Building with Nature in the Dutch Delta

Advice for an environmentally friendly design of the Energy Storage Lake

May 2019

CONSULTANCY REPORT

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About LEDTA7

LEDTA7 is a sustainable consultancy that was set up during the ACT (Academic Consultancy Training) at Wageningen University. Our team consists of seven students from various disciplines. For the ACT, Delta21 commissioned us to produce an expert advice for an environmentally friendly design of the Energy Storage Lake.

In this report we provide Delta21 with the demanded advice and propose further actions and research our commissioners may conduct.

Executive summary

Delta21 is an innovative plan that aims to provide water safety in combination with energy production and storage in the Dutch delta. The construction of an Energy Storage Lake within this plan is expected to strongly affect nature. Therefore, the goal of this project is to provide ecosystem services in harmony with water safety and energy production and storage. The main research question to reach this goal is: *What are the consequences of the ESL design on the physical and ecological dynamics, and which possibilities exist to turn the ESL into a valuable biodiverse nature area that is attractive for visitors?* Sub-research questions were also defined to more specifically answer the main research question. We used literature research; a field trip to the study area; the knowledge of our academic advisors and inhabitants of the study area; brainstorm sessions and a multi-criteria analysis to answer our main research question and sub-questions.

This study area is located in the Natura 2000 area Voordelta, which consists of a rich and biodiverse ecosystem. The construction of the initial ESL design is expected to strongly affect the hydrological regime and sediment dynamics in the region, resulting in changes in flora and fauna. However, it is difficult to predict what is exactly going to change following the construction of the ESL. We came up with three purposes with corresponding ideas that could lead to the enhancement of nature in and around the ESL; Dynamic Dunes, Myriad Marine Life and Biodiverse Bird Life. Furthermore, we included options for recreation in all variants to enhance the attractiveness of the design. The multi-criteria analysis showed that all variants are expected to have strengths and weaknesses. In our opinion, it would be best to make a combination of the three variants, by implementing some ideas from all variants and combining these. However, choices will have to be made if ideas are not compatible or if finances are a constraint.

It is recommended to perform additional research on the effects of the ESL on sediment dynamics, hydrological conditions and systems ecology and on options to make the ESL more environmentally friendly. Besides, it is important that Delta21 pursues an active dialogue with the local population and relevant stakeholders to create a broader acceptance.

Reading guide

In the first section, the project context, analysis and problem definition are introduced. The problem description is followed by stating the research questions and introducing the vision, mission and objectives of LEDTA7. The second section describes the research methods to gain knowledge, as well as to create, order and evaluate ideas. The third section encompasses a description of the study area, thereby focussing on location, climate, geology, hydrology, habitats, flora, fauna, stakeholders and policy. Section four includes a description of the initial design of the ESL. Section five explains the anticipated impact of the initial ESL design on its environment. The three variants we designed are described in section six. In the seventh section, a multi-criteria analysis (MCA) is used to evaluate the different variants. Section eight discusses the outcome of the MCA, thereby indicating how variants complement and constrain each other. Conclusions of our project are provided in section nine. The tenth section describes our recommendations for further research.

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1. Introduction

1.1 Context and multi-perspective problem analysis

The Dutch have always cherished the wish to conquer the seas. In the past decades, land reclamation, drainage and dyke construction have been the major forms of coastal defence (Klein *et al.*, 1998). The major floods in 1953 lead to the creation of a barrier between land and sea: the “Deltawerken” (Watson & Finkl Jnr, 1992). This battle against the influences of the sea has, however, created issues regarding the discharge of river-water and does not provide protection from flooding in the hinterlands when high river discharge and sea storms occur at the same time (Braakhekke *et al.*, 2008). The traditional approach is also likely to be economically and practically ineffective in providing water safety in the light of climate change and sea level rise (Berke & Lavooij, 2018c). Therefore, in 1990 the Dutch government decided upon a transition from traditional forms of coastal defence to more dynamic preservation (Arens *et al.*, 2013).

Delta21 is an innovative spatial plan for sustainable flood protection that is currently being developed in the Netherlands (Delta21, n.d.) and aims to work with the sea, instead of fighting against it. By constructing a basin in front of the coastline, river water can be pumped into the sea when seawater is pushed up onto the coast, as river-discharge is high in the meantime (Berke & Lavooij, 2018c). To ensure the functioning of these pumps is guaranteed, Delta21 decided to use them every day (Lavooij, pers. communication, March 25, 2019). Following this approach, the concept of Pumped Hydro Energy Storage (PHES) can be applied (Berke & Lavooij, 2018a). Energy that was generated by for instance solar panels, but not directly consumed, is used to pump seawater out of the lake. Since the lake is placed below seawater level, water can then flow into the lake and provide energy when there is a peak-request (Rehman, Al-Hadhrmi & Alam, 2015). This Energy Storage Lake (ESL) can thus be used as a battery for green energy generated by wind-parks and solar panels, as these types of energy do not conform to energy demands but are rather produced when wind or sunshine is available (McLean & Kearney, 2014). Delta21 furthermore includes the construction of a tidal lake, where energy can be generated using the tidal fluctuations in sea level and opts for the addition of a wind park, solar panels, or the storage of thermal energy (Berke & Lavooij, 2018a).

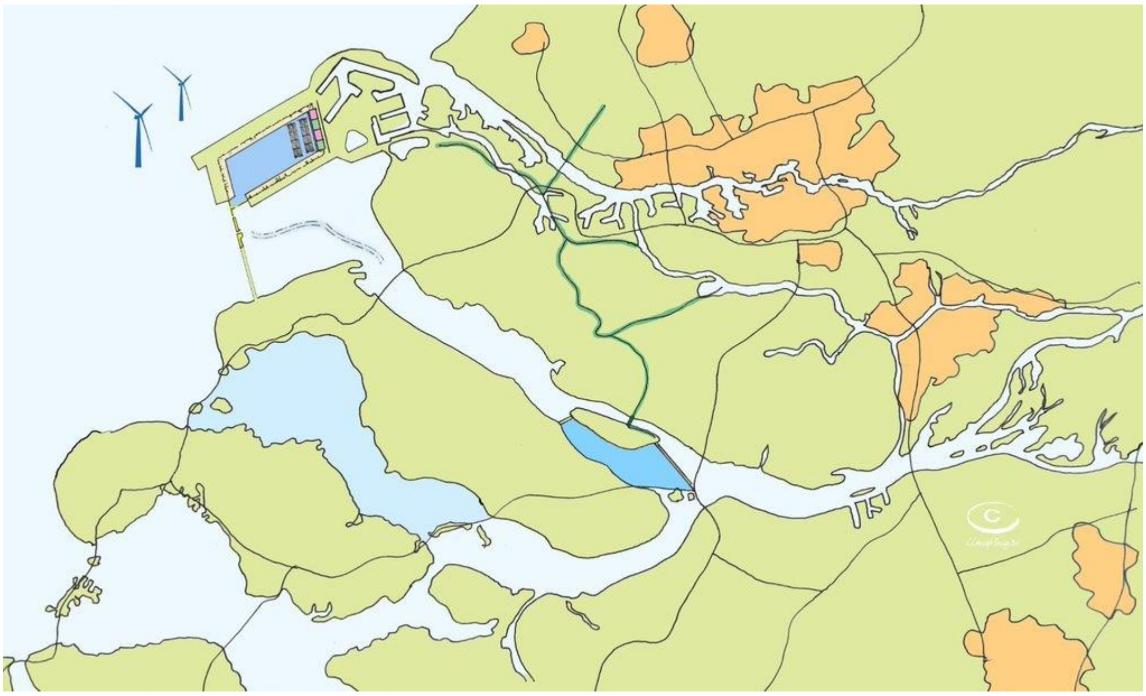

Figure 1: Delta21 design with ESL (“Valmeer”), tidal lake (“Getijdebassin”), brackish water area for fish migration (Haringvliet), fresh drinking-water supply, and optional wind-park, solar panels, and storage of thermal energy (Het Plan - Delta21, 2012).

In addition to the construction of an ESL ("Valmeer") and a tidal lake ("Getijdebassin"), Delta21 is designed to allow the re-opening of the Haringvliet (Berke & Lavooij, 2018b) (Figure 1), the closure of which was part of the Deltawerken. Apart from forming a barrier to fish migration (Braakhekke *et al.*, 2008), the construction of the Dutch Deltawerken resulted in a severe decline in breeding and foraging areas of coastal birds (Meininger & Graveland, 2002). Since this area is one of the prime breeding habitats for coastal birds internationally, the creation and restoration of sparsely vegetated, dynamic habitats is of vital importance (Meiniger & Graveland, 2002). Delta21's ambition is to integrate these environmental considerations and aims not only to restore brackish dynamic habitats and allow fish migration, but to build these constructions through "Building with Nature" (BwN) instead of "Building in Nature" (Berke & Lavooij, 2018b). The Building with Nature principle abandons traditional, reactive engineering approaches by pro-actively integrating ecology and ecosystem services into the design of sustainable hydraulic infrastructures (Borsje *et al.*, 2011; Wilms *et al.*, 2017). The resulting constructions make use of or provide ecosystem services which are meant to create benefits for nature and society (de Vriend *et al.*, 2015; Wilms *et al.*, 2017). This approach aims to "*minimize anthropogenic impacts of coastal protection structures on ecosystems and [...] [to] even offer possibilities to enhance ecosystem functioning*" (Borsje *et al.*, 2011).
The high interest of copious stakeholders in Delta21's aspirations illustrates the "strong need for innovative, sustainable and cost-effective protection against flooding solutions that deal with threats related to climate change" (Borsje *et al.*, 2011). The commissioners operate with the ambition to create "*a project that no one can be against*" (Lavooij, pers. communication, March 25, 2019), thereby including recreation and natural values. The name Delta21 arises from the commissioners' ambition to adopt these sustainable coastal protection measures in the 21st century. In the coming two years, Delta21 aims to elaborate on the spatial plan and to receive the required permissions for constructing the ESL.

1.2 Project problem definition

Delta21 addresses the demand to provide solutions for pressing societal and environmental problems that are sustainable, multi-functional and involve stakeholders (de Vriend *et al.*, 2015). Within the multiple goals the Delta21 project aims to accomplish, our project will focus on Building with Nature in the Dutch Delta: Advice for Environmentally-friendly design of the Energy Storage Lake. The specific goal of LEDTA7 is to adopt the Building with Nature principle in the construction of the ESL to maintain and enhance natural and recreational values in the area. Our ACT-team keeps in mind that long-term effects of Building with Nature have not been monitored yet (in the Netherlands). Therefore, it is important to consider the possible long-term effects of our ecological design.
After ample research and considerations with a manifold of stakeholders, Delta21 is transforming into a plan that no one can be against. Yet, environmental organisations such as WWF still have doubts regarding the direct and cascading effects of the project on natural values (Lavooij, pers. communication, March 25, 2019). For most components of the total Delta21 concept, the possibilities regarding restoration and creation of natural values were already considered in earlier research. However, in no previous research the development of natural values within and around the ESL is addressed. Therefore, the main problem to tackle now is to design the ESL in such a way that it combines its function as storage lake and generator of green energy with natural and recreational values. This can be accomplished by aiding in the colonisation of floral species and settlement of faunal colonies. These species will need to conquer and flourish in a salt-water environment and in a lake with water level fluctuations of about 20 metres. Furthermore, once every 5-10 years there will be a freshwater influx in the lake, and these species should be capable to cope with this temporary presence of fresh water.

1.3 Integrative project purpose and research questions

Our ACT-project aims to design the environment created by the ESL in such a way that a lively habitat with plentiful potential for the development of nature is constructed, that is in the meantime also appreciated by visitors. It is important that this goal does not affect the functionality of the ESL to store and generate green energy, as well as to provide coastal protection. To lead Delta21 towards a path where nature and recreation-related stakes are included into the design of the ESL, we have assembled a general research question and sub-questions, in congruence with the problem to tackle as given in section 1.2. The general research question is:

What are the consequences of the ESL design on the physical and ecological dynamics, and which possibilities exist to turn the ESL into a valuable biodiverse nature area that is attractive for visitors?

The following sub-questions will be considered in order to answer the general research question:

1. Which current species and habitats will be affected and how, as a result of changes in hydrological regime and sediment dynamics caused by the design of the ESL?
2. Which species can tolerate the varying water levels and salinity in the ESL?
3. Which species can colonize the dunes surrounding the ESL, thereby creating a resilient and robust dune system?
4. Which alterations and additions to the design of the ESL can we identify to turn the ESL into a valuable biodiverse nature area?
5. How can the recreational value of the area be increased, without compromising natural values?

Biodiversity is commonly defined as the variety of life (Network, 2010) and multiple approaches to define and measure it exists. In this report, we define biodiversity through species richness (the number of species) and species abundance (the number of individuals within each species) (Hamilton, 2005). Natural values refer to ecosystems and floral and faunal species. Regarding nature development, our focus is to create nature to enhance natural values. Additionally, we could develop nature for human pleasure if it does not interfere with the natural values within the area.

1.4 LEDTA7

1.4.1 Our vision, mission and objectives

Our vision, mission and objectives are guidelines that support us in achieving our goals and to ensure that our values are reflected in our consultancy work (Community toolbox, n.d.). The vision of LEDTA7 is to build with nature for people and planet. Our mission is to integrate nature and hydraulic innovations in sustainable designs. The overarching goal we strive for is to provide ecosystem services in harmony with hydraulic functioning. Ecosystem services are defined as the supporting, regulating, provisioning and cultural services that ecosystems provide for human beings (Fisher *et al.*, 2009).

Our objectives are to:

- Adapt hydraulic structures to the needs of floral and faunal species characteristic to the local environment;
- Enhance biodiversity within the environment created by hydraulic structures;
- Understand and derive benefits from hydrological and aeolian processes such as erosion and sedimentation;
- Support the transitions towards green energy and sustainable flood protection by securing the functionality of technological innovations;
- Increase the attractiveness of the environment by creating aesthetic structures and offering experiences and activities in symbiosis with the environment;
- Ensure future functioning and appreciation of the hydraulic structure through adaptive and flexible management and design.

1.4.2 Team members

Our interdisciplinary project team consists of MSc students of Forest and Nature Conservation, Earth and Environment, Animal Sciences and Biology at Wageningen University.
Anna Maartje studies Earth and Environment and is from the Netherlands. She has a background in soil geography, earth surface dynamics and geology and is the manager of the team. Marte is a Dutch student in the programme Earth and Environment. She has disciplinary knowledge on soil formation, landscape evolution and the effect of hydrology on soils and the landscape. Alberic is from France and likewise studies Earth and Environment. He has disciplinary knowledge on hydrology, hydraulics and water management. The combined disciplinary knowledge of Anna Maartje, Marte and Alberic contributes to our insight into the effects of the ESL on hydrological conditions, sediment dynamics and the corresponding available habitats.
Susanne is from the Netherlands and studies Biology and Animal Sciences with a focus on ecological systems and biodiversity. She is also the controller of our team. Manuel is a Forest and Nature Conservation student from Spain with expertise on ecology, wildlife conservation and management and ecosystem dynamics. Janneke is a Dutch student in the programmes Biology and Forest and Nature Conservation. She has a background in systems ecology and wildlife conservation. Julia studies Forest and Nature Conservation and is from Germany. Her disciplinary knowledge is mainly on ecology, human-nature relationships, sustainability and policy and she is the secretary of our team. The combined disciplinary knowledge of Manuel, Janneke, Susanne and Julia contribute to understanding how ecosystems might be affected by the ESL and how its ecological functions can be improved. Julia's knowledge contributes to the project since the presence of humans in the area and their role in policy will affect the construction of the project and the ESL itself.

2. Research Methods

To answer our research questions (Section 1.3) we carried out the activities and applied the research methods as specified in the following section.

2.1 Acquiring background information

To answer the first part of our main research question (What are the consequences of the ESL on the physical and ecological dynamics?) we conducted a literature research and used expert knowledge to provide a description of the abiotic and biotic characteristics in the ESL area. This information enabled us to deduce whether and how the dynamics and characteristics of the physical and ecological values within the ESL area would be affected. We also investigated relevant stakeholders and policy in the study area to get an overview of important interests. We, as LEDTA7, take these stakes into account for our advice. Stakeholders whose interests were identified as specifically relevant for our project were contacted and asked to do an interview with us. The interview questions are provided in Appendix 2.1. Interviewed parties were always asked for permission to use their answers in this report. The interviews were incorporated as expert knowledge in the report and served as inspiration for creating ideas on designing a more environmentally friendly and recreational attractive ESL. Regarding literature, the management plans of the Voordelta constituted a valuable source of information since the area around the planned ESL is a designated Natura 2000 area. We also explored additional peer-reviewed articles and websites that contained relevant information. To accomplish an effective search and use of literature, topics were divided between the team members according to individual expertise. The literature research provided us with a baseline understanding of the stakes in and characteristics of the system, as well as the potential for natural values to be established inside the ESL.

2.2 Field trip to study area

Visiting the study area increased our understanding of the issues and processes to be considered in our advice. A visit to the area also aided in visualising what is at stake. We visited the study area on the 16th of April, together with our commissioners and another ACT-group working on fish migration within the design of Delta21. The participation of the commissioners in the excursion provided us with deep insights in the dynamics occurring in the ecosystem; what type of biodiversity we can encounter, and how nature responds to human impact (e.g. considering the Maasvlakte). During the visit, we took an observational position and asked critical questions to our commissioners. During the field trip we were able to interview Henk Bal and Pieter Mout who live close to the area where the ESL is supposed to be constructed. These interviews aided in our understanding of stakeholder views and generated new ideas and constraints that we could take into account in our advice.

2.3 Generating creative ideas

To answer the second part of our main research question (*Which possibilities exist to turn the ESL into a valuable biodiverse nature area that is attractive for visitors?*) creative thinking was required. We found projects like Delta21 (e.g. Marker Wadden, Holwerd aan zee) and explored their ideas as a source of inspiration. We also visited a congress with lectures and workshops on the application of Building with Nature related to the project Marker Wadden on the 18th of April at Deltares in Delft.
The interviews with stakeholders (see section 2.1) provided another relevant source of inspiration for ideas on how to make the ESL more valuable in terms of nature and recreation. During the interviews we uncovered concerns regarding the ESL. Additionally, stakeholders were asked whether they see opportunities in improving the design.
Finally, to generate creative output, we carried out brainstorming sessions with our whole ACT-team. Such sessions are essential to integrate information and interdisciplinary expertise that lead to the creation of innovative ideas that are “out of the box” (Dousay, 2018).

2.4 Organisation of ideas

We decided to present our creative ideas ordered according to three purposes we aim at achieving within the design of the ESL. These purposes were defined after conducting the research related to our first research question. In this way, we created three design variants for our commissioners with each variant targeting a specific purpose within the main goal of turning the ESL into a biodiverse nature area (section 6). For each design variant, we provided ideas on how to adapt the initial ESL design to reach the specific purpose. We also elaborated on the constraints to reach the purpose. Within each design variant we included ideas on how the recreational value of the ESL could be enhanced without compromising the specific nature-related purpose.

2.5 Multi-criteria analysis

We used a simple scoring system to compare our designed variants to the initial ESL design that is not specifically designed for natural and recreational values. The comparison provides Delta21 with a qualitative indication to what degree our ideas improve the initial ESL design. Alongside the variants that contain our ideas related to specific purposes, we also included the current situation without the ESL into the comparison. This enabled us to evaluate the possible effects of constructing the ESL on the current system. The resulting table indicates how each variant performs relative to the initial ESL design. In this way, strengths and weaknesses of each variant became apparent that were discussed in more detail in the accompanying paragraph. The scoring gives a qualitative indication of to what extent each variant provides solutions to our defined problem (Section 1.2) of designing the ESL in such a way that it combines its function as storage lake and generator of green energy with natural values as well as recreational values. It also provided us with information on how the variants can be combined with each other into one holistic design for the Energy Storage Lake. Additionally, we were able to detect conflicting ideas within the variants that might be difficult to combine. To be able to compare the variants, we defined criteria that are relevant for the realization of Delta21 and our problem statement (Proctor & Drechsler, 2003). The criteria were grouped into the categories of ecosystem services, recreation, functionality and economics. The criteria assembled under ecosystem services assess the natural values included in the variants based on biodiversity (species richness, species abundance, threatened species), biotic and abiotic processes (self-regulation) and visual attractiveness (aesthetics). To compare the recreative attractiveness we defined criteria for different types of recreation (sports, education, tourism) and accessibility. Ensuring the functionality of the ESL plays a central role in our problem statement. Therefore, three criteria were defined to assess to what extent the main functions of energy generation, energy storage and flood protection are maintained within each variant. Lastly, we also defined criteria that relate to economic costs of the implementation and maintenance of each variant, as well as the potential profit that could be gained on the long-term.

2.6 Academic advice

We regularly consulted our academic advisor, Luuk Gollenbeek, and the contact person for Delta21 at Wageningen University and Research, Marnix Poelman. They supported our consultancy project with advice from an academic perspective and additional inspiration.

3. Description study area

3.1 Location

Our study area is located on the southwest coast of the Netherlands, in the provinces of Zuid-Holland and Zeeland. Delta21 plans to make adaptions in the Haringvliet and the northern part of the Voordelta. The Voordelta is the marine area in front of Zuid-Holland and Zeeland (Figure 2). This region includes the shallow sea, sandbars and beaches in the delta of Haringvliet, Grevelingen and Oosterschelde (Natura 2000 Rijkswaterstaat, n.d.). The Voordelta was appointed as a Natura 2000 region and seabed protection area in 2008 to protect the valuable nature in this marine environment and to compensate for the construction of Maasvlakte II (Natura 2000 Rijkswaterstaat, n.d.; Wageningen University & Research, n.d.). Our consultancy project concentrates on the location within the Voordelta where the Energy Storage Lake of the Delta21 project is planned to be constructed (Figures 1&2) (Berke & Lavooij, 2018a).

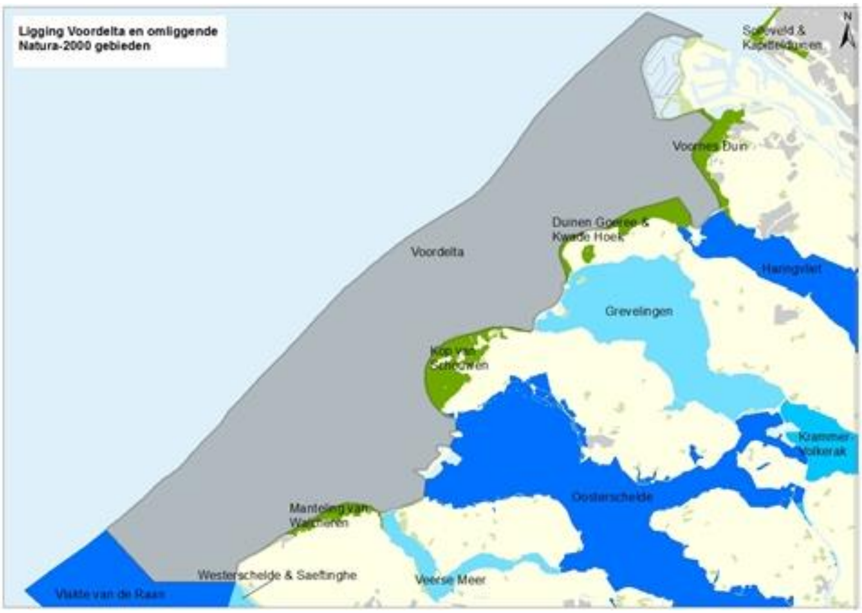

Figure 2: Location of the Voordelta, indicated in grey (Natura 2000 Rijkswaterstaat, n.d.)

3.2 Climate

The Netherlands has a temperate maritime climate that is strongly affected by the close presence of the North Sea and Atlantic Ocean, which results in relatively mild temperatures (KNMI, 2011). Mean annual temperature ranges between 9.3 °C in the northeast and 10.8 °C in the southwest. Mean annual precipitation is 847 mm and regularly spread over the year (KNMI, 2011). Spatial differences in precipitation are caused by the presence of relief and cities. Average annual evapotranspiration is 560 mm in the southwest and 610 mm in the northeast of the country, resulting in an annual excess of precipitation. The dominant wind direction in the Netherlands is from the west, thus coming from the sea (KNMI, 2011).

3.3 Geomorphology and Hydrology

During the Weichselian ice age, the northern part of Europe was covered by a glacier. Sea levels were much lower than nowadays, which led to a dry North Sea (Figure 3).

