Biodiversity in the Delta21 area
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Deltide

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Image front page: *Figure 1. Logo of Deltide.*

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About Deltide

Deltide is a consultancy team consisting of six MSc students from Wageningen University. A broad variety of expertise is present in our team. Although natural science is the main background of our team, the team members are specialized in different topics.

Maxime Weber and Talitha Salsabila have a background in Aquaculture and Marine Resource Management, in which they specialize in Marine Resources and Ecology. Myrthe Bouma and Gino Dessauvagie both have a background in Forest and Nature Conservation and are specialized in Management. Tom Raats and Maartje van den Bosch are specialized in Ecology, but approach this from a Biology perspective.

These different knowledge backgrounds and the variety of expertise in our team result in a broad perspective. This broad perspective is of great importance in this ACT project, as Delta21 is a big and challenging project. Therefore, different perspectives are needed in order to make Delta21 realizable. The combination of backgrounds in marine ecology, terrestrial ecology and management make our team an excellent partner in working on the impact on and possibilities for biodiversity in the Delta21 area.

Figure 2. Group members of Deltide. From left to right: Maartje van den Bosch, Tom Raats, Myrthe Bouma, Talitha Salsabila, Gino Dessauvagie and Maxime Weber.

Summary

This research was commissioned by Delta21 and has the aim of providing advice on ways to increase biodiversity on the seaside of the Delta21 area. The Delta21 plan has three main aims: flood management, energy storage and nature development. The last was the main focus of this research. The main problems in the Delta21 area concern a degraded seafloor due to dredging activities and bottom trawling by fishers. Delta21 is also trying to find solutions to the problems caused by sedimentation. Currently, this is being counteracted by dredging activities. Stakeholders in the area are aware of these problems as well, and this research also looks for ways to implement the wishes of these stakeholders for the area. Furthermore, the Delta21 plan will be built in a Natura2000 area that has very strict regulations. If the Delta21 plan is realised, nature should be compensated. These legislation restrictions, environmental problems and stakeholder challenges are what led to the following main research question: "What are the opportunities for biodiversity in the Delta21 area?''. With the specific research questions: 'What are opportunities for marine biodiversity in the Delta21 area?' and 'What are opportunities for terrestrial biodiversity in the Delta21 area' and 'To what extent do the habitats of the selected target species need to be improved'. Six target species in the categories of marine mammals (Harbour porpoise and Harbour seal), birds (Common eider and Arctic tern), fish (European eel), crustaceans (European lobster), molluscs (Flat oyster) and bristle worms (Sand mason worm) were identified. A literature study was carried out to find information about habitat requirements and the status of these species. Three reference areas were chosen to support the main ideas for biodiversity opportunities: the Blokkendam reef, rope grown mussel cultures in Devon, United Kingdom, and the National park Zuid-Kennemerland. Six semi-structured interviews were carried out with four experts and two stakeholders to identify stakeholder opinions and to gain more information and insights for the main ideas. All of these activities led to the final idea of implementing a combined reef and aquaculture system in the Delta21 plan and adjusting the design of the energy lake to provide the establishment of embryonic dunes. These two ideas support habitat requirements for our six target species and provide opportunities for sustainable fisheries. In the section of this report 'final advice', a more detailed description of the recommendations for Delta21 can be found.

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1. Advice to Delta21

The final advice is focused on the north-western- and southern side of the energy storage lake (ESL), and consists of a separate set of recommendations for the dune and beach area and for the reef area in combination with sustainable fisheries that we propose to be realised in the sea (figure 6). This advice is mainly focused on biodiversity and nature development. To do this, six target species were identified in the categories of marine mammals, vegetation, (migratory) birds, fish, crustaceans, and shellfish. The proposed measurements are part of an integrative advice based on the needs of the six different target species we identified. Table 1 shows the final advice per area summarised.

Table 1. Final advice, summarised.

Target Area	Final advice

Dune area	• Southern beach as a nature reserve
	• Use sand from dredging and excavation ESL and other dredging areas
	  ○ Check for pollutants
	  ○ Check for N-content
	• North-western beach open to tourism
	• Adjust design of dune area
	• Dune forest might be difficult to realise
	• Facilitate ecotourism

Reef and Aquaculture	• Reef area combined with mussel rope culture located above • Rope culture will provide mussel clutches than can establish on the seafloor • Facilitate the establishment of shellfish (such as flat oyster) by providing concrete reef dome structures • Balance species communities by providing habitat for sand mason worm reef to develop ○ Will develop naturally with minimised disturbance • Most important measure: area without any seafloor disturbance; no bottom trawling • Replace existing fisheries with sustainable fishing methods and aquaculture

1.1 Dune area

When the Delta21 plan would be realised, the dunes near Rockanje and Westvoorne will lose the dynamics of sea, sand and wind. This will result in the loss of the typical dune landscape, resulting in the loss of suitable habitat for species dependent on this area. However, this loss is currently already taking place, as sandbank Hinderplaat is moving landwards. The beach and dune area is also of great importance for recreation. The dune area that is lost in Rockanje and Westvoorne in the realization of the Delta21 plan, cannot be easily replicated on the beaches of the ESL.

1.1.1 Requirements beaches

The coastal dynamics of wind, sea, and sand are of great importance for the development of dunes. There are multiple factors to take into account when designing dunes. The width of the beach is an important factor. The beach needs to be wide enough because the sand particles need to be dried out. After drying out, sand can be transported by the wind and accumulate to form dunes. The width is essential for the dynamic character of (embryonic) dunes. Research conducted by Van Puijenbroek et al. (2017) showed that maximum aeolian transport was reached at their site with the dune having a width of 900m, which is the minimum we would also advise. We advise using Nitrogen-poor sand on the beaches, to avoid succession. N-rich sand will facilitate the succession of the beaches (BassiriRad, 2015). Furthermore, it is essential to use non-polluted sand for nature as well as the tourism beach. To make a natural landscape, without promoted succession by management, the continuous aeolian sand disposition should be maintained.

1.1.2 Southern beach

For the southern tip of the ESL, a beach is placed in the design of Esmée van Eeden. In this design, the beach is 400m wide. As mentioned above, we advise widening the beach to 900m, to facilitate the forming of (embryonic) dunes. This results in an adjusted form of the southern beach, to take the erosion patterns into account (Figure 3). The beach will be widened in places where erosion

streams are expected to be absent. To prevent further erosion, we advise placing breakwaters ('golfbrekers') on the edges of the beach.

By expanding the width of the beach by 500m, the formation of (embryonic) dunes will be facilitated. We advise making the southern beach a nature reserve. This area will be closed off to the public and therefore, the surfer village, as is proposed in Van Eeden's design, will not be realised.

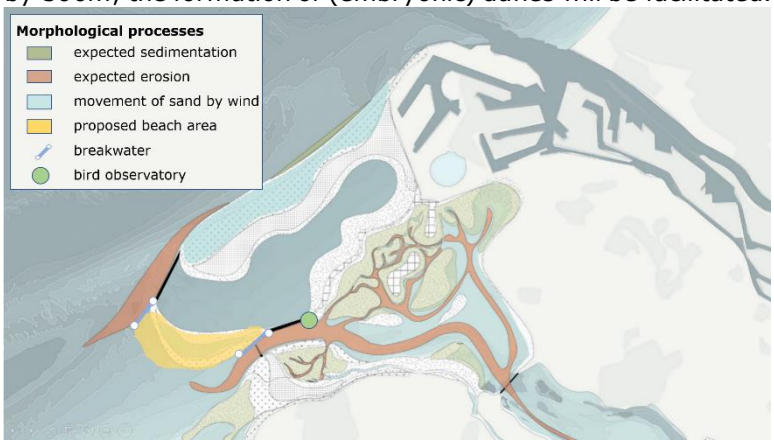

Figure 3. Map of the ESL (adapted from Van Eeden, 2021).

In the current design of Van Eeden, the southern beach is connected to the north-western beach via the storm surge barrier. This barrier needs to be accessible for maintenance. Van Eeden proposes to use this barrier as a road for visitors and as an ecological corridor between the mainland and the island. We advise making this barrier only accessible for maintenance and not using it as a road and ecological barrier. When the southern island is closed off, predators that prey on birds cannot disturb the resting and breeding birds. People are not allowed to enter the southern beach, to prevent disturbance of this nature reserve which is a necessity for seals to rest.

To compensate for the prohibition of people on the southern beach, a dedicated bird- and marine mammal watching place can be realised. From this observatory, people can enjoy their view of animals without disturbing the environment. This observatory could be placed near the tidal lake (figure 3). At this spot, tourists can have a great view of the ESL, the tidal lake and the beach area.

For the southern beach, we recommend keeping the area as natural as possible. To avoid too much succession, no vegetation will be planted on the southern beach. The wind, sea and sand would create opportunities for pioneer plant species to establish themselves. For instance, plant species that are characteristics of embryonic dunes such as sea rocket, prickly saltwort and sea sandwort require flood marks for their establishment. Seaweed and shells washed ashore provide nutrients essential for the growth of these plant species. In addition, this will create structures that allow seeds to establish and thus the formation of embryonic dunes. Therefore, it is advised to not take away seaweed and shells that are washed ashore. Furthermore, with this ideology in mind, we advise to not plant any plant species, such as marram grass, in the area. These plant species will eventually establish in the area if the conditions are suitable.

Species such as the common eider, the Arctic tern and the harbour seal benefit from this habitat type. Due to the strong dynamics, no further succession than embryonic dunes is expected. This type of habitat is very suitable for these species, as they rely on open, pioneer habitat and vegetation for their breeding success. The impact of the sea is expected to be strongly present on the southern beach. Sandy beaches that partly submerge or are separated from the mainland are expected to be present, resulting in suitable habitat for the Arctic tern, common eider and the harbour seal.

1.1.3 North-western beach

In the current design of Van Eeden, the area between the sea and the ESL would approximately be 3km wide. The coast is designed as follows: sea – beach (500m) – young dunes (1500m) – forest edge – dune forest (~1000m) – inner dune edge – energy lake slope (~250m). Van Eeden suggested that sand would be placed in parabole dunes, to create opportunities for an interesting dune landscape. The old dunes, further from the sea, would consist of a (planted) forest. This design is very optimistic in our opinion and the realization of it is expected to be very difficult. The succession of dune areas goes slowly, especially new dunes in areas where the dynamics of wind, sea and sand are strongly present. Due to these dynamics, embryonic dunes will be the most probable dunes present here. Even if succession takes place and old dunes are formed, the formation of a water bell to sustain vegetation might take a long time. It is also not a given that this water bell will contain freshwater that can sustain the dune forest. As Reijers states in the interview, the formation of a saltwater bell might also be a possibility. If this is the case, the presence of a saltwater bell will result in a different vegetational composition.

Our advice for the design of the north-western beach is visualised in figure 4 and is the following:

- Beach: 500m
- Embryonic dunes: 400m
- Shifting dunes: 1100m
- (Semi-)fixed dunes: 1000m
- Gradient to ESL: 250m

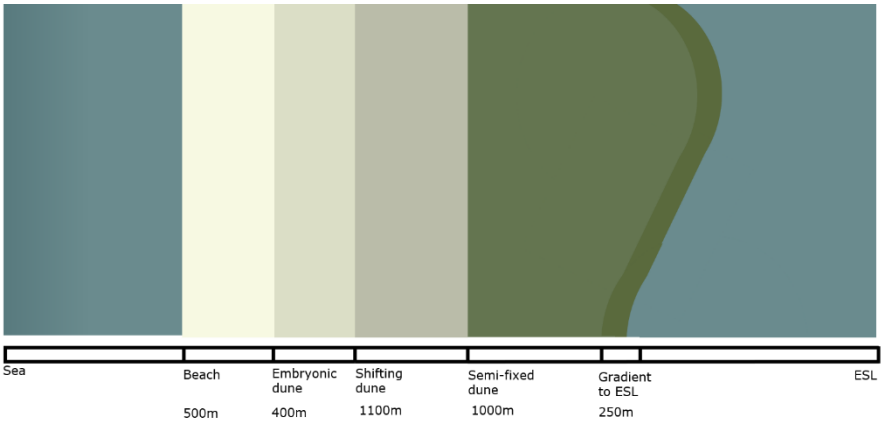

Figure 4. The proposed landscape structure (adapted from Van Eeden, 2021).

With this division, dune formation and dune succession are more likely to occur. As is visible in figure 3, sedimentation is expected to occur at the north-western beach. We expect this to result in a more stable beach, in which eventually succession might take place. If it will eventually take place, it will take a very long time. However, barriers like the dike that is planned to be constructed near the lake barrier, might result in the accumulation of sand in certain areas. This accumulation might facilitate the succession of shifting dunes towards (semi-)fixed dunes. As Reijers suggested, embryonic dunes need sufficient space to develop. Therefore, a width of 900m for the beach and the embryonic dunes is advised.

For the development of embryonic dunes on the north-western beach, it is recommended to not manage the area intensively. Flood marks should remain in the first 900m of the area on the seaside. Although this will not be perceived as attractive by beachgoers, it is a requirement for the establishment of embryonic dunes. Besides, it is advised to not construct any buildings in the area since this would speed up the accumulation of sand in an unnatural way and creates faster suitable conditions for plant species of the second phase of dune succession.

For the development of the second phase of dune succession, shifting dunes, it is advised to plant marram grass. This grass fixates sand and thereby facilitates the formation of stable dunes. After a certain time, the formed hills create gradients in height. The lower areas on the ESL side, are less impacted by the wind. These spots could provide suitable conditions for plant species that are characteristic for the next phase of dune succession.

In Van Eeden's plan, a dune forest is designed to be realised after 20 years. We are in doubt whether forests in the dunes can develop this fast. Shrubs and trees need more substrate and water than is present in 'just sand hills'. What could be possible is that N-richer sand is used for these dunes. N-richer sand might, however, result in the succession of dunes towards other vegetational states, resulting in lower biodiversity (BassiriRad, 2015).

After planting marram grass, we advise letting the dynamics of the wind do its work since this results in the most natural succession.
However, there are still many uncertainties in the construction of a dune area. If you would place the marram grass in the middle of the area, sand will build up on top of it. The conditions that

The tourism that is proposed in the design of Van Eeden, will be difficult to realise. Currently, the dune forest plays an important role in the proposed tourism possibilities. As stated above, the realisation of a dune forest is not something that we envision in our advice. The creation of holiday homes and bird watching were planned to be the main attractions in the forest area, however, they are difficult to realise in our vision. Other forms of tourism might be possible in the beach and dune area. Especially ecotourism could be thriving in the Delta21 area, as there are many areas where nature could be observed.

1.1.4 Realisation

We advise using the sand that is excavated for the ESL for the supplementation of the beaches. However, the sand first needs to be analysed for heavy metals and Nitrogen and Calcium content. N speeds up the succession of dune systems, which is something that we want to avoid, and therefore it is recommended to use sand with an N content lower than 20 kg N/ha. Furthermore, embryonic

dunes are characterized by pH levels higher than 6.5, thus the sand needs to be Ca-rich. It is necessary to check if the pH level of the sand is higher than this pH value.
For the development of a beach on the southern border of the ESL that is envisioned by Van Eeden (2021), the beach will approximately be 4.5 km long. We advise having a beach and dune area with a minimum width of 900m (Van Puijenbroek et al., 2017). To prevent erosion of the beach, an extra meter is required. The average depth of the sea at the location of the ESL is 15m. Therefore, in total, $\sim 648*10^5$ m^3 sand is required to create this beach. In addition to the southern beach, a new beach will be built on the north-western side of the ESL lake as well. In the design of Van Eeden (2021), this beach will be 13.5km long. Taking into consideration the width of the beach and dunes, and the depth of the sea, $\sim 162*10^6$ m^3 sand is required.

Besides the excavation of sand from within the ESL, additional sand excavated elsewhere is needed to build the beaches. Since the ESL will be approximately 25m deep, and the seafloor is 15m under sea level, only 10m of the seafloor will be excavated. The ESL will be approximately 490m^2, therefore only 4900 m^3 of sand can be excavated from the ESL. Consequently, $\sim 162*10^6$ m^3 sand needs to be excavated from the North Sea for the construction of beach areas. Besides investigating the N and Ca content of this sand, it is also advised to investigate the composition of the sand and the size of the grains to see if it is similar to the sand extracted from the ESL. Sand that is smaller in grain size is more easily picked up by the wind.

In the current plan of Delta21, wind turbines on the edges of the ESL are placed. We advise excluding wind turbines from the Delta21 design, as wind turbines negatively impact migratory birds.

Appendix
To calculate the amount of sand required for building the dunes, In the design of Van Eeden, the north-western beach will be on average 3km broad and 13.5km long. Moreover, the average depth of the sea at the location of the ESL is 15m; meanwhile, the ESL will be approximately 25m deep, therefore, 10m needs to be excavated where the lake is going to be located. Therefore, $40,5*10^7 m^3$ sand is required for the

1.2 Reef & aquaculture

With the realisation of the ESL, a significant part of the marine environment of the Voordelta will be lost. This will, most likely, have a major impact on the current marine ecosystem. However, the current ecological state of the Voordelta is not optimal. Anthropogenic interferences in the past and the present have been causing disturbances to the seafloor. This, most probably, resulted in a reduction of heterogeneity in the area. Currently, the majority of the seafloor in the Voordelta consists of sandy substrate. However, it has been estimated that, before human interventions, 30% of the seabed of the North Sea consisted of reefs (ARK, 2018). In general, these reefs are associated with a greater diversity of species, compared to the bare sandy seafloor patches. Bringing back these reefs will boost biodiversity and increase the natural quality of the environment.

In this report, a couple of target species from different animal groups have been selected, which could be kept in mind when designing the reefs. The selected target species for the reefs are: European lobster, European eel, harbour porpoise, harbour seal, flat oyster and sand mason worm. To combine measures for the target species, we propose to combine a rope grown mussel culture with a reef structure beneath it. This reef will be a combination of a biogenic reef (a reef with substrate from dead or living shellfish), a hard artificial substrate reef, and a soft substrate reef with sand mason worms (figure 6). All these reef types are associated with increased biodiversity.

Figure 5. Example of concrete reef dome structures (Reef ball foundation, n.d.).

From the interview with John Holmyard from offshore shellfish, it became clear that beneath rope grown mussel lines, a biogenic reef was already naturally forming (appendix 2.2). The forming of a biogenic reef can thus be facilitated by introducing hanging rope mussel cultures. The main mechanism consists of clutches of mussels dropping from the ropes to the seafloor and reinforcing the development of a biogenic reef. If necessary, cultch (dead shells) of oysters, mussels or other shellfish can additionally be deployed, to further kickstart the formation of a biogenic reef. This only has to be done when the

clumps of mussel falling from the ropes turn out to not supply enough settlement substrate for other shellfish.

Additionally, we propose to implement an artificial concrete reef dome in the reef system (figure 5), which will provide a hard substrate for flat oysters to establish. This hard substrate will provide refuge for the target species European eel and European lobster. The reef will also attract multiple fish species, resulting in a foraging area for the harbour porpoise and the harbour seal. The target species common eider and Arctic tern can use the reef area for foraging as well, as these birds forage on shellfish and fish.

These reefs will only be able to establish when disturbances at the seafloor are diminished. We would strongly advise banning all bottom trawling, including shrimp fishing activities, in the area where reefs are desired. Doing this will allow for the natural establishment of sand mason worm reefs, but also the formation of shellfish reefs. At the reference area at the Blokkendam, these reefs have already started to emerge due to diminished seafloor disturbance.

Current bottom trawling practices, and especially shrimp fishery, is an important source of income for the local industry. However, more sustainable alternative options, that do not harm the seafloor as much, exist. Here we propose some new options in which economically attractive species are targeted. First of all, rope grown mussel cultures can be used as a sustainable alternative for shrimp fisheries. This type of aquaculture can be easily combined at one location with shellfish beds. The optimal depth for mussels to grow in is between 1-10m. The offshore shellfish rope grown mussels in England occurred at 20-30m depth. Not all parts of the seafloor west of the ESL will form a suitable habitat. Furthermore, an exposed area with a lot of wave action can potentially damage the aquaculture. If a reef beneath the ropes is realised, these structured can diminish wave action. However, to ensure the survival of rope grown mussels, an area with a relatively calm sea is advised.

Besides the rope cultures, we advise other sustainable fishery methods such as pot and creel fishing, which consists of cages on the seafloor that do not damage the seafloor. The animals that might be caught with this technique are lobster, octopus, crab and whelk. The second option is pole and line fishing, with hand-held or mechanical poles. This method mainly targets large pelagic, schooling fish, like seabass and mackerel. The last technique we advise is longline fishing, with small vessels with up to 1000 lines. Similar to pole and line methods, longlining can be applied to target pelagic fish. But, it can also be used to catch demersal species, such as cod or flatfish. The shape of the hooks and the weight of the line can be adjusted to mitigate the bycatch of sharks and seabirds.

Some important abiotic circumstances should be kept in mind when choosing a location for the reef. The habitat requirements for the most relevant reef-building species are discussed in section 5.1.3 (*Reef species habitat requirements and life history traits).* Most importantly, salinity levels, depth and seafloor disturbances induced by waves and currents should be considered. Annual average salinity levels should not be too low, most reef-building species do not survive periods with extreme low salinities. Also, the water should not be too deep. mussels, for instance, cannot survive in waters deeper than 10 metres. Lastly, sheltered places are preferred, as this would enhance the establishment of a shellfish reef. It is however hard to predict where such a reef should be located because the morphology of the seafloor will change once the ESL is realised Therefore, an assessment of the current state of biodiversity in the Voordelta seafloor would be relevant.

Figure 6. visual representation of the combined aquaculture + reef design (created by team member Gino Dessauvagie).

2. Introduction

2.1 Background information

For ages, the Netherlands has been in a constant battle with the water surrounding the country. Throughout history, the Netherlands has booked many successes in this fight, as land reclamations resulted in a significant increase in land surface area (Mostert, 2020). Partially because of this, around one-third of the country is below sea level, and in the absence of dikes and the Delta Works, 65% would be underwater during high tides (Hoeksema, 2007). In this everlasting battle, solutions have been found to prevent the land from flooding, by building the Delta Works and other dams and dikes.

However, over the last decades, the risk of floods has been increasing and will continue to do so in the future (Ministerie van Infrastructuur en Waterstaat, 2022). This increasing flood risk can be explained by several phenomena. Firstly, climate change is causing a rise in sea level and the frequency of extreme weather events like heavy storms, longer rainy periods and increased alpine snowmelt (Tol et al., 2003). Additionally, subsidence of peatlands is taking place in the western part of the country, induced by purposely lowering the groundwater level (Koster et al., 2018). Finally, the increasing urbanisation is associated with the occurrence of hard substrates, like buildings and roads. These structures do not allow infiltration of the water into the soil, resulting in increased runoff of the surplus water to water bodies outside of urban areas (Paul & Meyer, 2001). Consequently, this will eventually cause higher river discharges which could potentially become problematic.

Figure 7. Design of the Delta21 area in Zeeland (adapted from Delta21, 2019).

To mitigate the increasing risk of floods, the Dutch government came up with a plan. Part of this plan, as stated in "Deltaplan Waterveiligheid", is to strengthen the dikes (*3. Waterveiligheid,* n.d.). The initiators of Delta21, Huub Lavooij and Leen Berke came up with an alternative to achieve the desired water safety further upstream. The main aim of the Delta21 plan is to lower the chances of inland floods during high river discharges, without having to strengthen the dikes. The idea includes the construction of a flood defence mechanism consisting of a range of dunes, a pumping station and a barrier with closable locks (*Het Plan,* 2021). For this plan, a lake has to be constructed at the southern border of Maasvlakte 2 (figure 7). During high river discharge and heavy storms, the surplus of freshwater will be led into this lake and actively pumped into the North Sea.

Next to the main aim, Delta21 also formulated two other goals, which are energy storage and nature development (*Het Plan,* 2021). The demand for sustainable energy, such as wind and solar energy, is rapidly increasing. However, this kind of energy is generally associated with periods of both energy excess and shortage, due to their dependence on the weather conditions. The proposed lake can also be used to store the surplus energy in hydropower, and thus serve as an Energy Storage Lake (ESL) (Delta21, 2017). Within this plan, there is also room for nature to develop. By realising this plan, a tidal lake with a gradient from salt to freshwater will emerge. The Haringvliet used to be an estuary with such a salt to freshwater gradient. With the realisation of the Delta Works, this gradient, and consequently the migration of fish, disappeared from the Haringvliet. The Delta21 plan includes bringing back this crucial transition zone within the tidal lake and a fish migration river (personal communication Delta21).

