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Achieving Natura 2000 by Building with Nature in the Eastern Scheldt

Master Thesis Sustainable Development

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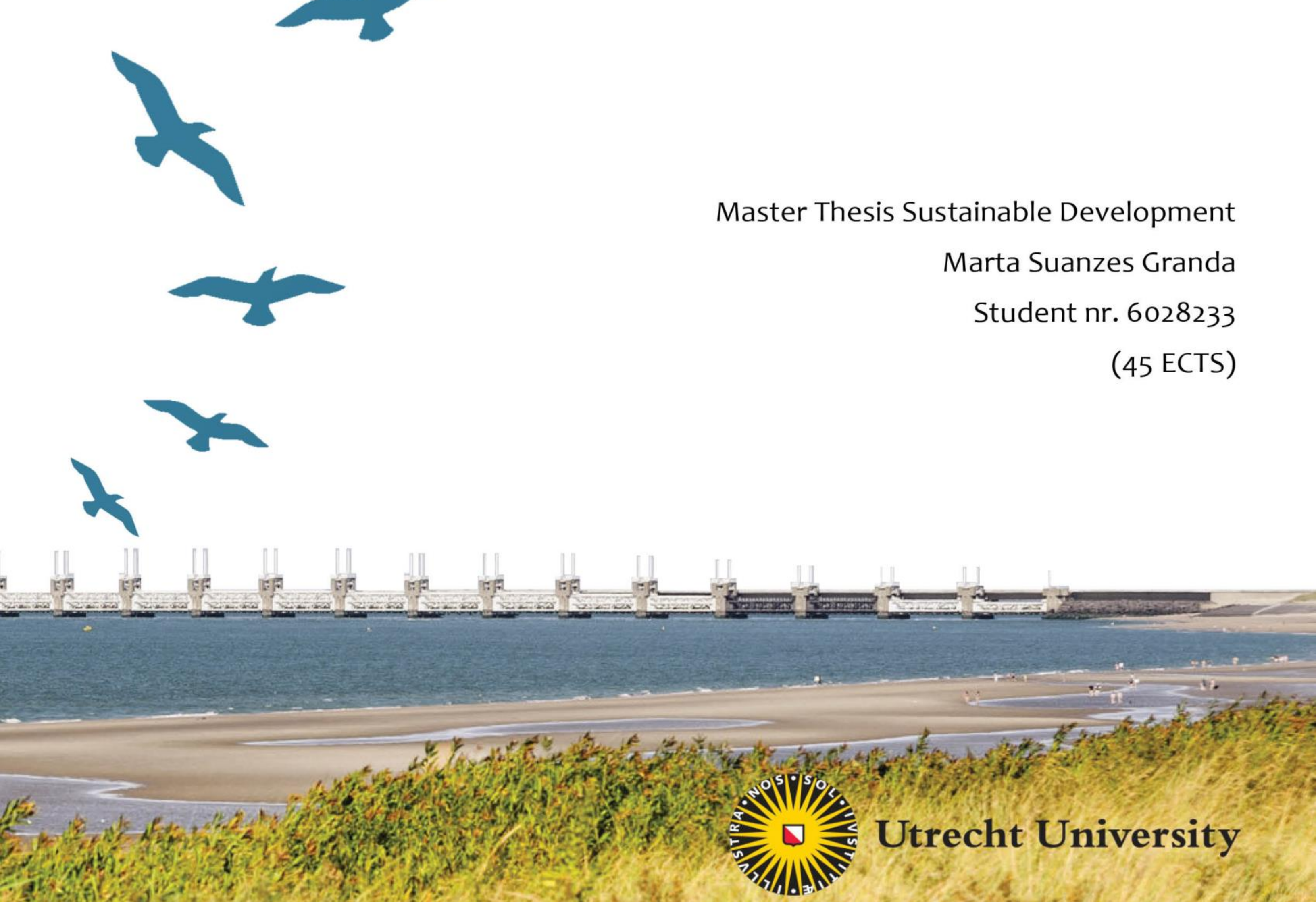

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Executive summary

Historically, hard engineering projects, such as the construction of dikes and surge barriers, have been the ultimate solution to protect coastal zones from flood disasters. However, there is an increasing awareness about the impacts that these traditional solutions have in valuable natural habitats and species. After the tragic consequences caused by the storm event occurred in 1953 in The Netherlands, the Deltaworks plan and the compartmentalization of the Eastern Scheldt by a storm surge barrier and secondary dams began. The finalization of this compartmentalization was considered an enormous success. However, changes produced in the hydrodynamics and geomorphology of the Eastern Scheldt, such the reduction in tidal prism, tidal range and maximum flow velocities, have influenced the equilibrium of the ecosystem. The Eastern Scheldt is in need of a high volume of sand so that the main channels can adapt and reach a new equilibrium. Since the storm surge barrier and secondary dams are blocking sediments from the North Sea and rivers, the channels are filling at the expense of the tidal flats and salt marshes. These tidal flats and salt marshes are suffering a net erosion, reducing their elevation and surface, and affecting other habitats and species that depend on them. This degradation process is called sand demand, and its degradation will accelerate as sea level rises.

Several habitats and species located Eastern Scheldt are protected by Natura 2000 goals, the largest network of protected areas in the world. In order to preserve and protect these valuable areas and species, strategies based in Building with Nature (BwN) approach were executed. Solutions based in BwN approach emerged to simultaneously guarantee safety standards and protect nature at the same time. The aim of this study is to investigate whether these strategies mitigate the effects of sand demand while contributing to Natura 2000 goals in relation to habitat conservation and species protection now and in the future (2050-2100). To achieve this, monitoring data with regard to two nourishment projects were collected and evaluated. These projects are the Galgeplaat nourishment and the Oesterdam nourishment.

Results showed that both nourishments are mitigating the degradation process of sand demand by increasing the bed elevation at both locations, by improving the surroundings through sedimentation processes, and by protecting valuable areas from erosion. Moreover, these strategies proved to restore to some extent the quality of the habitats and their closest surroundings, influencing the availability of benthic animals and the time birds spend in these areas foraging for food. However, this research can not conclude whether these strategies are benefiting the protection of the species affected by sand demand in the Eastern Scheldt due to the lack of information in this respect.

In the Eastern Scheldt, sand nourishments proved to be suitable strategies to maintain valuable areas in the short term (horizon 2050). However, they do not solve the problem of sand demand. Moreover, other causes of degradations, such as sea level rise, will have an impact on the effectiveness of these measures over the years. According to experts interviewed during this research, if habitats and species are to be preserved and protected in the long term (horizon 2100) in the Eastern Scheldt, the best solution is recovering the former hydrodynamics and geomorphology of the basin.

Acknowledgements

First, thank you to Obbe Tuinenburg for his guidance, flexibility, and critical input. Special thanks to Pieter Bart and Christiaan Tenthof van Noorden from Antea Group for reassuring advice and freedom to explore this interesting topic.

Additionally, thank you to Matthijs Boersema (RWS), Robert Jentink (RWS), Rienk Geene (Habitat Advice), Floor Arts (Delta Milieu), and Mark Hoekstein (Delta Milieu) for providing me with additional information and expert judgement during the interviews, questionnaires, and group discussions.

Last but definitely not least, thank you to Juan Manuel Sánchez Pueyo for his continuous support, and most importantly to my family for the long distance skype conversations, emails and calls.

Table of Contents

List of figures

List of tables

Glossary

Cross-section	a surface or shape exposed by making a straight cut through something, especially at right angles to an axis
Dam	large wall or barrier that blocks or stops the flow of water, forming a reservoir or a lake
NAP	Normaal Amsterdams Peil. Dutch Ordnance Datum corresponding to with mean sea level MSL
NGO	a non-profit organization that operates independently of any government, typically one whose purpose is to address a social or political issue
Sand nourishment	process by which sediment, usually sand, lost through longshore drift or erosion is replaced from other sources
Storm surge barrier	a specific type of floodgate, designed to prevent a storm surge or spring tide from flooding the protected area behind the barrier
Taxa	a group of one or more populations of an organism or organisms
Tidal flat	a nearly flat coastal area, alternately covered and exposed by the tides
Tidal inlets	short, narrow passage connecting two larger and wider bodies of water. Typically, tidal inlets link barrier lagoons or impounded estuaries with the sea and are maintained largely by tidal currents.
Tidal prism	total amount of water flowing through the inlet per tidal cycle. This tidal prism in turn determines the size of the inlet cross-section
Tidal range	vertical distance through which the tide rises and falls, the difference in water height between low tide and high tide, or, quite simply, the “size” of tide

Abbreviations

AFDW	ash free dry weight
BP	Before Present
ha	hectare
m	meters
m^2	square meters
m^3	cubic meters
RWS	Rijkswaterstaat

1. Introduction

1.1 Background

Coastal zones usually experience rapid urban development due to their economic and ecological relevance for humans. Today, 44 % of the world's population lives within 150 kilometers of the coast (UN Atlas of the Oceans, 2018). These coastal areas constitute the interconnection between atmosphere, hydrosphere and lithosphere, making them very attractive but also very sensitive to climate changes (Cendrero et al., 2005). Historically, flood disaster is one of the main threats that coastal zones had to deal with. Hard engineering projects, such as the construction of dikes or seawalls, have been the conventional solution to defend vulnerable coastlines from flooding. However, these conventional measures carried the challenge of growing maintenance costs due to their inflexibility to adapt to climate changes, such as the increasing flood risks caused by higher storm intensity, sea level rise, or land subsidence (Temmerman et al., 2013). Moreover, there exists an increasing social awareness about the potential threat that these solutions represent to valuable habitats and species that highly depend on the dynamics of the ecosystems in which these measures are constructed. The Eastern Scheldt area (*Oosterschelde* in Dutch), a former estuary located in the province of Zealand (The Netherlands), is a good example of ecosystems that experienced physical and ecological changes due to wide human interference. After the tragic consequences caused by the storm event occurred in 1953, a series of engineering projects took place in the Netherlands with the aim to reach certain degree of safety in the Delta. These construction projects are so-called Deltaworks (*Deltawerken* in Dutch). The Eastern Scheldt experienced a compartmentalization led by the construction of a storm surge barrier and a number of dams. The estuary was converted to a semi-closed tidal bay (RWS, 2015). Right after the closure of the basin, the Eastern Scheldt suffered a reduction in tidal prism, tidal range, and flow velocities, among other changes. Valuable natural areas are degrading since the construction of the Deltaworks, affecting the species that depend of the ecosystem services that these areas provide. The Eastern Scheldt belongs to Natura 2000, the largest network of protected areas in the world. The intertidal area of the Eastern Scheldt has a vital importance for migratory birds, coastal breeding birds, and mammals such as the harbour seal (RWS, 2016).

Habitats and species that belong to Natura 2000 network require protection. This network provides objectives and guidelines to achieve these requirements. Due to the increasing evidence on the impacts of the compartmentalization in the equilibrium of the Eastern Scheldt, solutions to mitigate these impacts had to be developed. These solutions had to simultaneously guarantee safety standards for the Dutch population and restore and protect nature at the same time. The concept of Building with Nature (BwN) emerged at the beginning of the 21st century to give answer to this dilemma. BwN is an innovative approach that includes natural components in infrastructure design, flexibility, and adaptability to changing environmental conditions, often at lower costs on a life-cycle basis than traditional engineering solutions (de Vriend et al., 2015). Several pilot projects based in the BwN approach were developed in the Eastern Scheldt with the aim to investigate whether soft and flexible solutions can maintain valuable areas and reach the requirements established by Natura 2000 with regard to the protection of habitats and species.

1.2 Problem definition

Right after the compartmentalization of the Eastern Scheldt, the morphological and ecological equilibrium of the ecosystem was lost. The Eastern Scheldt basin is in need of a high volume of sediments, so that the main channels can adapt to the reduced tidal prism and maximum flow velocities. Since there is a high evidence that the storm surge barrier and secondary dams are blocking sediments from the North Sea and the rivers, these channels are filled at the expense of the intertidal area. Several studies refer to this phenomenon as "sand demand", one cause of degradation led by the Deltaworks in the Eastern Scheldt. Sand demand supposes a threat for several habitats that are experiencing a continuous degradation process. In addition to this, the degradation of some habitats may be accelerated by sea level rise. Consequently, species depending on the food and nesting areas that these habitats provide can disappear from this unique area in the future.

According to De Ronde at al. (2013), several options were studied to maintain the most valuable areas of the Eastern Scheldt, and the replenishment of new sand with the use of ecosystem engineers, such as oyster reefs, were chosen as the best cost-effective solution. Several years have passed since the construction of the two main nourishments pilot projects located in two tidal flats of the Eastern Scheldt, the Galgeplaat and Oesterdam. Several years after their implementation, the question remains whether these pilot projects have contributed to the mitigation of the problem of sand demand while furthering to the objectives designated by Natura 2000. If the answer is positive, these measures would be a good solution to maintain the core areas in the Eastern Scheldt. However, sea level continues to rise and the effectiveness of these measures may be also affected by climate change.

1.3 Aim of the research

This research aims to fill the knowledge gap on whether strategies based in BwN approach can maintain the geomorphology and ecology of valuable habitats of the Eastern Scheldt, and contribute to Natura 2000 goals now and in the future. In contrast to other studies, this research integrates several study fields such as geomorphology, ecology, biology, and climate change. It will collect evidence on the effectiveness of BwN approaches by investigating to what extent pilot projects taking place at different locations in the Eastern Scheldt have contributed to the mitigation of sand demand, and to the achievement of the conservation objectives provided by Natura 2000. In addition, this research aims to collect expert opinions about how climate change under the KNMI'14 scenarios may influence the effectiveness of these solutions in the short term (2050) and discuss the future of the Eastern Scheldt (2100). Integrating the results will show if these nourishments projects are effective solutions to preserve valuable natural areas and the species that depend on them.

1.4 Research questions and sub-questions

RQ: To what extent can strategies based on the BwN approach help to achieve Natura 2000 goals in the Eastern Scheldt now and in the future?

This main research question is divided in the following sub-questions:

- *Which ecological conditions characterize a good conservation of the habitats according to Natura 2000 goals in the Eastern Scheldt area? Are these habitats experiencing shared causes of degradation?*
- *To what extent pilot projects based on BwN have a positive impact on the processes that are degrading the ecosystem until now?*
- *Is there scientific evidence that pilot projects have contributed to Natura 2000 goals regarding habitat conservation and species protection at each location?*
- *How climate change under KNMI´14 scenarios might influence the effectiveness of these solutions and the future of the Eastern Scheldt?*

1.5 Methodology and data collection

In order to answer the main research question and sub-questions, this research is divided in three main parts.

The first part investigates the whole Eastern Scheldt in order to study the main causes of degradation of this ecosystem. The aquatic system of the Eastern Scheldt and different parts of its land surface are protected by the Natura 2000 goals. The entire ecosystem will be studied from the perspective of the conservation objectives of Natura 2000 network with regard the habitat types. In this first part, the study of birds and mammals are not included. It is assumed that these habitats sustain the protected species, and that these species will benefit from the good conservation of the habitats. The study of the habitat types will follow a literature review strategy. The main sources in this respect are the Natura 2000 official documents such as the Natura 2000 Target Document (2006), the Natura 2000 habitat profiles, the Natura 2000 Deltawateren (2016), and the Delta Monitoring Plan (2015) developed by Rijkswaterstaat. In addition, this study uses historical and recent scientific literature. The result of this analysis will be a chart showing the whole Eastern Scheldt ecosystem according to Natura 2000, its main ecological conditions and the main causes of degradation observed in all habitats types.

The second part of the investigation focuses in the largest habitat of the Eastern Scheldt, the "large shallow inlets and bays". This habitat is predominantly aquatic, and contain the tidal flats. This part focuses in one cause of degradation thereof, the sand demand process. The aim of this part is to investigate whether strategies based in BwN approach mitigate the effects of sand demand at the location of the project and whether they are contributing to Natura 2000 goals with regard habitat conservation and species protection. Two nourishment pilot projects were selected for this section, the Galgeplaat and the Oesterdam nourishment projects, located in the central and southeast tidal flats of the Eastern Scheldt, respectively. The official monitoring plans of both projects were studied with the aim of identifying common parameters regarding morphology and ecology that could be used for the comparison and evaluation of the projects. These parameters are: bed elevation, sediment volume change, sedimentation and erosion patterns, time of exposure, benthic community, foraging time, and birds and harbor seal counts. Moreover, these parameters are organized and used following the next assumption (see also Figure 1): The replenishment of new sediments in an area that suffers from erosion will mitigate the effects of sand demand. By diminishing the effects of sand demand, the habitat will be restored by improving the availability of benthos, and the time it is exposed to air for birds to forage. Improving the habitat conditions will maintain or increase the numbers of protected birds by Natura 2000. In the case of the harbour seal, mitigating the effects of sand demand will increase their resting area, benefiting directly their species numbers.

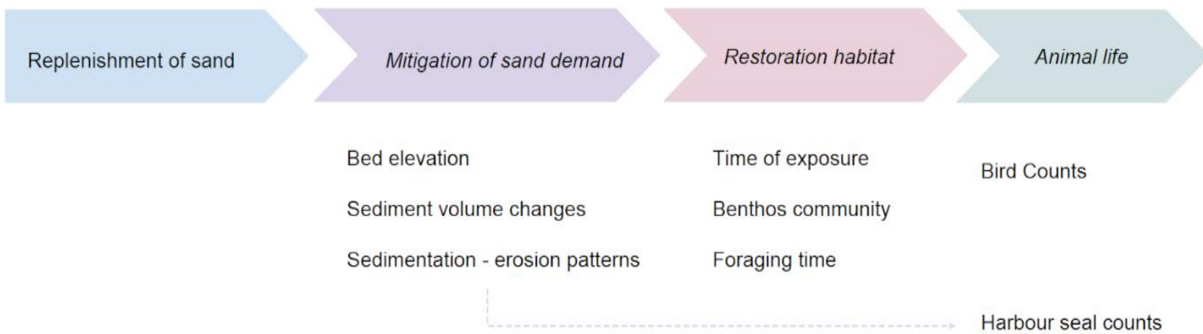

Figure 1. Parameters used for the comparison of the pilot projects organized following an assumption of this research. Source: own work

Since the main aim of these pilot projects is to preserve the geomorphology and ecology of these areas, the before and after situation with regard to these parameters at each location are compared. The main sources of data for this comparison were the official monitoring and evaluation documents. In addition, the coordinators and participants of the monitoring plan of both projects were contacted to gather additional documents and information that were not publicly available. Since some information was not available or incomplete, interviews and questionnaires with different experts in one or more subjects were conducted to fill the information gaps and improve the data. A brief overview of consulted organizations and experts is provided below:

- Rijkswaterstaat, Ministry of Infrastructure and Water Management – data request and interview with the coordinator of the Galgeplaat nourishment, Robert Jentink.
- HZ University of Applied Science – data request and interview with the coordinator of Building with Nature program and coordinator of the Oesterdam nourishment, Matthijs Boersema.
- Habitat Advice – data request and interview with the expert in ecology, Rienk Geene.
- Delta Milieu – questionnaire to the expert in ecology and biology, Floor Arts.
- Delta Milieu – questionnaire to the expert in ecology and biology, Mark Hoekstein.

Finally, the third part of the investigation intends to discuss the potential impact of climate change under the KNMI’14 scenarios on the effectiveness of the nourishment projects in the Eastern Scheldt. For this purpose, a multidisciplinary group discussion was organized in one of the facilities of Antea Group. Several experts in the areas of engineering, geomorphology, ecology and biology were invited to discuss the results of the previous parts of this investigation and how the KNMI’14 climate scenarios may affect these results in the future. A brief overview of the organizations and experts invited to this multidisciplinary discussion is provided below.

- Antea Group - Pieter Bart
- Antea Group - Christiaan Tenthof van Noorden
- University of Utrecht - Obbe Tuinenburg
- Rijkswaterstaat, Ministry of Infrastructure and Water Management - Robert Jentink
- HZ University of Applied Science - Matthijs Boersema
- Delta Milieu - Floor Arts

All the above-described methodologies were combined to deliver satisfactory answers on the posed research questions.

1.6 Reading guide

The structure of the research is as follows.

After this first section, the introduction, Section 2 presents the past and present of the Eastern Scheldt, with an especial focus in the Deltaworks plan. Section 3 describes briefly the Natura 2000 network and its main policy documents. After this, this section focuses on the five habitats protected by Natura 2000 in the Eastern Scheldt, their conditions for a good conservation, and their shared causes of degradation. Section 4 introduces the concept of Building with Nature. Section 5 describes the nourishment projects that will be study, the nourishments in the Galgeplaat tidal flat and the Oesterdam tidal flat. Section 6 presents the parameters that will be used for the evaluation. Right after, this same chapter shows and evaluates the collected data in relation to those parameters for each nourishment project. Section 7 presents the results of a multidisciplinary group discussion that took place in June 2018. The aim of that meeting was to discuss the future implementation of the projects discussed before under the KNMI´14 scenarios, and the future of the Eastern Scheldt. Finally, Section 8 discusses the conclusions of this research by answering the research question and sub-questions. This section also provides a selection of recommendations for the future implementation of nourishments projects in Easter Scheldt and for further research.

2. Past and present of the Eastern Scheldt

2.1. History of the Eastern Scheldt

The Netherlands can be characterized as a low-lying river Delta, where the rivers Rhine, Meuse, and Scheldt flow into the North Sea. The current configuration of the Eastern Scheldt area is the result of gradual morphological changes since the last ice age, sudden extreme natural events, and recent human interventions.