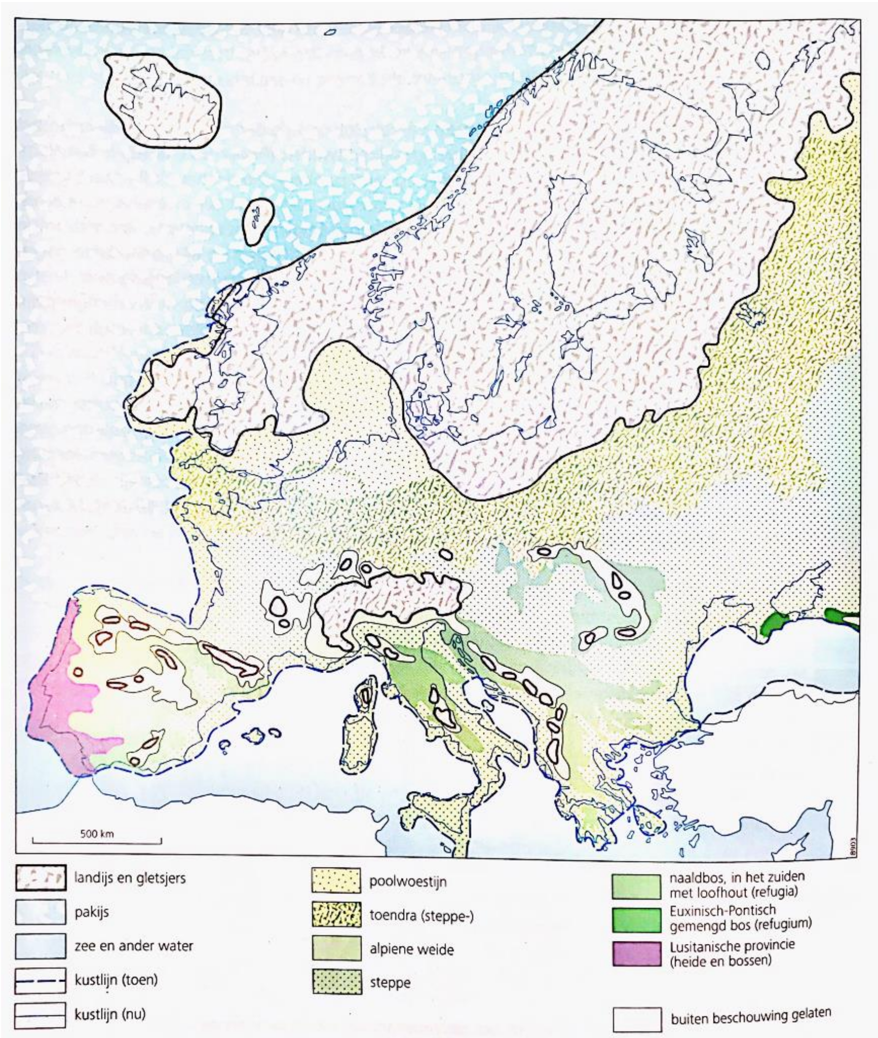

Figure 3: Glacial coverage and vegetation of Europe during the Weichselian ice age (Zagwijn, 1992)

11,700 years ago, the Weichselian ice age ended and the Holocene started. During the Holocene, the sea level started to rise, and the previously dry North Sea was flooded. This affected the location of the Dutch coastline (Goes *et al.*, 2009; van der Molen & de Swart, 2001). Sea level rise was the most important factor that led to a change in the dimensions of the North Sea, but sedimentation and erosion; isostatic rebound; tectonics, and compaction of the subsurface sediments had an impact (van der Molen & de Swart, 2001). Sea level rise can be split into two parts, an absolute or eustatic sea level rise, and a relative sea level rise. The first part results from global changes in ocean water, mainly because of the growth or melting of large ice sheets. The latter is sea level rise relative to the land surface and is therefore also affected by e.g. tectonic processes and isostatic rebound (van der Molen & de Swart, 2001). The continuous relative rise of the sea level affected the landscape of Zeeland during the Holocene. A combination of coastal and fluvial processes led to net aggradation and the formation of a Holocene sediment wedge, with a maximum thickness of 50 metres of both clastic and organic sediments (Goes *et al.*, 2009). The current morphology of the Dutch coastal plain is strongly affected by tides and waves, but the general features, for example the orientation of the coastline, are a result of processes in the Pleistocene (Beets & van der Spek, 2000). The subsurface of the Energy Storage Lake region mainly consists of fine sands until a depth of approximately 50 metres below sea level. There are some alternations with coarser sand, silt and clay layers. A thick clay layer can be found in the deposits around a depth of 60 metres below sea level (Berke & Lavooij, 2018c; TNO Geologische Dienst Nederland, n.d.). The tides in the North Sea are semidiurnal with an amplitude of around two metres, and maximum surface currents range between 0.7 and 1.0 m/s during spring tide along the Dutch coast (van der Molen & de Swart, 2001; Rijkswaterstaat, n.d.). North Sea sediment transport is influenced by tides, wind waves, wind-driven currents and density-driven currents (van der Molen & de Swart, 2001), and mainly takes place along the coastline in northward direction by a longshore drift (Beets & van der Spek, 2000). Coastline erosion is strong in the south of the Netherlands, near our study area (Beets & van der Spek, 2000). The coastal region, including the Voordelta, is nowadays a dynamic environment that consists of coastal waters, intertidal zones and beaches. It forms the transition between the (former) estuaries and the North Sea (Berke & Lavooij, 2018b). Erosion and sedimentation processes change the surface area of intertidal zones and dune regions. Tidal regime has a stronger effect on morphological processes than does wave regime, and therefore the sandbars are situated parallel to the direction of tidal currents (Berke & Lavooij, 2018b).

The construction of large structures near the Voordelta in the past has affected the physical environment. The construction of the Deltaworks has led to sand starvation in the former estuaries of Zeeland, because the natural equilibrium in the estuaries has been disturbed (Hesselink *et al.*, 2003; Nationaal Park Oosterschelde, n.d.). The amount of sediment that can pass through the opening in the Deltaworks is restricted by the small size of this opening, and therefore not enough sediment can pass towards the Oosterschelde. This leads to erosion of drying silts, plates and salt marshes. Furthermore, the dykes are no longer protected from erosion by the presence of sandbanks (Hesselink *et al.*, 2003; Nationaal Park Oosterschelde, n.d.). The Deltaworks furthermore affected the coastal processes in the Voordelta itself. Sediments were likely deposited in front of the coast (Berke & Lavooij, 2018b; Bal, pers. communication, April 16, 2019), as a result of the calmer environment with fewer currents and waves. The construction of Maasvlakte II likewise influenced coastal processes. The low flow velocity of seawater in between the Maasvlakte II and the Voornse dunes, for instance, likely has led to a strong deposition of relatively fine sediments. Directly South and Southeast of Maasvlakte II, wave penetration has been strongly reduced by the construction of the Maasvlakte. The waves from the Northwest are already breaking at the Maasvlakte II seashore, instead of at the Northern beaches of Voorne. Furthermore, the Voornse dunes nowadays lie in the wind shadow of Maasvlakte II, and therefore wind speeds are lower. A combination of these processes likely decreases the sea spray that used to transport salts into the dune soils, which in turn can affect vegetation in the dunes (P. Mout, pers. communication, April 16, 2019).

3.4 Habitats, flora, fauna

The planned location of the Energy Storage Lake overlaps with the Natura 2000 area Voordelta, a shallow part of the sea in the provinces of Zeeland and Zuid-Holland. The Voordelta comprises 83,530 hectares and is characterised by a diverse and dynamic environment of coastal waters, intertidal zones and beaches (Rijkswaterstaat & RIZA, 2008). The area forms a sheltered transition zone between the sea and the former estuaries of the rivers Rhine and Meuse. Within the Voordelta, seven habitat types can be distinguished (Rijkswaterstaat & RIZA, 2008):

- Sandbanks that are permanently flooded (H1110);
- Mudflats and sandflats not submerged at low tide (H1140);
- Salt-tolerant pioneer vegetation (H1310, A and B);
- Spartina swards (H1320);
- Salt marshes and salt grasslands (H1330, A and B);
- Embryonic dunes (H2110); and,
- White dunes (H21209)

Figure 4: From top left to bottom right: H1140 (Hinderplaat), H1310 (Salty pioneer vegetation) , H1330 (Salt grassland), H1320 (Spartina swards), H2110 (Embryonic dunes), H21209 (White dunes).

The location of these habitat types is illustrated in Figures 5 and 6. Figure 4 gives an impression of what these habitats look like. In the following sections a description of the flora and fauna of the habitat types is provided.

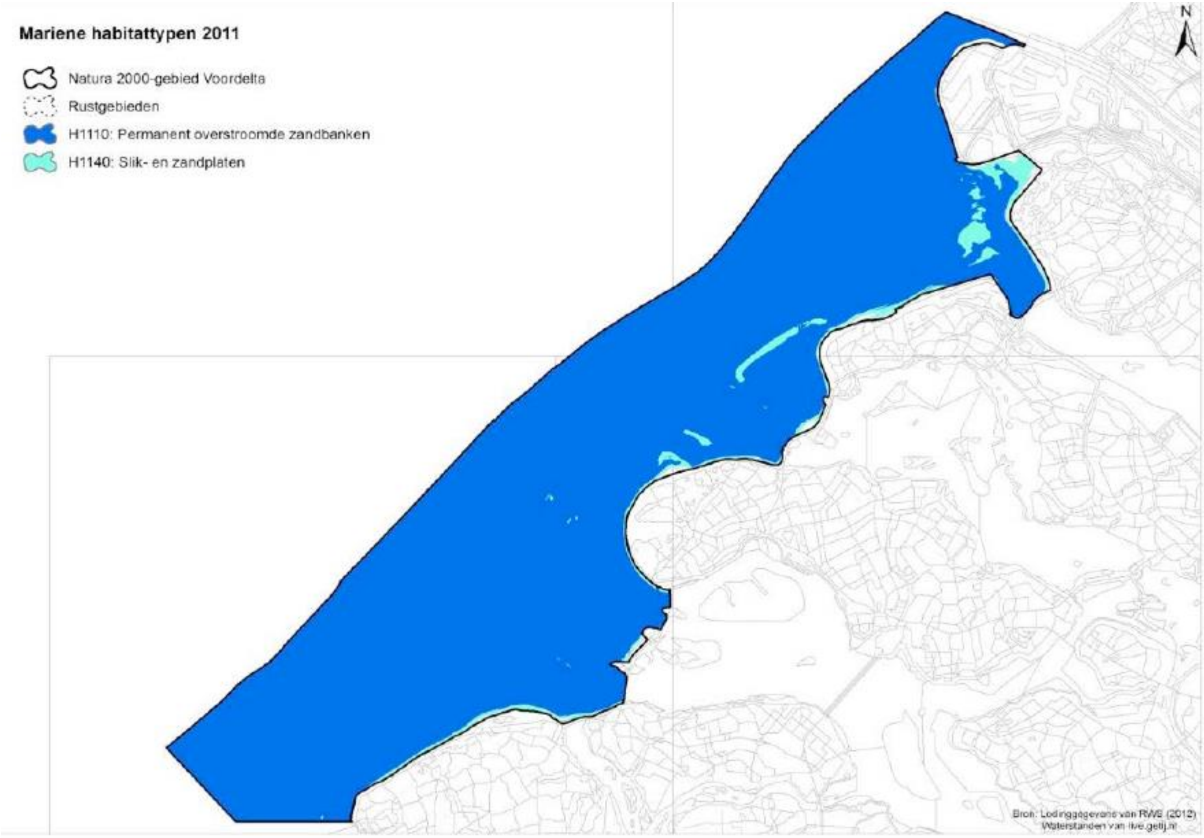

Figure 5: Habitat types H1110 (dark blue) and H1140 (light blue) in the Voordelta (HaskoningDHV, 2013).

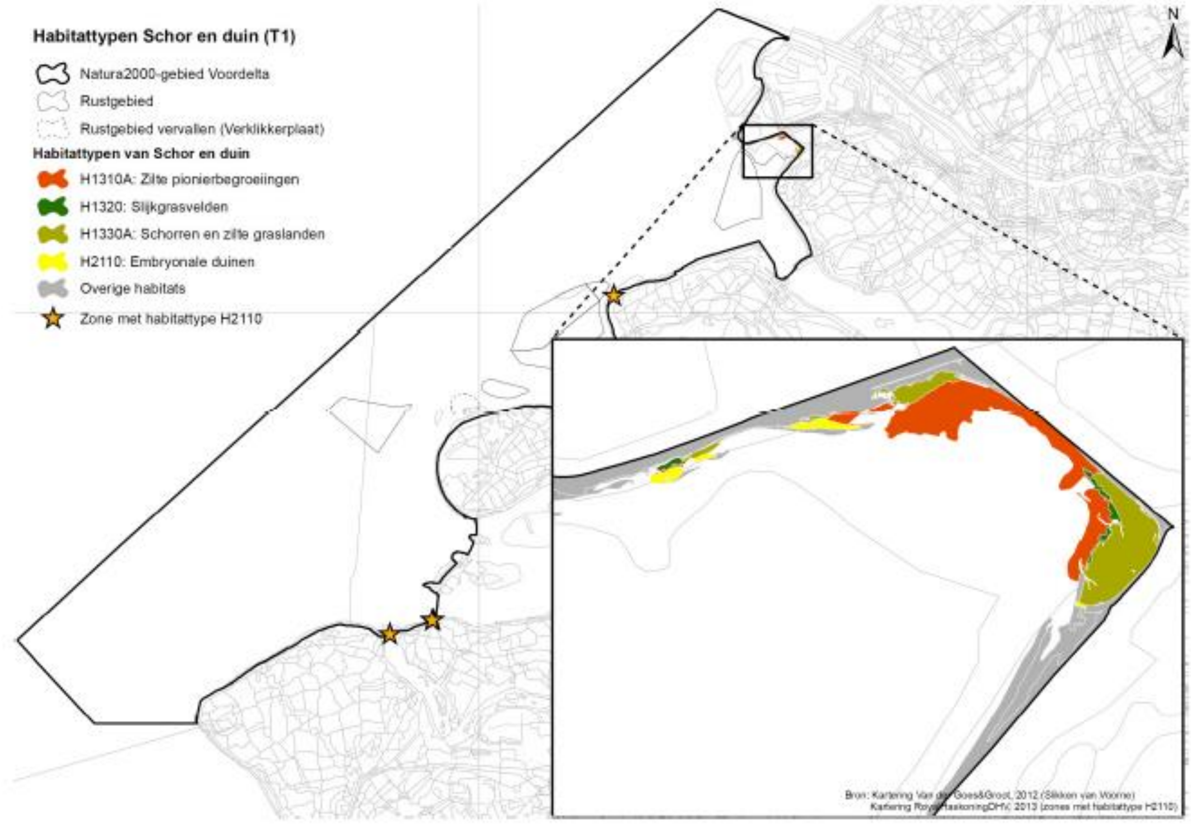

Figure 6: Habitat types H1310A (orange), H1210A (stars), H1320 (dark green), H1330A (light green), H2110 (yellow, but parts of H2210 have become H21209 through natural succession), other habitat types (grey) in the Voordelta (HaskoningDHV, 2013).

3.4.1 Sandbanks permanently flooded with shallow water (H1110)

The vast majority of the Voordelta (89,900 hectares) consists of sandbanks that are always submerged with a layer of seawater of about twenty meters (Rijkswaterstaat & RIZA, 2008). The planned ESL design is foremostly located within this habitat type (Figure 5). This habitat type includes deeper channels between the sandbanks that are used by migratory fish such as Allis shad (*Alosa alosa*) and Twait shad (*Alosa fallax*), as well as Plaice (*Pleuronectes patessa*), Flounder (*Platichthys flesus*), Sole (*Dover sole*), Whiting (*Merlangius merlangus*), Herring, Juvenile cod and Small sand eel. These channels have become narrower since the estuary was closed. In some areas, the sea bed is a hard substrate formed by peat, clay, cobbles, shells or other structures formed by organisms. Algae communities only occur in the shallower parts of the habitat, as turbid water impedes them to grow in deeper parts. Common eelgrass (*Zostera marina*) used to be present in this area, but this species has disappeared (Noordzeeloket, n.d.). Sandbanks provide an important habitat to a diversity of species that again serve as a food source, such as flatfish species like Plaice (*Pleuronectes patessa*), Flounder (*Platichthys flesus*), Sole (*Dover sole*) and Sand eels; worms; crustaceans and shellfish such as cockles, Azor clams (*Ensis*), mussels and *Spisula subtruncata*. Among the organisms that rely on this habitat to find their prey there are fish, marine mammals, fish-eating birds like the Red-throated loon *Gavia stellata*, gulls, terns and shellfish-eating birds such as the Greater scaup (*Aythya marila*), Black scoter (*Melanitta americana*) and the Common eider (*Somateria mollissima*). The population of *Ensis* has recently increased, and shellfish eaters might rely on them as an important food source (Rijkswaterstaat & RIZA, 2008).

3.4.2 Sand and mudbanks not covered by seawater at low tide (H1140).

The sandbanks of this habitat are periodically covered during high tide (Rijkswaterstaat & RIZA, 2008). Soil fauna such as cockles, Soft shell clam (*Mya arenaria*) and *Nephtys hombergi* are widely available in the sea beds of this habitat. These species are again a food source for shelduck and waders (e.g. Eurasian oystercatcher (*Haematopus ostralegus*), Pied avocet (*Recurvirostra avosetta*), Common redshank (*Tringa totanus*), Eurasian curlew (*Numenius arquata*) and Dunlin (*Calidris alpina*)). The area additionally serves as a resting area for birds such as Sandwich tern (*Thalasseus sandvicensis*) and cormorant, as well as mammals like grey seals. The total surface of this habitat type is decreasing nationally, however, it has increased in the Voordelta and it is expected to show even a slight increase in the future (Rijkswaterstaat & RIZA, 2008).

3.4.3 Salty pioneer vegetation (H1310, A and B) spartina swards (H1320) and salt marshes and salt grasslands (H1330, A and B)

On the North side of the Slikken van Voorne, one can find salty pioneer vegetation, spartina swards and salt marshes and salt grasslands (Rijkswaterstaat & RIZA, 2008). Over the past twenty years there has been a development from species-poor pioneer vegetation to richer grassland stages. Salicornia vegetation (H1310A) is commonly found on the lower parts of the Slikken van Voorne. An extension of this habitat-type is expected as a result of the slow increase of the intertidal area caused by sea level rise. At the transition from mudflat to dune, pioneer vegetation with Sea perlwort (*Sagima maritima*) is found. Locally, in Voorne, as well as nationally, the size of this habitat is small. This is due to the extensive growth of the invasive Common cordgrass (*Spartina anglica*) which outcompetes the native *Spartinion maritimae*. The salt marshes and salt grasslands (H1330A) outside the dykes are located on the higher parts of the Slikken van Voorne and this habitat type is expected to increase in size along with the extension of the intertidal zone. Saltmarshes are important resting and foraging areas for waders and other migratory species of bird, and they contain valuable floral species. The Voordelta is becoming increasingly shallow, resulting in the increase of saltmarsh habitat in southwestern direction (Rijkswaterstaat & RIZA, 2008).

3.4.4 Embryonic dunes (H2110)

Embryonic "walking" dunes only comprise a minor part of the Voordelta and can be found on the edge of beaches near Manteling van Walcheren (Breezand), the Banjaard-strand (Noord-Beverland) and the south side of the Slikken van Voorne (Rijkswaterstaat & RIZA, 2008). The habitat type concerns a species-poor pioneering vegetation with *Elytrigia juncea boreoatlantica* alternating with bare sand and floodmark vegetation. Nationally, the conservation status of embryonic dunes is promising (Rijkswaterstaat & RIZA, 2008).

3.4.5 White dunes (H21209)

Marram grass (*Ammophila arenaria*) colonises the outermost dune belt of the coast and forms an important part of the dynamic dune system (Ministerie LNV, 2019). However, natural Marram grass dunes are relatively rare in the Netherlands, since on many places the outer row of dunes was created or maintained by humans, and Marram grass was planted. These "fixed marram dunes" are not considered a part of this habitat type. In addition to Marram grass and Hybrid marram (*Calammophila baltica*), Sand rye grass (*Leymus arenarius*) and Perennial sowthistle (*Sonchus arvensis var. Maritimus*) are common. Furthermore, Sea holly *(Eryngium maritimum*), Morning glory (*Calystegia soldanella*) and Sea spurge (*Euphorbia paralias*) can be found, and Marram grass allows for several species of mushroom (*Agaricus devoniensis, Peziza ammphila, Phallus hadriana*) to establish (Ministerie LNV, 2019).

3.4.6 Marine mammals

The Voordelta and its surroundings are home to the common seal (*Phoca vitulina*) and the Grey seal (*Halichoerus grypus*) (Rijkswaterstaat & RIZA, 2008) (Figure 7). At the beginning of the last century, the common seal population in the Voordelta area had grown to 10,000 individuals. Disturbing influences of humans, such as pollution, hunting and a decline in habitat, caused the population size of Common seals to decrease to only a few dozens in the 1960's. The estimated population size in 2007 is around 100 individuals. The habitat of the Common seals is mainly situated in the Voordelta and the Eastern- and Western Scheldt where they are mainly observed between March and August. The population is composed of migratory individuals originating from the Dutch Wadden area, France and the United Kingdom. Raising young is not common in the Voordelta, and the survival of the population is therefore dependent on the possibility to migrate to other areas (Rijkswaterstaat, 2008). Some seals do rest and raise their young on plates in the Voordelta that fall dry at low tide. The main plates that are used are the Verklikkerplaat, the Bollen van de Ooster and the Hinderplaat (Rijkswaterstaat & RIZA, 2008).

The Grey seal arrived in the Netherlands in the 1980's and originates from the United Kingdom. Over the past few years, around 100 individuals are spotted in the Delta area annually. The Grey seals can be found in the same area as the common seals, but they are mainly situated in areas that stay dry during high tide when their young are not yet able to swim. Seals mainly feed on fish and crustaceans (Rijkswaterstaat & RIZA, 2008).

Figure 7: Common Seal and Grey Seal in resting areas.

3.4.7 Fish

There are four migratory fish species that were deemed important to protect by Natura 2000: Twait shad (*Alosa fallax*), Sea lamprey (*Petromyzon marinus*), River lamprey (*Lampetra fluviatilis*) and Allis shad (*Alosa alosa*) (Rijkswaterstaat & RIZA, 2008). These species are anadromous migrants which means that they live in the sea (salt water) but reproduce in fresh water. The Delta used to be an important resting and rearing area for migratory fish. However, because of pollution, overfishing and the construction of the Haringvlietdelta these species became nearly extinct in the Netherlands. In 2008, the Twait shad, River lamprey and Allis shad showed an increase in population size, but the possibilities for maintaining the current size are very unlikely. The sea lamprey has shown large annual fluctuations in population size, and its population size could therefore not be determined (Rijkswaterstaat, 2008). In June 2013, the Kierbesluit was accepted, resulting in the Haringvliet sluices partly opening as of 2019. This is hoped to bring back fish migration (Rijkswaterstaat & RIZA, 2008).
In 2016, 54 fish species were counted near the Haringvliet, on the sea side (Giels, van, 2016). Among these are some freshwater species (e.g. European perch, Zander, Round goby), diadromous species (e.g. Eel, European smelt, Salmon), estuarine species (e.g. European flounder, Common goby, European eelpout, Pig-fish), marine juveniles (e.g. Herring, Pouting, Common sole, Whiting, European bass), seasonal marine species (e.g Mullet spp., European sprat) and marine species (e.g. Common scad, Lesser weever). The main species are Herring (*Clupea harengus*), European sprat (*Sprattus sprattus*) and Goby spp. (*Gobiidae*, e.g. *Neogobius melanostmus, Pomatoschistus microps*).

3.4.8 Shellfish

Shellfish and other marine invertebrates are an important food source for birds and fishes. Allis shad (*Alosa alosa)* and European sea sturgeon (*Acipenser sturio*), for example, feed on invertebrates such as bristleworms. European bass (*Dicentrarchus labrax*) feed on shrimp, crustaceans and cephalopods (Emmerik, van, 2016). The shellfish population along the coast of the Netherlands was sampled in 2017 (Troost *et al.*, 2017). In total, 32 species were found, among which 25 Bivalves and 7 gastropod species. The most occurring species are part of the *Ensis* family, but *Spisula subtruncata*,mussels *(Mytilidae spp.*)*,* Common otter shell (*Lutraria lutraria)*, *Chamelea striatula* and bean clams (*Donax vittatus)* are furthermore found frequently (Figure 8). In the Voordelta specifically, a decrease in the biomass of small *Ensis* species was found, while the abundance of large *Ensis* species increased. The other groups of species have quite a good representation in the Voordelta compared to other Nature 2000 areas, especially near Maasvlakte II (Troost *et al.*, 2017).
In Blokkendam, located within the Voordelta, there is a shellfish bed that is composed of Pacific oysters (*Magallana gigas*) and Flat oysters (Sas *et al.*, 2018). Similar shellfish beds used to occupy around 20% of the sea bed floor, but have almost completely disappeared due to overfishing, habitat destruction and diseases (e.g. Bonamia disease). The establishment of this bed in the Voordelta therefore indicates that restoration is possible, especially in this Natura 2000 area where the detrimental bottom dredging fishery is prohibited. However, the current fresh water flow from the Haringvliet likely makes the Hinderplaat unsuitable for the survival of flat oysters. Furthermore, there is a low prevalence of the Bonamia disease in the Voordelta, and although only 4% of the population is affected, this disease can still spread (Sat *et al.*, 2018). On the other hand, shellfish beds can greatly benefit the biodiversity of an area. The (epi)benthic community found in and around the bed in Blokkendam was 60% higher than in sandy sediment nearby, and the oysters furthermore allow for blue mussels to colonize. When the old empty shells of these organisms accumulate on the soft sediments, they can provide an appropriate substrate for flat oysters to grow there as well. These shellfish beds host at least 70 species of animals including crustaceans, molluscs, fish, ascidians and cnidarians. Currently, the largest threat seems to be predation in the first stages of development and settlement. Furthermore, the settlement of flat oysters is determined by substrate cleanliness (e.g. fresh mussel shells) (Sas *et al.*, 2018).