2.2 Problem description

Although new opportunities are provided for nature, implementing the above-described plan will result in the loss of natural habitats. The ESL will be built in the Voordelta, an area that is protected under Natura2000 legislation. When realising this plan, both marine and terrestrial protected areas will be lost. This will have a potential negative impact on ecosystems that are already degraded. This means that according to Natura2000 guidelines, Delta21 needs to compensate elsewhere for the natural areas that are lost in the realisation of the plan (European commission, 2007).

Currently, the state of the Voordelta is highly influenced by anthropogenic disturbances and many important keystone species are declining in numbers. This mainly concerns migratory and breeding birds, filter feeders, migratory fish and marine mammals such as porpoises and seals (Troost et al., 2012; Camphuysen & Siemensma, 2011). The main threats to these species are diseases (for shellfish), the loss of habitat and habitat degradation due to disturbances at the seafloor caused by mainly bottom trawling fishery activities (Christianen et al., 2018). Due to these seafloor disturbances, reefs that provide refuge, food and nursery grounds to a wide variety of species, have disappeared (Smaal et al., 2015).

Reefs used to make up 30% of the North Sea, but nowadays almost no reefs have been able to establish. However recently, a new reef was discovered near the Blokkendam in the Voordelta, which mainly consists of flat oysters (ARK, 2018). Shellfish reefs are associated with high biodiversity and productivity and provide habitat for endangered species. They provide habitat and foraging grounds for birds and fish and provide shelter. Shellfish reefs also provide structures for fish to lay eggs on (ARK, 2018). Most of the Voordelta is currently protected by Natura2000 directives, and bottom trawling and fisheries are restricted in the seafloor protection area (restricted to fisheries with smaller vessels). As compensation for the establishment of Maasvlakte 2, around half of the seafloor is now protected area (Van Kooten & Jansen et al., 2015). Another problem exists in the sedimentation of the Voordelta, which is slowly causing the disappearance of Natura2000 habitat types (Elias et al., 2016).

The degraded state of the seafloor and different habitat types in the Voordelta provide opportunities for Delta21 to realise the desired nature compensation. The purpose of this project is thus to provide advice on what the opportunities could be for improving the biodiversity in the area around the ESL. The final advice is based on multiple target species from distinct animal groups. Here, the main focus is on the areas at the seaside the ESL. To answer the main research question "*What are the opportunities for biodiversity in the Delta21 area?"*, the following sub-questions were considered:

- *What measures can be implemented to develop a biodiverse terrestrial ecosystem at the seaside border of the energy storage lake?*
- *What measures can be implemented to increase the marine biodiversity in the northern Voordelta?*
- *What are the habitat requirements for the selected target species? And how can the habitats around the ESL be improved for these species?*

These questions are the basis of this project, which is to design a plan for the development of healthy and diverse marine and terrestrial ecosystems. The methods used for this research consist of carrying out interviews and performing literature research. The results will be combined into a final advice.

3. Area description

3.1 Voordelta: current status

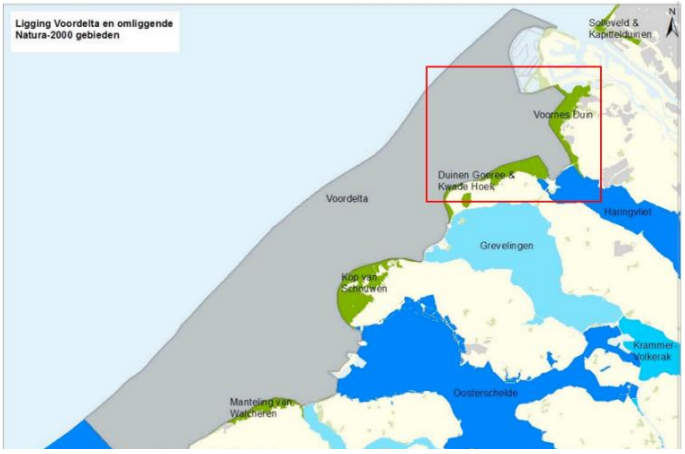

Figure 8. Map of the Voordelta and Natura2000 areas. The focus of the study will be on the area within the red square (adapted from Ministerie van Infrastructuur en Milieu & Rijkswaterstaat, 2016).

The Voordelta is the coastal area in Zeeland and the southern part of Zuid-Holland including the area of shallow sea adjacent to it (figure 8). On the eastern side, freshwater comes in from the Oosterschelde and the Haringvliet. This area is important for numerous habitat- and bird directives in Natura2000 regulations. Species in the categories of marine mammals, fish, and migratory birds are especially important according to the directives, and the Voordelta area is crucial for biodiversity and conservation thereof. The current management plan is directed toward conserving Natura2000 habitat types (Rijkswaterstaat, 2016). These habitat types range from coastal, dune and marine habitats. For the marine habitats, the management is focused on permanently flooded sandbanks (H1110), and silt- and sandbanks (H1140A). In the coastal zone, the emphasis is on salty pioneer vegetation (H1310), spartina swards (H1320), and Atlantic salt meadows (H1330). The management of dune habitats is focusing on embryonic dunes (H2110) and shifting dunes (H2120). Research conducted by Van Roomen et al., (2020) indicated that some species groups are declining in the Voordelta. Some of these groups include shellfish-eating birds, some big seagull species, and some coastal fish-eating birds. Numbers of marine mammals are increasing in the Voordelta (Van Roomen et al., 2020). Disturbances from dredging activities in the Voordelta are currently impacting nature negatively because of sediment resuspension and turbid water. These dredging activities are becoming more frequent, and an increasing amount of volume needs to be dredged (Rijkswaterstaat, 2016).

3.2 Morphological changes

With the construction of the Delta Works, the morphology of the Voordelta changed drastically due to changes in physical processes like; currents and wave patterns, the discharge of freshwater and the transportation of sand and silt (Tulp et al., 2018). From 1970 onwards, sandbanks emerged, which influenced wave action. These sandbanks started to grow in height and began slowly moving towards the coast until stabilization. Simultaneously, the old tidal creeks at the Haringvliet and Grevelingen started filling up due to sedimentation (Elias & Van der Spek, 2014; Elias et al., 2016). Here, a summary of the morphological changes is provided for the Haringvliet mouth (figure 9). At this location, net sedimentation is occurring (Tulp et al., 2018), and the Haringvliet mouth is slowly filling up. The supply of sediment is coming from the north and the south. These morphological developments resulted in changes in the Natura2000 habitat type compositions (Tulp et al., 2018). A total increase of areas above the average low-water levels has been taking place from 1970 onwards. This led to a decrease in habitat type H1110 (permanently submerged sandbanks) with about 20 ha/year since 1990. In the same time interval, the acreage intertidal areas have been increasing by approximately 15 ha/year. In 2007 however, a large part of the Voordelta is still assignable to habitat type H1110 (90.000 ha). By far, the biggest loss of this habitat type was caused by the construction of Maasvlakte 2 (1917 ha) (Tulp et al., 2018).

Main channels and shoals:

1. Noord Pampus
2. Slijkgat
3. Hinder
4. Hinderplaat
5. Hindergat
6. Garnalenplaat
7. Brielse gat
8. Bokkegat
9. Zeehondenplaat
10. Rak van Scheelhoek
11. Gat van de Hawk
12. Westplaat

M1 : MaasVlakte 1 (1954-1970)
M2 : MaasVlakte 2 (2008-2013)
S : Slufter (1986-1988)
B : Brielse Gat Dam (1966)
HV : Haringvlietdam and -Sluices (1958-1971)

Volume changes 1964-2009 (million m^3):

Location	Sed	Erosion	Net
a. Maasvlakte2	14.7	-33.7	-18.5
b. Coast (offshore)	5.8	-20.3	-14.5
c. Hinderplaat	0.2	-50.2	-50.2
d. Coast (nearshore)	0.0	-15.4	-15.0
e. Brielse Gat	0.4	-0.9	9.6
f. Scheelhoek	10.5	-2.2	64.5
g. Coast Goerree/Slijkgat	66.6	-4.4	50.2
Total	98.2	-127.1	26.1

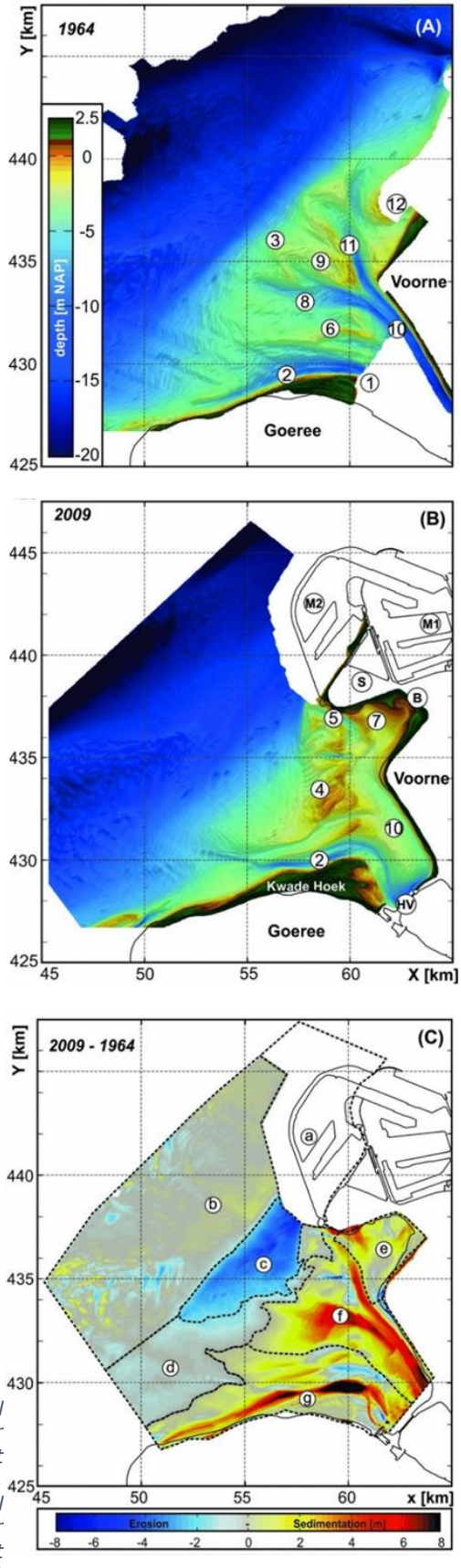

Figure 9. Overview of the bathymetry of the Haringvliet ebb-tidal delta for 1964 (A) and 2009 (B), the morphological changes over this time interval are summarised in a sedimentation-erosion plot and a table containing the volume changes over this period (C). *Figure 9. Overview of the bathymetry of the Haringvliet ebb-tidal delta for 1964 (A) and 2009 (B), the morphological changes over this time interval are summarised in a sedimentation-erosion plot and a table containing the volume changes over this period (C)* *(Elias et al., 2016).*

3.3 Abiotic factors

Next to the morphological characteristics, some other abiotic factors are shaping the Voordelta. The surface water temperature fluctuates throughout the year, with temperatures below 5 ºC in winter and above 20 ºC in summer (figure 10). Moreover, it can be noted that the average annual temperature has been slightly increasing over the last 10 years. The wind, and therefore the direction of the waves, are predominantly South-Westerly (Tulp et al., 2018). More important for the ecology of the Voordelta is the occurrence of storms. Storms influence the speed and the heights of waves and therefore influence the stress on the seafloor (Tulp et al., 2018). Especially this shear stress can have a major impact on benthic flora and fauna by inducing mortality. The shear stress at the seafloor is based on the wave heights, water levels and current speed (Adema, 2018). This stress is highest when the waves reach the steep slopes of the elevated sandbanks (figure 11; Tulp et al., 2018).

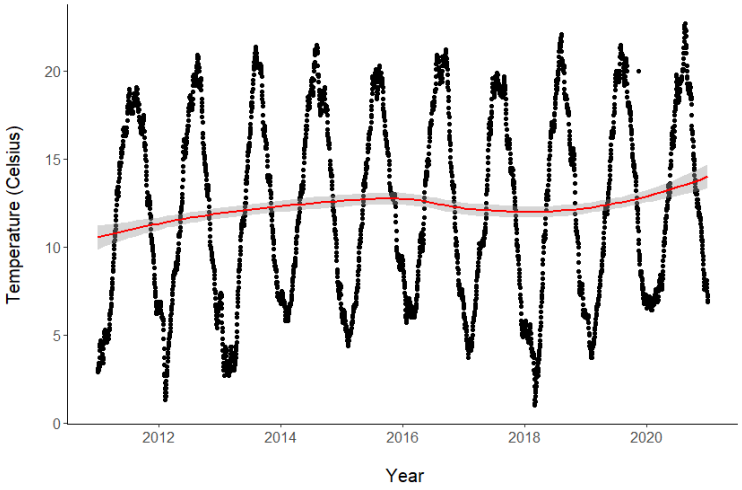

Figure 10. Daily temperatures at 12:00 of the surface water in Vlissingen from 01-01-2011 to 01-01-2022 (data retrieved from Rijkswaterstaat, 2022).

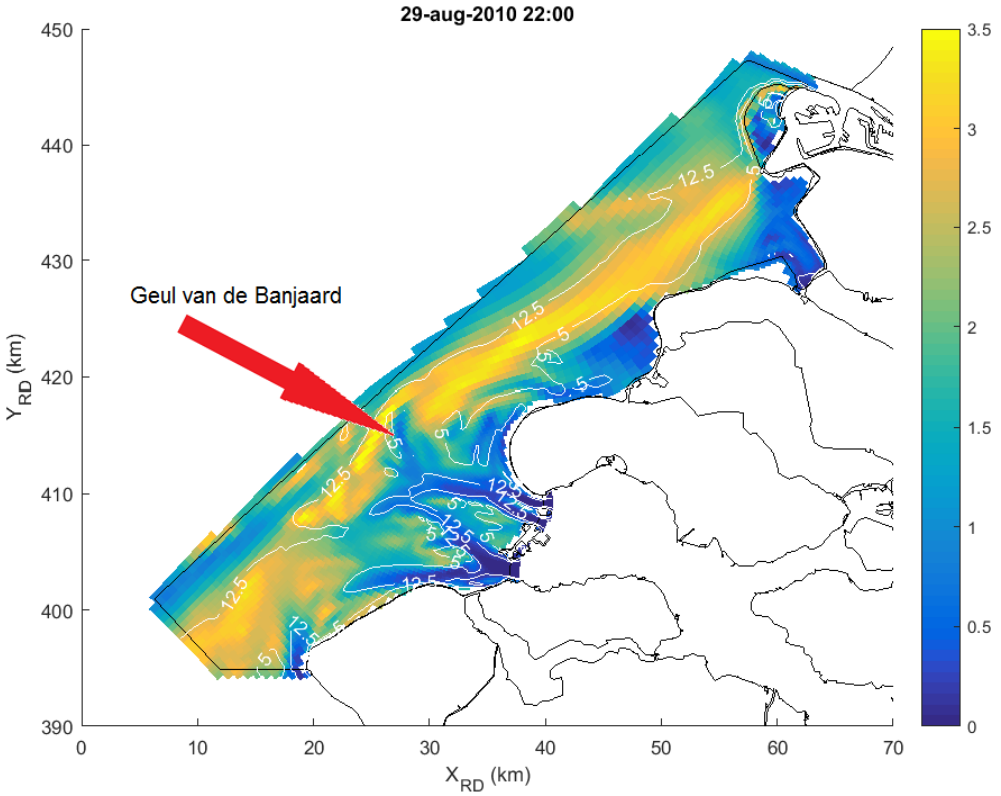

Figure 11. The shear stress at the seafloor in the Voordelta during a storm on August 29th 2010, the white lines represent the depth (Tulp et al., 2018).

The water quality and salinity in the Voordelta are dependent on the discharge of freshwater from the major rivers in the Netherlands, especially the Rhine. Currently, the majority of freshwater is flowing into the sea at the Haringvliet and the Nieuwe Waterweg (Tulp et al., 2018). Thanks to the strong influence of the rivers, the Dutch coastal waters have a high productivity with high concentrations of nutrients and phytoplankton (Baretta-Becker et al., 2009). In general, the Voordelta is considered to be salty (salinity >30 ppt), except for the northern part, where the average annual salinity is lower (figure 12). The lower average salinity is mainly caused by the influx of freshwater from the Haringvliet (Tulp et al., 2018). The salinity in the northern part of the Voordelta is highly variable, as it depends on the amount of freshwater influx from the Haringvliet sluices. In this part, the salinity can, occasionally, get very low (<10 ppt) which could cause increased mortality of benthic fauna (Craeymeersch et al., 1996).

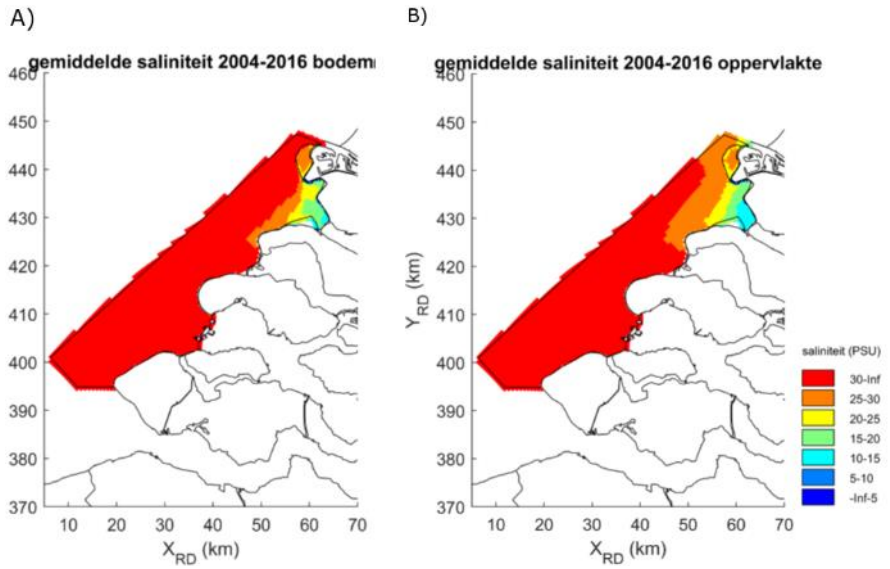

Figure 12. Average salinity (PSU) at the seafloor (A) and the surface (B) in the Voordelta (Tulp et al., 2018).

4. Methods

4.1 Literature study

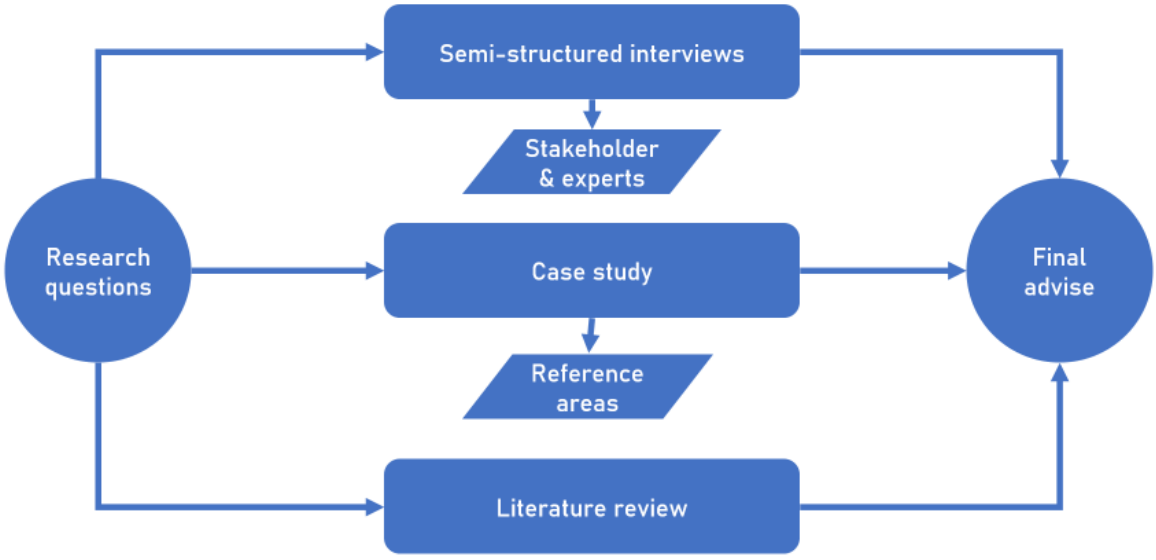

Figure 13. Schematic overview of the research methods.

To answer the question "*What are the opportunities for biodiversity in the Delta21 area?*" we conducted multiple types of activities. First of all, a literature study was done to answer the sub-research questions (figure 13). We looked into developing terrestrial biodiversity (the seaside border of the ESL), improving marine biodiversity (northern Voordelta), the status of the habitats and the target species, and sustainable fishery methods.

Literature studies were done on target species from the following groups: marine mammals, molluscs, migratory birds, crustaceans, fish, and bristle worms. Moreover, literature on biogenic and artificial reefs, dune development and current fisheries practices in the Voordelta were looked into.

We analysed reference area studies for building reefs, dune development, and sustainable fisheries. Papers were selected based on their relevance, e.g. the date of publishing. We searched for scientific papers using Google (Scholar) and the WUR Library.

4.2 Interviews

4.2.1 Conducting interviews

Semi-structured interviews were conducted with the identified main stakeholders and experts (figure 13). This provided a basis of set questions that were thought to be relevant for the interview. Furthermore, it allowed the interviewer to be flexible and adjust the set of questions throughout the interview. This is for instance possible when the interviewee came up with new relevant insights or when more in-depth answers were required. This type of interview model was chosen because it provides the most in-depth knowledge of a specific topic, and it still allowed comparing data afterwards between different stakeholders and experts. Furthermore, questions could be explained in the interviews and semi-structured interviews are very useful in very complex situations (Reed et al., 2009).

To clarify stakeholders' opinions on the Delta21 plan and to assess their wishes for the Natura2000 area, we conducted interviews with relevant stakeholders and experts. At first, we did research on who to interview. Per subject we wanted to speak to at least one expert: one for dune systems, one for reef systems and one for sustainable fisheries. Our goal was to interview at least one stakeholder from the fisheries- and tourism sector in the Voordelta and local municipalities. We looked up contact information from stakeholders and experts and contacted them via e-mail to ask for participation in an interview.

For each interviewee, a separate set of interview questions was formulated. These questions focused on the expertise and/or interests of the interviewee. Before the start of each interview, a general introduction of the team and our project goal was discussed. Furthermore, permission of the interviewee was requested to record the interview for transcription. After the introduction, the interview took place. If needed, follow-up questions were asked. Meetings with a maximum duration of one hour were held in Microsoft Teams. Two team members were present at each interview, one to chair the meeting and ask the questions and one to take notes. The division of these tasks was agreed upon beforehand.

4.2.2 Transcribing and analysing interviews

Using the recording, the interviews were transcribed. It was made clear which sentence was said by who, by starting a paragraph with the letter T (team) and the letter I (interviewee). The interviews were analysed with the qualitative analysis method of deductive coding (Appendix 1). Topics that were discussed were divided into the nodes: target species, reef, dune or sandbanks, stakeholders, aquaculture, and water/ flood management. These nodes were divided into sub-nodes plus a description of the condition a sentence should abide by to be categorized into that (sub-)node. All these (sub-)nodes correspond to the topics discussed in the literature analysis. Afterwards, each (sub-)node was linked to a colour and this colour was used to highlight all text that correspond to a specific (sub-)node in Microsoft Word. After the transcriptions had been analysed and divided into (sub-)nodes, the data was compared to look for similarities and differences per (sub-)node among the different interviews. Finally, the transcriptions were also summarized per interviewee to get an overview of what was learned.

4.3 Excursion

An additional activity was an excursion to the area in Zuid-Holland. The project commissioners showed the team around the area, to get familiar with the current situation of the area. As researchers, this gave opportunities to visualise ideas in the current situation and to come up with new additions to the plan.

