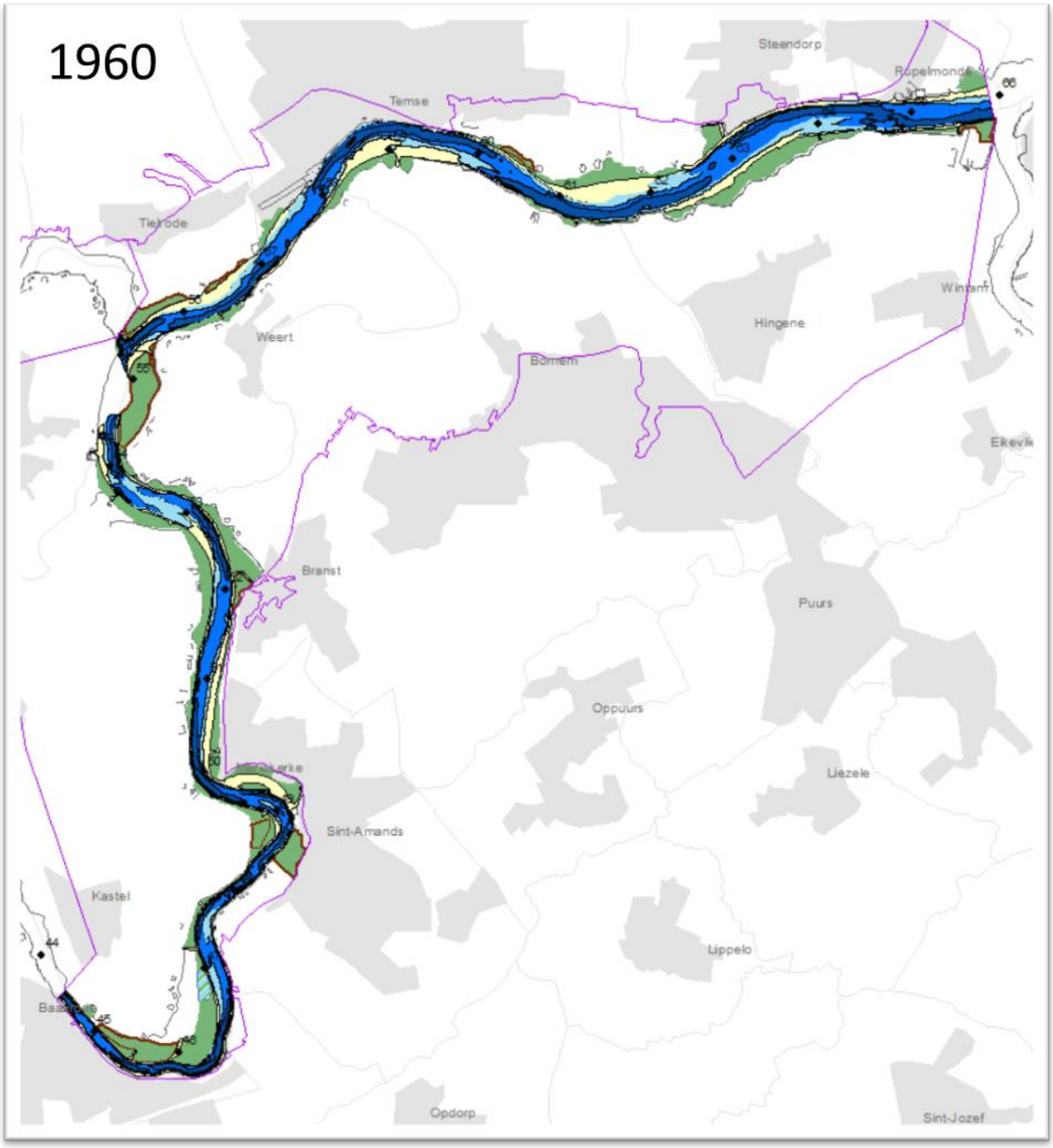
An area of 157ha of summer polder habitat disappears between 1880 and 1930. From the total area it can be derived that about 110ha is taken from the tidal river, which means that about 47ha is converted into salt marsh habitat and tidal flat habitat in 1930.



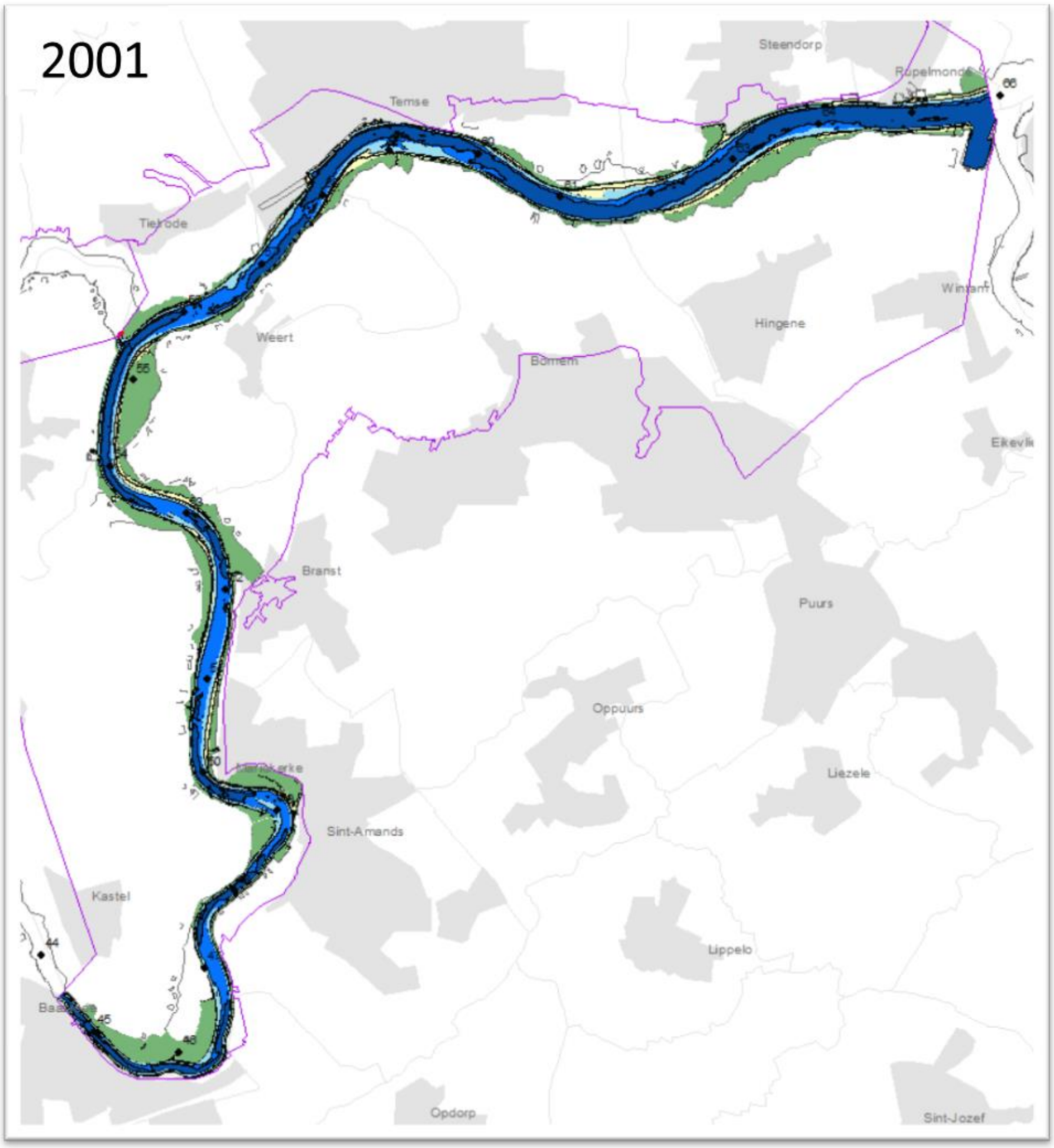
A - 27: Map showing the TIDE – zone 3 (Freshwater zone 3) in the Schelde from 1870 – 1880 (without Drume)



A - 28: Map showing the TIDE – zone 3 (Freshwater zone 3) in the Schelde in 1930 (without Drume)



A - 29: Map showing the TIDE – zone 3 (Freshwater zone 3) in the Schelde in 1960 (without Drume)



A - 30: Map showing the TIDE – zone 3 (Freshwater zone 3) in the Schelde in 2001 (without Drume)

8.2.3.4 Durme (TIDE zone 3) Fresh water zone 3

TIDE zone 4 stretches from Rupelmonding to Oosterweel. Table A - 31 gives the habitat areas (ha) for TIDE zone 4. This zone includes the Rupel tributary for all maps except 1870-1880.The Rupel is a more or less straight river section without adjacent flooding zones, connecting the 2nd generation tidal tributary rivers Nete, Dijle and Zenne to the Schelde. Like in the Zeeschelde all subtidal and intertidal habitats of the Rupel are classified as high energy habitats.

A - 31: Overview of areal distribution within the TIDE zone 3 (Drume)

<table>
<tr><th></th><th>TIDE habitat</th><th>1880</th><th colspan="2">1930</th><th colspan="2">1960</th><th colspan="2">2001</th></tr>
<tr><td rowspan="6">Subtidal</td><td>1 deep subtidal habitat (high energy)</td><td rowspan="6"></td><td rowspan="6">75</td><td></td><td rowspan="6">38</td><td></td><td rowspan="6">26</td><td></td></tr>
<tr><td>2 deep subtidal habitat (low energy)</td><td>2</td><td>0</td><td>0</td></tr>
<tr><td>3 slope habitat (high energy)</td><td></td><td></td><td></td></tr>
<tr><td>4 slope habitat (low energy)</td><td>18</td><td>4</td><td>0</td></tr>
<tr><td>5 shallow water habitat (high energy)</td><td></td><td></td><td></td></tr>
<tr><td>6 shallow water habitat (low energy)</td><td>54</td><td>33</td><td>26</td></tr>
<tr><td rowspan="2">Intertidal</td><td>7 Tidal flat habitat (high energy)</td><td rowspan="2"></td><td rowspan="2">47</td><td></td><td rowspan="2">60</td><td></td><td rowspan="2">42</td><td></td></tr>
<tr><td>8 Tidal flat habitat (low energy)</td><td>47</td><td>60</td><td>42</td></tr>
<tr><td rowspan="3">Suprati-dal</td><td>9 Salt marsh habitat</td><td></td><td></td><td>132</td><td></td><td>88</td><td></td><td>91</td></tr>
<tr><td>10 Summer polder</td><td></td><td></td><td>728</td><td></td><td>291</td><td></td><td>0</td></tr>
<tr><td>11 Stagnant water in foreland</td><td></td><td></td><td>3</td><td></td><td>22</td><td></td><td>0</td></tr>
<tr><td></td><td>Total area</td><td></td><td colspan="2">985</td><td colspan="2">499</td><td colspan="2">159</td></tr>
</table>

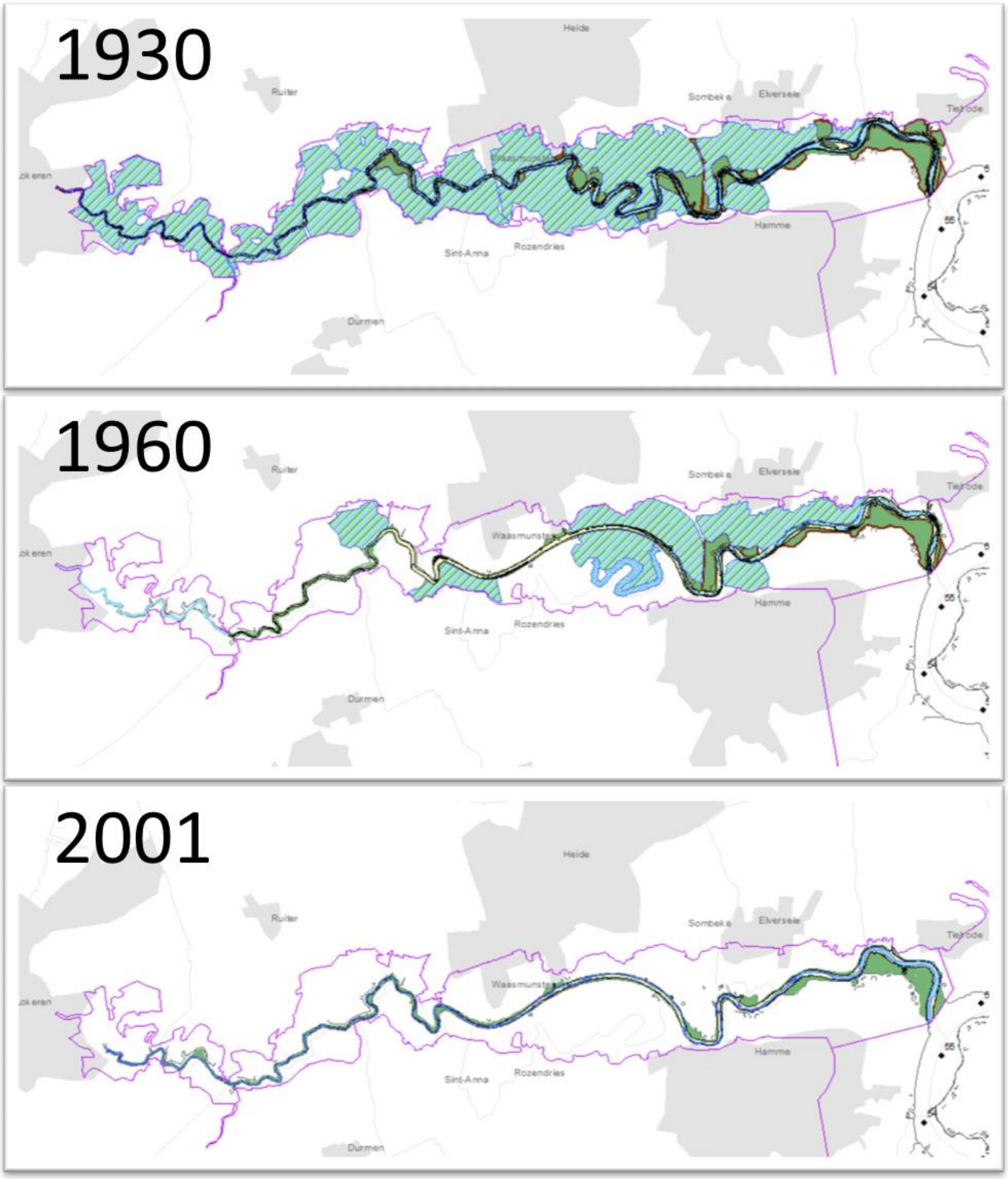
Subtidal habitats

The total subtidal area reduced because of straightening of the river (cutting off meanders). The deep subtidal habitat and slope habitat completely disappear and also the shallow water habitat decreases .

Intertidal and supratidal habitats

The area of tidal flat habitat changes little but the location of the tidal flat habitat shifts to middle of the river. Subtidal habitats are converted into tidal flat habitat and tidal flat habitat is converted on its turn into salt marsh habitat or disappears.

An area of 728 ha of summer polder in1930 has completely disappeared in 2001. The stagnant water in the foreland increases in 1960 due the remaining water bodies of the tidal river parts that have been cut off.



A - 32: Maps showing the different available time steps for the Drume within TIDE – zone 3 (Freshwater zone 3)

8.2.3.5 TIDE zone 4 without Rupel - Oligohaline zone

TIDE zone 4 without Rupel stretches from Rupelmonding to Oosterweel. Table A - 33 gives the habitat areas (ha) for TIDE zone 4 without Rupel.

