The Eastern Scheldt Survey

A concise overview of the estuary pre- and post barrier - Part 2: SURVEY

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Part 2: SURVEY

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June 2016

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Part 2: Survey

A joint research project by
Urban Integrity
Waterworks @ B Business Energy
Delft University of Technology

Client: **Severe Storm Prediction Education and Evacuation from Disasters (SSPEED) Center**
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Cover image: Salt marshes at Rattekaai, in the western part of the Eastern Scheldt estuary (1982).
Source: Rijkswaterstaat Beeldbank, photo by Harry van Reeken.

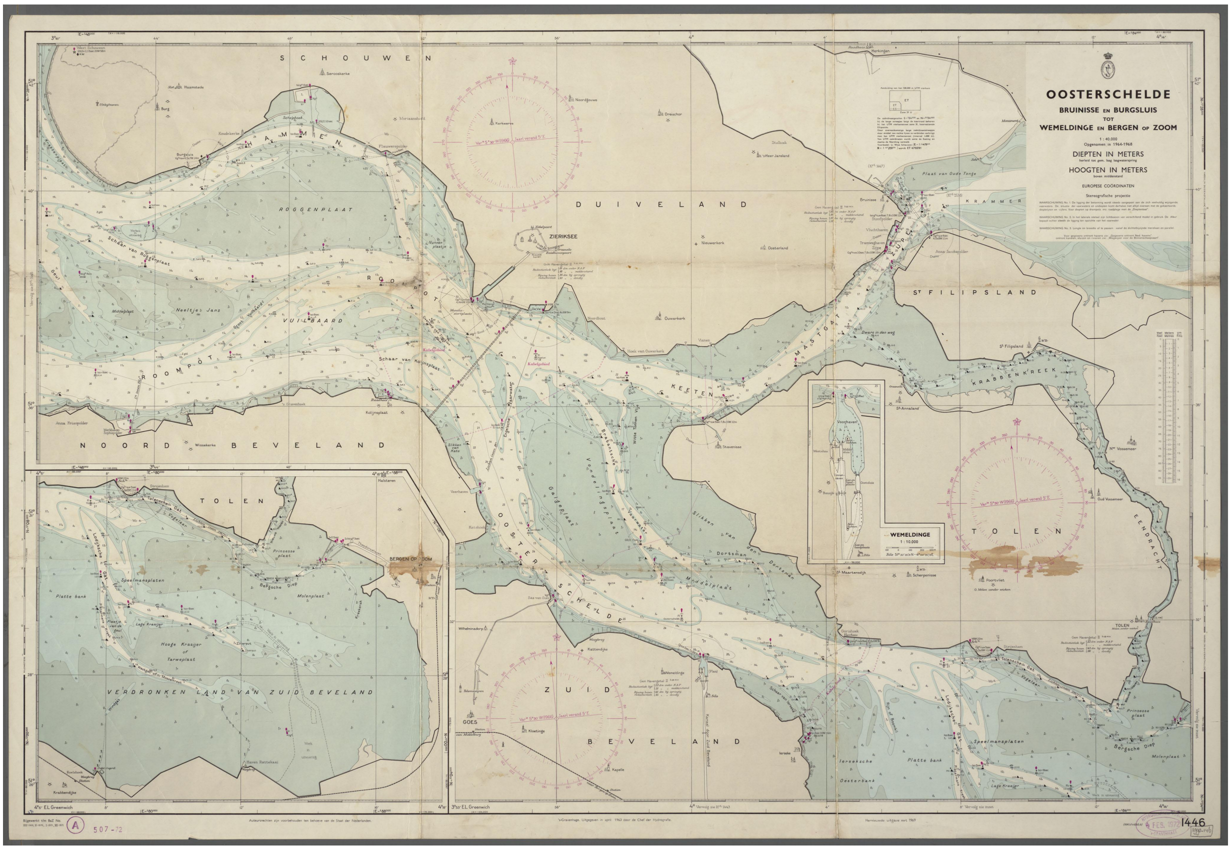

Figure 1: A bird's eye view of the Eastern Scheldt barrier, Roggenplaat and pillar dam (2008). *Source: Rijkswaterstaat beeldbank, photo by Joop van Houdt.*

Figure 2: Eastern Scheldt hydrographic map, 1972, pre-barrier. *Source: Frisian Shipping Museum www.geheugenvannederland.nl*

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Introduction

The aim of this survey is to give a concise overview of the pre- and post-barrier functioning of the Eastern Scheldt estuary. The semi-permeable Eastern Scheldt Barrier, constructed in 1986 in the southwestern delta of the Netherlands, is acknowledged as the global textbook example of compromise between flood safety and environmental preservation. As a result of the Eastern Scheldt's reputation, the estuary's environmental performance is monitored on a regular basis, providing a rich body of knowledge for future flood control projects.

The survey builds upon the Eastern Scheldt Memo (dated March 2016), which explored possible sources and shortlisted leading publications, key institutes and contacts. In response to the memo's reception by the commissioner of this study, the Severe Storm Prediction Education and Evacuation from Disasters (SSPEED)-centre, the survey has focused on two fields of interest:

1. The first field targets **key environmental changes** in the estuary after 1986. These have been grouped under five main categories: hydrodynamics, morphology, benthos & primary production, fish & aquaculture, and wader bird population. These include topics like salinity, channel alignment and (re)location of aquaculture plots.
2. The second field describes **contemporary management- and mitigation efforts** aimed to preserve the functioning of the estuary's ecosystem.

For a full view, the two parts of this study are to be read in concert, as the survey (part 2) only elaborates on selected issues from the memo (part 1).

The Eastern Scheldt Survey summarizes up to date knowledge on the effects of the barrier, to the extent that these are known. Overall, the focal point of attention within the existing body of knowledge has been on the **erosion of the tidal flats** (with an average lowering rate of 1 cm per year) and the anticipated long-term effects of **loss of foraging acreage** for the international wader bird population.

Other associated effects of the barrier's construction – like **reduced amounts of suspended particulate matter** and **increased penetration of light in the water column, relocation of the aquaculture plots for mussel-farming**, and a slight **increase in salinity** – have received less attention. Data drawn from various reports and publications have been complemented and checked in an interview with Eric van Zanten, a *Rijkswaterstaat*-based senior expert with a long-standing involvement in the estuary's management.

As such, the authors would like to thank Eric van Zanten, and also Lodewijk de Vet, PhD-candidate in Hydraulic Engineering based at Delft University of Technology and Deltares, and prof. Aad Smaal from Wageningen UR and Imares, in supplying data that have completed the Eastern Scheldt Survey. In order to enable smooth reading, a basic chapter describing the key features of the Eastern Scheldt Barrier is included. The survey concludes with lessons learned for future flood control projects in estuaries.

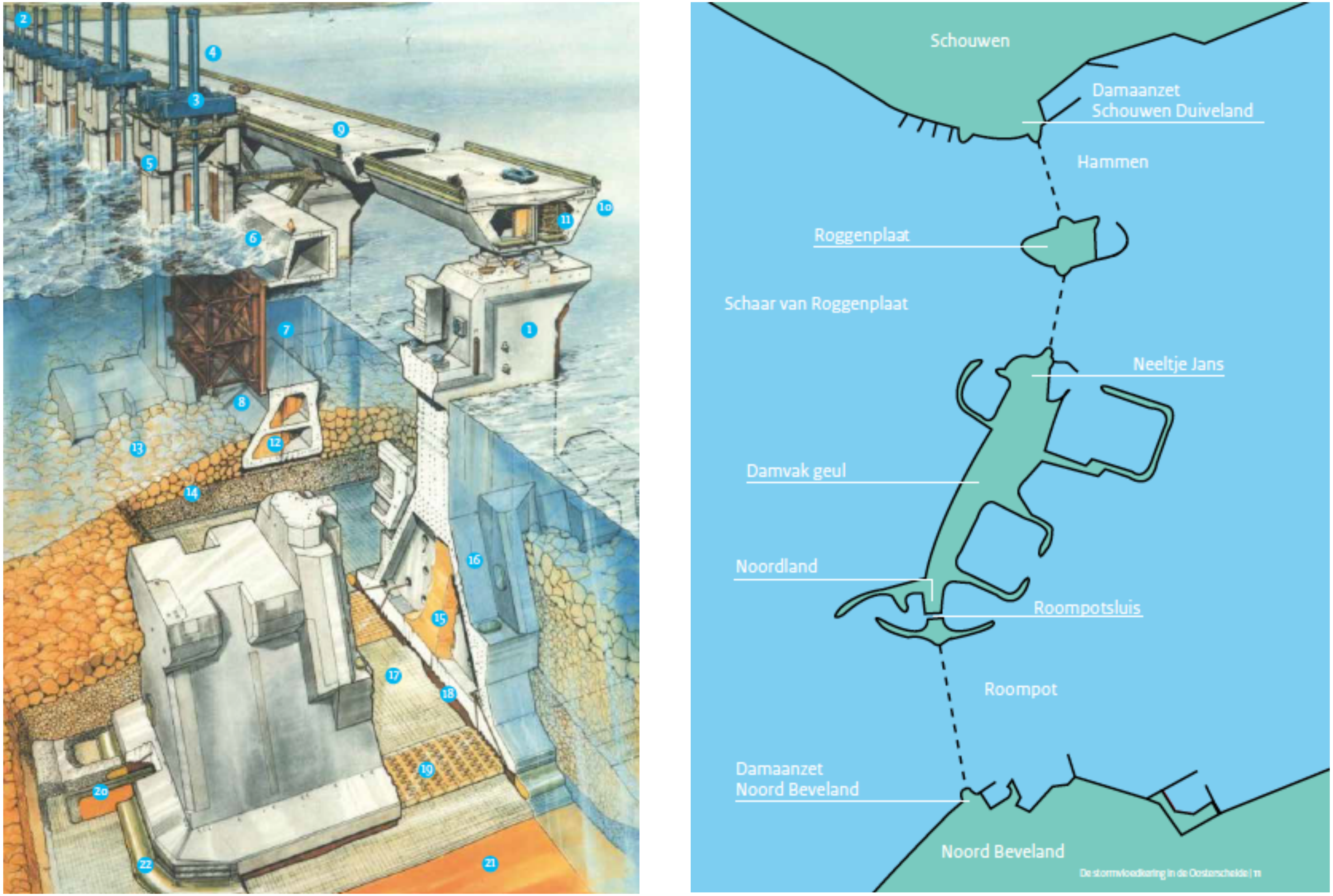

Figure 3: An overview of the Eastern Scheldt barrier's construction parts (right) and a cross section of its pillars (left). *Source: Steenepoorte (2014), De stormvloedkering in de Oosterschelde.*

1. The Eastern Scheldt barrier: the basics

The semi-permeable Eastern Scheldt barrier, constructed in 1986, is acknowledged as the textbook example of compromise between flood safety and environmental preservation in the Netherlands. The barrier is part of the Delta Works (1985-1997), a series of construction projects that protect the Dutch Southwestern delta from storm surge. The Delta Works were a radical response to the 1953 flood event, where 1836 people perished during a northwesterly storm that produced storm surge levels of 4 to 5 meters above Amsterdam Ordinance Datum (Steenepoorte, 2014). In concert, the thirteen dams and floodgates of the Delta Works protect the Southwestern Delta up to a safety standard of 1: 4,000 per year.