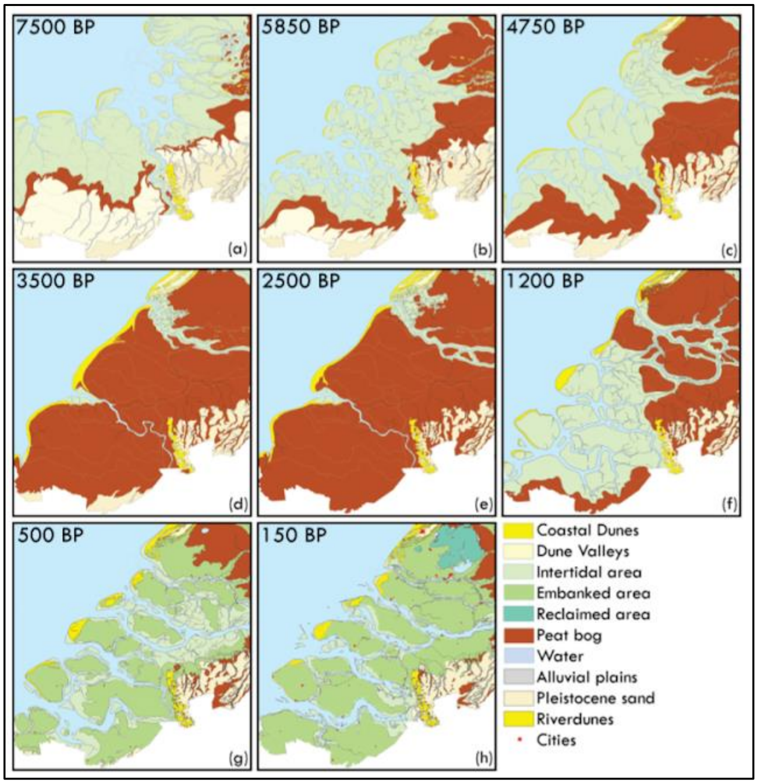

Figure 2. Geological development of the Eastern Scheldt area from 7500 BP to 150 BP. Source: Vos et al., 2011.

Before 6000 BP, increasing sea level mainly caused by the melting of the Scandinavian and Laurentide ice caps invaded the Scheldt River system, transforming the area known today as Zealand into a tidal landscape connected to the North Sea. Between the 5000 and 4500 BP, the deceleration of sea level rise and sedimentation processes silted up the landscape, turning the area behind the barriers into a large peat marsh (Beets and Van der Spek, 2000). In the Roman period, it is believed that the estuary comprehended only 10 to 20% of the current area (RWS, 1987) (see Figure 2(e)). After this period, sea level rise and the subsidence caused by human action submerged the area (Eelkema, 2013). From the Middle Ages onwards, the tidal prism increased hundreds of millions of cubic meters due to floods, land losses, and the disappearance of most of the peat, resulting in a wide estuary. This estuary was formed by channels, tidal flats and salt marshes (RWS, 1987; Eelkema, 2013). From the 15th century onwards, land reclamation was interrupted by erosion processes and storm surges. More recently, in the 20th century, dredging works in the low-lying parts of the country increased the tidal prism around 15% in the period from 1870 to 1960. For 1000 years the Eastern Scheldt ecosystem was adapting to an increasing tidal volume, something that would completely change due to the completion of the Deltaworks at the end of the 20th century. This change and the consequences thereof are discussed in the section below.

2.2. The Deltaworks plan

Before the beginning of the engineering plans, known as Deltaworks, in the second half of 20th century, the Eastern Scheldt was connected to the rivers Rhine and Meuse, which provided the main fresh water supply to the estuary (see Figure 3). Nevertheless, the main influx of water into the estuary was tide driven. This situation would change after the night of January 31 to February 1st of 1953. A northwesterly storm provoked tides 3 meters above NAP causing the collapse of the dikes. This large flood disaster caused 1,835 deaths, the loss of 200.000 cattle heads, and damaged 47.000 houses and farms (Nienhuis and Smaal, 1994; RWS, 2016). A special delta committee was created to propose measures to increase safety in the whole country. This committee gave a number of recommendations between 1953 and 1955 for the closure of several tidal channels. This is how the Deltaworks (in Dutch: *Deltawerken*) and the compartmentalization of the Eastern Scheldt area began.

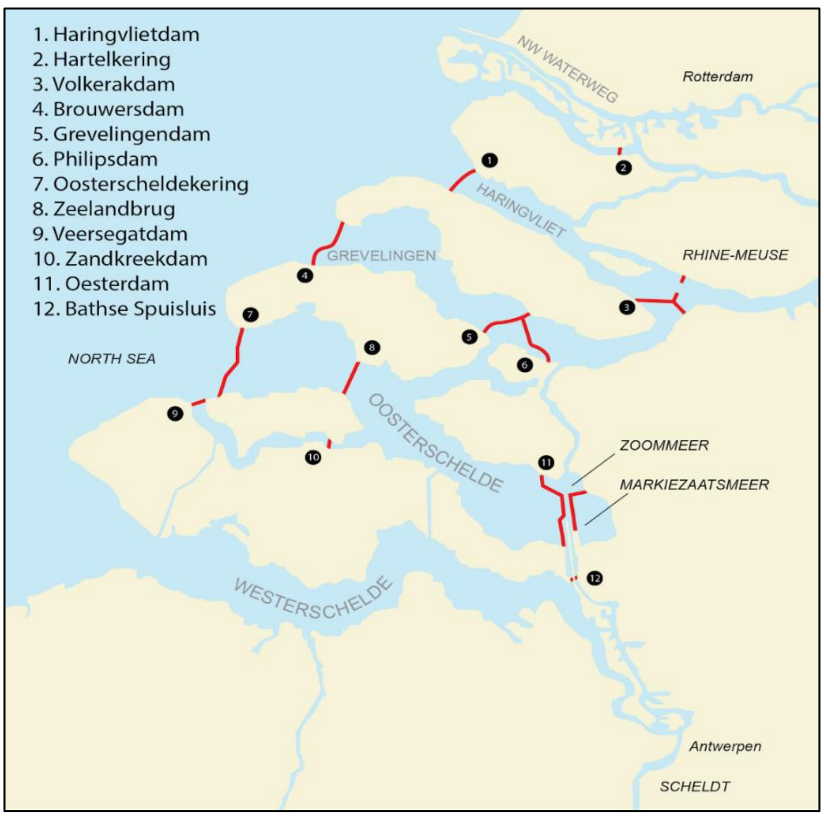

Figure 3. Scheme of the Deltaworks located in the Dutch Delta. Source: own work.

One of the first recommendations of the committee was to close the tidal inlets *Haringvlie*t, *Grevelingen* and Eastern Scheldt at their mouths. There was no recommendation to close the De *Nieuwe Waterweg* and the *Westerschelde* seaways due to the trade importance of the ports of

Rotterdam and Antwerp. In order to build the primary barriers at the mouths of the estuaries, secondary compartmentalization barriers had to be implemented to reduce current tidal velocities (Nienhuis and Smaal, 1994). In 1958, the Deltaworks started with the *Hollandse IJssel* barrier, which would protect the Randstad area (the Western part of the Netherlands) from floods. Right after the completion of the *Hollandse Ijssel* barrier, the *Zandkreekdam* (1960) and *VeerseGatdam* (1961) were build, closing that inner basin and turning it to a freshwater area. The *Grevelingendam* was constructed in 1964, after which the tidal prism flowing through the opening of the Eastern Scheldt increased in volume. Between 1971 and 1972, an array of sluices were built in the mouth of the *Haringvliet*. Thereafter, the Brouwers dam, south of the Haringvliet, was finished. The storm surge barrier known as the *Oosterscheldekering* was projected to completely close the Eastern Scheldt basin from the North Sea, as it had been done with the *Haringvlie*t and *Grevelingen* basins. Its construction, however, was halted due to public and politic pressure (Deltawerken, 2017). The objection to the surge barrier focused on the fact that a complete closure with a traditional dam would eliminate the tides, resulting in large impacts to the last saltwater ecosystem and fishing activities located in this area. Finally, an innovative barrier composed by piers and movable gates that allow the tides to enter the basin replaced the dam. When extremely high water levels occur (more than 3 m above NAP), the gates are lowered. The construction of the barrier resulted in the reduction of the cross section at the mouth of the Eastern Scheldt from 80000 m^2 to 17550 m^2 in 1986 (Leeuw et al., 1994). Lastly, the compartmentalization of the Eastern Scheldt was completed by the construction of the *Oesterdam* (1986), which separates the sea-arm from the freshwater compartment, and the *Philipsdam* (1987), which separates the estuary from the newly created freshwater lake *Krammer-Volkerak* (see Figure 3). This compartmentalization turned the Eastern Scheldt into a shallow bay with salt water (Natura 2000, 2017). The Deltaworks, especially the storm surge barrier, were considered an enormous success both in terms of effective communication between scientists and civil engineers and in terms of the use of innovative methods for the construction in open water (Nienhuis and Smaal, 1994).

2.3. The Eastern Scheldt today

The Eastern Scheldt area is located in the province of Zealand, south-west of the Netherlands. With a surface of 36,976 ha, it is the largest natural park of the country. The area is formed by several natural and human-made elements. The tidal basin is surrounded by land and connected to the sea. It consists of a supratidal zone, area above high tide; an intertidal zone, area above low tide but under water at high tide; and a subtidal zone, area only exposed to air at the lowest low tides. At the same time, these zones are characterized by: (i) tidal channels, important elements for the processes of erosion and sedimentation; (ii) tidal flats, areas regularly flooded in which rich food for birds and nesting areas can be found; (iii) salt marshes, higher areas where marsh vegetation grows; and (iv) artificial littoral and sublittoral rocky shores. Due to its location and abiotic characteristics, the Eastern Scheldt has been for centuries an important area for commercial and recreational shipping, fishing, cultivation of mussels and water and underwater sports. In addition to its significance for human activities, the Eastern Scheldt area is of great ecological value. The area is relevant for mussel and oyster fisheries and it serves as a stopover on the migration routes for hundreds of thousands of waders from Siberia, Scandinavia and Canada to the south and back again. It also offers nest and resting areas to the harbor seal and to a number of coastal breeding birds. This ecosystem depends largely on the intertidal zone, due to its richness in food sources for higher species. The intertidal zones are uncommon in the Netherlands, they can only be found, in addition to the Eastern Scheldt, in the Wadden Sea and the *Westerschelde*.

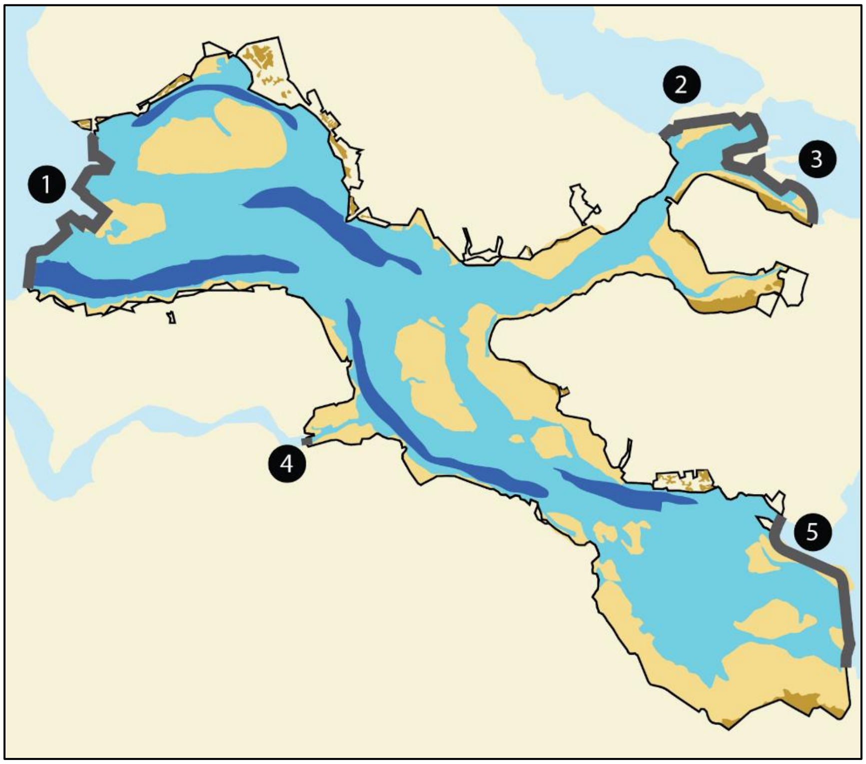

Figure 4. The compartmentalization of the Eastern Scheldt led by (1) the storm surge barrier (Oosterscheldekering), and the dams (2) Grevelingedam, (3) Philipsdam, (4) Zankrekdam and (5) Oesterdam. Source: own work.

According to Louters et al. (1993) and Huisman and Luijendijk (2009), the compartmentalization of the Eastern Scheldt by dams (*Zandkreekdam* (1960), *Veerse Gatdam* (1961), *Philipsdam* (1987) and *Oesterdam* (1986)), reduced the tidal prism of the basin. Moreover, the completion of the storm surge barrier accentuated further this problem due to the substantial reduction of the cross-section at the basin entrance. The reduction of tidal prism and cross section decreased the tidal volume, the tidal range, and the flow velocities in the main channels. According to Nienhuis et al. (1994), flow velocities decreased from 1.5 to 1 m/s for an averaged tide, the mean tidal range measured in *Yerseke* station also decreased from 3.7 to 3.25 m, and the total tidal volume was reduced from 3,050 to 2,750 m^3 x 10^6 after the completion of the barrier. Huisman and Luijendijk (2009) modelled and analyzed the sediment transport from the North sea, and concluded that there is a high probability that the barrier is blocking sediments from the North Sea due to (i) asymmetries in flow velocities during ebb and flood tide, (ii) turbulence by the elevation of the barrier, and (iii) the effect of the slopes of the barrier in both sides. These changes in hydrodynamics have impacts in the geomorphology and ecology of the Eastern Scheldt. Firstly, due to the reduction of tidal prism and maximum flow velocities, the channels are not in equilibrium (dark blue color in Figure 4). Currently, they are filling up slowly by sedimentation processes to reach a balanced size. However, since the barrier is blocking sediments coming from the North sea, and the *Volkerakdam* and the *Philipsdam* are blocking sediments from the river, this sediment fulfillment is at the expense of the intertidal area

(Nienhuis et al., 1994; Natura 2000-gebieden, 2018; De Ronde et al., 2013). This phenomenon is called by many studies sand demand or sand deficit. This phenomenon will be further elaborated in section 5.

3. The Eastern Scheldt ecosystem according to Natura 2000

This section studies the Eastern Scheldt area according to the conservation objectives provided by Natura 2000 network. Firstly, this section gives a short introduction on the network of Natura 2000 in Europe. It follows with the objectives Natura 2000 designated to the Netherlands, and to the Eastern Scheldt itself. After this, it presents the main documents that Dutch public authorities developed for the conservation and protection of habitat and species. Finally, it studies the Eastern Scheldt ecosystem in relation to its habitats, identifying the ecological conditions for a good conservation of the area and the main causes of degradation. The study of the whole ecosystem will serve later as a reference to discuss the importance of using sand nourishment projects as solution to mitigate processes of degradation and achieve Natura 2000 goals.

3.1 Introduction to the Natura 2000's network and policy documents

Since the second half of the 20th century, social awareness increased with regard to the impact of humans in the environment. A special concern was in relation to endangered species and the disappearance of valuable habitats within European boundaries. This resulted in the creation of new organizations, such as WWF and Friends of the Earth, the increase of nature reserves and national parks (Evans, 2012), and the rise of conventions for the conservation of species and relevant natural areas, such as the Ramsar Convention (1971). However, pressure from conservationists and NGOs concerning the protection of birds kept on increasing in Europe. This concluded in the adoption of the Directive on the Conservation of Wild Birds, commonly known as Birds Directive, in 1979. State members were asked to designate the Special Protection Areas (SPAs) in relation to a list of species considered rare and/or threatened together with sites, which were important for migratory species. Some years later, in 1992, a Directive on the Conservation of Natural Habitats and of Wild Fauna and Flora was adopted, more commonly known as the Habitats Directive. This directive includes the designation of protected sites for selected habitats and species known as Special Areas of Conservation (SACs) (Evans, 2012). These SACs, together with the SPAs designated under the Birds Directive, compose today the Natura 2000 network. It constitutes around 18% of the European surface and almost 6 % of its marine territory (Natura 2000-gebieden, 2018). All Member States agreed to take the necessary measures to achieve a good conservation and protection of the species and habitats relevant for the community.

In the Netherlands, 162 areas contribute to the Natura 2000 network. These areas were designated for the protection of 52 habitat types, 36 mammal species, and 95 birds species (MEZ, 2014). It constitutes a total volume of approximately one million hectares (Ministry of Agriculture, Nature and Food Quality, 2006). Within the Eastern Scheldt area, it has been designated some level of protection to 5 habitats, 2 mammals, and 45 birds (breeding and not breeding species) (Natura 2000-gebieden, 2018). For the development of suitable policies and measures, Dutch public authorities elaborated a series of documents. The next paragraphs explain briefly the general content of these documents that are used later for the study of the habitat types.

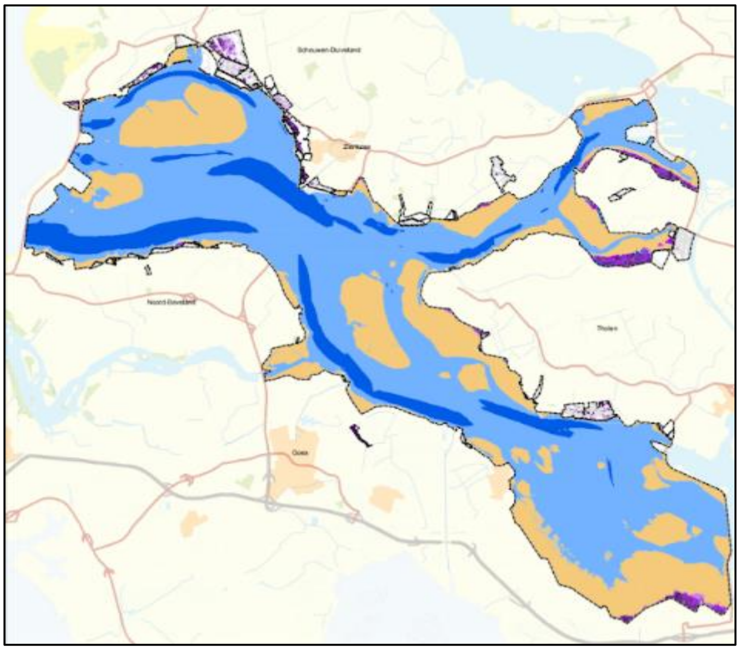

Figure 5. The Eastern Scheldt area and its protected habitats. This image is in the Annex 1 with its legend. Source: Natura 2000

3.1.1 Habitat and species profiles

The Ministry of Economic Affairs of the Netherlands, in collaboration with experts and research institutes, developed a series of profiles providing the necessary scientific background with regard to the ecological characteristics and requirements for each habitat and species to be protected at a national level.

Each profile provides a short description of the habitat and species type considered, its relative importance within Europe, the requirements for a good conservation, stressor and threads for the habitat, and a final assessment of national state of conservation made by experts. For the habitat types, this last assessment considers four aspects: (i) natural distribution, which measures how stable is the diffusion image of the habitat with regard former years, (ii) surface, which measures the extension of the area, (iii) quality, which measures how stable are the main features of the habitat, and (iv) future prospect, which express the predictions for the habitat from experts. Every aspect can score as favorable, moderate unfavorable, very unfavorable, or unknown. Even though these assessments evaluate every habitat at a national level, they are used in this research as an initial guidance of their status.

3.1.2 The Natura 2000 targets document

It delineates the Natura 2000 sites in the Netherlands and provides the objectives that need to be achieved at a national level and at specific local sites for those 162 areas.

For each habitat type, a table is developed containing basic information for its conservation. This information is derived from the habitat profiles:

Type of Habitat	Conservation objective	Trend	State of conservation	Relative contribution	Bottleneck

- Type of habitat: Name and code of the habitat type (and subtypes)
- Conservation objective: Core goals that need to be achieved, These can be maintaining the extent and/or quality, increasing the extent, or improving the quality of the habitat.
- Trend: Recent developments or changes occurring in the habitat.
- Conservation status: Current status of the habitat, which can be favorable, moderate unfavorable or very unfavorable.
- Relative contribution: The degree to which the Netherlands can contribute to achieving a favorable conservation status of that habitat type on a European scale (or Atlantic region for the case of the Netherlands). It depends on the surface and quality of the habitat. It can be designated as low, significant, large or very large.
- Bottlenecks: Processes that may restrict the good conservation of the habitats in the future.

3.1.3 Natura 2000 Management Plan and Monitoring Plan

After the Natura 2000 targets document and profiles are established, the Natura 2000 Management Plan and the Natura 2000 Monitoring Plan document are developed by provincial governments, Ministry of Defence, Ministry of Transport and Water Works, and of Ministry of Agriculture, Nature and Food Quality. These documents describe in more detail the location, the extent and time schedules of the conservation targets, the measures that are planned and being executed, and the monitoring process.

3.2. The Eastern Scheldt ecosystem defined by its habitat types: ecological conditions and causes of degradation

This section studies the Eastern Scheldt ecosystem in relation to the habitat types protected by Natura 2000 goals. The identification of the ecological conditions and causes of degradation of the habitats will serve as a base to discuss later the importance of the BwN strategies that are being developed in the Eastern Scheldt.

3.2.1 Habitat types

Due to the importance of its habitat types, almost the whole area of the Eastern Scheldt is protected. This section only studies the habitats types considered by Natura 2000 goals, but general impacts to the protected species are described at the end for better understanding of the ecosystem for the reader. These habitats are: (H1160) Large shallow inlets and bays, (H1310) Salicornia and other annuals colonizing mud and sand, (H1320) Spartina swards (Spartinion maritimae), (H1330) Salt marshes and meadows, (H7140) Transition mires and quaking bogs. See Figure 6.

Figure 6. Habitats protected by Natura 2000 in the Eastern Scheldt. From left to right, and top to bottom: Large shallow inlets and bays, Salt marshes and meadows, Salicornia and other annuals colonizing mud and sand, Spartina swards (Spartinion maritimae), Transition mires and quaking bogs. Source: Natura 2000 (2017).

Habitat type and code	Subtype	Area (ha)	(National) Conservation status	Importance within Europe	Conservation objective in Eastern Scheldt
Large shallow inlets and bays (H1160)		34700	Very unfavorable	Very large	Improve quality
Salicornia and other annuals (H1310)	Samphire	139	Moderate unfavorable	Large	Increase extension
	Sea Pearlworton		Favorable	Large	
Spartina swards (H1320)		208	Very unfavorable	Very low	Preserve quality and extent
Salt marshes and meadows (H1330)	Outside dikes	292	Moderate unfavorable	Very large	Preserve extent and quality
	Inside dikes		Moderate unfavorable	Large	Increase extension
Transition mires and quaking bogs (H7140)	Peat moss land	0.2	Moderate unfavorable	Very large*	Increase extension, improve quality

Table 1. Habitat types and subtypes in the Eastern Scheldt and their designated Natura 2000 goal. Source: own work using the sources explained in section 3.1.