A - 33: Overview of areal distribution within the TIDE zone 4 (without Rupel)

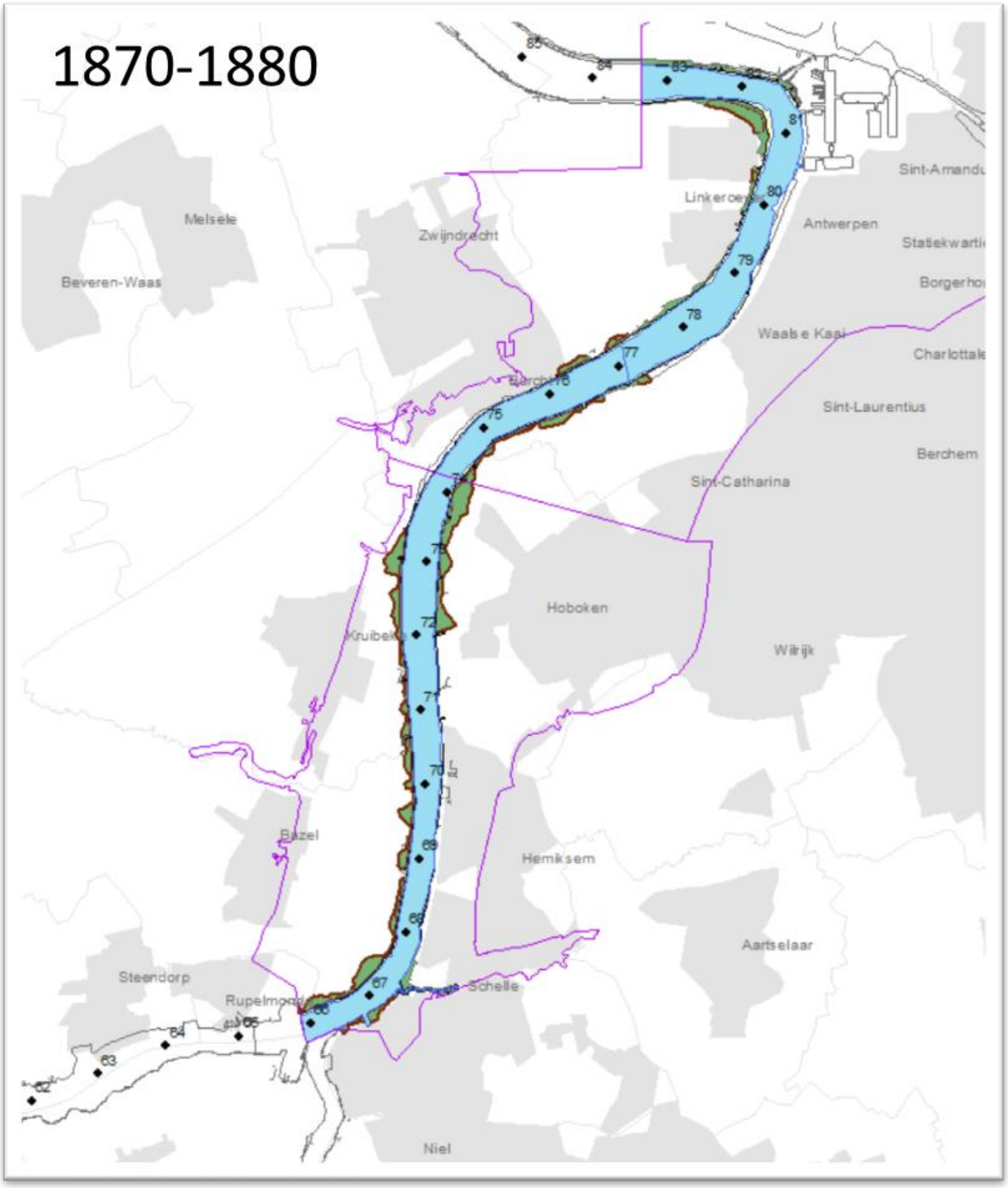
	TIDE habitat	1880	1930		1960		2001	
Subtidal	1 deep subtidal habitat (high energy)	676	604	439	600	435	595	480
	2 deep subtidal habitat (low energy)							
	3 slope habitat (high energy)			101		107		75
	4 slope habitat (low energy)							
	5 shallow water habitat (high energy)			65		58		39
	6 shallow water habitat (low energy)							
Intertidal	7 Tidal flat habitat (high energy)	58	124	124	99	99	104	104
	8 Tidal flat habitat (low energy)							
Supratidal	9 Salt marsh habitat	172		152		111		57
	10 Summer polder	0		0		0		0
	11 Stagnant water in foreland	0		0		0		0
	Total area	**906**	**880**		**809**		**755**	

Subtidal habitats

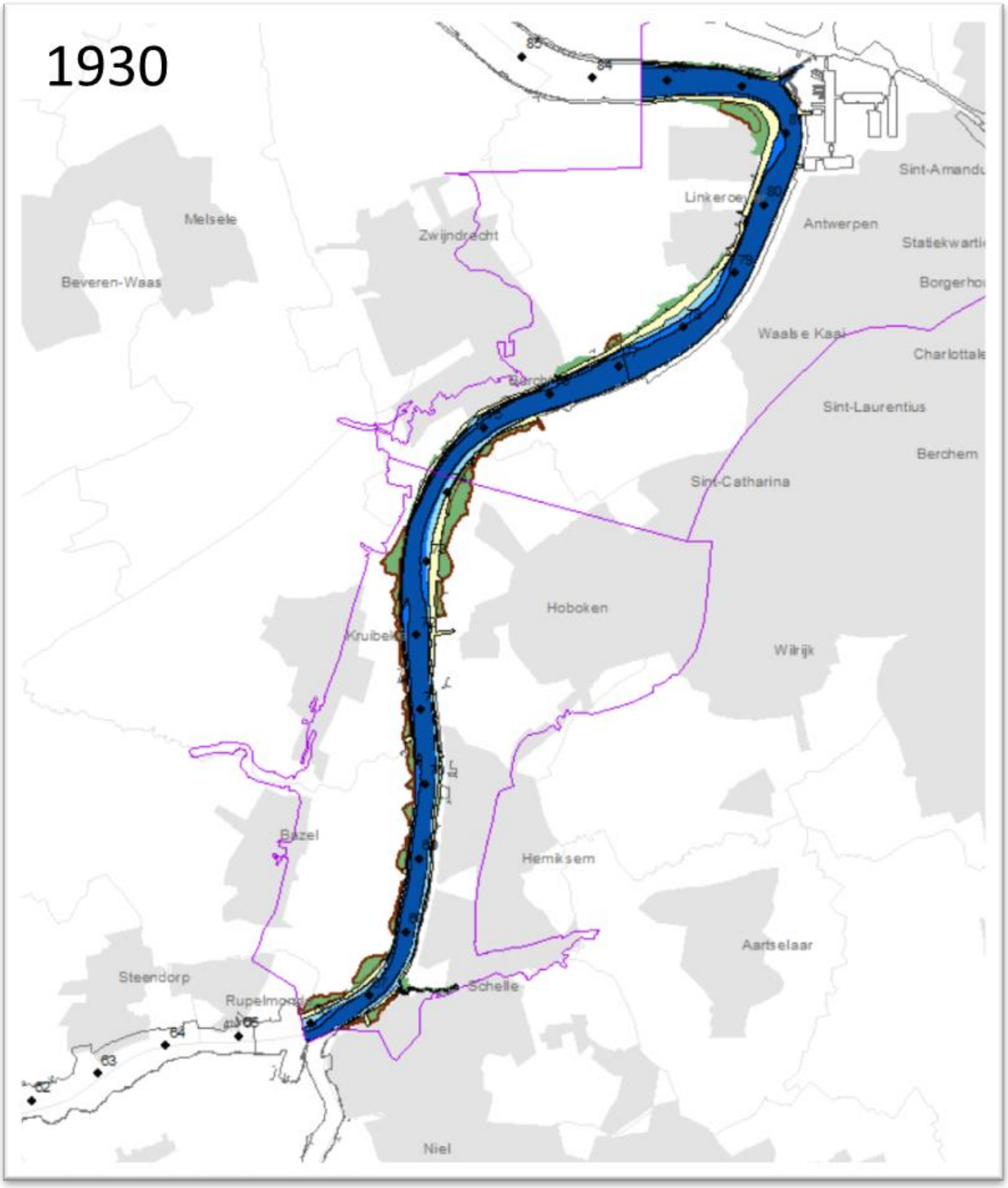
The moderately deep subtidal habitat and the shallow water habitat decreased since 1930 in favour of the deep subtidal habitats.

Intertidal and supratidal habitats

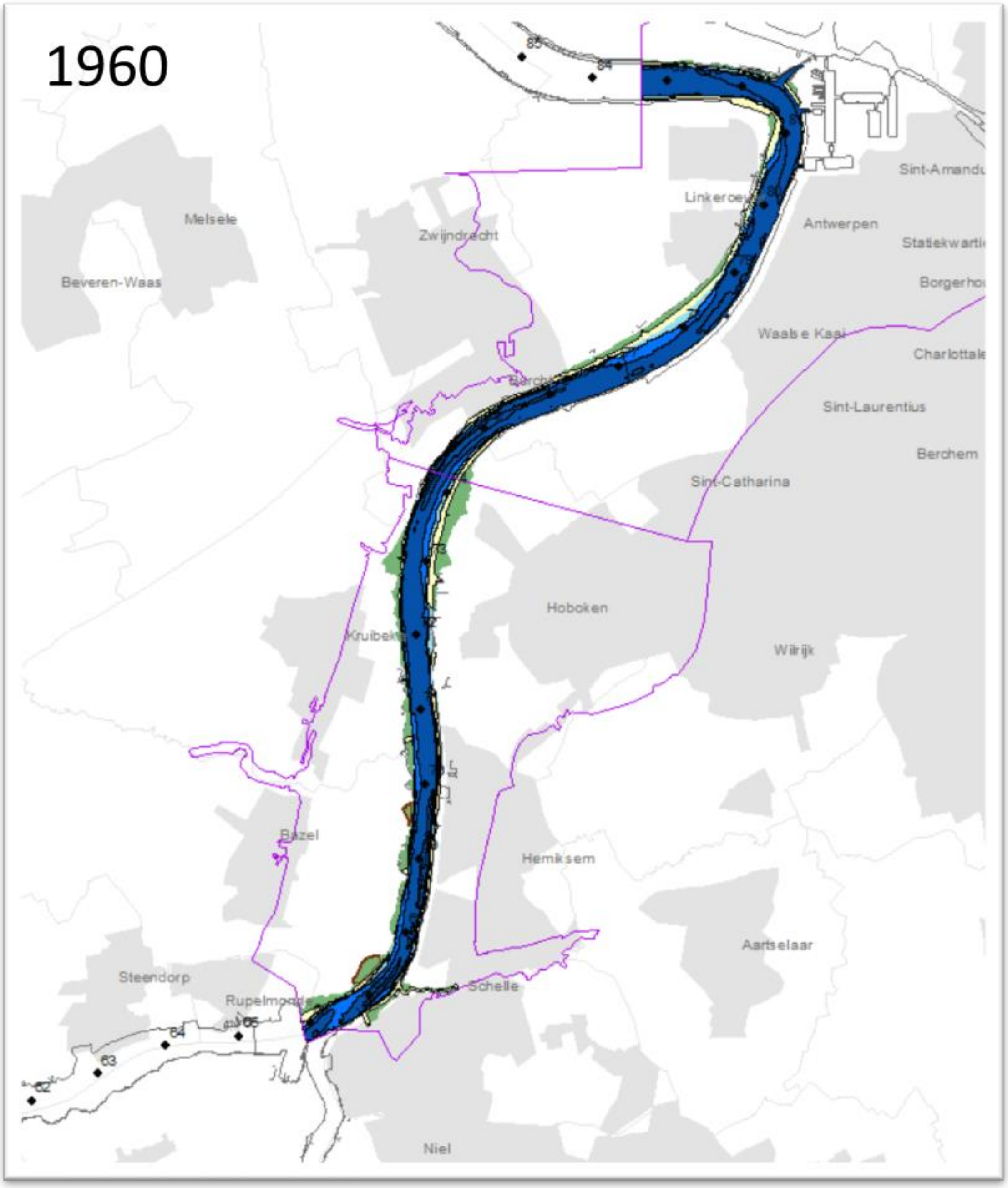
The intertidal flat habitat doubles between 1880 and 1930, but this observation might be biased by the 1880 mapping technique (aerial pictures). The salt marsh habitat area decreases from 172ha in 1930 to 57ha in 2001. This decreases explains most of the total decrease in TIDE zone 4.



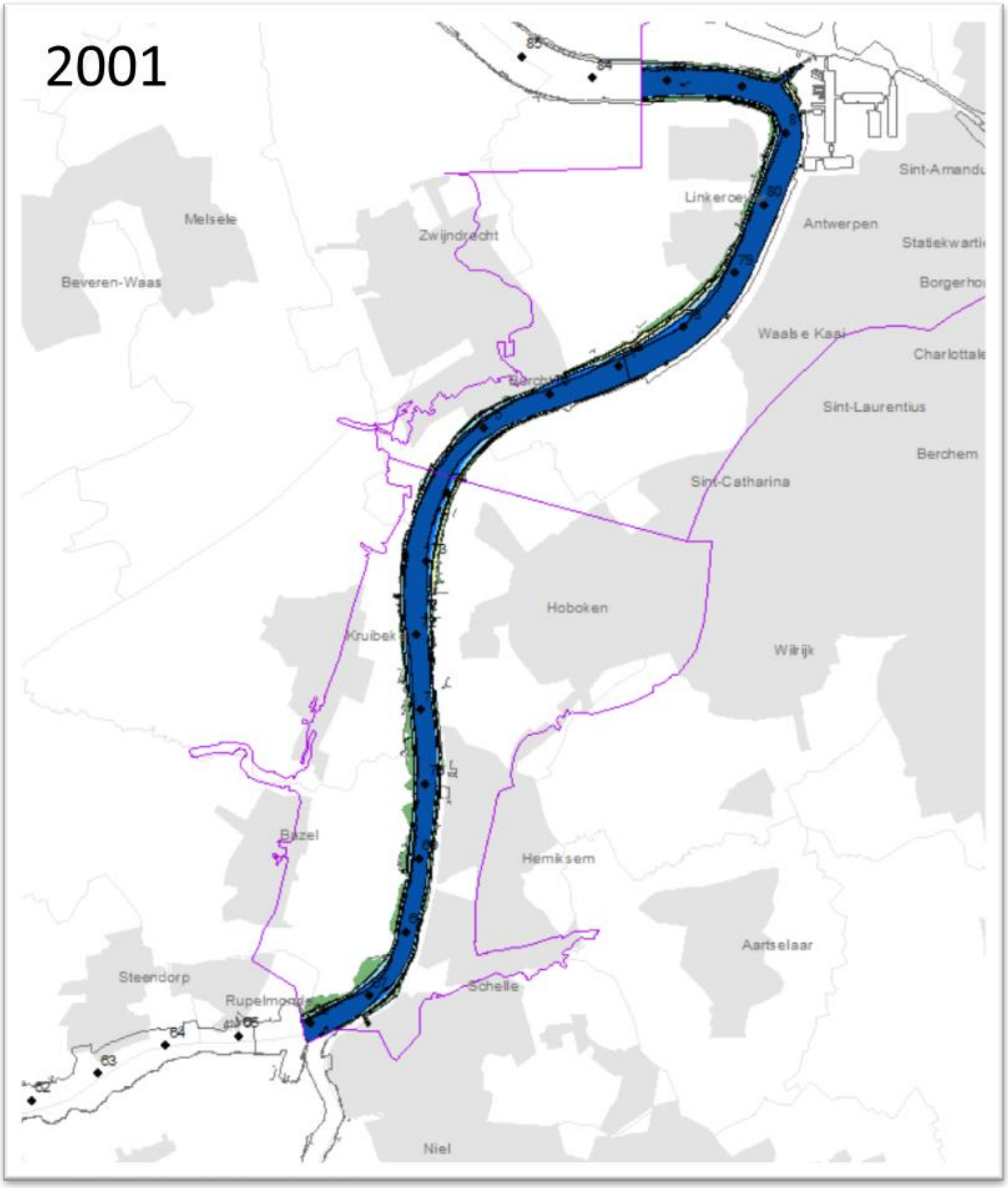
A - 34: Map showing the TIDE – zone 4 (Oligohaline zone) in the Schelde from 1870 - 1880 (without Rupel)



A - 35: Map showing the TIDE – zone 4 (Oligohaline zone) in the Schelde in 1930 (without Rupel)



A - 36: Map showing the TIDE – zone 4 (Oligohaline zone) in the Schelde in 1960 (without Rupel)



A - 37: Map showing the TIDE – zone 4 (Oligohaline zone) in the Schelde in 2001 (without Rupel)

8.2.3.6 Rupel (TIDE zone 4) - Oligohaline zone

Information on the Rupel tributary is available for all maps except 1870-1880.The Rupel is a more or less straight river section without adjacent flooding zones, connecting the 2nd generation tidal tributary rivers Nete, Dijle and Zenne to the Schelde. Like in the Zeeschelde all subtidal and intertidal habitats of the Rupel are classified as high energy habitats. On the 1930 and 1960 a tidal anabranch 'Eikenvliet' of the Rupel was present.