Figure 8: Three common species of shellfish that are found in the Voordelta.

3.4.9 Birds

Coastal breeding birds need relatively unvegetated and dynamic habitats (tides, sedimentation, salt) (Meininger & Graveland, 2002). Over the past twenty years many of these bird species have benefitted from the new areas that established through the construction of the Deltawerken, such as sand banks, dykes and dry places. Yet, due to succession of the vegetation and a change in environmental dynamics through the Deltawerken, most of these areas are now not useful anymore for coastal-breeding birds, and management is needed (Meininger & Graveland, 2002). Furthermore, extensions of harbours, industrial development and recreation decrease the area available for these birds. The coastal breeding birds that forage, breed or rest in the Voordelta can roughly be separated into ducks and geese, fish eaters, benthos eaters and wading birds (Rijkswaterstaat & RIZA, 2008).

The Voordelta is designated as a Natura 2000 area to protect seven species of fish-eating birds: Red-throated diver (*Gavia stellata*), Horned grebe (*Podiceps auritus*), Great crested grebe (*Podiceps cristatus*), Great cormorant (*Phalacrocorax carbo*); Red-breasted merganser (*Mergus serrator*); Sandwich tern (*Thalasseus sandvicensis*) and Common tern (*Sterna hirundo*) (Rijkswaterstaat & RIZA, 2008). The Sandwich tern and Common tern breed in adjacent Natura 2000 areas but use the Voordelta as feeding area. At the moment, the conservation status of these two species is very unfavourable. They hibernate in Africa, unlike the rest of fish-eating species that instead spend the winter in the Voordelta. The conservation status of the other fish-eating birds in the Voordelta is favourable, except for Red-throated divers and Great crested grebes, whose conservation status is moderately unfavourable. The population size of the latter two does show an increasing trend (Rijkswaterstaat & RIZA, 2008).

Benthic invertebrates eaters are birds that feed on the animals living in the soil of shallow waters or mud flats (H1110 and H1140) (Rijkswaterstaat & RIZA, 2008). Here, we can find the Greater scaup (*Aythya marila*), Common eider (*Somateria molissima*), Common scoter (*Melanitta nigra*) and Common goldeneye (*Bucephala clangula*). The Greater scaup only spends the winter in the Voordelta. The population sizes of Greater scaup and Common eider are decreasing in most of the Netherlands, but not in the Voordelta. The Common scoter is also in an unfavourable conservation state, and the Voordelta is one of the areas important for the conservation of this species. A species that does show an increasing trend in terms of population size is the Common goldeneye (Rijkswaterstaat & RIZA, 2008).

The ducks and geese of the Voordelta feed on soil animals, algae, and seeds that they find on the beaches and sand banks (H1310, H1320, H1330) (Rijkswaterstaat & RIZA, 2008). Common shelduck (*Tadorna tadorna*), Eurasian wigeon (*Mareca penelope*), Northern shoveler (*Spatula clypeata*), Greylag goose (*Anser anser*) and Gadwall (*Mareca strepera*) show a favourable status, while Pintail (*Anas acuta*) and Common teal (*Anas crecca*) have a moderately unfavourable status of conservation. Over the past few years, population sizes of the latter three species have been declining in the Voordelta (Rijkswaterstaat & RIZA, 2008).

Finally, some wading birds make use of the Voordelta: Ruddy turnstone (*Arenaria interpres*), sanderling (*Calidris alba*), Black-bellied plover (*Pluvialis squatarola*), Dunlin (*Calidris alpina*), Bar-tailed godwit (*Limosa lapponica*), Redshank (*Tringa totanus*), Oystercatcher (*Haematopus stralegus*), spoonbills (*Platalea leucorodia*), Pied avocet (*Recurvirostra avosetta*), Ring plover (*Charadrius hiaticula*) and Eurasian common curlew (*Numenius arquata*) (Rijkswaterstaat & RIZA, 2008). Spoonbills only make use of the Voordelta in summer. Wading birds feed on the organisms that inhabit sand banks with different levels of vegetation growth (H1310, H1320, H1330), except for the Ruddy turnstone and the Sanderling which forage for organisms found on hard substrates and beaches, respectively. Oystercatchers and Ruddy turnstones are in a very unfavourable conservation state nationally, but population sizes in the Voordelta are stable. Piet avocets, Sanderlings and Redshanks are in a moderately unfavourable state, while the remaining species of waders and the Spoonbill have a favourable status of conservation. The Voordelta is furthermore a foraging area for the Little gull (*Hydrocoleus minutus*) which has a moderately unfavourable conservation state (Rijkswaterstaat & RIZA, 2008).

3.5 Stakeholders

Delta21 consults with a range of parties that have a stake in their plan since the implementation of the ESL depends on the cooperation of numerous stakeholders (Lavooij & Berke, 2019, March 25). Investigating the stakeholders' degree of interest and power is relevant for our consultancy project to understand whom to consider and consult in our research. A stakeholder long list can be found in Appendix 1. The original list included the parties Delta21 is already cooperating with (Lavooij & Berke, 2019, March 25) as well as parties we expected to be interested in the project for various reasons. From this list, we chose stakeholders that are of more direct interest to us and evaluated them based on their degree of interest and power (Figure 9).

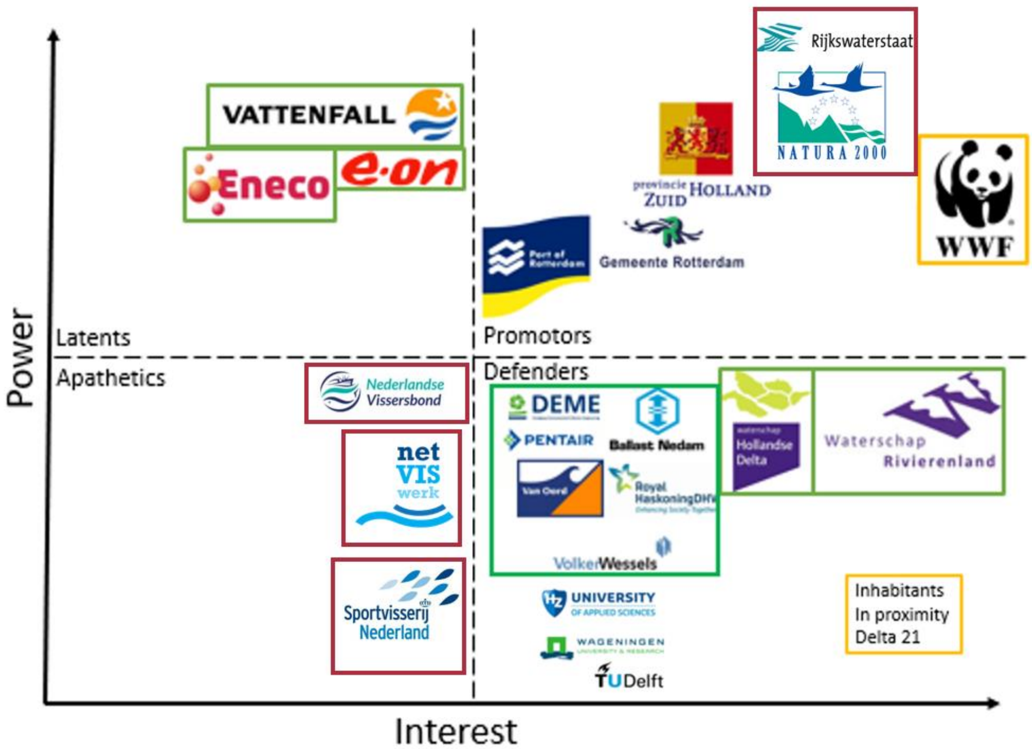

Figure 9: Diagram of stakeholder analysis. Stakeholder lined in green support the plan of Delta21 while those in red do not. Neutral stakeholders are not lined. Parties that support the project partially and have specific requirements before complete agreement, are indicated in orange.

This selection included energy companies (Vattenfall, Eneco and E-on), provinces and municipalities, the port of Rotterdam, Rijkswaterstaat (responsible party for the management of the Natura 2000 protected area, the Voordelta), environmental organisations (WWF), water boards (Hollandse Delta and Rivierenland), commercial fishermen (Nederlandse Vissersbond, NetVisWerk), recreational fishermen (Sportvisserij Nederland), as well as stakeholders that aid in the construction and design of Delta21 (Deme, Pentair, Ballast Nedam, Van Oord, Royal Haskoning DHV and Volker Wessels). Other stakeholders are inhabitants who live close to the proposed Delta21 region, and researchers and students of universities. Most companies, like energy companies and aquaculture organisations, are in favour of the project. WWF and Rijkswaterstaat (taking care of Natura 2000 regulations) are concerned about the plan of Delta21 due to the disturbance in the Voordelta during and after the implementation of the ESL (Lavooij, pers. communication, March 25, 2019).

Our ACT-team aims to design the ESL in such a way that it combines its function as storage lake and generator of green energy with natural and recreational values. Therefore, we are specifically interested in the stakeholders that have a high interest related to natural and recreational values. Based on this, we concluded from the stakeholder analysis that we should specifically consider the interests of inhabitants of the ESL-area, environmental organisations and governmental institutions related to Natura2000 in our consultancy project, since they have great interest in the project with regard to nature. They constitute a powerful stakeholder group that opposes the project for reasons connected to natural values. The authorities responsible for Natura 2000 (Appendix 3) are especially important since they will reject permission if their interests are not met. They have by far the most influence on and interest in the Delta21 plan since the location where the ESL would be built is situated in a Natura 2000 area. The construction of the ESL will conflict with the current policy in nearly 50% of the protected area, depending on the size of the Energy Storage Lake (Berke & Lavooij, 2018b). Governmental organisations agree with the policy of Natura 2000 and nature protection and restoration are important agenda points for them. Therefore, the ESL should provide options to compensate for potential losses regarding habitats and species. The opening of the dams in the Haringvliet area is meant as such an attempt for compensation by improving fish migration in the rivers Rijn and Maas and benefitting nature development in the surrounding area.
During the field trip to the study area we talked with two inhabitants, Henk Bal and Pieter Mout. The questions and transcripts of all interviews can be found in Appendix 2. Bal and Mout made us aware of additional relevant environmental organisations with a stake in the Voordelta area: “Natuurmonumenten”, “Stichting Zeeuws Landschap”, “Stichting het Zuid-Hollands Landschap”, “Natuur- en Milieufederatie Zuid-Holland” and “Staatsbosbeheer”. These were subsequently included in the stakeholder long list (Appendix 1). After the field trip we reached out to a range of these environmental organisations (Natuurmonumenten, Natuur- en Milieufederatie Zuid-Holland, WWF) as well as Rijkswaterstaat. Only WWF replied in time to conduct an interview (transcript provided in Appendix 2). The answers of all interviewees were used in this report.
Since we were only able to reach two inhabitants and one representative of one environmental organisation (Appendix 2), Delta21 should put more effort into contacting more people to get a more complete picture of the positions of the local population and environmental organisations. Bal specifically mentioned that active participation of municipalities in the planning process of Delta21 would be desirable (Appendix 2.2).

3.6 Policy

In 2008, the ministry of agriculture of the Netherlands assigned the area of the Voordelta as a Natura 2000 area (Figure 10). Natura 2000 constitutes a European network of nature areas which are indicated as such in order to protect certain habitats and species. The Natura 2000 areas are indicated based on the European bird and habitat directives (Rijkswaterstaat Zee en Delta & Royal HaskoningDHV, 2016). The main goal of Natura 2000 is to harbour and protect the diversity of soil, plants and animals. The policy of the Voordelta is directed towards the connection between nature and people. Therefore, recreation is an important factor in the policy of the Voordelta. Activities such as kite surfing, beach recreation and canoeing are allowed in the area, if they do not interfere with the ecological wellbeing (Natura 2000, n.d.).

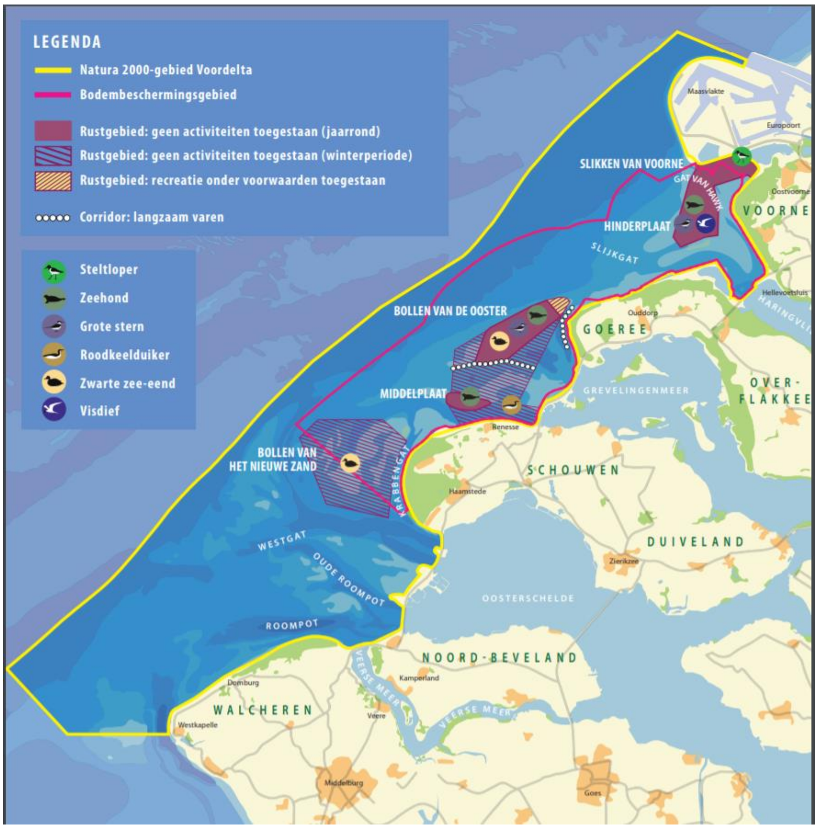

Figure 10: The Voordelta in front of the Dutch coastline. The yellow line indicates the Natura 2000 area in the Voordelta (RoyalHaskoningDHV, 2013).

3.6.1 Policy 2008-2014

The Natura 2000 management plan designates measures to protect natural values in the Voordelta and to stop deterioration of protected nature characteristics in collaboration with economic aspects and the possibility for recreation. The construction of the Maasvlakte II in 2008 disturbed the breeding ground, foraging area and resting area of multiple bird species that were formerly situated in the Voordelta. Because of the status as Natura 2000 area compensation had to take place for these disturbances. The compensations happened in the form of a soil protection region and five resting areas where human access is limited (Rijkswaterstaat & RIZA, 2008).

Activities

The possibilities of activities inside the protected area can be divided into four categories (Rijkswaterstaat & RIZA, 2008):

- No permit necessary and allowed.

- No permit necessary and allowed under conditions that are mentioned in the policy.
- Permit necessary. Each individual case is evaluated and considered independently.
- Not allowed.

Animal protection

For the protection of animals and their habitats, five resting areas have been appointed that can be divided into three categories directives (Rijkswaterstaat Zee en Delta & Royal HaskoningDHV, 2016).

- Total resting area: No activities are allowed throughout the whole year.
- Winter resting area: No activities are allowed in the winter period.
- Partial resting area: Only limited activities are allowed.

Soil protection

The sea bed is an important habitat and food source for different animal species. To maintain the biodiversity in the Voordelta, a soil protection region was appointed. No dredging, shellfish fishing, fishery using beam trawls and other activities or recreation that can harm the sea bottom are allowed in this area. Other recreation is allowed in this area directives (Rijkswaterstaat Zee en Delta & Royal HaskoningDHV, 2016).

3.6.2 Policy 2015-2021

The management plan 2015-2021 is an addition and adaption to the 2008-2014 plan. In the new management plan, more attention is given to creation of resting areas for (migratory) birds. The main adaptations are the implementation of a winter resting area for the Red-throated Loon and the addition of the area Gat van Hawk to the protected areas (Figure 10). The Gat van Hawk is located between the Hinderplaat and the Slikken van Voorne. The current agreements from the management plan 2015-2021 can be found in Appendix 3. They are indicated on four levels, being possibility of recreational activities (Appendix 3, table 1), possibility of fishery (Appendix 3, table 2), maintenance (Appendix 3, table 3) and possibility of other activities (Appendix 3, table 4) in the Voordelta directives (Rijkswaterstaat Zee en Delta & Royal HaskoningDHV, 2016). These agreements are mentioned in this report because they indicate possibilities and constraints for activities within the Voordelta. Supervisors and investigating officers of the Dutch authorities are involved with checking whether people are complying with the rules. If rules are broken, a warning will be given, and measures are taken according to the Nature protection law of 1998 directives (Rijkswaterstaat Zee en Delta & Royal HaskoningDHV, 2016).

4. Description Energy storage lake

This section explains the concept of the Energy Storage Lake and its design. Most information used is derived from the Delta21 reports about Energy and Water Safety (Berke & Lavooij, 2018a; Berke & Lavooij, 2018c). If information was retrieved from another source than Delta21, a reference is provided in the text. This section only comprises the initial design of the Energy Storage Lake (ESL) and not the complete design of Delta21 (including e.g. the tidal lake). Also, this report mainly considers the design of the ESL itself and not the possibilities for the generation of green energy outside the ESL.

4.1 Energy concept

The demand for energy has strongly increased throughout the 20th and 21st century (Figure 11) and is nowadays sixteen times higher than in 1950 (CBS, 2015). There is an ongoing shift towards more sustainable energy sources. Yet, a knowledge gap remains with regard to storage of energy. Once energy is generated, it is preferred to be stored in such a way that it can become available whenever the demand is high. At all times, "Dunkelflaute" - temporal shortages in wind and solar energy supply - should be prevented. Traditional sources of energy, such as coal plants, are currently used to prevent

"Dunkelflaute". However, in alignment with climate agreements, more sustainable solutions for energy storage are necessary. An initiative called EnergyStorageNL is working on different concepts to store energy in the Netherlands (EnergyStorage NL, 2019). They state that the transition to sustainable energy will lead to overcapacity, meaning a waste of energy due to uncertainties in the capacity of energy storage accommodations. One of the concepts considered by EnergyStorageNL is an Energy Storage Lake (ESL). How and when an ESL should be using its pumping and turbine functions is closely linked to energy availability, demand and prices. Solar energy is for instance only available during the day when the sun shines. Wind energy is more prone to changing weather conditions and its availability likewise fluctuates. The energy demand is highest during the morning and early evening, when inhabitants of the Netherlands start and end their working day. These time constraints result in varying energy prices over the day. Energy is most expensive when the demand is the highest. During the night, the energy price is very low, in congruence with the demand. The concept of ESL is anticipating on these fluctuations in energy prices, supply and demand (Section 4.2). Delta21 designed such an ESL that can generate and store energy. In the next sections we provide a description of the planned ESL of Delta21.

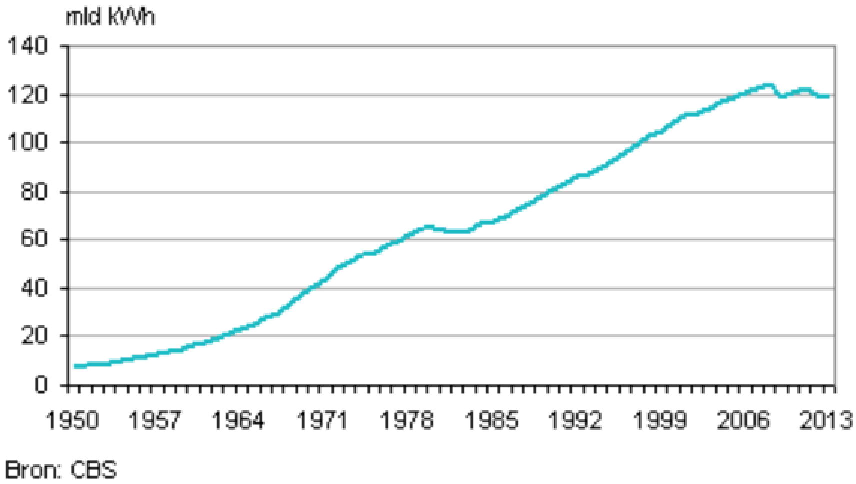

Figure 11: Changes in energy demand over time (1950-2013) (CBS, 2015).

In addition to the concept of the ESL, Delta21 indicated four other ways for sustainable generation and storage of energy in and around the lake. Firstly, there are possibilities to make a heat storage lake next to the ESL. This heat storage lake will function on the principle of converting power to heat. Hot water can directly be used to warm houses, which is an interesting alternative to heating with gas. Secondly, the power needed for the functioning of the ESL (i.e. the pumps) can in part be generated using solar panels on the lake and/or dunes. Delta21 indicated that there is 300 ha of land area available for solar panels in their initial design. On the water the area available for solar panels varies between 1200-2000 ha. At this point in time, Delta21 assumes that 200 ha of land area and 400 ha of water area can be assigned to the generation of energy with solar panels. Thirdly, there are possibilities to build a wind park along the Dutch coast. The last possibility presented is the concept of Blue Energy, where energy is generated by using the differences in salt concentration between fresh and salt water. In summary, Delta21 came up with different concepts to store and generate energy sustainably. However, this report will mainly consider the design of the ESL itself, and not the possibilities for the generation of green energy out of the ESL.

4.2 Functioning

This section provides a brief description to clarify the functioning of the Delta21 Energy Storage Lake. As the ESL is located below NAP, there is a difference in elevation between the sea and the lake. When energy is cheap and superfluous, the water in the lake is pumped out of it, thereby using energy. During peak energy demand, water flows into the lake via turbines, thereby generating energy. The Delta21 ESL is planned to be emptied and filled once a day. The functionality of the pumps can be switched between pumping and turbine functioning within a few seconds. The aspiration is to use green energy as main source for the pumps. Delta21 suggests that this green energy should be generated in and around the lake, for example through solar panels (on the lake /dunes) or a wind park. To ensure the functioning of the pumps, the water level in the ESL will never be lower than 5 metres from the bottom of the lake.

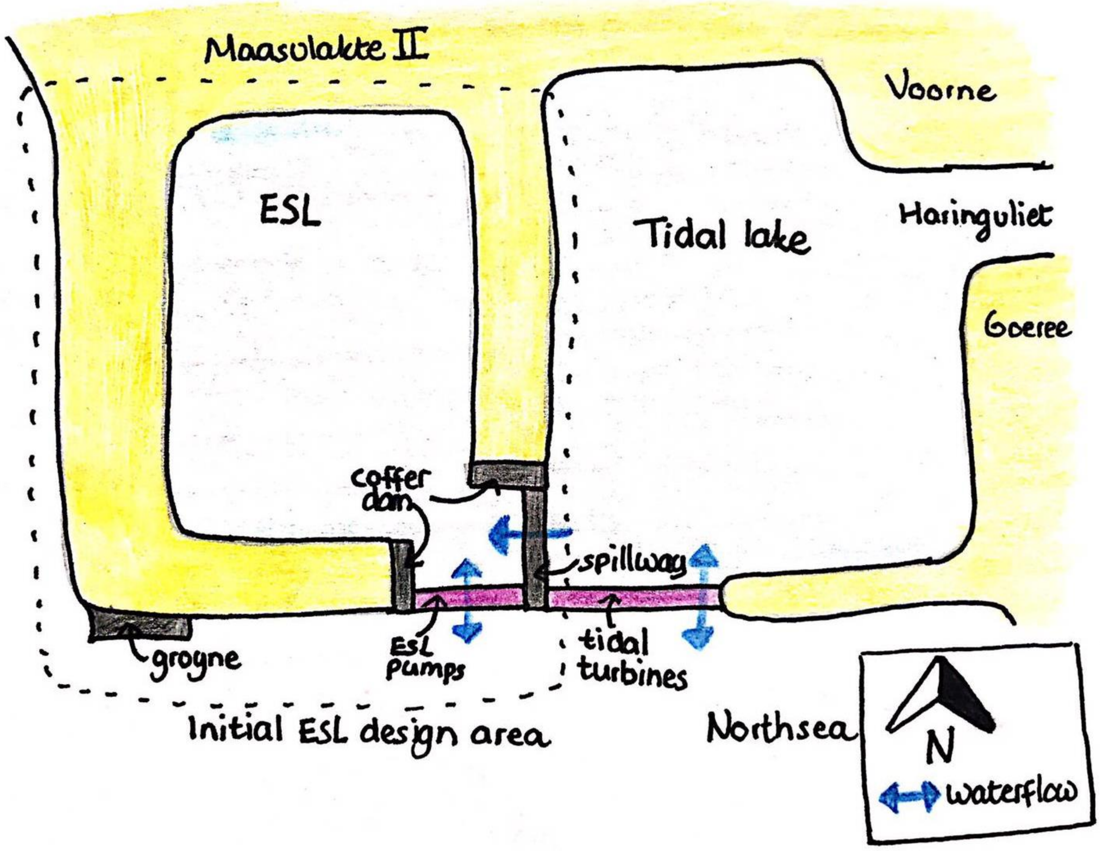

Figure 12: Functioning of the ESL

With climate change, the Dutch rivers are expected to flood once every five to ten years. The main purpose of the ESL is to protect inhabitants from (river) flooding. If water levels in Dutch rivers are dangerously high, the ESL can function as a retention basin for that excess of fresh water. In a normal situation, the river water flows into the Haringvliet where it encounters seawater. When high river discharge occurs simultaneously with high sea levels and storms, river water can flow into the ESL via a spillway from where it will be continuously pumped into the sea. Freshwater is expected to only form a shallow layer on top of the saltwater lake (Figure 12). During such days, the ESL cannot be used to generate and store energy, but it will require energy to pump excess water into the sea.