Table 1 shows a summary of the Natura 2000 goals in relation to the habitat types. It can be seen that two habitats score very unfavorable for their current status, the large shallow inlets and bays and the spartina swards. The rest scores moderate unfavorable, with the only exception of the

Salicornia subtipe, sea pearlworton, that scores favorable. The large shallow inlets and bays and salt marshes, the largest areas in the Eastern Scheldt, have a very large importance within Europe. There are three types of objectives: improving the quality of the habitat, increasing the extension of the habitat, or preserving the quality and extension. The next paragraphs describe the identified ecological conditions for a good conservation of the habitats and the main causes of degradation. Sources used in the following subsections are explained in section 3.1. See Annex 1 for the spatial division of habitat types in the Eastern Scheldt (in Dutch).

Large shallow inlets and bays (H1160)

This habitat comprises the aquatic system of the Eastern Scheldt, in which tidal flats and sandbanks are located. It is the largest habitat in the Eastern Scheldt, covering an area of 34,700 ha. It is considered a unique habitat in the Netherlands. This uniqueness comes from the fact that the construction of the storm surge barrier and the dams changed its estuarine character to a shallow bay with limited freshwater input. For this reason, its importance within Europe is very large.
According to the H1160 profile (2008), the good quality of this habitat is determined by the large variation of ecotopes, such as high or low tidal flats, sandbanks, and the channels that are permanently underwater. In order to improve the quality of this habitat the presence of abiotic factors such as tides, currents, waves, salinity gradient and a good water quality are necessary. It also requires the presence of typical species like soil organisms, fish fauna, shorebirds and marine mammals.

Due to the compartmentalization of the Eastern Scheldt, the abiotic conditions have largely change. As explained in section 2, the phenomenon called sand demand is largely affecting this habitat. Since the channels are adapting to the new tidal prism and flow velocities, the tidal flats present in this aquatic habitat are experiencing a continuous erosion. This erosion influence the quality of the tidal flats by reducing their elevation and time of exposure to air during low tide. This ultimately affects the presence of typical species. In addition to sand demand, sea level rise is also an increasing threat. It will accelerate the erosion process and submersion of the tidal flats in the future.

Salt marshes and meadows (H1330)

Salt marshes are coastal wetlands that occur in the upper intertidal zone. It is periodically flooded by the tides. This type of habitat can be found in the Wadden sea and South Holland. In the case of the Eastern Scheldt, it covers an area of 292 ha, and they are mainly located in the eastern and northern part of the Eastern Scheldt (see Annex 1). The soil consists of silt and silty clay, deposited on the sandy subsoil of the tidal flats. The habitat is divided in two subtypes: salt marshes outside the dikes, and salt marshes inside the dikes. According to H1330 profile (2008), the first subtype, salt marshes outside the dikes, includes the meadows and dunes that are regularly flooded by seawater from the tides. The second subtype, salt marshes inside the dikes, comprises grasslands that have a marine history. Due to the construction of the dikes, the latter are not periodically flooded anymore. Its development continues thanks to the brackish or saline groundwater located in the area.

According to the assessment of the H1330 profile (2008), the subtype salt marshes outside the dikes is deteriorating across the country due to the low rejuvenation of the salt marshes. There is an imbalance of vegetation within the salt marshes produced by the continuous decrease of these areas. In the case of the Eastern Scheldt, the process of sand demand, provoking erosion and accentuating the ever-steeper slopes of the salt marshes, causes this reduction of surface. This ultimately affects their vegetation. For the second subtype, salt marshes inside the dikes, the quality is threatened by the reduction of salt and brackish seepage flow. Regarding the future prospect, the main threat is the unchanged management of the area that is affecting the sedimentation process. Moreover, sea level rise will accelerate the submersion of this habitat.

Salicornia and other annuals colonizing mud and sand (H1310)

This habitat is present in South Holland, Zeeland and the Wadden sea. It includes pioneer vegetation that colonizes inundated muds and sands in the salt marshes. In the Eastern Scheldt, it covers an area of 139 ha (Natura 2000 data form, 2018). Two subtypes compose the habitat type: (i) Samphire (Salicornia), and (ii) Sea Pearlworton communities. According to the H1310 profile (2008), the Samphire subtype grows on high swallows and low salt marshes areas, prolonged daily flooded spots where high salinity gradient is present. Typical species of this habitat is the Salicornia and it forms the transition between tidal flats and the higher salt marsh vegetation. The Pearlworton subtype grows in areas that are flooded only by high water levels, and it forms the transition zone between salt marshes and dunes. The environment is characterized by a sandy, relatively nutrient-poor substrate with a varying salinity and fluctuating moisture content.

Following the assessment in H1310 profile (2008), the first subtype (Samphire) is greatly deteriorated in the Eastern Scheldt. It has a low vegetation cover, which highly depends on the sediments of the tidal flats and salt marshes. Due to the continuous erosion affecting tidal flats and salt marshes, the vegetation of this habitat type is threatened. Sea level rise and future subsidence can also increase this trend. The second subtype, Pearlworton, scores as favorable in all aspects of the assessment. Since this subtype grows on the transition between salt marshes and dunes, at a higher elevation, the consequences of sand demand or sea level rise might not affect yet.

Spartina swards (Spartinion maritimae) (H1320)

This habitat includes perennial pioneer grasslands of coastal salt muds dominated by periodic floods with strong brackish-salt water. It is formed by the species *Spartina* or similar grasses (H1320 profile, 2008). This habitat type is found in the Wadden sea and in the intertidal areas of the southwest of the Netherlands, sometimes together with the habitat Salicornia (H1310). In the Eastern Scheldt, this habitat covers an area of 208 ha. They are mainly located at the salt-marshes. As it has occurred in other countries, the *Spartina maritimae* has almost disappeared due to the loss of estuarine characteristics of the area, land loss after the Deltaworks, or due to its replacement by *Spartina townsendii*. This species was planted in the 90's to prevent erosion at the tidal flats and it is taking over the area (Natura 2000-gebieden, 2018; H1320 profile, 2008). As seen in other habitats, the relative drop in the marsh surface elevation by sand demand, which support this type of Spartina vegetation, can influence its loss due to continuous erosion (Roman et al., 1984).

According to the assessment table of the H1320 profile (2008), the disappearance of the typical species *Spartina maritimae* is what makes it scored very unfavorable.

Transition mires and quaking bogs (H7140)

This habitat type concerns peat forming vegetation that grows under relatively nutrient-poor to moderately nutrient-rich conditions. They present a large and diverse range of plant communities influenced by base-rich groundwater or surface water, which it is mixed with acidic, oligotrophic precipitation (H7140 profile, 2008). Although this habitat is divided in two subtypes, only one of them is present in the Eastern Scheldt: Peat bog (association *Pallavicinio-Sphagnetum*). It develops in low-lying peat areas after acidification of quaking bog and can also be found in peat areas with brackish water in North Holland. Here, the subtype covers a very small area, 0.2 ha (Natura 2000 data form, 2018).

According to the assessment of H7140 profile (2008), all aspects for this subtype do not perform adequately. The natural distribution is becoming weak and tenuous, and the extension of this habitat is declining nationally. Regarding the quality aspect, the balance between water of different origins and abiotic factors are difficult to manage even in places where management is adequate. Pressures for this habitat are the water quality and nitrogen from the air.

3.2.2. General ecological conditions and common causes of degradation

The hydrodynamics, such as tides and currents, and different gradients of salinity play a big role for the conservation of most of the habitats in the Eastern Scheldt. While some of the habitats require a high gradient of salinity, others find necessary a brackish-salinity water. According to Nienhuis and Smaal (1994) and more recent literature, the salinity gradient and hydrodynamics changed right after the completion of the Deltaworks. The compartmentalization of the Eastern Scheldt supposed a significant decrease of the freshwater inflow from the rivers. Moreover, even though the storm surge barrier was built to allow the tidal exchange, the tidal range was reduced from 3.7 m to 3.5 m, while the tidal volume and tidal velocity decreased by 30% and 13%, respectively (ten Brinke at al., 1994). The morphology and hydrodynamic changes led to an imbalance in the channels as explained section 2. The consequently erosion provoked by sand demand is therefore affecting the tidal flats and salt marshes. The surface of the tidal flats were reduced from 18,300 to 11,800 ha, while the surface of the salt marshes decreased from 1,725 to 643 ha right after the compartmentalization (Nienhuis et al., 1994; Natura 2000, 2017). The degradation of the tidal flats and salt marshes was predicted before the construction of the delta projects, however the erosion process turned to be faster than expected (van Zanten and Adriaanse, 2008). Sand demand is considered a long term bottleneck for many habitats located in the intertidal zone (Stuijfzand and Maas, 2015; Rijkswaterstaat et al., 2016); it influences the natural processes of erosion and sedimentation, affecting the surface and elevation of tidal flats and salt-marshes from which other habitats like Salicornia and Spartina highly depend on. The reduction of elevation and surface of the tidal flats has an impact on their time of exposure, the percentage of time these areas are exposed to air during low tide. This reduction may affect the availability of food present in these area, the time birds spend foraging for food, and the resting areas used for other species like the harbor seal (Delta Monitoring Plan, 2015). Thus, the disappearance of these habitats can ultimately affect the protection of several species. Since Natura 2000 contemplates the whole aquatic system as a tidal bay, and not anymore as an estuary, the loss of freshwater input required for habitats such as the Salicornia, is not considered as a threat. Another shared cause of degradation is sea level rise. It will accelerate the submersion of tidal flats and salt marshes, and can increase the wave loads on these areas. This again will have an impact on the habitats Salicornia and Spartina that depend on the surface of the tidal flats and salt marshes.

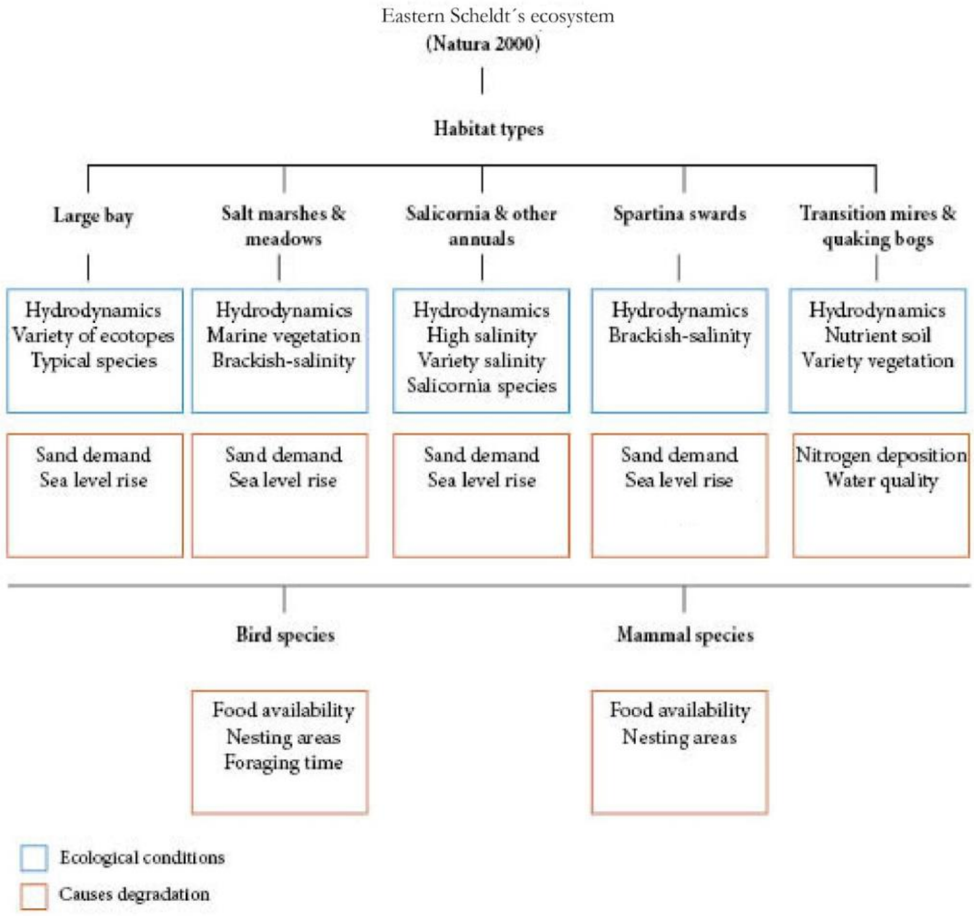

Figure 7. Chart of the Eastern Scheldt ecosystem in relation to its habitat types. It shows the ecological conditions for a good conservation and the shared causes of degradation. It also includes the general influences on birds and mammals. Source: own work.

4. Introduction to Building with Nature: the answer to Building in Nature

This section aims to introduce the approach Building with Nature (BwN). It also presents some successful interventions, and its main results. The strategies and solutions shown here are similar to the ones that will be studied for the Eastern Scheldt.

In the past, the implementation of hydraulic projects and coastal protection strategies did not pay much attention on the impact these projects had on nature and the ecosystem services it provides. These traditional measures are nowadays considered as mono-functional solutions, since they only attempt to protect humans and its assets (Vriend et al., 2014). Changes in flow regime, in sediment transport, and in morphology are some of the impacts that, for example, rivers and estuaries have experienced after the implementation of hydraulic projects within their ecosystem. These changes had, consequently, many undesired effects in valuable habitats and the species depending on them. In addition to these undesired effects, sea level rise worsen this prospect. These rigid structures are unable to adapt to changing situations, making them sometimes not cost-effective measures for the long term.

At the end of the 20th century, European laws emphasized the need to prevent, mitigate and compensate negative effects in the environment. In this new context, the approach Building with Nature emerges as new way of thinking, acting, and interacting when implementing hydraulic solutions. Thinking differently, because it takes a proactive approach instead of reacting when the problem has manifested. Acting differently, because it usually combines natural forces and innovative measures in order to reach better results. And interacting differently, because the design and implementation process of each solution requires the involvement of experts from different disciplines, problem owners, and stakeholders. Finally, this new construction philosophy also considers that an infrastructural solution can be multi-functional: protecting assets while creating opportunities for nature to develop.

This approach has been tested in a great number of projects around the world. A successful project well known internationally is the Delfland Sand Engine in the Holland coast. The Dutch coast has been traditionally maintained by small nourishments, a nature-friendly solution but also a reactive strategy: when the coast's retreat exceeds a given reference, a small amount of sand is replenished. This sand is placed every 5 years approximately, creating a state of disturbance every time it buries the current ecosystem with new sand, killing its organisms. To improve this situation, the Province of Zuid-Holland and Rijkswaterstaat implemented a mega-nourishment, 21.5 m3 of sand. The idea was that natural forces, such as waves, winds and currents, would distribute the sand slowly through the coast for the following decades. In this way, this strategy allows a better recovering of the ecosystem by decreasing the disturbance to the effects of only one nourishment (Vriend et al., 2014). Moreover, this mega-nourishment creates opportunities for nature, such as dune formation, pilot vegetation, nesting areas for birds and seals, and opportunities for recreational activities. It is currently considered the best place for kitesurfing. It has been proved that the lifespan of this measure, calculated as 20 years before its application, was underestimated. Nowadays, it is thought that it can last 50 years (Matthijs Boersema interview, Annex 2).

Other example consist in the use of the so-called ecosystem engineers. These special engineers create, modify or maintain the habitats in which they live through positive interactions between them and their environment (Walles, 2015). Dense seagrass, salt marsh vegetation, reef forming bivalves or mangroves are considered ecosystem engineers. Oyster reefs prove to be able to develop into self-sustaining reefs and contribute to coastal protection (Walles et al., 2015). The development of some experiments in the Eastern Scheldt conclude that ecosystem engineers as the oyster reefs can grow out into living persistent reefs, reduce erosion of intertidal flats through wave attenuation and trapping and detention of sediment, increase local diversity in a sandy habitat by providing a hard substrate habitat (Ecoshape, 2018).

5. Study of the pilot projects' area

This section focuses on the first of the six habitats described in section 3.2, large shallow inlets and bays, and in one cause of its degradation, the phenomenon of sand demand. As explained before, this habitat consists of the totality of the aquatic system of the Eastern Scheldt where tidal flats and sandbanks are located. This section elaborates on the consequences of sand demand in this particular habitat, since the pilot projects that will be studied later aim to mitigate those effects. In addition, this section introduces the tidal flats Galgeplaat and Oesterdam, and the nourishment pilot projects.

As introduced in section 2, due to the hydrology and morphology changes in the Eastern Scheldt caused by the compartmentalization, the main channels need to reach a new equilibrium for the reduced tidal prism and maximum flow velocities. The fulfillment of the channels by sediments is at the expense of the intertidal area. However, due to the reduction of tidal forces, these sediments are not able to return from the channels to the intertidal area and, consequently, the tidal flats and salt marshes are eroding. Right after the construction of the barrier, their surface was reduced from 183 to 118 km^2. More recently, Van Zanten and Adriaanse (2008) showed that the total intertidal area was reduced to 104 km^2 in 2001 (15 years after the construction of the barrier). This corresponds to a yearly loss of intertidal area of approximately 0.5 km^2 or 50 ha. This erosion also has other effects, such as the reduction in time of exposure of the tidal flats, which is decreasing 0.3 % per year (around 2 minutes per year) (De Ronde et al., 2013). This reduction of time of exposure affects the availability of food and the time birds spend in these tidal flats foraging for food. Moreover, the tidal flats provide a natural flood protection, dissipating wave energy and building land seaward by the accretion of sediments. The loss of this natural protection would increase the need of reinforcing the dikes around the Eastern Scheldt. Furthermore, tidal range reduces the inundation frequency in the highest zones of the estuary. It also increases the period that the tidal zone is exposed to wave energy, increasing the process of erosion. Finally, the reduction of tidal volume affects the residence time of the water in the Eastern Scheldt. The residence time increased from 1.5 to 3 months in the eastern part of the Eastern Scheldt, while in the northern part is longer than 3 months.

According to Brinke (1994), examples around the world have shown that the tidal range relates to the cross-sectional area of the channels in a linear way, leading to an equilibrium in the system. It was estimated by Rijkswaterstaat that the cross-sectional area of the tidal channels need to be reduced by 25% (with respect to the present situation). Koshiek et al. (1987) calculated the sediment deficit of the area, which is approximately 400-600 million m^3, 2 to 3 times the sediment volume stored in the tidal flats (see Figure 8). If this volume of sediments is not provided to the Easter Scheldt´s system and the compartmentalization continues as it is today, the tidal flats will drown eventually. Consequently, species depending on these tidal flats will disappear from this area in the future.

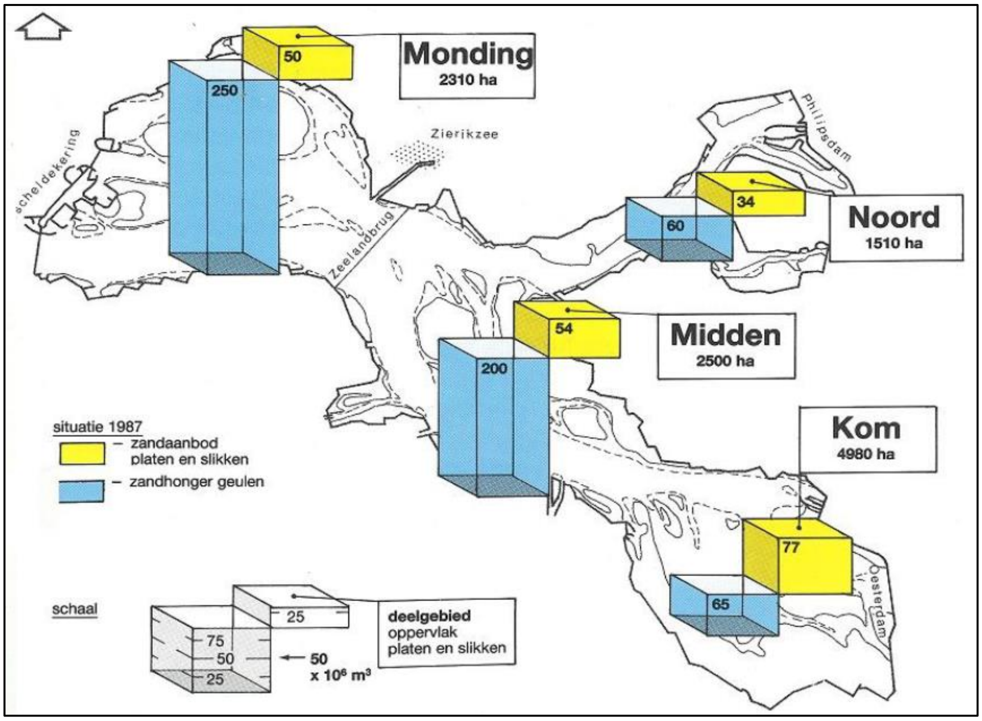

Figure 8. The volume of sand necessary to reach a new equilibrium in the Eastern Scheldt, 600 million m3 sand. The total volume stored in the tidal flats is 160 million m3. Source: Koshiek et al (1987).

In order to preserve the most valuable areas of the tidal flats, De Ronde et al. (2013) studied a number of options to recover or maintain the so-called core areas. These areas contain the majority of the birds. This study stated that restoring the morphological balance in the Eastern Scheldt is the most sustainable solution. However, removing the barrier and dams is not realistic in the short term. Small adaptations in the barrier hardly contribute to solve the problem of sand demand. Moreover, importing more than 400 million m^3 from the North Sea to reach the new equilibrium is unrealistic due economic reasons. Therefore, flexible and soft measures such as the nourishment of sand and the use of ecosystem engineers, such as oyster reefs, is the optimal short-term solution to maintain these core areas. It was estimated that maintaining the core areas would require 30 million m^3 of sand.