5. Results

5.1 Opportunities for biodiversity

5.1.1 Target species

Table 2. Summary of the characteristics of the target species.

Target species	Value	Status	Diet	Habitat requirements	Threats	Natura2000 legislations	Improvements
Harbour porpoise	Top-end predator	Favourable, 'least concern' on IUCN red list	Whiting, sprat , herring, sand eel and squid	sea and no disturbances,	Bycatch, underwater noise disturbance, chemical pollution	X	Reduction disturbance from fisheries, more food availability
Harbour seal	Top-end predator	'Least concern' on IUCN Red List	Flatfish, herring, whiting and sprat	Sandbanks and rocky coast to rest	Habitat loss, entangled in fishing gears, chemical contaminant	1.11	Reduction of habitat degradation, sustainable fisheries
Common eider	Essential part of the food chain	IUCN Red List	Shellfish, crustaceans	Open sea, sand banks, mud flats	Toxic compounds, overfishing	H1.01, H1.11	
Arctic tern	Essential part of the food chain	'Threatened' on Dutch Red List	Small fish, fish spawn, crustaceans, shrimps	Pioneer landscapes like embryonic dunes	Predation, overfishing, flooding of nests	X	Sustainable fisheries, restoring coastal dynamics
European eel	Food source for many animals and humans	'Critically endangered' on IUCN Red List	Molluscs, crustaceans, worms, insects	Bottom area of freshwater or brackish water, spawning ground: sea	Overfishing, pollution, inaccessible migration route	(EC) No 1100/2007	Sustainable fisheries, habitat restoration
European lobster	Top-end predator, economically attractive	Frequently reproducing, declining in numbers in estuaries	molluscs, crustaceans, fish, echinoderms, polychaetes	Juveniles: gravel or coarse sand Adults: hard structures (hard mud, rocks, shellfish beds)	Over-exploitation, establishment of American lobster	X	Restoration of feeding ground, reduction in seafloor disturbing fishing activities
Flat oyster	Ecosystem engineer	Declining population (OSPAR Commision 2009)	Microalgae, phytoplanktons, diatoms	Tidal or intertidal area with firm sediment of sea floor	Bonamiasis and Marteiliosis disease, trawl fishery	X	Reduction of damaging seafloor fisheries
Sand mason worm	Ecosystem engineer	x	Foraminiferans, ciliates, copepods, algae and the faeces of echinoderms and molluscs.	Sandy substrate	x	X	x

Marine mammals

Harbour porpoise

The harbour porpoise (*Phocoena phocoena*) (figure 14) has been selected as a target species because it is listed in the Natura2000 Habitat Directive of the Voordelta. Furthermore, this species is a top predator in the North Sea and, thus, plays a great role in this ecosystem.

Figure 14. Harbour porpoise (Van Franeker, 2018).

The harbour porpoise is widespread in the North Atlantic Sea (Natura2000, 2014). They can be found in the Dutch part of the North Sea and adjacent waters, where it mostly occurs in shallow waters up to 200m deep. The diet of the porpoise exists mainly of fish like whiting, sprat, herring, sand eel and squid (Natura2000, 2014). Important habitat requirements for this species are good water quality (no pollution), no bycatch fisheries and no disturbances (loud noises and vibrations) (Natura2000, 2014).

The harbour porpoise was locally almost extinct in the 1960s and 1970s but it made a comeback in the Dutch waters late 20th century (NIOZ, n.d.). The estimation of the number of porpoises in the North Sea and the western entrance of the Channel was 250.000 individuals in both 1994 and 2005 (Natura2000, 2014). The biggest threats the porpoise faces are bycatch, underwater noise and chemical pollution (Ministry of Agriculture, Nature and Food Quality, 2020). High rates of noise made by vessels were seen to disrupt the foraging behaviour of harbour porpoises (Wisniewska et al., 2018). Natural mortality is caused by predation by grey seals or resource depletion. The impact climate change and food availability have on the species remains unknown in the Southern North Sea. The porpoise is a protected species, however international and national legislation to protect the species is complex and conflicting (Camphuysen & Trouwborst, 2009). On international, European and national levels different tools are set in place simultaneously (Trouwborst & Dotinga, 2008). Also, coordination between these levels is not optimal. In the Voordelta, the harbour porpoise has recently been added to the Standard Data Form and it needs to be taken up in the management plans of the area per Articles 6.1 and 6.2 of the Habitat Directive (Ministry of Agriculture, Nature and Food Quality, 2020). The status of the species has changed from unfavourable/inadequate (2011) to favourable (2019) for their population range and habitat. Because many uncertainties exist, conservation efforts are still needed that will limit the impact of human activities on the abundance and distribution of the harbour porpoise.

Harbour seal

The harbour seal (*Phoca vitulina*) (figure 15) is of interest as a target species since it is listed as protected in the Habitat Directive and is the most common seal species in the Netherlands. It is categorised as "least concern" by the IUCN Red List.

Figure 15. Harbour seal (Noordzeeloket, n.d.).

The habitat of the harbour seal is characterised by a marine environment with resting areas. The seal is mostly found on sandbanks in the Wadden Sea and the Delta area (Natura2000, 2014a). They have a preference for resting areas that are located on the edge of tidal flats that are adjacent to deeper waters. The seals also use beaches or rocky coasts to rest when the sandbanks are submerged (Natura2000, 2014a). In these resting areas, the seals are moulding, suckling and resting. For these activities to occur at the coast, it is a necessity that habitats are not disturbed. Most seals stay within a radius of 100-150km from the coast to forage, but they can travel over the entire north continental flat (Natura2000, 2014a). Seals mostly eat fish, which they forage from open sea. Diet research based on faeces shows that seals in Dutch waters have a broad diet existing of flatfish, herring, whiting and sprat. However, the diet varies per individual and per season (Natura2000, 2014a).

In the past, the harbour seal population has increased in population size. Suitable habitat has been lost as a result of the Delta Works and an increasing trend in recreation leading to disturbances which have a negative impact on reproduction (Natura2000, 2014a). Over the last 50 years, seal populations have increased due to the illegalising hunting activities in the Delta area and Wadden area (Rijksoverheid, 2021). In the '80s and the early 2000s, the Phocine Distemper Virus (PDV) killed around half of the harbour seal population. The population recovered and has been growing ever since. The recovery of the population in the Wadden Sea was due to improvement of water quality, immigration of new individual seals and measures against disturbances (Brasseur et al., 2018). The population numbers appear to be stable since 2012, even though the number of young keeps increasing (Galatius et al., 2021). Meanwhile, the population of the Delta area is showing an increasing trend since the late '90s (Natura2000, 2014a) (figure 16). However, this is mainly due to the migration of seals from the Wadden Sea and not because of reproduction since the number of pups is relatively low (Brasseur, 2018).

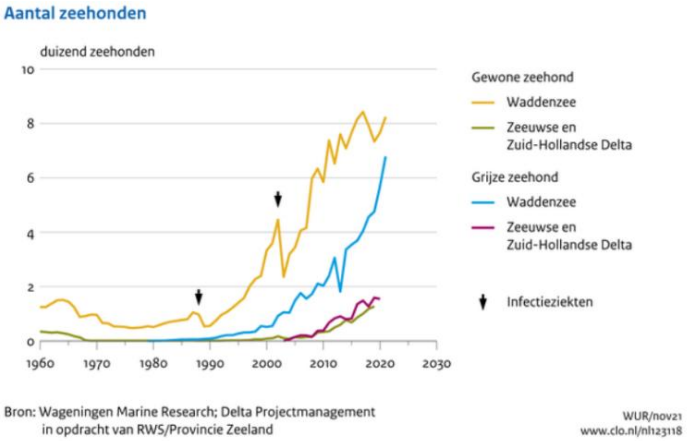

Figure 16. Number of harbour and grey seals for the Wadden Sea and Delta area of South-Holland and Zeeland from 1960 to 2020 (Wageningen Marine Research, 2021).

Birds

The Voordelta is of crucial importance for migratory birds. The birds rely on the sea, and the diversity of landscapes like sandbanks, estuaries and dunes. Two types of birds are selected as target species for migratory birds in the Voordelta: the common eider (*Somateria mollissima*) and the Arctic tern (*Sterna paradisaea*). The Arctic tern was chosen as a representative for migratory birds that rest on- and forage on beaches. The common eider was chosen as a representative species that breeds in The Netherlands and feeds on shellfish. Just like the Arctic tern, the common eider also rests in beach and dune areas.

Common eider

The common eider is placed on the IUCN red list, due to decreasing population numbers, because of threats such as climate change, pollution, and disturbances from aquaculture and recreation (BirdLife International, 2018). The bird is not placed on the Red List of Dutch breeding species, as ~3500 breeding pairs are found in the Netherlands (Sovon Vogelonderzoek Nederland, 2018).

Figure 17. Common eider (Barker, 2017).

The common eider is a large sea duck which has the southern tip of its breeding grounds in the Netherlands. The common eider breeds most often in the dunes near the Wadden Sea, but some breeding pairs have also been found in the estuaries of the Dutch delta. The diet of the common eider consists of shellfish and crustaceans.

The current common eider population size is equal to the population size in 1960, but large fluctuations in population numbers have occurred due to toxic compounds and overfishing of mussels and cockles in forage areas (Kleunen et al., 2017). Other threats that the common eider faces are getting entangled in fisher's nets and getting disturbed in their breeding area by recreants (Vogelbescherming, n.d.). The common eider is incorporated in two goals in the Natura2000 plan for the Voordelta:

- H1.01: Restore the undisturbed sea-ecosystem with permanently flooded sandbanks.

- H1.11: Maintain mudflats for resting and foraging non-breeding birds.

These goals are set to better the foraging area for the common eider (Ministerie van landbouw, natuur en voedselkwaliteit, n.d.).

Arctic tern

The Arctic tern is a bird species from the tern (*Sternidae*) family. The bird has the status of 'threatened' on the Red List of Dutch breeding birds since 2017 (Vogelbescherming, n.d.). The Arctic tern is well-known for the distance it migrates from its wintering place to its breeding place and vice versa, as this distance is between 15.000 – 20.000 km.

Figure 18. Arctic tern (d'Entremont, 2020).

The Netherlands is the southern tip of the tern's breeding distribution. The bird breeds in colonies, often consisting of Arctic terns, common tern (*Sterna hirundo*) and black-headed gull (*Chroicocephalus ridibundus*). Breeding spots of the Arctic tern can be found in pioneer biotopes, especially on sandy beaches that partly submerge or are separated from the mainland, due to the absence of predators on these 'islands'. The diet of the Arctic tern consists of small saltwater fish, fish spawn, shrimps and crabs (Vogelbescherming, n.d.).

As the Arctic tern forages for fishes and shrimps in gullies and estuaries near the coast, overfishing has a great impact on this bird. This is one of the reasons that the Arctic tern's population is declining (Sovon, 2019). Another reason for the declining population is the increase in floods during the breeding seasons, in which the nests are drowned. To protect this species, sustainable fisheries should be implemented, ensuring enough available food for the terns. Coastal dynamics are of great importance for the Arctic tern. Therefore, the facilitation of suitable breeding habitats for terns is of great importance in the protection of the species. This includes shielding the (artificial) breeding areas from predators, but also protecting the breeding areas from disturbance caused by humans (Kleunen et al., 2017).

Fish

European eel

The European eel (*Anguilla anguilla*) is selected as a target species since it is categorised as critically endangered by the IUCN Red List. It lives in marine and brackish water and has recently been discovered that 100 individuals are living in artificial reef structures in the Voordelta close to the Hinderplaat (Schuurs, 2021). Therefore, it would be interesting to create more habitats near this area for this endangered species to occur. Furthermore, the European eel has high economic and ecological value. They are an important source of food for many aquatic species and play, therefore, an important role in the food web. In addition, their migration behaviour results in the distribution of organic matters between marine and continental waters (Ringuet et al., 2002).

Figure 19. European eel (Meinderts, n.d.).

The European eel is categorised as a catadromous fish which is born at sea, and then grows and forages in inland water (Riede, 2004). They can live for 5-20 years in freshwater and brackish water with a depth range of 0-700m before returning to the sea to spawn and die. Spawning is taking place at the Sargasso Sea. The larvae migrate towards the European coast through the Gulf Stream current (Deelder, 1984). The European eel distribution

ranges include the Atlantic Ocean and the rivers of the North Atlantic, Baltic, and Mediterranean seas (Deelder, 1984). The European eel has a complex life cycle. When the larvae encounter the European shore, they transform into glass eels which are characterised by their transparent or slightly coloured body. Then, a long feeding period occurs in this stage, which is from the yellow eel to the silver eel stage. At this stage, the eels live at the bottom of rivers, lakes and brackish environments where they can be found under the rocks or buried in mud. The feeding period can last 6-12 years for males and 9-20 years for females (Whitehead et al., 1984). After transforming into silver eels and completing their growth period, the eels become sexually mature and migrate to the sea for spawning.

The European eel is a critically endangered species that is faced with several threats. Pollution, overfishing, habitat degradation and inaccessible migration routes have been assessed to be sources that threaten the eel (Laffaille et al., 2005). The European eel is a revenue source for many fishers. Overexploitation of this species could be indicated by the declining number of landings over several years in many areas (ICES, 2002; Dekker, 2003). European eels have a high-fat content, which makes them vulnerable to the bioaccumulation of pollutants. The accumulation of pollutants, for instance, heavy metals and organic contaminants can damage organs, such as the liver and intestine, then result in impaired migration capability (Pierron et al., 2008). Another major threat to the eel population comes from the construction of barriers and structures such as hydropower stations, dams, canals, land reclamation, and sand mining (Solomon and Ahmed, 2017). These constructions cause the loss of the eel's freshwater habitat and prevent them to reach the spawning grounds (Solomon and Ahmed, 2017).

Crustaceans

European lobster

The European lobster (*Homarus gammarus*) (figure 20) has been chosen as a target species in this report for a few different reasons. First of all, adults are considered top-end predators and thus have an important role in shaping the environment (Rozemeijer & Van de Wolfshaar, 2019). In addition, lobster is commercially valuable, as it is a desirable species for human consumption. Lastly, the lobster has been targeted since population numbers are in decline, especially in the estuarine Delta areas (figure 21).

Figure 20. European lobster (Arrancoast, n.d.).

The European lobster is a widespread species in the Eastern Atlantic, with a geographical distribution ranging from northern Norway to the Azores and the Atlantic coast of Morocco, but is also found along the northwest coast of the Black Sea and in the Mediterranean Sea (Holthuis, 1991). Adults are relatively sedentary with home ranges varying from 2-10 km (Bannister et al., 1994; Prodöhl et al., 2007). The European lobster usually lives on hard substrates like rock, hard mud, or shellfish beds at a maximum depth of 150m, but is generally not found deeper than 50m (Holthuis, 1991). The European lobster is a nocturnal animal that spends the daytime in holes or crevices (Holthuis, 1991; Phillips, 2013). These holes and crevices are particularly important for younger and smaller individuals, as it provides protection against predation and cannibalism (Mercer et al., 2001; Rozemeijer & Van de Wolfshaar, 2019).

The European lobster is a solitary, territorial animal that hunts during the night. Little is known about the diet of the European lobster but more information is available on the American lobster. It is commonly believed that these two species are very similar in size, range and ecology, suggesting that the American lobster can serve as a model species for the European lobster (Phillips, 2013; Rozemeijer & Van de Wolfshaar, 2019). Therefore, literature on the feeding ecology of the American lobster has been used here. The American species is omnivorous, with a broad diet consisting of plants, algae and zooplankton but mainly remains of larger animals like molluscs, crustaceans, fish, echinoderms, and bristle worms (Rozemeijer & Van de Wolfshaar, 2019; Sainte-Marie & Chabot, 2002).

European lobsters typically reach adulthood at an age of 5-8 years and this is largely dependent on water temperature (Prodöhl et al., 2007). *Homarus* species reproduce multiple times throughout

their life, with relatively small clutch sizes and large eggs (Phillips, 2013; Rozemeijer & Van de Wolfshaar, 2019). The lobsters start their life with three pelagic, planktonic larval stages, after which it settles on the seabed during moulting stage IV (Cobb & Wahle, 1994). Appropriate nursing grounds for these post-larval individuals usually consist of gravel or coarse sand. During the first period of their benthic lives, the juveniles are almost permanently underground in burrows (Rozemeijer & Van de Wolfshaar, 2019). After a while, older individuals emerge from these burrows to forage on the seafloor (Rozemeijer & Van de Wolfshaar, 2019).

In the Netherlands, the European lobster occurs in the open Dutch North Sea but is mainly found in the Zeeuwse Delta (figure 18). More specifically, the majority of the lobsters live in the Oosterschelde and Grevelingen. However, population numbers have been declining at both of these locations. Especially in the Oosterschelde, where lobsters are less frequently observed by divers or caught by fishers over the years. In the Grevelingen lake, the lobsters showed an increase in abundance until 2014, after which a strong decline has been observed (Van der Loos & Gmelig Meyling, 2019) (figure 21). Over-exploitation is most likely the cause of these population declines (Phillips, 2013). Little literature has been available on the population numbers of European lobsters in the Voordelta, but it is believed that this species profits from reduced seafloor-disrupting fishing activities. The European lobster has, for example, been observed at the Blokkendam shellfish bed (Van der Loos & Gmelig Meyling, 2019).

Another threat the European lobster faces is the potential establishment of the non-native American lobster (Pavičić et al., 2020). Possible risks of introduction of this species to the system include competition with and predation on native lobsters (Øresland et al., 2017), the transmission of new diseases (Stebbing et al., 2012) or possible hybridization of the two different species (SwAM, 2016). However, it should be noted that it is very hard to predict what the actual impacts would be of the establishment of the American lobster in European waters.

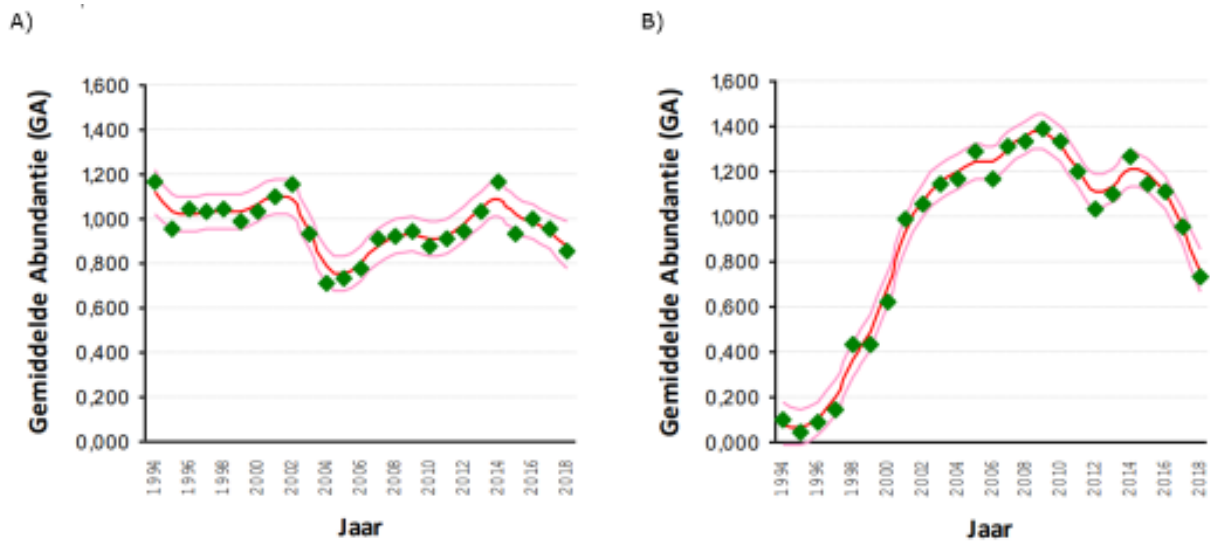

Figure 21. Average abundance over time of the European lobster in the Oosterschelde (A) and Grevelingen (B) (Van der Loos & Gmelig Meyling, 2019).

Bivalves

Flat oyster

The European flat oyster (*Ostrea edulis*) was selected as a target species since they can create reefs that provide a hard bottom structure in a predominantly soft bottom marine environment. The oyster beds become a foraging ground and shelter area for many marine animals (Bruno et al., 2003). Flat oyster beds were once abundant in the North Sea, but their number has greatly reduced recently.

The European flat oyster lives along the western European coast, extending from Norway to Morocco in the north-eastern Atlantic and the whole Mediterranean Basin. The European flat oyster can withstand a temperature between 2-30ºC. In the Netherlands, flat oysters can be found on the Yerseke Bank and in the Grevelingen (Van Banning, 1991). A mix of a Pacific oyster (*Magellana gigas*) reef and a flat oyster reef was also found near the Brouwersdam, which is located between Grevelingen and the Voordelta (Christianen et al., 2018).

Figure 22. Flat oyster (Bos, n.d.).

Flat oysters thrive in subtidal and sublittoral areas with high salinities. The species settles on firm sediment, like mud, rocks, hard silt, or artificial habitat made of broken shells (Jackson and Wilding, 2003). Abiotic factors that significantly impact the growth of flat oysters are temperature, water turbidity (the amount of suspended inorganic particles), salinity, current velocity, water depth, and oxygen availability (Smaal et al., 2015). Since flat oysters are filter feeders, they help clear the water column, but their growth will also be negatively affected if the suspended sediment concentration is above 50 mg/l since it decreases the rate of pump and feeding (Loosanoff and Tomers, 1948). The flat oyster female produces 500.000 to 1 million eggs per spawning. Then, the oyster spends 8-10 days for incubation, depending on temperature. The pelagic period lasts for 6-10 days before the larvae will find a suitable substrate to attach themselves to. For the optimum larval growth, the salinity has to be at least 20‰, although they can survive at salinity as low as 15 ppt. The larvae will become 'spat' after 6 months of settlement (Walne, 1974).

In the early 1970s and 1980s, the flat oyster population was greatly decreasing due to lethal diseases caused by the parasites *Marteilia refringens* and *Bonamia Ostrea*. New management practices have been put in place, but the oyster population remained low. Besides diseases, the decreasing population is also caused by a combination of the flat oyster fishery and habitat disturbance. At the end of the 19th century, flat oyster fishery became too intensive and caused a quick decline in oyster population, then by the beginning of the 20th century, oyster beds were greatly reduced in the North Sea (Gercken and Schmidt, 2014). The activity of shrimp trawling is very damaging to the reefs and seafloor. The damaged seafloor hinders the settlement and growth of the oysters. Currently, according to the OSPAR assessment in 2020, the flat oyster status was still critical with the main threats coming from fisheries, habitat damage, and diseases.

Bristle worms

Sand mason worm

The sand mason worm (*Lanice conchilega)* (figure 23) is selected as a target species since it is considered a typical species for permanently flooded sandbanks in the coastal area of the North sea (Natura 2000, 2014b). In addition, this species has been selected as a conservation objective (instandhoudings-doelstelling) for the Natura2000 area of the Voordelta (Van de Have et al., 2019). This species is part of the Polychaetes class.

Figure 23. Sand mason worm (Van Dijk, 2010).

The sand mason worm lives in intertidal and deeper areas, mostly in sandy bottoms, but also in silty bottoms and rock crevices filled with silt (Schrieken, 2014). The sand mason worm builds a tube made out of sand and shell pieces and it catches plankton and detritus with small tentacles. In the Netherlands, the species is common and can occur in high densities. High densities of over 500 tube worms per m^2 covering an area bigger than 1000m^2 are considered a biogenic reef (Hendrick & Foster-Smith, 2006; Rabaut et al., 2009). A biogenic reef can deliver multiple ecosystem functions by increasing species number and species diversity in comparison to soft sediment without *Lanice* reefs (De Smet et al., 2015). The reefs provide nursery

areas for juvenile flatfish and foraging areas for adult flatfish (Kaiser et al., 2002; Rabaut et al., 2009).

Species associated with *Lanice* reefs are significantly impacted in subtidal areas exposed to beam trawling (Rabaut et al., 2007). The density of sand mason worms themselves was temporarily affected after being exposed to beam trawling (Van de Have et al., 2019). The reefs can withstand areas with little fishing but will disappear with high fishing intensities. Multiple studies touch upon the fact that this species delivers ecosystem services, but that the species still does not benefit from any legal protection (Habitat Directive) in Europe despite its value (Braeckman et al, 2014; Godet et al., 2008; Godet et al., 2006).