The barrier, which has an overall length of 9 kilometers, consists of a semi-permeable part of about 3000 meters and two artificial islands from which the construction of the barrier was undertaken (Steenepoorte, 2014). The semi-permeable part consists of 65 concrete pillars and 62 metal gates. Under normal conditions, when the gates are open, **two-thirds of the original tidal amplitude remains**. On average, the Eastern Scheldt storm surge barrier closes once a year, when a storm surge of 3 meters above Amsterdam Ordinance Datum is expected. The barrier has been designed for a time-span of 200 years (Rijkswaterstaat, 1994); from the 12 billion guilders ultimately allocated to construction of the Delta Works as a whole, more than half – 7 billion - was spent on the Eastern Scheldt storm surge barrier (Steenepoorte, 2014).

Before, during and after construction of the barrier, the (partial) closure of the Eastern Scheldt has been subject to extensive public and expert debate. Apart from resulting in an alternative design for the barrier itself, this debate has contributed to extensive monitoring of the estuary's environmental performance. In general, the Eastern Scheldt is perceived as a test bed for research on environmental effects of flood risk reduction measures.

Initially, the Delta Works scheme intended the Eastern Scheldt estuary to be dammed off completely. The Southwestern Delta, a collection of estuaries where the tributaries of the Rhine and Meuse rivers meet the North Sea, was to be compartmentalized: variable fresh water in the Haringvliet, stagnant fresh for the Volkerak-Krammer tributary and Veerse Meer, and stagnant salt for Grevelingen and the Eastern Scheldt. Implications for the natural environment were accepted during the design-phase of the Delta Works in the 1950s (Duursma et al., 1982).

The underlying motivation was that this design would be most cost-efficient, reducing the length of primary flood defenses to be maintained according to the highest safety standards. Also, co-benefits were expected from the creation of new fresh water reservoirs intended to increase agricultural production in the region. However, in the 1960's the first protests were voiced about closing off the estuary - just parallel with the start of the construction of the dam.

Complete compartmentalization of the estuaries increased the net impact of contaminated water from the Rhine, and hydrological studies demonstrated that the Eastern Scheldt estuary itself was not suitable as a fresh water reservoir (Dubbelman, 1999). Henk Saeijs, the first biologist ever hired by *Rijkswaterstaat* (the Dutch equivalent of the US Army Corps of Engineers), did alarming findings regarding the water quality in the dammed Haringvliet, Grevelingen and Volkerak. This undermined a key argument to pursue full closure (Dubbelman, 1999) at a time where the public awareness of the diverse ecosystem of the Eastern Scheldt grew rapidly. Oyster- and mussel farming interests, traditionally centered in the Eastern Scheldt estuary, and environmental pressure groups joined forces.

In 1973, a state commission investigated the possibility of combining the goals of flood risk reduction and ecological preservation. They dismissed full closure for ecological and economical reasons. In 1974 the construction works were put to a stop. In 1976, Dutch central government decided for a compromise: a storm surge barrier that could be closed during severe storms, but would be open under normal conditions.

Consequently, discussion focused on the size of the openings and their ecological effects. The US-based Rand Corporation played a decisive role in delivering an innovative 'energetic' quantitative ecosystem-model, specifically developed for the case. For each of the alternatives, this so-called Policy Analysis of the Oosterschelde (POLANO) analyzed a wide range of consequences or 'impacts', ranging from the security of people and property from flooding; financial costs of construction and maintenance; employment and other economic and social impacts; to the expected changes in the kind and populations of biological species that constituted the ecology of the region (Rand Corporation, 1977). Based on the mathematical concepts used, civil engineers were able to integrate ecology as a parameter in the design options for the barrier (Disco, 2000; Bijker, 2002). In 1984, the final decision to construct a semi-permeable 'environmental' barrier was taken. The construction of the Eastern Scheldt Barrier was finished in 1986.

Nonetheless and up to today, environmental consequences remain a topic of debate, increasingly so since long-term environmental effects have become tangible since the 1990s (Rijkswaterstaat, 1991; Nienhuis & Smaal, 1994; Committee Vellinga, 2006; Cozolli et.al, 2013; Ministries of EA and I&E, 2014). Specifically morphological changes, demonstrated by the net erosion of the tidal flats and the potential detrimental effects for the European wader bird population, have captured a lot of attention. Erosion of the tidal flats in the Eastern Scheldt estuary is of international importance, as loss of feeding capacity cannot easily be replaced in other estuaries.

In 2013 a concise report, commissioned by *Rijkswaterstaat*[1], addressed the effects of sediment starvation resulting from the construction of the Eastern Scheldt barrier. The report

[1] Titled: Eindadvies 'ANT Oosterschelde' (Final Recommendation 'Autonomous Downward Trend Eastern Scheldt')

proposed mitigation measures in order to achieve environmental goals stated in the European Natura 2000-policy. Currently, a 2015 draft management plan for the maintenance of the Eastern Scheldt Natura 2000-site is into procedure (Rijkswaterstaat, *Ontwerp beheerplan Oosterschelde*).

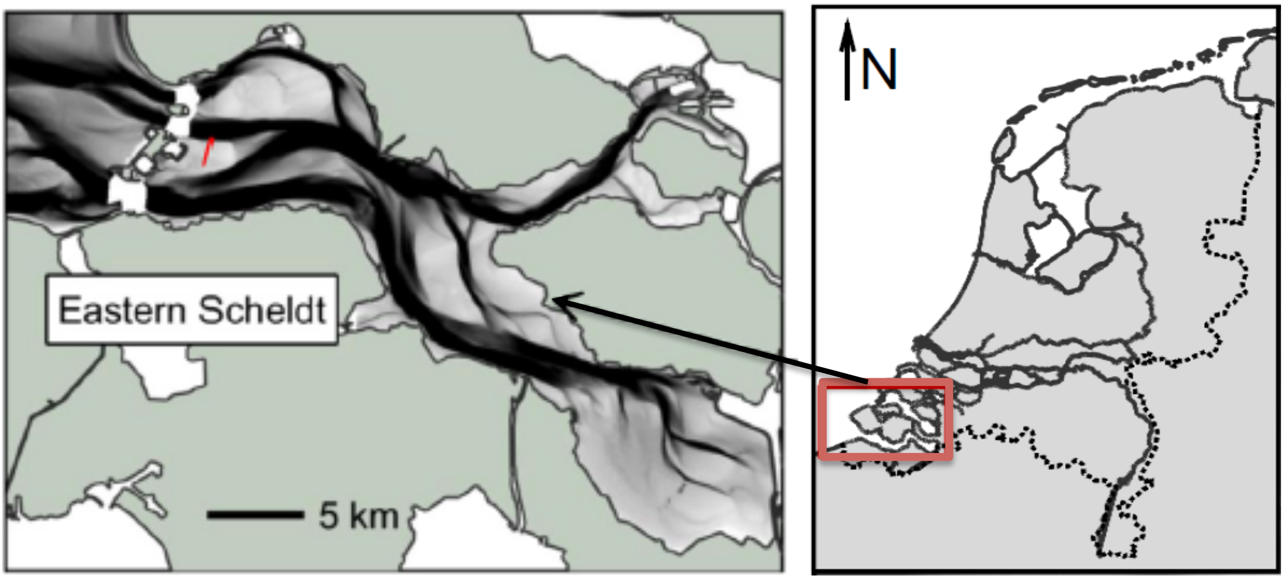

Figure 5: The semi-permeable Eastern Scheldt Barrier and its location in the Netherlands. *Images courtesy of L. de Vet*

Figure 6: Eastern Scheldt and barrier, seen from the North Sea. *Source: Rijkswaterstaat beeldbank, photo by Joop van Houdt.*

2. Functioning of the estuary pre- and post-barrier

The contemporary Eastern Scheldt estuary is a tidal system of 350 km^2 with intertidal flats (110 km^2), deep gullies, artificial rocky shores for coastal protection, and shallow water areas. During regular conditions, when the gates in the dam are open**, a tidal range exists varying from 2.5 m at the entrance to 4 m** at the eastern boundaries. The system has an **average freshwater load of 25 m^3/s** and is mesotrophic, with an **average salinity of 30 ppt**; there are no untreated wastewater discharges (Nienhuis and Smaal, 1994 - according to Troost et al. 2012).

The pre- and post-barrier performance of the Eastern Scheldt estuary can be described using several key comparative studies. In 1991, *Rijkswaterstaat* published a first comparative study called *Veilig getij* (*'Safe tides')* where the effects of the storm surge barrier between 1987 and 1991 were assessed for the issues of water, soil, and life in the estuary, aquaculture and shipping. The benchmark comparative study to changes in hydro-morphology, flora and fauna as a consequence of completion of the storm surge barrier in the 1990s, is the publication of Nienhuis & Smaal in 1994 (*The Oosterschelde Estuary: A Case-study of a Changing Ecosystem*), which assembled scientific papers from the academic journal *Developments in Hydrobiology*. In the second decade of the 21st century key studies have been performed by Troost et al. (2012, *Biodiversity in a changing Oosterschelde: from past to present*) and, with a focus on wader birds, Troost & Ysebaert (2011, *ANT Oosterschelde: Long-term trends of waders and their dependence on intertidal foraging grounds*).

Troost et al. (2012) combined available long-term datasets on (macro)benthos, fish, birds, and key species (sea grass and sea mammals), with the aim to present reliable and factual information on changes in biodiversity in the Southwestern Delta in the past few decades, and how the Delta works influenced it. However, in many cases there were no time series available that cover the period around, or just after, the construction of the Delta works. Furthermore, **a series of severe winters** in the years before completion and a series of mild winters in the years after completion **complicate analysis** of ecological changes (Troost et al. 2012). In that sense, a full-blown pre- and post-barrier comparison using the same parameters is unfeasible.

A **combination of sources and parameters**, however, does give an indication of the long-term performance of the Eastern Scheldt. Key comparative studies have been complemented with information from expert sources per topic. For certain topics, the latest, unpublished, data from ongoing research based at Delft University of Technology was used.

a. Hydrodynamics

Although the Eastern Scheldt storm surge barrier is only fully closed during severe storms, the effect on the tidal flow during mild (regular) conditions is significant. According to Troost et al. (2012) the hydrodynamic characteristics of the Eastern Scheldt were changed as follows: the construction of the storm surge barrier diminished the cross sectional area of the channels of the inlet from 80,000 m^2 in 1984 to approx. 17,900 m^2 in 1987. During the construction works of this barrier, the tidal volume, tidal current velocities and the tidal range gradually decreased. The smaller opening of the estuary has resulted in a **reduction of tidal amplitude** and **tidal flow**, and subsequently in a **reduction of tidal prism**. This is demonstrated in Table 1 as given in Louters et al. (1998).

Note that not only the barrier caused these changes: the damming in the eastern part of the basin and the closing of the northern branch also affect these hydrodynamic parameters. The closure of the Oesterdam (1986) and the Philipsdam (1987) led to a decrease of **tidal volume** of almost 30%. Due to this decrease, the current velocities in the Eastern Scheldt are reduced by about 30%. In total, **the tidal range** is reduced by about 12%, but this reduction varies throughout the estuary. At Yerseke, the mean tidal range changed from 3.70 pre-barrier to 3.24 post-barrier. As a consequence of this tidal reduction, wave energy dissipation is concentrated on a smaller part of the intertidal flats and salt marshes.