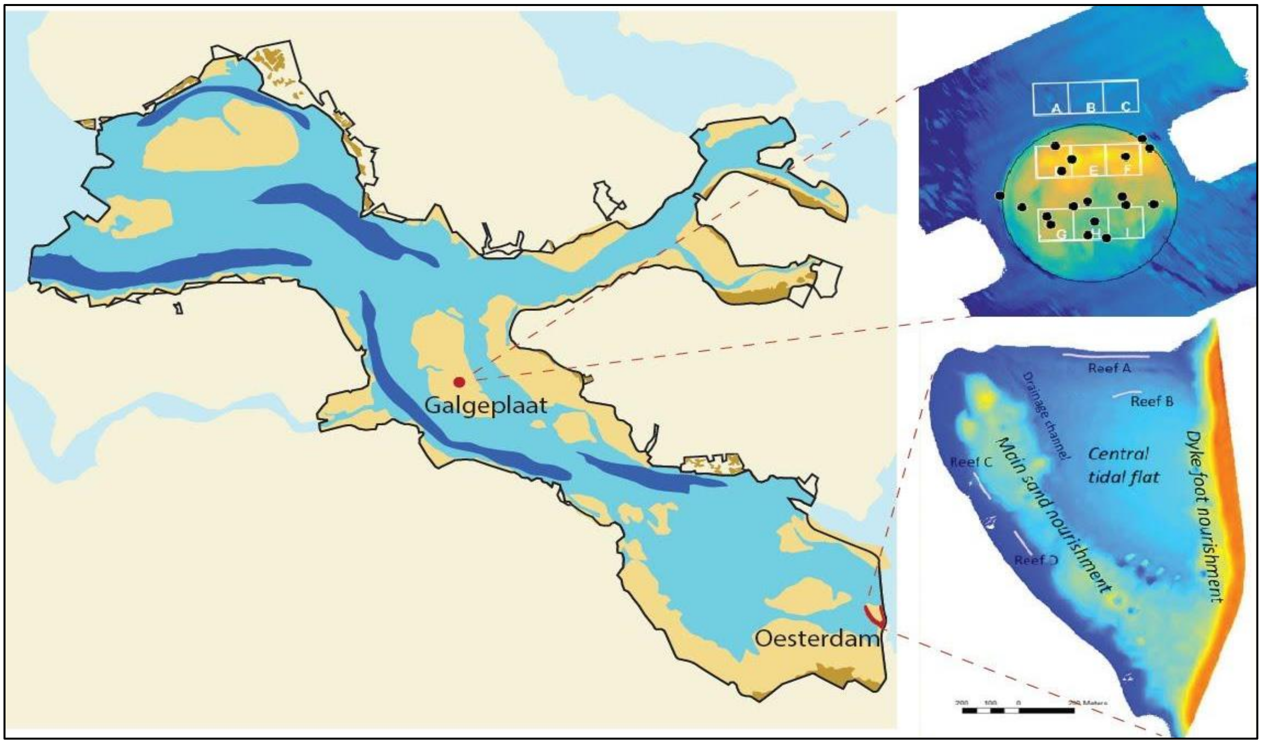

Figure 9. Eastern Scheldt map showing the location and shape of the pilot projects: Galgeplaat nourishment (top-right figure) and Oesterdam (bottom-right figure). Source: own work.

Following these suggestions, pilot projects were launched at five locations: sand nourishment in Galgeplaat, cascade nourishment at Schelphoek, constructed oyster reefs in Vianen and De Val, a dune foot nourishment at Sophiastrand, and sand nourishment in Oesterdam (Presentation Matthijs, 2018). Currently, a sand nourishment in Roggenplaat is being designed (Matthijs Boersema interview, Annex 2; Robert Jentink interview, Annex 2). This research focuses in the performance of the nourishments at Galgeplaat and Oesterdam (see Figure 9).

5.1. Introduction to the pilot projects

5.1.1 The Galgeplaat nourishment project

The Galgeplaat is one of the largest tidal flats in the Eastern Scheldt, located in the middle of the basin (see Figure 9). It is one of the areas strongly affected by erosion. Following Van Zanten and Adriaanse (2008), the surface of the tidal flat decreased from 1 to 0.96 km^2 between 1985 and 2001, while its average bed elevation was reduced from -0.32 to -0.65 m (NAP). This is a reduction of 33 cm, which gives an average erosion rate of 2 cm/year, approximately. Between July and September 2008, the nourishment was built in the central south area of the tidal flat. According to one of the main evaluation documents of this project, van der Werf et al., (2012), 130,000 m3 of sand were nourished following a circular shape in an area of 200,000 m2, which resulted in an average height increase of 65 cm. As the first constructed project in the Eastern Scheldt, it was considered an experiment. The main initial goal was to find out if nourishments were a suitable measure to maintain valuable habitat for bird life in order to apply this measure at other locations. The monitoring information about this project usually compares the undisturbed area (A, B and C in the previous figure) with the nourishment area (D, E, F, G, H and I).

5.1.2 The Oesterdam nourishment project

The Oesterdam is located in the southeastern part of the Eastern Scheldt, next to the small Markiezaat basin. After the construction of the Oesterdam´s dike, the exchange of water between the two basins, the Eastern Scheldt and Markiezaat, stopped. The height of the Oesterdam tidal flat has decreased by 25 to 50 cm since 1986 (Pezij, 2015). The information about this project usually refers to three different areas (see Figure 9): the main nourishment area, the dike foot nourishment and the central tidal flat, which was not nourished. Moreover, in addition to the nourishment, four constructed reefs were built (reefs A, B, C and D in Figure 9). Before the nourishment, the average height in the main nourishment area was -1.07 m (NAP), -0.70 m (NAP) in the central tidal flat, and -0.51 m (NAP) in the dike foot (Boersema et al., 2017). The nourishment started in November of 2013. The sand volume deposited this time was bigger than in the Galgeplaat; 350,000 m^3 of sand together with the construction of 4 constructed oyster reefs. The sand was artificially deposited in the foot of the dike and in the edge of the tidal in the form of a hook shape (see Figure 9). The goal of the measure was to decrease the negative effect of sand demand, protect the main central part of the tidal flat from erosion, and postpone the reinforcement of the dike for at least 25 years. The oyster reefs were built to stabilize the sand in the central tidal flat (reefs A and B) and to reduce erosion and wave energy on the main sand nourishment area (reefs C and D).

6. Monitoring data of the pilot projects and its evaluation

This section presents and studies the parameters concerning the morphology and ecology of the nourishment pilot projects. These parameters are part of the monitoring plan of the nourishments. This research collected them from different sources and completed them with the conduction of interviews and questionnaires to experts and participants in the execution of these projects. The aim of using these parameters is to investigate how pilot nourishment projects mitigate the effects of sand demand at the selected locations and to evaluate their contribution to Natura 2000 goals with regard to protected habitats and species. Since the main goals of these projects is to maintain the morphology and ecology of these area, its performance will be evaluated by comparing the before and after situation to the extent possible and by studying the development of the surroundings. Section 1.5 explains further the selection of these parameters.

6.1 Introduction to the individual parameters of the study

The next paragraphs provide a brief description of each parameter and the monitoring strategy used by experts during the implementation and evaluation of the pilot projects.

6.1.1 Parameters in relation to the mitigation of sand demand

Bed elevation (m NAP): this parameter measures the height of the nourished area and its development over the years after the replenishment of sand. The bed elevation of the area is developed by using the Real Time Kinematic (RTK) approach, which uses satellites to study position information. The images created using this parameter show the height differences between the nourishment area and the surroundings (see examples in Figure 10 and 14).

Sediment volume change (m^3): this parameter aims to evaluate the sediment loss's trend in the nourishment area. In addition to the height data derived from the RTK approach, the Digipol interpolation method is used. This is a model used by Rijkswaterstaat for height interpolations, and it was used in the monitoring plan for volume and erosion calculations. Besides the volume change, the lifespan of the nourishment is calculated for the Oesterdam nourishment interpolating the erosion rates (see examples in Figure 13 and 16).

Sedimentation and erosion patterns (m, cm): this parameter shows the stabilization of the nourishment after the replenishment of sand. This parameter also shows how the nourishment area may influence its surroundings by sediment deposition. The monitoring tools are the same as for the sediment volume change. The images created using this parameter show which parts of the nourishment are experiencing erosion and sedimentation (see examples in Figure 11 and 15).

6.1.2 Parameters in relation to habitat restoration

Time of exposure (% of time): this parameter calculates the percentage of time a location is exposed to air during low tide. This is an important ecological indicator for both birds and their food supply, benthic animals. When a location is exposed to air for longer periods, birds have more time to forage for food. However, high exposure time (above 60%) might affect benthic community structure, which prefers exposure times between 20-40% (van der Werf et al., 2015). Therefore, it is important to have exposure times that benefit both birds and benthos. The exposure time is computed using the bed level elevation data from RTK surveys and water level data from a nearby station (see example in Figure 19).

Benthic community [species richness (number species), biomass (mg AFDW m^2), density (ind m^2)]: Food supply for waders consists essentially of benthic animals located in the tidal flats (mollusks, worms, shrimps, etc). The new replenishment of sand kills all these organisms. Therefore, is crucial for these nourishment projects to evaluate how fast the benthos recover. For this indicator species richness, density and biomass are evaluated. These parameters are mostly analyzed using information about the before and after the implementation of the projects, In the Galgeplat case, the nourished area is also compared to an undisturbed area (not nourished). In the case of the Oesterdam, three areas are compared, the two main nourishments and the central part which is not nourished. The monitoring of this indicator sometimes combines two types of methodologies: analysis of sediment samples in laboratory (small and big organisms using microscopes), and analysis of sediments at the field (only big organisms, less detailed) (see examples in Figure 20, 22 and 23).

Foraging time (minutes): this parameter evaluates the total or average minutes that birds spend in the nourishment or surroundings areas foraging for food. It is also a good indicator of the quality of the habitat. It is compared with the pre-values at the same location (before the nourishment) and with the surroundings (undisturbed areas). This parameter is usually calculated by individuals (private companies and bird experts) at the field that observe the behavior of the birds, making, sometimes, distinction between foraging or not foraging behavior, and type of species (see example in Figure 25).

6.1.3 Parameters in relation to number of animals

Birds and mammals counts (number of individuals): Since the pilot projects mainly aim to mitigate the consequences of sand demand, this research focuses on the monitoring data available of those species affected by this degradation process. According to the Monitoring Plan (2016) these species are:

- Mammals: harbor seals
- Coastal breeding birds: pied avocet, kentish plover, common ringed plover
- Waders: grey plover, red knot, sanderling, dunlin, bar-tailed godwit, eurasian curlew, common redshank, common greenshank, ruddy turnstone, and eurasian oystercatcher.

This study aimed to gather counts of these species before and after the nourishment in order to evaluate their contribution to Natura 2000 goals. Surprisingly, none of the projects analyzes them for a good comparison. Thus, in order to obtain data that can provide insights for final conclusions, this study uses the birds and harbor seal counts calculated for the whole Eastern Scheldt (see Table 4), and the results of two interviews conducted to the individuals in charge of this evaluation. This is not optimal, and therefore this study proposes some recommendations at the end of the research.

6.2. Study of the parameters of the pilot projects

This section evaluates the parameters described previously for both pilot projects to conclude whether they are (i) mitigating the problem of sand demand, (ii) contributing to the Natura 2000 with regard to the restoration of the habitat, and (iii) contributing to the Natura 2000 with regard to the protection of birds and harbor seal.

6.2.1. Mitigation of sand demand in Galgeplaat and Oesterdam

Sand demand in the Eastern Scheldt is producing a net erosion in the tidal flats. The goal of these nourishment projects is to maintain the most valuable areas of the tidal flats. In order to evaluate if these pilots are performing as expected, this research shows information collected in relation to the indicators of bed elevation, sediments volume change, and sedimentation and erosion patterns before and after the implementation of the nourishment.

The Galgeplaat pilot project

The replenishment of new sand in the Galgeplaat produced several morphological changes in the area and its surroundings. Before the nourishment, the bed elevation of this area varied from -0.8 to -0.5 m (NAP) (Van der Werf et al., (2012). Figure 10 shows the development of bed elevation right after the implementation of the nourishment between 2008 (right after the implementation of the nourishment) and 2012. In October 2008 the bed elevation increased, especially in the northern area of the nourishment. Heights varied between -0.6m (NAP) in the south, to +0.4 m (NAP) in the north part. This is a significant increase in the nourishment when compared to the surroundings, which are predominantly under mean sea levels. The biggest morphological changes happen during the first year after the implementation (between 2008 and 2009). After 2009, the nourishment flattens and becomes more stable. Although the nourishment becomes more homogenous over time, in 2012 the northern areas are still predominantly higher than the southern areas. As shown below in the next parameters, this heterogeneity has an effect in the erosion patterns, since higher areas usually erode faster due to the higher influence of wind forces. Moreover, these differences in height also have an impact in the benthic community.

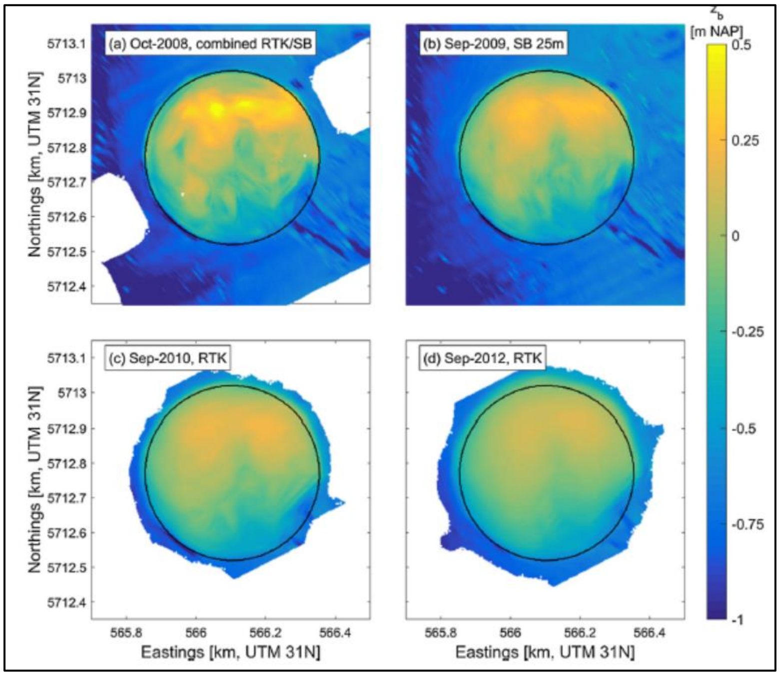

Figure 10. Morphological evolution of the Galgeplaat nourishment: in October 2008 (just after construction), September 2009 (after 1 year), September 2010 (after 2 years) and September 2012 (after 4 years). Source: van der Werf et al. (2015).

The nourishment is influencing the surroundings. Wind forces erode the higher areas and place these sediments in the closest areas around the nourishment. Figure 10(d) shows how a small area located in the north next to the nourishment is increasing its elevation. This can be confirmed by the sedimentation and erosion patterns shown in Figure 11.

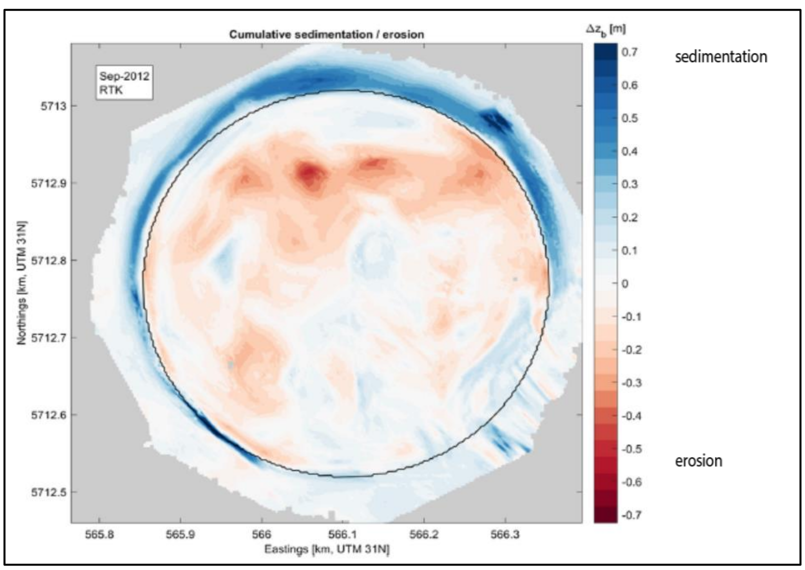

Figure 11. Cumulative sedimentation and erosion of the Galgeplaat nourishment in September 2012, four years after the construction. Source: van der Werf et al. (2015).

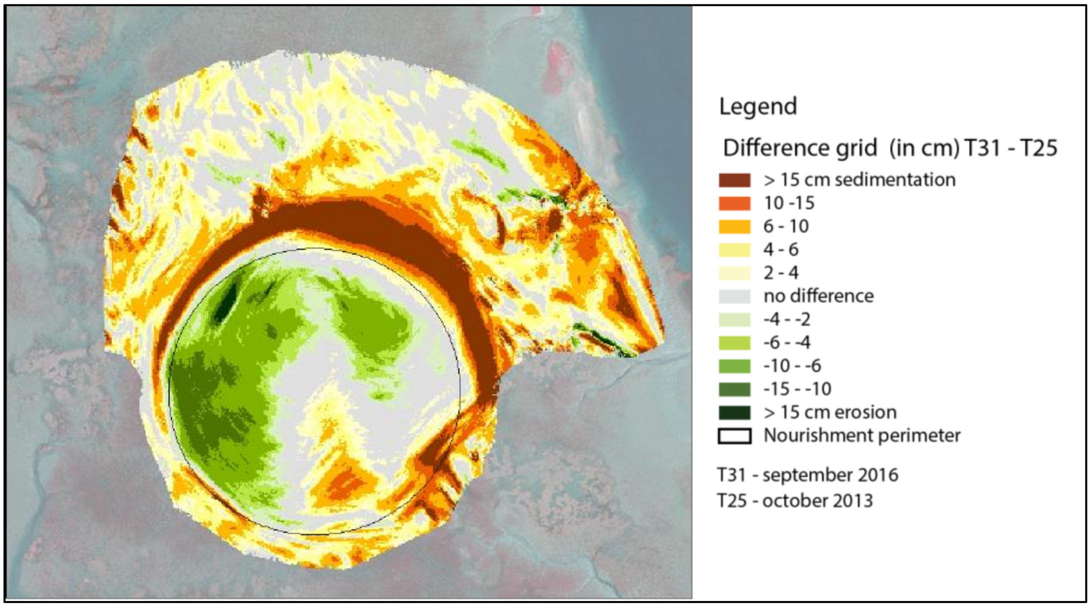

Figure 12. Cumulative sedimentation and erosion of the Galgeplaat nourishment from October 2013 to September 2016. Source: Jentink (2016)

According to Van der Werf et al., (2012), the higher, northern parts of the nourishment eroded faster than the rest of the nourishment. Figure 11 suggests that sediments move to the north outside the nourishment, and thus this area experiences a stronger sedimentation. This suggests that the nourishment not only increases the bed elevation at the project location but also at the the surroundings over the years, improving a larger area than expected in the initial plan. Jentink (2016) again confirms this trend. Figure 12 shows the sedimentation and erosion changes produced between 2013 and 2016. The nourishment area together with its surroundings seem to experience more sedimentation (red areas) than erosion (green areas). The hypothesis is that sediments are also coming from the south-west of the tidal flat (Robert Jentink interview, 2018).

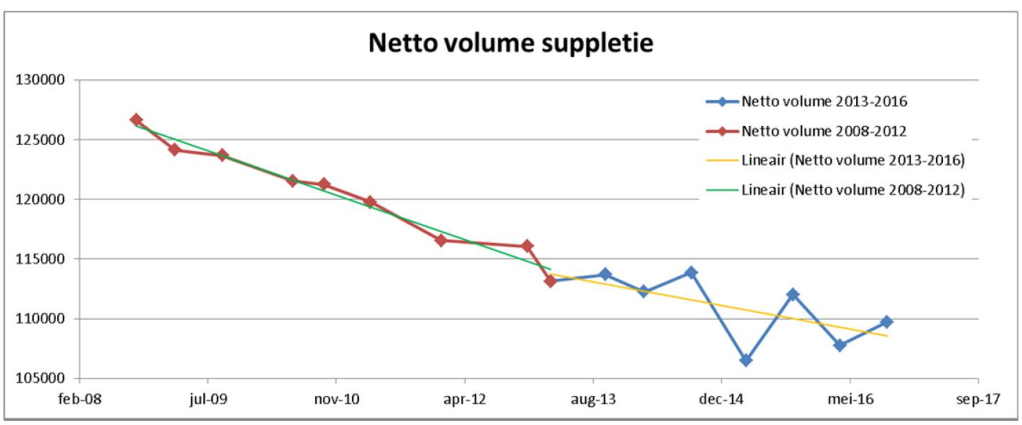

Figure 13. Net sediment volume change in the period 2008-2016. Red and blue lines represent the sediment volume changes over the years, while the green and yellow lines represent the linear trends for the two periods. Source: Jentink (2016).

Finally, Figure 13 shows the sediment volume changes from 2008 to 2016. From 2008 to 2012, the nourishment lose 17,000 m^3, 10% of its initial volume (red line in Figure 13). This corresponds to an average erosion of 1.5-2 cm/year. After 2012, this erosion process appears to be slower (yellow line). From 2012 to 2016 only 3,000 m^3 were lost. This decrease in volume changes since 2012 confirms that the nourishment becomes more stable over the years; when the nourishment reduces its elevation over the years, it becomes less vulnerable to wind forces. Moreover, the nourishment also experiments a big seasonal pattern, especially since 2013, losing more sediments in winter than in summer. This can be due to harder storm and wind conditions during winter than during summer.

These are all, in general, good results with regard the mitigation of sand demand. The nourishment is increasing the elevation of the areas and influencing the surroundings by sedimentation processes. Robert Jentink from Rijkswaterstaat confirmed these results. He stated, during the interview for this research (Robert Jentink interview, Annex 2), that the nourishment is performing better than expected, staying longer than previously predicted, and improving also the surroundings.