5.1.2 Dunes

Coastal dunes provide important ecosystem services such as delivering coastal protection, recreation, and the storage of drinking water (Everard et al, 2010). Furthermore, dunes shelter unique biodiversity. Developing new dunes can mitigate the threats from climate change-induced rise in sea level (Van Puijenbroek et al., 2017). Van Puijenbroek et al. (2017) stated that we know little about factors determining the speed of early dune devolvement, but that understanding these factors is essential for preserving these ecosystem services.

Interaction between vegetation and aeolian processes starts the dune development (Maun, 2009). Sand deposition and reduced erosion are the results of established vegetation that forms a small dune (Dong et al., 2008). A shadow dune is also formed on the lee side of the vegetation with a ridge parallel with the wind (Clemmensen, 1986). The dune formed is now called an embryonic dune (Hesp, 2002). The growth of the dune depends on the accumulation of sand, erosion vegetation growth, and vegetation loss (Montreuil et al, 2013).

Van Puijenbroek et al. (2017) studied how embryonic dune growth is affected by individual dune characteristics as they describe that factors like size, vegetation, and shelter are less studied. They found that the relative growth rate over summer depends on the frequency of aeolian transport events. Also, a minimum beach width is necessary to reach maximum aeolian transport, also known as the fetch length (Delgado-Fernandez, 2010). The net growth of their foredune was around 30 m^3/m and they assumed that the maximum aeolian transport was reached (0.9 km wide beach). They expected also smaller beaches to have a lower net dune growth in comparison to wider beaches caused by a lower sand supply by a reduced fetch length and higher storm erosion (Van Puijenbroek et al., 2017). They stated that vegetation is essential for dune development. However, the species did only affect dune growth over the winter, and only two species occurred at their site. Embryonic dunes with sand couch-grass (*Elytrigia jucea ssp. Borea-atlantica*) had a significantly lower relative growth rate than embryonic dunes with marram grass (*Ammophila arenaria)*. Also, a positive linear relationship between the initial dune volume and the absolute change in dune volume over summer is dependent on the degree of shelter from the sea. Dunes more landward increased less in volume than dunes more seaward. The height of the dunes seemed not to have a large effect on the wind flow pattern and the deposition of sand.

Embryonic dunes

Embryonic dunes are the dunes that develop in the first phase of dune succession (figure 24). They can be found across coastal zones of Europe; for example, in the Netherlands, they can be found on De Hors (Texel), Schiermonnikoog, Griend and Kwade Hoek (Bij12, n.d.). Often, they can be found in front of foredunes, sea inlets and dune plains. The areas where embryonic dunes occur are extremely dynamic and are influenced by wind and sea, creating a mosaic of small sandy hills and vegetation. Several bird species use embryonic dunes for breeding or foraging, e.g., the Arctic tern, common eider, and little tern *(Sternula albifrons*) (Bij12, n.d.). Moreover, these types of dunes are characterised by small pioneer dunes with small plant species diversity. Sand couch-grass, sea rocket (*Cakile maritima*), prickly saltwort (*Salsola kali ssp. Kali*), and sea sandwort (*Honckenya peploides*) are species that occur on embryonic dunes. In specific, the sand couch-grass is a characteristic species of this vegetation type (Natura2000, 2008). This plant is part of the *Poaceae* family and thrives on sandy saline soils. For the sand couch-grass to grow, the soil moisture content needs to

Figure 24. Figure 1: Embrynoc dune (alamy.com).Embrynoc dune

have a salinity level of 2% (Ecomare, n.d.). Seeds are taken up by the sea through wind and floods and are deposited again at beaches by the wind or during floods (Ecopedia, n.d.). However, the seeds only germinate with rainwater (Flora van Nederland, n.d.). After germination, the plant grows and traps drifting sand which creates small hills. These hills can retain rainwater creating a transition from freshwater to seawater which is essential for full-grown sand couch-grasses. When the embryonic dunes reach a certain height, the freshwater content increases creating a freshwater bubble. This provides more suitable conditions for other plant species to grow on and could eventually take over the dunes to form white dunes (Flora van Nederland, n.d.). In specific, marram grass is a characteristic species for white dunes and often coexists next to embryonic dunes (Natura2000, 2008). The other plant species that occur on embryonic dunes can especially be found near washed up plant remnants (Bij12, n.d.)

Furthermore, embryonic dunes are characterised by pH levels higher than 6.5 and moderate nutrient content (Runhaar et al., 2009). High quantities of nitrogen deposition could result in a further succession of the dunes. Van Dobben et al. (2012) created a model in which the critical level of nitrogen deposition of drifting sand dunes was simulated and found that the critical level is 20kg N/ha/yr. Additionally, for optimal functioning of embryonic dunes, the area needs to be at least a few hectares (Natura2000, 2008). Increased nutrient levels could increase biomass and thus the accumulation of organic matter. Moreover, this could increase the speed of soil formation processes and, therefore, increases the rate of succession and the deterioration of embryonic dunes (Bobbink & Hettelingh, 2011). Besides, intensive dune management negatively affects embryonic dunes (Lemoine & Faucon, 2005). Measures such as placing drift screens, extracting washed on plant remnants and constructing obstacles on the foredune are hindering the formation of embryonic dunes (Dynamisch Kustbeheer, n.d.). Washed up plant remnants are taken away to create more suitable conditions for beach tourism (Dynamisch Kustbeheer, n.d.). Drift screens increase the build-up of drifting sand which creates more suitable conditions for the plants growing on white dunes and thus, speeds up the rate of dune succession (V. Reijers, personal communication, April 13, 2022). Furthermore, if the erosion of beaches occurs to a larger extent than sand deposition, the area on which embryonic dunes develop will decrease (Smits et al., n.d.).

5.1.3 Case study dunes Zuid-Kennemerland

National park Zuid-Kennemerland is located between Ijmuiden and Zandvoort (figure 25) (Valdés-Correcher et al., 2018). PWN, Staatsbosbeheer (state forestry services) and Natuurmonumenten are the main nature managers of the area (Nationaal park Zuid-Kennemerland, n.d.). This reference area was chosen because it is a nearby dune system that has the dynamics that are important for the development of a self-sustaining dune system, and can therefore provide knowledge on the factors needed to achieve this.

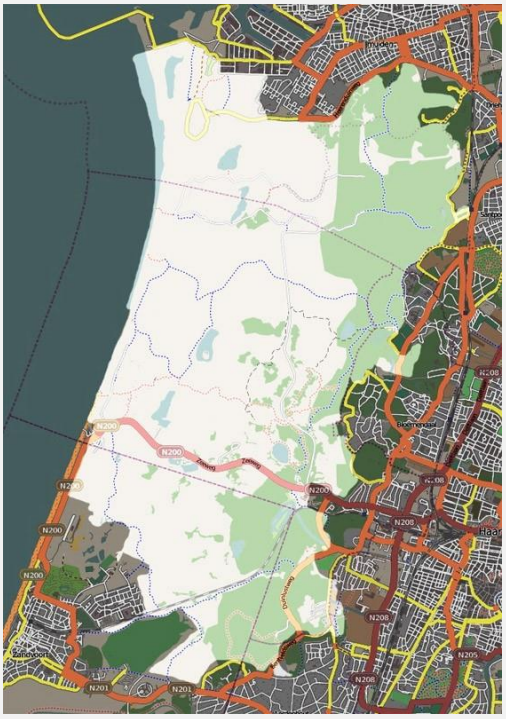

Figure 25. Map of National Park Zuid-Kennemerland (openstreetmap.com).

The main management objective is directed towards a dynamic dune area with an open structure where the sand can be blown away freely by the wind. To keep this open structured, vegetation is removed in several places, especially near the sea. And in other areas, big grazers such as Highland cattle (Bos taurus) and Koniks (Equus caballus var. konik) are used to keep the landscape in the early stages of succession (Natuurmonumenten, n.d.). In the past, dunes were mostly protected from erosion by planting dune vegetation that could stabilise the sand. This was mainly done to protect the land from the sea and to avoid villages from being buried with sand. This caused a decline in biodiversity because the dynamic nature of the area was lost. The constant moving of sand by the wind would cause a constant reset of succession. When this process was halted, pioneer vegetation was mostly lost, which caused soil acidification (Arens et al., 2013; Ruessink et al., 2018). In addition, N deposition became more prevalent because of the constant burial of sand, due to aeolian transportation laid down a fresh sand layer. This would decrease nitrogen deposition, but this mechanism was now also lost (Ruessink et al., 2018). After 1980, nature management was adapted to increase biodiversity again.

Nowadays, a lot of effort is put into restoring the dynamic, open sand systems in de the dunes. However, this proves to be very difficult as a lot of measures such as soil and vegetation removal is needed to go back to a dynamic system (Arens et al., 2013). Ruessink et al., (2018) found that excavation of notches (figure 26) proved to be an effective measure to restore a self-sustaining dynamic dune system where aeolian sand transport is dominant. This study does not confirm a clear increase in biodiversity, because that would need to be assessed in a few years (Ruessink et al., 2018). However, if endemic vegetation of dune systems can re-establish itself, this would be highly beneficial for the food web in general. The main Natura2000 habitat type that is the focus in this report and which also is part of the target value areas in the National park Zuid-Kennemerland is N08.02: Open dunes, as well as N08.01: beach and embryonic dunes. These open dune systems are important for many species such as Northern wheatear (*Oenanthe oenanthe*), and whinchat (*Saxicola rubetra*). This habitat is also suitable for amphibians and reptiles such as the natterjack toad (*Epidalea calamita*) and sand lizard (*Lacerta agilis*). Invertebrates such as Niobe fritillary (*Abriciana niobe*) and blue-winged grasshopper (*Oedipoda caerulescens*) (Province Noord-Holland, 2020).

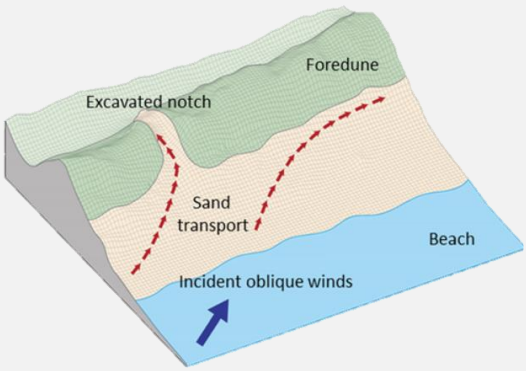

Figure 26. Schematic view of notch excavation on beach and dune area (adapted from Nguyen, D., Hilton, M., & Wakes, S., 2021).

In the management plan of the national park, the target species related to the Natura2000 habitat type of embryonic dunes are described, as well as the ecological requirements. Embryonic dunes need a natural inflow of sand and continuous aeolian sand disposition. The characteristic plant species for embryonic dunes is sand couch-grass. This embryonic dune system is combined with white dunes habitat type (H2120) and dunes with Sea-buckthorn (*Hippophae*

rhamnoides) (H2160) (Provincie Noord-Holland, 2018). This area provides a sufficient reference for the final design of the beach and dune area and there exists great potential for the implementation of a dynamic system in which the wind provides constant disturbance which resets succession and can maintain the pioneer vegetation. This type of habitat is desirable, because before mentioned rare species can exist there, and will therefore be beneficial to biodiversity. Similar to the goals of the Delta21 plan, the National park Zuid-Kennemerland also aims toward flood management, recreation and biodiversity (Provincie Noord-Holland, 2018).

5.1.4 Reefs

Biogenic reefs

Biogenic reefs are structures on the seabed that consist of dead or living shells or other hard remains of invertebrates. Reef-building species mainly include shellfish, like oysters, and mussels, but also the sand mason worm (de Smet et al., 2015). This species also forms biogenic reefs, and in 2015, a naturally grown reef was found near the Blokkendam in the Voordelta (Van der Have et al., 2019). These biogenic reefs fall under the Natura2000 habitat 1110B. This habitat type consists of permanently submerged sandbanks. This habitat type already needs to be compensated for in the Voordelta due to the construction of Maasvlakte 2. On a national scale, this habitat type is degraded according to Natura2000 guidelines, which makes it an interesting reef type to consider (Van der Have et al., 2019).

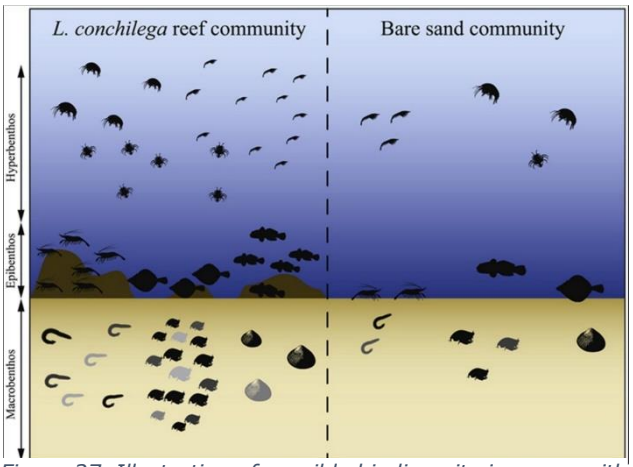

Figure 27. Illustration of possible biodiversity increase with a biogenic reef (with sand mason worms) on the left, and bare sand on the right (de Smet et al., 2015).

Sand mason worms are allogenic and autogenic ecosystem engineers that create sediment reef structures and provide structure on the seabed where especially microbenthic species can find habitat, as well as a refuge (figure 27) (de Smet et al., 2015). Species such as brown shrimp (*Crangon crangon*), and flatfish (*Pleuronectiformes*) were more abundant according to the research done by De Smet et al. (2015). Shellfish also increased in abundance with the presence of a sand mason worm reef. It was also found that positive feedback loops with these species on higher trophic levels occurred in reefs with mainly sand mason worms.

Biogenic reefs in the Voordelta also consist of shellfish beds, with mainly Pacific oysters (*Magallana gigas*), flat oysters and mussels (*Mytilus edulis)*. Like sand mason worms, oysters are ecosystem engineers and biodiversity is found to be higher in oyster reefs in comparison to soft substrate environments (Van der Have et al., 2019). It was found from research on these shellfish reefs in the Voordelta, that the oysters need substrate to grow on, such as empty dead shells, and they need undisturbed sediment. This means that for all biogenic reefs, bottom trawling has a very negative impact (Van der Have et al., 2019).

Hard substrate reefs

According to the study done by ARK (2018) on the effectiveness of different reef substrates, concrete reef domes are associated with an increased biodiversity and are easy to deploy and handle. They are also much cheaper than 3D printed structures. In the study by ARK (2018), different types of substrate were dropped in the Voordelta in different plots. The study mainly focused on the effectiveness of reef-building by the flat oyster and did not find concluding results. However, it was stated that this may be due to several factors including the first establishment of oysters. The concrete structures contained the most size variation in oysters attached to them at the end of the research. This provides us with evidence that these concrete structures do promote flat oyster growth. The structures used in this study were 1m x 1m in size and weighed 800kg (ARK, 2018). The use of 3D artificial concrete structures to build reefs was already widely researched and found to be beneficial to biodiversity by many authors (Clark & Edwards, 1994; Lemoine et al., 2019). It was also mentioned by Lemoine and colleagues (2019) that the 3D structural characteristics of the artificial reef structures should be tailored to the specific environment. In the annual report by Sas

et al. (2017), it was again mentioned that concrete reef dome structures are a feasible option for the Voordelta area (Sas et al., 2017).

Biodegradable reef substrate

Figure 28. Picture of placement of biodegradable BESE elements on mudflats in the Wadden sea (Nitsch et al., 2021).

Reef-forming species need substrate to grow on and develop. Recent research on biodegradable reefs offers a possible alternative for hard substrates like concrete and steel that are usually used in artificial reef-building. Marin-Diaz et al., (2021), stated that one of the main causes of the failure of biogenic reef restoration is because of hydrodynamics and wave action. Using a biodegradable reef as a wave breaker might negate this effect (Marin-Diaz et al., 2021). These reefs can accumulate sediment, and therefore provide a kick-start for different types of shellfish and also sand mason worms to grow on. The experiment by Marin-Diaz and colleagues was, however, performed on semi-submerged tidal flats in the Wadden Sea. It did prove to be able to stabilize sediment and sandbanks which might be still applicable in our Delta21 area. The material that is used mostly for biodegradable reefs is BESE-elements® (Biodegradable EcoSystem Engineering Elements) (figure 28). This material is almost completely able to degrade in roughly 5-7 years. It releases C, P, and N while degrading, but this was to such an extent that it did not have any impact on soil nutrient composition and reef composition. The material was found to promote oyster and shellfish recruitment. A consideration to keep in mind is that it degrades relatively fast and that the reef needs to be stable, and needs to be able to sustain itself by the time the substrate is completely degraded (Nitsch *et al.*, 2021).

Reef species habitat requirements and life-history traits

Currently, two types of reefs can be found in the Voordelta. The first type is shellfish beds, which mainly consist of Pacific and flat oysters and to some extent blue mussels. For the establishment of shellfish beds, some requirements should be met: abiotic circumstances should be suitable, larvae should be present in the area, a substrate for settlement should be sufficiently available and seafloor disturbance should be minimal (Van der Have et al., 2019). Here the requirements and life history for the three mentioned bivalve species are briefly summarised.

Flat oyster

A summary of the habitat requirements and life history traits of the flat oyster (*Ostrea edulis*) is provided (table 3). Flat oysters are found on a wide variety of substrates, as long as it is a hard substrate to which the oyster can attach itself (Perry & Jackson, 2017). Growth rates are usually faster in areas providing shelter from waves, which is mainly attributed to the seston volume; the volume of suspended particles in water (plankton, detritus, minerals etc.) (Valero, 2006). Flat oysters are protandrous hermaphrodites. This means that each oyster starts their life as a male and can switch sex after 3 years (age at maturity). Eggs are fertilised in the gills and mantle cavity and retained within the female individual for 7-10 days, after which the larvae are released into the water (Perry & Jackson, 2017).

Oyster settlement is highly sporadic and spat can suffer mortality of up to 90%, mostly due to abiotic and biotic factors like temperature, food availability, suitable settlement areas, the presence of predators and overexploitation (Cole, 1951; Kennedy & Roberts, 1999; Perry & Jakson, 2017). Environmental cues also play a major role in the settlement of flat oysters. High light intensities and high food concentrations stimulate larval settlement (Bayne, 1969). Moreover, the presence of bacterial chemicals (Fitt et al., 1990) and chemical cues from conspecifics (Bayne, 1969) influence settlement. Oyster larvae have a preference to settle at places where previous larvae have established before, and are therefore considered to be gregarious. Recovery of oyster beds is considered to be very slow. Hard substrate, preferably shells from adults, is required for larval settlement. It might take up to 25 years for a population to re-establish itself after it has disappeared. Flat oysters are sensitive to local temperature and salinity decrease, but more severely to changes in seabed type, removal of hard substrates, disturbances of the substrate, sedimentation and siltation (Perry & Jackson, 2017).

Table 3. Habitat requirements and life history traits of the flat oyster (Perry & Jackson, 2017).

Substrate	Bedrock, cobbles, gravel, boulders, mud, muddy gravel, muddy sand, pebbles
Tidal strength	Weak to very weak (<0.5 m/sec)
Wave exposure	Exposed to very sheltered
Salinity	18-40 ppt
Depth	0-80 m
Reproductive type	Protandrous hermaphrodite (starts as male, shifting sex after maturation)
Reproductive frequency	Annual protracted (breeds every year over an extended or drawn out period)
Fecundity (number of eggs)	>1.000.000
Age at maturity	3 years
Life span	5-10 years
Larval development	Planktotrophic
Duration of larval stage	10-30 days
Larval dispersal potential	>10 km

Blue mussel

Habitat requirements and life history traits of the blue mussel (*Mytilus edulis*) are summarised in table 4. The blue mussel can be very abundant in subtidal areas, but it is primarily an intertidal species, that can withstand extreme wave exposures (Seed & Suchanek, 1992). Life span is highly variable and depends on local habitat associated predation levels (Seed, 1969). Blue mussels are gonochoristic reproducers, meaning that there are both female and male individuals. The mussels reproduce through protracted spawning events in which the eggs are fertilized externally. Unlike the flat oyster, the blue mussel is a lot less susceptible to disturbances. After the removal of a population, mussels are recovering relatively quickly thanks to their high annual recruitment rates (Tyler-Walters, 2008).

Table 4. habitat requirements and life history of the blue mussel (Tyler-Walters, 2008)).

Substrate	Artificial, bedrock, biogenic reef, caves, crevices, boulders, mixed, muddy gravel, muddy sand, rockpools, sandy mud
Tidal strength	Strong to weak (<0.5 - 3 m/sec)
Wave exposure	Very exposed to very sheltered
Salinity	18-40 ppt
Depth	0-10 m
Reproductive type	Gonochoristic (two separate sexes)
Reproductive frequency	Annual protracted (breeds every year over an extended or drawn out period)
Fecundity (number of eggs)	>1.000.000
Generation time	1-2 years
Age at maturity	1-2 years
Life span	Up to 18-24 years
Larval development	Planktotrophic
Duration of larval stage	1-6 months
Larval dispersal potential	>10 km

Pacific oyster

Habitat requirements and the life history of the Pacific oyster are summarised in table 5. The Pacific oyster will attach mostly to hard surfaces in sheltered waters. Like other shellfish, this oyster species can modify ecosystems and is thus considered an effective ecosystem engineer. It provides a substrate for the settlement of benthic fauna, forms new habitats and changes local hydrodynamics and dynamics of nutrients and sediments (Ruesink et al., 2005; Padilla, 2010). Like the flat oyster, pacific oysters start their life as a male and can change sex multiple times. Spawning is dependent on temperature and usually occurs in summer when temperatures are high (16-30 ºC) (Troost, 2010). Pacific oysters are the most fecund oyster species and fertilisation occurs externally (NIMPIS, n.d.).

The Pacific oyster was introduced in the 1960s for aquaculture and is commonly cultured in Dutch waters (Troost, 2010). Nowadays, the Pacific oyster can be found alongside the Dutch North Sea coast, Wadden sea and Delta area, where it is impacting the marine environment. First of all, the Pacific oyster is competing with native species in terms of space and food. It has the ability to overgrow mussel beds (Nehls et al., 2006). Moreover, it has a great filter capacity, and consumes a lot of the available food, but also larvae of other shellfish (Troost, 2010; Wolff & Reise, 2002). Effects are not necessarily negative, the presence of Pacific oysters has been found to facilitate the settlement of other shellfish (Fey et al., 2010; Van der Have et al., 2019). In addition, it provides habitat and shelter to many invertebrate species that are important sources of food for bigger animals, like birds and fish (Van der Have et al., 2019; *Species - Magallana (Crassostrea) gigas.*, n.d.).

Table 5. Habitat requirements and life history traits of the Pacific oyster (Species - Magallana (Crassostrea) gigas., n.d.).

Substrate	Artificial, bedrock, boulder, cobble, shellfish, reef, clay, sand
Wave exposure	Sheltered
Salinity	20-35 ppt
Depth	0-40 m
Reproductive type	Protandrous hermaphrodite (start as male, shifting sex after maturation)
Reproductive frequency	Reproduction usually during summer
Fecundity (number of eggs)	>1.000.000
Age at maturity	1 year
Life span	Up to 30 years
Larval development	Planktotrophic
Duration of larval stage	2-4 weeks
Larval dispersal potential	>10 km

Sand mason worm

The second type of reef is typically characterised by the presence of sand mason worms. Compared to the bivalve species, the sand mason worm is less extensively studied. Therefore, less information is available on this species. The available information has been summarized in table 6. Adult sand mason worms have been observed releasing gametes in June 1991 (Ansell, 1995) and larvae occur from April to October (Kuhl, 1972). The larvae lead a pelagic, planktonic life for up to 60 days, allowing them to spread over great distances. The biggest threats to the sand mason worm are loss of substrate, low temperatures and an increase in wave exposure. After disturbances, sand mason worm populations can recover within a few years. Recovery is considered to be faster in areas where sand mason worms are already present (Ager, 2008).