A - 38: Overview of areal distribution within the TIDE zone 4 (Rupel)

<table>
<tr><th></th><th>TIDE habitat</th><th>1880</th><th colspan="2">1930</th><th colspan="2">1960</th><th colspan="2">2001</th></tr>
<tr><td rowspan="6">Subtidal</td><td>1 deep subtidal habitat (high energy)</td><td rowspan="6"></td><td rowspan="6">165</td><td>12</td><td rowspan="6">164</td><td>15</td><td rowspan="6">153</td><td>25</td></tr>
<tr><td>2 deep subtidal habitat (low energy)</td><td></td><td></td><td></td></tr>
<tr><td>3 slope habitat (high energy)</td><td>82</td><td>88</td><td>92</td></tr>
<tr><td>4 slope habitat (low energy)</td><td></td><td></td><td></td></tr>
<tr><td>5 shallow water habitat (high energy)</td><td>71</td><td>62</td><td>36</td></tr>
<tr><td>6 shallow water habitat (low energy)</td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">Intertidal</td><td>7 Tidal flat habitat (high energy)</td><td rowspan="2"></td><td rowspan="2">69</td><td>69</td><td rowspan="2">66</td><td>66</td><td rowspan="2">51</td><td>51</td></tr>
<tr><td>8 Tidal flat habitat (low energy)</td><td></td><td></td><td></td></tr>
<tr><td rowspan="3">Suprati-
dal</td><td>9 Salt marsh habitat</td><td></td><td></td><td>89</td><td></td><td>62</td><td></td><td>37</td></tr>
<tr><td>10 Summer polder</td><td></td><td></td><td>79</td><td></td><td>73</td><td></td><td>0</td></tr>
<tr><td>11 Stagnant water in foreland</td><td></td><td></td><td>0</td><td></td><td>0</td><td></td><td>0</td></tr>
<tr><td></td><td>Total area</td><td></td><td colspan="2">402</td><td colspan="2">366</td><td colspan="2">242</td></tr>
</table>

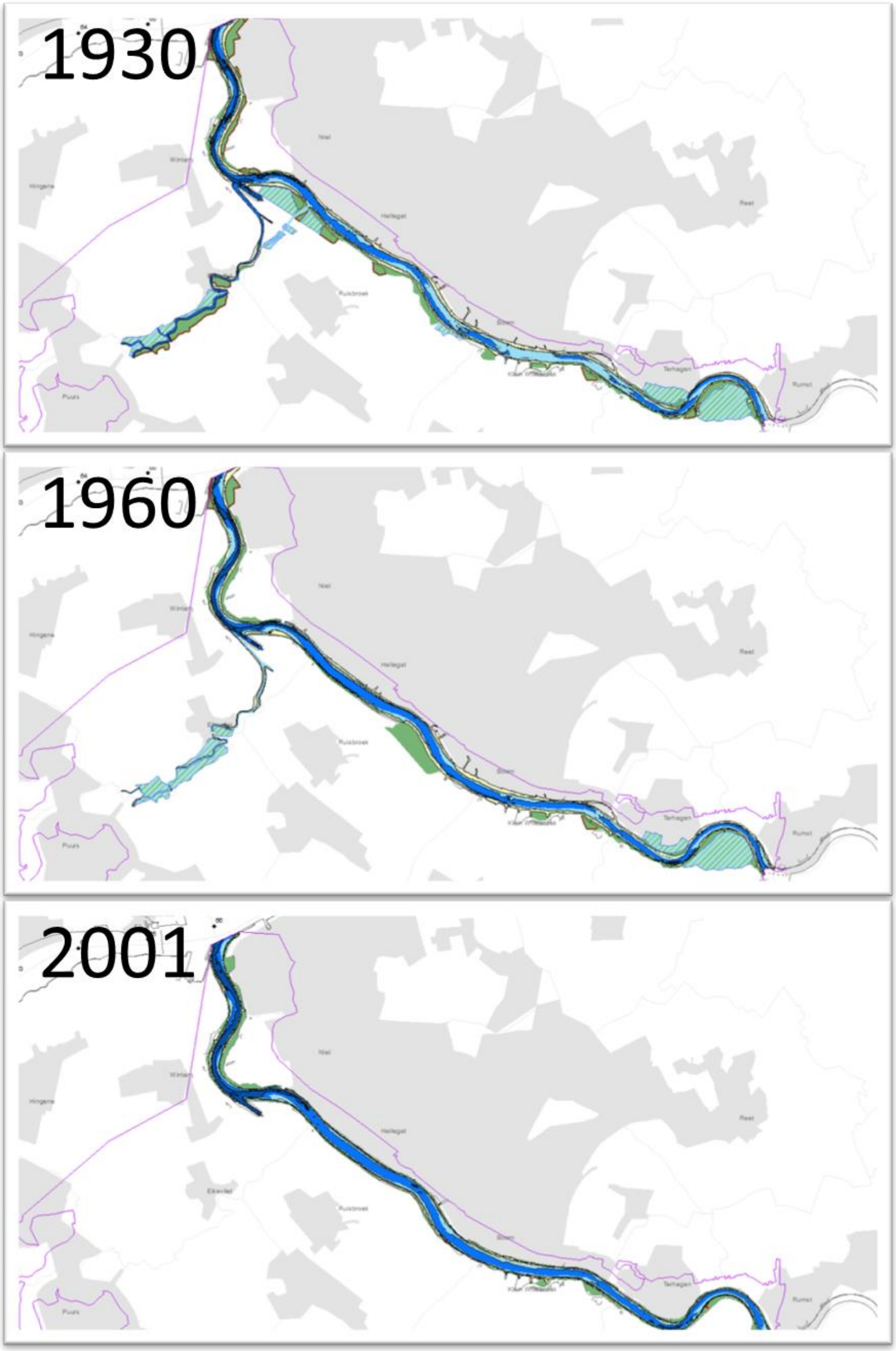
Subtidal habitats

The total subtidal area reduced between 1960 and 2001 because the tidal anabranch Eikenvliet was disconnected. The area of shallow water habitat decreases in favour of the slope habitat and the deep subtidal habitat.

Intertidal and supratidal habitats

Tidal flat habitat decreases from 69ha in 1930 to 51ha in 2001. Part of this habitat loss is related to the disconnection of the Eikenvliet.

A large area of salt marsh habitat and all floodland disappears.



A - 39: Maps showing the different available time steps for the Rupel within TIDE – zone 4 (Oligohaline zone)

8.2.3.7 TIDE zone 5, Zeeschelde - Mesohaline zone

TIDE zone 5 stretches from Oosterweel to Hansweert (Westerschelde). This TIDE zones contains part of the Zeeschelde and part of the Westerschelde. Historical habitat information for this zone is derived from both the ecotope maps of both sources.

A - 40: Overview of areal distribution within the TIDE zone 5 (Zeeschelde)

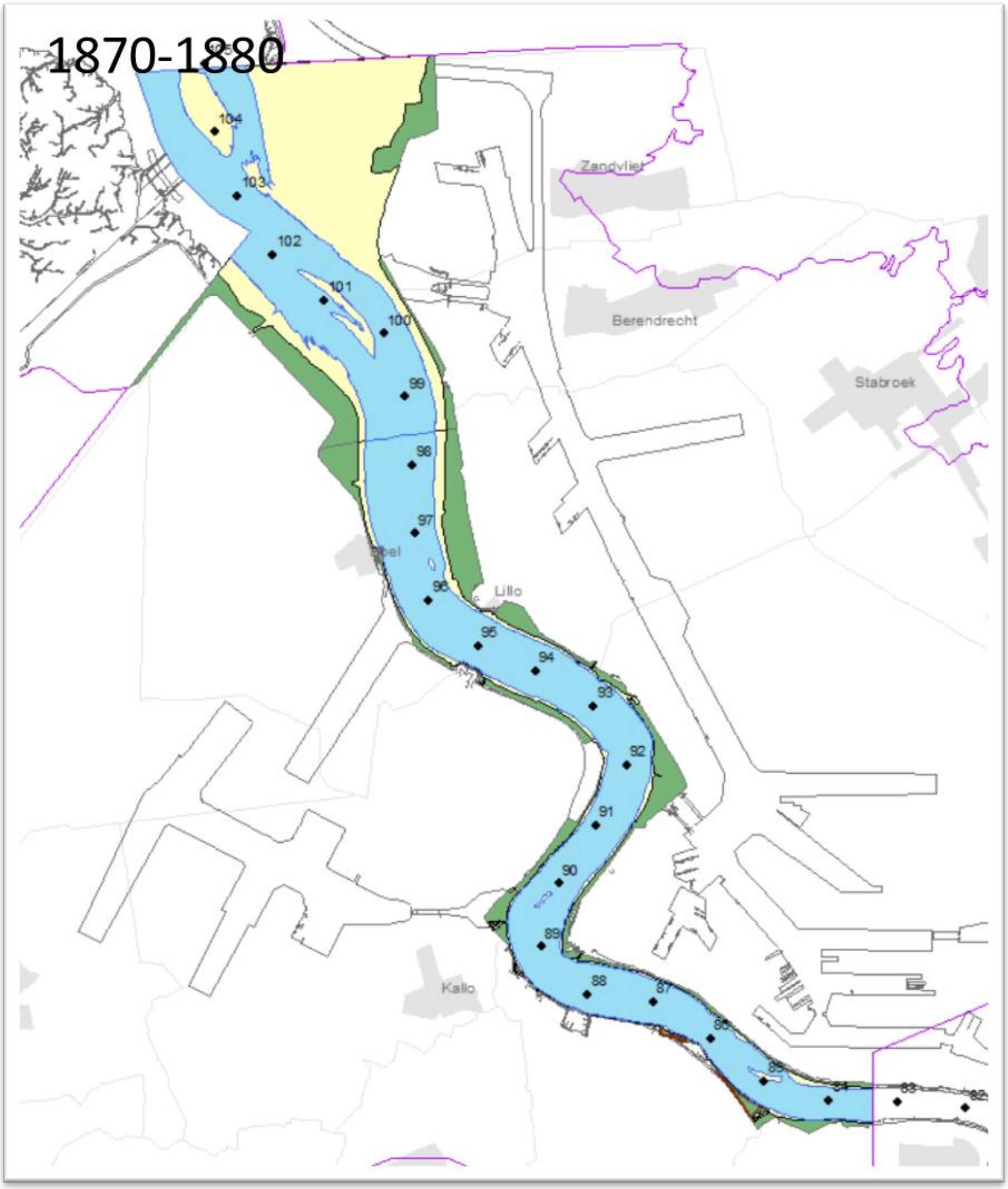
	TIDE habitat	**1880**	**1930**		**1960**		**2001**	
Subtidal	1 deep subtidal habitat (high energy)	1.688	1.722	1.060	1.754	1.051	1.826	1.305
	2 deep subtidal habitat (low energy)							
	3 slope habitat (high energy)			427		413		320
	4 slope habitat (low energy)							
	5 shallow water habitat (high energy)			286		290		201
	6 shallow water habitat (low energy)							
Intertidal	7 Tidal flat habitat (high energy)	865	459	459	442	442	437	437
	8 Tidal flat habitat (low energy)							
Supratidal	9 Salt marsh habitat	487		705		413		150
	10 Summer polder	0		0		0		0
	11 Stagnant water in foreland	0		0		0		0
	Total area	**3.039**	**2.937**		**2.609**		**2.413**	

Subtidal habitats

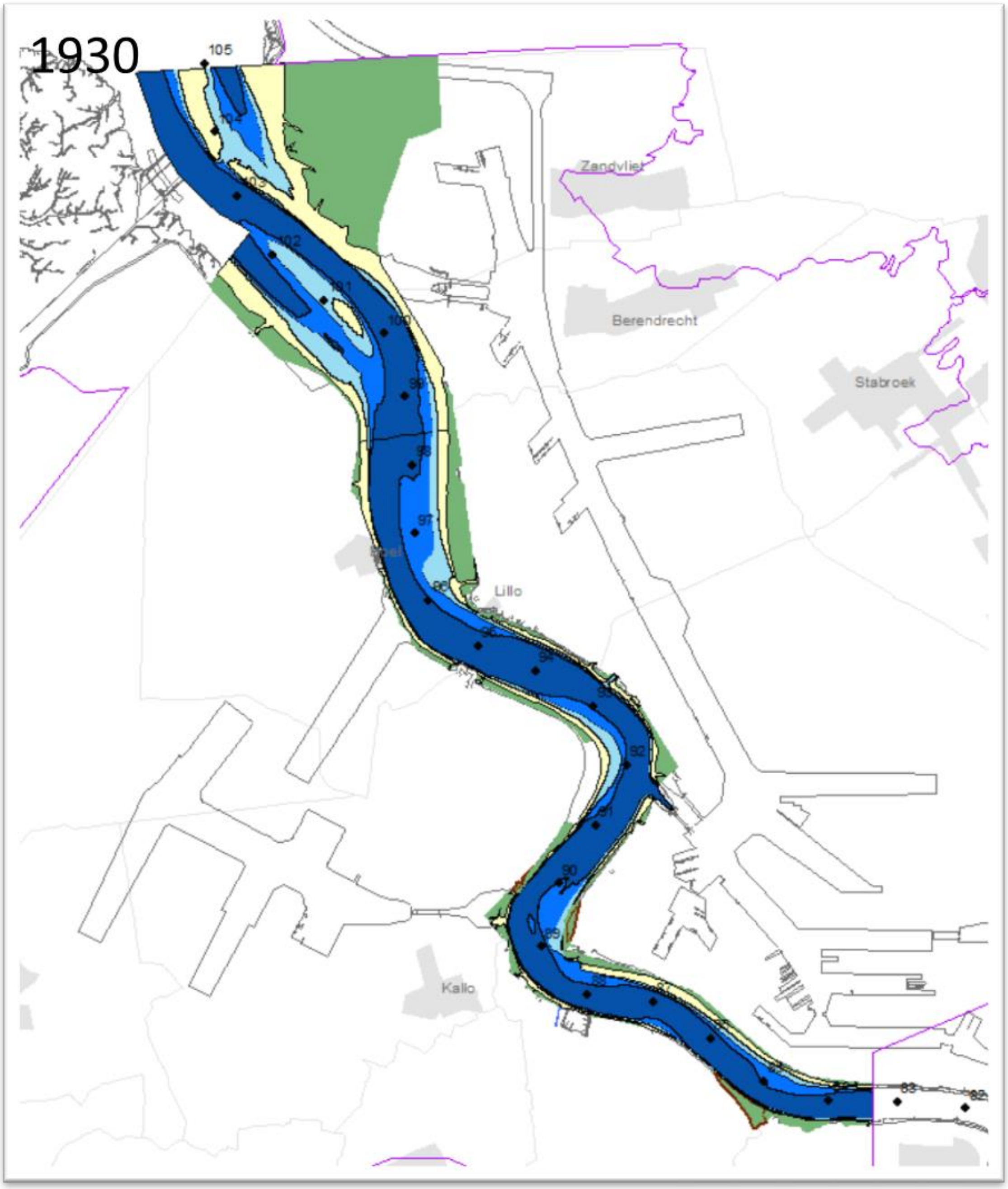
The total subtidal area increases at cost of the intertidal flat habitat. The deep subtidal habitats increases with about 300ha since 1930. A shift of about 100ha occurs from both the moderately deep subtidal habitat and the shallow water habitat.