The Oesterdam pilot project

As it happened in the Galgeplaat pilot project, the replenishment of new sand in the Oesterdam produced several morphological changes in the area and its surroundings. Figure 14 shows the bed elevation changes between 2013 (before the nourishment) and 2016. As it shown in section 5.1.2, the Oesterdam project consists of three areas: the dike foot area, the main nourishment area, and the central tidal flat. Before the nourishment, their average elevations were (NAP) -0.51 m, -1.07 m and -0.70 m, respectively (Figure 14, T0). Right after the nourishment, their elevation changed to (NAP) 0.78 m, -0.28 m, and -0.73 m, respectively (Figure 14, T1). This is an elevation improvement of 1.27 cm for the dike foot area, and an increase of 37 cm for the main nourishment area. The central tidal flat remained with the same elevation since it was not nourished. As it happened in the Galgeplaat nourishment, the bed elevation suffered a significant increase after the implementation of the project, and over the years it became slightly flatter. The central tidal flat does not seem to experience many changes. One of the reasons can be that this area is better protected due to the nourishments at both sides.

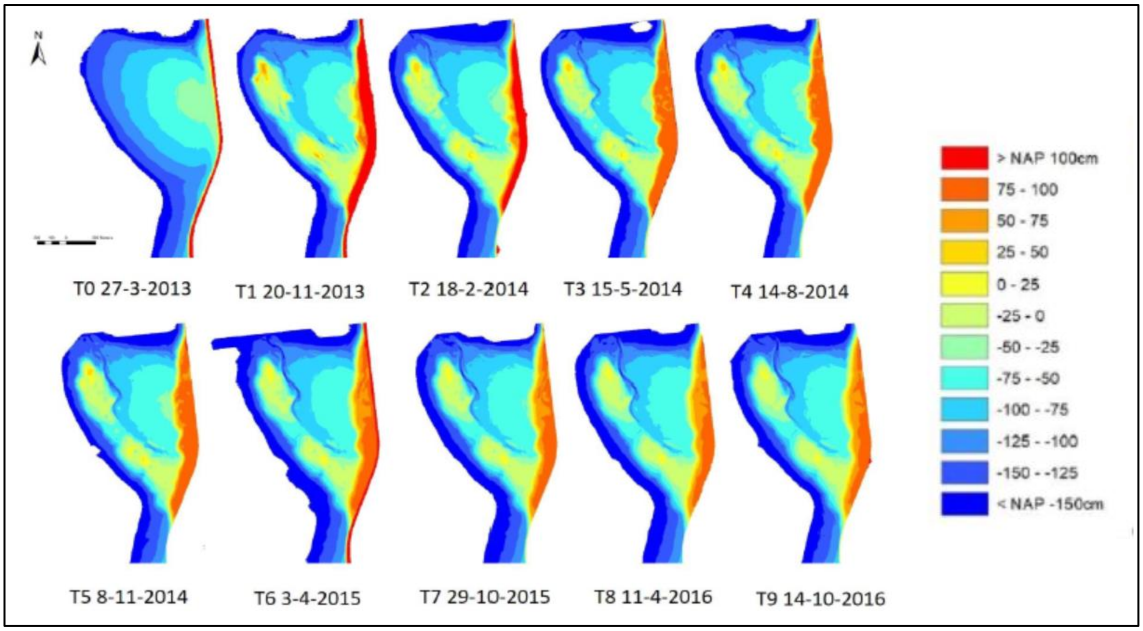

Figure 14. Bed elevation maps of the study area over the period: March 2013 until October 2016. Source: Boersema et al. (2017).

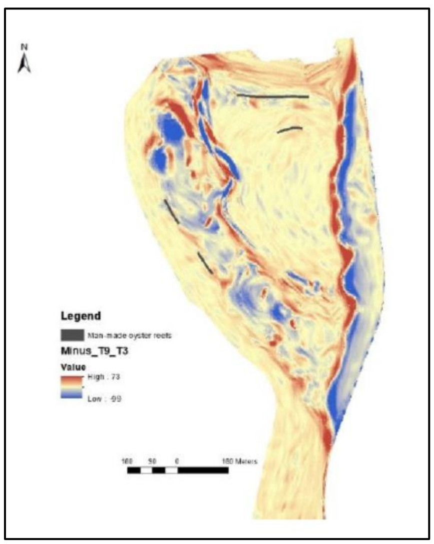

Figure 15. Erosion (blue) and sedimentation (red) map over the period May (T3) 2014 until October 2016 (T9). Source: Boersema et al. (2017).

Figure 15 shows the sedimentation and erosion patterns between 2014 and 2016. Both the main nourishment area and the dike foot area are eroding, although there are some sub-areas that are not. The dike foot dike shows a stronger erosion than the rest of the areas. The main nourishment area experiences stronger erosion especially in the north. The central tidal flat, in contrast, experienced little changes over these years. Sediment volume changes (see Figure 16) confirms the latter; the dike foot experiences a faster erosion rate than the main nourishment area (see Figure 16, grey and cyan color lines). This is caused by the differences in heights; areas with a higher elevation, as the case of the dike foot area, are more vulnerable to wind forces, and they therefore erode faster. Three years after the replenishment of new sand, in 2016, the average height of the main nourishment and dike foot were (NAP) -0.34m and +0.61 m, respectively.

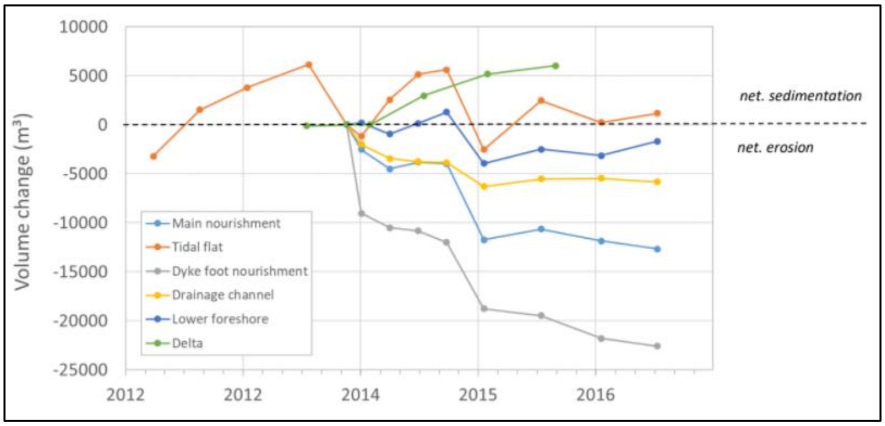

Figure 16. Volume changes from November 2013 to June 2016. Values below the value 0 experience net erosion, values above 0 experience net sedimentation. Source: Boersema et al. (2017).

The volume change of the central tidal flat, the area to be protected from erosion, fluctuates around a value of 0 (see Figure 16, orange line), meaning that it mainly stays stable. According to Boersema et al. (2017), the main nourishment area is eroding at a rate of 2cm/year, while the dike foot area is eroding faster, at a rate of 5 cm/year. For the Oesterdam pilot, Boersema et al. (2017) also calculated the lifespan of the nourishments using linear regressions of average height. The main sand nourishment can last until 2030-2035 (20 years, approximately), while the dike foot may last longer, until 2040-2045 (30 years, approximately). However, these estimations are just an indication due to the inability to predict future storms (Boersema interview, 2018).

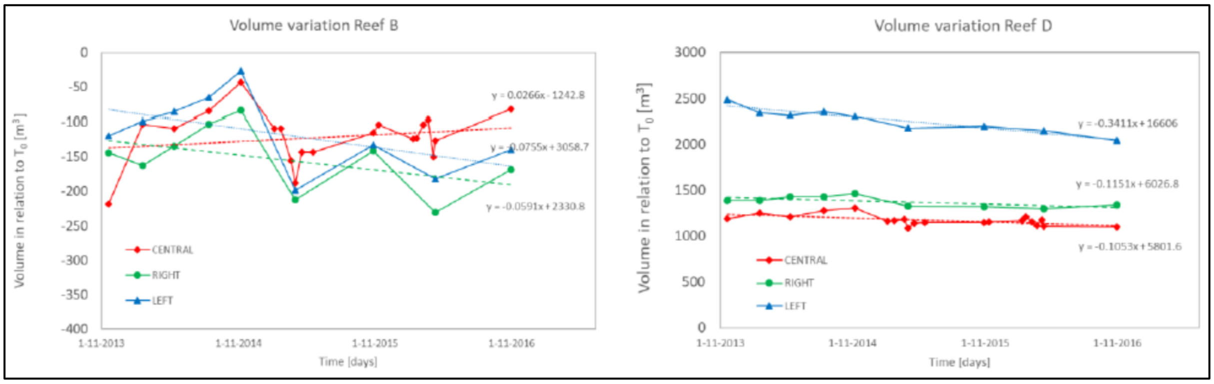

Figure 17. Total volume variation (CENTRAL, red line) on reef B and D in m3. The rate of change expressed in the charts is in m3/day. The reference areas (LEFT and RIGHT, blue and green lines) are similar in dimensions and characteristics but located on the left and right of each reef at a certain distance to make sure that they are outside the influence area of the reefs. Source: Boersema et al. (2017).

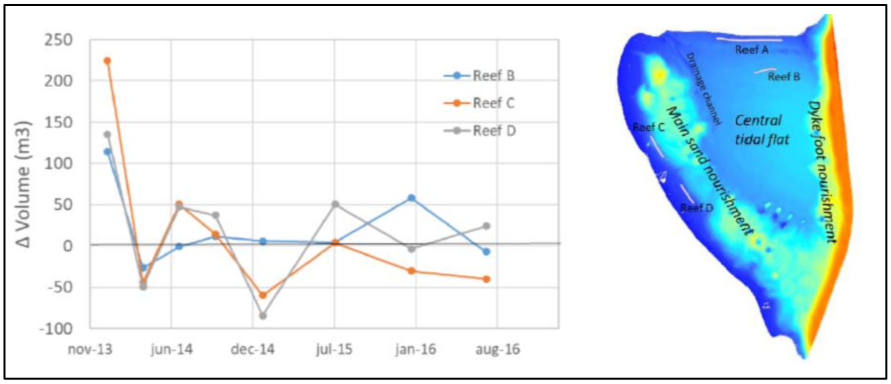

Figure 18. Difference between sediment loss or sediment accretion between the area behind the reef and the reference area. If area behind the reefs (B, C, or D) are behaving equal as the reference areas than ΔV = 0. When ΔV = positive than the area behind the reef are collection more sand than the reference areas.

In contrast to the Galgeplat pilot project, in the Oesterdam project four constructed oyster reefs were built with the additional objective to reduce erosion and capture sediments. The monitoring of these reefs showed that the oyster reef B located in the central flat performed better than the rest. Figure 17 shows that reef B captures sediments while areas next to the reef are eroding. The same figure also shows that, in the case of reef D, the results are negligible. Figure 18 exhibits a small positive effect in sedimentation in the range of 0 to 50 m3 for reef B, while reefs C and D are fluctuating around zero. According to Boersema et al. (2017), the use of more constructed reefs in the future might have a higher impact. Constructed reefs are considered good adaptation strategies since they can adapt to changes such as sea level rise. However, Matthijs Boersema, during the interview for this research (Matthijs Boersema interview, Annex 2), stated that more research is needed, since their impact in the Oesterdam project was lower than it was initially expected and their construction can increase considerable the costs of the project.

As in the Galgeplaat case, the results of the nourishment in the Oesterdam nourishment with regard the mitigation of sand demand are positive. It is performing, in general terms, as initially expected. The nourishment increased the bed elevation of the dike foot area and the main nourishment area. The central tidal flat remains stable over time, not suffering erosion due to its better protection. The oyster reefs, although with a small influence, are benefiting the stabilization of the nourishment and tidal flat. According to the lifespan calculation, this area will stay preserved at least 20 years.

6.2.2. Habitat restoration in Galgeplaat and Oesterdam

One of the consequences of sand demand is the disappearance of habitats needed for the species that depend on them. Due to the reduction of surface and height of these tidal flats, time of exposure is also reduced. This influences the availability of food (benthos) and the time birds spend in these areas foraging for food. However, the nourishment has immediately negative effects in the area. The replenishment of new sand on the top of the original sand surface kills all the microorganisms at the project location. Therefore, the monitoring of these pilot projects intends to evaluate the changes in time of exposure, how fast the recovery of benthos develops after the disappearance of the initial benthic community, and the time birds spend in the area foraging with respect the original situation and the surroundings. In order to evaluate whether these pilots projects are performing as expected, this research shows information collected in relation to time of exposure, benthic community, and foraging time before and after the implementation of the nourishment.

The Galgeplaat pilot project

The following figures show the ecological information of the Galgeplaat in relation to the quality of the habitat. Figure 19 shows bathymetry images with their respective time of exposure. These images were only developed for the year 2008 (before and after of the nourishment) and for the year 2012. Even with only three bathymetry graphs, the information exhibited is relevant to understand the changes at this location. Before the nourishment, the largest part of the area was exposed 30-40% (see Figure 19(a)), a low value for birds to get the necessary energy by foraging. Right after the nourishment, in 2008, the exposure time increased significantly (see Figure 19(b)). According to Van der Werf et al., (2012), 11 ha were exposed to air more than 50% of the time and almost 1 ha was exposed more than 60% of the time. In 2012 (Figure 19(c)), the effect of the nourishment was still clearly visible, almost the entire area is exposed to 40-60% of the time. This is a good result, although more recent bathymetry images would have provided more information about its development over the years. As explained above in the definition of this parameter, theoretically, a value between 40 and 60% maintains a balance for both benthos availability and foraging time necessary for birds. Since the nourishment is not homogeneous, the differences in time of exposure have an impact in the development of benthos.

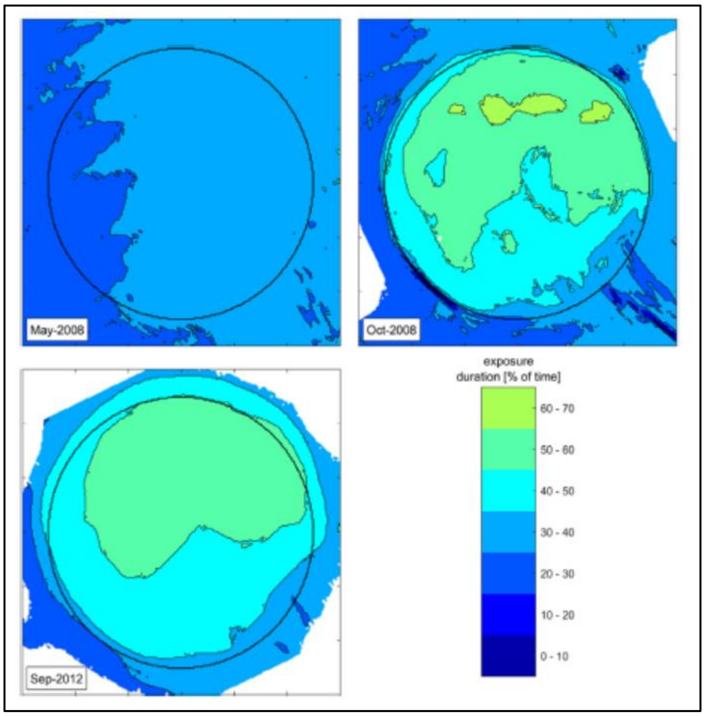

Figure 19. Exposure time just before (May 2008) the nourishment, just after (October 2008) the nourishment, and 4 years after (September 2012) the nourishment. Source: van der Werf et al. (2015).

The following figures (Figure 20, 21, 22 and 23), show data with regard to benthos (species richness, density and biomass) in the area and in the surroundings. In relation to species richness, data was collected between 2008 (before the nourishment) and 2016. This data compares the nourishment area to an undisturbed area over time. Figure 20 shows data between 2008 and 2012 based on a measurement performed in laboratory. Since 2013, species richness measurements were developed directly in the field. This method used in the field is simpler, only counting organisms larger than 1mm (Robert Jentink interview, Annex 2). Figure 21 shows data between 2013 and 2016 based on this latter type of measurement. Figure 22 shows data in relation to benthos density between 2008 and 2012. Here, again, the nourishment area is compared to an undisturbed area over time. Since 2012, benthos density is not available. Lastly. Figure 23 shows data collected in relation to benthos biomass between 2008 and 2016. This graph was developed using different sources.

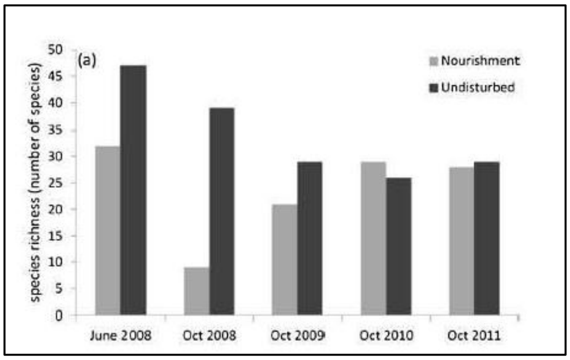

Figure 20. Species richness (total number of species observed) between June 2008 (before the nourishment) and October 2011. Source: van der Werf et al. (2015).

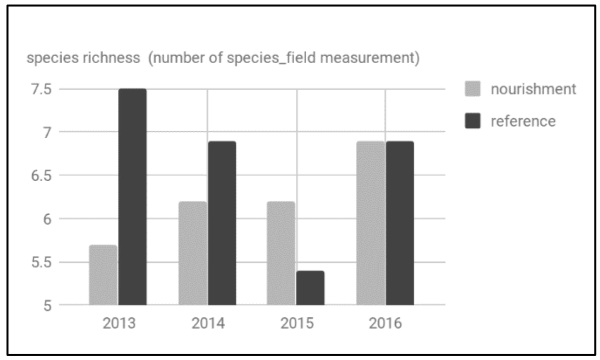

Figure 21. Average number of species per year between 2013 and 2016. In contrast to the previous graph, this table used a less detailed method in the field, in which only the organisms larger than 1 mm were counted. Source: Jentink (2016).

In June 2008, before the nourishment was built, total species richness in the undisturbed area was 47 taxa, whereas in the area where the nourishment was going to be constructed species richness was lower. Average density and biomass were also higher in the undisturbed area, although not significantly. Just after the nourishment, October 2008, species richness, density and biomass suffered a significant decline at the location of the nourishment. This was expected since the replenishment of new sand kills all microorganisms at the early beginning. Since 2009, all parameters start to recover but with some differences. Species richness seems to reach in 2011 almost the same value as the year before the nourishment. Since 2013, species richness in the nourishment area suffered a decline, and it remains below the values of the undisturbed area for some years. In 2016, species richness reaches again same values as the undisturbed area.

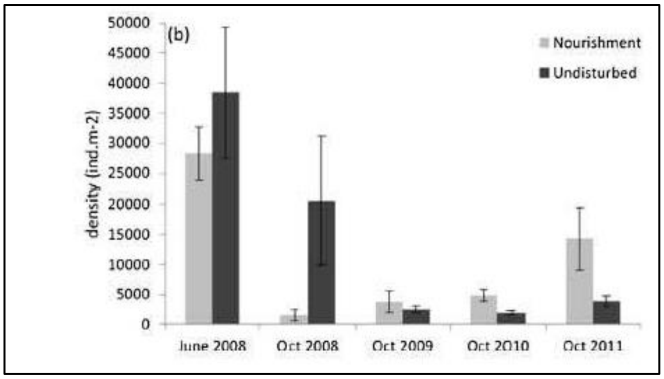

Figure 22. Average density at the nourishment and in the surrounding undisturbed area between June 2008 (before the nourishment) and October 2011. Source: van der Werf et al. (2015).

In relation to benthos density, Figure 22 shows that, after the expected decline in density in 2008 after the implementation of the project, density starts to recover although slowly. In 2011, density in the nourishment is higher than in the undisturbed area. However, values in the nourishment have not reached the values before the nourishment. Surprisingly, the undisturbed area also suffers a decrease until 2010, and in 2011 it seems to start again its recovery.

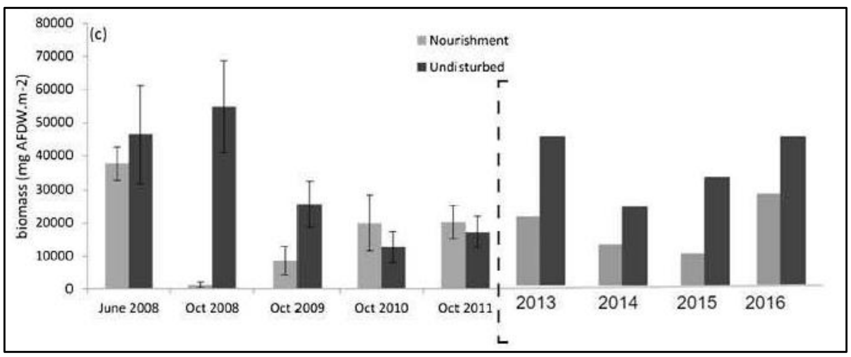

Figure 23. Average biomass at the nourishment and in the surrounding undisturbed area between June 2008 (before the nourishment) and 2016. Source: own work using the following references: van der Werf et al. (2015) and Geene et al. (2017).

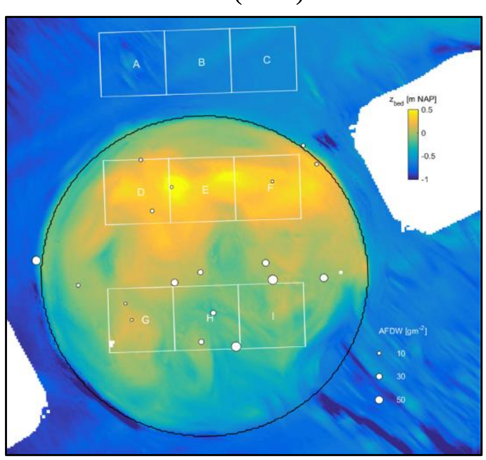

Figure 24. Biomass in gram/m2 at the different sampling locations on the nourishment in the fall of 2011. Source: van der Werf et al. (2015).