Selected hydraulic and area characteristics in the period before (1983), during (1983-1987) and after (1987) implementation of the Eastern Scheldt project.				
	Before implementation of the Eastern Scheldt project (1983)	During implementation of the Eastern Scheldt project (1983-1987)	After implementation of the O Eastern Scheldt project (1987)	Change in Hydrodynamic and Morphometric Characteristics due to Eastern Scheldt Project (%)
Mean tidal range (m) at Yerseke	3.70	2.50	3.24	- 12 %
Maximum current velocity (m/s)	1.5	1.0	1.0	- 30 %
Mean tidal prism (m^2*10^6)	1,230	-	880	- 28%
Total area (m^2*10^6)	452	-	351	- 22 %
Area below AOD (m^2*10^6)	362	-	304	- 16 %
Intertidal area (m^2*10^6)	170	-	118	-31 %
Salt-marsh area (m^2*10^6)	17.2	-	6.4	-63%

Figure 7: Selected hydraulic and area characteristics of the Eastern Scheldt project. *Source: Louters et al. (1998).*

Residence time of water in the estuary has increased with a factor 2, and the influence of the North Sea on the system has been reduced with 30% (Rijkswaterstaat, 1991). However, due to the construction of dams in the eastern half of the Eastern Scheldt, the impact of fresh water supply from the Rhine and Meuse-rivers has been reduced even more. As a result, the relative impact of the North Sea on the system has increased, giving the Eastern Scheldt the appearance of an inlet rather than an estuary.

As a consequence of damming the estuary, **salinity** has increased. Figure 7 shows the salinity at Yerseke in the southeast part of the basin, where increase is most profound. The salinity is approximately 28 parts per thousand (ppt) for the period before 1986, and around 31 ppt for the period after 1988. Over the last decade, salinity seems to have stabilized.

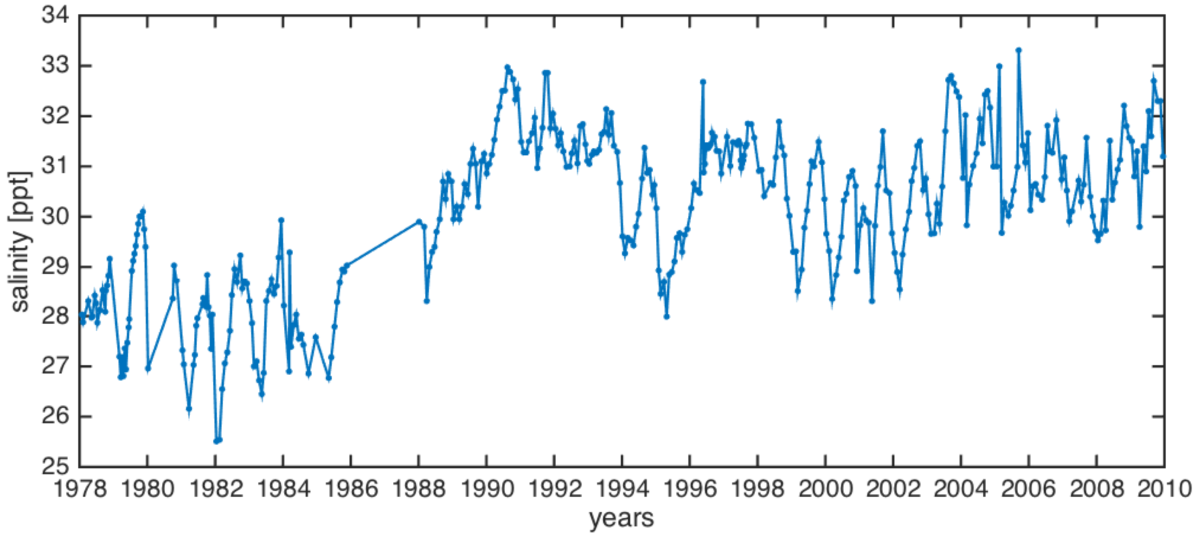

Figure 8: Salinity in parts per thousand (ppt) for station Yerseke. *Table by L. de Vet & B. van Prooijen based on Verwaterplaats, live.waterbase.nl.*

The changes in tidal energy also lead to a **reduction in suspended particulate matter** (SPM). Less material is kept into suspension, due to the reduction in tidal mixing. The water became clearer, allowing light to penetrate into the water column (Figure 9). Also, the reduced impact of the rivers Rhine and Meuse resulted in reduction of heavy metals and toxic substances within the estuary from 1987 on (Rijkswaterstaat, 1991).

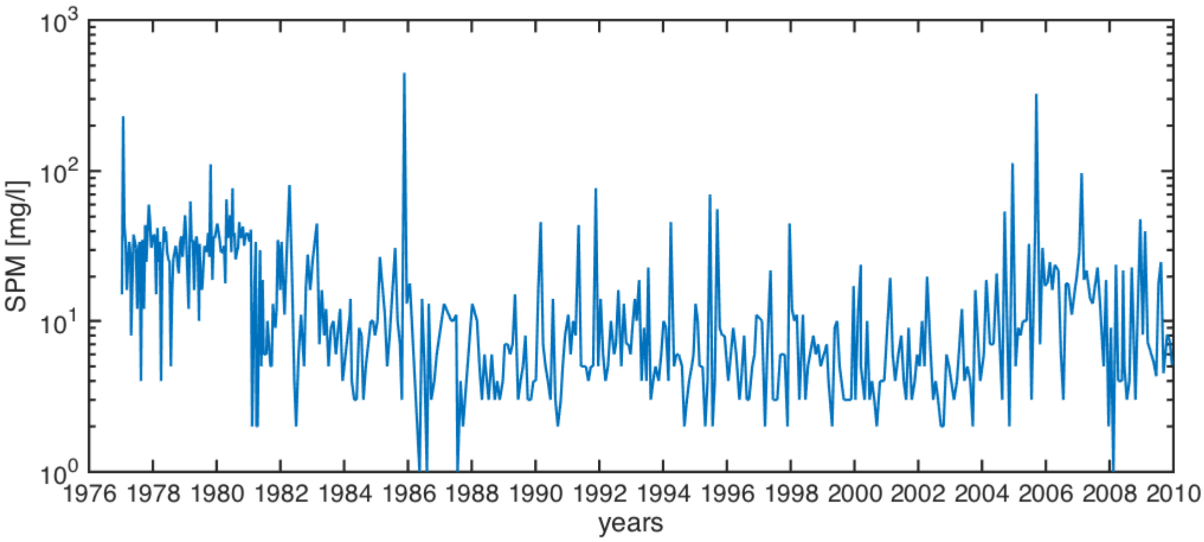

Figure 9: Suspended Particulate Matter (SPM) in mg/l (=g/m³) for station Yerseke Verwaterplaats. *Table by L. de Vet & B. van Prooijen based on live.waterbase.nl.*

b. Morphology

Overall, no radical changes have been observed in **channel alignment**. Various bathymetry maps are available (1968; 1983; 1987; 1990; 2001; 2010). To give an overview of the channel pattern, the bathymetry of 1986 and 2001 is shown in Figure 10. The variations in bathymetry over the period 1983-1987 and 1990-2001 are shown in Figure 11. The Eastern Scheldt is still a multiple channel system, with the notable exception of the basin in the southeast. Overall, the Eastern Scheldt became less "morphologically active": the variations in bed level over the period 1983-1987 are much larger than over the period 2001-2010. This can be attributed to the reduction in tidal velocities. The branch in the northeast has been disconnected from the northern basins, and subsequently turned into a dead end with associated small tidal volumes and velocities.

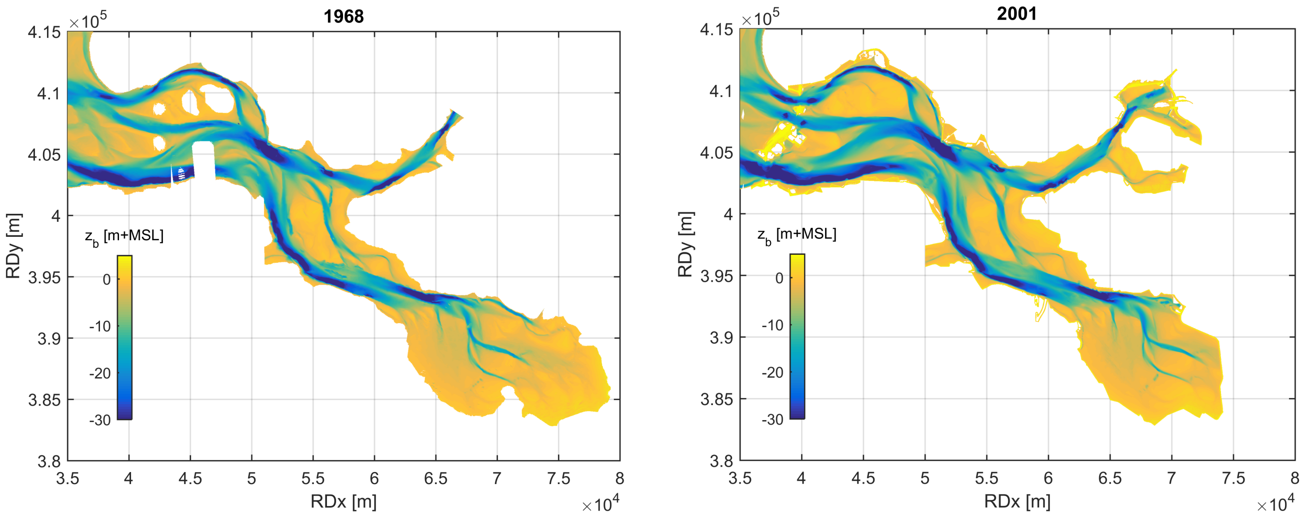

Figure 10: Bathymetry of the Eastern Scheldt in 1968 (left), and in 2001 (right). The bed levels are defined with respect to the Amsterdam Ordnance Datum (NAP), which is approximately Mean Sea Level. *Maps by L. de Vet & B. van Prooijen.*

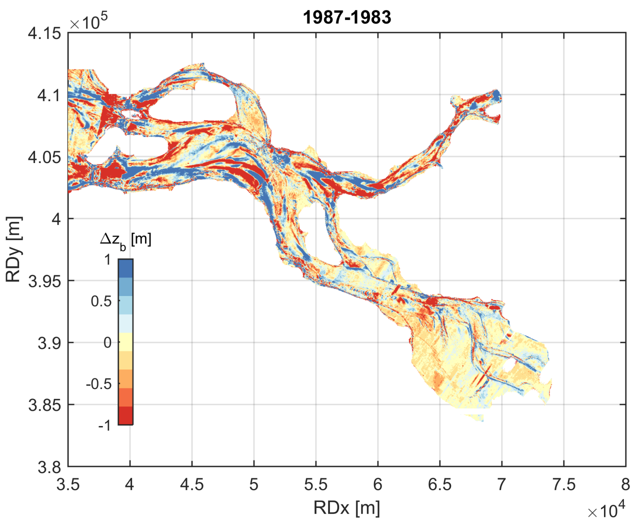

Figure 11: Changes in bathymetry of the Eastern Scheldt over the period 1990-2001. Blue indicates accretion and red erosion. *Map by L. de Vet & B. van Prooijen.*

Tidal flats can be considered to be in a dynamic equilibrium: while tidal flow brings sediment onto the flats, wave action results in erosion. In practice, many subtle processes play a role like tidal asymmetries, bioturbation, biostabilization, cohesiveness of sediment, and trapping of sediment by oyster reefs.