The Haringvliet itself is beyond the scope of this research. However, energy will also be generated at the border between the estuary and the sea. The tidal range at this location along the Dutch coast is around 2 metres and occurs twice a day. The planned dam between the ESL and the mainland of the province of Zeeland can therefore be used to generate energy. Turbines will be installed to generate energy from tidal fluctuations. There is a possibility to also provide these turbines with a pumping function. In that way, these pumps could drain an excess of fresh water if the ESL basin should have a big enough capacity. For the initial design, Delta21 calculated that the water volume capacity of the ESL is big enough to temporarily store expected river water excesses.

Summing up, water can flow in or out the ESL at two locations. The first location is the connection of the ESL with the sea, where a 600 metres long row of pumps with turbine function will be installed in order to store and release seawater. The second location is a connection between the ESL and the Haringvliet estuary that can be used as a spillway for an excess of riverine water. This spillway will have a length of 400 metres and will not have any build-in pumps or turbines.

4.3 Pumped Hydro Storage systems (PHS)

The technical system behind the energy storage function is called a Pumped Hydro Storage (PHS) system. PHS is the concept of temporarily storing energy in water, and is already used in countries like Norway, Sweden and Spain. In these examples, water is pumped higher up into the mountains and is then released to flow downwards to generate energy. In the Netherlands, it is not possible to use this concept in the traditional sense, since there is a lack of mountainous areas. Different concepts have been developed before, like the O-PAC (Ondergrondse Pomp Accumulatie Centrale) project in Limburg; storage at sea, and storage at the IJsselmeer. In the O-PAC project, ideas were generated to store water in old mines and use the PHS concept to generate energy. However, this idea never became reality.

Delta21 reverses the traditional concept of PHS: instead of pumping water to mountainous areas, water will be pumped from below sea level to above NAP. Traditionally, water was stored in high lying basins as potential energy. The potential energy was generated when it flew downslope. In the case of Delta21, water is no longer stored as potential energy since the energy will be generated when the water flows into the storage basin. Therefore, the whole sea can be seen as potential energy. This adapted situation better fits to the Dutch delta situation. As indicated before, it is required to use pumps that have a turbine function next to a pumping function. Figure 13 shows the principal of PHS: water is pumped to a higher level and generates energy when flowing down into the ESL. The Pump can also function as a turbine: it is a reversible pump turbine (RPT).

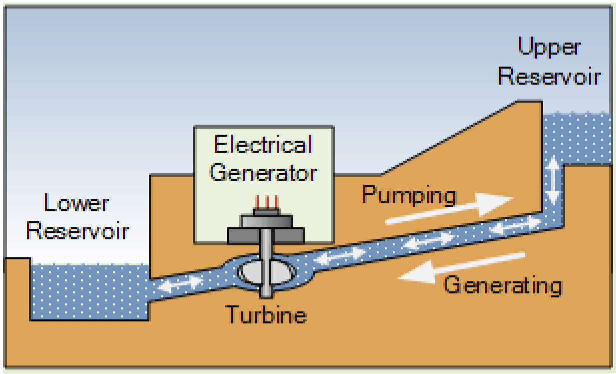

Figure 13: The concept of PHS. Source: http://www.alternative-energy-tutorials.com/energy-articles/pumped-hydro-storage.html

4.4 Basic information about the design: dimensions and materials

The sea bottom at the foreseen location to build the ESL currently varies between -6 till -14 meters NAP. The designed ESL will have a depth of around 30 metres in total, and locally the lake bottom is expected to vary between -25 and -27.5 metres NAP. To construct the lake, sediments must be dug out at the construction site. It is expected that 325 million m^3 of sand and mud will be excavated. Those sediments will be used to build the dune system around the ESL. An amount of 250 million m^3 of sand is needed to build the dune system. The excavation of the lake provides enough sediment to do build the system, but since the excavated sand likely contains a lot of silty lenses, around 20-30% of the obtained sediment will be lost. An additional amount of 10 million m^3 of sand will be made available by the deepening of the gully to the estuary, and the deepening of the Ouddorp harbour. The depth of the lake is maximized till 30 metres since there is a 10-meter-thick clay layer at a depth of -50 meters NAP. There are concerns that the pressure below the clay layer becomes too high. Therefore, it is suggested to include vertical drainage into the initial ESL design. To relieve the clay layer from the water pressure, drainage tubes till a depth of -70 metres can be placed: the water can find its way out and the pressure will be lowered. Other measures could be the use of water glass injections, where the material will be injected into the concerned layer and fills the pore space between the sediment particles. In this way, the layer would be strengthened and can handle a higher water pressure.

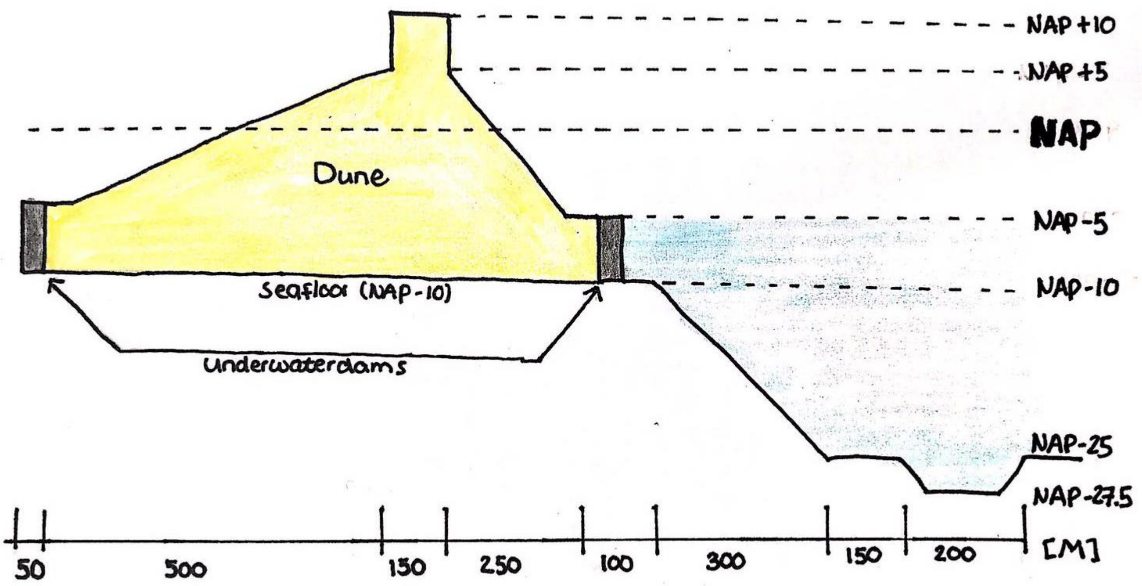

Figure 14: Dimensions of the ESL and surrounding dunes

The dune system around the ESL will have a width of around one kilometre (Figure 14). The top of the dune will be at a height of +10 meters NAP. At a height of +5 meters NAP the dune will have a width of approximately 250 meters. The dune slopes on the sea- and lakeside will consist of different materials and are constructed under different angles. The dune slope on the seaside will have an angle of 1:60 and will consist of fine sand. The 1:60 ratio is chosen because this slope is comparable to original beach slopes in the surrounding areas. Above water level, the slope will not be steeper than 1:15, and below water level the slope will nowhere be steeper than 1:20. If the slopes become unstable, a gravel layer could be applied. On the inside of the ESL, the dunes will be much steeper, since they are not subjected to wave action (slope angle of 1:25). On the ESL side the lake will be dug out with a slope of 1:20 for sides of the lake. The dune system will be supported by underwater dams or bunds. Underwater dams are vertical dams which support the dune at the transition between dune and sea bottom. Alternatively, bunds are made of sand asphalt and are another way of supporting the dam underwater. These measures are considered in the design because they will limit the width of the dune systems and without these infrastructural measures, the dune systems would become much wider. Especially on the seaside, where the slope is very gentle. The use of water asphalt concrete will only be necessary on the seaside of the dune system, because of the higher wave action over there. This concrete will be used to support the underwater dams and/ or bunds.

The ESL has a maximum capacity of 350 million m^3. To pump out the total water volume within 12 hours, 93 pumps with a capacity of each 20MW are needed. This represents a mean pumping volume of 8,100 m^3/s. The speed of pumping can be fine-tuned between 6,000 and 10,000 m^3/s. Those pumps will be placed at the Southside of the ESL and will pump the water from the ESL back into the sea. They can also function as turbines and let water flow down from the sea to the lake. The current sea bottom depth of the future pump location is 12 metres below NAP. The effective height difference which can be reached in the lake is 17.5 metres and the mean height difference of the water level within the lake will be 14 metres compared to NAP. Per hour, there is a maximum increase or decrease of the water level of 1.2 meters. The river water spillway will be constructed eastwards of the pump location and connects the ESL with the Haringvliet.

The construction of the ESL entails several constraints. The general idea is to make use of a dam by which the sandy sediments will be captured. In order to minimize erosion during the construction and afterwards, the dam can be strengthened with concrete or sand-asphalt. After the construction it can take several months for the groundwater level to adapt to this new situation. This fact is important for our advice: it entails several consequences for ecosystem development in an early stage. At this moment it is unclear whether the sand layer below the ESL is stable enough, since the sand layer(s) are alternated by silt lenses. Silt lenses are less impermeable than sand layers and can therefore cause instability when filling or emptying the lake. Measures to decrease instability can be the usage of vertical drainage at a depth between -25 and -50 metres NAP. On the other hand, the silt lenses have the advantage that they retain the ground water level better. If ground water losses would be too big, cement can be injected in an aquifer to turn it into an aquitard.

5. Anticipated impact of ESL on environment

In this section we elaborate on the initial ESL design without active creation and management of natural and recreational values. When the initial design of the ESL, as explained in section 4 is implemented in the Voordelta, the abiotic and biotic environment will be affected. Afterwards, changes in the abiotic system will directly and indirectly lead to changes in the biotics of the ESL environment.

5.1 Abiotic environment

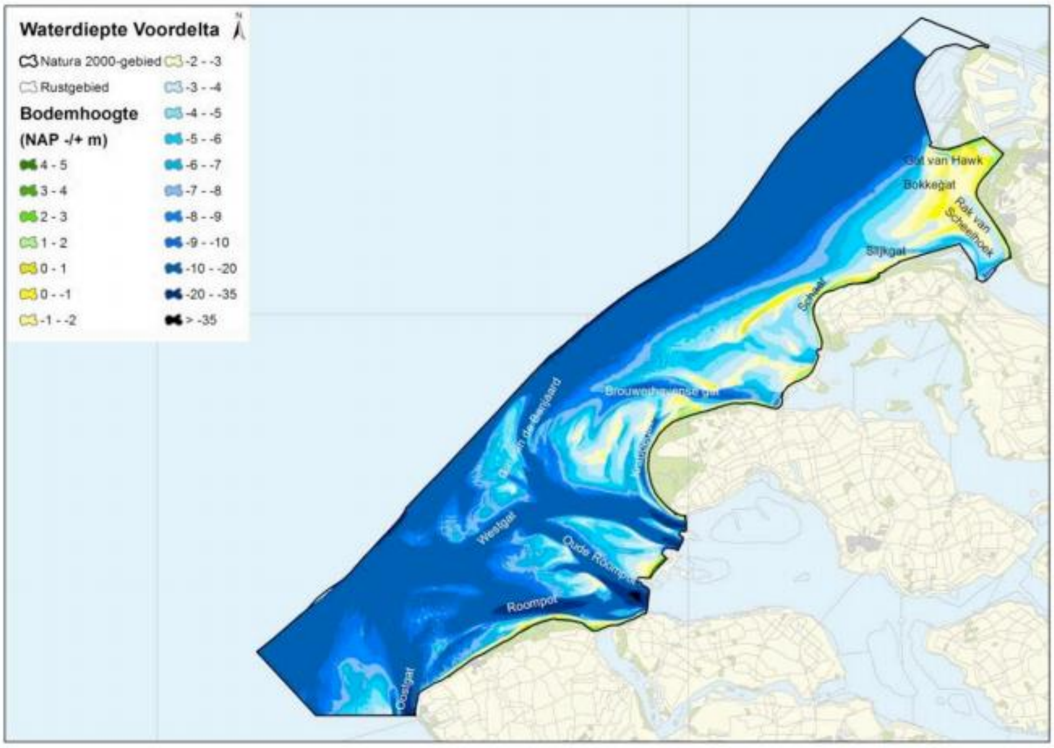

Figure 15: Water depth in the Voordelta (Rijkswaterstaat Zee en Delta & Royal HaskoningDHV, 2016)

Since the possible effects of the initial ESL design on hydrological and sedimentological dynamics have not yet been modelled or measured, the expected abiotic changes in the environment are retrieved from general scientific knowledge and interviews with experts. The first part of this section focusses on the current influence of the Deltawerken and Maasvlakte II on the environment. The effect of the ESL construction in the future could possibly result in similar geomorphological changes. The marine accumulation of sand in front of the coast is known to have strongly increased since the construction of the Deltawerken, which resulted in the formation of giant sandbanks in the Voordelta (Kohsiek & Mulder, 1989). The construction of Maasvlakte II, with an area of 20 km^2, led to reductions in wave height and wave intensity south of this region (H. Bal, pers. communication, April 16, 2019). This resulted in an increased sedimentation rate in the nearby surroundings of Maasvlakte II. Sand is accumulating in front of the Voornse dunes since the realization of Maasvlakte II (Figure 15). The effective water depth is decreasing, and wave action at the coast has decreased in intensity. Furthermore, the construction of Maasvlakte II has led to a decrease in salt spray, since salt spray occurs as a result of breaking waves and depends on wind speed (De Leeuw *et al.*, 2011; P. Mout, pers. communication, April 16, 2019).

Due to the lack of available modelling studies, it is still hard to expect how the sediment dynamics in the area will be affected. Two opposite processes can be expected in the study area. On one hand a reduce in wave action can be expected, therefore the stirring up factor of the waves at the sea bottom will be reduced. On the other hand, due to the filling and emptying of the Haringvliet every tide and the ESL filling and emptying every day, the current velocity will increase. Particularly directly outside the ESL and outside the Tidal Lake a current velocity can be expected. In order to prevent erosion in that area near the inlet, the sea bottom must be protected with rock protection. Within the Tidal Lake the currents will increase due to the filling of the Haringvliet. However, the wave action will reduce the stirring up of the bottom particles further. The reduced wave action and the higher current velocities have an opposite effect on the erosion or sedimentation within the tidal lake and will differ from point to point. Modelling of the area is needed to predict the amounts of possible erosion and of sedimentation in the Tidal Lake and in the area outside of the ESL and the Tidal Lake (H. Lavooij, pers. communication, May 1, 2019).

According to Delta21 it can be expected that the tidal amplitude in the area will not change due to the initial ESL design. Furthermore, it is expected that the construction of the ESL will even further decrease the salt spray in the Voornse dunes (P. Mout, pers. communication, April 16, 2019). However, there will be salt spray at the northwest side of the ESL, since this is where waves will have the strongest impact.

The Dutch dunes are strongly affected by aeolian processes. The borders of the initial ESL design consist of sand, and in the first years after the construction there will be little organic material present in the dune sand. This will make the dunes susceptible to wind erosion, because sand without organic material is cohesionless. However, if after some time a small amount of organic matter or a layer of mosses or algae is present, the soil will become more protected against erosion (Jungerius & van der Meulen, 1988). The eroded material will be transported towards other areas. The dominant wind direction in the Netherlands is from the West (KNMI, 2011). Therefore, the dunes on this side of the ESL are expected to experience most wind erosion, and sediments might be blown into the ESL. This could indicate that there is a necessity to dredge the lake every now and then, although it is hard to estimate the extent of this problem. Furthermore, the turbidity of the lake could be relatively high at certain moments, as a result of loose sediments (sand and sludge) and water movement.

The ESL contains salt water, but once every 5-10 years fresh water will enter the ESL with high river discharge. This will lower the salinity of the lake, although the density difference between salt and fresh water is likely to result in a freshwater layer on top of the salt water that was already present in the lake (H. Lavooij, pers. communication, April 23, 2019).

5.2 Biotic environment

To construct the initial ESL design, sand will be dug from the sea bottom to build the dune system. The subtraction of vast amounts of sand from the sea bottom could have a detrimental impact on the benthic community found on the sea bottom. Literature indicates that deep sand extraction will lead to severe detrimental effects on the current benthic community (Boers, 2005). Yet, the benthic fauna can get used to the new conditions in the pit. However, the sand excavation should be carried out according to certain regulations to ensure recovery of benthic fauna (Stolk & Dijkshoorn, 2009) and in such a way that the abiotic environment is disturbed as little as possible. The re-establishment of benthic fauna will take time, and it cannot be expected that the benthic community will directly recover (Boers, 2005).

In the Voornse dunes, a reduction in salt spray could have been the reason for the decrease in habitat with open drifting dunes and dune grassland (Bakker *et al.*, 1996), and the rapid growth of dune thickets and forests. Especially the first dune row close to the sea is vulnerable to a reduction in salt spray (Sanders *et al.*, 2004). The vegetation on the first dune row is highly adapted to and dependent on salt. The amount of salt spray deposition furthermore depends on abiotic factors and the structure of the vegetation present. On the other side, the initial ESL design includes a wide dune system on the seaside, and therefore will be exposed to high levels of salt spray.

The construction of the ESL, like the Maasvlakte construction, will change at least some of the habitats designated under Natura 2000, not only for the Voordelta area but also for the Voornse dunes and the Duinen Goeree & Kwade Hoek. Sandbanks permanently covered by sea water (H1110) are expected to decrease in the tidal lake and in the area in front of the ESL turbines towards the coast, assuming that sedimentation increases, and thus leading to sandbanks and mudflats covered by water only temporarily (H1140). Next to this change, areas with less wind influence will develop, and this can lead to the creation of new habitats such as salt marshes, green beaches and primary dune valleys (Sanders *et al.*, 2004). It is important to mention that despite the increase in habitats that can serve as a potential resting area, seals will not be able to access them if the closing of the tidal lake does not allow them to.
Without any active enhancement of natural values in and around the ESL, it is not expected that the area remains completely barren, but any development of nature will likely take many years. Furthermore, only the first stages of dune development and vegetation succession will form, since sandy soils are very low in nutrients. Pioneer species such as mosses like *Tortula ruralis*, and grasses like *Corynephorus canescens* or *Ammophila arenaria* are the first colonizers to be expected on the dunes, belonging to habitat type H2120 “White dunes”. Their colonisation without active seeding or planting would be slow and limited by the organic content of the soil. In calcareous soils where pH is high, as is the case on the coast of the Netherlands, the microbial community tends to be dominated by bacteria, which have a higher nitrogen demand than other microbes like fungi. This limits vegetation growth even more (Grootjans *et al.*, 2013). Regarding birds, the initial design is only expected to attract birds whose food source would be provided in the ESL. Thus, birds that feed on the fauna and algae that are found on mudflats, sandbanks and very shallow waters are not expected to arrive. Only fish-eating birds could be naturally attracted to the ESL as they can feed on the surrounding waters and also on the schools of fish that could naturally enter the ESL from the tidal lake. The fact that these fish would be restricted to swimming inside the ESL could be an advantage for these fish-eating birds. However, unlike aquatic animals that go through a larval phase in their lifecycle, most fishes do not and are therefore not expected to occur in the lake without introducing them actively.

The functioning of the ESL is expected to affect nature and wildlife in several ways. Regarding bird occurrence in and around the lake, it might be affected by turbine noise when they are functioning. If it is loud, birds will be startled. The functioning of the lake might also have an effect on fish. They can get caught in the current created by the pumps and be pumped out of the ESL, which can potentially cause their death. The currents can furthermore retard the settlement of soil organisms, especially when the water level is low and in the areas that are closer to the turbines. Turbidity created by the currents will suppose another difficulty for the development of soil organisms, by affecting the amount of light they receive. This turbidity is expected to be higher closer to the turbines, although further from the turbines soil organisms will face the difficulty or growing under higher sedimentation rates. Such water flow mentioned before will lead to a constant income of new water to the ESL, limiting the conditions for algal blooms to establish. Algae are the base of the seafood chain, so a limitation on their growth will also limit the development of the groups of animals that depend on them. However, algal blooms can also have detrimental effects on marine life, since they can shift the system from a clear to a turbid state and take away the oxygen (Scheffer, 2009).

The freshwater shock occurring every 5-10 years is not expected to affect nature development on the dunes above the surface. The soil organisms inhabiting the bottom of the lake, are also not expected to be affected given that it is likely that salt water and fresh water would not mix due to the density differences. The greatest effect of fresh water will be on the organisms growing on the upper parts of the ESL interior dunes under the water level: shellfish, algae, plants and fish. Shellfish are expected to survive in the freshwater for 1 or 2 days, but seaweed is probably not able to handle it (M. Poelman, pers. communication, April 10, 2019). In the case of fish, the response to fresh water will depend on the species, but many species are unlikely to survive such a shock. However, since these shocks do not occur frequently, nature can develop in the years between, and the shocks will serve to reset the system to allow pioneers to grow and establish again.

6. Ideas for improving the ESL design

In this section, we aspire to answer the second part of our main research question: *Which possibilities exist to turn the ESL into a valuable biodiverse nature area that is attractive to visitors?* As a conclusion from section 3, we specified dunes, marine life and birds to be essential natural characteristics of the local environment. The Voornse dunes are valued for their richness in terms of biodiversity, but their survival might be affected by the realization of the ESL (Section 5). Within the purpose "Dynamic Dunes" we aim to convey the biodiversity of the Voornse dunes to the dunes surrounding the ESL. The Dutch Delta, including the Voordelta, furthermore used to be the nursery for many (migrating) fish species (Section 3.4.7). Therefore, within the purpose "Myriad Marine Life" we focus on designing the ESL in such a way that marine life can flourish and resting and rearing areas for marine organisms can be restored. Finally, the Voordelta is an important foraging, breeding and resting area for many (migratory) birds, serving as a key habitat both nationally and internationally (Section 3.4.9). Maintaining this important function is part of the third and final purpose "Biodiverse Bird Life".

For each purpose, we will provide ideas on how to adapt the initial ESL design, altogether serving the main goal of turning the ESL into a biodiverse nature area. These ideas are assembled in three variants, and each variant targets one of the aforementioned purposes. We will furthermore elaborate on the constraints to reach the purpose and include ideas on how the recreational value of the ESL can be enhanced without compromising the specific nature-related purpose.

6.1 Dynamic Dunes

The Voornse dunes are thriving in term of biodiversity, with at least 1053 plant species, abundant bird life, insect communities and mammalian species (P. Mout, pers. communication, April 16, 2019). However, due to an anticipated reduction in abiotic processes like salt spray when the ESL is constructed, some of these species might be replaced by forest and bushes (section 5.2). Since the ESL will be located further away from the coastline, salt spray is expected to be higher here, and some of the Voornse dunes richness could establish on the ESL dunes. The current species in the Voornse dunes are dependent on the many habitats and micro-climates that exist within the area. Therefore, to convey part of the richness of these dunes to the dunes surrounding the ESL, these local circumstances need to be shaped. The aim is to create a resilient self-functioning ecosystem, thus although there is active intervention in the first stages, the aim is to have as little management as possible on the long-term.

Within this purpose, we must consider several constraints. The dunes of the ESL, for instance, are only 250 meters wide on top, and this might not be large enough to allow for a full vegetation succession along the wet-dry gradient. Furthermore, the dunes are more exposed to wind and salt spray than the Voornse dunes are. For pioneer vegetation this is likely to have a positive effect, but it is a constraint for habitat types that do not cope well with this kind of abiotic conditions (e.g. dune forests). Within this variant, we mainly explore the options to convey part of the richness of the Voornse dunes to the dunes surrounding the ESL. Active planting of important species in each habitat will accelerate the development of nature, and certain ecosystems for certain locations could be predefined. Plants could alternatively be seeded, so they can grow by themselves.