Regarding benthos biomass, Figure 23 shows that, after the expected decline in biomass in 2008, values starts to recover but with high variations. Biomass in the nourishment area increases until 2013, and then it decreases again until 2015. In 2016, biomass experiences a significant increase. However, values in 2016 are still below the values before the nourishment. According to Rienk Geene (Rienk Geene interview, 2018), ecologist in charge of the evaluation of benthos biomass since 2013, the results are unexpected. He expected that, 8 eight years after the constructed nourishment, the biomass would have recovered the original values of the year before the nourishment. Therefore, in his opinion the nourishment is not performing as it should, or it may need more years to recover. However, when looking at the performance of the three parameters together, all values in the undisturbed area suffer also high fluctuations over the years. This can mean that both areas, the nourishment and the undisturbed area, are highly influenced by the yearly dynamics happening in this central area of the Eastern Scheldt. Therefore, it can also be a reason why the recovery of benthos is slow in the nourishment area. Nevertheless, there is also some direct influence of the nourishment in the area, which can be seen in Figure 24. This graphs shows that the southern area of the nourishment contains higher values of biomass than in the northern area. This is due to the differences in bed elevation. The northern areas, as the last section showed, has a higher bed elevation than the southern areas. This influences the appearance and development of benthos, since they prefer areas that are wet for a longer period. Robert Jentink and Rienk Geene (Robert Jentink interview, Annex 2; Rienk Geene interview, Annex 2), stated that a good level of moisture is very important for the development of benthos, and the nourishment area in Galgeplaat project dries up quickly, especially the northern areas.

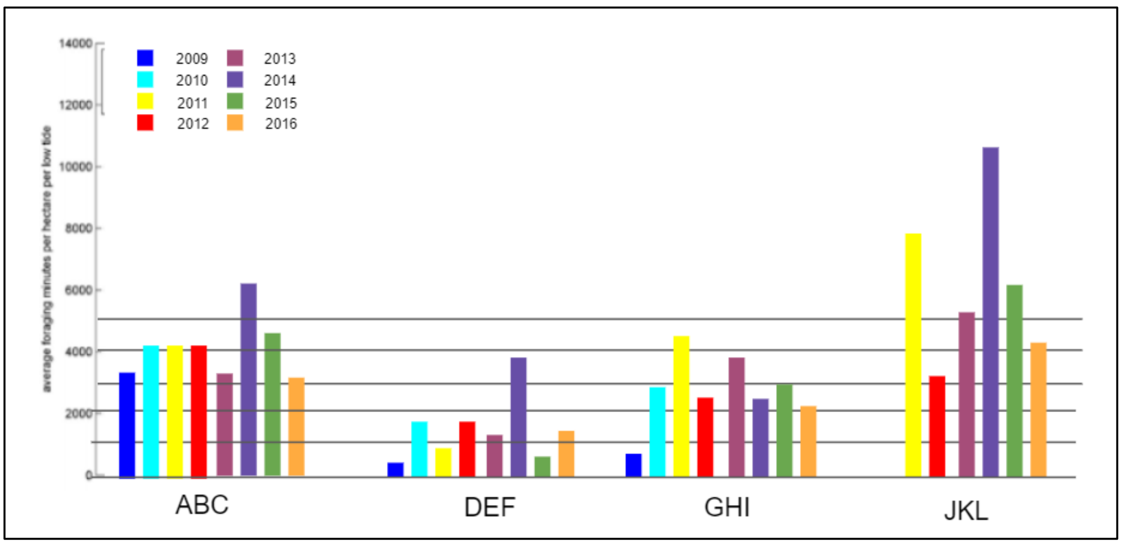

Figure 25. Average foraging minutes per hectare per low tide for areas ABC (reference), DEF (northern part nourishment), GHI (southern part nourishment) and JKL (reference) from 2009 (right after the nourishment) to 2016. Source: own work using the following references: van der Werf et al. (2015) and Geene et al. (2017).

Figure 25 shows the foraging time of birds in the nourishment area and in the undisturbed area between 2009 and 2016. The graph is divided by the designated areas: ABC (undisturbed area in the north), BCD (northern area within the nourishment), EFG (southern area within the nourishment), and HIJ (undisturbed area in the south of the tidal flat) (see right-top corner in Figure 9 for the designation of areas). According to Van der Werf et al., (2012), the average foraging time for all species present in the area per hectare was 2790 minutes per low tide.

Figure 25 shows that, since 2009, all areas experience fluctuations over the year. However, foraging time in the undisturbed areas (ABD and HIJ) are higher than in the areas within the nourishment, especially the areas JKL. Within the nourishment, there exists some differences as well. The southern area of the nourishment (areas GHI) shows higher foraging time than the northern area (areas DEF). This is due to the relationship between bed elevation, time of exposure and benthos availability. As shown above, the bed elevation in the southern area is lower than in the northern area. This influences time of exposure, being the southern areas less exposed to air during low tide. Time of exposure can influence the distribution of benthos biomass, which in 2011 was clearly higher in the south (Figure 24). Therefore, birds spend more time in the southern area than in the north of the nourishment due to the higher availability of food. Looking at the results displayed in Figure 25 with regard foraging time, it could be concluded that the nourishment area (areas DEF and GHI) hardly reach the original average value of 2970 foraging minutes. This is not a good results. However, this study also calculates the average time of the whole area, displayed in Table 2 below, by taking into consideration the nourishment areas and the closest undisturbed areas (ABC-DEF-GHI).

	2008	2009	2010	2011	2012	2013	2014	2015	2016
Average foraging time	2790	1955	2900	3083	2716	2733	4133	2700	2166

Table 2. Average foraging time for the areas ABC - DEF - GHI together. The area JKL was not included due to its distance from the nourishment. Source: own work.

The aim of this calculation is to evaluate whether the nourishment has improved foraging time for the whole area. As stated before, the average foraging time per hectare was 2790 before the nourishment (year 2008 in Table 2). After the nourishment, the foraging time suffers a significant drop. This is due the fact that the nourishment killed the majority of all available food. Since 2010, the average foraging time recovers that initial value of 2970 minutes and continues to improve for the majority of the subsequent years. This calculation for the whole area shows better results. This is confirmed by Robert Jentink (Robert Jentink interview, 2018), who stated that the purpose of the nourishment was to improve the whole area (nourishment and surroundings). Now birds can start foraging earlier than before and spend more time in the area due to the nourishment.

In light of the foregoing, it is concluded that time of exposure improved and the average foraging time of birds per hectare has recovered the original values (when measuring together both the nourishment and surrounding areas). However, the benthic community have not reached the values before the nourishment, meaning that the recovery of benthos is still slow in this area. Besides these results, something to take into account is that this project was the first nourishment pilot developed in the Eastern Scheldt. The results and lessons learnt in this first project were applied in the development of the next pilot project, the Oesterdam project. One of the lessons learnt, according to Robert Jentink (Robert Jentink interview, 2018), was that the nourishment was too steep, making more difficult for the benthic community to develop well. In addition, tidal flats are naturally formed by sand, silt and organic matter, which keep the surface wet longer. However, the nourishment consists of only one type of sand, which causes the area to dry faster. This situation will be different in the Oesterdam project.

The Oesterdam pilot project

The following table and graphs show information about the quality of the habitat in the Oesterdam before and after the nourishment. They have been developed using several sources. However, information with regard foraging time was not possible to find.

	Main nourishment	Central tidal flat	Dike foot
T0 (March 2013)	≃20%	≃30%	≃40%
T3 (April 2015)	43%	29%	64%

Table 3. Time of exposure before and after the nourishment. Source: own work using the following references - Boersema et al. (2017) and Zwarts et al. (2011).

Before the nourishment (see row T0 in table 3), the time of exposure of the main nourishment, central tidal flat and dike foot were, approximately, 20%, 30% and 40% respectively. As shown before these values are low because they do not provide enough time for birds to forage. Right after the nourishment, time of exposure increased in all areas except in the central tidal flat, which area was not nourished and kept the same elevation. In 2015 (see row T3 in table 3), the changes in time of exposure were still noticeable. In the main nourishment and the dike foot, time exposure has a value of 43% and 64%, respectively. The central tidal flat remains with a similar value, 29%. These are good results. As it was previously explained in the definition of this parameter, theoretically, areas with a time of exposure between 40 and 60% are ecologically important for the Easter Scheldt.

With regard benthic community, Figure 26, 27 and 28, show information in relation to species richness, density and biomass before and after the replenishment of sand. However, the biomass value before the nourishment was not available and, therefore, values of the central tidal flat are used for comparison.

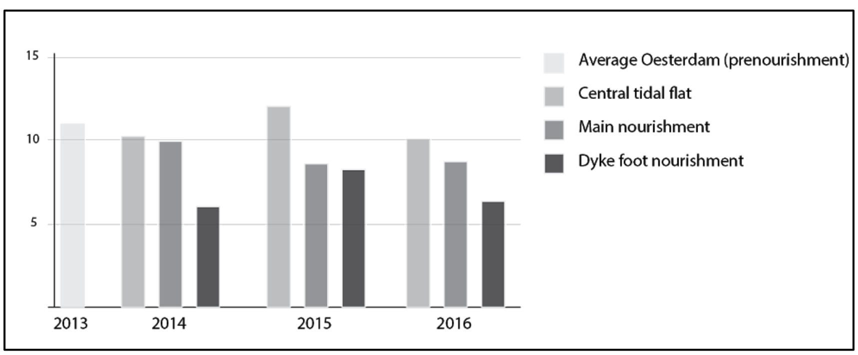

Figure 26. Species richness (average number of taxa per sampling station) in 2013, 2014, 2015 and 2016 on the central tidal flat, main sand nourishment and dyke foot nourishment respectively. Source: own work using the following references: Boersema et al. (2017) and Ysebaert et al. (2017).

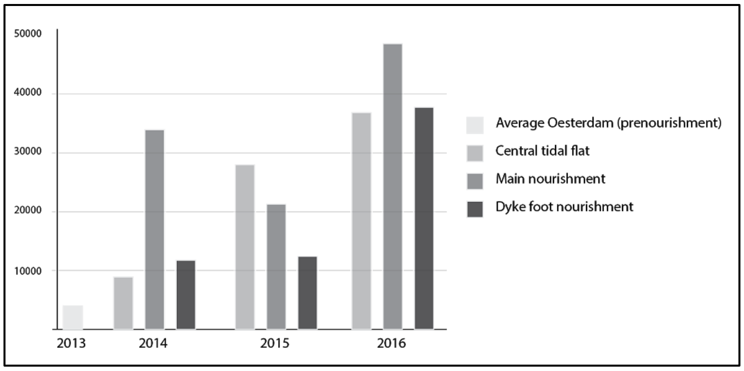

Figure 27. Average benthic density (ind/m2) and average biomass (gAFDW/m2) in 2013, 2014, 2015 and 2016 on the central tidal flat, main sand nourishment and dyke foot nourishment respectively. Source: own work using the following references: Boersema et al. (2017) and Ysebaert et al. (2017).

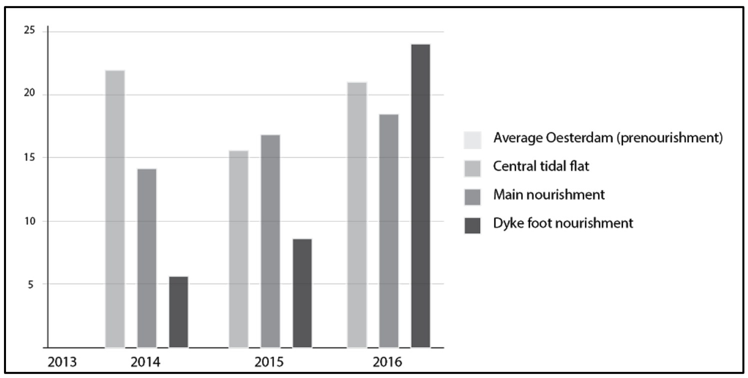

Figure 28. Average benthic biomass (gAFDW/m2) in 2013, 2014, 2015 and 2016 on the central tidal flat, main sand nourishment and dyke foot nourishment respectively. Source: own work using the following references: Boersema et al. (2017) and Ysebaert et al. (2017).

Figure 26 shows species richness. Before the nourishment, the Oesterdam had an average value of 11 number of taxa. One year after the nourishment, both the main nourishment and the dike foot areas had recover to similar values, although the dike foot values was lower. The rest of the years, none of the areas do not experience significant changes. Total density of benthos values shows large variation among areas and years but, overall, density increased significantly compared to the average pre-conditions, also in the central tidal flat. Lastly, the total biomass value also shows an improvement. Even though an average biomass value of the pre-conditions was not available, when the nourished areas are compared to the central tidal flat it can be seen that the nourished areas have significantly lower values in 2014. This may be due to the replenishment of new sand. However since 2015, the main nourishment area has already reach the values of the central tidal flat and, in 2016, all three areas have similar values.

In general, benthos in the Oesterdam seem to recover well. Species richness does not show significant changes, and density and biomass increase over time. The dike foot area always show lower values due to the higher elevation. Interestingly, when comparing these results with the result of Galgeplaat, benthos in the Oesterdam seem to recover faster and with fewer fluctuations over the years. This can be attributed to a better nourishment design, due to the lessons learnt from the Galgeplaat case. Benthos benefited from the protection that the nourishments provide at the internal edge of the main nourishment area. This allows the appearance of benthos hotspots at several locations (Boersema et al., 2017). Moreover, the design of the Oesterdam allows better connection with water, increasing moisture and benefiting a faster recovery of benthos (Matthijs Boersema interview, 2018). All this should provide a good baseline for birds to forage. However, information with regard the foraging time could not be found during the sources review and the execution of interviews. According to Boersema et al., (2017), foraging time increased after the nourishment. However, it does not show any information that can confirm this affirmation. Therefore, the present study can not show any conclusion in relation to foraging time.

6.2.3. Animal life in Galgeplaat and Oesterdam: bird and mammal counts in the Eastern Scheldt.

The ultimate objective of the nourishment pilots is to investigate whether tidal flat nourishments are a good management measure to maintain valuable intertidal habitat for animal life.

In the Eastern Scheldt, there are two species of mammals, 4 species of breeding birds, and 37 species of non-breeding bird that are protected by Natura 2000. Nevertheless, according to the Delta Monitoring Plan (2015), sand demand supposes a bottleneck for the conservation objectives of only some of them. San demand affects the conservation of some species because if either area or the time exposure in the tidal flats diminish further, the number of birds can significantly decline in the near future (De Ronde et al., 2013). Since the pilot projects mainly aim to mitigate the consequences of sand demand, this section only focuses in the monitoring data available for those species that are affected by sand demand, which species were discussed in Section 6.1 above.

However, the monitoring data with regard to bird and harbor seal counts was not available for any of the nourishment pilots. In the Galgeplaat, only foraging time was calculated. In the Oesterdam, neither foraging time nor bird counts sufficient for a proper comparison were found. A similar parameter, bird density per hectare, was calculated. However, this parameter lacked information about the preconditions of the area. This was surprising since the Delta Monitoring Plan (2015) proposes that counts or similar parameters should be monitored in the Eastern Scheldt. According to the Delta Monitoring Plan (2015), the organization in charge of any measure in the Eastern Scheldt should be also in charge of the monitoring of the conservation objectives regarding Natura 2000.

In order to overcome the lack of data regarding bird and harbor seal counts for both projects, this research studies the whole Eastern Scheldt for which data was available. This analysis renders, at least, a broader picture on the conservation status of birds and harbor seal in the Eastern Scheldt since the development of the first pilot project. Although this is not optimal, it is necessary to reach some conclusions for this second part of the study, and to generate the first insights for the final part of this research. In this analysis, official reports from Rijkswaterstaat "Watervogels en zeezoogdieren in de Zoute Delta" (in English: Water birds and marine mammals in the Salt Delta) from 2007 (a year before the nourishment in Galgeplaat) until 2016 were used for the calculations. "Watervogels en zeezoogdieren in de Zoute Delta" is a series of annual documents that show the monthly counts of every protected species in the Delta. This research uses these counts to calculate the yearly average of every selected species affected by sand demand. In addition, these first results are compared to the objectives assigned for each of the species by

Natura 2000. These designated objectives are gathered from the document Natura 2000 Deltawateren (2016). The following table shows the evolution of the harbor seal and the different bird species affected by sand demand over the years for the whole Eastern Scheldt area and its comparison to the Natura 2000 goals. In addition, a trend (negative, positive, unclear) is shown at the end to provide additional information about their development over the last decade.

Species (EN)	2007-2008	2009-2010	2010-2011	2012-2013	2014-2015	2015-2016	Natura 2000 goal	N2000 STATUS	TREND
Pied avocet	922	559	555	411	421	473	510	NO	-
Kentish plover	50	55	57	44	34	23	50	NO	-
Grey plover	4812	5391	5078	4898	4738	4024	4400	unclear	unclear
Red knot	8940	7913	3047	4667	3586	5049	7700	NO	-
Sanderling	765	604	572	733	486	1009	260	YES	unclear
Dunlin	19465	18127	14587	14941	16042	15328	14100	YES	unclear
Bar-tailed godwit	3986	5025	5106	4620	4535	4220	4200	YES	unclear
Eurasian curlew	11423	13247	13007	11669	12357	12235	6400	YES	unclear
Common redshank	2306	1875	1857	1097	1033	1047	1600	NO	-
Common greenshank	132	167	169	106	64	77	150	NO	-
Ruddy turnstone	1164	972	997	793	740	597	580	YES	-
Eurasian oystercatcher	22456	25345	24142	21509	16994	16777	24000	NO	-
Common ringed plover	322	212	302	186	179	165	280	NO	-
Harbor seal	130	214	296	418	533	605	200 (regional)	YES	+

Table 4. Birds and harbor seal counts from 2007 to 2016, the Natura 2000 goals assigned for every species, its current status, and its trend. Source: own work using different sources.

According to De Ronde et al. (2013) the 1300 ha of intertidal area lost since 1987 in the Eastern Scheldt has not led to a marked decrease in numbers of birds, with the exception of the oystercatcher. However, this research, although using only data from 2006, partially disagrees with this opinion.

The table 4 shows that the mammal harbor seal and the bird species sanderling, dunlin, bar-tailed godwit, eurasian curlew and ruddy turnstone reached the objectives assigned within the Natura 2000 goals (see column Natura 2000 status, green cells). However, the bird species pied avocet, kentish plover, red knot, common redshank, common greenshank, eurasian oystercatcher and common ringed plover did not achieve the objectives proposed (see column Natura 2000 status, red cells). For the grey plover the achievement of the objective is unclear. These results show that half of the species selected for this research are not well protected in the whole area of the Eastern Scheldt. Besides this, the last column of Table 4 shows the trend that these species are following over the years since 2006. The results in this column are even worse. All bird species show a declining or unclear trend, being the mammal harbor seal the only species that shows an increasing trend in its numbers.

Since there is not information available for the pilot projects that can be used to confirm or rebut these broader results, there is no way to conclude whether the nourishments are improving the situation of the animal life that depend on the tidal flats. Mark Hoekstein, one of the authors of the sources used for this part, confirms the results and conclusions of Table 4 (Mark Hoekstein questionnaire, Annex 3). He stated that, in addition to sand demand, other disturbance factors are affecting these locations, for example, large areas open to the public with very little regulation. According to Mark Hoekstein "there has to be done a lot more research on the complete life-cycle of these species, starting with 'Integrated Population Monitoring', which combines studies reproduction, recruitment, mortality, migration, etc". It is concluded that, in general, an analysis of the Natura 2000 goals with regard to bird species do not render a positive great picture for the whole Eastern Scheldt. The results in section 6.2.1 and 6.2.2 shows that nourishments are mitigating the problem of sand demand and restoring to some extent the habitats. These results may contribute to the protection of the species depending on them. For this reason, it should be mandatory for every measure developed in this area to plan and to monitor bird counts before and after the implementation of the project, or similar parameters. By doing this, it could be analyzed and evaluated which strategies have a positive impact on birds. This should be combined with the integrated population monitoring strategies proposed by Mark Hoekstein in order to study further the causes of declining trends.

7. The effectiveness of future nourishment projects in the Eastern Scheldt

The previous sections discussed sand demand as one of the main causes of degradation of the Eastern Scheldt, and the use of sand nourishments as a way to mitigate this problem on the tidal flats and support the animal life that depend on these habitats. As stated before, De Ronde et al. (2013) investigated the problem of sand demand in the Eastern Scheldt and concluded that the best short-term solution was the use of soft and flexible measures, such as the use of sand nourishments and ecosystem engineers. De Ronde et al. (2013) is based on past climate scenarios; it assumes a sea level rise of 60 cm by the end of the century (moderate scenario in KNMI´06). De Ronde et al. (2013) estimated that, assuming 60 cm of sea level rise from 1990 to 2100 (24 cm over the period 2010-2060), in 2060 about 65% of the tidal flats area will remain, when compared with the area in 2010. Moreover, by the end of the century, only about 40% of these tidal flats will remain, again compared to 2010. This is a big concern, since this study stated that the majority of the bird species are predominantly located in the 50% of the total tidal flats. Thus, De Ronde et al. (2013) concludes that in order to maintain these "core areas" for birds (this 50% of the total tidal flats), approximately 30 million of m^3 of sand is necessary, at a cost of approximately 165 million €. However, in 2014, KNMI, the national data and knowledge institute for climate science of the Netherlands, launched new estimations regarding climate scenarios. If the same moderate scenario is taken today, the Eastern Scheldt will suffer an increase of 10 cm of sea level rise by the end of the century compared to the past climate scenario, totaling 70 cm.

Figure 29. Picture taken during the multidisciplinary group discussion on 21 June 2018. From left to right: Pieter Bart, Robert Jentink, Matthijs Boersema, Christiaan Tenthof van Noorden, and Floor Arts.

The idea behind this final part of this research is to discuss the effects of sea level rise under the KNMI´14 climate scenarios on the effectiveness of sand nourishments and on the Eastern Scheldt itself. To achieve this, a multidisciplinary expert group discussion was organized in one the offices of Antea Group. The coordinators of both pilot projects studied, Robert Jentink and Matthijs Boersema, and the biologist in charge of bird counts for the whole Eastern Scheldt, Floor Arts, were invited. Moreover, Pieter Bart and Christiaan Tenthof van Noorden, civil engineers from Antea Group, joined the conversation. The intention of this expert group discussion was to gather expert judgement on how the new climate scenarios may affect the effectiveness of the nourishments, discuss if they can be considered cost-effective solutions, and gather insights about the future of the Eastern Scheldt. This facilitates the identification of new areas for further research, for both Antea Group and future researchers, and the identification of recommendations for the future implementation of these measures in the Eastern Scheldt. During this discussion, a small presentation of the previous findings was exhibited and a list of questions were extensively discussed. The following paragraphs show the main conclusions of this expert group discussion.