The reduction in tidal range by the storm surge barrier has led to a **reduction in the mechanism that builds the tidal flats**: the eroding mechanism is hardly changed, as wave forcing is mainly caused by locally generated wind waves (Louters et al., 1998). Only in the mouth of the Eastern Scheldt, wave penetration from the North Sea plays a role. De Ronde et al. (2013) estimate that without mitigation interferences and an expected sea level rise of 60 centimeters between 1990 and 2100, the **existing acreage of tidal flats and salt marshes** will **decrease to 65% of its 2010 surface in 2060** (8000 hectare). De Vet et al. (2016, in prep.) have recently confirmed this basin scale trend. However, De Vet et al. also stress that there is a significant variation between the different tidal flats, and even on a single shoal strong variations occur. The data since 2010 do not show the decreasing trend anymore. However, it is too speculative to conclude that the lowering of the tidal flats in the Eastern Scheldt has stopped. Currently, there is no direct physical explanation for a reached equilibrium at this stage.

Interesting is the comparison of the development between the flats in the Eastern Scheldt and the Western Scheldt. The flats in the Western Scheldt are following an opposite trend (steepening and heightening of the flats) due to the dredging works for the fairway to Antwerp (De Vet et al., 2016 in prep.).

c. Benthos and primary production

The storm surge barrier also affects the benthos communities. As shown in Cozzoli et al., (2013) the recent coastal engineering works in the Eastern Scheldt are the main cause of the decoupled association between stronger hydrodynamics and coarse sediment. This decoupling leads to change in benthic communities: **increase in species richness** and **increase in biodiversity**. Lower velocity has led to a **reduction in suspended sediment concentration** with a consequently **higher primary production**. However, no direct relation could be found between the eroding flats and the benthic community (Troost & Ysebaert, 2011). Nevertheless, there is the concern that lowering of the tidal flats will eventually lead to a reduction in benthos and subsequently in a reduction of food for wading birds.

Benthos on the intertidal flats covers a range of species like mollusk, mud snail and lugworm. An extensive overview is given in Troost & Ysebaert (2011). For the post-barrier period data sets are presented in the MWTL-program[2], which shows significant inter-annual variations.

[2] Monitoring Waterstaatkundige Toestand des Lands (Monitoring of the Hydraulic Conditions of our Country).

Figure 12 shows such a variation for the biomass of the cockle, an important prey for the oystercatcher. It is therefore difficult to define a causal relation between the presence of the barrier and the changes in benthos. This is moreover the case as the barrier was not the only human intervention: changes in aquaculture management took place in the same period, like the move from intertidal to subtidal mussel plots. This has contributed to the disappearance of mussels on intertidal flats in the mid nineties.

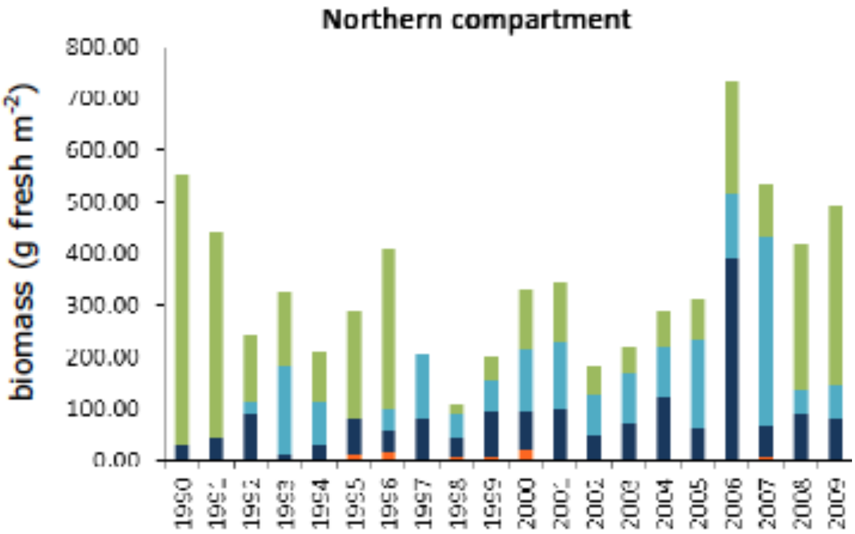

Figure 12: Biomass of cockles for the northern compartment of Eastern Scheldt. *Source: Troost & Ysebaert (2011).*

A possible positive effect of the barrier on the benthos community could be identified. As mentioned before, the reduction in flow velocities leads to a reduction in sediment concentration, more light penetration, and consequently higher primary production. This relation becomes clearer if a comparison is made with the Western Scheldt, where the opposite trend was observed: higher velocities, higher concentration, and lower primary production (see Cozzoli et al., 2013). Figure 12 shows the occurrence and biomass of the most important species in the Eastern Scheldt and Western Scheldt. In general, the Eastern Scheldt shows higher occurrence percentages and more biomass.

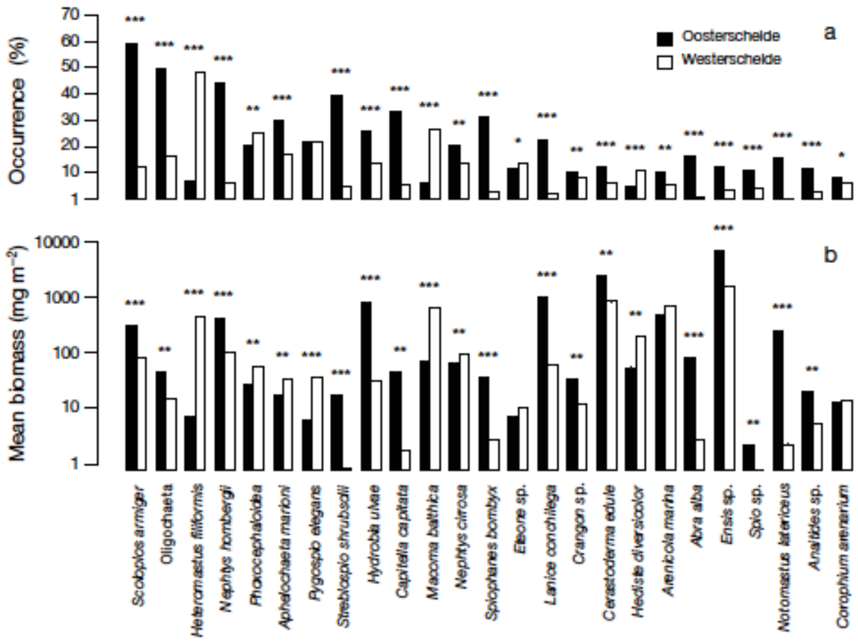

Figure 13: Mean (a) biomass and (b) occurrence of the 25 most common species in the Eastern Scheldt and the Western Scheldt. Asterisks show the significance of Fisher's test and ANOVA of differences between basins (*p <0.005, **p<0.01, ***p<0.001). *Source: Cozzoli et al. (2013).*

The occurrence and biomass of benthos depends on the emergence time. Troost & Ysebaert (2011) demonstrate that the higher parts (e.g. 60-80% emergence time) do have the lowest biomass. As shown in De Vet et al. (2016, in prep.), the tidal flats are lowering. When these flats are uniformly lowering (see Figure 14) there will be a loss of acreage with high bed levels, while the acreage of somewhat lower bed levels will increase. The net effect will be that during the lowering process benthos will benefit, as there are larger areas with higher biomass. On the long term however, these areas will also drown, leading to a future decrease in intertidal benthos again.

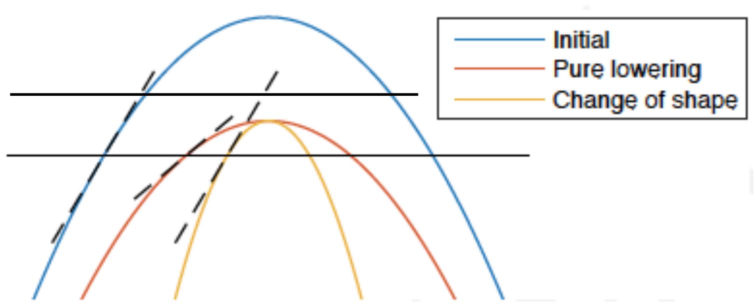

Figure 14: Sketch of lowering of tidal shoals. In case of pure lowering, there will be a decrease in areas with long emergence times, whereas the areas with lower emergence times will increase. *Courtesy De Vet et al. (2016 in prep.).*

Summarizing, the barrier seems to have a positive effect on benthic species for the short term, whereas it is expected that on the long term the lowering of the tidal flats will eventually lead to a decrease in biomass and biodiversity.

d. Aquaculture, habitats and aquatic animals

Aquaculture: oyster and mussel-production

The Eastern Scheldt estuary is the centre of Dutch shellfish culture (Troost et al, 2012, 19). Pacific oysters (*Crassostrea gigas*) and blue mussels (*Mytilus edulis*) are cultured on subtidal bottom plots (respectively 1550 and 2250 ha). As water in the Eastern Scheldt circulates less, construction of the barrier may have affected both the (commercial) oyster- and mussel-production. However, due to a variety of causes, aquaculture in the Eastern Scheldt has undergone many transformations since 1986, which obfuscates the extent of the impact of the storm surge barrier and the constructions in the eastern part of the estuary. According to prof. dr. A. C. Smaal, an expert based at Wageningen University and Imares Yerseke, one of the main authors of leading reports on the Eastern Scheldt's performance (Nienhuis & Smaal 1994), the general impression is that the barrier did not have a strong immediate effect on shellfish.[3]

In 2000, a study into the **stock development of cockles, mussels and clams** in the Eastern Scheldt demonstrated that the cockle stock has dropped with 70% between 1985 and 1999; mussels have disappeared altogether outside of the relocated plots (RIKZ, 2000).[4] The net amount of shellfish in the estuary dropped (with a yearly average from 11 to 7 million kilo's of meat), with increasing dominance of the oyster at the cost of cockles, mussels and other shellfish. Although the Eastern Scheldt is exceptional in this – the Western Scheldt and the Wadden Sea did not experience a comparable development – no direct relation could be established with the barrier.

Since 1976, a rapid expansion of the Pacific Oyster in the estuary was observed, but the increase appears to have stabilized. The intertidal area covered by oyster beds increased to circa 9% in 2011. The **oyster production** sites, located traditionally in the eastern quadrant of the estuary, had been facing difficulties since the late 1960s, first due to a series of harsh winters and later due to the *Bonamiasis*-disease (RIKZ, 2000). There are 1,550 hectares of oyster culture plots, all located in the eastern part (Troost et al., 2012). Widespread introduction of the Japanese oyster, a foreign species, overcame this issue for the oyster farmers. Nonetheless oyster stock varies on a yearly basis, often due to variations in temperature. In general the Japanese oyster has thrived in the Eastern Scheldt estuary since large-scale introduction in the 1980s, also outside the farms, and is successful in the creation of oyster reefs (and therefore contributes to biodiversity). However wild oysters now compete for nourishment with their commercial counterparts, and also with mussels and cockles (RIKZ, 2000). This may exacerbate lack of food for the shrinking oystercatcher population (as, in contrast with the name, oystercatchers don't feed on oysters).