The Voornse dunes consist of six main habitat types: White dunes (H2120), Grey dunes (H2130), Sea buckthorn bush (H2160), Dunes with willow (H2170), Dune forests (H2180) and Dune valleys (H2190) (Ministerie van Landbouw, Natuur en Voedselkwaliteit, n.d.). To recreate the Voornse dunes in the dunes of the ESL, each habitat should be represented.
The different habitats are described in the next sections. The important species per habitat in Table 1 were derived from Ministerie van Landbouw, Natuur en Voedselkwaliteit (n.d.) and Mout (n.d.).

White dunes (H2120)
Within a complete dune system, a gradient from wet to dry can be found from the border of the dunes at the coast, towards the middle part of the dune. White dunes are the dunes that form the outermost dune belt, and these could likewise form the first habitat that occurs in the dunes of the ESL. This habitat type is considered poor in species and is dominated by Marram grass (Ammophila arenaria). Along the coast of the ESL dunes, rocks can be added, so both pioneer species that grow on a sand substrate and those that might prefer a rockier substrate, like Saxifraga tridactylites, can establish.

Grey dunes (H2130)
Grey dunes, or dune grasslands, are dunes that can be found more inland than white dunes. They are characterised by more closed vegetation that generally consists of grass, but it can also consist of mosses and lichens. This habitat is therefore more diverse in species than are the white dunes. In the ESL, this habitat can be planted right behind the white dunes and towards the middle of the dunes. To create variation, this habitat can start at different distances from the water along the dunes. There are two types of grey dunes, and both can be created by adding different amounts of lime to the dune soil. When a low lime content is present, nutrient-poor grasslands can establish, while with a high lime content, nutrient-rich dune grasslands are created. Another option would be to let nature develop such nutrient-rich environments over time. However, this process likely costs a lot of time, and trials with the use of sludge for the development of vegetation on the Marker Wadden have shown to be effective (Marker Wadden Congress, pers. communication, April 18, 2019). Therefore, we advise to actively alter the lime content.

Dune thicket with Sea buckthorn (H2160)
Dune thickets with buckthorn spatially overlap with the grey dunes and contain many of the species that are also found in the latter habitat. We find these thickets in dune valleys and on drier dunes. The main difference with grey dunes is the growth of bushes, which can dominate the habitat. Dune thicket vegetation could be planted in the central part of the ESL dunes. On the side of the dunes that faces inland—where plant communities are more protected from strong winds and salt spray—some parts of the white and grey dunes can eventually show succession to sea buckthorn bushes without human intervention. Therefore, dune thickets with Sea buckthorn are likely not restricted to the central part of the ESL dunes.

*Table 1: Species per habitat type, subdivided into species groups. *collected from the separate pages devoted to each habitat type on the website of SynBioSys Alterra (SynBioSys, Alterra, LNV, 2019).*

General appearance*	Habitat	Species group	Latin (English) species names
	White dunes	Grasses	*Ammophila arenaria* (Marram grass); *Leymus arenarius* (Sand rye grass); *Elytrigia juncea*
		Flowering plants	*Sonchus arvensis var. Maritimus*; *Euphorbia paralias* (Sea spurge); *Eryngium maritimum* (Sea spurge); *Eryngium maritimum* (Sea holly); *Cynoglossum officinale* (Houndstooth); *Erodium lebelii*; *Sedum acre* (Wall pepper); *Viola curtisii*; *Saxifraga tridactylites* (Nailwort)
		Mosses & lichens	*Tortula ruralis* (Star moss); *Cladonia rangiferina* (Reindeer lichen)
	Grey dunes – nutrient rich	Grasses	*Luzula campestris* (Field wood-rush)
		Flowering plants	*Polygala vulgaris* (Common milkwort); *Carlina vulgaris* (Carline thistle); *Erigeron acer* (Blue fleabane); *Acinos arvensis* (Basil thyme); *Galium mollugo* (Hedge bedstraw); *Thymus pulegioides* (Broad-leaved thyme);
	Grey dunes – nutrient poor	Flowering plants	*Galium verum* (Lady's bedstraw); *Dianthus deltoides* (Maiden pink); *Thymus pulegioides* (Broad-leaved thyme); *Thymus serpyllum*, (Elfin); *Hieracium pilosella* (Mouse-ear hawkweed); *Rumex acetosella* (Sour weed); *Achillea millefolium*, (Common yarrow); *Cerastium arvense* (Field mouse-ear); *Lotus corniculatus* (Common bird's-foot trefoil); *Jacobaea vulgaris* (Common ragwort); *Leontodon taraxacoides* (Hairy hawkbit)
	Dune thickets with sea buckthorn	Flowering plants	*Viburnum opulus* (Guelder-rose); *Lithospermum officinale* (Common gromwell); *Polygonatum odoratum* (angular Solomon's seal); *Viola hirta*, (Hairy violet); *Agrimonia eupatoria* (Sticklewort); *Asparagus officinalis*; *Eupatorium cannabinum*, (Hemp-agrimony)
		Shrubs & trees	*Hippophae rhamnoides* (Common sea buckthorn); *Ligustrum vulgare* (Wild privet); *Crataegus monogyna* (Common hawthorn); *Berberis vulgaris* (Common barberry); *Rhamnus cathartica* (Common buckthorn); *Rosa rubiginosa* (Eglantine); *Rosa canina* (Dog rose)
	Dune thickets with creeping willow	Flowering plants	*Pyrola rotundifolia* (Round-leaved wintergreen); *Pyrola minor* (Common wintergreen); *Monotropa hypopitys* (Dutchman's pipe)
		Shrubs & trees	*Salix repens* (Creeping willow)
	Dune forests	Flowering plants	*Arum italicum* (Italian arum); *Arum maculatum* (*Wild arum*); *Allium ursinum* (Wild garlic); *Narcissus pseudonarcissus* (Wild daffodil); *Hyacinthoides non-scripta* (Common bluebell); *Eranthis hyemalis* (Winter aconite); *Allium paradoxum* (Few-flowered garlic); *Anemone nemorosa* (Wood anemone); *Doronicum pardalianches* (Leopard's bane); *Galanthus nivalis* (Common snowdrop)
		Shrubs & trees	*Betula pubescens* (European white birch); *Quercus robur* (*Common oak*); *Populus tremula* (Common aspen); *Ligustrum vulgare* (Wild privet); *Fagus sylvatica* (Common beech)
	Wet dune valleys	Flowering plants	*Parnassia palustris* (Bog-star); *Blysmus compressus*; *Baldellia ranunculoides* (Lesser water-plantain); *Gentianella amarella* (Autumn gentian); *Blackstonia perfoliata subsp. serotina* (Yellow-wort); *Anagallis tenella* (Bog pimpernel); *Mentha aquatica*, (Water mint); *Eleocharis palustris* (Common spike-rush)
		Shrubs & trees	*Schoenus nigricans* (Black bog-rush); *Salix repens* (Creeping willow)
		Orchids	*Liparis loeselii* (Fen orchid); *Gymnadenia conopsea* (Marsh fragrant orchid); *Dactylorhiza incarnata* (Early marsh-orchid)
		Aquatic plants	*Potamogeton coloratus* (Fen pondweed)

Dune thicket with Willow (H2170)
Dune thickets with Willow are characterised by the presence of Creeping willow (*Salix repens),* and are mainly found in dune valleys. In general, these dune tickets consist of overgrown bushes. In the ESL dune system, this habitat could be planted along with patches of dune thickets with sea buckthorn, in the central part of the dunes.

Dune forests (H2180)
Dune forests are characterised by trees and shrubs, with an undergrowth of flowering plant. As mentioned in the restrictions, this habitat type is the least likely to develop, since the ESL dunes are likely not wide enough to allow dune forests to develop. On the other hand, dune forests are the least likely to be affected by the construction of the ESL, and they might even benefit. Therefore, even if dune forests are not developed on the ESL dunes, they would still be conserved in the Voornse dunes. It would, however, be interesting to construct a part of the ESL dunes a bit wider than the rest, to see what kind of vegetation succession occurs there. This would be easier to do on the dune facing the tidal lake, since the sea bottom is shallower on this side, and increasing the width and size of the dunes is therefore easier and less prone to erosion.

Wet dune valleys (H2190)
Wet dune valleys are especially rich in biodiversity. The habitat is typically a pioneer vegetation, and encroachment by bushes and trees can easily lead to succession and disappearance of the characteristic species for this habitat type. Grazing herbivores can aid in counteracting bush-encroachment, as they feed on young trees and grasses that might otherwise overgrow dune valley vegetation (Bakker *et al.*, 1996). However, large grazers might not be able to find a suitable habitat within the dunes surrounding the ESL, considering the dunes likely do not provide enough space for e.g. food, shelter and territory. Smaller grazers, such as rabbits, could survive in the area, and their introduction can be considered (Bakker *et al.*, 1996). Furthermore, predators are neither expected to naturally regulate their populations, since the area is likewise too small for a predatory population to establish. A complete food-cycle is therefore hard to establish, and the population of herbivores might therefore need active maintenance.
Another major restriction for wet dune valleys to develop is the availability of wet soil. The possibilities for a freshwater lens to develop within the dunes is limited. Therefore, on both long sides of the ESL a depression can be excavated, where underneath the surface a layer of clay is placed. This will create a less permeable layer that helps to retain water (Figure 16). Within dune valley vegetation, a distinction can be made between lime-rich and acidified, mostly older dune valleys. The former can best be established in the ESL dunes, since the created valley will be a young dune valley. Salt spray and sand spray bring basic material, decreasing the acidity of the soil (Sanders *et al.*, 2004). Therefore, the more sheltered dune valley on the tidal-lake side, closest to the coast, might over time turn into an acidified dune valley. Species such as Common sedge (*Carex nigra)* and *Carex trinervis* grow in acidic dune valleys.

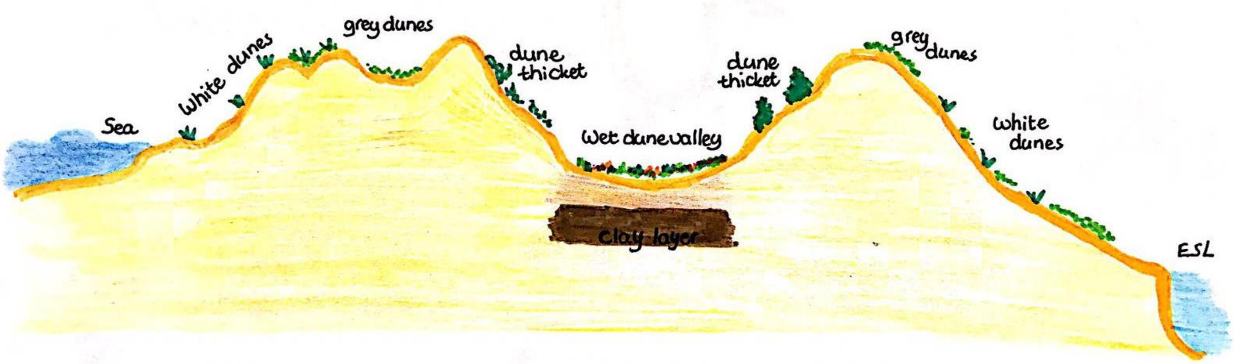

Figure 16: Design of a wet dune valley, using a clay layer within the dune. Furthermore, the locations where specific habitat types can establish within the ESL dunes are shown.

Sediment dynamics play a crucial role in creating wet dune valley ecosystems. Dune development is a dynamic process and can counteract valley formation. Figure 17 shows that the formation and establishment of a dune system go hand in hand with (local) erosion and sedimentation. On the seaside (stoss-side) the process of erosion is predominant, and on the lee-side of the dune sedimentation is ascendant (Sloss *et al.*, 2012). The valley system should therefore be located in such a way that its formation will not be counteracted by predictable sedimentation and erosion dynamics. The created dune valleys could therefore be surrounded by stable high dunes, for instance provided by dune thickets with buckthorn or willow (H2160, H210).

Finally, groundwater management is essential for the development of a dune valley. Further research is need on the presence and effects of seepage underneath the dunes. For dune valley vegetation, seasonal fluctuations in groundwater level are needed. These fluctuations could for instance be generated artificially. It should therefore be noted that the designed dune valley is rather artificial, and not as much a natural system.

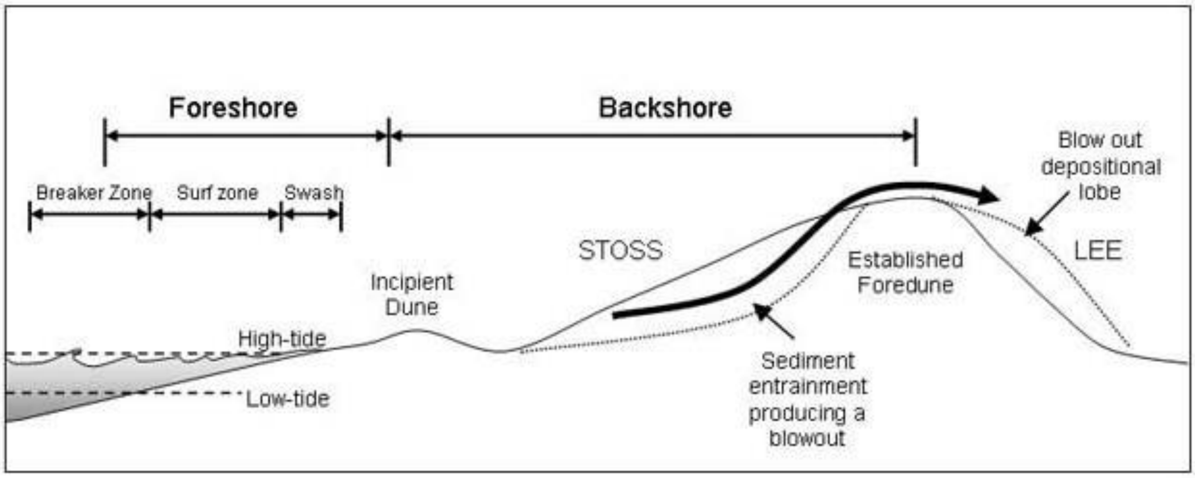

Figure 17: Beach-dune system showing the formation and establishment of foredunes (Sloss et al., 2012).

Recreation

Dunes are an attractive ecosystem for nature lovers, and they are easily accessible. Thus, when part of the biodiversity of the Voornse dunes is conveyed to the ESL dunes, opportunities for recreation arise. Activities should, however, be limited to for instance hiking and bird-watching, since other activities like horse-riding and (mountain)biking likely put too much pressure on the plants and can destroy the dunes themselves. A network of walking tracks could for example be constructed, allowing visitors to walk through the dunes by foot. The paths should be designed and placed in such a way that visitors can experience the different habitat types, showing the process of succession within dune vegetation. An elevated boardwalk could be used to walk through the dune valleys, allowing plants to grow underneath it and reducing the effect of trampling. For conservation purposes, only parts of each habitat are accessible. This could allow birds, for instance, to find a resting area within the dunes. Furthermore, a visitor centre could be built for educational purposes. Such a centre could be located in the ESL dunes, but could also be placed on the Maasvlakte, the Voorne dunes, Goedereede, or other surrounding areas. The visitor centre could show maps and contain a small museum with information on the biodiversity of the dunes; why they are so biodiverse, and why they are important to conserve. Furthermore, it could cover aspects dealing with Dutch flood prevention over time. Finally, it might be of interest to conduct studies on the high biodiversity. Therefore, a scientific field station can be built. The area has enormous potential as a test area for nature development and resilience in artificial systems, with potential applications for restoration techniques. The field station could be linked to universities, and students could carry out studies as part of dissertations and internships. In addition, it could host volunteers that help with the research projects and that could also work for the visitor centre as field guides.

6.2 Myriad Marine Life

The purpose of this design is to support and introduce marine life in the Energy Storage Lake, focusing on both the animals and plants that live in or close to seawater. Marine ecosystems are of great importance since they can provide ecosystem provisioning services such as seafood for humans, as well as regulating services like flood prevention and erosion control, and supporting services such as maintenance of biodiversity. Hence, marine biodiversity provides both direct and indirect benefits for people and planet, in alignment with LEDTA7s vision.

We aim to develop a diversity of habitats inside and around the ESL, that can sustain a large variety of species. These species should be able to cope with a variation in soil moisture content, temperature or water level. Furthermore, there is strong water movement that can cause erosion. An example of a coastline with strong fluctuating water levels is the Bay of Fundy in Canada, which has the world's highest tidal amplitude with a maximum of 20 meters difference between high and low tides (Klein, 1963). Although the water level in the ESL is designed to show fluctuations similar to this Canadian bay, local climatic and environmental circumstances are very different from the Netherlands. It does show that the development of nature is possible in areas with such high tides.

A coastal area contains many different habitats which each have their own characteristics and possibilities to accommodate different types of species. For this section we are inspired by the coast of Wimereux, in the North of France (WUR, EZO-20306, 2016). The tidal fluctuation in this coastal area is only eight meters, but local circumstances are comparable to the Dutch coast and can therefore serve as an example of what can be achieved in the ESL.

Biodiversity in coastal areas (rocky, sandy and muddy)

The foreshore can be divided into three general vertical zones based on the exposure to seawater during the tides: the supralittoral, eulittoral and sublittoral (Figure 18). Those zones can contain rocky areas, sandy areas and mudflats. The rocky shores have in general a larger biodiversity than sandy shores and mudflats. The supralittoral zone, or spray zone, is the area above the high spring tide line. It is never completely submerged, and seawater only penetrates via ocean spray during e.g. a storm. Characteristic species for this area are green algae, which can tolerate large fluctuations in salinity as well as water level. In the eulittoral zone we distinguish between the upper-shore, middle-shore and lower-shore. The upper-shore or high tide zone is the area that is only submerged during high tide. In rocky coasts, the highest line of the upper-shore is characterized by a band of barnacles. Furthermore, there are many small green algae, where periwinkles can feed upon. The middle-shore is inundated twice a day, under influence of the tides, and is mainly covered by green and brown algae. Therewith, this area provides protection and forage resources to a diversity of species. During part of the year, the rocks are covered with a layer of silt, and Bristleworms (*Polydora ciliata*) can then inhabit these areas. Life underneath this short-lived silt layer is harsh, and only a species of sea slug (*Goniodoris nodosa*) was found to survive in this relatively anoxic environment. The lower-shore is always submerged, except during very low tides. This zone harbours most of the marine vegetation and is a typical red algae zone. These algae cannot cope with drought for a long time, and their survival therefore depends on the presence of small puddles in case of extremely low tides. In small cracks and openings or underneath rock structures, a multitude of small fauna species can be found. A large part of the faunal species that inhabits the sublittoral can also survive in the lower-shore. Lastly, the sublittoral is permanently covered with water and starts below the lowest water level at low tide. Most of the organisms that inhabit the lower-shore are also present in the sublittoral. An elaborate overview of which species can be found in the different tidal areas can be found in Table 2.

Table 2: Overview of species that can be found in the different tidal areas of Wimereux, France. Table was composed using information from (WUR, EZO-20306, 2016).

Water level	Zone	Habitat	Species group (Latin species names)
Never completely submerged by sea water	**Supralittoral**	Rocky beach	**Lichens** (*Verrucaria maura, Ramalina siliquosa; Caloplaca spp., Xanthoria spp.*), **Periwinkles** (*Littorina neritoïdes, Littorina saxatalis*), **Green algae** (*Ulva, Enteromorpha, Cladophora*), **Bivalves** (*Lasaea rubra*), **Sea slater** (*Ligia oceanica*)
		Sandy beach	**Sandhoppers** (*Talitrus saltator, Talorchestia*)
		Mud flats	**Ragworms** (*Hediste diversicolor*), **Lugworms** (*Arenicola marina*), **Bristleworms** (*Capitella, Cirratulus*), **Amphipods** (*Corophium*)
	Eulittoral – Upper-shore	Rocky beach	**Barnacles** (*Elminius modestus, Balanus balanoides, Chtalamus stellatus*), **Green algae**, **Brown algae** (*Pelvetia canaliculate*), **Periwinkles** (*Littorina littorea, Littorina saxitalis*), ***Mussels*** (*Mytilus edulis*)
		Sandy beach	**Lugworm** (*Mytilus edulis*)
	Eulittoral – Middle-shore	Rocky beach	**Green algae**, **Brown algae** (*Polysiphonia lanosa*), **Red algae** (*Hildenbrandia rubria*), **Periwinkl**es (*Littorina obtusata, Littorina littorea*), **Crustaceans**, **Sea snails** (*Gibbula, Nucella lapillus*), **Bristleworms** (*Polydora ciliata*), **Sea slug** (*Goniodoris nodosa*)
		Sandy beach	**Amphipods** (*Bathyporeia*), **Isopods** (*Eurydice*)
	Eulittoral – Lower-shore	Rocky beach	**Red algae** (*Fucus serratus, Chondrus crispus, Mastocarpus stellatus, Lithophyllum, Lithothamnion, Corallinai*), **Crustaceans, Bristleworms, Sponges, Hydroids, Anemones, Bryozoans, Tunicates, Small fish, Worms, Crustaceans, Molluscs, Echinoderms**
		Sandy beach	**Lugworms** (*Arenicola marina*), **Bristleworms**, **Heart urchin** (*Echinocardium*), **Sword razor** (*Ensis ensis*), **Saltwater clam** (*Mya*), **Bivalves** (*Cardium*), **Sand mason worm** (*Lanice conchilega),* Anemones (*Peachia hastata*)
		Mud flats	**Bivalve molluscs** (*Tellina, Macoma, Scrobicularia, Venerupis*), **Cockles** (*Cardium*)
	Sublittoral	Rocky beach	**Red algae, Brown algae** (*Laminaria saccharina, Laminaria digitate)*
		Sandy beach	**Sea cucumbers** (*Leptosynapta*), **Acorn worms** (*Saccoglossus*), **Sand lances** (*Ammodytes*), **Sand shrimp** (*Crangon crangon*), **Shore crabs** (*Carcinus maenas*)
Permanently submerged by sea water		Mud flats	**Peacock worms** (*Sabella pavonia*), **Polychaete** worm (*Amphitrite*)

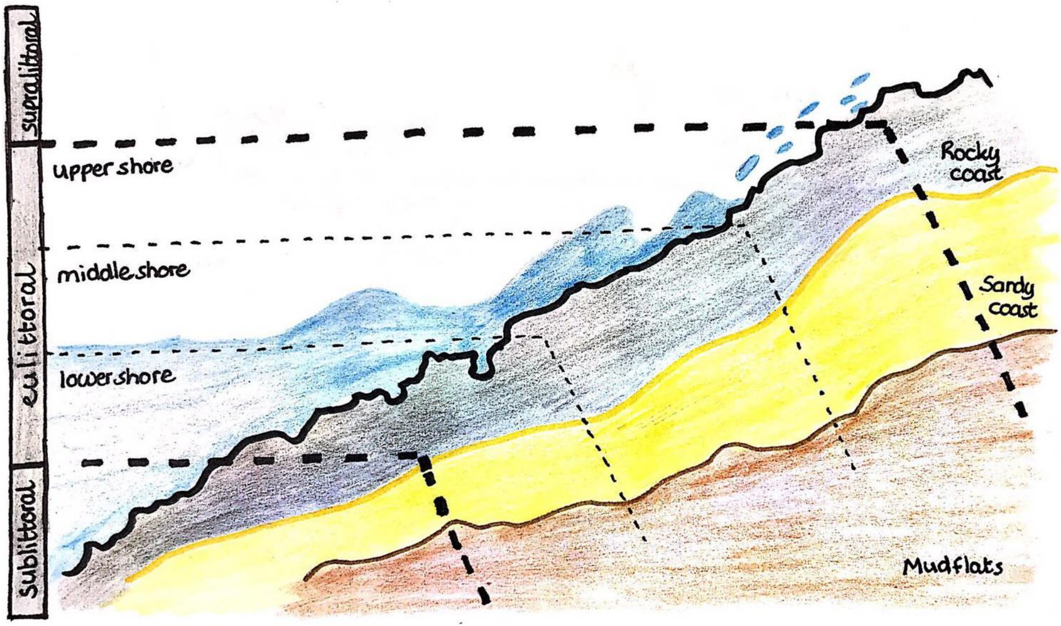

Figure 18: Indication of the zones as found in rocky, sandy and muddy coast.

Biodiverse marine life in and around the ESL

Marine life in and around the ESL

To establish a biodiverse coastal ecosystem, we recommend creating both a rocky as well as a sandy coastline on the sea-side of the ESL. The sandy coastline would require the construction of dunes, and a reef-like structure can be added to create a rocky coastline. This reef can either be designed as an integral part of the dunes around the ESL, or the dam in which the pumps are found can be created as a rocky reef-like structure (Figure 19). Within the ESL itself, an underwater cave, tree trunks and stones can be built or added to allow for the settlement of marine vegetation, and to accommodate the needs of organisms such as fish, anemones, crustaceans, mussels and oysters. Outside of the ESL, oyster reefs can be created, which will add natural value. Moreover, it will aid in coastal protection since the oyster reefs will reduce wave action (Paiva & de Vries, 2014).