Table 6. Habitat requirements and life history traits of the sand mason worm (Ager, 2008).

Substrate	Coarse clean sand, fine clean sand, muddy sand, sandy mud
Tidal strength	Strong to very weak (0 - 3 m/sec)
Wave exposure	Moderately exposed to extremely sheltered
Salinity	18-40 ppt
Depth	0-1700 m
Reproductive type	Gonochoristic (two separate sexes)
Larval development	Planktotrophic
Duration of larval stage	1-2 months
Larval dispersal potential	>10 km

5.1.5 Case study reefs Blokkendam

Reference area Blokkendam (figure 29) was chosen to investigate since the area is near the area where the ESL will possibly be in the future and is expected to have relatively similar (a)biotic characteristics. The effectiveness of building a reef is therefore expected to be comparable.

Figure 29. Blokkendam Brouwershaven (Gmelig Meyling, A., n.d.)

In the context of the project "Schelpdierbankherstel" from WNF and Ark Natuurontwikkeling, a shellfish reef of flat oysters was discovered in 2015 at the Blokkendam (near the Brouwersdam) (Van der Have et al., 2019). Moreover, another type of reef, mainly consisting of sand mason worms, was found close by (Rabaut et al., 2009). Since the discovery of the reefs, research and conservation efforts have been conducted on the reefs. They concluded that the reefs mainly consisted of Pacific oysters and flat oysters and to a lesser extent mussels (Sas et al., 2016, 2018a; Didderen et al., 2019a).

A diving team has from 2015 to 2018 researched the shellfish reefs to set up a flat oyster research pilot (Sas et al., 2016, 2018; Didderen et al., 2019b) and to do research on the overall biodiversity (Christianen et al., 2018). Also, video recordings have been made of the seafloor and sonar surveys were conducted to get data on the bottom conditions. Pacific oysters were found on and around the Blokkendam shellfish reef on the rocks but also the soft sediment. Algae and epifauna were found to grow on the oysters. At first, mussels were found to exist in small numbers (Sas et al., 2016), however, numbers increased leading to the formation of an entire mussel reef (Didderen et al., 2019c). Van der Have et al. (2019) concluded that flat oyster larvae have travelled with the tidal current from the Grevelingen towards the Blokkendam, and have in this way managed to settle near the Blokkendam. The flat oysters were found to attach significantly more often on (empty) Pacific oyster shells that were already attached to the stones. From 2015 to 2018, 157 species were observed by the diving team in the Blokkendam shellfish reef and 75% of these species use hard substrates (table 7).

Table 7. Number of species per group found in the Blokkendam shellfish bed.

Species groups	Count
Fish	26
Crustaceans	26
Cnidarians	21
Molluscs	20
Red algae	18
Sea squirts	11
Sponges	11
Bryozoans	6
Bristle worms	5
Brown algae	4
Echinoderms	4
Green algae	4
Comb jellyfish	2
Cord worms	1
Sea squirrels	1

In 2017, of a total of 74 epibenthic species, 60% were found in areas with oysters in comparison to areas with soft substrates (Van der Have et al., 2019). It was concluded that the shellfish reefs had led to higher biodiversity. The highest coverage of *Lanice* reefs was found in areas where the fishing intensity was low. Biogenic reefs in general were not found in areas with high fishing intensity. The shellfish reefs were found in areas where long-term fishing activities were absent.

All in all, Van der Have et al. (2019) concluded that the abiotic factors in the area of the Blokkendam are suitable for the formation of biogenic reefs and that a biogenic reef can form in a soft sediment habitat (Christianen et al., 2018; Didderen et al., 2019; Sas et al., 2016, 2018). Moreover, the quality of both permanently flooded sandbanks (H1110B) and reefs (H1170) may increase because of conservation on the development of biogenic reefs like the *Lanice* reefs and shellfish reefs and can be enhanced the by the absence of fishing activities that impact the seafloor.

5.1.6 Fisheries & aquaculture

Current fishery

In 2008, the land reclamation for Maasvlakte 2 started, to allow the harbour of Rotterdam to grow. Due to this reclamation, 2455 ha of the marine environment has been lost. For the realisation of this plan, rules for nature compensation had been included in legislations and permits. Moreover, the European Commission advised that the nature damage, caused by the construction of Maasvlakte 2, should be compensated for (Prak, 2022). To achieve this goal, a "seabed protection area" (Bodem Beschermings Gebied = BBG) was determined (figure 30). Bottom trawling vessels with a motor capacity higher than 191 KW, which were regularly used for catching flatfish, became forbidden in the BBG.

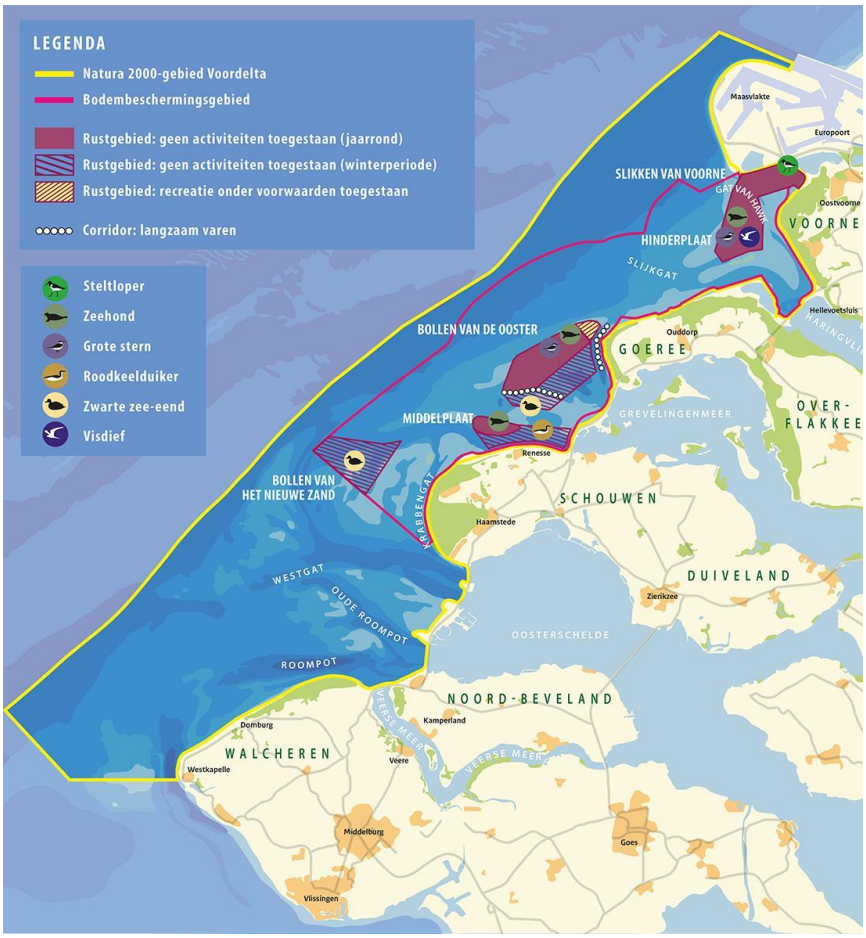

Figure 30. Map of the Natura2000 area "Voordelta" (yellow line) with the BBG (red line) and the "rustgebieden". For each of these areas, the target species are indicated (Rijkswaterstaat, n.d.).

Large bottom trawling vessel activity indeed declined in the BBG and the entire Voordelta. However, after the realisation of this protected area, a simultaneous rise in brown shrimp (*Crangon crangon*) fishery intensity has been observed in the Voordelta, and especially in the BBG (Van der Have et al., 2019). The decline in large bottom trawling and the increase in shrimp fishery vessels is, however, a trend observed in all of the Dutch coastal areas and is probably not related to the realisation of the BBG (Tulp et al., 2018).

Within the BBG there are areas ("rustgebieden") in which activities are generally not allowed. These "rustgebieden" are assigned to provide undisturbed habitat to seals and some typical bird species (figure 30). In some of these areas (Slikken van Voorne, Hinderplaat and part of Bollen van de Ooster and Middelplaat), activities are never allowed, while in the remaining areas (Bollen van het Nieuwe Zand and the remaining parts of Bollen van de Ooster and Middelplaat) activities are only banned during the winter months. In general, fishing activities are not allowed in these areas, but there are a few exceptions (Nederlandse Vissersbond, 2019). Bottom trawling vessel (<191kW) activity is banned from the "rustgebieden", however, two fishers are still allowed to apply this fishing method at the Hinderplaat. Shrimp fisheries are normally not permitted in the "rustgebieden", but at the Middelplaat and near Bollen van de Ooster and Bollen van het Nieuwe Zand fishing for shrimp is allowed in the period from 1 November to 15 December. For the latter two, fishing must take place at a minimal distance of 250m from the tidal sandbanks.

Shrimp fisheries are economically and in number of vessels one of the most important and largest fisheries in the Netherlands and the most prevalent fishing activity in the Voordelta. Similar to large bottom trawling vessels, shrimp fishery vessels have nets or trawls on both sides, which are dragged along the seafloor. The nets of shrimp vessels are less heavy compared to the trawls of flatfish vessels. In addition, rubber bobbins instead of tickler chains are used when fishing for shrimp. These bobbins roll over the seafloor, resulting in a decreased seafloor disturbance (Tulp et al., 2018).

Moreover, there is relatively little bycatch of big fish, thanks to the mandatory use of sieve netting. By applying this method, fish larger than 10 cm. are kept out of the trawls (Prins et al., 2014).

Figure 31. Shrimp fish nets (https://engelnetze.com/en/shrimp-bobbins, n.d.).

Shrimp fisheries are most likely to impact the seafloor and the associated benthic fauna less, than flatfish fisheries. However, the exact effects of shrimp fisheries on marine ecosystems are not known (Tulp et al., 2018). Some studies have been focussing on the effects of shrimp fisheries on Natura2000 areas, but this was particularly difficult as local fishers are usually not willing to cooperate in these studies. Therefore, non-fished areas did not exist and were not available for research. However, some literature can still provide useful insights. In addition, there seems to be a relationship between the shrimp-fishing intensity and the occurrence of biogenic reefs or shellfish banks. Shellfish banks (e.g. Blokkendam) have been found at locations where fishing intensity has been low or even absent, whereas frequently fished areas do generally not contain reefs (Van der Have et al., 2019). It is plausible that under high fishing intensities a few disturbance-tolerant species can thrive, while the absence or low intensity of fishing allows for a more diverse landscape, with higher species richness and evenness.

Sustainable fishing alternatives

To allow biodiversity to improve, the bottom disturbing fishing activities should be cut down. These activities, however, provide a lot of jobs and a large source of income for the local industries. Ideally, more sustainable fishing methods are applied, that do not cause as much disturbance on the seafloor as the current practices. Some options have been explored and are briefly discussed underneath. These methods can be used to target (other) economically attractive species, and will thus still supply local fisheries with a source of income.

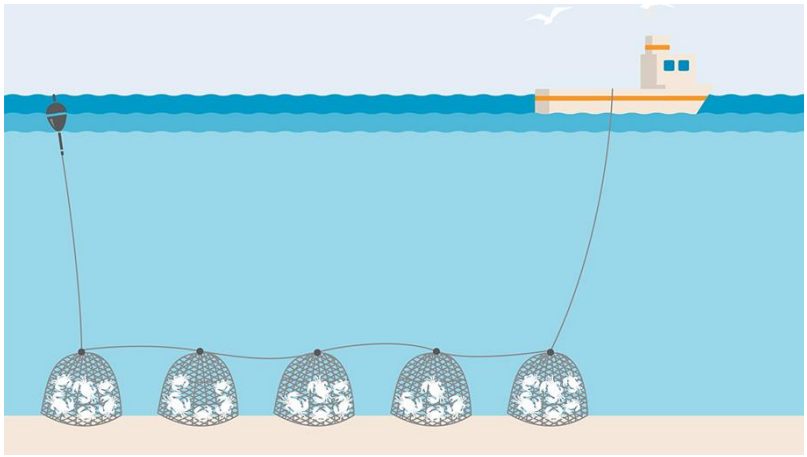

Figure 32. Schematic overview of pot or creel fishing. Retrieved from Marine Stewardship Council (n.d. -c).

Pot and creel fishing

Pots or creels are passive baited traps that attract bottom-dwelling animals like some fish species, but mainly lobster, crabs and molluscs like whelks (figure 32; Petetta et al., 2021). The pots and creels are small enclosures with one or multiple entrances through which the target species can enter, but cannot leave as easily (Pol et al., 2010). The gear is deployed on the seafloor and retained by a vessel after some hours or days (Petetta et al., 2021). On deck, the traps are emptied and non-target species can be discarded back into the sea.

Pot or creel fishing has many advantages compared to other fishing methods. It is a highly selective method with low discard rates (1.6% - 9%) when compared to for instance bottom trawling (up to 90%) (Tsagarakis et al., 2014). This high species and size selectivity are particularly interesting when targeting species with a high commercial value (Brčić et al., 2017), such as lobsters. Usually, specimens caught with the traps are uninjured and command a price increase (Kopp et al., 2020). Simultaneously, unwanted or undersized catches can be released with high chances of survival (Petetta et al., 2021). The obligated release of female individuals of the snow crab (*Chionoecetes opilio*), for instance, has proven to be an effective management measure for this species (Nguyen et al., 2017), indicating the sustainability of this method. Moreover, the traps sit on the seabed and are not dragged along the seafloor like trawls. Therefore, damaging impacts on the seabed habitats are minimised by applying this fishing method (Suuronen et al., 2012).

However, using pots or creels also has its downsides. The traps have reportedly lower capture efficiencies, especially for fish species (Suuronen et al., 2012). Subsequently, pot and creel fisheries cannot be easily combined with fisheries that use active gears like trawls or dredges (Petetta et al., 2021). Pot and creel fisheries generally thrive in areas in which bottom trawling methods are not applied (Macher & Talidec, 2008) and would supposedly benefit from a ban on bottom trawling. Finally, ghost fishing might be a problem. Gear that is lost or abandoned at sea is likely to continue to catch organisms (Petetta et al., 2021). Using biodegradable structures or natural fibres for the pots might provide a solution to this problem, as it would facilitate escape from the traps (Bilkovic et al., 2012).

Pole and line or handline fishing

Pole and line fishing is a method applied to catch large pelagic schooling fish species (figure 33). Water is sprayed from the back of the vessel and small fish baits or chums are scattered onto the water surface to attract a school of the target fish (*Pole and line fishing gear - Marine Stewardship Council, n.d.*). Because of this chumming, the target fish enter a feeding frenzy in which they attack everything they see. Mechanic or hand-held fishing gear with hooks can then be used to bring the fish onto the deck of the vessel. Target species for this method, for example, include mackerel and seabass (*Pole and line, trolling and handline (hooks and lines)* | *Sustain, n.d.*).

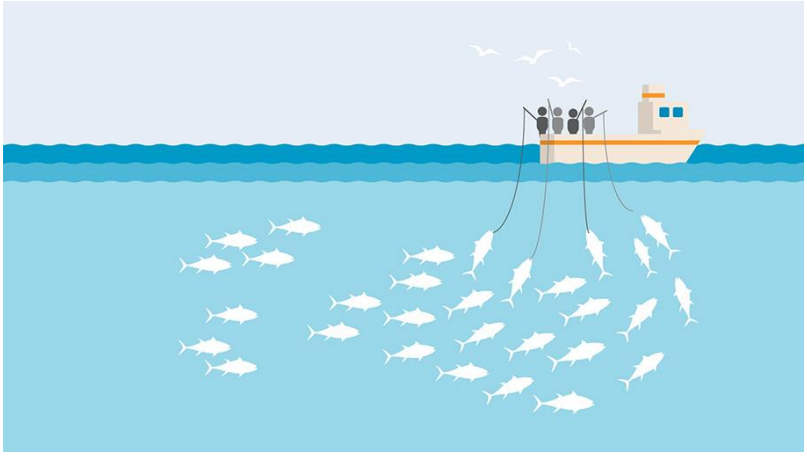

Figure 33. Schematic overview of pole and line fishing. Figure 33. Schematic overview of pole and line fishing (Marine Stewardship Council, n.d -b).

Currently, pole and line fishing methods are mainly used for catching tuna in the Pacific Ocean. Baitfish are required for this fishing method. From the tuna fisheries in the Pacific, it has been concluded that the amount of available baitfish is not sufficient for the desired number of tuna landings (Gillett, 2011). Potential solutions for this problem are the culture of baitfish and transportation of baitfish from other areas. The main problem with baitfish culture and transport is the high added costs to the pole and line methods (Gillett, 2011). Moreover, using non-native species can result in the establishment of that species or the spread of disease, facilitated by the baitfish (Eldredge Noumea, 1994; Gillett, 2011). In addition, pole and line fishing are quite labour intensive.

Despite these disadvantages, pole and line fishing also has some positive sides (*Pole and line, trolling and handline (hooks and lines)* | *Sustain, n.d.*): 1) The fishing gear does not come into contact with the seafloor, minimising the disturbance of the seabed and the associated benthic fauna. 2) Like the pots and creels method, pole and line fishing is a very selective method with little unintentional capture of non-target species. 3) In general, pole and line fishing are small-scale methods using small vessels and are not impactful on the target species stocks in the area.

Longline fishing

In longlining, a long fishing line (up to 10 km offshore) with branch lines containing baited hooks is used for catching both pelagic (mackerel, seabass) and demersal (bottom-dwelling: cod, halibut) fish (figure 34; *Longlining* | *Sustain, n.d.*). Like the previously described fishing methods, longlining is not harmful to the seafloor, the lines are not dragged along the seafloor. In addition, it can be applied as a small-scale method near the coast; small inshore vessels usually have up to 1000 hooks (*Longlining* | *Sustain, n.d.*).

The major problem with longline fishing methods is the unintentional bycatch of non-target animals like birds and sharks (Anderson et al., 2011; Gallagher et al., 2014). These interactions with the non-target species should be mitigated to minimise the destructive effects on the ecosystem. For the seabirds, weighted lines, bird-scaring streamer lines or fishing at night could reduce unintentional capture, and generally, a combination of methods proves to be most effective (Løkkeborg, 2011). In addition, the shape of the hooks can be increased in size and adapted from a J shape to a circle to reduce the bycatch of sharks or rays (Piovano et al., 2010).

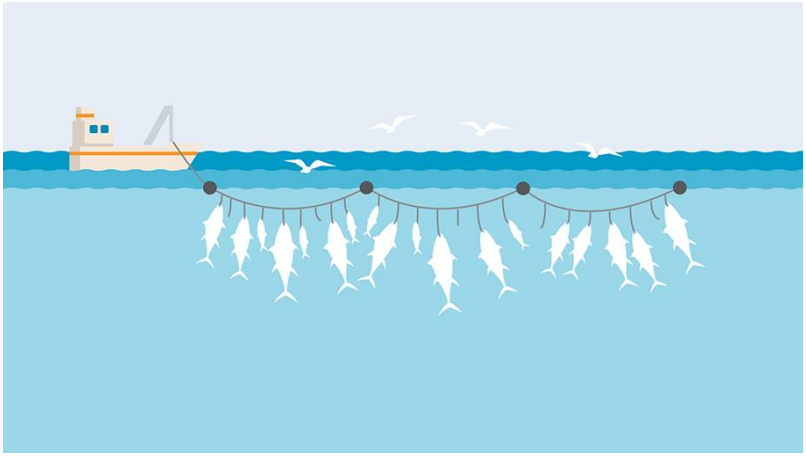

Figure 34. Schematic overview of longlining (Marine Stewardship Council, n.d. -c).

Rope culture Lyme Bay, Devon

Sustainable fisheries can mitigate environmental impacts. To further conserve natural wild populations, aquaculture can provide a solution. An intriguing method is used in Devon, which consists of a rope grown mussel culture (figure 35). This method could potentially be applied in the Voordelta and is described further below.

One of the fastest-growing food sectors is the marine bivalve industry, because of their high nutritional value and taste, but also their positive effects on the environment (Sheenan et al. 2019). The global production of shellfish has increased by up to 89% in 2016 to 16 tonnes/year in comparison with 1950 (FAO, 2018). Apart from the culture providing an important food source, the culture provides other services such as nutrient remediation and coastal defence and acts as a carbon sink (Van der Schatte et al., 2018). The bivalve aquaculture is traditionally executed in inshore areas causing problems in stagnant waters where the accumulation of waste pollutes the seabed and locally decreases biodiversity (McKindsey, 2011).

In the UK, offshore bivalve industry in deeper and more exposed areas has been expanded. Also in China, the US, Canada, France, Japan and New Zealand offshore farms are expanding (Sheenan et al., 2019). Offshore aquaculture is more space-efficient and has a lowers impact on the environment (Lester et al., 2018). The UK is one of the biggest producers in the aquaculture industry in Europe, with the bivalve culture of mussels accounting for the biggest part of the total shellfish production (Hambrey et al, 2016). Rope-grown mussel farming in the UK has been recognized with the highest rating for sustainability by the Marine Conservation Society (MCS, 2018). Partnerships between scientists from the University of Plymouth and the mussel farmers are investigating the benefits of offshore mussel farming concerning food production but also marine biodiversity.

Figure 2. Figure 35. Rope culture mussels (Offshore shellfish, n.d.).

Since 2013 the University of Plymouth has been monitoring the ecosystem effects of the offshore mussel farm in Lyme Bay, Devon on the South coast of England (Sheenan et al, 2019) (figure 36). The farm is owned by Offshore Shellfish Ltd., a family-run business with more than 30 years of experience in mussel farming, with an aim to produce sustainable high-quality seafood offshore (Offshore Shellfish Ltd, n.d.). The farm is located between 4.8 kilometres and 9.6 kilometres off the coast (Sheenan et al, 2019). The farm cultivates the native blue mussel (Sheenan et al, 2019). The larvae settle naturally on special ropes that are hung in the water column. The mussels feed on plankton that live in the water column, so no additional feed is needed for the culture. The farm will be covering 15.4 km^2 of area and is expected to be growing 10.000 tonnes/year of mussel.

The scientists of the University of Plymouth show with observations that the mussel ropes also a lot of other different species like plants and animals that live around the farm or settle on the ropes (Sheenan et al, 2019). The farm is considered to be a species-rich ecosystem and is being compared to a floating reef, sheltering crabs and lobsters that feed on the mussels that fall off the ropes on the seabed.

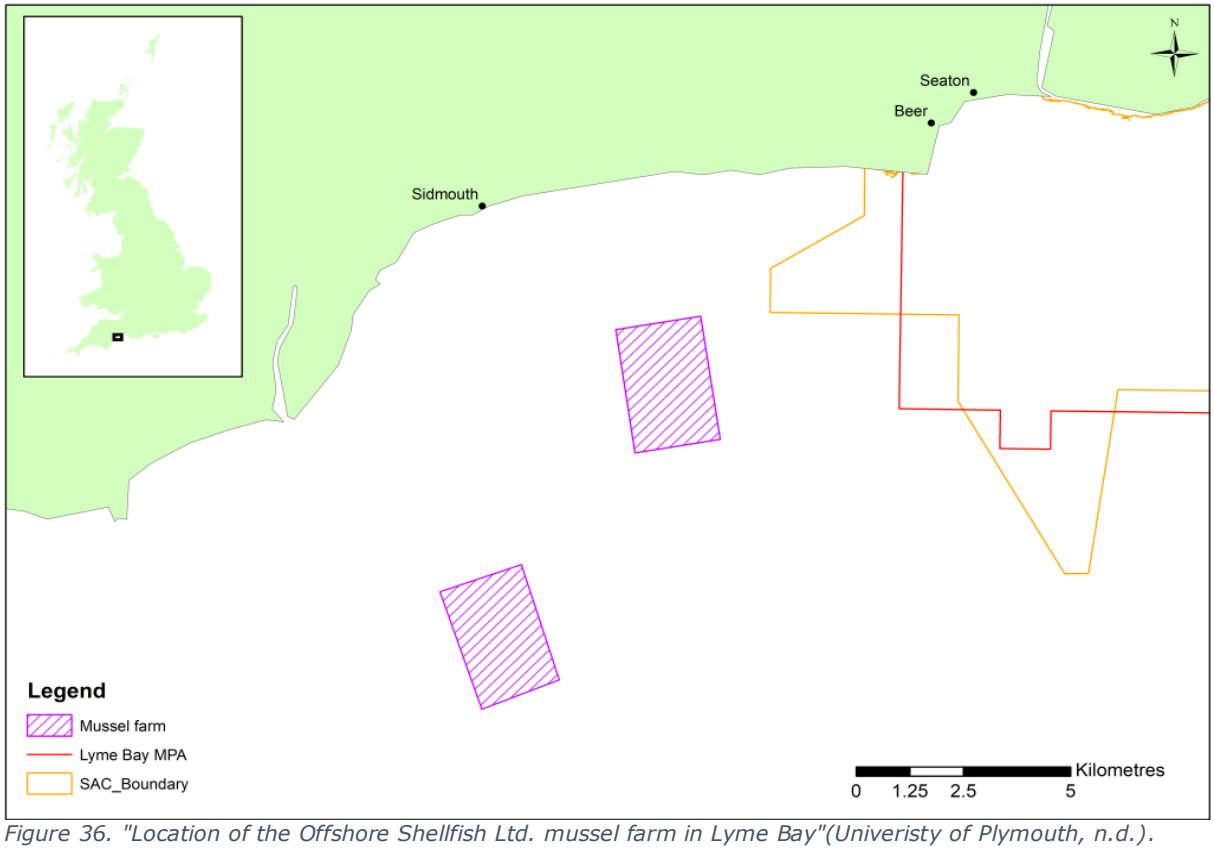

Figure 36. "Location of the Offshore Shellfish Ltd. mussel farm in Lyme Bay"(Univeristy of Plymouth, n.d.).