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[3] Personal correspondence, May 31, 2016.

[4] The study, called *Korte Termijn Advies Voedselreservering (Short Term Advice Food* , was performed with the explicit purpose to reconsider the food reserve for the oystercatcher. In the estuary, commercial fishing of shellfish is stopped if the existing stock drops below an established level, which guarantees sufficient food supply for the registered oystercatcher population.

Mussel production is strictly regulated in the Netherlands with a government quota on spatfall (mussel seed), and government-owned subtidal bottom plots that are leased out. In 1991, the productivity of the original **mussel-production** sites was reduced with 33% compared to the pre-barrier situation. The construction of 40 new sites in the western quadrant compensated for this loss only in part. In the mid 1990s, mussel farms were relocated closer to the mouth of the estuary to subtidal bottom plots in order to maximize nutrition from the North Sea (Troost & Ysebaert, 2011). As mentioned in §2.c, disappearance of mussels from the natural intertidal beds is likely due to change in management.

Figure 15: Mussel banks, Yerseke (2008). *Source: Rijkswaterstaat Beeldbank, photo by Joop van Houdt.*

Habitats

There is no clear base-line study that properly describes or visualizes the pre-barrier situation of the Eastern Scheldt Estuary. At least, not using a methodology that is comparable to the habitat-categorization of Natura 2000, which is the contemporary standard of describing natural habitats within Europe.

In 1991, *Rijkswaterstaat* commissioned a large survey studying the pre- and post-barrier state of the estuary. This study, called *Veilig getij* ('Safe tides'), edited by Smaal & Boeije (1991), contains a simple map demonstrating only three types of habitats in 1991: only those regarding tidal flats, excluding flats that are permanently submerged. The 1977 RAND-study does not include habitat-maps. It seems that the original debate regarding habitats has focused on the single issue of erosion of the tidal flats, and that a wider perspective which includes other natural environments, is a fairly recent phenomenon.

According to Troost et al. (2012), the variety of habitats and the different habitats present, did not change due to construction of the barrier; although the natural tidal water movement and morphological balance (erosion and sedimentation) were disturbed, demonstrated by the sediment starvation phenomenon.

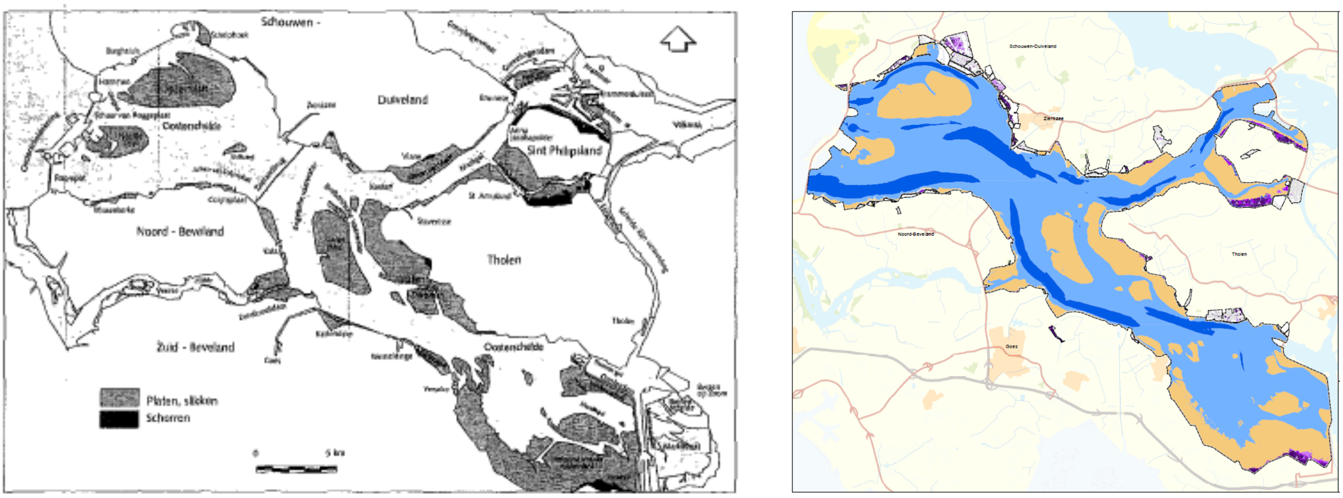

Figure 16: On the left, the basic habitat-map from the 1991 *Rijkswaterstaat*-study into the environmental effects of the barrier, presumably demonstrating the situation in the early '90s. On the right, the recent habitat-map (Rijkswaterstaat, 2015), based on data from 2006. The oldest map only identified intertidal flats in two-3 categories, based upon their location (isolated flats or adjacent to land) and exposure time. The more recent map does not acknowledge a difference in location but only in exposure time: the deep blue flats are always submerged. These tidal flats were not acknowledged in the 1991 study. *Sources: Rijkswaterstaat (2011, 2015).*

Aquatic animals

Although the amount of zooplankton has increased, and changes in the variety of phytoplankton were observed, no changes were demonstrated in the population of aquatic **animals like shrimp, fish and seals** (Rijkswaterstaat, 1991). Among the 70 species of fish, the relative size of diverse populations did vary somewhat due to changes in turbidity resulting from lower velocities. The barrier had a limited effect on the occurrence of fish in the estuary, with the only tangible impact being **decrease in a number of migratory fish species that migrate from salt water to spawn in fresh water** (anadromous fish), due to the decoupling from the rivers (Troost et al 2012).

Fish abundance showed fluctuations in species richness, with a significant increase from year to year in the period 1996 – 2000 (see Table 1 in the Appendix). This did not result in significant changes in the trend in biodiversity, which showed a large year-to-year variation. Species richness was lower during the construction period of the storm surge barrier, but recovered within 10 years. Among the different trophic groups (benthivores, bentho-piscivores, piscivores and planktivores), not much change could be detected except for a **significant increase in abundance of planktivores** in the late 90s. For an overview, a table is included in the Appendix (Table 3).

Erosion of the tidal flats is unlikely to affect the seal population in the Eastern Scheldt. Seals do not depend on the flats for their nourishment, and loss of sites for resting and nursing can be compensated elsewhere. Seals are mobile, and increase in number since the 1990s (Troost et al., 2012).

e. (Wader) birds

The wader bird population and the possible impact thereon of erosion of the tidal flats have received a lot of attention in reports. This is likely the result of two factors: first, based upon existing ecological knowledge, wader birds are likely to experience a real threat by the reduction of foraging acreage due to loss of tidal flats in the future; and the adverse consequences in migratory pattern are a international matter, as they affect the entire European population. Second, (wader) birds in the Netherlands have a protected status whereas seals and fish do not.

The available data set of bird counts starts in the year 1987, right after completion of the storm surge barrier. Biodiversity indices of non-breeding bird numbers showed a significant increase, which leveled off after 2002 (Troost et al, 2012, 26; 45). Breeding birds appeared to be affected by the completion of the storm surge barrier, since they showed a temporary decrease in biodiversity. In the period 1985 – 1990, the proportion of Black- headed gulls (*L. ridibundus*) was higher than 70% and the abundance of this species was relatively high. The Little tern (*S. albifrons*) occurred in relatively low numbers. In later years, although the Kentish plover (*Ch. alexandrius*) declined by about 50% in 1987, the total abundance of breeding birds increased, as did species richness. This may be due, in part, to **active management aimed at improving breeding opportunities** for shorebirds and wetland birds, and development of wetlands such as Plan Tureluur (executed from 1999 onwards).

Despite the positive general trend described by Troost et al. (2012), the population of wader birds may face issues in the future (Troost & Ysebaert, 2011). Decrease of the bird population of the Eastern Scheldt – wader, curlew, red knot, bar-tailed godwit, dunlin, grey plover and common shelduck – has not been observed between 1987 and 2010 (de Ronde et al., 2013; Ministry of Infrastructure & the Environment, 2015). The oystercatcher is a notable exception. However, this may be due to other factors as the oystercatcher population is declining in the Netherlands as a whole.

Surprisingly, no clear evidence can be found on the effects of erosion of tidal flats on the presence of waders. However, it's anticipated that if the bird population will decrease as a result of diminished acreage of foraging surface, it will be abrupt and irreversible. Such a regime shift will have huge consequences for the ecological system, and as mentioned earlier, the loss of feeding capacity cannot easily be replaced in other estuaries. The anticipated decrease of wader birds is the primary motivation for a number of contemporary mitigation efforts.

Figure 17: Tidal flats Eastern Scheldt, western part (2008). *Source: Rijkswaterstaat beeldbank, photo by Joop van Houdt.*
Figure 18: Tidal flats Eastern Scheldt, eastern part (2008). *Source: Rijkswaterstaat beeldbank, photo by Joop van Houdt.*

3. Contemporary management of the estuary: mitigation

a. Protected status & policy

The Eastern Scheldt estuary is subject to national and international policy that mitigates future detrimental effects of the barrier. Nourishment of the tidal flats is also supported by European legislation: Natura 2000.

In order to protect critical habitats, the estuary is included in the European Natura 2000-network (Appendix: Map 1). In 2015, a draft management plan for the maintenance of the Eastern Scheldt Natura-2000 site has gone into procedure (*Rijkswaterstaat*, *Ontwerp beheerplan Oosterschelde*). The plan lists required measures to achieve the environmental goals stated in **European Natura 2000-policy**. Natura 2000 states that certain 'conservation goals' (*instandhoudingsdoelen*) that are the foundation for Dutch national nature conservation policy, and therefore for the nourishment projects in the Eastern Scheldt Estuary. The conservation goal for the Eastern Scheldt estuary is conservation of foraging sites for wader birds.

From 2001, the Eastern Scheldt estuary also enjoys the status of **designated national park**. The designation, performed by the Province and supported by a steering committee, went uncontested. According to Van Zanten, due to the label 'national park including crucial economic activities', thus pacifying potential resistance from fishing-industry. The status came with a management and development plan (*Overlegorgaan Nationaal Park Oosterschelde (2001), Van de parels en het slik*). The management plan for the national park only addresses the estuary itself: the land-part is not included.

Plan Tureluur, a regional nature conservation plan executed from 1999 onwards, is a form of **active management aimed at improving breeding opportunities for shorebirds and wetland birds**, and development of wetlands (Troost et al., 2012). It was designed to compensate for the loss of intertidal flats as a consequence of sand starvation. The overall aim of this plan is to develop 850 hectares of saltwater inland nature along the borders of the estuary, mainly on Schouwen-Duivenland at the northern shore of the estuary. Between 1999 and 2009, a total amount of 510 hectares of nature divided over numerous larger and smaller areas, was developed. These areas are of high importance as foraging and breeding grounds for birds. It is likely that the growth of breeding bird couples was supported by this increase in habitat. Especially the pied avocet (*Avocet Recurvirostra avosetta*) showed high increase in abundance.[5]

[5] 'Plan Tureluur' concerns inland, saltwater nature areas lacking tidal influence and should therefore not to be confused with saltmarshes that are part of the estuarine ecosystem.

b. Mitigation measures and efforts

Various measures for mitigation have been undertaken, most of them as pilot studies. Figure 18 demonstrates the sites of completed nourishment projects at the Galgenplaat and along the Oesterdam, plus the artificial oyster reefs at Viane and De Val. Starting in 2017, large-scale nourishment is planned at the Roggenplaat.