Intertidal and supratidal habitats

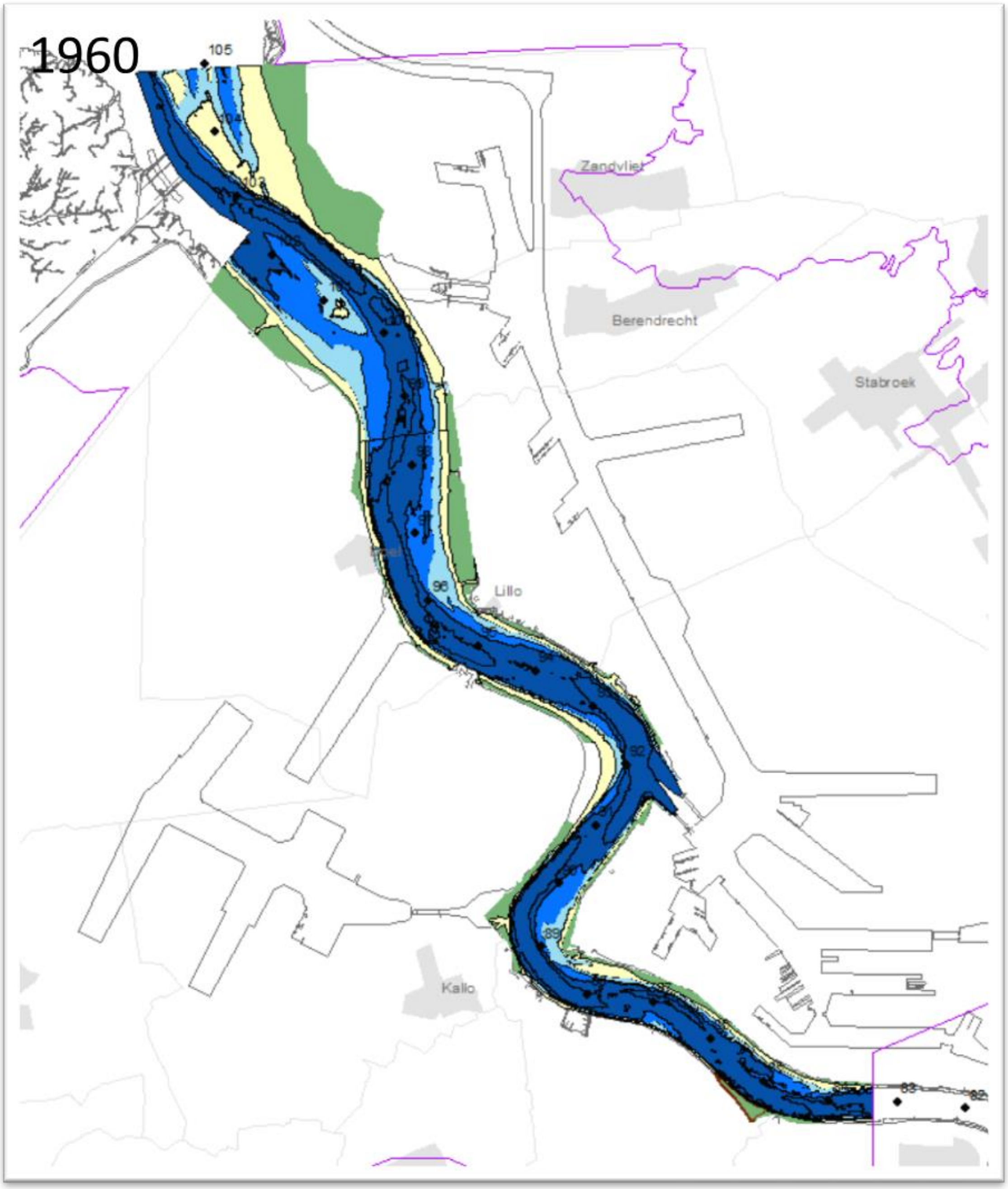
Tidal flat habitat decreases with about 430ha, of which 100ha is shifted to the subtidal habitats. Between 1880 and 1930, almost 300ha of tidal flat habitat in 1880 is classified as salt marsh habitat in 1930. From 1930 on, almost 550ha of salt marsh habitat is lost due to port development.



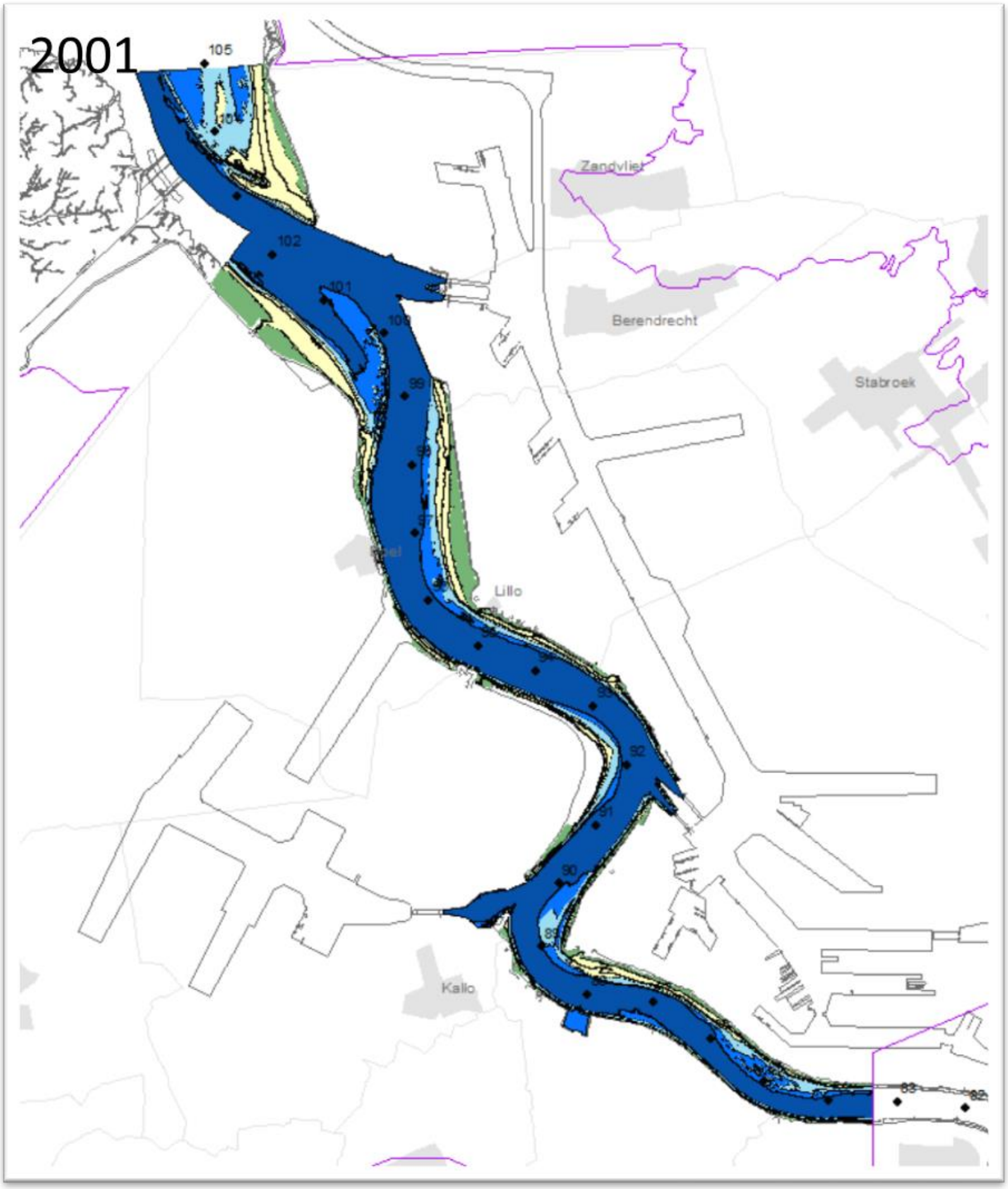
A - 41: Map showing the upper part of the TIDE – zone 5 (Mesohaline zone) in the Zeeschelde from 1870 – 1880



A - 42: Map showing the upper part of the TIDE – zone 5 (Mesohaline zone) in the Zeeschelde in 1930



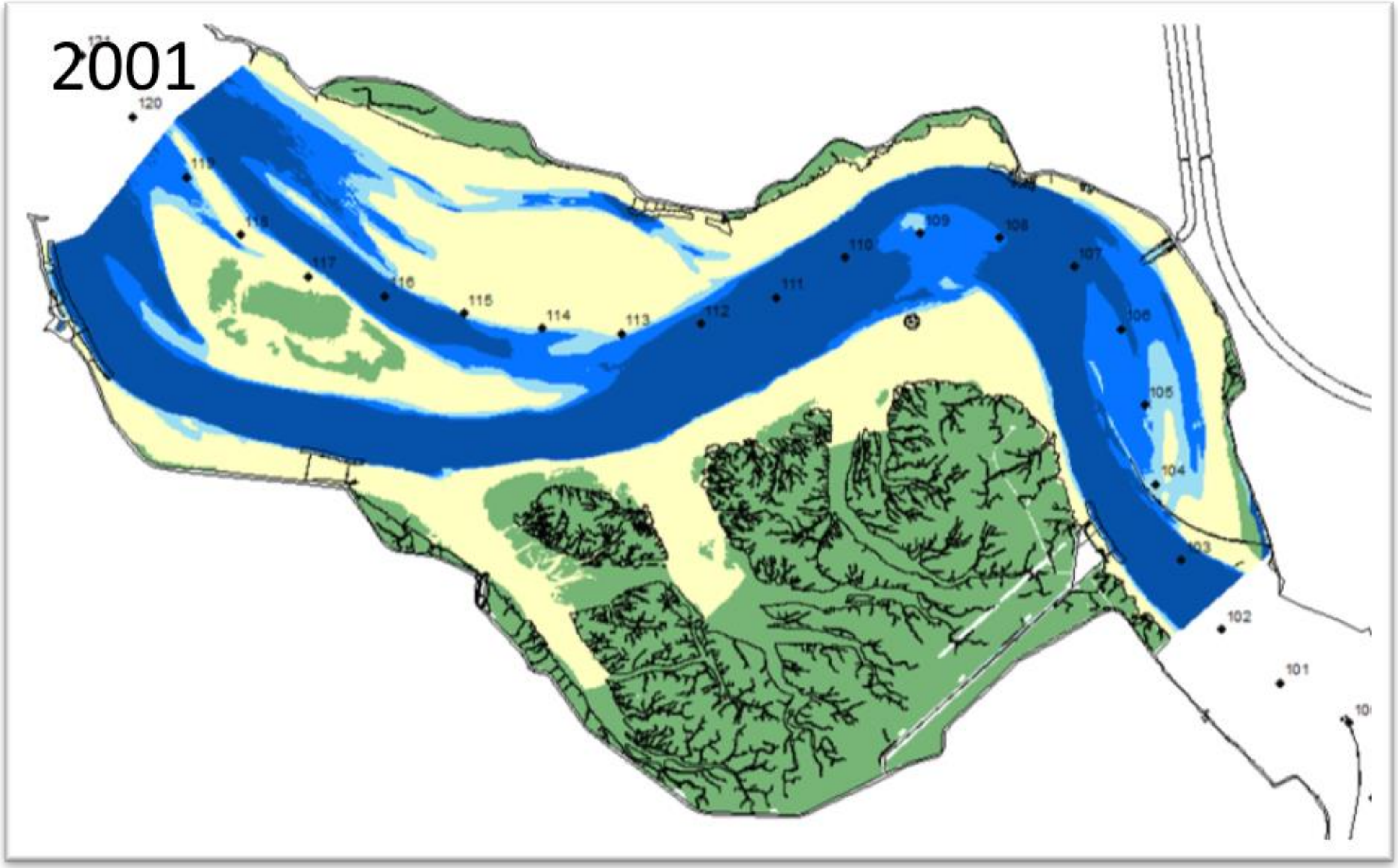
A - 43: Map showing the upper part of the TIDE – zone 5 (Mesohaline zone) in the Zee-schelde in 1960



A - 44: Map showing the upper part of the TIDE – zone 5 (Mesohaline zone) in the Zee-schelde in 2001

8.2.3.8 TIDE zone 5, Westerschelde - Mesohaline zone

TIDE zone 5 stretches from Oosterweel to Hansweert (Westerschelde). This TIDE zones contains part of the Zeeschelde and part of the Westerschelde. Historical habitat information for this zone is derived from both the ecotope maps of both sources.