One of the question discussed with the expert group was the implications of KNMI´14 scenarios for the future implementation of nourishments and for the Eastern Scheldt itself. The differences between KNMI´03 (past climate scenarios) and KNMI´14 (new and updated climate scenarios) were shown to the discussions group. The group discussed that, in a natural situation, the tidal flats can adapt and grow as sea level rises. However, since the storm surge barrier and the secondary dams are blocking the influx of sediments from the North Sea and rivers, sea level rise can result in a faster submergence of the tidal flats and an increase of wave attack and flooding in the Eastern Scheldt. This will have a negative impact in time of exposure and foraging time, which will decrease the biodiversity that depend on the tidal flats. Moreover, this will also result in a decrease of the nourishment's lifespan. Thus, in order to maintain the core areas suggested by De Ronde et al. (2013), more sand will be necessary in the future. This will undoubtedly increase the costs of the implementation of the nourishment projects. Experts agreed with these forecasts. It was argued that the nourishments are effective and feasible for the short-term (2020-2050). However, if these core areas are to be maintained in the long term (2100), a serious debate regarding the future of the storm surge barrier must take place. One expert stated that restoring the sediment inflow can be the only real solution for the problem of sand demand in the Eastern Scheldt, which will require the (innovative) adaptability or the complete removal of the storm surge barrier. However, another expert argued that only removing the barrier will not solve the problem of sand demand, since the total prism reduction of the area is also due to the compartmentalization produced by the secondary dams, such as Philipsdam and Oesterdam. It was stated that the Eastern Scheldt is the most important area for waders right now, so it should be really addressed its ecological value during the discussion of the future of the barrier. Thus, subjects that need to be addressed in order to take a decision about the future of the Eastern Scheldt and its compartmentalization is safety, the conservation of the tidal flats, and the ecosystem services that they provide. The storm surge barrier was designed for a sea level rise of 40cm. This means that in order to cope with the 70 cm that KNMI´14 forecasts, a new plan must be designed soon. This can be a good opportunity to address the ecological value and future of the Eastern Scheldt.

Another discussion point presented to the group was the identification of ways to improve the results of the nourishments in relation to habitat restoration and species protection. One expert argued that, thanks to the Galgeplaat project, it was discovered the importance that the level of moisture has for the recovery of benthos. Due to the lessons learnt from this project, areas in contact with water but also protected from dynamic conditions due to the nourishment's design experience a strong and fast recovery of benthos in the Oesterdam project. These conditions seem to benefit the benthic community and, therefore, it should be replicated in future nourishments. Another expert stated that the previous modelling and design of the nourishment was very important for the Oesterdam project. The objective of the Oesterdam project was double: the increase of safety and the protection of the tidal flat. Although these double objectives were met to some extent, there is a lack of knowledge as to whether the central tidal flat is receiving sediments from the main nourishment area. In addition, the wave energy dissipation in the dike seem to be lower than expected. Therefore, the model and design of the nourishment need special focus during the implementation of the project and should be improve in the future. With regard to the monitoring strategy, an expert stated that if the plan is to continue with nourishing strategies in the future, the monitoring process should be simplified. Only the first 2 or 3 years should be intensively monitored, in order to prove that everything develops as expected. This monitoring should include morphology changes and benthos recovery. After this intense monitoring period, the monitoring process of the next years should be simplified and spread over time. For example, the use of laboratory for the monitoring of benthos is costly, and it should be combined with measurementz in the field, which are cheaper and less detailed but still valuable. This would help economizing the monitoring, allowing other parameters to be included, such as bird counts.

The reinforcement of regulations in natural areas was also discussed. Currently, some of the preferred areas for birds are open to the public and for recreation activities. This is the case of the Oesterdam, for example, which experiences disturbance from bait diggers, kite surfers, the presence of domestic animals, etc. This creates a high disturbance on birds and the time they spend foraging for food. Nourishments or any other measure that aims to improve the conditions for animal life in the Eastern Scheldt should be combined with more regulations and restrictions to the public.

One of the recommendations proposed to the expert group during the discussion was the necessity to include bird and harbor seal counts in the monitoring strategy of each nourishment project. This would provide information about the projects' effectiveness to achieve Natura 2000 goals in relation to the species that highly depend on these habitats. One expert argued at the beginning that this type of monitoring strategies suppose a significant increase on the budget reserved for the monitoring. That was the reason why, for the Galgeplaat project, it was decided that monitoring foraging time would deliver conclusions concrete enough as to the quality of the nourishment. However, as stated above in Section 6.2.3, the Oesterdam project included the following parameter: bird density per hectare. This parameter is similar to the bird count parameter that this research recommends, as it can deliver conclusions about the contribution to Natura 2000. Data collected in the Oesterdam project regarding bird density per hectare was not included in this research because it lacks the pre-conditions of birds in the Oesterdam before the nourishment. This substantially complicates the assessment of to what extent birds benefit from the nourishment. In this respect, one expert argued that the next nourishment project, which is going to be executed in the Roggenplaat, will include bird counts. In fact, bird experts have been monitoring birds for the last two years , before the nourishment takes place, in order to obtain data regarding the pre-conditions in the area. This fact strengthens the recommendation already provided by this research: the monitoring of birds can show whether the nourishments contribute to Natura 2000 in relation to species protection. A participant suggested that since the nourishment projects have proved to benefit the closest areas, the monitoring of birds should include the surroundings of the nourishment project. This will increase the area of evaluation, improving the conclusions.

During the discussion of monitoring bird counts, on of the experts confirmed what Mark Hoekstein stated during the questionnaire submitted to him (see Annex 3): more research needs to be done regarding the bird populations and how relevant the tidal flats are for them during the different stages of their life cycle. That is the reason why this expert stated that the monitoring of bird counts at the project location should be combined by fundamental research on these threatened bird species at a higher scale (e.g. Delta, The Netherlands, and Europe). This research should aim to achieve an integrated population monitoring strategy including studies about reproduction, recruitment, mortality, and migration. The combination of bird count and integrated population monitoring strategy would help identify trends at different scales and provide indications about why bird species experience a decrease in number while the conditions of the habitat are improving.

The last discussion point presented to the expert group was how the future of the Eastern Scheldt looks like from the perspective of each expert. It was emphasized again by one of the experts that the results of the pilot projects developed in Galgeplaat and Oesterdam show that nourishments are suitable measures to maintain the core areas for the short term, until 2050. The estimation is that these nourishment projects can maintain the areas nourished for 30 or 40 years. This expert hoped that these measures become more accepted in the close future, as currently there is some opposition to them, especially from the fishery sector (mussel's farms). However, these measures are not intended to solve the problem of sand demand, and the tidal flats will eventually disappear. As stated by one of the experts, there are three plausible scenarios for the Eastern Scheldt: a closed system (current situation), a semi-open system (by the removal of the barrier), and fully open system (by the removal of the barrier and secondary dams). The first scenario, closed system, can not cope with the problem of sand demand and sea level rise. Tidal flats and the species depending on them will disappear from this area in the future within this scenario. The second scenario, the removal of the barrier, would restore to some extent the tidal prism, tidal range and the inflow of sediments. However, the original conditions would not completely recovered if the secondary dams remain. As a result thereof, the process of erosion of the tidal flats would continue, although probably at a lower rate. This can postpone the disappearance of the tidal flats, and give extra time to policy makers to decide on the future of the Eastern Scheldt. The third scenario, fully open system, will recover the original hydrodynamics and influx of sediments. This should allow the tidal flats to grow and adapt again to sea level rise. To all participants, this third scenario seemed the best option. One expert stated that recovering the natural state of the Eastern Scheldt is a better option than the current continuous maintenance through nourishments. However, another expert stated that there is not penalty imposed to the countries that do not reach the Natura 2000 goals in relation to habitat restoration or species protection. Therefore, recovering the natural state of the Eastern Scheldt only for ecological reasons may not be sufficient for policy makers.

8. Conclusions and recommendations

The goal of this study is to investigate whether strategies based on the approach Building with Nature can maintain valuable habitats of the Eastern Scheldt and support the animal life depending on them now and in the future. The study goals are attained by answering the research questions stated in section 1.4. This section show these answers. Firstly, the sub-questions are answered. Subsequently, the research question. These questions are stated again below. After these conclusions, this section presents a list of recommendations.

RQ: To what extent can strategies based on the BwN approach help to achieve Natura 2000 goals in the Eastern Scheldt now and in the future?

This main research question is divided in the following sub-questions:

- *Which ecological conditions characterize a good conservation of the habitats according to Natura 2000 goals in the Eastern Scheldt area? Are these habitats experiencing shared causes of degradation?*
- *To what extent pilot projects based on BwN have a positive impact on the processes that are degrading the ecosystem until now?*
- *Is there scientific evidence that pilot projects have contributed to Natura 2000 goals regarding habitat conservation and species protection at each location?*
- *How climate change under KNMI´14 scenarios might influence the effectiveness of these solutions and the future of the Eastern Scheldt?*

8.1 Conclusions

In this paragraph the research questions, as stated at the beginning of this chapter, are answered.

Which ecological conditions characterize a good conservation of the habitats according to Natura 2000 goals in the Eastern Scheldt area? Are these habitats experiencing shared causes of degradation?

According to Natura 2000 goals, the Eastern Scheldt consists of five habitats: (H1160) Large shallow inlets and bays, (H1310) Salicornia and other annuals colonizing mud and sand, (H1320) Spartina swards (Spartinion maritimae), (H1330) Salt marshes and meadows, and (H7140) Transition mires and quaking bogs. For almost all habitats in the Eastern Scheldt, the presence of hydrodynamics (e.g. tides, currents) and different gradients of salinity (e.g. high salinity gradient, brackish-salt water) of the water are required for their good conservation. The presence of hydrodynamics and gradients of salinity benefit typical marine and estuarine vegetation happening in these habitats. However, since the implementation of the Deltaworks, several changes occurred in relation to hydrodynamics and geomorphology in this area. These changes lead to the phenomenon of sand demand. The Eastern Scheldt is in need of a high volume of sand, and this is causing the degradation of some protected habitats, especially the large shallow inlets and bays, and the salt marshes. Tidal flats and salt marshes are experiencing a net erosion, and they are not able to build up due to the lower flow velocities of the water. Other habitats, such as Salicornia and other annuals colonizing mud and sand and Spartina swards, depend on the surface, elevation and sediments that these tidal flats and salt marshes provide. Therefore, the sand demand phenomenon is affecting all habitats except for the habitat transition mires and quaking bogs, habitat that is degrading due to other processes such as nitrogen deposition. In addition to sand demand, sea level rise accelerates the process of submersion of the tidal flats and salt marshes, and can increase the wave loads on these areas. This can have again impacts on other habitats such as Salicornia and other annuals colonizing mud and sand, and Spartina swards. Therefore, both sand demand and sea level rise can be considered shared causes of degradation in the Eastern Scheldt.

To what extent pilot projects based on BwN have a positive impact on the processes that are degrading the ecosystem until now?

This study selected two pilot projects based on the approach BwN, the sand nourishments in Galgeplaat tidal flat and Oesterdam tidal flat. Data collected on bed elevation, sediment volume change, and sedimentation and erosion patterns were used to evaluate the effectiveness of these nourishments in respect the mitigation of sand demand. Both nourishments projects proved to mitigate the effects of sand demand. Right after the implementation of the nourishments, bed elevation significantly increased at both locations. Over the years, they flatten and become more stable. The sediment volume change showed that the higher zones of the nourishments erode faster, as expected initially. In the case of the Oesterdam, the lifespan of the nourishments was estimated between 30 and 40 years. Although the lifespan of the Galgeplaat was not calculated, experts stated that it is lasting longer than expected. The sedimentation and erosion patterns showed that, under natural forces such as wind, the nourishments are influencing the closest surroundings. They do this by increasing the bed elevation of the surroundings through sediment deposition (Galgeplaat project), or by protecting these surroundings from erosion (Oesterdam project).

In the Oesterdam project, four constructed oyster reefs were built with the aim to reduce erosion and facilitate sediment deposition. These oyster reefs prove to grow as living and strong structures. They also prove to grow as sea level rises. However, their impact in reducing erosion and benefiting sediment deposition was lower than expected.

Is there scientific evidence that pilot projects have contributed to Natura 2000 goals regarding habitat conservation and species protection at each location?

Taking into consideration the same nourishments projects, data on the indicators of time of exposure, benthic community, and foraging time was collected to evaluate the restoration of the habitat. Regarding the contribution to Natura 2000 in relation to species, this research aimed to collect data on birds and harbor seal counts.

Time of exposure increased at both locations. After the implementation of the nourishments, both projects revealed a time of exposure ranging between 40 and 60%. These values maintain a balance for both benthos availability and foraging time necessary for birds in the Eastern Scheldt.

One of the disadvantages of using the nourishments is that they kill all organisms living at the project location due to the replenishment of new sand. It is crucial to evaluate how fast the benthic community recovers. The benthic community in Oesterdam project recovered very fast. After 3 years, species richness, density and biomass reached similar values at the three main areas. The design of the nourishment, which protects some areas from environmental dynamics while keeping them in contact to water and moisture, revealed to be very important for the development of benthic hotspots. In the case of the Galgeplaat project, the recovery is slower. Species richness have reached similar values as the undisturbed areas. However, after 8 years, benthic density and biomass are still experiencing some fluctuations and not reaching the values of the pre-nourishment. One of the reasons can be that the nourishment was not built homogeneously; the northern areas are higher than the southern areas. This can obstruct the spatial development of benthos. Data showed that the southern area of the nourishment is more suitable for the development of benthos, resulting in higher biomass in this area. Moreover, the design of the Galgeplaat nourishment lacks a close connection to water, affecting further the lack of moisture necessary for the development of benthos. Even though benthic community is taking more time to fully recover the initial conditions in the Galgeplaat project, the indicator of foraging time showed that the nourishment is benefiting birds. If in the analysis the surroundings of the nourishment are included, foraging time shows that birds are spending a little bit more time foraging for food than before the implementation of the nourishment. This supports the idea that the nourishment is not only improving the conditions of the area nourished, but influencing a bigger area. Due to the nourishment, birds can start foraging for food sooner than before. In the case of the Oesterdam project, no conclusion can be made regarding foraging time. The monitoring of this project lacks data regarding this parameter.

Surprisingly, none of the pilot projects studied for this research gathered suitable information on the species affected by sand demand, 13 bird species and the harbor seal. This research could only find available information about these species for the whole Eastern Scheldt. According to the available information and the Natura 2000 goals designated to each of the species, only half of the species affected by sand demand have reached their designated objective over the last decade. However, when evaluating the trends performed by these species, only the harbor seal show an increasing trend for the last decade. All bird species affected by sand demand show a decreasing or unclear trend in the Eastern Scheldt. The monitoring of the nourishment projects have not information to contradict this big picture, and therefore their contribution to Natura 2000 regarding species is unknown.

How climate change under KNMI´14 scenarios might influence the effectiveness of these solutions and the future of the Eastern Scheldt?

To answer this question, a multidisciplinary expert group was organized at the end of the research. Experts discussed that, in a natural situation, tidal flats would adapt and grow as sea level rises. However, due to the compartmentalization (barrier and secondary dams) of the Eastern Scheldt, these valuable areas may disappear in the future due to the changes in hydrodynamics and morphology of the current basin. Tidal flats are not able anymore to build up as sea level rises. Experts confirmed that sea level rise will, therefore, suppose a faster submergence of the tidal flats, an increase of wave attack, and an increase in flooding in the Eastern Scheldt. Subsequently, this will have an influence in time of exposure and foraging time, which will decrease the number of animals that depend on the tidal flats in the future. Moreover, the nourishments' lifespan will decrease, lasting less years than currently do. Thus, in order to maintain the main tidal flats areas, more sand will be needed in the future. This will undoubtedly increase the costs.

Experts concluded that strategies based on BwN, such as the use of nourishments, are effective and feasible for the short-term (2020-2050). However, if these core areas are to be maintained in the long term (2100) and sea level rise may increase 70 cm by the end of the century, a serious debate about the future of the Eastern Scheldt need to take place. There are three plausible scenarios for the Eastern Scheldt: a closed system (current situation), a semi-open system (by the removal of the barrier), and fully open system (by the removal of the barrier and secondary dams).

All participants agreed that the third scenarios is the best solution to avoid the complete disappearance of the tidal flats in the long term. However, there is not penalty imposed to the countries that do not reach the Natura 2000 goals in relation to habitat restoration or species protection. Therefore, recovering the natural state of the Eastern Scheldt only for its ecological value may not be sufficient reason for policy makers to act on this respect.

Combining the answers to the sub-questions, this study finally answers the main research question:

To what extent can strategies based on the BwN approach help to achieve Natura 2000 goals in the Eastern Scheldt now and in the future?

Strategies based on the approach of BwN have proved to mitigate the effects of the degradation process of sand demand. Sand demand is a shared cause of degradation within the ecosystem of the Eastern Scheldt, according to Natura 2000 goals. By mitigating the effects of sand demand, valuable areas and its surroundings can be preserved longer, slowing down processes of erosion. This will postpone the disappearance of valuable areas in the Eastern Scheldt.

Moreover, these strategies have proved to restore to some extent the quality of the habitats and their closest surroundings, influencing the availability of food and the time birds spend in these areas foraging for food. However, the parameter birds and harbor seal counts is lacking in both projects. All bird species are experiencing a decreasing or unclear trend within the whole Eastern Scheldt. Therefore, this research can not conclude whether these strategies are benefiting the protection of the species affected by sand demand in the Eastern Scheldt.

Sand nourishments are suitable strategies to maintain valuable areas in the short term (horizon 2050). However, they do not solve the problem of sand demand. Moreover, other causes of degradations, such as sea level rise, will have an impact on the effectiveness of these measures over the years. According to experts consulted during this research, if habitats and species are to be preserved and protected in the long term (horizon 2100) in the Eastern Scheldt, the best solution is recovering the former hydrodynamics and geomorphology of the basin. This means the removal of the barrier and the secondary dams.

8.2 Recommendations

During this study it appeared that there are several subjects that need extra attention. Therefore, a list of recommendations is presented, divided in two categories.

Future implementation of nourishments

- Sand nourishments or any strategy based on BwN that aims to support the animal life in the Eastern Scheldt, should include in the monitoring strategy the evaluation of species included in Natura 2000 network, especially birds. This can be done by evaluating the counts or similar parameters before and after the execution of the project. Another way is the evaluation of the project area with an undisturbed area with similar conditions as the project location. By doing this, the results can show to what extent the projects are contributing to Natura 2000 goals in relation to species protection. Since external factors can also affect the trends followed by these species, this monitoring at the project location should be combined with fundamental research at a higher scale (e.g. Eastern Scheldt, Delta, Europe). This research should include studies in reproduction, recruitment, mortality, and migration of these species. The combination of bird counts at the project location and integrated population monitoring strategy at a higher scale would help identify trends at different scales and provide indications about why bird species experience a decrease in number while the conditions of the habitat are improving.

- The monitoring strategy should be consistent at every location. It was found that some relevant indicators were lacking data about the conditions before the nourishment. Moreover, indicators like foraging time could only be found in one of the projects. By being consistent in the way parameters are collected and evaluated, projects with similar characteristics can be compared. This will provide conclusions about the suitability of the strategy in an area such the Eastern Scheldt.

- Some characteristics of the nourishment project located in Oesterdam proved to provide better results in terms of ecology. The protection that the nourishment provides to some areas and the close connection to water, were crucial for the fast recovery of the benthic community in the Oesterdam project. This should be taken into consideration in the future implementation of nourishments at other locations. Moreover, the oyster reefs proved to develop into living and strong structures as sea level rises. However, they had a low impact reducing erosion and facilitating sediment deposition. More research about where and how these oyster reefs should be located is necessary to increase their potential.

Follow-up study

- Sand nourishments have proved to be a suitable strategy to preserve valuable areas in the Eastern Scheldt in the short term (2050). However, due to the rise of sea level and the compartmentalization of the Eastern Scheldt, these valuable areas may disappear in the future due to the changes in hydrodynamics and morphology of the current basin. The Eastern Scheldt is a vital link in the migration of birds within Europe and an important resting area for harbor seals within The Netherlands. Losing this area in the future will have an impact on the species relevant for the European community. If the Netherlands wants to achieve Natura 2000 goals in this area in the long term, options to allow the tidal flats to adapt to sea level rise need to be investigated. Experts interviewed during this research stated that recovering the former hydrodynamics and morphology of the Eastern Scheldt (tidal prism, tidal range, and flow velocities) might be the only viable solution to achieve Natura 2000 goals. This means opening the storm surge barrier and secondary dams. However, this have an impact in flood protection. Hence, a serious debate about the value this area has in terms of ecology, economy, safety, and recreation may take place soon. This study proposes that follow-up research should study the implications of opening the barrier and the secondary dams in the current hydrodynamics and morphology of the Eastern Scheldt. This study should focus on whether tidal flats manage to build up again with the increase of tidal prism, tidal range and maximum flow velocities.