Although the existence of sediment starvation or sand hunger resulting from the construction of the barrier has been acknowledged since 1987, it was not considered to be a problem at the time. **Nourishment of the tidal flats** started as **late as the 2000s**, in response to a letter from the National Park Eastern Scheldt to the secretary of state in charge. In 2006-7, *Rijkswaterstaat* performed a study in order to quantify the adverse affects of sediment starvation. The final report, *Verminderd getij. Verkenning naar mogelijke maatregelen om het verlies van platen, slikken en schorren in de Oosterschelde te beperken* (Van Zanten & Adriaanse, 2008), stated that adverse environmental effects could be significant, and that minor effects on flood safety were also present.

According to Eric van Zanten, an expert based at *Rijkswaterstaat* and author of the 2007 final report that quantified the effects of sediment starvation, projects have been **prioritized** based upon exposure time (1) and acreage (2) of the tidal flats, and their susceptibility to erosion (3). Isolated tidal flats are much more prone to erosion resulting from wave action than those adjoining the mainland, making nourishment here urgent. Also, the Eastern Scheldt has serviced wader birds throughout the basin and loss of foraging opportunities in one quadrant cannot be replaced in another. Thus, the decision to nourish at a certain location is therefore based upon the **optimal allocation of foraging acreage for wader birds** in the estuary.

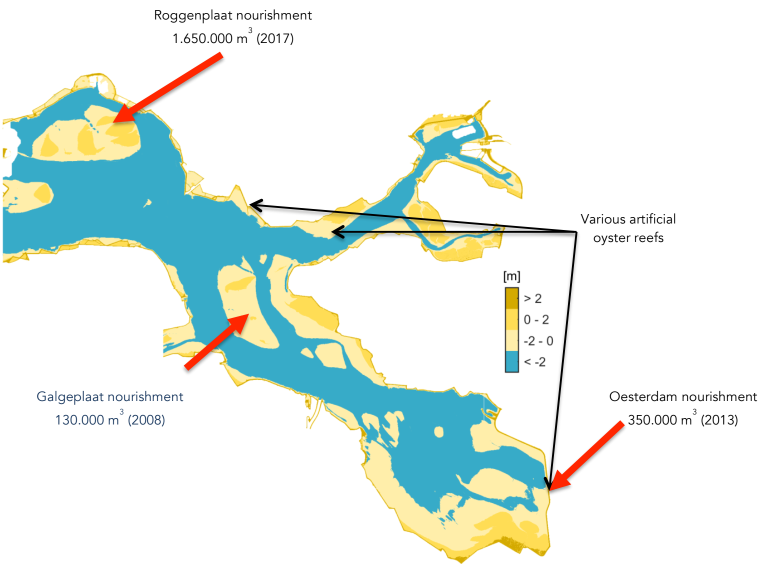

Figure 18: Overview of mitigation projects in the Eastern Scheldt estuary. *Courtesy of L. de Vet.*

The investment required to **counteract sediment starvation** has been estimated at **40 million euro's until 2060**. This, however, is a low estimate: Van Zanten expects the costs to be higher in practice. The date of 2060 has been chosen strategically, as this is the end of the expected life span of the current nourishment projects. Nourishment of these tidal flats should be renewed by then, rebooting the cycle of artificial nourishment and natural erosion by wave action. Quantitative data on the required amount of sediment and the concomitant financial costs are found in a 2014 environmental impact assessment (Commissie voor de milieueffect rapportage, report no. 2595-65). The EIA complements the Structuurvisie Zandhonger Oosterschelde (central government's comprehensive plan to address sediment starvation), and is the basis for the key-study *ANT Oosterschelde* summarizes the adverse effects on the wader bird population, and the measures required to mitigate these.

The initiative for the upcoming nourishment at Roggenplaat was started by *Rijkswaterstaat* together with *Natuurmonumenten*, the national nature conservation organization, and is planned for 2017. Delft University of Technology is involved in the design of the nourishment via research project EMERGO[6]; a joint project between NIOZ and TU Delft. Noteworthy is the crowd-funding initiative to buy sand: Koop-een-kuub-en-red-de-Roggenplaat[7], initiated by Oosterschelde National Park and *Natuurmonumenten* to help save the Roggenplaat from drowning.

The purpose of the **oyster reefs** is to **counteract erosion by reduction of waves** on the lee side. This larger-scale pilot project was initiated within the building with nature program (www.ecoshape.nl). It can therefore be considered as a research project, although with the aim to apply it on a larger scale. In addition to these pilot reefs, natural reefs have been studied as well; see for example Walles et al. (2015; 2016). However, the effects on morphology are restricted to the direct surroundings of the reef. Preliminary findings indicate that the water higher than the top of the reef is not affected. Oyster reefs are therefore **not suitable for coastal protection**, but can contribute to a local reduction of erosion. At present, within the EMERGO project, TU Delft is studying the added value of the reefs for biodiversity, specifically fish.

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[6] http://www.nwo.nl/onderzoek-en-resultaten/onderzoeksprojecten/i/85/11285.html

[7] https://www.natuurmonumenten.nl/nieuws/koop-een-kuub-en-red-de-roggenplaat

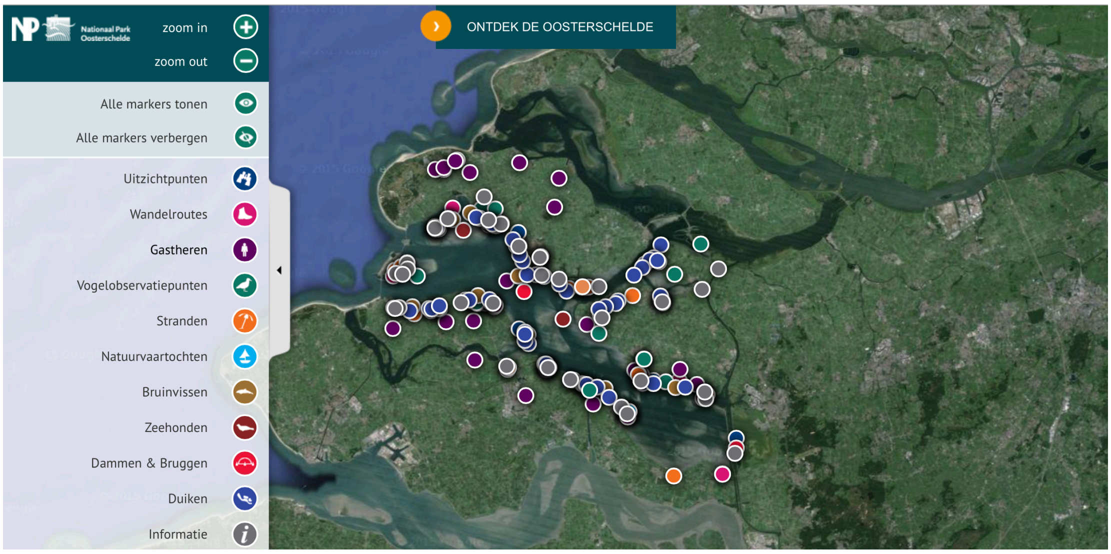

Figure 19, 20, 21, 22. National Park Eastern Scheldt. *Source: www.nationalparkoosterschelde.nl; Photo of kayak expedition by Guido Krijger.*

Concluding remarks

Key to understanding the post-barrier performance of the Eastern Scheldt Survey are the reduced hydrodynamics in the system, the related decrease in circulation (prolonged residence time) and turbidity, and the erosion of the tidal flats.

The Delta Works in the Eastern Scheldt (the construction of the storm surge barrier and the back-barrier dams) have had an obvious and substantial impact on the estuary's **morphological development**; moreover, the morphological response of such a large-scale engineering project on a tidal basin is bound to take centuries. Despite the obvious sediment starvation over the last decades, long-term predictability of this trend remains a complex matter.[8]

Key changes in the aquatic system over the last two decades are likely due to **decreased turbidity** and **increased light penetration**. **Reduction in suspended sediment concentration,** with a consequently **higher primary production** and **changes in variety and diversity** in **the benthic community,** result from this. However, it should be kept in mind that the effects of the Delta works on biodiversity among marine and aquatic communities are highly diverse and depend on many different factors and histories that are specific for the different water bodies.

Changes in the relative size of certain fish species within the population are also related to decreased turbidity and increased light penetration - although the decrease of anadromous, migratory fish species results from **reduced migration possibilities with fresh water**. The introduction of species associated with deep-water aquatic systems, like sea bass and codfish in the western quadrant, may be related to increased salinity. Overall salinity has increased, but seems to have stabilized over recent years.

With the exception of the oystercatcher, **birdlife has flourished** (both in abundance and variety) since 1986, which may however be a direct result from *Plan Tureluur*, a nature conservation plan that has effectively preserved and extended nesting grounds for birds since 1999. However based upon theoretical insights, the long-term perspective of the wader bird population, due to reduced foraging acreage, may be under threat.

Despite the large body of knowledge, some issues remain unclear:

- No direct relation has been demonstrated between the eroding flats and changes in the benthic community, despite their obvious theoretical correlation;
- No clear evidence has been found for the effects of erosion of tidal flats on the presence of waders, either;

[8] In recent findings by De Vet et al. (2016, in prep.) the decreasing trend seems to stabilize, in spite of the fact that there are no obvious explanations for a stadium of equilibrium, at this stage. Also, the uncertain development of sea level rise will affect future trends.

- The relation between the Delta Works and the **changes in aquaculture** – decreased stock of mussels and cockles, relocation of subtidal bottom plots for mussel cultivation, and fluctuations in oyster stock – **remain opaque** to a certain extent.

As the decrease of the wader bird population is likely to be sudden and irreversible, reaching the tipping point is prevented by sophisticated yet costly mitigation measures that target the erosion of the tidal flats. Most of these, though supported by national and European policy and government funds, have the status of pilot projects and are matched by NGO-funding. Nonetheless, efforts dedicated to preserve the Eastern Scheldt's performance seem to be coherent and supported by a wide variety of sources and instruments.

As a result of the disturbance caused by the construction of the storm surge barrier and the associated dams in the eastern part of the estuary, the system yet has to achieve a new balance. The main lesson taught by the Eastern Scheldt project is that although flood protection and environmental values can be balanced successfully, the effects caused by disturbance may take decades and even centuries to surface.

In the case of the Eastern Scheldt, intervention started a cycle of long-term commitment to costly mitigation efforts since the first decade of the 21st century. For the Delta Works in general, a loss in species strictly associated with the intertidal and brackish zones in estuarine salinity gradients has been demonstrated (Troost et al. 2012). Even the Eastern Scheldt, with its semi-permeable storm surge barrier the least affected by this issue, experienced a reduction of migratory fish.

Restoration of connections between saltwater and freshwater systems, and estuarine gradients and dynamics that allow for migration and salinity gradients as well as some tidal movement, may lead to a higher species richness locally. However the effects are likely to occur on a scale that is much more reduced in comparison with the situation before the Delta works.

Last but not least, understanding the performance of estuaries and other aquatic systems is still under development. The importance of transition gradients between salt and fresh water for biodiversity for example, has been acknowledged only recently.