A - 45: Map showing the lower part of the TIDE – zone 5 (Mesohaline zone) in the Westerschelde in 2001

A - 46: Overview of areal distribution within the TIDE zone 5 (Westerschelde)

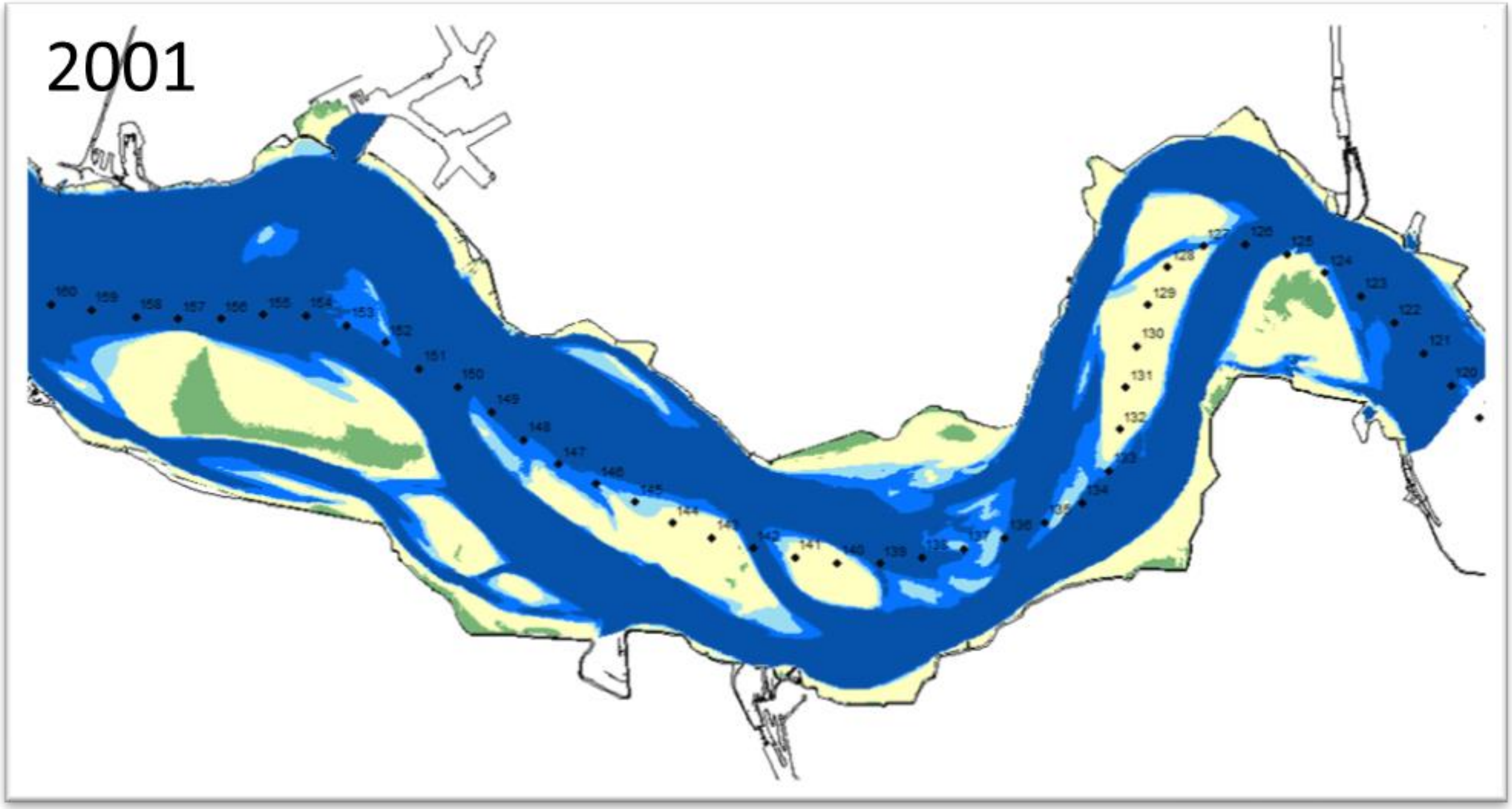
	TIDE habitat	1880	1930		1960		2001	
Subtidal	1 deep subtidal habitat (high energy)						3.225	1.902
	2 deep subtidal habitat (low energy)							53
	3 slope habitat (high energy)							741
	4 slope habitat (low energy)							59
	5 shallow water habitat (high energy)							324
	6 shallow water habitat (low energy)							146
Intertidal	7 Tidal flat habitat (high energy)						2.594	1.260
	8 Tidal flat habitat (low energy)							1.335
Supratidal	9 Salt marsh habitat							2.860
	10 Summer polder							0
	11 Stagnant water in foreland							0
	Total area						**8.680**	

8.2.3.9 TIDE zone 6 - Polyhaline zone

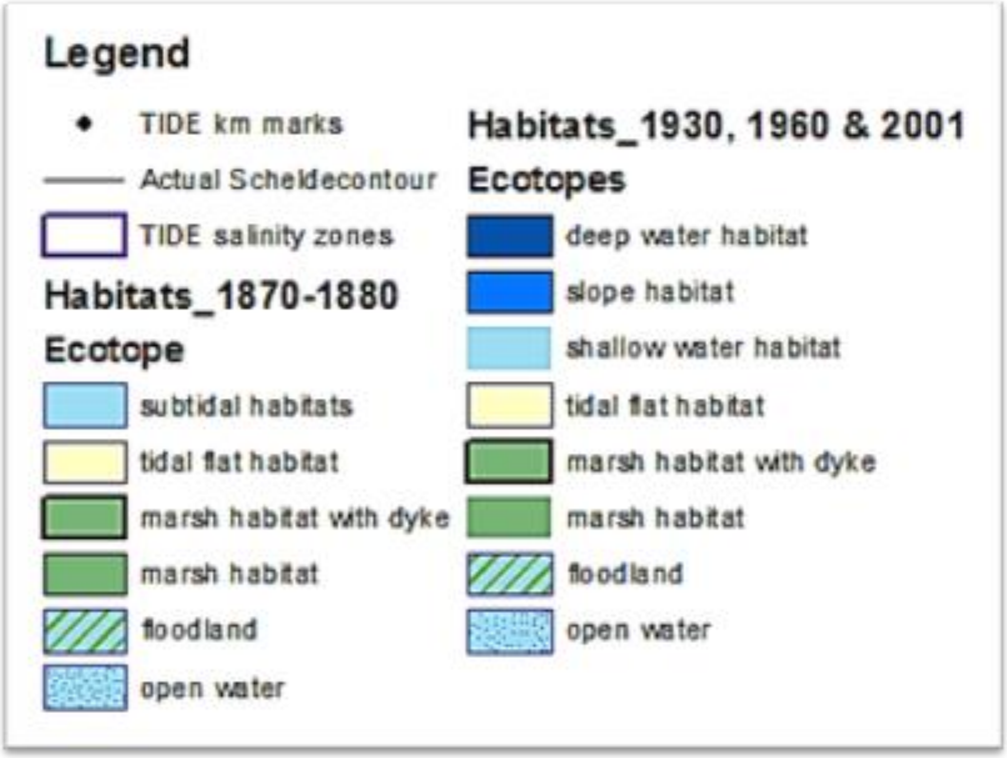
TIDE zone 6 stretches from Hansweert to Vlissingen.

A - 47: Overview of areal distribution within the TIDE zone 6

	TIDE habitat	1880	1930		1960		2001	
Subtidal	1 deep subtidal habitat (high energy)						16.639	12.444
	2 deep subtidal habitat (low energy)							487
	3 slope habitat (high energy)							1.896
	4 slope habitat (low energy)							424
	5 shallow water habitat (high energy)							768
	6 shallow water habitat (low energy)							620
Intertidal	7 Tidal flat habitat (high energy)						5.134	2.396
	8 Tidal flat habitat (low energy)							2.738
Supratidal	9 Salt marsh habitat							762
	10 Summer polder							0
	11 Stagnant water in foreland							0
	Total area						**22.535**	



A - 48: Map showing the TIDE – zone 6 (Polyhaline zone) of the Schelde in 2001



A - 49: Legend for all Schelde - maps

8.2.4 Weser

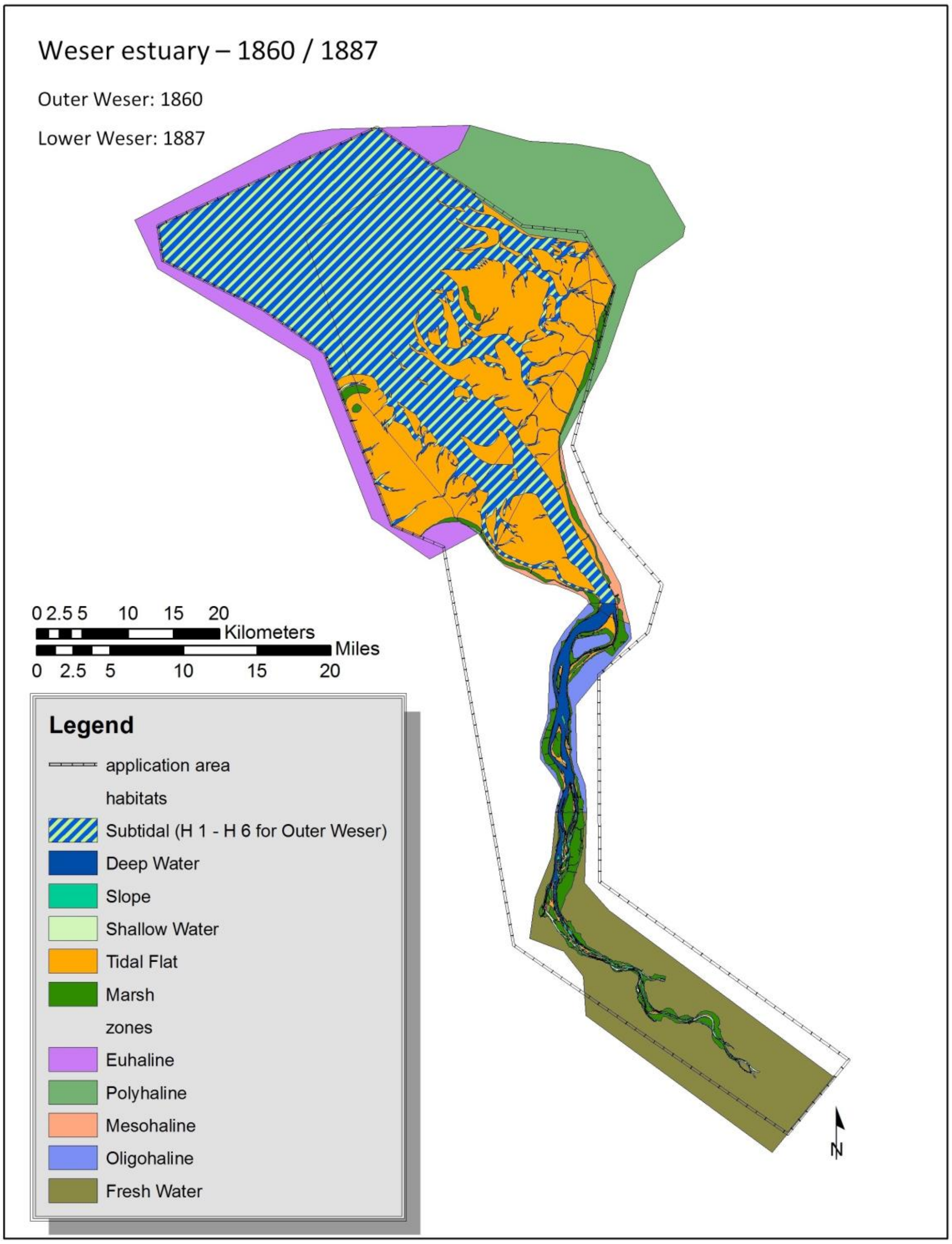
Within this study, anabranches are assumed to host the low energy habitats while the main channel of the Weser is assumed to give space for high energy habitats.

8.2.4.1 Time step MAP 1900

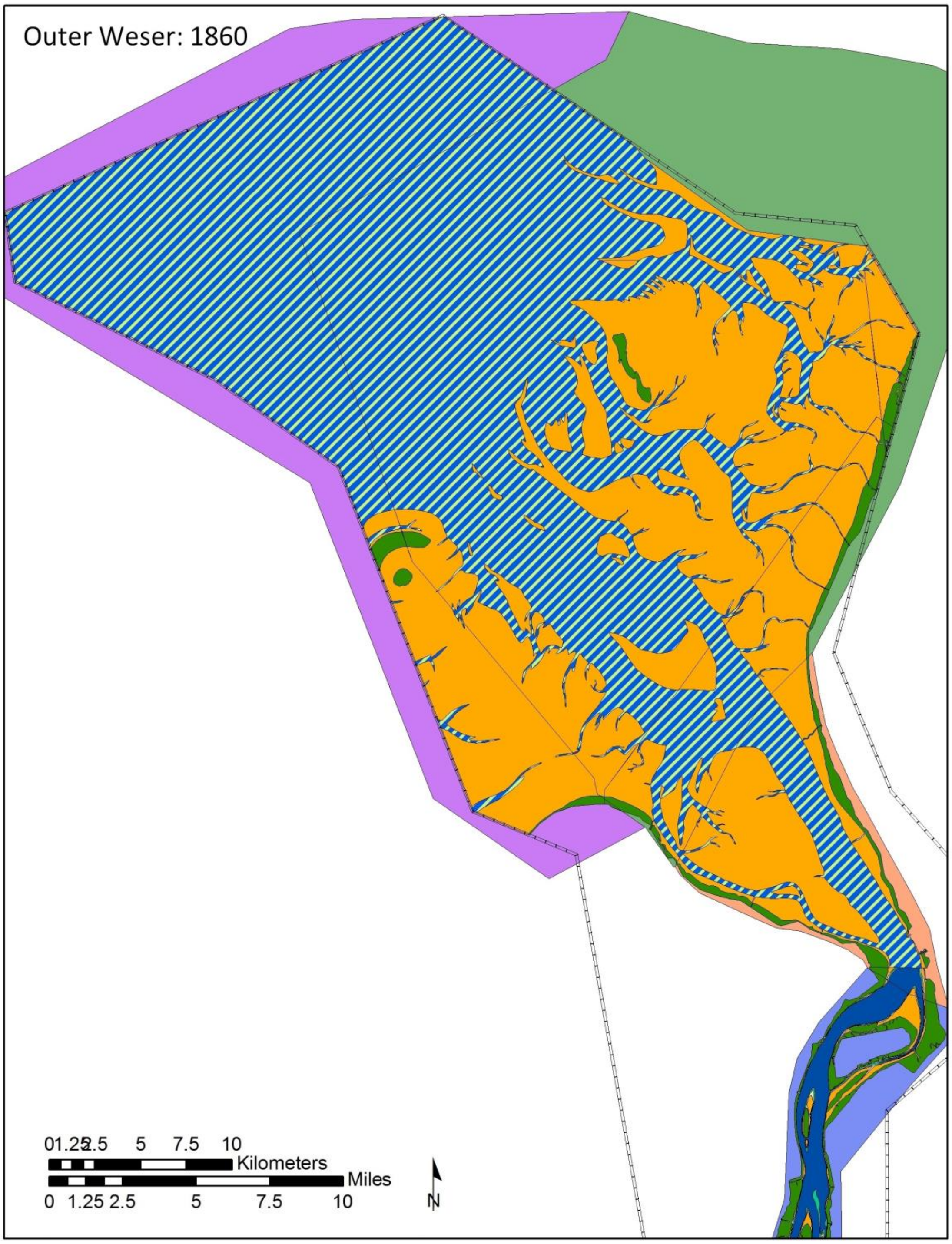
Charts from Franzius and Bücking (1895), which had been mapped in 1887 before starting the Weser correction of the lower Weser were used as reference scenario. These four sea charts, showing the lower Weser, had no coordinate information included, so they have been georeferenced by using referenced shapes taken from HARBASISNS report (Elsebach *et.al.*, 2007).