Next to observations, the farm has been monitored intensively long-term using underwater video techniques, samples of the seabed and visual surveys of seabirds, dolphins and seals. Key findings are:

- Number of mobile predators has increased. The ropes were found to act as fish aggregation devices, attracting large schools of the Atlantic horse mackerel that feed on the mussels.
- Large predatory fish have been observed around the farm (including European bass and Grey Mullet)
- Increasing number of crabs at the farms, feeding on the mussels. The brown crab which is a commercially important species has been observed.
- How these predators move around the farm, or how long they remain present is still unknown.

5.1.7 Recreation

An important part of the realization of the Delta21 plan will be recreation in the Delta21 area. Due to the focus of our project on the possibilities for biodiversity in the Delta21 plan, we would suggest exploring the options for ecotourism in the Delta21 area. Ecotourism is defined as "the responsible travel to natural areas that conserves the environment, sustains the well-being of the local people, and creates knowledge and understanding through interpretation and education of all involved" (Global Ecotourism Network, 2016). The combination of nature development and ecotourism could be realised in the beach area on the western side of the energy storage lake.

5.2 Expertise stakeholders & experts

In total six people were interviewed, four experts and two stakeholders (table 8). Some stakeholders we requested to participate in this study did not respond, including the fisheries, recreation sector and nature management organisations and are therefore not represented in our research.

Table 8. Overview of the interviews, summarized.

Expert	Function	Expertise
Klaas Timmermans	Senior scientist and head of department Estuarine and Delta systems (NIOZ-Yerseke)	Expertise on seaweed and also biological oceonography
John Holmyard	Owner of family company that has been in the mussel and seafood industry for over 30 years (Offshore shellfish)	Expertise on rope grown mussels
Martin Baptist	Senior scientist in marine ecology at the Wageningen University	Expertise on hydraulic engineering, flood safety, nature conservation, interaction between infrastructural works and ecology
Valerie Reijers	Assistant professor and coastal ecologyist at the University of Utrecht	Expertise on dune building and coastal erosion
Stakeholder		
Tea Both	Councilwoman Goeree-Overflakkee	Can state council opinions as well as give information on locals, fisheries, and nature organisations
Lies van der Pol	Councilwoman municipality Westvoorne	Can state council opinions as well as give information on locals, fisheries, and nature organisations. Knows about problems in the Voordelta and the process of stakeholders assessment

Klaas Timmermans

The interview with Klaas Timmermans taught us primarily about reefs and aquaculture The biggest advice Klaas Timmermans has given is to decide on what are we going to do. Is it going to be for tourism and tidal energy? Is it for tidal energy and aquaculture? Because if we want to combine all functions he is afraid that we will end up with nothing because it is simply a little bit of everything and not worthwhile for anyone to step into. To increase biodiversity Mr. Timmermans mentions that it is good to have all kinds of different landscapes, such as dunes, marshes and underwater structures for all kinds of organisms to establish themselves. However, as described in his advice, he states to take into consideration that these goals might conflict with tourists (or other stakeholders) and to combine it all would be rather complicated.

Reefs

He explains not to be an expert on reefs, however, he thinks that there are many opportunities to implement a reef for higher biodiversity. In the North Sea, windmill farms and all kinds of structures are being placed on the seafloor and that is attractive for all kinds of organisms to establish. It's also attractive for commercial purposes. However, a reef could also conflict with other functions such as swimming or sailing. He mentions thinking about the question of whether the carrying capacity will be enough for sustaining the reef with large populations of for example mussels and oysters. He taught us about biodegradable reefs. They are made of some sort of starch and when organisms have established themselves, the structure will dissolve which will make the reef more or less natural. The structure could give a reef a kickstart since the phase of establishment is the most difficult one.

Aquaculture

When asked about incorporating seaweed culture in the design of the area Klaas Timmermans mentions that in principle it is possible and that there are already quite some plans in the region. However, the freshwater discharge from the rivers makes the water around the lake not 100% salty, which could limit the species of seaweed you want to cultivate.

By increasing biodiversity, Klaas Timmermans mentions that it can perhaps be possible to harvest that biodiversity. He is involved with an initiative in the Voordelta where there will be co-cultivations of mussels and seaweeds. The mussel culture will also be done with ropes. He states that it is not easy to anchor all those structures. So, if our main aim is to work on biodiversity, we should work on structures on the seafloor and not so much hang them from the surface down. But if companies are interested and see it as an attractive root, he sees no reason why not to try it. He expects the rope mussel culture to attract organisms, but the effect on the seafloor will be much larger. The combination of the rope mussel culture and a reef could be very efficient because you can have the same ship go there and service/monitor it. However, by making it more complicated, more problems can arise. He mentions that lobsters are in high demand and can grow in reefs and we could think of harvesting and selling them.

John Holmyard

The interview with Mr. Holmyard was especially focussed on rope grown mussel aquaculture. The farm is located on the South-coast of England, 7-10km away from the shore. The method used in the farm is called the longline system. At the moment, the system is semi-submerged, with some floats on the surface, but most equipment below the surface. The main species used in the farm is the mussel. When mussels reach the right size, they collect them from the ropes and put them back on the farm where there are lower densities. The harvest cycle they use is that they reseed in August when the mussels are 3-4 months old. Then one year later they are ready in August. As for the environmental requirements, the lines they operate are around 20-30 meters long. Mr. Holmyard told us that big waves are a problem for a farm, and in shallow waters in an exposed location, waves get bigger. Other requirements are sufficient food availability for the mussels, and enough flow of water to deliver the food to the mussels. The farm uses vertical, long, and narrow floats that allow them to operate in rough conditions. The size of a farm needs to be tailored to market demand. Predators do not form a big problem right now but could be in the future. The main predators are starfish, mussel-eating fish (Gilthead bream), Eider ducks and Golden eyed ducks. Some of these species could potentially be more problematic. From Mr. Holmyards point of view, the farm has a positive effect on the environment, mainly because of higher biodiversity in and around the farm. This was proven by a study from the University of Plymouth. Specific species that benefit from the mussel cultures are, according to Mr. Holmyard, brown crab and lobsters. Schooling fish like mackerel, horse mackerel, whiting, and pouting are spotted regularly. These species either feed on the detritus that falls to the bottom or directly from the ropes. A study was done on the movements of fish between the farm and estuaries, and it became clear that the fish travel back and forth and use the farm as a foraging area.

Mr. Holmyard thinks that combining a reef and rope culture system is possible to create, as it is now already happening with mussels falling from the ropes and settling on the seabed. These colonies under the ropes also attract lots of different species. Big, hard structures under the farm may not be advisable because they might disrupt the water flow, but designing a reef system could be possible. Mr. Holmyard was quite clear that it's important to talk to fishers about their ideas and to not get into an argument with them. Fishers mostly benefit from the farm because there are more fish around the farm, and the fish are generally fatter, from feeding on the mussels. There are a lot of animals such as worms and amphipods on the ropes as well.

Martin Baptist

The interview with Martin Baptist taught us in summary about oyster and mussel reefs, some important target species, dunes, and aquaculture in the Voordelta.

Reefs

Martin Baptist explained that the structure of oyster reefs is more resistant to waves than mussel reefs by taking away wave energy. However, he stated that for coastal safety you need a string of measures. Next to a reef, you would also need a dune or dyke. For coastal protection he mentioned choosing oyster reefs, however, for birds, he mentions mussel reefs to be a better option. He explained that mussel beds are more valuable to birds than oyster reefs because the mussels can be eaten by a variety of birds such as the Eider duck and Oystercatcher. Both oyster and mussel beds form substrate and habitat for many other species. Mussel beds enrich the sediment, leading to different benthic diversity, which is more attractive for birds in comparison to the oyster reef. He also mentioned that shellfish reefs are not quite abundant in the Voordelta, because of the high dynamics of waves, and the sediment is too sandy. Reefs do exist in the Voordelta, but more in sheltered parts. Natural hard substrates in the Voordelta could be peat, wood, shells, and flat oyster for organisms to attach themselves to. The Voordelta has naturally a sandy environment and shore with some remnants of hard substrate, and some sheltered pockets for oysters to live. For the energy lake, he mentions that creating sheltered places, where habitat conditions are suitable for shellfish reefs could be possible. He taught us that by providing a substrate, species can attach themselves and biodiversity will fill in for itself. It could however be interesting to think of ways of luring species towards these structures or planting species artificially. Currently, you have reef blocks and open structures to build reefs. To facilitate (multiple) species to an area he advises diving into the specifics of the requirements of the species. He states the philosophical choice we need to make with this project. Do we want the most natural situation or an artificially high biodiverse situation? He raises the question of what the biodiversity gain would be from placing an artificial hard substrate to build reefs in a soft substrate environment.

Target species: Fish
Martin Baptist explained that the eel does occur in the Voordelta, but only for its migrating route and that we cannot do a lot for that species in the area. The fint is also a migratory fish. The Voordelta is according to him not suitable for this species, however, it would be interesting to him to improve the Haringvliet area locally for it.

Target species: Marine mammals
Mr. Baptist told us that the harbour porpoise is mostly an offshore species, but occurs along the coast in spring to forage on schools of fish like herring that are present at that time. Except for providing quiet conditions with no boating and fishing, and providing interesting habitats for the fish they forage on, there is not a lot you can do for this species along the coast he states. The seal is a coastal species, that uses a central place like sandbanks to rest. From there they forage for fish. He mentions the Voordelta to be a good habitat for seals, because of its undisturbed sandbanks. Grey seals are known to hunt for porpoises. When he was asked about creating an artificial floating platform he stated that the artificial structures for seals to rest on could work, however, the Habitat Directive will not allow changing the tidal sandbanks into marshes or an energy lake. The EU will find it ridiculous to take away sandbanks and replace them with artificial floating structures. This is not what protecting a nature conservation area entails. Also, the platforms can break or sink and leave plastic in the environment. Creating sandbanks is a cheaper, more nature-friendly solution.

Aquaculture
Martin mentions that the rope cultures are also applied in the Oosterschelde and the Wadden Sea and that sheltered conditions for it are needed. He mentions that in the Voordelta the conditions can be quite rough, but that there are some sheltered areas. However, legally it would be a problem to implement aquaculture in a nature reserve and the effects should be studied. He mentions that biodiversity is not only about species numbers, especially in nature conservation it's about protecting what is there naturally. So he can see that mussel farmers see an opportunity but he explains that from a legal perspective it will be difficult to practice aquaculture inside the nature reserve.

Dunes
When asked about the opportunities for creating a new dune area next to the ESL he mentions that a newly developed dune does not have rare or special plants, that there are only a few species in the embryonic stage (Biestewaregras and Zeeraket). In the Netherlands, he mentions, we create hills with marram grass (second species succession stage) and call it dunes. A valuable dune system takes a long time but is valuable. About half of the protected plant species occur in dunes. He explains that the Voornes Duin is one of the best dunes there is and that the ESL in front is probably not good for the dune system. The ESL would take away wave action and salt spray needed for rejuvenation of the dune vegetation. Explaining that this is another problem in getting the license for the lake.

Tea Both
The main takeaway from the interview with councilwoman Tea Both, was that the municipalities surrounding the Voordelta and the Delta21 area, do not see a necessity in realizing the Delta21 plan, and are very critical of it. During the interview, it became clear that Mrs. Both was still under the impression that the Kierbesluit was still part of the Delta21 plan. However, this was recently adapted. The Haringvliet will stay closed for the majority of the year (Source: personal communication Delta21). Mrs. Both also mentioned that they do not view the ecosystem in the Voordelta as degraded. This was based on personal opinions and general opinions of locals and tourists. Tourists and locals are focused on recreation and the beach. The beach has won a prize for sustainability, and it is generally viewed by locals and municipalities as their unique selling point. Mrs. Both stated that she thinks tourists and locals see enough biodiversity and do not see any concerns regarding the ecological state of the Voordelta. Moreover, in her viewpoint, fishermen are open to sustainable fisheries, especially younger fishermen. However, many of them are still traditional fishers and are not happy with the limitations that will come with the Delta21 plan to the area where they are still allowed to fish shrimp.

Valerie Reijers
Valerie Reijers explained that she was familiar with the plan to some extent, but that she mostly works in the Wadden Sea. She mentioned doing dune surveys to see how a dune should be developed to get the desired biodiversity. The problem with the Oostvoorne beach is the coastal squeeze resulting in a more narrow beach. She stated that the implementation of the plan would cause natural dynamics (erosion & sedimentation) present at the beaches of Oostvoorne and Rockanje to decrease and that these dynamics are very important for the natural functioning of the dunes. Depending on

the management, the ESL could be catastrophic or an opportunity. She sees the moving of the Hinderplaat not as a threat but as a natural process with opportunities as well.

To create a new dune area she mentions considering the space needed to do so and the type of dune (dimensions) we want to develop since they have different characteristics. The higher the dunes the wider the beach needs to be because of aeolian transport of sand. According to Mrs. Reijers, identifying bottlenecks when building a new dune system is of utmost importance. Measures of the beach and the material being used is very important. To create a dune similar to the one in Oostvoorne, she mentions it will not be possible since the dunes have been developing since the Holocene. An embryonic dune is more feasible and it is possible for a dune to stay in the embryonic state and not develop further into a larger dune.

Sand coach, *Ammophila*, Sea rocket and *Leymus arenarius* are mentioned as important species for embryonic dunes. However, she is in favour of letting the dune develop naturally instead of giving it a kickstart by planting vegetation. The first stage of the dunes (bare and flat) could be optimal for tern species. The habitat however would not be optimal for the Dunlin (*Calidris alpina)* which needs some vegetation. Leaving the dune natural (not planting any vegetation) makes it possible for the dune to develop into a larger dune.

Another bottleneck mentioned is nitrogen deposition leading worldwide to making dunes too grassy and with too much vegetation there are no natural dynamics. The development of a dune is also dependent on chance (number of storms for example).

Lies van der Pol

The main takeaway from the interview with councilwoman (municipality Westvoorne) Lies van der Pol is that the municipality is in cooperation with a lot of stakeholders to come up with solutions concerning upcoming sand which is changing the coastal area and that the Delta21 plan is disturbing these processes. Mrs van der Pol mentions that the people within the municipality are very concerned about the sedimentation problem and that for them it is hard to see the distinction between the work of the municipality ("with great care and involvement") and the "beautiful pictures" Delta21 comes up with. The municipality is working on a design for the area by balancing out different values and interests including nature water safety, tourism, fisheries etc. At the moment they are trying to make a shared vision for the area with shared ambitions. She mentions it being hard to balance all the interests and to get people to cooperate and nature preservation parties are very disappointed with the national government and the compensation of the Maasvlakte 2 is lacking. The lack of promised nature compensation has led to big disappointments and to be able to have a structural and constructive conversation about the future is therefore hard. Lies van der Pol sees big opportunities to make the Voordelta more interesting for nature, however, the approach of Delta21 she considers disturbing. To conclude the municipality believes that they are creating a plan for the area together with society to make a feasible plan and the Delta21 plan is just a personal dream with the rendering of beautiful pictures.

6. Discussion & conclusion

From the results, it can be concluded that opportunities exist to improve the biodiversity in the area of the Voordelta around the energy lake. From the literature research and expert-and stakeholder interviews implications of building a biogenic reef, practise sustainable aquaculture and developing a dune area seem possible, however, the fact that multiple stakeholders are opposed to the plan or have a lack of trust that nature will be compensated should be considered with the utmost importance.

6.1 Discussion

6.1.1 Dunes

The advice about the dunes in the Delta21 area is to a lesser extent related to the opportunities for biodiversity. In our report, we mainly focused on the realisation of the dune design of Van Eeden. The current design of Van Eeden appeared to be ecologically quite difficult to realise.

Firstly, to design a dune area and reef structures on the western side of the energy storage lake it is essential to first assess the future morphology of the area. These habitats require certain conditions related to morphological dynamics. One prerequisite for embryonic dunes is that the rate of sedimentation should be greater than the rate of erosion (Smits et al., n.d.). In this way, it allows succession on the older embryonic dunes but also younger embryonic dunes to develop on newly

established land. When the rate of erosion is greater, then more beach and dune areas are being eroded, leading to a decrease in area on which embryonic dunes can develop; meanwhile, succession could still occur on the older embryonic dunes which further decreases the area of embryonic dunes. Therefore, it is necessary to first understand potential morphological dynamics.

Currently, there is a lack of data on morphological dynamics for the Delta21 situation. On the seaside, Van Eeden expects erosion to occur especially near the exit of the pumping station and the storm surge barrier. Sedimentation is expected to occur on the northern part of the northwestern beach area (figure 37). However, sedimentation processes are very dynamic and show different patterns (Van Eeden, 2021). Van Eeden only uses global predictions on the hydrodynamics and she did not model future morphological processes. Although these dominant flows of water would probably remain in the area, detailed sedimentation patterns are not yet known. Therefore, there are still great uncertainties in future morphological dynamics in the Delta21 area which is essential to know for the creation of a dune area.

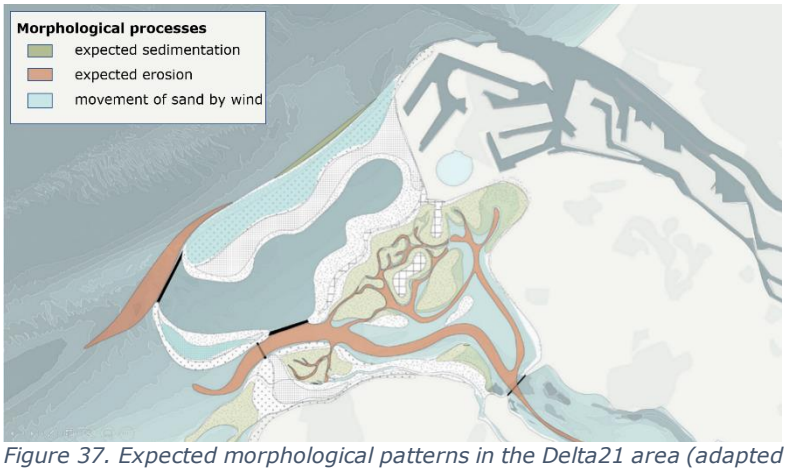

Figure 37. Expected morphological patterns in the Delta21 area (adapted from van Eeden, 2021).

6.1.2 Reefs

As mentioned above, a reef could increase biodiversity in the area of the ESL. The damaged seafloor by fisheries has left a sandy soft substrate, which has significantly lower biodiversity than reefs. As was argued by one of the interviewees, this is not necessarily problematic, because species related to soft substrate also hold their place in a food web. However, some of these soft substrate species, such as the sand mason worm, are currently also affected by disturbance of shrimp bottom trawling activities. Due to less disturbance, the Blokkendam reef developed spontaneously, showing the opportunities for biodiversity within reef development in the Voordelta.

A reef structure underneath the rope cultures is advised, to initiate the development of a biogenic reef. Living and empty shells like oysters, mussels, and cockles can be placed on the seafloor as substrate and the mussel clumps falling from the ropes could add to the development of the biogenic reef. Hard substrates like concrete domes are found to provide suitable substrates for a mixed shellfish reef (Ark, 2018). As mentioned before, lobsters find refuge and forage in the reef and could be harvested sustainably with pots and creels. The reef attracts fish, which can be beneficial as well for the porpoise and harbour seal.

It should be considered that the Voordelta currently has a soft substrate environment with species related to these characteristics. Martin Baptist mentioned that a reef providing a hard substrate would increase biodiversity, but that it would substitute the soft substrate species already living there. Therefore, a balance must be found between creating reefs and adding hard substrate and keeping the natural, soft substrate, environment as it is now. The development of a sand mason worm reef, a *Lanice* reef, could still increase biodiversity and keep the natural soft substrate environment. These reefs will provide forage and nursery areas for fish, and will attract predators important for a healthy food web. For reefs to develop in the Voordelta, it is of crucial importance that the bottom is no longer disturbed by (shrimp) fishing activities. Therefore, regulations to manage this area should be put in place. As mentioned by multiple experts and stakeholders, this process will be very difficult, as it is hard to get a dialogue between fishers, scientists and political parties. Therefore, future research should also focus on the governance part of this plan.

6.1.3 Fisheries

The reinforcement of the Delta21 plan will result in (shrimp) fisheries losing fishing grounds. Hanging rope mussel culture could be a sustainable aquaculture method to substitute the damaging shrimp fisheries in the Voordelta. The culture does not damage the seafloor, does not need food, and competition for space on land forms no problem. Also, mussel clumps that fall off create a habitat on the seafloor for crustaceans. Using pots and creels, lobsters and crabs could potentially be harvested

in a habitat-safe way. The increased fish species are hypothesized to create foraging areas for the harbour seal and the harbour porpoise.

The fact remains that current fishers might not be willing or do not have the knowledge or capital to change their current fishery practices to more sustainable methods. The methods mentioned would mean that the fishers have to switch their focus to other species, since the pole and line fishing, trolling, handline, landline and rope cultures do not result in the same species and the same volume caught with bottom trawling methods. However, the pots and creels methods are applicable to catch shrimp without dredging the bottom (Petetta et al., 2021). Also, as mentioned by John Holmyard, a big boat is needed for a successful rope culture and this can financially be less accessible to small fisheries. Financially compensating fishers could be a solution to make the transition towards sustainable aquaculture more attractive. A downside to the floating reefs might be that organisms feeding on the mussels could potentially decrease yield. The common eider, for example, one of our target species, is estimated to eat 0.5-2.5 kilograms of mussel a day, and therefore could cause a major change in the abundance of the mussels (Hario & Öst 2002; Baltic Mussel Eco, 2003).

6.1.4 Stakeholders & expert opinions

From our stakeholder- and expert interviews we can conclude that the opinions on the implementation of the Delta21 are very diverse. The difficulties expected concerning the legislation of the plan was mentioned by Martin Baptist because the Voordelta is an area protected by the highest European standards (Habitat directive). In his opinion, it would be best for nature to let it run its course and do nothing. He raised the question to think about what is more valuable: Intervene and increase biodiversity (artificially) or have lower biodiversity with keeping the natural environment?

Moreover, a lot of resistance from stakeholders (in this case Municipalities in the Voordelta) exists towards the Delta21 plan. Tea Both (councilwoman Goeree-Overflakee) spoke for instance on the fear of losing (part of) the fishing industry, which is the biggest sector providing livelihoods for the people of Goerree-Overflakkee, as a result of the implementation of the plan. Also, anger and mistrust resulted from the lack of promised nature compensation for the implementation of the Maasvlakte 2 in 2008. Lies van der Pol (municipality Oostvoorne) has long-term plans to get every stakeholder together to form plans to increase biodiversity in the Voordelta. She mentioned that Delta21 was very disturbing for this process. Valerie Reijers from Utrecht University stated that, depending on management, the plan could either create possibilities or be catastrophic for the Voordelta. On the other hand, opportunities to increase biodiversity by implementing reefs and sustainable aquaculture are seen by Klaas Timmermans and John Holmyard. To be able to create opportunities for the Voordelta by implementing the Delta21plan is of essence to research how to get stakeholders together and how to manage the area adequately. To be able to implement the plan, community building is necessary to gain trust, listen to stakeholders' opinions and implement their wishes.