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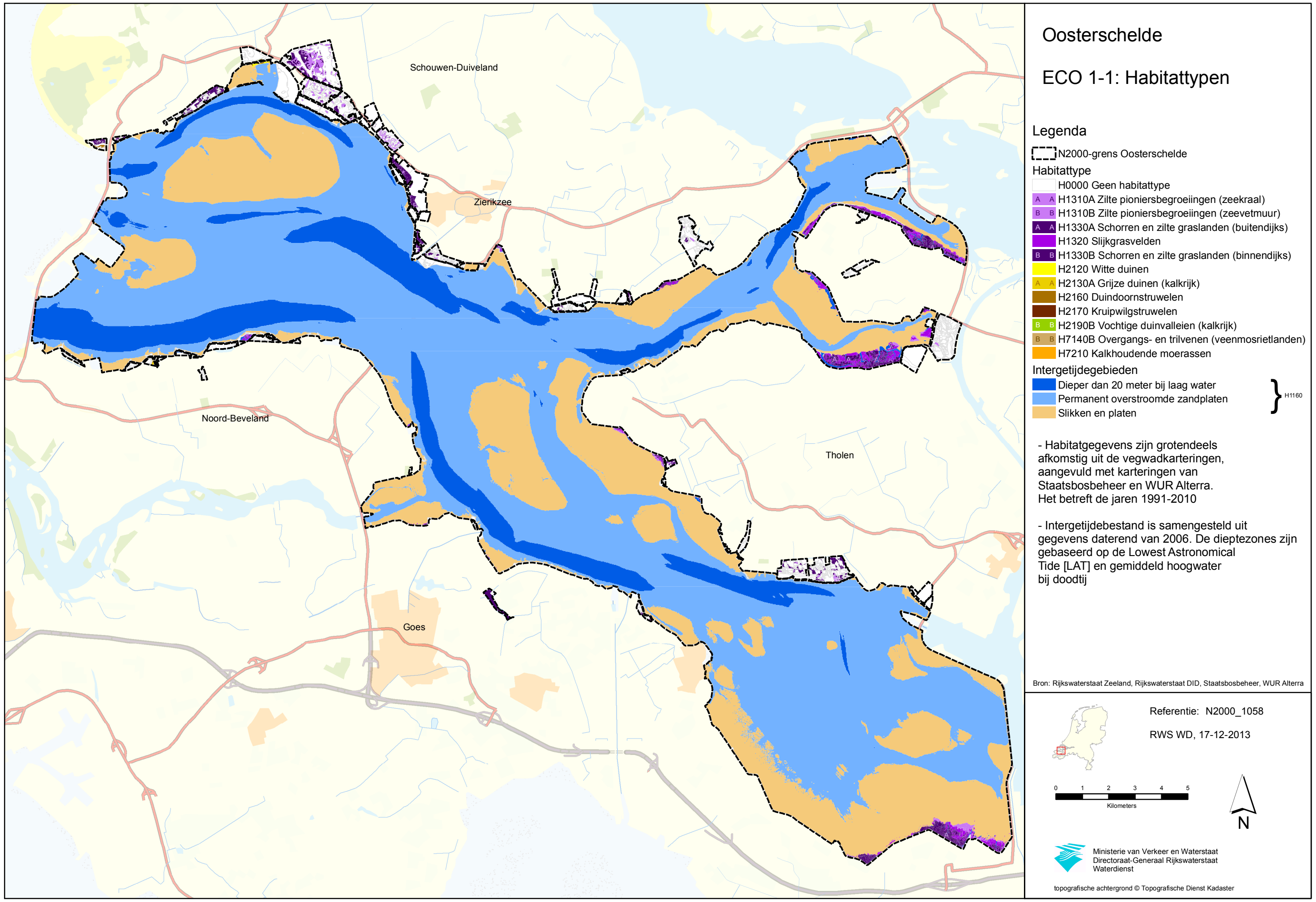
Glossary

Aquaculture	Breeding, rearing, and harvesting of plants and animals in all types of water environments.
Benthos	The community of organisms which live on, in, or near the seabed, also known as the benthic zone.
Bioturbation	The reworking of soils and sediments by animals or plants.
Biostabilization	Biological processes increasing sediment stability or reducing potential for erosion by tidal currents and wave action.
Ecosystem	Community of living organisms in conjunction with the non-living components of their environment.
Ecosystem productivity	Productivity or production refers to the rate of generation of biomass in an ecosystem. It is usually expressed in units of mass per unit surface (or volume) per unit time. The mass unit may relate to dry matter or to the mass of carbon generated.
Hydrodynamics	The study of liquids in motion: hydrodynamic parameters are the tidal prism, tidal amplitude and tidal flow.
Primary production	Synthesis of new organic material from inorganic molecules such as H2O and CO2.
Imares	Research institute for strategic and applied marine ecology, affiliated with Wageningen UR.
Rijkswaterstaat	Executive agency of the Dutch Ministry of Infrastructure and the Environment (the former Ministry of Transport, Public Works and Water Management). Its role is the practical execution of the public works and water management, including the construction and maintenance of waterways and roads, and flood protection and prevention.
Natuurmonumenten	Society for preservation of natural monuments in the Netherlands is a Dutch NGO founded in 1905 that buys, protects and manages nature reserves in the Netherlands.
Natura 2000	A network of nature protection areas in the territory of the European Union. It is made up of Special Areas of Conservation (SACs) and Special Protection Areas (SPAs) designated respectively under the Habitats Directive and Birds Directive.
NIOZ	The national oceanographic institution for the Netherlands.
Mesotrophic	Adjective describing the intermediate level of nutrients and minerals in a body of water. The mesotrophic stage is intermediate between the oligotrophic and eutrophic stages

APPENDIX: Map of Habitat-types in the Eastern Scheldt



Map 1: 13 Habitat-types are mentioned, including the (inter) tidal flats (H1150) which are in turn grouped in three categories: those deeper than 20 meters during low tide, permanently submerged sandbanks and tidal flats. *Source: Rijkswaterstaat (2015), Ontwerpbeheerplan Oosterschelde.*

APPENDIX: Table 1.

Eastern Scheldt – Fish - Average catch (per 1000m2) per species per year																			
Year	**1960**	**1962**	**1963**	**1964**	**1965**	**1966**	**1967**	**1968**	**1969**	**1970**	**1971**	**1972**	**1973**	**1975**	**1976**	***Average over 1960-1976***	**1988**	**1991**	**Year**
Fish species																			**Fish species**
Agonus calaphractus	0.16	0.12	0.04	0.36	0.08	1.32	0.36	0.64	0.08	0.08	0	0.04	0.24	0.2	0.12	*0.26*	0.084	0.085	Agonus calaphractus
Ammodytes tobianus	0.12	0.24	0.04	0.12	0.04	0.04	0.04	0.04	0.08	0.04	0.12	0.04	0.04	0.04	0.12	*0.08*	0.507	0.067	Ammodytes tobianus
Anguilla anguilla	0.24	0.44	0.04	0.04	0.16	0.24	0.12	0.08	0.04	0	0.04	0.04	0.08	0	0.16	*0.11*	0.029	0.098	Anguilla anguilla
Aphiaminuta	0	0	0	0	0	0	0	0	0	0	0	0.04	0	0	0	*0.00*	0.017	0.005	Aphiaminuta
Arnoglossus laterna	0.04	0	0	0	0.04	0	0	0	0	0	0	0	0	0	0	*0.01*			Arnoglossus laterna
Atherina presbyter	0.04	0	0	0	0.04	0	0	0	0.04	0	0.04	0	0.04	0	0.08	*0.02*	0.043	0.116	Atherina presbyter
Buglossidium luteum	0.04	0	0	0	0.04	0	0	0	0	0	0	0	0.04	0	0	*0.01*			Buglossidium luteum
Callionymus lyra	0.12	0.24	0	0.2	0.08	0.12	0.04	0	0.04	0	0	0	0.08	0.04	0.04	*0.07*	0.854	1.541	Callionymus lyra
Ciliata mustela	0	0.08	0.04	0.16	0.04	0.08	0	0.04	0	0	0	0	0.08	0.16	0	*0.05*	0.003	0.015	Ciliata mustela
Clupea harengus	0.08	0.52	0.56	0.04	0.2	0.04	0.08	0.04	0.08	0.04	0.24	0.08	1.64	0	0	*0.24*	4.909	1.325	Clupea harengus
Cydopteruslumpus	0	0	0	0.04	0	0	0	0	0	0	0	0	0	0	0	*0.00*			Cydopteruslumpus
Dasyatis pastinaca	0	0	0.04	0	0	0	0	0.04	0	0	0	0	0	0	0	*0.01*			Dasyatis pastinaca
Dicentrachus labrax	0	0.04	0	0.04	0	0	0	0	0.04	0	0	0	0.04	0	0	*0.01*	0.012	0.003	Dicentrachus labrax
Engraulis encrasicolis	0	0	0	0	0	0	0	0	0.04	0	0	0	0	0	0	*0.00*	0	0.008	Engraulis encrasicolis
Enophrys bubalis																	0.005	0.013	Enophrys bubalis
Enturulus aequoreus																	0.010	0.008	Enturulus aequoreus
Eutriglagurnardus	0	0	0	0	0	0	0	0.04	0	0	0	0	0	0	0	*0.00*			Eutriglagurnardus
Gadus morhua	0.32	0	0.04	0.12	0.04	0.2	0.04	0.04	0.04	0.04	0	0.04	0.04	0.04	0	*0.07*	0.124	0.012	Gadus morhua
Gasterosteus aculeatus	0.08	0.04	0.04	0	0.08	0	0	0.04	0.04	0.12	0.04	0.04	0.04	0.04	0	*0.04*	0.096	0.031	Gasterosteus aculeatus
Gobius niger																	0.002	0.003	Gobius niger
Gobius spec.	4.32	4.28	1.28	11.5	4.92	16.8	3.56	7.76	9.4	1.96	2.2	2.04	9.72	12.4	1.52	*6.25*	0.026	0	Gobius spec.
Hyperoplus lanceolatus	0	0	0.04	0	0.04	0.04	0.04	0.04	0	0	0	0.04	0.04	0.04	0	*0.02*			Hyperoplus lanceolatus
Lampetrafluviatilis	0	0	0	0	0.04	0	0	0	0	0	0	0	0	0	0	*0.00*			Lampetrafluviatilis
Limanda limanda	0.32	0.88	0.16	6.2	1.16	17.9	10.8	2.96	5.44	1.08	0.92	1	4.76	20.2	0	*4.93*	16.34	5.126	Limanda limanda
Liparis liparis	0.16	0.08	0	0.36	0.12	0.4	0.04	0.12	0.12	0.32	0.08	0	0.2	0.2	0.04	*0.15*	0.003	0.003	Liparis liparis
Merlangius merlangus	0.12	0.08	0.04	0.32	0.08	0	2.88	0.48	0.04	0	0	0.04	0.04	0.04	3.2	*0.49*	1.023	0.923	Merlangius merlangus
Microstomus kitt	0	0	0	0	0.04	0	0	0	0	0	0	0	0	0	0	*0.00*	0.053	0.028	Microstomus kitt
Mugilidae spec.																	0	0.023	Mugilidae spec.
Mullus surmelulus																	0	0.003	Mullus surmelulus
Myoxocephalus scorpius	0.08	0.08	0.36	0.56	1.72	0.48	1.48	0.16	0.48	0	0	0.88	0.12	0.24	0.04	*0.45*	1.662	0.111	Myoxocephalus scorpius
Osmerus eperlanus	0	0.04	0.04	0.04	0.2	0.36	0.6	0.4	0.32	0.32	0.28	0.08	0	0	0	*0.18*			Osmerus eperlanus
Pholis gunnellus	0.12	0.12	0.28	0.04	0.28	0.04	0.04	0.04	0	0.04	0	0	0	0	0.04	*0.07*	0.163	0.046	Pholis gunnellus
Platichthys flesus	0.28	1.48	0.44	0.24	0.96	0.6	1.2	1.32	1.64	1.2	0	0.08	0.08	0.76	0.04	*0.69*	0.034	0.026	Platichthys flesus
Pleuronectes platessa	7.92	2.16	5.56	7.52	7.44	2.24	14.5	10.4	14.1	16.4	0.12	3.44	3.92	6.6	1.48	*6.92*	16.03	8.833	Pleuronectes platessa