Based on this information, the polygon shapes were created. High and the low-energy habitats were not distinguished, since at that time the Weser was characterized by many anabranches giving the river the character of a braided stream. A distinguishing between a main fairway with high velocities and further branches with low velocities was impossible

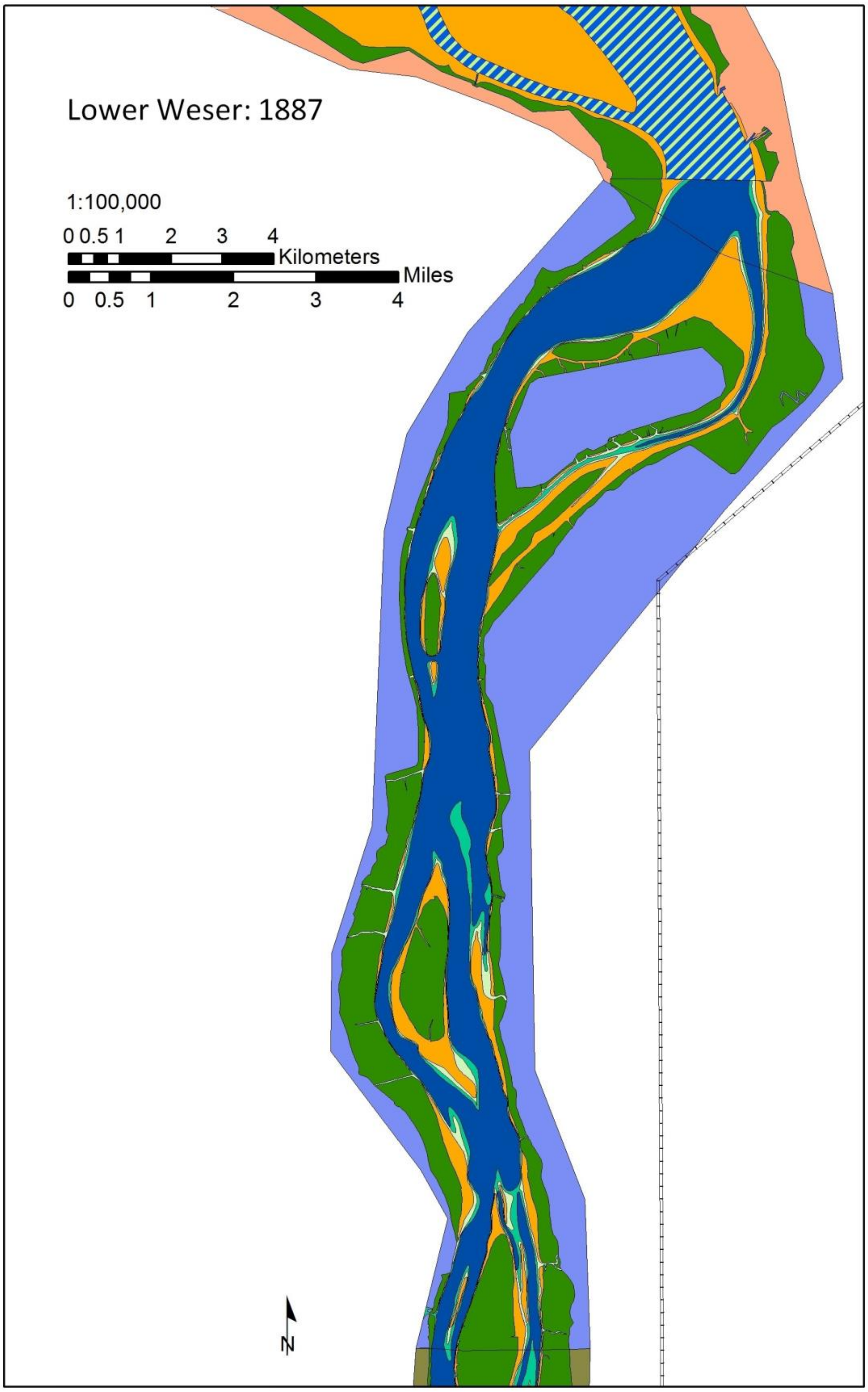
Since the oldest sea chart from the Federal Maritime and Hydrographic Agency, showing the area of the outer Weser, is dated 1904 and there are no older sources of information on the water depth, a map showing the subtidal, intertidal and supratidal in 1860 (Homeier, 1962) has been used to calculate the area for these three zones.



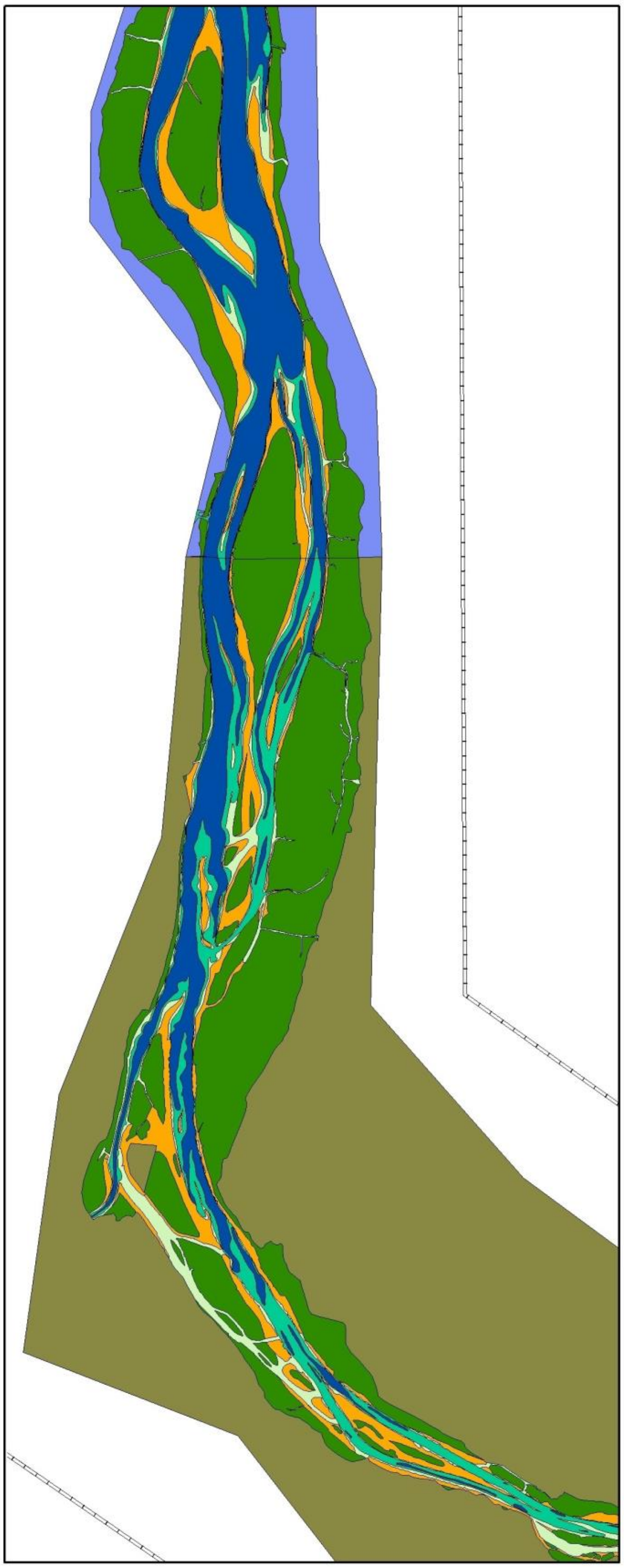
A - 50: Overview of the Weser Estuary in the 19th century



A - 51: Overview of the Outer-Weser in the 19th century



A - 52: Overview of the lower part of the Lower Weser in the 19th century



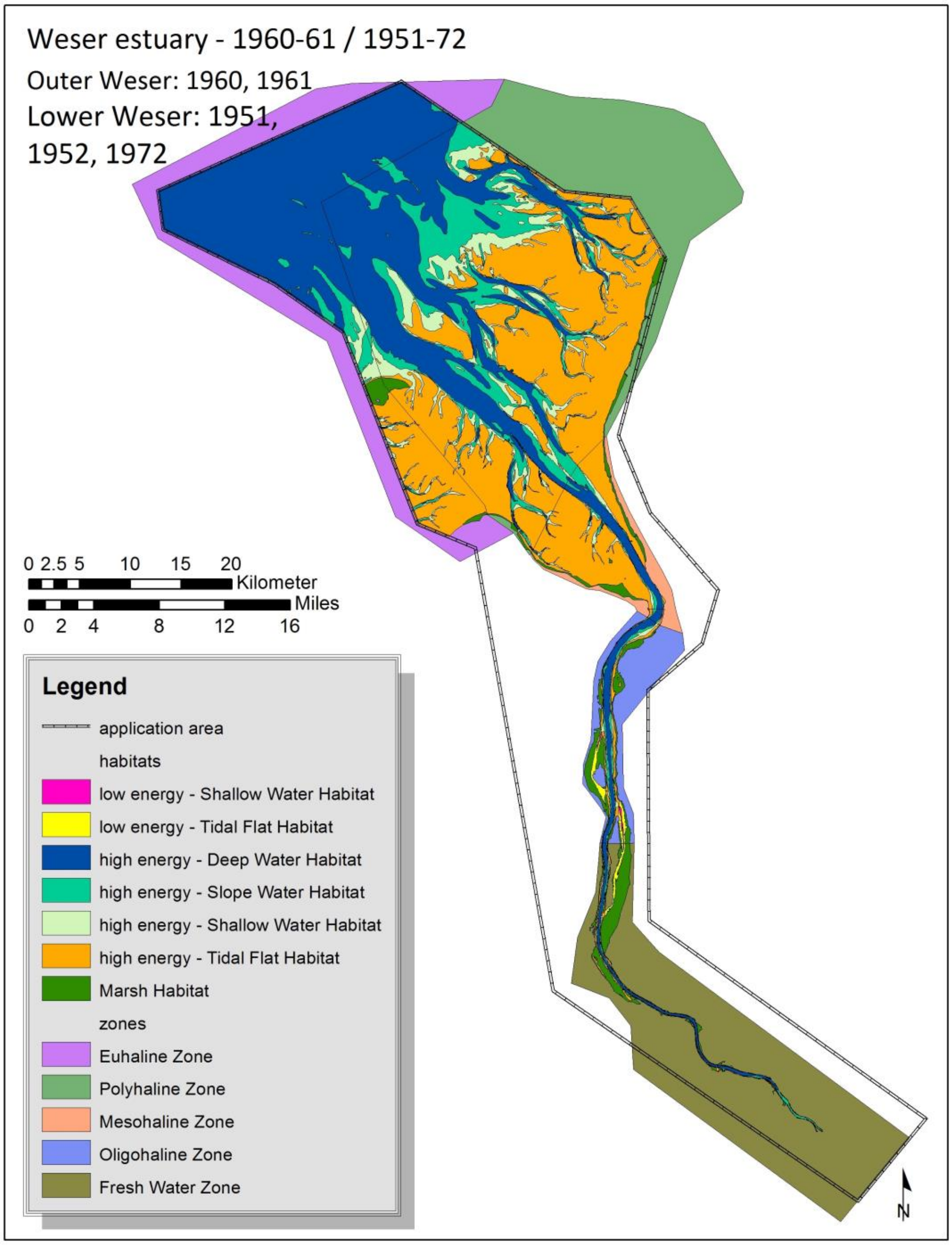
A - 53: Overview of the middle part of the Lower Weser in the 19th century

8.2.4.2 Time step MAP1950

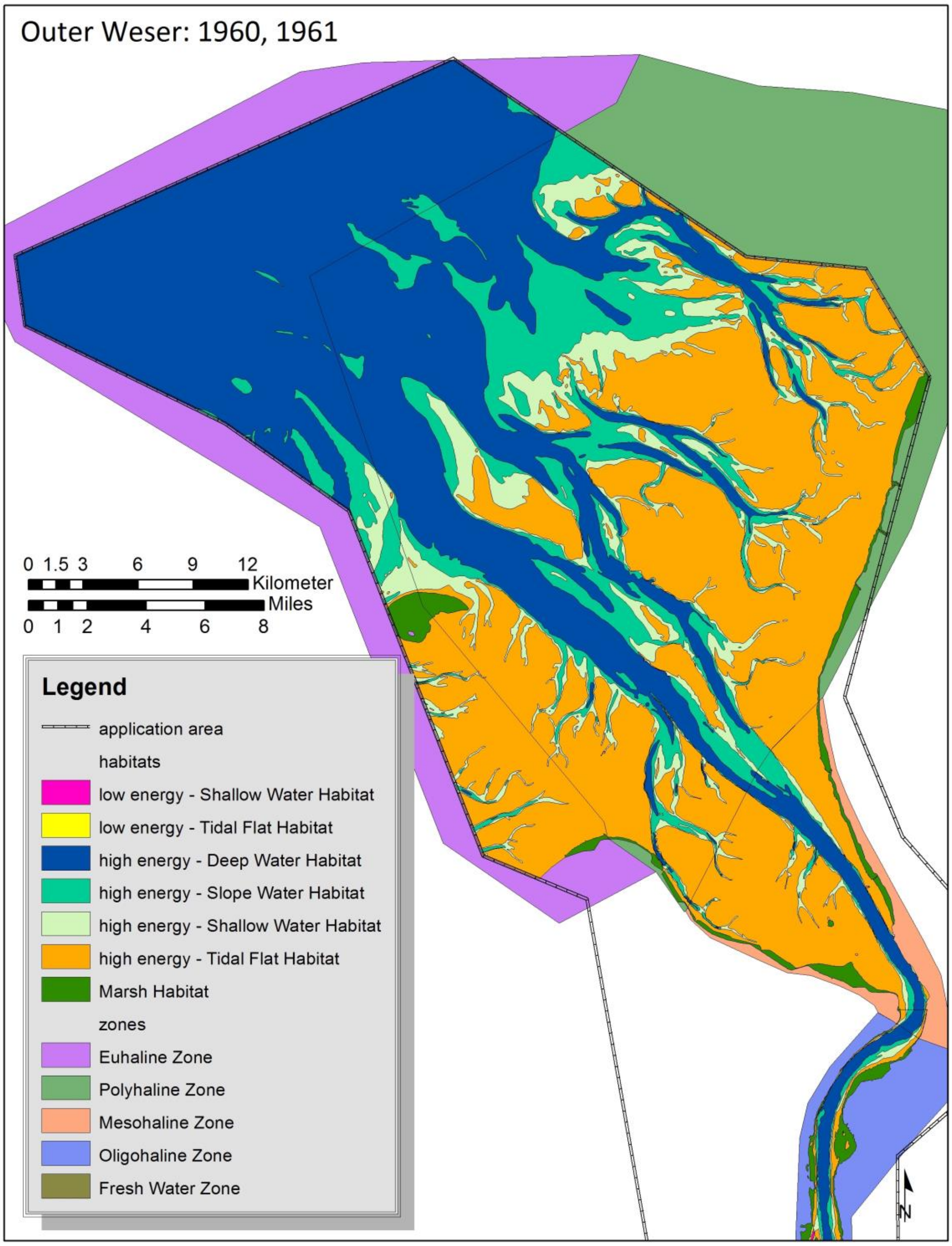
For the lower Weser the sea charts 5 (BSH, 1952) and 6 (BSH, 1951) provided a basis for the creating of the required shapes of the subtidal zones. Together with available data representing supratidal and intertidal physiotopes (HARBASINS 2008), the required information were complete for the lower Weser.

The region of the Outer Weser was represented by the sea chart 2 (BSH, 1960), 4 (BSH, 1961a) and 7 (BSH, 1961b), where shapes representing subtidal, intertidal and supratidal physiotopes could be created.