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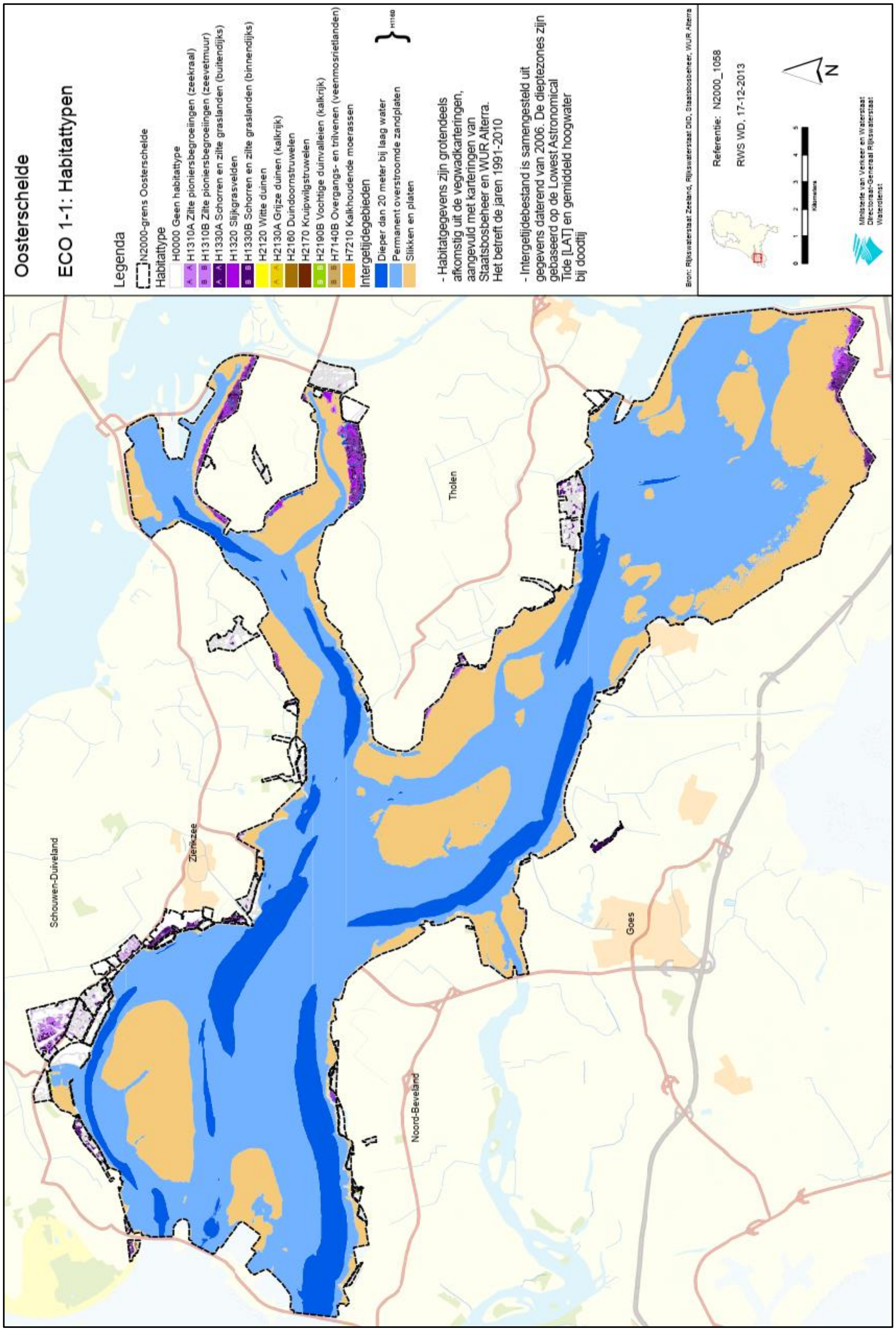
Annex 1


Oosterschelde
ECO 1-1: Habitattypen
Legenda
N2000-grens Oosterschelde
Habitattype
H0000 Geen habitattype
H1310A Zilte pioniersbegroeiingen (zeekraal)
H1310B Zilte pioniersbegroeiingen (zeevetmuur)
H1330A Schorren en zilte graslanden (buitendijks)
H1320 Slijkgrasvelden
H1330B Schorren en zilte graslanden (binnendijks)
H2120 Witte duinen
H2130A Grijze duinen (kalkrijk)
H2160 Duindoornstruwelen
H2170 Kruipwilgstruwelen
H2190B Vochtige duinvalleien (kalkrijk)
H7140B Overgangs- en trilvenen (veenmosrietlanden)
H7210 Kalkhoudende moerassen
Intergetijdegebieden
Dieper dan 20 meter bij laag water
Permanent overstroomde zandplaten
Slikken en platen
- Habitatgegevens zijn grotendeels afkomstig uit de vegwadkarteringen, aangevuld met karteringen van Staatsbosbeheer en WUR Alterra. Het betreft de jaren 1991-2010
- Intergetijdebestand is samengesteld uit gegevens daterend van 2006. De dieptezones zijn gebaseerd op de Lowest Astronomical Tide [LAT] en gemiddeld hoogwater bij doodtij
Referentie: N2000_1058
RWS WD, 17-12-2013
Tholen
Schouwen-Duiveland
Zierikzee
Goes
Noord-Beveland

Annex 2

The following paragraphs provide a summary of the interviews conducted to the experts: Rienk Geene, Matthijs Boersema, and Robert Jentink.

Interview to Rienk Geene

Rienk Geene is a biologist and an ecologist working in Habitat Advice. He studies the behavior of birds and the availability of food in the ecosystem: mussels, cockles and benthos. He is one of the ecologists participating in the monitoring evaluation of the Galgeplaat pilot project. He is in charge of the evaluation of benthic biomass in the nourishment and the foraging time of birds. He also participated in the analysis of benthos in Oesterdam pilot project, and in other similar projects for Rijkswaterstaat.

The following paragraphs show a summary of the interview that took place the 19th March of 2018 in Middelburg, the Netherlands.

Do you think that BwN strategies, such as nourishment or constructed oyster reefs, are effective solutions to restore habitats and achieve Natura 2000 goals?
To my surprise, the findings in relation to benthos are not very positive (Galgeplaat). Since other solutions are lacking, nourishments are the main strategy for now. If nothing is done, then these habitats will be lost in the future. Since the data of the last 2 or 3 years are hardly showing any improvement, thus we do not how long it will take to recover the benthic community.

Who is monitoring birds in the Eastern Scheldt?
Delta project Management. They do counts for the whole Eastern Scheldt, but the evaluation is not divided by sub-areas. You can use this to see if Natura 2000 goals are met in general. But within the Galgeplaat pilot project specifically, you will find only calculations for foraging time. RWS decided that foraging time was the most suitable parameter to measure.

How did the parameters of bed elevation, sedimentation and volume change evolve from 2012 until 2016? Are these parameters still analyzed? Is there data available?
Bed elevation is still measured and probably the best person to address this question is Mariska Bijleveld from RWS. She is the project coordinator and she is in charged of the data collection.

Do you *know* if the lifespan of the nourishment was calculated?
I do not know if they calculated it, but the erosion process is slower than it was predicted.

How did the parameters of time of exposure evolve from 2012 until 2016? Are these parameters still analyzed? Is there data available?
They are probably measured.

In your opinion, how does time of exposure influence the availability of benthos or presence of birds? What is a good value?
There is a relation between these parameters, but it is an indirect relation. There can be other variables that can affect the availability of food or the presence of birds. There is extensive research about this. The dehydration of the higher parts (northern area of the nourishment) play a role in the availability of benthos. These higher northern areas of the nourishment become drier faster and benthos animals go to the bottom. This is less easy for birds to forage. Then birds decide to go to the south since it is easier to find food over there.

How did the parameters of species richness and density evolve from 2011 until 2016 available? Is this information available? If not, is biomass a good parameter for my discussion?
Since we wanted to know the amount of food for birds, biomass is the best parameter and the one that used for my report for RWS.

Is there any hypothesis about the high variation in benthos?
They main reason is that ecology is very complex. This is usual, especially for short living species. Storms, for example, can make them disappear entirely very fast in one season. [..] Cockles, worms, are very important for curlew and oystercatcher. [..] There is still more biomass in the undisturbed area than in the nourishment. My work shows that the Galgeplaat is not doing very well. To my surprise, birds and their food were less than in other areas. The new habitat is less suitable than the habitat that was before. The accumulation of other factors may also have an influence. This makes this habitat less natural. They are not performing as they used to be perform before. The saturation of the sediment by water is playing a big role here. [..] Eventually, this area will be the same as it was at the beginning.

How is the process of calculating foraging time?
Number of birds multiplied for the minutes. I counted every 15 minutes during low tide.

Is there also a bird count analysis in addition to foraging time?
No. The Eastern Scheldt is divided in several areas and they do the counts. But there is not more than that.

Only waders are represented in this figure? What about breeding birds or harbor seals?
No, because here there are not breeding birds. During high tide, there is 2 meters of water. Harbor seals are also uncommon in this area.

Why oystercatcher and curlew dominate the area? Related to benthos type?
Their preferable food might be more numerous in the area. Oystercatcher eats clams (like cockles). Curlew feeds from earthworms, leatherjackets. Other birds might need different animals.

What would be an optimal solution for the Eastern Scheldt?
Restoring the hydrodynamics.

How do you think new climate scenarios (increase of sea level, storms, winds, colder winter and warmer summers) can affect the availability of food, or the presence of birds?
It is going to have a negative effect. But these will be slow changes. These are very small changes (mm per year) compared to the changes that the barrier and dams are producing in the Eastern Scheldt. But sea level rise will require more sand in the future. In a natural situation they will grow with the sea, the energy of the sea bring sediments to the intertidal area. So with 50 cm at the end of the century is going to have a big impact on them.

Interview to Matthijs Boersema

Matthijs Boersema was the coordinator of the Building with Nature program, and the coordinator of the Oesterdam nourishment project at the beginning of this research. Currently, he works for Rijkswaterstaat.

The following paragraphs show a summary of the interview that took place the 4th April of 2018 at HZ Applied Science located in Vlissingen, the Netherlands. During the interview, a presentation with the data collected until that day was shown to Matthijs Boersema. These were mainly graphs and data collected from Boersema et al. (2016).

Regarding the first figure, is the average bed elevation per areas from situation T0 to recent years available?
There is a table in the report with the heights and they show the bed elevation before the nourishment (T0). [...] In addition, I calculated the lifespan of Oesterdam. I did a linear regression. You can use it. The lifespan is usually underestimated. The sand motor, foe example, is going to last 50 years. They thought at the beginning that it will only last 25 years. That changes the story for the stakeholders.

Regarding morphology and countering the effects of sand demand, what are the objectives of the nourishment?
We do not want to solve the problem of sand demand. It is impossible to solve it this way.
[...] There are only ecological reasons, while with the sand motor there were safety reasons as well. The volume needed in the Eastern Scheldt exceeds 25 times the sand motor, and nobody wants to pay those costs only for ecology. The only thing we can do is to maintain the core areas, the most valuable areas for birds. We do this by relocating the sand within the system; we do not import new sand. So at the end, it is just mitigating the problem.

Observing the figure regarding bed elevation, sedimentation and erosion patterns, and volume changes (10% loss in total), and erosion rates, were these results expected?
In general, it was quite expected. The idea was that the nourishment will feed the central tidal flat, and it seems that is happening but very little. Also, the main nourishment area should lower the energy wave energy in the dike. But the main nourishment area is not doing much, only the dike foot nourishment.

What are the objectives of the reefs? Improve accretion and avoid erosion? Were the results expected? Are they functioning differently?
They prove to develop into a living and strong structure. They can grow with sea level rise. They were used to reduce erosion and capture sediments but they were not very successful. You can try adding more reefs, it could have a higher impact. But they are expensive.

I would like to compare time of exposure of both projects. Is this information available for the Oesterdam? In the main report (2016), it is said that emersion time improved, however no graphs or data are shown. Are they available?
It is not difficult to calculate the immersion time. You must use the elevation, and download the data from the tidal curve of one of the closest stations.

The table shows species richness, biomass and density of benthos. However, pre-values of the nourishment are not shown, so I can not study if it has improved or not. Are they available?
There were not estimations at the location of the nourishments, but there are some prevalues at the central tidal flat. I will mail to you some documents that can help you.

Are the results regarding benthos expected? Is the area recovering?
The recovery of benthos was faster, so much faster than in the Galgeplaat. The Oesterdam was better protected, and that benefited the development of benthos after the replenishment of new sediments. Especially in term of biomass, one year after the implementation, preconditions were already recovered. The conclusion of Tom Ysebaert (the coordinator of the ecological part of the project) in relation to benthos was that the extra protection because of the shape of the nourishment and the connection to water due to the drainage channel played a big role.

The main report (2016) says that since emersion time increased, foraging time increased as well. However, no graphs or data are shown in this report. Is this information available in any other report? Were bird counts made or only foraging time?
They were doing some research, but I do not know. Maybe you need to contact Tom Ysebaert.

How do you think new climate scenarios (increase of sea level, storms, winds, colder winter and warmer summers..) can affect the project in the close future (sand demand, the availability of food, or the presence of birds)? What concerns you about it?
Sea level rise makes the sand demand even worse, because it makes the cross section even bigger.

Do you think that this type of measures will be still successful in the future with the new climate scenarios or, on the other hand, other type of measures need to be implemented to recover tidal flats?
You can try to adapt the barrier and enter more water into the system. Or to remove it. It seems that in a few years the barrier will not able to cope with sea level rise. They need to do something about it. So maybe that will be the time when this is discussed. It is going to cost a lot of money, but it is preferable to remove the barrier and allow the natural processes to intervene in this area, than the continuous maintenance that we are doing.

Interview to Robert Jentink

Robert Jentink works for Rijkswaterstaat. He is the coordinator of the Galgeplaat nourishment pilot project. He studied the morphology and ecology changes experienced in the nourishment area since 2015.

The following paragraphs show a summary of the interview that took place the 4th April of 2018 at one of the office of Rijkswaterstaat located in Middelburg, the Netherlands. During the interview, a presentation with the data collected until that day was shown to Robert Jentink. These were mainly the graphs and data collected from Van de Werf et al. (2012) and Geene et al. (2017).

As we can see in the first figure, bed elevation improved from 2008 to 2012. Does RWS have this information (similar figure) for recent years that I can use for my research?
We have similar graphs showing the bed elevation since 2013 until 2016. They are available. We can provide you with some data about the development of this parameter.

One of the goals of the project is to counter the effects of sand demand. Observing sedimentation and erosion patterns and volume changes, what can be concluded? What was RWS expected before the project? Is the nourishment performing differently? Is RWS satisfied with these results?
The nourishment is performing morphologically better than expected. It is staying longer that previously predicted. It was thought for some people that it would last only a few months, and it is lasting years. It is actually gaining sediments from the southeast of the tidal flat. [...] The nourishment is maintaining this area, and it is becoming stable.

Did RWS estimate the lifespan of the nourishment? How many years is suppose to last the nourishment?
It was not estimated. There were many ideas about how long it would last, but there was not real estimation. Some people thpught it would last only a few months. Therefore, it is lasting longer. In contrast to the this project, the Oesterdam pilot project has to estimate the lifespan due to the dike reinforcement.

In the former report of Van de Werf et al. 2012 was displayed the time of exposure, the time that the nourishment remains dry after tide, (see first figure). It can be seen that it improved after the nourishment. Does RWS have this information for recent years?
Time of exposure is not available for the following years. But the nourishment is flattening, so the time of exposure is therefore decreasing over time.

In the last report you provided me, Table 1 was displayed. However, the numbers seem to be very different from species richness (first figure) displayed in the former report of Van de Werf et al. (2012). If both are correct, it means that species richness greatly declined from 2011 to 2013. Is this correct? What could be the reason?
They are completely different graphs. They are developed by different methodologies, that is the reason why numbers are significantly lower. The first graph, species richness graph from Van de Werf et al. (2012), shows higher values because they collected samples and analyzed them in laboratory, which it is a more detailed method. Another type of campaign, developed in the field,

does the other graph in Jentink (2016). Here, only organisms larger than 1mm are counted. Moreover, this graphs shows the average of number of species found in one station, while species richness graph from Van de Werf et al. (2012), counted the total number of species found in all stations. I compared to reference area that has similar conditions. The nourishment is improving, and the reference area is staying the same.

In my last interview with Rienk Geene (Habitat Advice), I discussed the variation in biomass of his last report. According to him and his results, benthos have not recovered yet. The undisturbed area is still much higher after several years. It could be concluded that the ecological objective (restoring habitat and improve food availability for birds) has not been achieved with the nourishment yet. What does RWS think about this fact?
I don't really share his opinion. You can't compare the before and after situation, because it is higher than it was before, and it is drier than it was before. It is very hard to decide when it is recovered, because the situation is different. The goal of the nourishment is to maintain the surroundings, and it is exactly what it is doing, although with some fluctuations. I think we can be quite satisfied with the results. There are quite a lot of benthos.

This was an experiment, and we have learnt a lot from it. This nourishment was very steep. Also, the amount of water stored in the nourishment was also an important lesson learnt. Moisture is very important for the recovery of benthos. Biomass and species richness will improve eventually because it is flattening. The type of sand is also important.

It seems there is a correlation between benthos availability and foraging time. Foraging time is higher in the south part of the nourishment, where there is more benthos biomass. However, the undisturbed area is still doing so much better that the nourishment after many years. It could be concluded, after observing numbers regarding foraging time of birds, that the nourishment is not helping achieving Natura 2000 goals in this area yet. What does RWS think about this fact?
I don't share this conclusion. If you look at birds, they start foraging at the higher parts because they dry before. When other areas start to dry later, they move to the other parts. Of course, the nourishment is very small, so it is hard to have conclusions. But when the nourishment was not there, they started to forage later and for less time. So, in general, the total time has increase if the nourishment and the close surroundings are taken into consideration. So they are using the nourishment before other areas are still under the water.

Both Van de Werf (2012) and Habitat Advice report estimate foraging time. However, none of them calculate bird counts. Why RWS is not interested in bird counts at this specific location? I only manage to get this data for the whole Eastern Scheldt? Wouldn't it be a recommendation for future researches like this?
I am not very sure but I think it is very hard to gather conclusions from projects. There are so many factors that can influence the bird counts. We chose to evaluate the abiotic conditions of the habitat, the macrobenthos. Bird counts is it a very expensive monitoring strategy. We assume that they will be benefited from this.

How do you think new climate scenarios (increase of sea level, storms, winds, colder winter and warmer summers..) can affect the project in the close future (sand demand, the availability of food, or the presence of birds)? What concerns RWS about it?

Sea level rise can be a great problem for the Eastern Scheldt. It is also related to the phenomenon sand demand. If there is sediment available, tidal flats would grow with the sea. But in the Eastern Scheldt there is not sediment available. Sea level rise will accelerate the process of erosion and submersion of the tidal flats.

Do you think that this type of measures will be still successful in the future with the new climate scenarios or, on the other hand, other type of measures need to be implemented to recover tidal flats?
For now, it is the only short term solution available to maintain the tidal flats. Adaptation in the barrier are really expensive. For the long term, there will be done something about the barrier. But it will not solve of the problem, because the reduction of the tidal amplitude is also because of the secondary dams. And the first goal of RWS is always safety.

Is RWS confident about recovering the tidal flats and the ecological value of the Eastern Scheldt?
For the short term, this is what we are going to maintain them. On the very long term, I don't know. It will really depend on the availability of technology, budget, etc. And the value that we give to this areas in the future.

Annex 3

The following paragraphs provide the transcript of the questionnaires conducted to the experts: Floor Arts and Mark Hoekstein.

Questionnaire to Floor Arts

Can you briefly tell me how the monitoring of birds and seals is carried out every year?
See annual reports monitoring waterfowl and marine mammals Delta on website: https://www.deltamilieu.nl/projecten/rapporten

In your opinion, what are the reasons why some species do not meet the target as an expert in birds? Can sand hunger be the main reason, or are there other variables that need to be taken into account?
It is a combination of several factors, including suspected sand hunger and external influences. We know too little about ecology birds in Eastern Scheldt to be able to say something sensible about this.

Do you think that projects such as sand replenishment on Galgeplaat and Oesterdam are good solutions for restoring habitats and achieving Natura 2000 objectives with regard to the numbers of birds and seals?
I can not say that. That will have to prove long-term research to those nourishments.

According to KNMI, the sea level rise varies between 2050 and 2100 along the Dutch coast between 25cm to 100 cm. How do you expect this sea level rise to affect the numbers of birds and seals in the area in the future?
No idea. Depends on many factors. Little is known about the ecology of birds in the Eastern Scheldt.

In your opinion, what would be the optimal solution or optimal situation for the Eastern Scheldt to achieve the Natura 2000 targets with regard to birds and numbers of the seals?
Remove the storm surge barrier, Oosterscheldekering.

Questionnaire to Mark Hoekstein

First of all I made a little adjustment to your table. In the column you call 'Trend' there seems to be just the Natura 2000 status, or species numbers are up or below that level. So I changed the name of the column 'Trend' as I see it. Nothing scientific, but just as I see it in the table: a minus sign if the species is declining, a plus where it is increasing and a '0' for the unclear trends. There are no avian species that really increase in this table.

In your opinion, what are the reasons why some species do not meet the target as an expert in birds? Can sand hunger be the main reason, or are there other variables that need to be taken into account?
There are for certain other factors. For a lot of species there is increasing disturbance along the borders of the area and inside it. Lots of high-tide roosts have become useless because of it and

also that birds are disturbed over large areas. Then for the Kentish Plover the breeding success is too low for years. This probably also applies to the Avocet.With other species there could also be problems on their breeding or wintering grounds. There is a lot more research on the complete life cycle of these species, starting with Integrated Population Monitoring, combining reproduction, recruitment, mortality, migration etc.

Do you think that projects such as sand replenishment on Galgeplaat and Oesterdam are good solutions for restoring habitats and achieving Natura 2000 objectives with regard to the numbers of birds and seals?
It has to be done as long there is no better solution. The best solution would be to restore the former tidal estuary, but I doubt that will ever happen. If it is done the right way and the need for recovery I do not know. I know there is research going on, but too much is unknown. As far as I know the benthos is recovering only slowly, but that's something for the benthologists.

Do you think that every sand replenishment should keep track of the number of birds to evaluate the numbers at each specific location?
At the moment only foraging time is being measured and evaluated. However, I think that you should have the birds at home or resting.

According to KNMI, the sea level rise varies between 2050 and 2100 along the Dutch coast between 25cm to 100 cm. How do you expect this sea level rise to affect the numbers of birds and seals in the area in the future?
If this would happen, the intertidal area will be much smaller and I think it will be too small. This means that the area can supply food for fewer benthos-eaters. For the seals it will not be a problem, as long as there are enough areas without disturbance.

What would be, in your opinion, the optimal solution or optimal situation for the Eastern Scheldt to achieve the Natura 2000 targets with regard to birds and numbers of the seals?
Again, I think the best solution would be the former tidal estuary, but I doubt that will ever happen. Another important thing is to stop the increasing disturbance by closing large areas for the public, and more important: to enforce these rules. That is also a problem, there are rules and closed areas, but the government is too weak to enforce rules.