Year	1960	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1975	1976	*Average over 1960-1976*	1988	1991	Year
Fish species																			**Fish species**
Pollachiuspollachius	0	0	0	0	0	0	0	0	0	0	0	0.04	0	0	0	*0.00*			Pollachiuspollachius
Pomatoschistuslozanoi																	0.716	0.445	Pomatoschistuslozanoi
Pomatoschistus microps	0	0.04	0.48	0.12	0.32	0	0	0.04	0.36	0	0	0	0.48	0.04	0.08	*0.13*	0.120	0.095	Pomatoschistus microps
Pomatoschistus minutus	4.32	4.24	0.8	11.4	4.6	16.8	3.56	7.72	9.04	1.96	2.2	2.04	9.2	12.4	1.44	*6.11*	18.29	19.70	Pomatoschistus minutus
Pomatoschistus pictus	0	0	0	0	0	0	0	0	0	0	0	0	0.04	0	0	*0.00*	0.031	0.049	Pomatoschistus pictus
Raja clavata	0.04	0.04	0	0	0	0	0	0	0	0	0	0	0	0	0	*0.01*			Raja clavata
Scophthalmus maximus	0	0	0	0	0	0	0	0.04	0	0	0	0	0	0	0	*0.00*			Scophthalmus maximus
Scophthalmus rhombus	0.04	0.04	0	0.04	0.04	0	0	0	0.04	0	0	0	0.04	0	0.04	*0.02*	0.042	0.041	Scophthalmus rhombus
Solea solea	0.4	1.32	0.08	6.24	1.08	3.32	0.08	3.84	0.32	0.04	0.16	0	0.28	1	0.56	*1.25*	0.225	0.298	Solea solea
Sprattus sprattus	0.04	0.64	2.04	0.12	0.28	0	0.16	0.04	0.48	0.2	0.12	0.08	0.72	0.08	0.2	*0.35*	1.918	2.094	Sprattus sprattus
Syngnathus acus	0	0	0	0	0.04	0	0	0	0	0	0	0	0	0	0.04	*0.01*	0.104	0.049	Syngnathus acus
Syngnathus rostellatus	0.24	0	0	0.04	0.36	0.08	0.04	0.4	0.04	0.04	0.08	0.08	0.4	0.04	0.2	*0.14*	0.775	1.795	Syngnathus rostellatus
Syngnathus spec.	0.24	0	0	0.04	0.4	0.08	0.04	0.4	0.04	0.04	0.08	0.08	0.4	0.04	0.24	*0.14*			Syngnathus spec.
Enophrys bubalis	0	0	0	0	0.04	0	0	0	0	0	0	0.04	0	0	0	*0.01*	0.005	0.013	Enophrys bubalis
Trachurus trachurus	0.04	0.04	0.04	0.08	0	0	0	0.04	0.04	0	0	0.04	0	0	1.6	*0.13*	0.031	0.304	Trachurus trachurus
Triglops lucerna	0	0.04	0	0.08	0	0	0	0	0	0	0	0	0	0	0	*0.01*	0.063	0.049	Triglops lucerna
Trisopterus luscus	0.4	0.08	0	0.04	0	0.36	1.24	0.04	0.04	0	0	0.04	0	0.04	0	*0.15*	2.521	1.767	Trisopterus luscus
Trisopterus minutus																	0.007	0.010	Trisopterus minutus
Zoarces viviparus	0.32	0.08	0.32	0.4	1.28	0	1.8	0.76	0.28	0.24	0	0.04	0.04	0.56	0.16	*0.42*	0.694	0.327	Zoarces viviparus

Table 1. Based on:
Oosterschelde 1960-1976. Average catch (per 1000m2) per species per year. *Source: Doornbos et al. 1981., and*
Oosterschelde 1988 -1991. Average catch (per 1000m2) per species per year. *Source: Hostens & Hamerlynck, 1991.*

APPENDIX: Table 2

Overview of birds in Eastern Scheldt Estuary

As considered in Troost & Ysebaert (2011) [1]

Species	English name	Dutch Name	Highest numbers in Eastern Scheldt Estuary	Food	Population Estimate[2]	Target Population Eastern Scheldt in Natura 2000[3]
Tadorna tadorna	Shelduck	Bergeend	November – April (peak in winter)	Small benthos (Hydrobia), diatoms	300,000	2,900
Haematopus ostralegus	Oystercatcher	Scholekster	August - February	Mainly bivalves (Cerastoderma > 8 mm)	1,020,000	24,000
Recurvirostra avosetta	Avocet	Kluut	April – June	Crustaceans, polychaetes	73,000	510
Charadrius hiaticula	Ringed Plover	Bontbekplevier	May, August - October	Small polychaetes and amphipods	200,000	280
Pluvialis squatarola	Grey Plover	Zilverplevier	August - May	Polychaetes (Nereis, Arenicola)	247,000	4,400
Calidris canutus	Knot	Kanoet	October - February	Mainly bivalves (Macoma, Cerastoderma < 10 mm)	canutus 340,000 canutus islandica 450,000	7,700
Calidris alba	Sanderling	Drieteenstrandloper	April – May, August - October	Small polychaetes and amphipods	123,000	260
Calidris alpina	Dunlin	Bonte strandloper	October - May	Small polychaetes and amphipods	1,330,000	14,100
Limosa lapponica	Bar-tailed Godwit	Rosse Grutto	August – May	Large benthos: Arenicola, crabs	120,000 lapponica 520,000 taymyrensis	4,200
Numeniusarquata	Curlew	Wulp	July – April (peak in autumn)	Large benthos: Arenicola, Mya, crabs	420,000	6,400
Tringa erythropus	Spotted Redshank	Zwarte Ruiter	July – October	Polychaetes, crustaceans, small fish	100,000	310
Tringa totanus	Redshank	Tureluur	July - November	Polychaetes, crustaceans, small fish	250,000 totanus 65,000 robusta	1,600
Tringa nebularia	Greenshank	Groenpootruiter	July - September	Polychaetes, crustaceans, small fish	310,000	150
Arenaria interpres	Turnstone	Steenloper	August - May	Crustaceans, polychaetes	94,000 Canada 83,000 N Europe	580

[1] Troost, K & Ysebaert, T. (2011),. Imares Yerseke.

[2] Based on: Delany, S, Scott, D (2006). *Waterbird Population Estimates, Fourth Edition.* Wetlands International; and: Aarts BGW, Van den Bremer L, Van Winden EAJ, Zoetebier TKG (2008). *Trendinformatie en referentiewaarden voor Nederlandse kustvogels.* Wettelijke Onderzoekstaken Natuur & Milieu, Wageningen.

[3] NATURA 2000 is the ecological network for the conservation of wild animals and plant species and natural habitats of community importance within the European Union. It consists of sites classified under the Birds Directive and the Habitats Directive (the Nature Directives).

APPENDIX: Table 3

Overview of habitat types & endangered mammals in Eastern Scheldt Estuary

As considered in Ministry of I&E (2015) [1]

Habitat type / species English name	Habitat type / species Dutch name	State of conservation nation wide	Volume conservation objectives ES	Quality conservation objectives ES	Problem case	Realization of objectives in the short-term < 6 yrs	Realization of objectives in the long-term > 6 yrs
Habitat type							
H1160 Large shallow inlets and bays	Grote baaien	--	M	I	Yes, in future	Yes, by continuation of current measures	Unknown
H7140B Transition mires and quaking bogs (bog moss canebrake)	Overgangs- en trilvenen (veenmosrietlanden)	-	E	I	Yes	No deterioration with current measures	Yes, by continuation of current measures
H1330B Atlantic salt meadows (Glauco-Puccinellietalia maritimae – inside the dike)	Schorren en zilte graslanden (binnendijks)	-	E	M	Yes	Yes, but only if extra measures are taken	Yes, by continuation of current measures
H1330A Atlantic salt meadows (Glauco-Puccinellietalia maritimae – outside the dike)	Schorren en zilte graslanden (buitendijks)	-	M	M	Yes, in future	Yes, by continuation of current measures	Unknown
H1320 Spartina swards (Spartinion maritimae)	Slijkgrasvelden	--	M	M	Yes, in future	Yes, by continuation of current measures	Unknown
H1310A Salicornia and other annuals colonizing mud and sand (marsh sampire)	Zilte pionierbegroeiingen (zeekraal)	-	E	M	Yes, in future	Yes, by continuation of current measures	Unknown
Endangered mammal							
1365 Common seal (Phoca vitulina)	Gewone zeehond	+	I	I	Yes	Yes, but only if extra measures are taken	Yes, by continuation of current measures
1340 Root vole (Microtus oeconomus arenicola)	Noordse woelmuis	--	E	M	Yes	Yes, but only if extra measures are taken	Yes, by continuation of current measures

LEGEND				
Habitat type/Species #	**Conservation objectives**	**State of conservation nationwide**	**Problem case**	
Natura 2000[2] Habitat type or Species code	*M Maintain current status* *E Extend current status* *I Improve current status*	*-- Extremely unfavorable* *- Moderate unfavorable*	(red)	*Conservation objectives will be attained with continuation of current management, but problems might develop in next phase*
			(light red)	*Conservation objectives will not be attained with continuation of current management*

[1] Ministry of Infrastructure & Environment (2011). *Oosterschelde Juni 2015. Natura 2000 Deltawateren Ontwerpbeheerplan 2015-2021*. Den Haag: Rijkswaterstaat. [Eastern Scheldt June 2015. Natura 2000 Draft management plan for Delta waters 2015-2021. The Hague: Rijkswaterstaat]

[2] NATURA 2000 is the ecological network for the conservation of wild animals and plant species and natural habitats of community importance within the European Union. It consists of sites classified under the Birds Directive and the Habitats Directive (the Nature Directives).

APPENDIX to 'Eastern Scheldt Survey. A concise overview of the estuary pre- and post barrier' by A.D. Brand, B.L.M. Kothuis & B.C. van Prooijen (2016).

Eastern part of the Oosterschelde

The Oesterdam and the Philipsdam are two barriers that close off the eastern part of the Eastern Scheldt. They form part of the compartmentalization of the Zeeland and the South Holland waters to manage fresh water supply and navigation. The construction of these dams in the 1960's contributed to the development of the Zoommeer (a fresh water lake) and the tide-less Rhine-Scheldt Canal, providing a convenient river shipping traffic connection to and from Antwerp. In addition, the closure prevented further influx from riverine waters - at the time strongly polluted with heavy metals - into the Eastern Scheldt estuary.