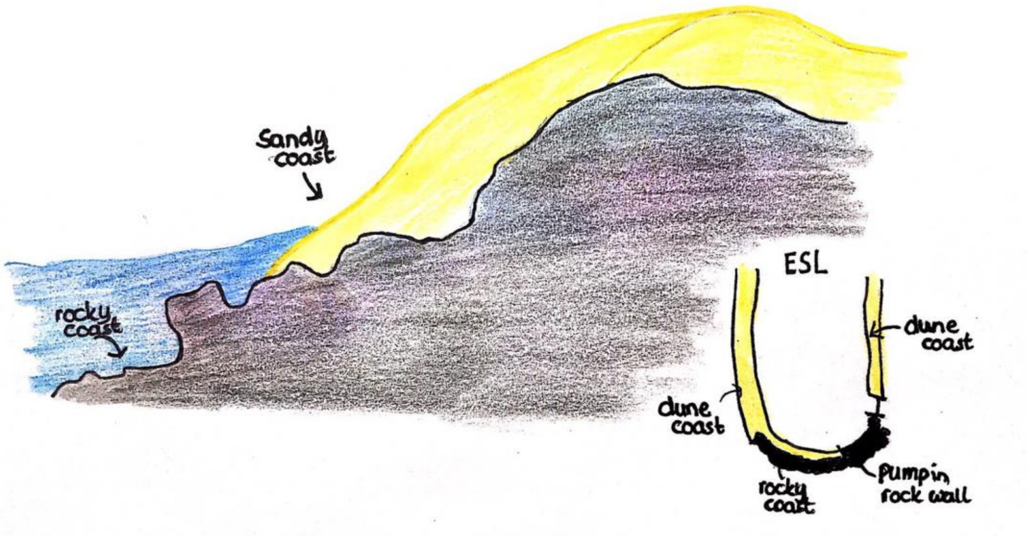

Figure 19: Aesthetics of rocky and sandy coastlines surrounding the ESL, with the position of each indicated in the bottom right figure. Cross-section of the sea-side part.

Vegetation

Multiple species of flora and fauna can live in and around mudflats. This habitat can be established on the inner side of the dunes, inside the ESL, or on the tidal lake side of the ESL. To create mudflats inside the ESL, permeable barriers can be constructed on the slopes of the ESL (Figure 20). By constructing these barriers, the area behind it can have tidal fluctuations, and when the structure is e.g. made of stones, it can trap sediments and allow soil development or silt collection. This will allow a different type of vegetation to grow and can attract species common to mudflats. If the barrier would be less permeable, a more permanent waterbody can be created behind it, only allowing for water replenishment when the water level inside the ESL is high. Eelgrass (*Zostera marina*) could grow in such an area, since this species requires permanently submerged, but relatively shallow saltwater bodies where water is replenished frequently (Zhang *et al.*, 2015). Eelgrass used to be a common species along the Dutch coast, but it is now a threatened species. To optimize the establishment of this species, seeds could be placed inside burlap bags with silt, which creates a more stable environment for these seeds to grow (Zhang *et al.*, 2015). When a passive barrier is constructed on one side of the ESL, and a complete barrier that only allows for overflow at high water level on the other side, both a mudflat and an eelgrass habitat could establish.

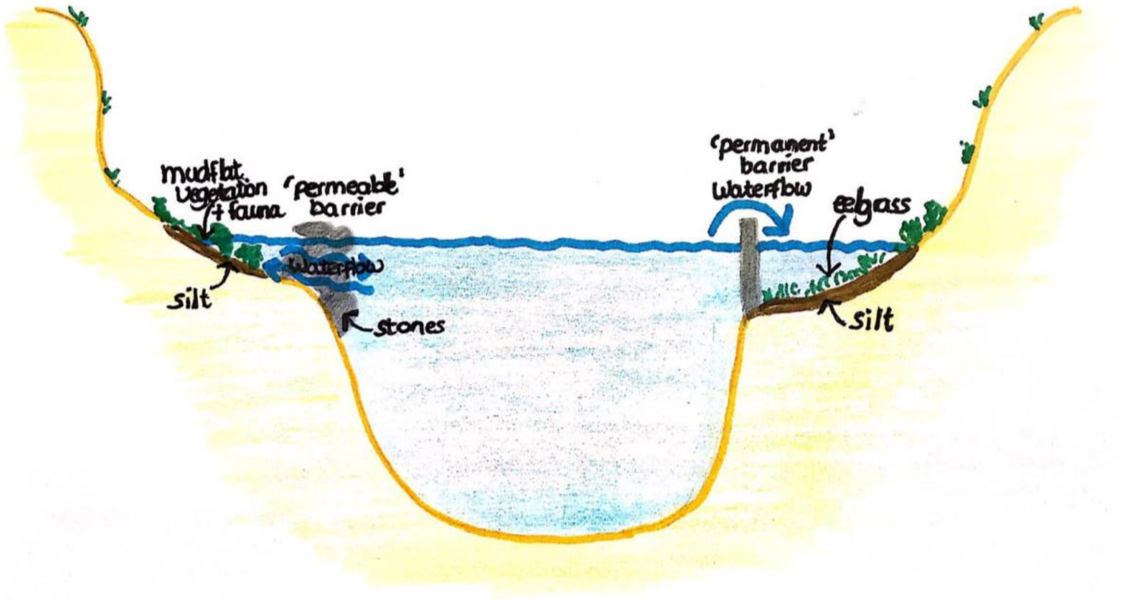

Figure 20: Aesthetics of the ESL with permeable (left) and permanent (right) barrier. Cross-section in the width.

Figure 21: Three species of fish that could occur inside the ESL.

Fish species

To further increase the biodiversity within the ESL, fish species could be introduced. The Round goby (*Neogobius melanostomus*), gunnels (*Pholidae*), European sea sturgeon (*Acipenser sturio*), Atlantic herring (*Clupea harengus*), lumpsucker (*Cyclopterus lumpus*) and perhaps even the Common dragonet (*Callionymus lyra*) can be set free in the ESL (Figure 21). These species need shelter to for example accumulate eggs and larvae. Underwater caves or a shipwreck can provide hiding places as well as a safe and stable environment for reproduction. The main concern for the possibility for fish to live inside the lake is the amount of nutrients that are available. The effects of the daily fluctuations of the water level in the ESL on the nutrient balance are still unknown, but it is unlikely that algae will be able to grow inside the lake. These water level fluctuations will also have a large effect on the ability of fish to survive and establish a population due to the light climate inside the ESL. Because of the large differences in water level, light intensity will differ throughout the day. Not all marine flora and fauna species will be able to adapt to those fluctuations. Currently, the minimum water level is set at 5 metres, but perhaps it would be necessary to maintain a higher minimum water level. This is expected to create less stressful conditions, since the fish are less exposed and can hide from predating species of bird (or perhaps even predatory fish). Some of the species of fish, like the common dragonet, need more shallow waters than designed in the ESL. Therefore, we recommend building the sides and slopes on the inside of the ESL in a step-wise structure (Figure 22). This method to create different water levels is also used at the Marker Wadden (Marker Wadden Congress, pers. communication, April 18, 2019).

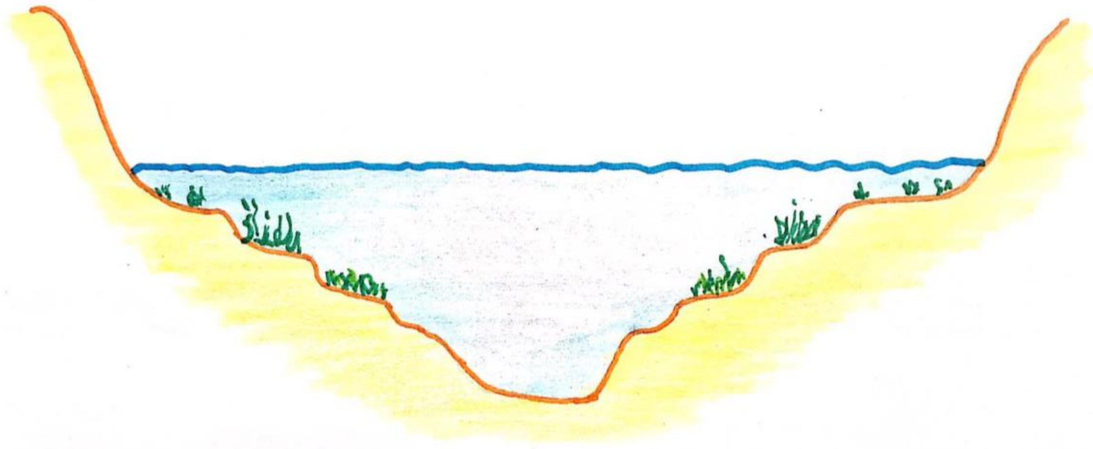

Figure 22: Aesthetics of a stepwise slope inside the ESL. Cross-section in the width.

Such a step-structure would also allow for a more diverse ecosystem, since different kinds of vegetation can grow at the various depths that are created with the steps. In addition, the steps can also help to create a more stable environment for marina fauna, since the water depth varies between parts of the ESL and faunal species could then move between areas during water fluctuation in order to be in an area that has their preferred water depth. These species of fish, as well as other marine fauna and flora, are furthermore used to semidiurnal tidal fluctuations in water-level. We therefore recommend to accordingly empty and fill the lake twice a day, creating artificial tides. The pattern could then follow a 6-6-6-6 rhythm, emptying or filling the lake for 6 hours consecutively. Alternatively, to accommodate the (peak) demand for energy, the lake could be filled (generating energy) between 6h and 10h in the morning, and between 16h and 22h in the afternoon and evening.
A major constraint for the settlement of fish populations within the ESL is the fish-friendliness of the pumps. Due to the expected strong water flow, fish are likely to be sucked into the pumps once they swim near them. Therefore, a construction is needed to prevent this from happening. Since reducing the water flow is not feasible, and likely not effective enough if done on small scale, solutions need to be found in disabling fish to swim nearby these pumps. Such a structure should, however, not affect the functioning of the pumps. One can think of a permanent barrier, far enough from the pumps, behind which the water stream generated by the pumps does not disturb marine life. To allow water to flow through this structure, this "wall" should be a sort of sieve (Figure 23). Apart from an optimal distance to the pumps, the optimal grid size of such a "sieve-wall" should still be determined, allowing water, but not fish to pass. This sieve-wall would, however, require active maintenance, since aquatic plants such as algae are expected to settle on this structure, thereby decreasing its functionality.

Some fish species might need to be able to migrate in and out of the ESL, for instance if they are migratory species. A passage for these species could be added, using the concept of a fish-elevator (Vislift, n.d.), or a fish-ladder.

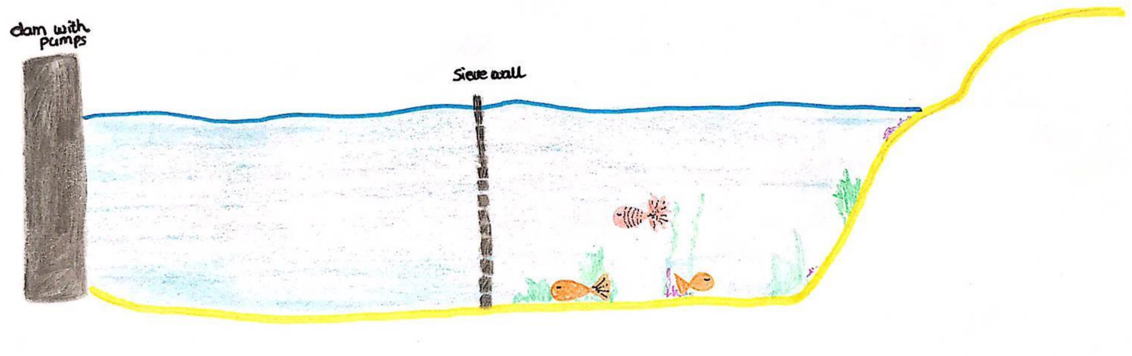

Figure 23: Aesthetics of a sieve wall inside the ESL. Cross-section in the length.

Marine mammals

Regarding marine mammals, there are two species of seal that make use of the Voordelta to rest. As indicated in section 3.4.6, two main resting areas for both seals as well as coastal breeding birds are located within the designated tidal lake area. Seals will not be able to pass a dam armed with tidal turbines since these only allow fish to pass through. To allow seals to reach their resting areas, the tidal lake should either be opened (i.e. without tidal pumps), or a seal-passage is required. Such a passage could be a channel, starting next to the tidal dam, flowing through the neighbouring beach of “Kwade Hoek”. If this channel extends towards the northern part of the Voordelta, just in front of the Maasvlakte, it can also function as a swimming area for tourists (Figure 24). Considering that the coastline near Oostvoorne now mainly consists of silt and it is therefore not attractive for swimming or bathing, such a swimming pool could increase attractiveness of the area for tourists. Alternatively, new resting areas outside the ESL or tidal lake can be designated, for instance by creating a sandbank in front of or next to the ESL.

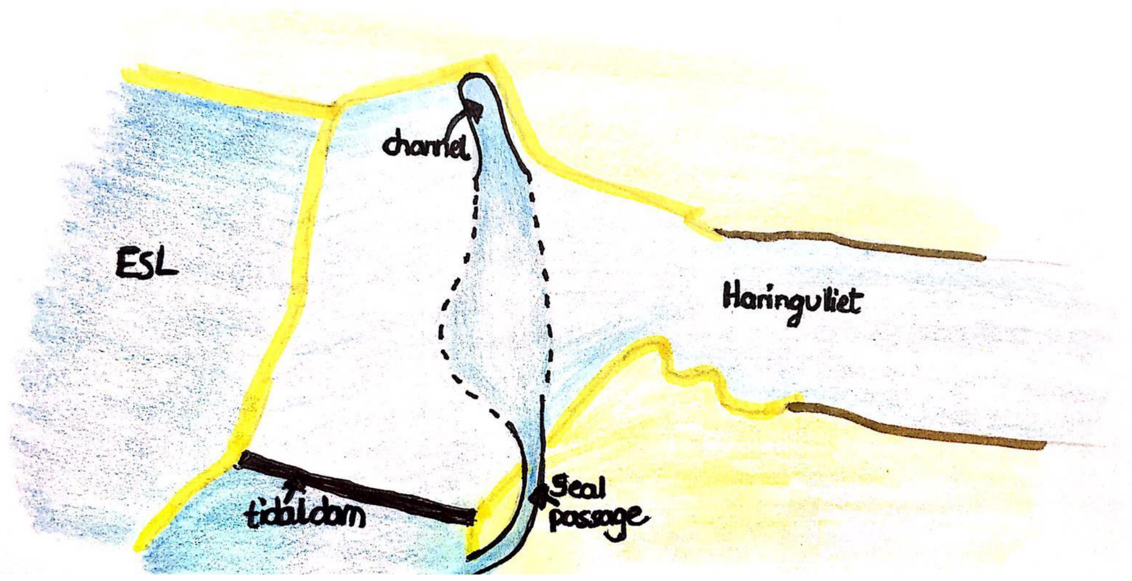

Figure 24: Design and location of a seal passage, extended towards the coastline of Oostvoorne to create a swimming channel.

Recreation

Besides its function to enhance marine life within the storage lake, this variant could be combined with possibilities for recreation. When creating the aforementioned sieve wall, the part of the ESL that is closer to the pumps can have a recreative function for thrill-seeking divers and kayaking trips. This area can also be used for aquaculture, or a floating information centre. Another option is to build a restaurant, which serves local fish provided by aquaculture within the lake. Divers could furthermore explore the biodiverse marine area on the other side of the sieve wall. It is recommended to only provide for guides tours, to make sure diving activities do not disturb marine life, and to include an educational aspect. A diving school could be started, and marine guides could apart from diving lessons provide information on the species that inhabit the ESL. Close to the dunes, on the edge of the ESL, a plastic statue could be built from plastic found in the area. Such a sculpture can make plastic pollution more visible to tourists and other visitors, providing education for sustainable development.

6.3 Biodiverse Bird Life

After the implementation of the Energy Storage Lake, one of the possibilities is to create a biodiverse area, with the focus on attracting bird life. In this variant we aim to design the ESL in such a way that we optimize the attraction of locally occurring bird species and give possibilities to attract additional bird species. An ideal area for birds to live, breed and rest can be defined in different ways, based on the amount of species and the kinds of species that will have to occur in the area. A group of people with diverse backgrounds and interest in birds at the Markermeer Congress (Delft, April 18, 2019) made criteria for their definition of a bird paradise. We partly use these criteria for inspiration to generate ideas for the design of the ESL:

- Biodiversity
- Predatory birds
- Availability of fish
- International ambitions
- Excursions to learn about birds

The purpose of creating an attractive area for birds is closely related to the previous two variants; creating a biodiverse dune system and attracting marine life. In both the ESL as well as in the dune system, adaptations will have to be made to make the area more attractive for birds.

As the design of the Energy Storage Lake will cause the environment to be a saltwater habitat, the attraction of birds will mainly be restrained by the possibility to create a rich diversity in salt-water habitats. However, the current environment in the Voordelta also consists of a salt to brackish area, and there are possibilities to increase the number of bird species in the area and to create a more suitable living environment than the current situation.

Birds have some basic requirements for the area they can live in. First, the area needs to provide the right food sources for every bird species we want to attract. For a diversity in bird species, we will need a variety of food sources of sufficient quality and quantity. This includes, among others, zooplankton, crustaceans, plants and fish (Rijkswaterstaat & RIZA, 2008). Secondly, the right habitats for different bird species need to be created. Therefore, a large diversity in habitats, including shallow water, mid-water level, sand banks and parts with vegetation is necessary (Rijkswaterstaat & RIZA, 2008). The vegetation can function as food source, as it provides a suitable habitat for animals lower in the food web, and it can be used as shelter during stormy weather and to hide from predatory species. Shelter can alternatively be provided by abiotic structures, like rocks, caves and differences in dune height. The habitat should also provide resting and nesting areas where disturbance by humans or other animal species is minimal.

Table 3: The bird species that currently live in the area can be classified into four groups. Each group has its own preferred habitat and food type.

Bird group	Habitat	Preferred food choice
Fish-eating birds	H1110 & H1140	Fish
Benthic invertebrate eaters	H1110 & H1140	Benthic invertebrates
Ducks and geese	H1310, H1320 & H1330	Soil animals, algae and seeds
Wading birds	H1310, H1320 & H1330	Soil animals

The species that currently live in the Voordelta area (Section 3.4.9), can be divided into four different groups based on food preference and habitat type (Table 3). Therefore, we recommend the construction and protection of four habitat types after the construction of the Energy Storage Lake:

- Shallow water (foraging);
- Permanently submerged areas (foraging);
- (Pioneer) vegetation (foraging), and;
- Resting and nesting areas that stay dry for most of the time.

The following sections provide ideas to increase the availability and quantity of these habitats.

Mudflats and sandflats that are not covered by sea water all the time (Habitat 1140)
Mudflats and sandflats are mainly an important foraging area for waders and birds that eat benthic invertebrates (Rijkswaterstaat & RIZA, 2008). Sandflats can be created inside the dunes by making "trenches" for birds in the dunes that are flooded during high tide and become almost empty during low tide (e.g. Figure 20). Food sources for birds, like benthic invertebrates and shellfish, will settle in the trenches during high tide and can be caught by the birds when the water level lowers.

Sandbanks that are permanently flooded by shallow water (Habitat 1110)
On sandbanks, we can find birds that forage on benthic invertebrates, as well as fish-eating birds. (Rijkswaterstaat & RIZA, 2008). The permanently flooded sandbanks are expected to form on the edges of the dunes outside surrounding the ESL. Alternatively, they can be created by making larger sand banks that are permanently flooded outside of the ESL. Additionally, large rocks can be used to create pools of water during low tide inside and outside the ESL. During high tide, the whole area will be submerged in deeper water.

Salt march habitat (Habitats 1310, 1320 and 1330)
Salt marshes are important for ducks and geese and for wading birds (Rijkswaterstaat & RIZA, 2008). By creating a mud layer inside the dune, a small valley can be created (Figure 16), that provides a foraging area for those birds. To create a wet dune valley, a clay layer should be incorporated in the dunes to allow water to infiltrate slowly. Another option is to seal off part of the edges of the inside of the lake with stones (Figure 20). This area will only be flooded for a short time every day, when the lake is completely filled with water. Conditions are favourable for the establishment of a mudflat, where pioneer vegetation can colonise. However, the development of salt marshes in the ESL will only succeed if there is a positive sediment balance.

The supratidal beach
This supratidal beach can be found in the upper parts of the dunes (Figure 18). To maintain this area, vegetation growth in this habitat should be inhibited as much as possible, since it will disturb the resting area of shore birds (Meininger & Graveland, 2002). The dynamic characteristics of the dunes can inhibit plant growth, thereby creating a resting area for birds. Addition of rocks will improve the breeding possibilities in the area (Oregon coast aquarium, 2019) (e.g. Figure 19).
In addition to the habitats, constructions to create availability of breeding grounds for larger birds can be built, such as long poles. These poles can get a more natural look by providing the possibility for plants to grow on the sides of the poles. Floating constructions on the lake can provide additional resting areas for birds when these areas are of sufficient size.

Predatory birds
New species can be attracted to the area by improving the living environment and food quantity in the area. An additional value to the area is the ability for large predatory birds to breed, like the White-tailed sea eagle (*Haliaeetus albicilla*) and the Osprey or Sea hawk (*Pandion haliaetus*) (Troost & al, 2012). These birds need specific nesting areas, like trees and cliffs. Artificial cliffs can be created to accommodate a breeding site for the sea eagles (e.g. Figure 19), while for the osprey poles suffice. The main diet of both species is fish, which can be found in large quantities in the surroundings of the lake. Creating additional habitats for predatory birds will improve the natural value of the area as a complete food web will be present (Troost & al, 2012).

Recreation
The purpose of creating a bird paradise can be combined with a variety of recreational and educational activities. People can be educated on the habitat and food choice of birds, as well as in recognizing phenotypical characteristics of bird species. An information panel with a short description of the different bird species in the area can provide this knowledge. Additionally, a bird watching area can be created where a nice view of the area is provided without disturbing the birds. This area may contain a bird watching tower or smaller constructions that blend in with the area. The bird observation hut in the Haringvliet is a nice example of this (Figure 25).

Figure 25: Bird observation hut in the Haringvliet (Natuurmonumenten)

Additionally, bird watching telescopes can be provided. If a visitor centre is built near the Energy Storage Lake, binoculars can be sold or rented to gain profit and to provide the possibility of observing birds without disturbing them. These bird observation areas should be restricted to certain parts of the dunes, as the birds need resting, nesting and foraging areas where they are not disturbed by human activities. There is also a possibility of creating a walking track through the dunes of the Energy Storage Lake as the dunes are wide enough to provide space for both resting areas and walking tracks. However, to maintain a large number of birds, resting areas are required, which limits recreation opportunities.

This again creates new possibilities for education, since guided tours can be given. In such a tour, an ornithologist or bird-fanatic can lead a group of people through the dunes and educate visitors on the bird species that are present, as well as on the sustainability and functioning of the whole Energy Storage Lake, since the Energy Storage Lake is an innovative concept within the domain of sustainable construction projects.

7. Multi-criteria analysis (MCA)

In this section, the inputs of the MCA as found in Table 4 are discussed. For each variant, including the current situation and the initial ESL design, the category's ecosystem services, recreation, functionality and economics are considered. The explanations for the specific criteria per category are provided in Appendix 4, and the meaning of the symbols is given in Table 5.

Within the MCA, the “Initial ESL design” is used as a reference. The variants (focussing on the three purposes specified in section 6) are scored relatively to this baseline. We also included the situation without the ESL into the analysis to evaluate possible effects of constructing the ESL. For the MCA, we only consider the area within the sea where the ESL will be built (delineated with dotted lines in Figure 12). Effects on the surrounding area (e.g. Voornse dunes) were not taken into account.

Table 4: Results of multi-criteria analysis

Category	Criteria	Current situation	Initial ESL design	Dynamic Dunes	Myriad Marine Life	Biodiverse Bird Life
Ecosystem services	Species richness flora	+	0	+ +	+ +	+
	Species richness fauna	+	0	+	+	+
	Species abundance flora	+	0	+ +	+ +	+
	Species abundance fauna	+	0	+	+	+ +
	Threatened species	+	0	+ +	+	+
	Self-regulation	+ +	0	+	-	0
Recreation	Aesthetics	+ +	0	+ +	+	+ +
	Accessibility	0	0	+	+ +	+
	Sports	+	0	+	+	-
	Education	- -	0	+ +	+	+
	Tourism	-	0	+	+ +	+
Functionality	Generation of green energy	- -	0	-	-	- -
	Storage of green energy	- -	0	0	- -	0
	Flood protection	- -	0	+	+	0
Economics	Establishment costs	+ +	0	- -	- -	-
	Maintenance costs	+ +	0	-	- -	-
	Benefits	0	0	+	+ +	+

Table 5: Explanation of scoring system used in MCA table. The given meaning is used in the discussion of the results.