Another aspect that should be considered is that fewer stakeholders responded to participate in interviews than anticipated beforehand. No stakeholder was interviewed from the recreation sector, the fishing industry, and nature organisations, which could have given more valuable insights into the current state of the fisheries, the wishes for leisure and management objectives for the area.

6.2 Conclusion

All in all, creating biogenic or biodegradable reefs, embryonic dunes and practising sustainable fisheries with rope mussel cultures, could provide opportunities for the Voordelta to increase biodiversity with the implementation of the Delta21 plan. Due to conflicting opinions of stakeholders and experts, research on how to manage and legislate the plan is of the essence. Furthermore, research should be done to assess the future morphology of the area.

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Appendices

Appendix 1: Deductive coding for transcriptions

Table 9. Overview of the deductive coding for the transcriptions of the interviews. The (sub)nodes with description with each a colour.

Node	Sub-node	Description/ condition of sub-node
Target species	Marine mammal	References related to the species, habitat, ecology, behaviour, and diet of marine mammals in the Voordelta.
	Bird	References related to the species, habitat, ecology, behaviour, and diet of birds in the Voordelta.
	Shellfish	References related to the species, aquaculture, habitat, ecology, behaviour, and diet of shellfish in the Voordelta.
	Crustaceans	References related to the species, aquaculture, habitat, ecology, behaviour, and diet of crustaceans in the Voordelta.
	Plant	References related to the species, habitat and ecology of plants in the Voordelta.
	(migratory) Fish	References related to the species, habitat, ecology, behaviour, and diet of (migratory) fish in the Voordelta.
Reef	Coastal protection	References about the coastal protection characteristics of artificial reefs.
	Biodiversity	References related to the biodiversity at artificial reefs.
	Motivation	References about the motivation of stakeholders on artificial reefs.
	Preferences	References about the preferences of stakeholders in the design of artificial reefs.
	Type of reef	References related to the type of reef: biogenic or artificial
Dune or sandbanks	Biodiversity	References about species that exist in dune areas, or could exist there.
	Ecology	References about the ecology of existing dune areas or future dune areas.
	Recreation	References about recreation in the dunes. Or possible recreation in future dune areas.
Stakeholders	Fisheries	References about fisheries in the area.
	Locals	References about the opinions and behaviours of local people around the Delta21 area.
	Tourism	Reference
	Nature management	References about the managers of the natura areas in the Voordelta. (Staatsbosbeheer, Natuurmonumenten, Rijkswaterstaat, etc.)
	Scientists/experts	References about the opinions on the Delta21 plan of experts/scientists
Aquaculture	Aquaculture farm	References related to the practice of, and the species, reefs, systems, used in aquaculture
Water management/flood protection		References to water management and/or flood protection and the Delta Works

Appendix 2: Transcription interviews

2.1 Interview Klaas Timmermans – NIOZ

T: **Are you familiar with the Delta21 plan?**

I: Not really, I heard about it, but I do not know all the details.

T**: Do you want us to explain it a bit?**

I: Yes, please, please

T: Basically, what they (Delta21) want is to build an energy lake in the Voordelta just underneath Maasvlakte II. Their (Delta21) main goal was to help prevent floods and later, they also incorporated the idea to use it as an energy storage lake, they want to store energy in it… I guess with windmills

T: No, the idea is that during high tide energy can be stored there (in the lake). So that is also one of the aims of the project. We want to look into ways to enhance biodiversity in the area. This (Esmee her design is shown) is now a preliminary design, in which they integrated a marsh area, the energy lake and also a new beach area. This (marsh area + energy lake) has all been worked out already and Delta21 asked us to further look into creating new opportunities for biodiversity in the area. So, we are focussing on the dune region at the North of the lake, but also into the sea area. And we want to see if there are any opportunities to improve the biodiversity in the area and therefore we were wondering if you have any good input for us. We just finished the proposal and now we are looking into the possibilities of how we can improve the biodiversity and to see if we can have some nice inputs from other experts but also stakeholders. In these few weeks we are conducting several interviews with several people. And actually, you are the first one we have this week. So we are really curious to see what your thoughts are and we prepared some questions and they are mainly based on artificial reefs.

T: So perhaps we can start with the first question. **We were curious what you think would be the perfect situation for the Voordelta, what should it look like in your opinion? How can the ecological state (of the Voordelta) be improved?**

I: Ahh, that is a difficult one. Well, first of all, my expertise is, I'm a marine ecologist. I specialise in ecophysiology of seaweeds, but I am also head of the department Estuarine and Delta Systems at NIOZ, the Netherlands Institute for Sea Research in Yerseke. So, I am very familiar with the delta and if you look at this initiative. Then the parallel between all the bassins that have been enclosed during the Deltawerken is really remarkable, so Haringvliet, Grevelingen, Oosterschelde, they all have been dammed completely, or storm surge barrier. One of the major lessons learned from the Deltawerken is yes, they brought us safety in the end. It's the safest delta in the world, but also it brought with it a lot of problems because large stagnant bodies of water were created with all kinds of consequences. This is situated in front of Haringvliet. As you know, Haringvliet is now, where they are opening the Haringvliet dam in order to let in some salt water. But also the Grevelingen stagnant water body is characterised by large periods during the year when it's anoxic in the deeper layers, which is not a desired condition. One of the issues that I see is that in plans like this is that again. An enormous artificial basin is being created, well, apart from the fact that it is completely man-made and it will also have problems associated with, for example, sedimentation. So either spots where sediments are being removed which is happening in the Oosterschelde → sand hunger. Or what is normally happening is that more sediments are brought into the system than is being exported. So, before you know what you need to dredge in order to maintain it in a certain form. So I think it will not only need a lot of labour to maintain it in the condition it already is. Furthermore, a plan like this is far from new. For example, the Plan Lievense in mid-last century I think in the IJsselmeer where they had exactly the same plan or in the North Sea. So, to some extent, this is really something that has been around in the past. I wonder whether this way of tidal energy is the most efficient way, also the most cost-efficient way, to do it. Of course, tidal energy has been generated at several locations. In the Southwest delta. I have not seen the business case, but I can imagine there are some issues with that.

T: Like, because they are planning to build this (Delta21) in this Natura2000 area. They (Delta21) asked us for help to kind of overcompensate for the loss of the area where we would like to improve the ecological state of the rest of the area. **Therefore, our question was how do you think we can do that. How do you see an ideal situation?**

I: I don't know if an ideal situation will ever exist. But it is clear that if you want to work on biodiversity. It is good to have all kinds of different landscapes. So, from dunes to marshes, but also underwater structures that are really attractive for all kinds of organisms to establish themselves. But always take into consideration that there might be a conflict with tourists or people that want to go there on a nice sunny day so in order to combine it, it will be rather complicated, I am afraid. So, think for example about the problems that we have with the "Zandmotor" close to The Hague where this enormous amount of sand was nourished at the beach and an artificial lake was created and during the summer, lots of people get into problems because they want to swim there. Current

velocities of more than a meter per second, the baywatchers have their hands full of rescuing people that are being flushed out to sea, so yes, it is always wonderful to combine different functions, we want to work on biodiversity, we want to be attractive to people to go there during their holidays. In practice, it is rather complicated to combine all of this and that is the same idea that I have of this plan, more or less.

T: Ok, we were thinking of implementing reef structures into the Voordelta to kind of achieve a higher biodiversity. **What do you think the opportunities or the problems could be for reef structures? How can we do this actually?**

I: I think there are many opportunities there. I am personally not an expert, but colleagues of mine have run several projects not only in the Southwestly delta, but also in the North Sea for example in windmill farms where they have all kinds of structures being placed on the seafloor and that is really attractive for all kinds of organisms to establish themselves even for commercial purposes, think of oysters, mussels, but even lobsters. So I think there are plenty of opportunities. However, it will be hard to combine all the other things that you want to have. As soon as there are underwater structures, it is less attractive for sailing or swimming et cetera. Again, there might be a conflict of functions.

T: So indeed, that is something that we have to keep in mind when we want to talk to oher stakeholders. To see how we can come up with other solutions.

I: And the question of course is, will the carrying capacity be enough for sustaining large populations. Of course you can have large reefs there and have mussels and oysters. But is there enough food for these organisms to feed upon and I really have no idea, of course there are limits to that.

T: Then we also found in literature that there are biogenic reefs or artificial reefs. **Would it be a difference if we aim for one or the other?**

I: Normally, we have a lot of experience with reefs that in time dissolve. They are made of some sort of starch. In the beginning they are there but after some time they simply dissolve and as soon as the organisms have established themselves, the reefs will be more or less natural. There are different ways of dealing with that. If you look up some literature there are quite some structures that have those characteristics.

T: So, basically to give a kick-start to….

I: Exactly, exactly. The phase of establishment is the difficult one. As soon as organisms have established themselves somewhere where they can survive. But the initial phase is often the most difficult one. So, if you give them a kick-start, that helps.

T: We also look into incorporating sustainable fisheries or aquaculture. **Do you have any ideas about that? With your specialisation in seaweed culture, can we incorporate that as well with the reef?**

I: In principle, it is possible, there are actually already quite some plans in the region where it is drawn now there is already seaweed cultivation. The issue there is that the water in front of the Haringvliet is rather brackish; about 70% of all the Dutch freshwater from the rivers is being discharged via the Haringvliet. So it is not really salt water, but more brackish. So, not really attractive for all kinds of seaweed species. So I can see a problem there as well, because now it (freshwater from rivers) would go a bit further but still be drawn in this artificial lake. So there are not really salt conditions, that puts a limit on the species of seaweed that you can cultivate there and I would say be careful for all kinds of functions in still a relatively small area. There are limits to it. So, yes, it can be done, but I think it is wiser to have a choice, what are we going to do? Is it going to be for tourism and tidal energy? Is it for tidal energy and aquaculture? Because if you want to combine all functions I am afraid that you will end up with nothing, because it is simply a little bit of everything and not worthwhile for anyone to actually step into. So, making choices is probably the best advice that I could give. So, what is it for? And if you combine it with 2 functions then I think you are already doing it quite well. If you think you can combine 5 or 6 functions, I am afraid that it is not going to work. But yeah, I am not an expert on this. There are a few examples of this. But limit yourself on a few I would say.

T: Perhaps we can explain our idea a bit more with the map. The energy lake is over here (points at map), this is not our main focus. What we know about it now, is that it will be mainly used for tidal purposes.

T: And they are also looking into the possibilities of solar panels.

T: yeah, and they are also looking into aquaculture. So this is not the area that we are focussing on. We are focussing on the area over here (points at beach and sea area next to energy lake). It is still really broad. This area does not have a specific aim yet. But we are now focussing on the biodiversity part or the natural part. And I think we can still somehow integrate some other aims as well to our idea. But we are still in the designing phase, so it could be possible that at the end we think that we should focus on nature or if we should include aims for aquaculture or tourism. But we are now still in the exploratory phase to see what the possibilities are.

I: Of course, well in general, you can increase biodiversity to have a more diverse environment. So, if you have structures there, that is always attractive for organisms. So that would be your first aim to increase biodiversity. Perhaps you can do it in such a way every now and then to harvest from that biodiversity. So that would mean that you would go into the direction of aquaculture. And perhaps it is even attractive for scuba divers to explore that area and then you already have 3 functions that I already think you can combine but there I think it is more or less ends, I think that could be a good option in that particular area.

T: **So this area would be suitable for implementing this plan of reefs?**

I: Yeah, there are already similar kinds of initiatives going on in this area and also other areas in the North Sea; for example, windmill parks so that is not something really new. So yes, I think that should be feasible.

T: We also saw an English company, a mussel farm which uses ropes where the mussels can grow on for aquaculture. Do you think that that is a nice idea since it is less disruptive for the seafloor

I: I am personally also involved in an initiative in the Voordelta where there will be co-cultivation of mussels and seaweeds. Also the mussels hang from ropes so not on the seafloor. So yes that can also be possible. But it is not easy to anchor all those structures. So, if your main aim is to work on biodiversity, I would work on structures on the seafloor and not so much hang it from the surface down. But yeah, if companies are interested and see it as an attractive root, why not?

T: **Do you think that there are also some advantages for biodiversity?. So it is kinda a floating reef?**

I: Yes, that certainly will also attract organisms and that can be good for biodiversity. But I think the effect of the seafloor (placing reefs on seafloor) will be much larger.

T: **Do you think it might be possible to combine the floating and the reef? Both having at the same place?**

I: In principle, it can be very efficient of course if you can have multiple structures in the same place then you can have the same ship to go there and service it or monitor it. Yeah that can be attractive. But the more complicated you make it, the more likely it will be for all kinds of problems associated with it.

T: **And then we were also wondering what kind of shellfish species would be the best for such a reef?** We were thinking about mussels and oysters.

I: Yeah, those are the most likely ones. There is an enormous industry of shellfish in Zeeland, so you can benefit from that. And another one is of course the lobsters. THey are also very popular and there is also a high demand for them and it is also known that they can grow in structures like that.

T: Could you perhaps elaborate a bit on that? That also sounds really interesting, the lobsters.

I: Well, I am not an expert on that but I know the lobster season has started and they pay a lot of money for them. And I know there are also a lot of initiatives in windmill parks in order to have structures there that can house lobsters as well. Of course, you can also, at a certain point, think about harvesting them and selling them.

T: **And in what kind of way can we harvest them?**

I: When they are large enough, you simply take them out and you sell them. It is as easy as that.

T: **Is that by diving?**

I: Yeah, you can do that, but normally they use cages in order to catch them.

T: **And that is not harmful to the environment?**

I: That depends on the extent and the amount of lobsters that you take out of course. So far, if I look outside I see the small ships passing by often. So it is lobster season. The first one was sold out for 40000 euros. They usually don't sell out for that price, but it is typically the first one. But lobster is very popular, not so much for The Netherlands, but Belgium and France. I think they earn a lot of money but I don't know.

T: **So, will it be a good idea to keep the lobster in mind?**

I: Yes certainly.

T: We are also looking to develop a dune area on the northwestern part of the lake. We want to develop a dune area and make a management plan on that**. Do you have any knowledge on that?**

I: Dune is not something that I am very much specialised in. A colleague of mine, Valerie Reijers, she works at UU. She is an expert on that. But also Laura Govers, at RUG, they are much more specialised in the development of dune areas.

2.2 Interview John Holmyard – Offshore shellfish

T: **Can you tell us a little bit about yourself and your company, and how it works with the mussel cultures and what you do?**

I:My name is John Holmyard, operator of the company offshore shellfish limited. We are developing an offshore farm on the south coast of England. It's between 7-10km away from the shore. It's only partly build at the moment. We're producing around about 2000 tonnes at the moment per year. That metric tonnes, not mussel tonnes. I have been a mussel farmer since 1988. The current farm we've had since 2013, but prior to that we were operating farms in inshore waters in Scotland. The method we used is the longline system. The system we've got out in line bear at the moment is a semi-submerged system. So you see some of the floats on the surface, but most of the equipment is below the surface. As opposed to the system we had in Scotland which was surface floats, pretty much the standard which you can see around where you are, and also up in Denmark. They've got pretty much the same system as we use. We farm the same species as you, and we sell all our mussels down the road where you are.

T: **Is it mostly blue mussel you farm, or is it also other species?**

I: No, it's all *mytilus edulis.* There's a small amount of hybridization with gallows around here, but it's a very small percentage.

T: **How does the mussel culture work, how do you start building something like this, do they reproduce naturally or artificially?**

I: We collect all our own seed. We reserve part of the farm for putting expat collectors in much the same way …….. for collecting seed in The Netherlands. We collect on ropes not nets. when it reaches the right size we take it off the ropes and put it back on again at a preferred density. It tends to settle on ropes in very high density. Than we put it back on the farm where there's lower densities. Our collectors go in, in fact this week, we normally then see the first settlement in early June. And the mussels are big enough to take off the ropes. So late July. And from then onwards for the next three months we are taking seed off and then putting it back on again. Our harvest cycle here is our mussels that we reseed in august when they're three to four months old are then ready for harvest around about one year later. Then obviously the longer we leave them, the bigger they get.

T: **What are the environmental requirements for a mussel culture like this? (depth wise)**

I: We are operating between 20-30 meters. If you have shorter ropes you can operate in shallower water. But the more shallow you are, when you're in an exposed location, the more likely you are to have big waves. The waves break on the beach, not a mile out. You know what I mean. There's a calculation to be made there as to how long your ropes are, how deep your water is as to where the farm is going to go. The requirements of the site are that there is enough food for the mussels, and there is enough flow of water through the farm to deliver the food to the mussels. Because we're a pretty big farm, we've gone through an era where it's pretty high energy so any detritus and faeces and pseudo faeces that come off the mussels gets flushed away and doesn't build up under the farm. The design of the farm is a bit commercially sensitive but you can see the rough idea on our website. We use vertical, narrow, tall, long floats that allows us to operate in rough conditions. The farm survives in rough conditions but we can't work in rough conditions, you have to wait till the weather is reasonable till you can work it. But the basics are pretty simple, the tricky bit it in the detail.

T: **Does the size of the farm matter? Is there a minimum size that would be feasible?**

I: Yeah, if you are working offshore than you need a big boat. And if you're going to have big boat, you need to make sure you can pay for it. To pay for it, you need a certain size of farm. So its that sort of calculation you need to do. It also depends on the market. Of our mussels were three times as valuable then we could probably manage with a smaller farm, so you have to tailor things to what the market wants.

T: **What kind of struggles do you face with these cultures, is there disease or predators you have to take into account?**

I: No, not where we are. We are quite lucky where we are. We don't get much in the way of predators. Occasionally you get a settlement of starfish on the seed lines and then you can lose seed, they'll eat the seed and they'll cause the seed to tangle themselves with the lines to protect themselves from the starfish and then you can't get them off the ropes without damaging it. We don't really have any other predators. In Scotland you get a lot of problems from sea ducks like Eider ducks or Golden eyed ducks. We don't have that where we are. There are a few fish that eat mussels, but we don't have many of them here. Gilt head bream, I know they are a problem in Northern France. But so far they haven't reached us, but definitely will one day with global warming. But they can completely destroy a farm.

T: **Is there an impact of a mussel farm to the marine environment? Positive? Negative?**

I: Depends where you're looking from doesn't it? We always avoid positive and negatives because it invites criticism. But we think it's positive. For this particular farm before we started, we had a survey done by Plymouth university. The other week there was the Dutch Shellfish Conference, I don't know if they're publishing there. There was a presentation there form the team leader who does all the work on our farm, and took a lot of pictures from what goes on under the farm. We did a survey of the seabed and the general water conditions before we started and we've just repeated the same study every year since we've been going. And yes, it shows changes. Mostly it shows changes because its not getting trawled or dredging by scallop dredges. There's a lot more fish there than there used to be. There's obviously a lot more mussels than there used to be. The biodiversity is certainly higher than it was, and the productivity, I suppose, is a lot bigger cause there was hardly anything caught their fish wise. But now there's 2000 tonnes of mussels coming out so. But whatever you do, there's gonna be some sort of change isn't it? Depends on, you know, what your standpoint is. Whether you think it's positive our negative. If you don't like there to be a lot of biodiversity and you're quite keen on dead mud, then we're obviously not a good thing.

T: **We're also dealing with a lot of dead mud in our area, so that's why we're trying to think of a way to improve biodiversity.**

I:You can joke about it but there's plenty of people out there who think that dead mud is perfectly natural and we shouldn't be disturbing it, you know? But it's just a different viewpoint.

T: **Are there any specific species that benefit from a mussel culture?**

I: Well, brown crab and lobsters, there was none here before and now there are a very large number. But don't tell everybody that, because then they'll come and try to catch. There's a lot of schooling fish. Mackerel, and horse mackerel and whiting and pouting. And all that sort of thing. That, you

know, feed either directly of the ropes or from the detritus that falls to the bottom. There's a gradual change from filter feeders to detritus feeders. It's not a particularly significant change. It is quite a high energy area so there's not a big build up of deposits under the farm. There is an increase in the cover of the seabed under the farm. Mostly from mussels falling of the ropes and settling on there. A lot of them will be eaten by starfish but some of them will survive and form a new colony. And I can't remember the number of species, but because we export to the Netherlands, your government sent people over here to come and have a look and see what we've got on our lines, to check we haven't got anything nasty. I think the first time they came, they found something like sixty different species on the lines. And there's at least another sixty sitting on the bottom underneath the mussels that weren't there before. And there's a lot more in the pelagic as well. The various fish and so on, you just wouldn't have seen them. When we're doing the studies each year, they don't just study under the farm, they also study control zones within 500 meters of the farm, and then several kilometres form the farm. Just to see if there's any predation or sort of moving of things out of the farm. We're also taking part in one of the big inter… projects which is called fish intel I think. It's tagging various species on the farm and we've got a lot of hydrophones set on the farm so we can listen for fish that've got one of these little acoustic tags. It's quite interesting because you can see fish coming from estuaries back to the farm, to another estuary, back to the farm. We've learned that the farm is a place to find food.

T: **What we're looking into is to kind of make a combination of artificial or biogenic reef with mussels and perhaps with a construction like the one you have. Do you think there is a possibility to combine structures underneath with a farm like this?**

I: Putting hard structures underneath the farm you mean?

T: Yeah

I: I mean, we don't really have much in the way of hard structure other than the mussel clumps that fall off. Our ankers are seabed screws, so the only thing protruding from the seabed is a small piece of steel about the size of your hand. And then the rope is attached to that and goes up to the floats. So there's not a lot of hard structure there. But where there is some you tend to get something living around it. But mostly it's the clumps of mussels that provide a new structure and that's where the crabs and the lobsters live. So can you develop it on purpose? Yeah, I think you can. I think you'd need to think carefully about what the seabed conditions are, you know how fast the velocity of the current is. And also you gotta think about the depth and how big these structures are, because they're going to disturb the flow of water underneath the farm. And if you've got an enormous structure underneath the farm, then it's gonna deflect the flow of water upwards. And that may affect the way that the ropes move. But I doubt it's going to be particularly problematic.

I: What I've read about the lake thing, the biggest problem there is the depth of it, because when it's pumped out, it's going to be only 5 metres deep. Well, you know than it's going to be very difficult to operate a hanging culture mussel farm in only 5 metres of water. Certainly couldn't operate our design. You might be able to manage it with a raft type structure. I mean, it's obviously going to be very sheltered in that area, so. And it's a raft structure that's probably going to be your best bet rather than what we do.

T: **You have been in this industry for a very long time. Did you also try other methods besides from this rope mussel culture?**

I: When we started in Scotland in 1988, no we went for rope systems straight away. There were other farms near us that were trying raft culture. Similar structured they use in Calithia. They didn't work very well in Scotland. The productivity of the water up there in Scotland is not terribly high, and if you use a raft structure then you know the ropes in the middle of the raft don't get fed terribly well. I mean you can do it, but you gotta consider the size of the raft, and the flow of the water and that sort of thing. No, we've just been using long lines right from the beginning. But I mean various designs of long lines but not a lot different from what we do now.

T: **In comparison to bottom trawling fisheries is this a way of culturing more valuable in monetary terms as well?**

I:I would think so. I haven't got any figures for what they used to catch in our area, and we specifically chose an area where there wasn't a lot of fishing pressure. I mean there had been in the

past, but not much these days. I think because its been trawled so often its just not very productive anymore. We can at the moment land 2000 tonnes and when we're up to full size, we should be able to land 10000 tonnes a year. Mussels aren't as valuable as a sole, but you know, it's a lot of volume we're landing and I doubt that there was anything even close to that sort of production coming out of this area before. But the key point to remember is that we're not taking the fish away. There's, you know, people want to catch fish and they do still go around the edge of the farm. And you know, we know cause we speak to the fisherman. Some of them would really rather we weren't there because it's not traditional. Some of them think it's the greatest thing ever because they now catch more fish than they ever used to. Because they leak out of the farm and I guess when they get caught by somebody around the farm they're probably a bit fatter than they were before. You know, this obviously apart from the mussels there's an awful lot of other things on the ropes. There's huge numbers of little amphipods and worms and other little beasties. That all goes back into the water when we harvest the mussels. Something else eats it you know. So yeah, the whole place, I think, is a lot more productive than it would be without the farm. And yeah, the work we've had done by Plymouth pretty much proves that all these things take a while to prove, you can't show a difference in one year you know. But over eight years, we're showing a very significant difference.