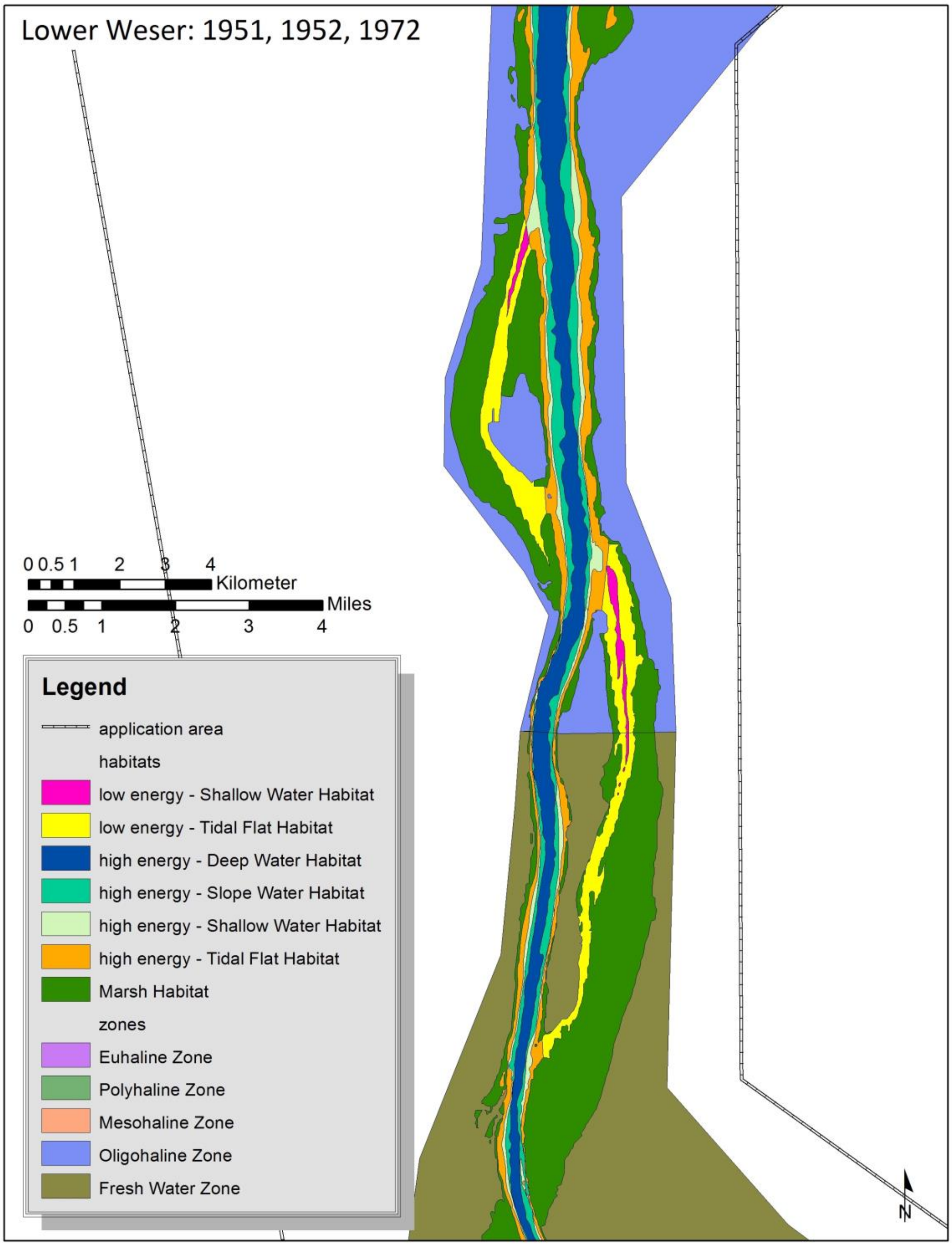
These sea charts required a transformation from the Mercator projection to the Gauss-Krüger coordinate system before geo-referencing. After the referencing all shapes are created the way described before.



A - 54: Overview of the Weser Estuary in the mid - 20th century



A - 55: Overview of the Outer-Weser in the mid - 20th century

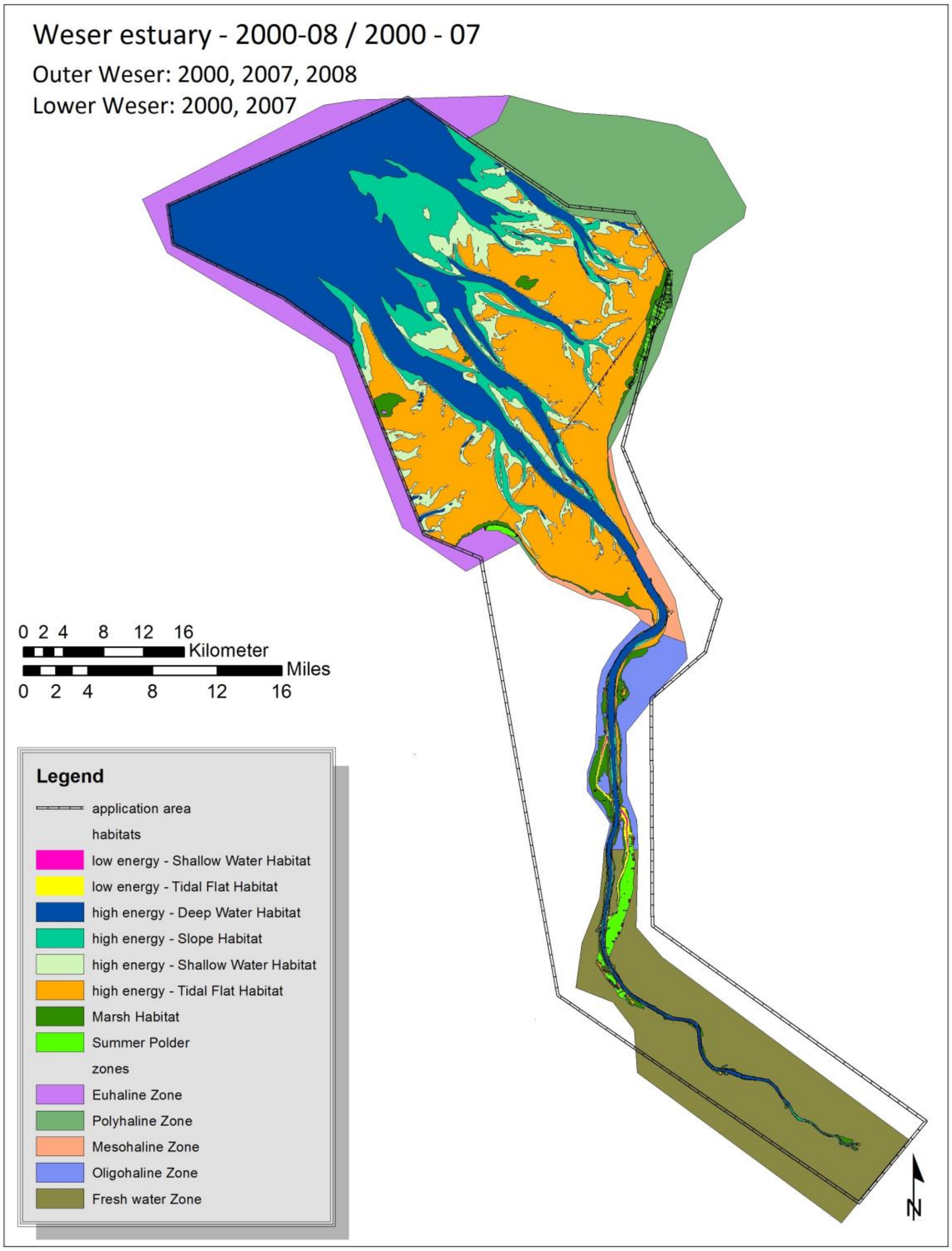


A - 56: Section of the Lower-Weser in the mid - 20th century

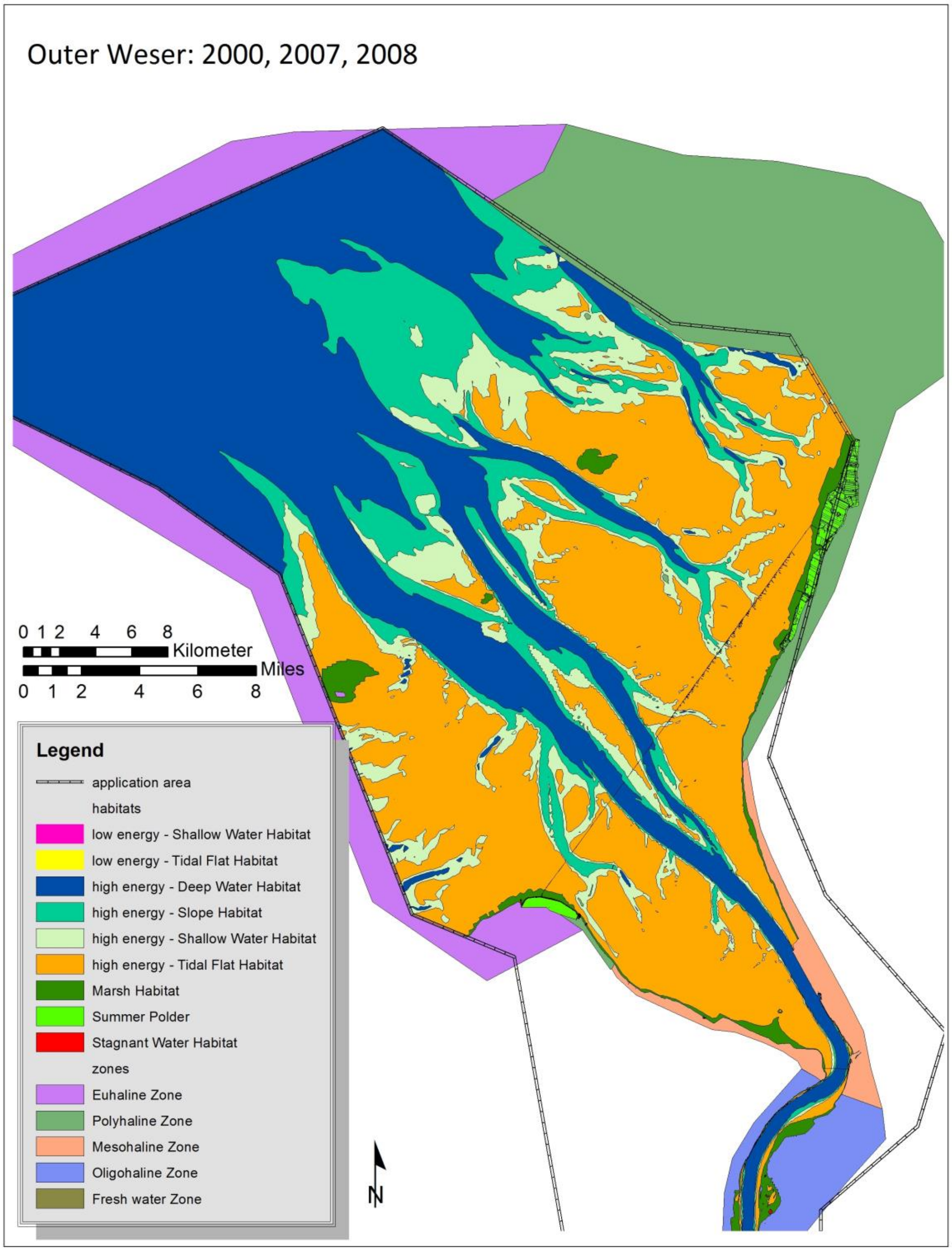
8.2.4.3 Time step map 2000

For the time step of map 2000 polygons were available from the HARBASINS project, however, had to be checked and complemented with information considering the slope and deep water habitats in the lower and outer Weser taken from sea charts 2 (BSH, 2008), 4 (BSH, 2007a), 5 (BSH, 2007b) and 6 (BSH, 2005) published by the Federal Maritime and Hydrographic Agency.
To distinguish the low energy from the high energy zones of the intertidal and subtidal polygons, the anabranches are manually separated from the main shipping channel.
The area of the stagnant water zones were taken from biotope type field mapping (NLWKN, 2006), which includes all standing water bodies as polygon shapes.

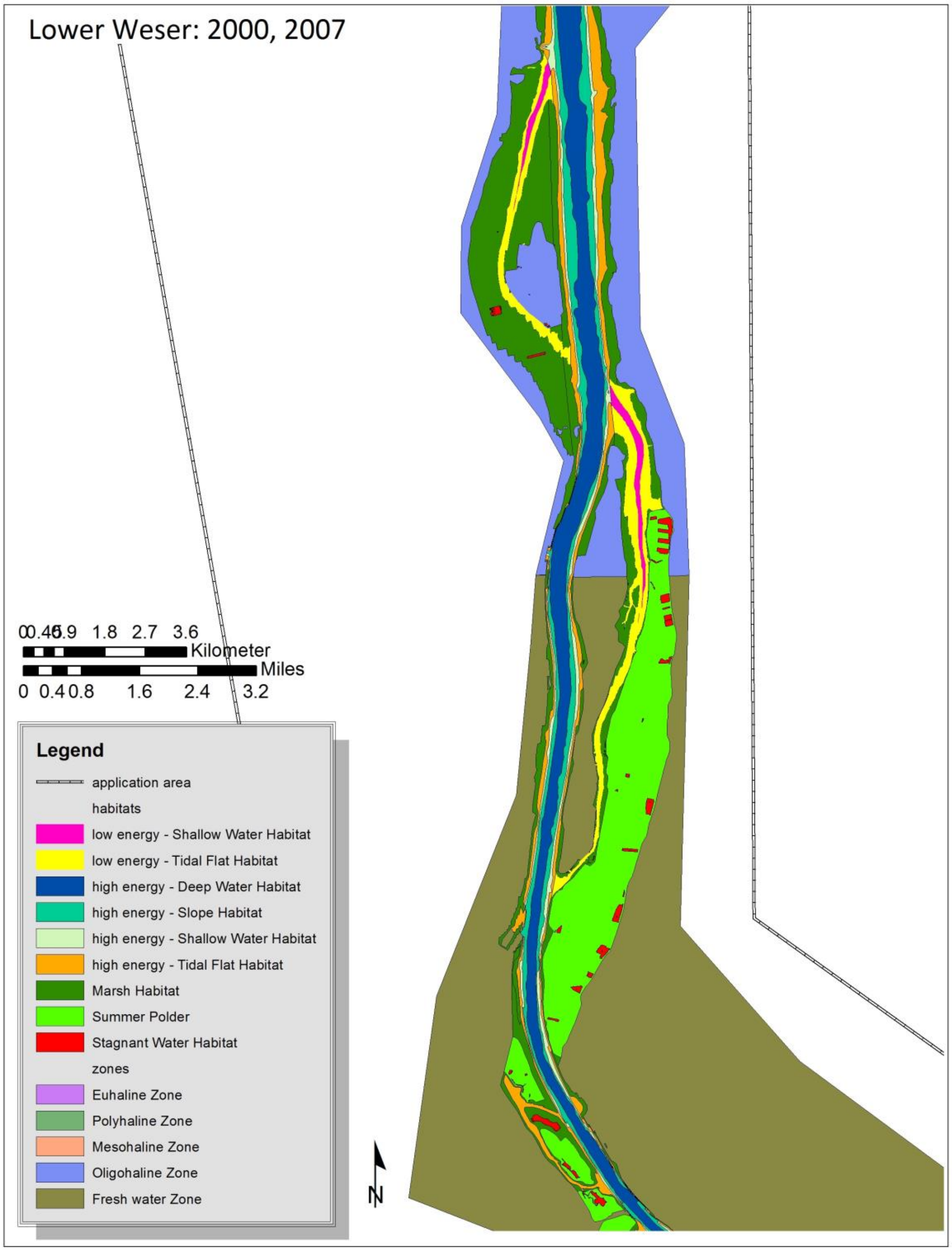
Polygon shapes containing information about the area of the summer polder zone are only available for the outer Weser (Arens, 2009) as additional areas to the Marsh physiotope. The information of the summer polder area in the lower Weser district was taken from Osterkamp *et.al.* (2000), however, Osterkamp et.al. defined the summer polder area within the Marsh physiotope.