Scoring symbols	Meaning
++	Strong improvement
+	Improvement
o	No change in criterion
-	Deterioration
- -	Strong deterioration

7.1 Ecosystem services

This section discusses the results of the multi-criteria analysis (MCA) with regard to ecosystem services. The aim is to describe how the variants support the main goal to create an environmentally friendly design of the ESL.

Floral richness and abundance

The strongest improvement in floral species richness and abundance is expected to occur within the Dynamic Dunes variant (++). This variant was specifically designed to increase floral biodiversity, aiming to convey part of the diversity within the Voornse dunes to the dunes around the ESL. Myriad Marine Life in part aims to increase floral diversity, with a focus on marine vegetation. Fewer aquatic species are expected to establish in and around the ESL than there are terrestrial plants that can colonise a full successional gradient within a dune system. Since the biodiversity in marine species is in general higher than aquatic plant diversity (80% terrestrial, 15% marine; Grosberg, Vermeij & Wainwright, 2012), the relative improvement regarding floral richness is considered equally strong for both Dynamic Dunes and Myriad Marine Life (++). Finally, the variant Biodiverse Bird Life is not specifically aimed at improving floral biodiversity. However, since plants are needed for birds to forage upon or to find shelter in, floral diversity and abundance will still improve compared to the initial ESL design, but the increase will be smaller than in the other variants (+). In the current situation, there are no other habitats such as mudflats or rocks that can harbour different groups of species. Marine species are only present on the sea floor (+).

Faunal richness and abundance

In general, all variants are likely to show an improvement regarding faunal richness and abundance compared to the initial ESL design. Although an increase in the number of plants on the dunes will in turn attract fauna, this is not the main ambition of Dynamic Dunes. Faunal species will not be actively introduced, in contrast to planting and seeding of floral species. Furthermore, since the dunes will not be as wide as the Voornse dunes, it is difficult to establish a complete ecosystem with all parts of the food chain. Species richness and abundance for fauna is expected to still improve compared to the situation with only the ESL, but the improvement will not be as large as is the case for flora (+). The richness and abundance of faunal species are likewise expected to improve for the Myriad Marine Life variant, but again not to the extent of the floral improvement (+). In this case, this is due to the harsh conditions that prevail inside the ESL and constrain reproduction and establishment of large populations of marine fauna. Although constructions were invented to create more stable habitats in which marine fauna can establish, it is uncertain whether these provide enough shelter and are attractive enough for a strong improvement in faunal richness and abundance. Within the Biodiverse Bird Life variant, an improvement in faunal richness and abundance is likewise expected (+). Most of the species of bird that can inhabit the Dutch coastal area are already present within the area, and therefore no strong improvement in faunal richness is expected. However, since the Biodiverse Bird Life variant is aimed at increasing the availability of breeding and foraging habitats, an improvement in the abundance of faunal species is expected (+ +). Finally, the current situation already harbours many species as well as individuals of migratory fish as well as birds (+).

Threatened species
The Voornse dunes harbour a range of red list species. Since the aim of the Dynamic Dunes variant is to re-create this biodiversity, the rarity of species that colonize the dunes surrounding the ESL is expected to show a strong improvement (++). This might, however, be misleading when comparing to the original Voornse dunes. The Dynamic Dunes variant is not expected to show a strong improvement in threatened species compared to the current Voornse dunes. It could, however, be one option to compensate for the loss of species and habitats that would be harmed by the construction of the ESL. Since we compare the variants to the initial ESL design without its surroundings, such as the Voornse dunes, the Dynamics Dunes variant would show a strong improvement in the number of threatened species. With regard to the Myriad Marine Life variant, many species of fish already occur in the current habitat, among which are several threatened species (+). Our aim is to provide circumstances under which these species can be maintained in the ESL, and to complement this richness with some red-list floral species that used to occur in the area, but are locally extinct nowadays (e.g. eelgrass, Section 6.2). Since the circumstances within the ESL are harsh and more artificial compared to the dunes surrounding the ESL, the number of threatened species that can colonize the marine habitat will be lower than on the dunes (+). Analogous to Myriad Marine Life, Biodiverse Bird Life does not lead to a strong improvement of the number of threatened species, although an improvement is expected (+). The ideas that are suggested mainly aim to ensure the proliferation of current (red list) bird species, and therefore the creation of habitats that are already in the Voordelta. By creating a diversity of habitats, other species might be attracted as well, but not many new species are expected to settle. Therefore, only a small improvement regarding the number of threatened species is expected for the Biodiverse Bird Life variant.

Self-regulation
Self-regulating capacity is essential for the resilience and proliferation of ecosystems. Self-regulation in the variant Dynamic Dunes is for instance improved compared to the initial ESL design because vegetated dunes are less likely to erode than dunes with almost no vegetation (+). This self-regulation is, however, only improved on the long-term, since the habitats first need to stabilize after being built. Within Myriad Marine Life, many constructions are needed to form an ESL that is suitable to harbour fish. The proposed sieve wall, for instance, needs to be regularly cleaned from algae. Therefore, this system with high marine biodiversity shows a deterioration in self-regulation compared to the initial ESL design (-). The Biodiverse Bird Life variant aims to create a food chain that is more complete than in the initial ESL, by for instance attracting larger birds. This might compensate for the maintenance needed for the created foraging and resting habitats. Therefore, the self-regulatory capacity of Biodiverse Bird Life is estimated to show no change compared to that of the initial ESL (0). Finally, the current situation likely is a relatively stable marine environment, and therefore is quite self-regulatory (++).

7.2 Recreation
This section discusses the results of the multi-criteria analysis (MCA) concerning recreational value. The aim is to describe how recreation can go hand in hand with the development and conservation of nature, without compromising natural values.

Aesthetics
In the Dynamic Dunes variant, we expect a strong improvement (++) in the aesthetics of the ESL. The vegetation would create a natural green landscape, with different environments, beaches, grasslands with flowers, bushes and valleys. The environment created by the Myriad Marine Life variant will likewise be appealing, but it will be less visible since most of it is underwater (+). It will still show improvement compared to the initial ESL design, since at low tide the shore with its plants, crabs and other organisms can be observed. The Biodiverse Bird Life variant would show a strong improvement in aesthetics both because of the possibilities for bird-watching, and because of the vegetation that

would be planted as part of their habitat in the dunes and as floating systems (++). Finally, the absence of any constructions currently enables residents and visitors to enjoy the aesthetics of the open sea (++).

Accessibility

Regarding accessibility, in all three variants it is planned to allow the entrance of visitors to perform different activities, showing an improvement compared to the initial ESL design. Within the MCA, we anticipated that the initial ESL would not be accessible for public at all. In case of the Dynamic Dunes, a network of tracks allows visitors to access the area, although some sections will be protected areas (+). In Myriad Marine Life, accessibility shows the strongest improvement (++), because the area within the ESL is opened for public. The accessibility in the Biodiverse Bird Life variant might be most restricted compared to the other variants. In order to avoid disturbance of breeding colonies, access to these should be limited, especially in the breeding season. However, since a tourist centre and bird observation tower could always be accessible, the Biodiverse Bird Life variant is anticipated to show a similar improvement in accessibility as the Dynamic Dunes variant (+). The current situation offers little recreational value that makes it attractive for access, since it is located in plain open water. Furthermore, there are restrictions of Natura 2000 on what is and is not allowed in the current area (Appendix 3), and accessibility is therefore estimated to be equal to the initial ESL design (0).

Sports

In the Dynamic Dunes variant, sport is mainly focussed on hiking. However, sailing and other water-related sport activities can still be practised inside the ESL. Due to the addition of hiking, an improvement regarding sports is anticipated for the Dynamic Dunes variant (+). An improvement is likewise anticipated for Myriad Marine Life, where sport-related activities mainly concern diving, swimming, sailing and kayaking on the ESL (+). In the Biodiverse Bird Life variant, restrictions to not disturb bird life constrain the possible sporting-activities that can be practised. Activities will be similar to Dynamic Dunes, but sport activities on sea would be restricted. Therefore, the possibility for sport-related activities will deteriorate for the Biodiverse Bird Life variant (-). In the current situation without ESL, it is possible to do some kitesurfing, kayaking and boating (+).

Education

Education is an important component of all three variants. The Dynamic Dunes variant is anticipated to show a strong improvement regarding educational services (++). It aims to provide guided tours, a research station, and includes a small museum in which the dune system as well as its functioning in coastal protection can be explained. In Myriad Marine Life, diving excursions should also be guided, but these do not solely focus on environmental education as tourists also learn how to dive. Within this variant, an improvement regarding educational services is expected (+). Bird-viewing towers with information panels and tours guided by ornithologists can provide an improvement in the educational services within the Biodiverse Bird Life variant (+). In all variants, education on sustainability can be added. In Myriad Marine Life, for instance, a plastic statue within the ESL is combined with education on plastic waste. Within the current situation, no education services are available (- -).

Tourism

There are possibilities for tourism in all variants. For Dynamic Dunes (+) and Biodiverse Bird Life (+), it would be more nature related tourism. For the Myriad Marine Life variant (++), diving would be an attractive activity for tourists. Furthermore, visitors could be attracted by a restaurant where they could taste the fish and other seafood provided by the lake. The current situation is not attractive for tourism, since it is just relatively inaccessible open sea (-)

7.3 Functionality

The functionality category refers to the other functions of the ESL: energy generation and storage, as well as flood protection. The aim of this category is to examine if these functionalities are compromised by the different variants.

Generation of green energy

The amount of energy that can be generated depends on the number of energy-creating elements like windmills, solar panels and turbines. For Dynamic Dunes a deterioration regarding generation of green energy is expected (-) since the dunes are covered in plants, which limits the space available for solar panels and wind mills. For Myriad Marine Life, we also expect a deterioration (-) since marine life could live around the windmills, but solar panels would prevent the sun from penetrating the water surface, which can have unwanted consequences for marine life. For Biodiverse Bird Life a strong deterioration is expected (- -) since there is limited space for wind mills and solar panels in an area filled with resting areas that are not to be disturbed in any way. Additionally, wind mills are not compatible with birds since they can die when they fly near to them, and solar panels might heat up and pose a threat to birds flying nearby. Finally, we consider the current situation a strong deterioration (- -) in comparison to the initial ESL design because there is currently no generation of energy in the area. Since it is a Nature 2000 area, perhaps is it not possible to build windmills and solar panels in the near future. Overall, all variants are expected to show a deterioration regarding the generation of energy because they interfere with the implementation of sustainable energy-generation elements.

Storage of green energy

The storage capacity depends on the volume of water contained in the lake. Hence, the Dynamic Dunes variant receives a neutral score (0), because the dunes do not affect the water storage. Unlike the Dynamic Dunes, the Myriad Marine Life variant is expected to show a strong deterioration (- -) in this sub-category, since less water can be stored in the lake when the corresponding ideas within the variant are implemented. As discussed in the description of the Myriad Marine Life variant, a higher minimum water level, for instance, can provide a solution to create less stressful environment for fish. The Biodiverse Bird Life receives a neutral mark (0). Since birds feed on fish, some of the implemented ideas will be shared with the Myriad Marine Life variant, although in this case the effect is much smaller due to a lower dependence on the water level compared to the Myriad Marine Life. Finally, the current situation shows a strong deterioration (- -), since there is no storage of energy at all.

Flood protection

This subcategory is related to the protection against flooding from both the sea and the river. The Dynamic Dunes and Myriad Marine Life variants are expected to show an improvement (+), since the establishment of oyster and mussel banks and dunes could increase flood protection from the sea. The Biodiverse Bird Life variant receives a neutral score (0), because nothing changed compared to the initial design in terms of flood protection. Finally, the current situation does not specifically include any structures to protect the coast from flooding (- -). Overall, the different variants are not expected to show a deterioration, which shows that nature development does not interfere with flood protection.

7.4 Economics

This section discusses the results of the multi-criteria analysis (MCA) concerning the economic aspects. It is not the objective here to discuss the economic effect in an absolute sense, it will be discussed in relation to the initial ESL design.

Establishment costs

Concerning the Dynamic Dunes variant, the establishment costs are ranked as a strong deterioration (- -) when comparing them to the initial ESL design. To establish the Dynamic Dunes, a lot of plant species and seeds would have to be bought. Additionally, these plant communities would be planted artificially in an area of about a kilometre wide. Another main idea in this variant is to create wet dune valleys. In order to do so, dunes should be excavated, and a clay layer should be added. These ideas are labour intensive and not an easy accomplishment. The Myriad Marine Life variant is also ranked as a strong deterioration (- -) concerning the establishment costs, as for example in this variant an underwater cave or stepwise sloping side would have to be built. Furthermore, expenses will be high regarding the safety issues of the pumping system for marine life. The last point for the marine variant concerns the fact that all the ideas would have to be constructed below water level which makes the costs significantly higher. Regarding the Biodiverse Bird Life variant, the establishment costs will still be higher than for the basic ESL design, but the costs will stay in a lower range (-) than for the other two variants. An environment should still be created for the birds (e.g. resting and breeding places). However, these measures ask for less labour intensive and difficult approaches. In the current situation, no large interferences are needed (++).

Maintenance costs

The maintenance costs are expected to be fairly high for all three variants, showing a (strong) deterioration (- or - -). For the Dynamic Dunes variant, the main maintenance costs are expected to be spent on the fact that the dunes probably will not be self-regulating in the short-term. It could be that sediment nourishments are necessary to maintain the dunes. However, when comparing this variant to the basic ESL design, the nourishments are needed less often because the vegetation will stabilize the dune system much better. However, this will mainly show in the long-term, and the vegetation system within this variant should also be maintained. For the Myriad Marine Life variant, it is expected that some general maintenance is necessary, such as cleaning the sieve wall and keeping the stepwise slope intact. The fact that this has to be done in a marine environment will further increase the maintenance costs (- -) The Biodiverse Bird Life variant also shows a deterioration (-) in comparison to the initial ESL design, because of the need to actively maintain the created habitats., such as a floating island. Within the current situation, no large interventions to maintain the area are needed, expect for sand-nourishments, for instance. Such activities are applied in many other areas and are more easily done than the maintenance required for the specific structures and habitats that are created in the other variants (++).

The benefits

The economic benefits with respect to tourism vary between the variants, because not every variant is equally suitable for tourism. Dynamic Dunes is expected to show an improvement (+) with respect to the initial ESL design. In this variant, a visitor centre and nature guides can generate economic benefits. Additionally, a small house can be assigned for scientific researchers, who must pay a fee. However, recreation in the area is limited by the need for protected areas. The Myriad Marine Life variant can generate more economic benefits with respect to tourism than both the Dynamic Dunes and the Biodiverse Bird Life variants can, thus this variant is expected to show a strong improvement (++). Marine development is expected to be more compatible with recreational activities without disturbing nature, especially on land but also in the form of a diving centre. A floating restaurant is can furthermore generate income in this variant. The Biodiverse Bird Life variant generates the same level of benefits as the Dynamic Dunes (+). In this variant nature guides can also generate a benefit, but tourists cannot go everywhere. The current situation is scored neutrally (0) because there is very little recreation and tourism in the open sea.

8. Discussion

This section discusses how far the three variants can be combined into joint designs. The results from section 7 (MCA) are consulted to discuss possible integration of the proposed ideas. This is done by looking which strengths of a certain variant can be used to complement weaknesses from another variant. The integration of ideas is explained per MCA-category.

Ecosystem services

Dynamic Dunes and Biodiverse Bird Life are expected to be the least compatible with each other. The reason behind this is that they are suggesting different options for the terrestrial ecosystem: birds need sparsely vegetated habitats, while the Dynamic Dunes variant aims at increasing floral richness and abundance. Myriad Marine Life is expected to be more compatible as it is the only variant focussing on the aquatic ecosystem. Biodiverse Bird Life and Myriad Marine Life are more compatible and complement each other. The latter variant provides fish and other sea animals which are necessary for the birds to feed on. Moreover, the birds regulate the populations of the marine organisms, thereby enhancing the self-regulating capacity of both systems. It should be ensured that bird colonies do not reach population sizes large enough to harvest the aquatic animal populations at a higher pace than the recruitment of new sea creatures (overharvesting). On top of that, the sand banks which are indicated as resting areas for birds, might be flooded temporarily, creating shallow water habitats. These are also favourable for soil animals, and these areas therefore provide benefits for both variants. However, this is where the latter two variants clash with the Dynamic Dunes variant. The creation of shallow water habitats and mudflats could change the broader environmental dynamics that allow the development of pioneer dune habitat (white dunes). Shallow waters would enable the dune habitat to develop towards a more grown vegetation corresponding to later stages in the succession. A compromise could be made to indicate some areas of the ESL to focus more on the Dynamics Dunes purpose and allow a pioneer dune habitat to develop on the beaches. In other areas the focus could be on the creation of shallow water habitats for birds and marine life.

The division between the amount of sandy and rocky beaches is another aspect that can complicate the integration of the different variants. The Dynamic Dunes variant constrains the integration with the other two variants because it entails the creation of big areas covered with vegetation and sandy shorelines. The birds in the Biodiverse Bird Life design would not prefer too much vegetation but would rather like rocks and beaches. On the other hand, birds need some vegetation to allow them to nest and shelter from storms or potential predatory birds. Some bird species that are lower in the food chain could also feed on the vegetation. In the Myriad Marine Life variant, a rocky coastline would be ideal for marine life development. Again, a compromise should be made, which entails that the coast of the ESL could include alternations in sandy and rocky areas.

Every five to ten years, a freshwater input into the ESL is expected due to high river discharge and high sea level occurring at the same time. It can be expected that the ecosystems are affected by this process. The short-lived presence of the freshwater will affect Myriad Marine Life substantially and there will mainly be a risk for the survival of marine organisms that live close to the surface. However, the extent of perishing depends on the height and the time period of high river discharges. Dynamic Dunes and Biodiverse Bird Life will be less affected by this event than Myriad Marine Life, since the organisms in these environments are not directly connected to the water surface.

Recreation

Regarding recreation, we find different levels of compatibility as well as constraints. Dynamic Dunes and Myriad Marine Life both represent a strong improvement in comparison to the initial ESL design, whilst the Biodiverse Bild Life is less of an improvement. The current situation is equally attractive regarding recreation as is the initial ESL design. The Biodiverse Bird Life variant is expected to constrain the recreation possibilities of the other two variants, as birds can be easily disturbed by human presence, even if they are not close by. Combining the Biodiverse Bird Life with the Dynamic Dunes variant would only allow for a limited and simple system of walking tracks. In both variants, it would be favourable to only allow access to a viewing tower or similar constructions, instead of enabling tourists to visit the complete system. The location of a visitor centre should furthermore be studied more in detail, since people can disturb vegetation by interacting physically with it (e.g. stepping on it). Limited accessibility would also restrain aquatic recreational activities, like kayaking or kite-surfing, whereas diving will be the only activity with a lower disturbance factor. The possible recreational activities to be carried out in Dynamic Dunes and Myriad Marine Life can be combined as they do not constrain each other. It would be most attractive for people to go to the ESL if they can do both forms of aquatic and terrestrial recreation, for example kayaking followed by a hike. Rocky coasts are not very attractive for recreational activities, therefore, the Biodiverse Bird Life variant and Myriad Marine Life variant furthermore limit recreation by the creation of this habitat. Rocky coasts furthermore create limitations for the Dynamic Dunes, since this would mean that less sandy beaches will be created. Therefore, the space for leisure activities like a beach picnic would be limited. Lastly, the idea of the restaurant that is suggested in the Myriad Marine Life variant is probably undesirable in the other variants. The restaurant can attract a big number of tourists, and this would be undesirable when aiming to limit recreation in protected vegetation and bird nesting areas.

Functionality

The functionality assessment shows that the functionality of the ESL deteriorates in Myriad Marine Life and Biodiverse Bird Life, compared to the initial ESL design. The Dynamic Dunes variant has the same score as the current ESL design. The generation of green energy is expected to be impeded by the development of habitats, and if nature is developed there is less space for solar panels and windmills in and around the ESL. The long-term consequences of solar panels and wind mills on ecosystems are still unclear, and research is still conducted to fully examine the impact they have, especially on single designated species (Akerboom *et al.*, 2018). A research centre could therefore be created to evaluate the impact of solar panels and wind mills on nature development in the short and long term. Storage of green energy is impeded by the amount of water and the waterflow in the lake. In that sense, Myriad Marine Life compromises this function since it requires a lower difference in water level and flow velocity to decrease fish stress. However, flood protection can also be increased by creating oyster banks, mussel banks and seaweed beds. These can reduce the impact of sea wave action on the flood defence structures and allow long-term viability of these structures (Paiva & de Vries, 2014; Asano *et al.*, 1992). These ecosystem engineers can be combined with dunes. The grass could help stabilize and raise dunes which have shown to be a good form of coastal protection. The Biodiverse Bird Life variant does not comprise particular organisms or ideas that can help to make flood defence extra effective. In both the Myriad Marine Life as well as the Biodiverse Bird Life variant, the possibilities of a partly rocky coast are discussed. Rocky shores can aid in coastal protection since they provide a stable system that is not as affected by wave action as are dunes.

Economics

The costs related to the implementation and maintenance of the different variants are higher than those of the initial design. The highest costs are expected for Myriad Marine Life and Dynamic Dunes, whereas it is expected that Biodiverse Bird Life will impede lower costs. All habitats require some construction a priori to let biodiversity thrive. However, when variants are combined the total costs can be lower than the sole addition of each separate variant, as some structures can be used for multiple variants. Maintenance costs are expected to be in the same order of magnitude for all three variants, with slightly higher costs for Myriad Marine Life. It would be preferable to combine the maintenance to minimize the overall costs. The maintenance costs of the Myriad Marine Life variant can hardly be combined with the maintenance of the other two variants since its maintenance would be conducted underwater (e.g. pumps, sieve wall). The Dynamic Dunes and the Biodiverse Bird Life maintenance costs could be combined to keep the habitat viable. The highest costs are needed to control the vegetation and sedimentation. As indicated in the discussion on ecosystem services, the functioning of the ESL as fresh water flood basin impedes several effects on the indicated variants. This is also increasing maintenance costs for the variants when such a situation happens, especially for the Myriad Marine Life. In terms of benefits, we expect every variant to generate profit with tourism and recreation. This benefit would partly compensate for the implementation and maintenance cost. The highest benefit can be obtained by combining the recreational activities of Dynamic Dunes and Myriad Marine Life, because they work in symbiosis. On the other hand, combining Biodiverse Bird Life would reduce the potential for recreation in the other variants, since recreation in Biodiverse Bird Life can be a limiting factor.

9. Conclusion

The aim of this project was to integrate nature within the design of the Energy Storage Lake, without impairing its main functions: energy storage and flood protection. The ESL is supposed to be constructed in the Voordelta, which currently is a Nature 2000 region with a rich biodiversity. Therefore, it is important that the local environment stays suitable for ecosystem services and nature itself.

The initial design of the ESL is expected to strongly affect the environment. The hydrological and aeolian situation and sediment dynamics in the region will change, which could in turn influence the availability of habitats. The construction and the design of the lake will affect flora and fauna, since the ESL might decrease foraging and breeding habitats for birds and the accessibility of resting areas for seals. Only few plant, fish and other marine species can tolerate the varying water levels and salinity within the ESL. Pioneering plant species are most likely to colonize the dunes surrounding the ESL, and these species could help to establish a resilient and robust dune system.

We developed three possible design variants for the Energy Storage Lake; “Dynamic Dunes”, “Myriad Marine Life” and “Biodiverse Bird Life”. The Dynamic Dunes variant focusses on recreating the biodiversity of the Voornse dunes by implementing the habit types that occur in the Voornse dunes. The Myriad Marine Life variant aims to support and introduce marine life in the ESL by creating a diversity of habitats for a large variety of species. The Biodiverse Bird Life variant focusses on attracting bird life by creating habitats that offer food and shelter for different bird types. Furthermore, there are options for recreation in all variants to enhance recreational values of the design. Since LEDTA7's vision and mission are mainly aimed at increasing natural values, recreational activities should not compromise the development of nature. Therefore, recreational activities in the ESL area should be restricted to e.g. guided tours and supervised sporting activities.

The multi-criteria analysis evaluated the strengths and weaknesses of all variants. Many ideas are applicable to more than one variant. Yet, there are also some ideas as part of one variant that would conflict with ideas of another variant. To create as much natural value as possible, it would be best to implement many different ideas. However, choices will have to be made when ideas are not compatible, or when finances are limited. A combination of the three variants would be the optimal solution to make the ESL more environmentally friendly and attractive to visitors (Figure 26).