A - 57: Recent overview of the Weser Estuary



A - 58: Recent overview of the Outer-Weser



A - 59: Recent section of the Lower-Weser

Arens, S. (2009) Bericht: WRRL - Bewertung Makrophyten und Angiospermen. Niedersächsischer Landesbetrieb für Wasserwirtschaft, Küsten- und Naturschutz, Oldenburg.

BSH (1951) Seekarte Nummer 6: Die Weser von Farge bis Bremen. 29 IX Ausgabe 47. Bundesamt für Seeschifffahrt und Hydrographie, Rostock.

BSH (1952) Seekarte Nummer 5: Die Weser von Nordenham bis Farge. 12 I Ausgabe 3. Bundesamt für Seeschifffahrt und Hydrographie, Rostock.

BSH (1960) Seekarte Nummer 2: Mündungen der Jade und Weser. 23 I; II; VI 12 XI Ausgabe 46. Bundesamt für Seeschifffahrt und Hydrographie, Rostock.

BSH (1961a) Seekarte Nummer 4: Die Weser von Robbennordsteert bis Bremerhaven und Nordenham. 23 XII Ausgabe 52. Bundesamt für Seeschifffahrt und Hydrographie, Rostock.

BSH (1961b) Seekarte Nummer 7: Jadebusen, innerer Teil. 10 XII Ausgabe 3. Bundesamt für Seeschifffahrt und Hydrographie, Rostock.

BSH (2005) Seekarte Nummer 6: INT 1459 - Die Weser von Farge bis Bremen. Ausgabe 2005 VIII. Bundesamt für Seeschifffahrt und Hydrographie, Rostock.

BSH (2007a) Seekarte Nummer 4: INT 1457- Die Weser von Robbennordsteert bis Bremerhaven und Nordenham. Ausgabe 2007 VII. Bundesamt für Seeschifffahrt und Hydrographie, Rostock.

BSH (2007b) Seekarte Nummer 5: INT 1458- Die Weser von Nordenham bis Farge. Ausgabe 2007 VI. Bundesamt für Seeschifffahrt und Hydrographie, Rostock.

BSH (2008) Seekarte Nummer 2: INT 1456- Mündungen der Jade und Weser. Ausgabe 2008 V.Bundesamt für Seeschifffahrt und Hydrographie, Rostock.

HOMEIER, H. (1962): Historisches Kartenwerk 1:50 000 der niedersächsischen Küste, Jahresbericht der Forschungsstelle Küste, Band XIII (Karten Nr. 8 bis 14)

NLWKN (2006) Biotopentypenkartierung. Niedersächsischer Landesbetrieb für Wasserwirtschaft, Küsten- und Naturschutz, Lüneburg.

8.3 *Areal distribution in the Estuaries*

8.3.1 Elbe

A - 60: Areal distribution of the Elbe Estuary

		Area (ha)			Area (ha)			Area (ha)		
		Habitat 1 - 4: Deep water			Habitat 5 + 6: Shallow water			Habitat 7 & 8: Tidal flat		
Zone	Salinity-zone	MAP 1900	MAP 1950	MAP 2000	MAP 1900	MAP 1950	MAP 2000	MAP 1900	MAP 1950	MAP 2000
0	*all*									
1	fresh water 1			635			121			145
2	fresh water 2	1310	1855	2341	690	165	50	129	169	28
3	fresh water 3	1749	2261	1496	1274	946	736	731	584	1121
4	oligohaline	5151	4745	4270	1059	1462	848	1044	1126	1832
5	mesohaline 1	6251	6046	5217	418	1038	628	3810	1564	2830
6	mesohaline 2	7367	9029	8032	4574	2778	2870	16034	10865	14884
7	polyhaline	11614	11696	12067	4344	3894	3738	12552	11463	12305
$\sum_6$	sum zone 2 - 7	33442	35632	33423	12359	10283	8870	34300	25771	33000
$\sum$	sum zone 1 - 7			34058			8991			33145

		Area (ha)			Area (ha)		
		Habitat 9: Marsh			Total area		
Zone	Salinity-zone	MAP 1900	MAP 1950	MAP 2000	MAP 1900	MAP 1950	MAP 2000
0	*all*						
1	fresh water 1			592			1494
2	fresh water 2	1749	325	350	3878	2513	2768
3	fresh water 3	2850	2678	766	6603	6469	4118
4	oligohaline	8032	8353	2603	15286	152686	9553
5	mesohaline 1	6463	5426	1778	16943	14074	10453
6	mesohaline 2	2458	1164	2667	30433	23836	28452
7	polyhaline	291	790	718	28802	27842	28828
$\sum_6$	sum zone 2 - 7	21843	18736	8882	101945	227420	84172
$\sum$	sum zone 1 - 7			9474			85666

8.3.2 Humber

A - 61: Areal distribution of the Humber Estuary

		Area (ha)					Area (ha)				
		Habitat 1 - 6: Subtidal					Habitat 7 & 8: Tidal flat				
Zone	Salinity-zone	1910/1924	1975	1988	1993	2008	1910/1924	1975	1988	1993	2008
0	*all*	17394	17206	16424	16596	16298	10142	10291	11105	10746	11078
1	**Inner Estuary**	2185	2987	1912	1856	1858	1925	1226	2304	2340	2279
2	**Middle Estuary (Inner)**	3190	2731	2834	2798	2711	910	1300	1191	1207	1280
3	**Middle Estuary (Outer)**	5161	5062	5234	5378	5109	2154	2271	2104	1952	2197
4	**Outer Estuary (North)**	3689	3459	3560	3558	3556	4041	4238	4184	4181	4189
5	**Outer Estuary (South)**	3169	2969	2884	3005	3063	1111	1255	1322	1066	1132
∑	sum zone 1 - 5	17394	17206	16424	16596	16298	10142	10291	11105	10746	11078

		Area (ha)					Area (ha)				
		Habitat 9: Marsh					Marsh: no flood				
Zone	Salinity-zone	1910/1924	1975	1988	1993	2008	1910/1924	1975	1988	1993	2008
0	*all*	808	242	334	481	633	78	391	308	225	208
1	**Inner Estuary**	381	141	139	191	284	20	166	163	130	108
2	**Middle Estuary (Inner)**	56	0	26	7	0	37	25	33	65	65
3	**Middle Estuary (Outer)**	143	97	165	170	245	22	70	12	29	35
4	**Outer Estuary (North)**	105	0	4	114	103	0	129	100	0	0
5	**Outer Estuary (South)**	123	3	0	0	0	0	0	0	0	0
∑	sum zone 1 - 5	808	242	334	481	633	78	391	308	225	208

8.3.3 Schelde

A - 62: Areal distribution of the Schelde Estuary (incl. Rupel & Drume)

			Habitat 1: Deep water habitat (high energy)				Habitat 2: Deep water habitat (low energy)				Habitat 3: Slope habitat (high energy)			
Zone	Salinity zone	TIDE-km	MAP 1880	MAP 1930	MAP 1960	MAP 2001	MAP 1880	MAP 1930	MAP 1960	MAP 2001	MAP 1880	MAP 1930	MAP 1960	MAP 2001
1	Limnetic 1	0-14	192	2	1	9				0	In H1	73	68	68
2	Limnetic 2	14-31	198	25	27	44					In H1	113	93	101
3	Limnetic 3	31-58	444	119	106	211					In H1	197	196	166
	Durme							2	0	0				
4	Oligohaline	58-74	676	439	435	480					In H1	101	107	75
	Rupel			12	15	25						82	88	92
5	Mesohaline	74-116	1.688	1.060	1.051	1.305					In H1	427	413	320
						1.902				53				741
6	Polyhaline	116-160				12.444				487				1.896
			3.198	1.656	1.635	2.074	-	2	0	0	-	994	964	823

Not applicable
Not covered by data

		Habitat 4: Slope habitat (low energy)				Habitat 5: Shallow water habitat (high energy)				Habitat 6: Shallow water habitat (low energy)			
Zone	Salinity zone	MAP 1880	MAP 1930	MAP 1960	MAP 2001	MAP 1880	MAP 1930	MAP 1960	MAP 2001	MAP 1880	MAP 1930	MAP 1960	MAP 2001
1	Limnetic 1				0	In H1	53	42	21				17
2	Limnetic 2					In H1	34	47	32				
3	Limnetic 3					In H1	113	106	77				
	Durme		18	4	0						54	33	26
4	Oligohaline					In H1	65	58	39				
	Rupel						71	62	36				
5	Mesohaline					In H1	286	290	201				-
					59				324				146
6	Polyhaline				424				768				620
		-	18	4	0	-	621	605	406	-	54	33	43

Not applicable

Not covered by data

		Habitat 7: Tidal flat habitat (high energy)				Habitat 8: Tidal flat habitat (low energy)				Habitat 9: Marsh habitat			
Zone	Salinity zone	MAP 1880	MAP 1930	MAP 1960	MAP 2001	MAP 1880	MAP 1930	MAP 1960	MAP 2001	MAP 1880	MAP 1930	MAP 1960	MAP 2001
1	Limnetic 1	0	15	34	16				18	5	10	-	37
2	Limnetic 2	27	35	39	37					114	111	96	91
3	Limnetic 3	157	180	148	137					239	271	251	219
	Durme						47	60	42		132	88	91
4	Oligohaline	58	124	99	104					172	152	111	57
	Rupel		69	66	51						89	62	37
5	Mesohaline	865	459	442	437					487	705	413	150
					1.260				1.335				2.860
6	Polyhaline				2.396				2.738				762
		1.106	882	829	782	-	47	60	60	1.016	1.470	1.021	682

Not applicable

Not covered by data

Zone	Salinity zone	Habitat 10: Summer polder MAP 1880	MAP 1930	MAP 1960	MAP 2001	Habitat 11: Stagnant water in foreland MAP 1880	MAP 1930	MAP 1960	MAP 2001
1	Limnetic 1	731	736	-	-	7	45	41	-
2	Limnetic 2	72	90	31	-	-	2	1	-
3	Limnetic 3	243	86	4	-	-	-	-	-
	Durme		728	291	-		3	22	-
4	Oligohaline	-	-	-	-	-	-	-	-
	Rupel		79	73	-		-	-	-
5	Mesohaline	-	-	-	-		0		-
6	Polyhaline								
		1.046	1.720	398	-	7	51	64	-

Salinity zone	MAP 1930	MAP 1960	MAP 2001
Limnetic 1	934	186	186
Limnetic 2	410	334	305
Limnetic 3	967	811	810
Durme	985	498	159
Oligohaline	880	809	755
Rupel	402	366	242
Mesohaline	2.937	2.609	2.413
meso wester-schelde	-	-	8.680
Polyhaline	-	-	22.535

Not applicable
Not covered by data

8.3.4 Weser

A - 63: Areal distribution of the Weser Estuary for all time steps (no distinction between high-/low-energy)

				Area (ha)			Area (ha)			Area (ha)		
				Habitat 1 + 2: Deep water			Habitat 3 + 4: Slope			Habitat 5 + 6: Shallow water		
Zone	Salinity-zone	(Weser-km)	TIDE-km	MAP 1900	MAP 1950	MAP 2000	MAP 1900	MAP 1950	MAP 2000	MAP 1900	MAP 1950	MAP 2000
0	*all*				53928	51856		17869	18191		12098	14895
1/2	fresh water 1 & 2	-4 - 27 & 27 - 40	0 - 31 & 34 - 44	589	696	802	844	392	455	680	193	166
3/4	oligohaline 1 & 2	40 - 65	44 - 69	2503	1128	1223	302	513	393	267	380	293
5	mesohaline	65 - 80	69 - 84		1390	1501		609	372		582	552
6	polyhaline	80 - 115	84 - 119		22989	20770		14410	15398		9714	12166
7	euhaline	115 - 130	119 - 134		27747	27584		1958	1585		1234	1736
∑	sum zone 1 - 7				53950	51879		17882	18203		12103	14913
Δ	variance (total)				21	23		13	12		5	18
‰	variance (‰)				0,39	0,44		0,72	0,64		0,43	1,22

	Area (ha)			Area (ha)			Area (ha)		
	Habitat 1 - 6: Subtidal			Habitat 7 & 8: Tidal flat			Habitat 9: Marsh		
Zone	MAP 1900	MAP 1950	MAP 2000	MAP 1900	MAP 1950	MAP 2000	MAP 1900	MAP 1950	MAP 2000
0	86984	83895	84939	47639	49134	46156	7984	5325	4329
1/2	2113	1280	1423	689	594	436	3141	1886	690
3/4	3072	2022	1908	802	1007	865	2337	1466	1653
5	3970	2581	2425	6114	7114	7118	931	691	448
6	47763	47113	48333	33159	34540	31903	1200	751	1043
7	30107	30939	30905	6939	5948	5890	381	534	490
∑	87024	83935	84994	47703	49203	46211	7990	5064	4324
Δ	41	40	56	64	69	56	5	2	5
‰	0,47	0,48	0.65	1,34	1.41	1.20	0,68	0.40	1.14

A - 64: Areal distribution of the Weser Estuary for MAP 1950 and MAP 2000 (all habitats)

	Area (ha)		Area (ha)		Area (ha)		Area (ha)		Area (ha)		Area (ha)	
	Habitat 1: Deep water (high energy)		Habitat 2: Deep water (low energy)		Habitat 3: Slope (high energy)		Habitat 4: Slope (low energy)		Habitat 5: Shalow water (high energy)		Habitat 6: Shalow water (low energy)	
Zone	MAP 1950	MAP 2000	MAP 1950	MAP 2000	MAP 1950	MAP 2000	MAP 1950	MAP 2000	MAP 1950	MAP 2000	MAP 1950	MAP 2000
0	53928	51856	0	0	17869	18191	0	0	12037	14814	61	80
1/2	696	802	0	0	392	455	0	0	188	164	4	3
3/4	1128	1223	0	0	513	393	0	0	323	214	57	78
5	1390	1501	0	0	609	372	0	0	582	552	0	0
6	22989	20770	0	0	14410	15398	0	0	9714	12166	0	0
7	27747	27584	0	0	1958	1585	0	0	1234	1736	0	0
∑	53950	51879			17882	18203			12042	14836	61	81
Δ	21	23			13	12			6	24	0	0
‰	0,39	0,44			0,72	0,64			0,47	1,63	2,11	1,81

	Area (ha)		Area (ha)		Area (ha)		Area (ha)		Area (ha)	
	Habitat 7: Tidal flat (high energy)		Habitat 8: Tidal flat (low energy)		Habitat 9: Marsh		Habitat 10: Summer polder		Habitat 11: Stagnant waters in the foreland	
Zone	MAP 1950	MAP 2000	MAP 1950	MAP 2000	MAP 1950	MAP 2000	MAP 1950	MAP 2000	MAP 1950	MAP 2000
0	48582	45768	551	388	5325	4329		2455		86
1/2	425	324	169	112	1886	690		1311		52
3/4	624	589	383	276	1466	1653		72		26
5	7114	7118	0	0	691	448		0		1
6	34540	31903	0	0	751	1043		1008		5
7	5948	5890	0	0	534	490		65		2
∑	48651	45823	552	388	5328	4324		2456		86
Δ	69	55	1	0	2	5		1		0
‰	1.41	1,20	0.96	1,21	0.41	1,14		0,35		0,46