In this project, we generated ideas that could improve the development of nature within the ESL, and in the meantime create recreational value. It is important to mention that further research is required to investigate their feasibility and exact effect on ecosystems. Furthermore, it is crucial to understand the environmental impact of the construction of the ESL in the long-term, to prevent unexpected but severe damage to natural systems. In conclusion, we expect that the Energy Storage Lake will affect the current ecosystems in the Voordelta, but Building with Nature would support the conservation of characteristic natural values and can create additional natural and recreational value.

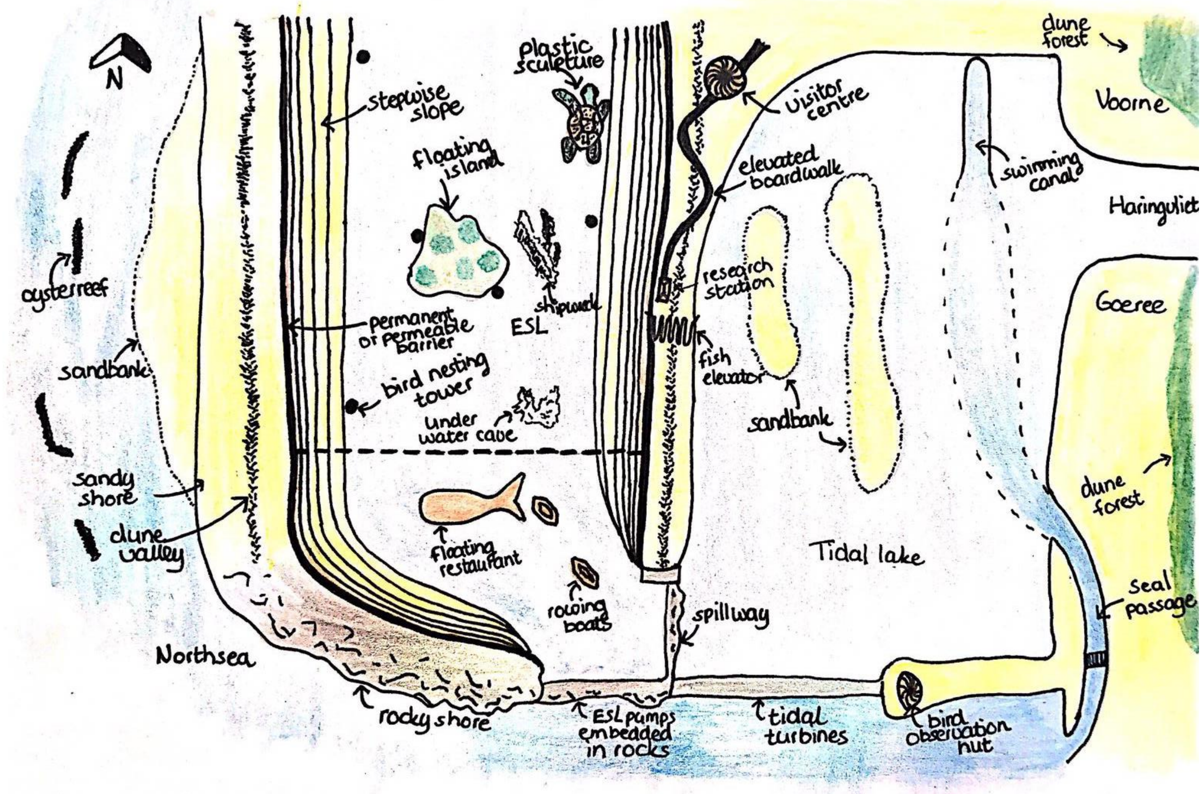

Figure 26: Integration of ideas out of multiple variants. Names of the structures are included in the figure.

10. Recommendations

Our research yielded a range of recommendations that can guide Delta21 in further improving their design for the ESL. LEDTA7 concluded that the current environment will be significantly affected by the construction of the ESL. We therefore advise Delta21 to carry out a thorough investigation of the environmental impact of constructing the ESL. Long-term effects are difficult to predict and for that reason it is even more important to take them into account when designing big infrastructural projects. Due to the limited scope of our ACT-project we were not able to provide such a study. Yet, this investigation is crucial for understanding how habitats and species will be affected in order to mitigate abiotic and biotic damage and negotiate appropriate compensation. This is even more important since the ESL is planned to be constructed in a Natura 2000 area which is protected under international law. Such an investigation should include:

- A hydraulic and morphological modelling study of the entire area, to predict the wave penetration and current development both inside and outside the ESL and the Tidal Lake.
- A study on the development of groundwater flows.
- A study on the creation of alternative seal resting areas next to the ESL on the seaside (due to the construction of the ESL, the seals present in the area will be limited in their living space).
- Additional modelling studies on sediment dynamics, systems ecology and hydrological conditions.

While LEDTA7 was asked to provide creative ideas on how to make the ESL more environmentally friendly and attractive for visitors, the next step is to examine how different ideas can be integrated. A first attempt of integrating various variants was provided in the discussion. Furthermore, the feasibility of implementing these ideas must be researched. Important questions that need to be addressed are, for instance:

- Is it possible to develop a healthy fish stock (for example for foraging birds) in the ESL?
- Are the fish species able to complete their life cycle?
- Do the fish species find enough food for their survival and reproduction?
- What foraging possibilities can the ESL dunes offer for breeding birds?
- What are the turbidity levels in the ESL at any given time and what impact would that have on present organisms?
- How does the suction of the turbines affect the habitats and organisms in the ESL?
- How can it be prevented that fish are sucked from the ESL to the sea and vice versa?

In this report we provided an idea on how to address the latter problem by constructing a sieve wall. This wall should have an optimal grid size, which can prevent different types of fish species present in the lake from drifting towards the pumps, and should be located at a minimal distance from the pumping installation. A problem with the sieve wall can be the development of algal growth on the sieves. Additionally, a fish-ladder or a fish-elevator should be implemented in the ESL design. However, research is needed on how and where to implement this, as for certain fish species it is crucial to have the possibility to travel in and out of the lake over time.

Our consultancy also advises Delta21 to provide a better description of the operational hydraulic regime in the ESL to be able to investigate the ecological functioning of the ESL in more detail. Central questions are:

- How does the daily water exchange affect the nutrient balance and organisms in the ESL?
- How does the influx of fresh water once every five to ten years influence the organisms in the ESL, especially marine life?
- What is the salinity of the incoming water into the ESL during normal circumstances, during high water discharges of the Haringvliet and during extreme situations when the pumps need to discharge huge volumes of river water to the North Sea?
- Where should the inflow and outflow of the ESL be located?
- How do different water levels and different filling and emptying velocities affect the bottom stability inside the ESL?

Another related research subject could be to examine optimal time ranges for emptying and filling the ESL. From an energy storage perspective, it is optimal to generate energy when there is demand for it. However, this does not necessarily align with what is best for nature development. Fluctuations in water level affect all flora and fauna in the ESL. Therefore, it would be interesting to design an optimally functioning tidal-scheme for the ESL with regards to energy storage and nature development. Regarding salt spray, a study on how to limit the reduction of salt spray in the Voornse dunes would be desirable. Possibly, changing the shape of the ESL could be useful for this.

The central factor to be considered by Delta21 is the desirability of implementing certain design ideas for the ESL. Our ACT-consultancy project confirmed that Delta21 should continue to pursue active dialogue with the local population and relevant stakeholders. The interviews our consultancy conducted were highly valuable in understanding various interests and concerns regarding Delta21 related to natural and recreational values and led to a more detailed problem-analysis, as well as suggestions on how the ESL design could be improved to create broader acceptance. We therefore strongly advice Delta21 to seek dialogue with those parties that have not been included yet and to stimulate active participation of all relevant stakeholders. This could for instance be in the form of a workshop or conference related to building with nature. Focussing on active participation and additional research as delineated above will work in the advantage of further development of the project.

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Appendices

Appendix 1: Stakeholder long list

The stakeholder longlist includes the parties Delta21 is already cooperating with (Lavooij & Berke, 2019, March 25) as well as additional parties that might be interested in the project for various reasons.

Authorities in the Netherlands: Authorities constitute a powerful group since they possess eligibilities in the Voordelta and provide permits for the development and maintenance of the area (Rijkswaterstaat Zee en Delta & Royal HaskoningDHV, 2016). The general interest of this group in relation to the project is to prevent the Netherlands from flooding and the management of activities and nature in the Voordelta. Rijkswaterstaat coordinates the preparation of the management plan for the Natura 2000 area Voordelta (Rijkswaterstaat, 2019, February 26). The Rijksoverheid, water boards, provinces and municipalities are also involved in the management plan (Rijkswaterstaat Zee en Delta & Royal HaskoningDHV, 2016).

- Rijksoverheid
- Rijkswaterstaat (leader of management plan for the Natura 2000 area Voordelta)
- Water board Hollandse Delta
- Water board Rivierenland
- Municipality of Rotterdam
- Municipalities Westvoorne, Hellevoetsluis, Goeree-Overflakkee, Schouwen-Duiveland, Noord-Beveland, Veere and Vlissingen
- Province of Zuid-Holland
- Province of Zeeland

Universities: Universities are mainly concerned with conducting research on various aspects of the ESL design. They also inform third parties, such as the government, on the consequences of the project. Interests of universities are mainly to gain knowledge, although such projects might also result in publicity and profit. This can merely influence the project indirectly.

- Wageningen University and Research
- TU Delft
- HZ University of Applied Sciences

Energy companies: The ESL provides opportunities for the storage and facetted release of (green) energy, as well as the generation of green energy. These stakeholders have a financial interest in the project. They have an intermediate level of power as there might be many energy companies that want to benefit from the ESL, but only a few will be involved with the project. There are numerous projects concerning green energy which makes these stakeholders less dependent on the ESL project.

- Vattenfall
- Nuon
- E-on
- Eneco
- RWE
- Solarfields

Environmental organisations: These organisations have an interest in protecting nature and biodiversity. They can influence the project by affecting the decisions of the government to provide a permit for the ESL or not. Given the current state of the "Voordelta" as a protected area the environmental organisations hold a powerful position. Except for WWF, all of these are involved with the management and setting up the management plans for the Voordelta (Rijkswaterstaat Zee en Delta & Royal HaskoningDHV, 2016).

- WWF
- Natuurmonumenten
- Stichting Zeeuws Landschap
- Stichting het Zuid-Hollands Landschap
- Natuur- en Milieufederatie Zuid-Holland
- Staatsbosbeheer

Aquaculture companies and associations: Many companies could benefit from the project because of the opportunities it provides for aquaculture. These companies have the interest of profit, but have relatively little power on the project, since there are other areas to fish and farm and they do not have a strong saying in whether the ESL will be constructed or not.

- Dutch Producers Organisation of Mussel Growers (POM)
- Dutch Oyster Association
- Stichting Noordzeeboerderij
- Vereniging Zeeuwse Hangcultuurkwekers

Affected groups: Companies, associations and resident to the area can be influenced by the project. Their interests vary from making a profit (companies) to having an attractive and safe living environment (residents). The power of these stakeholders is limited because they cannot directly affect the construction of the project. The project could negatively affect fishery who would be no longer allowed to work in the area. Therefore, they are concerned about the plan of Delta21 (Nederlandse Vissersbond, 2018, November 01).

- Port of Rotterdam
- Farmers in the area
- General population in the area
- Commercial (Nederlandse vissersbond, Netviswerk) and recreative fishery (Sportvisserij Nederland)

Companies involved with project management: These companies are involved with the design and execution of the project. Their interests are to deliver a product (the ESL) that meets the demands of the client and to make a profit by the construction of this lake. The power of these companies is relatively low, as there are a lot of companies that are specialized in construction projects.

- Ballast Nedam
- Van Oord Marine Ingenuity
- DEME
- Pentair
- VolkerWessels
- Royal HaskoningDHV

Appendix 2: Interview questions and transcripts

Appendix 2.1: Interview Questions

To learn more about the stakeholders' interests, concerns and suggestions regarding the Delta21 we set up the following interview questions.

- How and to what extent have you been involved with the "Delta21" project yet?
- What is your opinion on the project "Delta21" and the initial design of the Energy Storage Lake? If your opinion has changed, could you elaborate what made you change it?
- What do you like/value about the "Delta21" plan?
- What are your concerns regarding the design and construction of the Energy Storage Lake? Are your concerns related to nature and/or recreation?
- Do you see opportunities for improving the initial design of the Energy Storage Lake regarding nature and/or recreation?
- Is there something else you would like to tell us regarding the ESL or Delta21?

Appendix 2.2: Notes talk with Henk Bal (inhabitant study area)

The information about the interview questions were retrieved during the field trip to the study area (Kwade Hoek) on the 16th of April, 2019.

How and to what extent have you been involved with the 'Delta21' project yet?

- Lives in the municipality 'Goeree Overflakkee'
- Something has to happen with regard to climate change, wants to facilitate debate to get the best solution possible
- Wants to find a compromise between him and Delta21
- People in his municipality are a rather closed community, they do not want change

What is your opinion on the project 'Delta21' and the initial design of the Energy Storage Lake? If your opinion has changed, could you elaborate what made you change it?

- 70% positive about the plan

What do you like/value about the 'Delta21' plan?

- Flood safety, nature and new dunes
- Respect for nature and our children is important
- We must think in harmony with nature and people

What are your concerns regarding the design and construction of the Energy Storage Lake? Are your concerns related to nature and/or recreation?

- 50% of tourists will leave if windmills etc. destroy the beautiful coastline
- People/companies/organisations will think: if Delta21 can build there, we can do that too --> afraid of building of houses, a third Maasvlakte etc. near the dunes

Do you see opportunities for improving the initial design of the Energy Storage Lake regarding nature and/or recreation?

- In the initial design the ESL is too long, it should be egg-shaped so tourists and inhabitants of Ouddorp etc. have a free view on the sea
- The ESL should be 7-8km from the coast
- It would be best if municipalities are directly involved in planning process
- Lake and dunes should be natural
- Dunes should be nature friendly and dynamic, as in the Kwade Hoek
- ESL should only attract nature-aware tourists that visit the area to see something, not those that enjoy the sun lying on the beaches and leaving rubbish behind.

- No tourist centres, they should be where a lot of real tourists/sun enjoyers go

Is there something else you would like to tell us regarding the ESL of Delta21?

- Tides did not change after construction Maasvlakte, but waves are much lower/less intense
- North Sea here is only 20-25m deep through building of Maasvlakte II -> a lot of sand accumulates, creates shallow water
- With the Deltawerken-dam sand accumulated in the Voordelta (without it sand could go in and out)
- After Delta21 is built the sedimentation will stop as there is no sand coming from the sea anymore
- People in his municipality are more closed, they have lost a lot already through construction of Maasvlaktes and want to keep what there is now
- the taboo of changing things has to be broken, because there have to come changes because of the risks through climate change
- Contact Natuurmonumenten, Stichting Zeeuws Landschap and Stichting het Zuid-Hollands Landschap since they are important managing environmental organisations in the area

Appendix 2.3: Notes talk with Pieter Mout (inhabitant study area)

The information about the interview questions were retrieved during the field trip to the study area (Dunes of Voorne) on the 16th of April, 2019.

How and to what extent have you been involved with the 'Delta21' project yet?

- Biologist, teacher and principle for long time in Hellevoetssluis and Brielle
- Has been invloved with nature conservation and dunes for all of his life
- Involved with the Voornse dunes
- Very worried about Delta21 plan

What is your opinion on the project 'Delta21' and the initial design of the Energy Storage Lake? If your opinion has changed, could you elaborate what made you change it?

- Very worried about Delta21 plan
- Delta21will negatively affect Voornse dunes (1000-1500ha)
- Demarkatielijn (demarcationline): you cannot do anything beyond that line --> Delta21 will be beyond that line so the plan will not be implemented (even Rotterdam harbour was not allowed to cross the demarcation line)

What do you like/value about the 'Delta21' plan?

- It could be beneficial for the Haringvliet
- We need to prepare for climate change

What are your concerns regarding the design and construction of the Energy Storage Lake? Are your concerns related to nature and/or recreation?

- Dunes of Voorne is one of the most important and richest area for biodiversity in all of Europe and the richest nature reserves of NL (most species per km2)
- 2/3rd of all plant species in NL can be found here: 1053 species
- Attracts many species of insects and birds and it is (still) quiet regarding tourism
- Why is Voorne that rich in biodiversity? - dunes are rich already, never any water extraction (waterwinning) in the dunes over here (there has not been water contamination, natural hydrological system: winter-summer like nature wants it - dry in summer, wet in winter), four plant-geographical regions come together

- Compensation with Haringvliet will not compensate for loss of the Voornse dunes, Kwade Hoek and Tiengemeten
- Haringvlietdam has changed the dynamics and the area a lot already
- Delta21 plans to build in the middle of many Nature 2000 areas: Voordelta, Kwade Hoek, Voornes Duin, Haringvliet...
- Delta21 will bring dykes - expectation that building the ESL will lower the salt spray even more than is already happening --> nitrogen deposition will increasingly be a problem (by decreasing saltspray) --> damage and deterioration for Voornse dunes

Do you see opportunities for improving the initial design of the Energy Storage Lake regarding nature and/or recreation?

- Do not build it at this location
- Build Delta21 on the West Side of the Maasvlakte
- Richness Voornse dunes could be recreated on the Delta21 dunes

Is there something else you would like to tell us regarding the ESL or Delta21?

- He is willing to give a presentation of more than two hours about the Voornse dunes if we are interested
- Through the Deltawerken the Voordelta rose, sandplates come up at low tide or are already permanently visible, because surf and tides decreased a bit --> the surf (branding) is therefore now at the sand plates and not at the beach --> tourists do not like that

Appendix 2.4: Interview transcript Bas Roels (WWF)

The interview with Bas Roels from WWF was conducted by telephone on the 25th of April, 2019.

How and to what extent have you been involved with the 'Delta21' project yet?

- He knows the project well, or at least the information that can be obtained from the website. WWF is not actively involved in the project.

What is your opinion on the project 'Delta21' and the initial design of the Energy Storage Lake? If your opinion has changed, could you elaborate what made you change it?

- (-)

What do you like/value about the 'Delta21' plan?

- He likes the storage / transition of energy that is part of the plan, and thinks that the ESL is a good way to accomplish this. Energy storage is necessary and sustainable.

What are your concerns regarding the design and construction of the Energy Storage Lake? Are your concerns related to nature and/or recreation?

- He is not happy with the planned location of the ESL in front of the Rhine and Meuse estuaries. This will lead to the disappearance of certain habitats and will affect hydrology and morphology.

Do you see opportunities for improving the initial design of the Energy Storage Lake regarding nature and /or recreation?

- He did not mention any opportunities he sees to improve the design. He understands why the lake is placed at that location, because water safety is necessary there. However, another location where it fits better would be his preference.
- 'Gorzen and kwelders' have important natural values. The Kwade Hoek can be used as a reference for this. Migrating birds can forage at these locations. If the ESL design could be adapted in such a way the 'gorzen and kwelders' that are already there remain and new ones are established that would be great. It is important to take into account that this kind

of habitats/geomorphological systems are the result of a certain tidal dynamics and sediment supply from the south. Currents and waves will be changed with the ESL construction, what kind of an influence will that have on these land forms?
"Gorzen and kwelders" are endangered habitats ("staan onder druk"), also leading to decreasing numbers of migrating birds. This is already happening without ESL, so a goal could be to not only to maintain these land forms, but also improve/enhance them. Sea level rise is even further affecting the "gorzen and kwelders".

- If the gates between the tidal lake and open sea are closed, sediment cannot enter this region anymore. Sand starvation could result from this. Furthermore, wave intensity will be lower behind the ESL. A design for a gate that lets sediments through does not yet exist according to him.

Is there something else you would like to tell us regarding the ESL or Delta21?

- WWF likes the idea of fish migration through the Haringvliet of the Delta21 plan. WWF is already advocating for that for years. Fish migration (e.g. zalm, paling, haring, forel) could be strongly enhanced. The more / longer open, the better. WWF is in favour of energy storage, but prefers the transition of wind energy into hydrogen gas, because of its lesser spatial impact. WWF is actually looking for a system where the delta is more connected to the sea, to make sure that the delta can grow with sea level rise.

Appendix 3: Main agreements Voordelta management plan 2015-2021

Table 1: Possibility of recreational activities in the Voordelta.

Activity	Allowed in soil protection region	Allowed in resting area	Allowed in the rest of the Voordelta
Kitesurfing	Limited	No	Limited
Windsurfing/Wave surfing	Limited	Limited	Limited
Kitebuggying	N.A.	No	Limited
Extreme beach sports (flyboarding/ beach sailing)	N.A.	No	Limited
Sailing/ Sportfishing	Yes	Limited	Yes
Diving	Yes	N.A.	Yes
Canoeing	Yes	Limited	Yes
Sand-up paddling	Yes	No	Yes
Beach usage	N.A.	No	Yes
Building on the beach	N.A.	No	Yes

Table 2: Possibility of fishery in the Voordelta.

Activity	Allowed in soil protection region	Allowed in resting area	Allowed in the rest of the Voordelta
Beam trawl fishing larger than 260 hp (191 kW)	No	No	Yes
Trawl fishing smaller than 260 hp (191 kW)	Limited	Limited	Limited

Shrimp fishing	Yes	Limited	Yes
Shellfish fishing	Yes	No	Yes
Otter trawling	Limited	No	Limited
Fishing with baskets and traps	Limited	No	Limited
Fishery with static nets	Limited	Limited	Limited
Mussel fishing	Yes	No	Yes

Table 3: Maintenance in the Voordelta.

Activity	Allowed in soil protection region	Allowed in resting area	Allowed in the rest of the Voordelta
Beach and shore nourishment	Yes	Limited	Yes
Management beach	N.A.	N.A.	Yes
Management coastal defence	Yes	N.A.	Yes
Dredging Slijkgat	Limited	N.A.	N.A.
Spread of dredging spoil	No	N.A.	Yes
Marking and Maintenance Rijkswaterstaat	Yes	Limited	Yes
Monitoring	Yes	Limited	Yes

Table 4: Possibility of other activities in the Voordelta.

Activity	Allowed in soil protection region	Allowed in resting area	Allowed in the rest of the Voordelta
Maintenance cables and pipes	Yes	Limited	Yes
Commercial shipping	Yes	Limited	Yes
(Un)motorized aviation	Yes	Limited	Yes
Military flight activities	Yes	No	Yes
Other military activities	Yes	No	Yes
Controlled explosions of ammunition	Yes	No	Yes
Shell collection	Yes	No	Yes
Discharge cooling water power plant Maasvlakte	Yes	N.A.	Yes

Appendix 4: Explanation criteria MCA

Table 5: Description of criteria used in the MCA

Category	Criteria	Description
Ecosystem services	**Species richness flora**	Species richness is a common measure of biodiversity (Hamilton, 2005). Species richness flora is defined as the number of floral species.
	Species richness fauna	Species richness is a common measure of biodiversity (Hamilton, 2005). Species richness fauna is defined as the number of faunal species.
	Species abundance flora	Species abundance is a common measure of biodiversity (Hamilton, 2005). Species abundance flora is defined as the number of individuals per plant species.
	Species abundance fauna	Species abundance is a common measure of biodiversity (Hamilton, 2005). Species abundance fauna is defined as the number of individuals per animal species.
	Threatened species	Threatened species can be of specific interest within biodiversity (Hamilton, 2005). This criterion evaluates to which degree the variants take into account the amount and abundance of threatened species.
	Self-regulation	Self-regulation is the degree to which the created ESL-environment (biodiversity) is able to maintain itself without human intervention. Of importance here are biotic and abiotic processes such as erosion, sedimentation and decomposition (Swart *et al.*, 2001).
Recreation	**Aesthetics**	Aesthetics refers to the visual appeal of the ESL-environment to people (Proctor & Drechsler, 2003; Swart *et al.*, 2001). We evaluate aesthetical attractiveness based on the assumption that people find natural landscapes visually appealing (Proctor & Drechsler, 2003). Following this, the ESL-environment would become less attractive to people with an increase of visible human elements. We chose this definition of aesthetical attractiveness since Delta21 opts for a natural design of the dunes and the ESL.
	Accessibility	Accessiblity is an important factor in recreation and tourism (Proctor & Drechsler, 2003). Accessiblity is defined as the degree to which people can access the area and the number of visitors that can visit the ESL at the same time.
	Sports	The availability and amount of sports activities that can be carried out in the ESL environment.
	Education	The availability of educational programmes and activities, for example related to nature and sustainability.
	Tourism	The degree to which other tourism is possible, such as restaurants and boat tours etc.
Functionality	**Generation of green energy**	The generation of green energy is a central function of the ESL that must not be compromised. The amount of energy that can be generated depends on the number of energy-creating elements like solar-panels, windmills and turbines.
	Storage of green energy	The storage of green energy is a central function of the ESL that must not be compromised. The storage capacity of the ESL depends on the size of the lake.
	Flood protection	Flood protection is a central function of the ESL and must not be compromised.
Economics	**Establishment costs**	The costs to implement the ideas to achieve the purpose of the variant.
	Maintenance costs	The costs to maintain the created biodiversity of the ESL environment.
	Benefits	The financial benefits that result from tourism in and around the ESL.