T: **So you think that a combination of these mussel cultures and sustainable fisheries would be possible?**

I: You need good dialogue between the two parties. Fishermen are well known for not wanting to listen to anybody else. They get up early and they go out and stay out late and do they want to spend their evenings reading reports? Probably not, you know. And so that's half the problem. But yeah, you gotta work out a way of getting good dialogue between the two. Just so you don't get any damaging interactions like I don't want to have stuff drifting around that is getting in the way of people that shouldn't be. On the other hand, I don't want fisherman trawling through my farm and they do. And we've lost a lot of gear over the years from fisherman. As I said earlier, they know they can get a lot of fish near the farm so they try and get a as close as they can and sometimes they get too close, then they get tangled up in the lines and then, well, if they gotta cut either their nets or my lines away, you know which one they're gonna cut. You know, it's always my lines they cut, and it's very expensive.

T: I can imagine. **Are there any things things you would like to say or tell us about before we close the interview?**

I: No. (asks question about our project and we proceed to tell him about it).

2.3 Interview Martin Baptist – WUR

T:**What type of shellfish reef would be most effective to use for coastal protection?**

I:For coast protection…that would be oyster reefs, there is a lot of research already been done with oyster reefs in the Netherlands, in the eastern Scheldt, you probably have found it. There is also a lot of experience in the US, with Virginica, oyster reefs, and oyster structures.

T:**And are oyster reef structures more stable compared to other reefs?**

I:Yes exactly, mussels are attached to each other with byssal threats, while oyster really glue themselves together. So their reef structures are more firm and resistant against waves. And of course, you should keep in mind that an oyster reef cannot be the only solution to coastal safety, you always need a dune as a nature defense or a dyke, for really high flood defence. Oysters live almost exclusively under water and sometimes they fall dry, during low tides, but they are quite low in the sea. They protect the coast, take away wave energy. So behind the oyster reef, there will be more sedimentation, it is a component in a string of measures you should take to provide coastal protection.

T: We were also thinking of the possibilities of the coastal protection qualities of shellfish reefs and then we can go to the second question. **What type of shellfish, crustaceans and/or tube worms can be combined in a reef to facilitate the highest biodiversity?**

I:How do you combine them? Are you going to plant them there? Usually, all the species you name here, their larvae are floating in the water. So what is usually happening, is when you provide the substrate, with hard substrate so that species can attach to it, then the larvae of snails, or anemones, or tubeworm, or whatever they float around and can find a substrate there. However, you might, some species might need some help. And I don't know how far you need to go, but the larvae of tubeworms especially ….tubeworms which are really interesting I think. They have chemical sensors in the larvae, they smell reefs of other tubeworms, of their conspecifics, species, if they smell it, they settle to the reef and attach to them. There are many ways that these larvae find these hard substrates, sounds may also play a role. We are now researching oyster larvae that listen to other reefs and then respond to it.

T: **But is it then the sounds that the species make?** Or is it some kind of frequency that yeah it sounds a bit vague to my still.

I: It is also vague to us, that is what is being studied. Is it the hissing, popping and plopping of other species that live in the reef? Or is it the breaking of the waves or other?...We are not sure. But what we do know is that the oyster larvae have the capability of hearing or sensing sound, water vibration should be the correct term, and that they have behavioural change, show behavioural changes probably associated to their sensing organs but what they are listening to is beautiful research. But maybe a bit out of the question, but the point that I want to make is that if you provide structure, a lot of biodiversity will fill in for itself, but it would also be interesting to think of ways of luring the species towards these structures or planting species or whatever if you want to make it artificial. But that is also kind of a philosophical choice, are you looking for the most natural situation or are you looking for some kind of artificially high biodiverse situation? Because the first question should maybe be: why do you want a reef at that location?

T:**We are also still doubting between those two options, but what we have read and heard so far is that giving a kickstart to all of those species by attaching them to a substrate would give the quickest benefit to biodiversity and it is also possible to combine several species together or is it better to only have one species attached to a substrate?**

I:It is all a bit in the experimental phase I think. If you want to design a scientific experiment on this you can try different options and study it. But maybe the first question is, if you look at it more critical. What is the biodiversity gain of placing an artificial hard substrate in a soft substrate environment of which the only hard substrate I know of are flat oyster. If you look at this project from a perspective of conservation of nature and maybe restoration of nature, then restoring flat oyster reef beds would be preferred over using pacific oyster in a structure and actually that would be preferred over using an artificial substrate made out of concrete or whatever. So you can also rank different approaches on an axis from a very natural environment to an unnatural environment but maybe with a high biodiversity?

T:**Wood being used as a substrate as well, would you see that as a better option compared to the concrete?**

I:Yes I think I do. If you look at nature; hard substrates in an environment like this could be remnants of peat and wood that could be there. It could be old shells, dead shells, they are also used for hard substrate organisms to attach themselves. And it could be the flat oysters that form a hard substrate. It is not that my personal opinion is very important, but you could make a ranking of the most natural hard substrate you can think of, going towards some unnatural hard substrate but the latter may contain more biodiversity but again biodiversity is not only about the species number, but all processes and interaction between species and also the natural situation. Naturally we have the Voordelta with a sandy environment and a sandy shore with indeed in some parts remnant of hard substrate and in some sheltered pockets some opportunities for oysters to live.

T: I don't know exactly the history of the area. But I know that in the US in the east coast, there used to be a lot of mussel reefs there, but they were all taken away due to the extraction of mussels or the shellfish ..

I: I think it all oyster there

T: **What is also the case here in the NL, that there used to be a lot of oysters reefs here, or is the present situation a good representation of the past?**

I:How far back do you want to go? But not too far back, the shellfish reefs are not quite abundant in this Voordelta area, because the dynamics are too high, too much wave dynamics and the sediment is too sandy. So what you still see and what you saw in the past, is that the shellfish reefs are more in in the estuaries of the Eastern and Western Scheldt and formally the Grevelingen and Haringvliet. Of course they are still there but before the delta works, the situation resembled the Waddden Sea, a more sheltered area. Shellfish reefs have had quite some difficulty in maintaining themselves in these wave battered locations in the Voordelta. Although we have found natural occurring flat oysters in the Voordelta, but again in the very sheltered subparts. So yes if you think of Delta21 terminology and you want to make this energy lake, you might be able to create sheltered places, where the habitat conditions are suitable for shellfish reefs.

T: **Thank you then we can go to the next questions. What possibilities are there to integrate migrating birds and reef structures?**

I: That is interesting, because these reef structures of mussel beds are much more valuable to birds than the reef structures of oyster, because the mussels themselves can be eaten. The mussels are eaten by a variety of birds. When the mussel beds are primarily under water it is, for instance, the eider duck that is feeding on them, or the oystercatcher. These are food sources to the birds themselves. Pacific oyser and also flat oysters are difficult to open for birds. On the other hand these reef structures provide a habitat for a variety of other organisms like crabs, small shrimps etc. And there are many birds that feed in the holes in between these the mussel/oyster structures and feed on it. In that case, they are quite alike, they both form a substrate and habitat for many other small species that can be eaten by other types of birds. An there is also the surroundings, and then again mussel beds score a bit higher than oyster reefs in that they change their surroundings. But mussels make these faecal pellets and collect a lot of fine sediment, and in the vicinity of these mussel beds is a lot of fine sediment, enriching the sediment, making the benthic diversity different and actually making it more attractive to birds to feed in the vicinity of mussel beds and that effect is bigger for a mussel bed than for an oyster reef. So for birds, you should go to mussels. For coastal protection, you should go to oysters

T: **So in the end the best idea is the combine both to create a more diverse area, which is more suitable for the birds and perhaps coastal protection and better for marine biodiversity?**

I: In the end it might be best to not create this energy lake, that is maybe another discussion because the energy lake is a really big environmental disaster for this area. And also not forget that there are many birds, there are also fish-eating birds that need open water. Cormorant and divers etc, they used to live there. And now you are constructing above water habitat and and intertidal habitats. What about the fish-eating birds? Don't they deserve a place there? I understand your reasoning, but please keep in mind that if you are creating something for a species at a certain location you are not improving it for another species that might live there and has other habitat demands.

T: **What I vaguely remain that there is a lack of fat-rich fish species in the area is that correct?**

I: I think that can be correct, that is quite a national problem, not only there but everywhere.

T: **And how can we best facilitate them in the area? Would reef structure be a good option or would there be another way to improve the population?**

I: That is a really good question, but I can't answer that question now. Then I need to know about which species we are talking. But that is of course the way we can analyse this. What species are we talking about, what are their habitat requirements? Are they migrating species? Are they temporarily living in this area, or are they permanently living in the area? Are these species typically pelagic fish in the water column, like schooling herring? Herring is a nice fat fish, or are we looking at other species that are associated with the bed, and do they live in sandy or muddy beds or are they associated to hard substrates? There are many different habitat requirements for many different species and if you want to improve it for certain species, you should dive into their specifics.

T: **We still have to make a selection for the fish species, but the species I can up with now, I don't know their English names, but the Paling is an Eel, right?**

I: Well that is actually more an inland species, they do occur in the Voordelta, but it's only their migrating route going from the rivers to the sea. So paling is an interesting species but you cannot do a lot for the paling in the Voordelta. They want to swim to land and when they look for their spawning area they swim towards the sea and the Sargasso sea.

T: **And the Fint?**

I: That is also another migratory fish. Herring-like species. But Fint is also on its way to the Voordelta, it's on its way inland not too far inland, the Biesbosch would be suitable, because it spawns in these freshwater tidal areas. Can we then make the Voordelta an interesting spawning area for the Fint? That would be an interesting question. That you really improve this area locally for Fint, it is not suitable now, and I am not really certain how to do that. But that would be kind of nice. Haringvliet for instance, to make that a Fint spawning area.

T: There are a lot of possibilities for species we can select, we still have to select the fish species but we also look into other types of animals also into marine mammals and specifically we want to target porpoise and seal species. **But what possibilities are there to implement for measures for both these species?**

I: Harbour porpoise is more an offshore species, they do occur along the coast especially in March and April when a lot of these pelagic small fish like the herring migrate from deeper water to the shores and they also migrate into the estuaries of Zeeland and into the Wadden Sea and that is then also the period when harbour porpoises are more observed in these coastal areas because they follow these fish which are their food source. But apart from that, porpoises are real offshore species, so there is not a lot you can do on the coast except provide quiet conditions no boating, no fishing. And somehow provide interesting habitats for these schools of herring and other species. Seals are a different story they are more coastal species. Central place foraging as we call it, they use a central place where they rest on these sandbanks and form a central place where they go out and forage for fish. Because the Voordelta is quite good for seals: nice sandbanks. They are great because people cannot really go there. Seals are quite vulnerable to disturbance. So these sandbanks are nice for seals to rest on and they need enough fish preferably at close distances but they also are quite capable to swim a long distance to fish. So they easily go offshore to the north sea and go fish there.

T: We also heard from Tinka, because there was a lack of fat fish in the area. I don't know where exactly, but somewhere in the North Sea. **Seals were hunting the smaller porpoises in the area, do you think that would also be a problem?**

I: That would be for certain a problem for the porpoises but not for the seals. If it is because of a lack of fat fish that is a hypothesis I think. Indeed grey seal have learned somehow to attack porpoises and eat parts of the porpoises, never the whole porpoise, they cut it open and eat some of it. That is quite a nice trick that is being used by grey seal. And why they do it I don't know. Well of course because they need food but what I want to say is it if we can provide enough fat fish we don't know if they will stop eating porpoises or not.

T: **Perhaps they like it better?**

I: Yes perhaps it may be more easy or perhaps yeah. But its quiet cruel so the one sea mammal is eating the other

T: But yeah I think it's an interesting dynamic that is something that we see as new, maybe it has been going on for a longer time. But yeah thank you

I:Well it is quiet new actually. Around 2010 we first saw these harbour porpoises stranded on shore with really crazy wounds on them. And we did not know what was causing those wounds, we were suspecting fishing and dredging industry, well everybody. Actually, there was a clever Belgian researcher that found bite marks in the skin of porpoises, and the distance between the two teeth

the canine teeth, he measured and it was comparable to the teeth of big grey seals. And what they then did, they collect DNA samples and they found DNA of grey seals in the bite marks and then we could link them to each other

T:That sounds really interesting. We were also thinking, due to the construction of the energy storage lake, the Hinderplaat is going to be a Marsh area, that is the idea now. So there is less space for the sandbanks or for the seal to rest on. **So we were thinking creating a structure in the sea similar to a floating deck. Do you see any possibilities in there for seal? Or would that be not a good idea?**

I:I think that could work, but I am not really sure if we have any experience with harbour or grey seals. Of course it's very well-known of sea lions in cape town or San Fransicsco but here I am not sure. But of course on the other hand this idea is nice but ridiculous. What we're are talking about here is a protected nature area with the highest European protection standards that there are. It is protected by the Habitat directive and it will not be allowed to change these tidal sandbanks into marshes or energy lake or whatever. Everything we are doing, sorry for you guys, it is a nice assignment to work on but ultimately this system it will not be allowed to change it in this way. Because the EU will find it ridiculous to take away sandbanks and replace it by artificial floating structures. This is not what the protection of a nature conservation area entails.

T: So you would think that, construction is okay, ethically doable with keeping, with also forgetting about the Natura2000 legislation. **Would you think it would also be better to create sandbanks instead of the floating platforms?**

I: Sure of course, that is a much better nature based solution. These floating platforms will break, they will break down, they will fail, there will be big waves that will sink them. Then we will have plastic concrete whatever in the environment. It can be done technically, but what would be the life time of it, what are the costs? Then providing sandbanks is a much cheaper and nature-friendly solution.

T: Okay then we can go to the next question. **Do you have any information on innovative ideas that exist right now about artificial/biogenic reefs?**

I: Well I don't know what you already know, because there are these reef blocks and these open structures and I also know that we are working now at the material that you build these reefs with, the substrate itself. So that species better attach to them or even that species are even attracted to them with chemoreceptors. Those are now the innovations that are made

T: We have not really looked into the chemoreceptors so that might be interesting.

I: We are working on that at WMR, Pauline Kamermans is working on it

T: Interesting. We also had an interview last Wednesday with a mussel cultivator in England from Devon. He is cultivating rope-grown mussels. When thinking of also implementing culture into the Voordelta. **Do you think that would be a good option?**

I: No, but it is an option. It is also being applied into the Eastern Scheldt, these rope cultures. And ofcourse it is also applied in the Wadden Sea where we have mussel seed collectors on ropes. You need sheltered conditions for that, that is always very important. So in the Voordelta what we are now dealing with, well some is sheltered, it is not that bad. But I think it is more cost-efficient if it's more sheltered than it is now. It can be quite rough in the Voordelta. But of course the other problem is nature conservation, why would we put some aquaculture in a nature reserve. It should be really well studied, what the effects are on the goals of this nature reserve.

T: So what we heard yesterday, I did not conduct the interview so I don't know the details but they said that over the years ,they were doing it for 30 years already and the biodiversity had increased in the area and also that sometimes some shellfish fall on the ground, that there was also substrate created for a new reef there. So that the biodiversity, in the end, was higher than before the idea.

I: I agree on that but that is not what the problem is here. The problem is that we are conserving an area without hard structures. That is the goal of this nature reserve it is an area with sandbanks with seals on it, and with demersal fish in the seafloor, and soft substrate benthic species with birds that feed on them. So it might be that by having these mussel farms that you increase the species number, but so what. You add species that not naturally belong there. With the exception of peat remnants and wood and flat oysters, but it is really delicate question. Biodiversity is not only about species numbers, especially in nature conservation it's about protecting what is there naturally. So I can see that mussel farmers see an opportunity but I am telling you from a legal perspective that it will be difficult to put it inside this nature reserve.

T: I was also thinking. Of course fishing was not allowed in the Voordelta, or perhaps in specific areas during specific times, but it is still occurring. So we thought it would be better to integrate somehow those stakeholders into our design so that they have an area in which it is allowed. Otherwise, they would continue to disrupt a protected area and that is also problematic.

I: Often the best things for nature are doing nothing, but that is not in our system, we always want to do something, use the system, we need fish, shellfish, and shellfish aquaculture has a big potential, very fast-growing species, lot of protein, etc. But finding the best location to do that is quite a puzzle

T: Yes, that is also something that we are kind of struggling with and I do agree with us that is better to not do anything. I think eventually better to stop with the entire fishing industry. But yeah that is really difficult, we can't do that, unfortunately. But thank you for answering this question. And I had a final question. **We are looking into development of a new dune area on the west side of the energy lake, do you have any insights in dune development?**

I: Such as? Do you need sand or do you need plants?

T: **Which plant species would you think would be good addition to a newly constructed dune area?**

I: So if you make a newly constructed area, the plants that grow there are not really rare or special. There are only a few species that can live in an embryonic stage and that is what you need to start with. And these species there are actually only two, I don't know their English names. "Biestarwegras" and "Zeeraket". So those are the two species that actually start in a natural environment with formation, but what we do in the Netherlands is that we already plant the dunes with marram grass, which is actually the second stage in the succession. So what we usually do is that we already create hills that we call a dune and plant marram grass and call it a dune, but it is not a dune system at all. Is a field experiment included in this course? Go to Voorne-Putten, the dune system there, and look at the Parnassia fields and the dune valleys. There are literally maybe 100s different floras you can find in those dune systems. It is because these dune systems are there for a very long time already and a lot of habitats have been created with different moisture and different organic matter contents, different carbon content, carbonate, calcium carbonate contents, pH, different salinities, all these environmental gradients and the salt spray that has been going over it. And of course there is a gradient in the salt spray. Salt spray is more heavy near the coast and gradually diminishing. That has been created in a lot of time, a lot of succession, feedback loops that has been creating these dune systems that we have in the NL that contain all these special plants. Because I don't know, what is, almost half of the protected plant species in the NL is living in the dunes, there are really special. And the Voornes Duin is one of the best dunes there is and this Lake, this Energy lake in front of Voornes Duin is probably not really good for this existing dune system so that is another problem in getting this license. Because you take away the wave action, you take away the salt spray needed for rejuvenation of the dune vegetation. Anyhow if you create a dune, do not expect too much of it at first. There are only a couple of species and you need a lot of time, to develop it in at least 10,20,30,40 years of time to have something with a high flora diversity.

T: That is good to know for our project. These were the questions we had. **Are there any things you would like to say before closing the interview?**

T: No but I am curious of your background

….

T: **Our deadline is at the end of April we can send you a pre-version of the final report if you would like that?**

I: Yes, I would certainly like to see your final report but a pre-version would be nice. I can read it through if I find the time and add something to it.

T: Thank you so much for today and for your contribution, I think it gave a lot of new insight and I indeed agree with you that keeping a nature area as the same would indeed be the best, so it is good to have that as a reminder in my head that that is also pretty important.

I: Yeah, it can be only of the criteria if you make some kind of multi-criteria analysis or something, the naturalness of the area is also important.

2.4 Interview Tea Both – Municipality Goeree-Overflakkee

This interview could not be included yet because of delayed response from the Interviewee.

2.5 Interview Valerie Reijers – University Utrecht

Interviewers:Maartje (M) & Talitha (T)

T: **Are you familiar with Delta21 project?**

I: To certain extend, yes, I know it's there and I know there's some plan right to extend the Maasvlakte 2 as well to built the Voordelta differently. But I work mostly in the Waddensea so I'm not complete expert in this.

T: Yeah, so the plan indeed on the South of Maasvlakte 2, they want to create an energy storage lake and that completely would be in the Voordelta and then on the eastern side of the energy storage lake will be kind of salt marsh, there's also tidal, like the Waddensea. So, that's very interesting on the land side that would be. Furthermore, they want to create an open water way for the Haringvliet so that would be brackish water as well. But, there's a lot opposition for that, there are a lot different opinions how the area should be. And we're mainly focusing on the western side of the energy storage lake so that would be then the marine biodiversity as well as the dune and coastal area of the energy lake. And for now, the dunes that are near Westvoorne and Rockanje, with this plan, they would have some structure of the beach still but would not entirely open for seabirds. More like, there is some inflow, but not the super dynamic. Not really the sea, the wind, water dynamics that it currently has. That would kind of move towards the western side of the energy storage lake, and for us the challenge to design the area in which yeah really the coastal dynamic is present because a lot of places in the Netherlands have been structured to dunes but they need all the space they have because all you want is proper system. So yeah that's very interesting and challenging to work for us on. So that's a short summary on what we study. So, you told us that you specifically work on the Waddensea. **But are you familiar with the situation of the dunes and southern Holland?**

I: Well, what I know about the dunes, we did actually do the survey along the dunes in the Netherlands, so 35 transects all over the Netherlands, covering also the delta and Holland. And we looked at how much space we needed to have maximum diversity and species number for example. So, I did some work there and other that I know in Oostvorne, there are problems with the beach becoming more narrow. So they also experience something that called coastal squeez. Coastal squeez always work two ways, either it is land inward because we build human structure close and close to the shore and of course there's relative sea level rise which also takes away part of the shore line. And I think in the Oostvoorne, they have some trouble with that as well.

T: Yeah, and the founding father of the Delta21 also said that the Hinderplaat is kinda moving towards the Rockanje and Westvoorne. So they will eventually lose their beach as well.

I: it was a popular beach to drive on. I remember when I was young, my best friend, she was on the Oostvoorne.

T: **Just with the cars?**

I: Yeah, just with the cars.But, I think on some point it wasn't allowed anymore. But it was one of the beaches that was allowed to drive on

T: Yeah? Oh that's funny, interesting. We were thinking about the Delta21 plan creating the energy storage lake. **What do you think of current dune near the Westvoorne and Rockanje and the island would look like if something kinda a big structure is further in the sea?**

I: If this structure is going be there, right? It means the beaches that are already present and Oostvorne and Rockanje, they will lose their dynamic character to a great extend because they will become tight, dominate. If the Haringvliet opens, a lot of waves dominated processes that are currently there, they would be lost. So that means if you don't have a constant input of new sediment, of course that takes away the erosion of forces but it also takes away the increeding forces as well so that would be less dynamic, windblown sand, etc.

T: Interesting. **Because a lot of vegetation relies on that sand, right?**

I: Yeah, so dynamic is indeed very important for the natural functioning of these dunes, so already we experience this everywhere because we stabilize the coast, so we have the "basis kust, we just say this is where the coast should be, so we have nourishment in front of it to make sure that enough sand is being deposit into the system again. And of course we also, well artificially keep the coast there if storms come then we go plant more filament and make sure the dunes are present exactly where we wanted to be. Well, if you change the coast, it's not even mega nourishment, right? It's energy lake and in front of that would be the coast and you would extend the coast to a certain extend. That means this area would not be coastal area anymore and it will not function that way either, so there will be less calcium, for example in the system. Yeah, everything will change.

T: Yeah, cause there will be some brackish water and that is of course a whole lot different

I: Yeah, there's no wave and absolutely no fetch anymore, right? Because you have energy lake in front of it so that also means that even this is a tight dominated environment again, let's say the Haringvliet is open and we have tidal fluctuation, and if there's a large fetch, then the possibility of course if you have a wave run up again, which is been driven, in this case that would not be a case either, right? Because in front of it there is a lake, so the fetch is minimum

T: Yeah, on the southern side of the energy lake but that's more than Goeree Overflakke, near that, that would be an open water way from the Haringvliet to get out and some water to get in, but that would be minimal.

I: I think it would be minimal indeed. Then, you also need to know the amount of the big storms that come from the southwest and the northwest it's more dominant the wave forces, wind forces during storm surges.

T: Interesting. **What's your personal opinion, what do you think of it?**

I: Depends on what you look at. I think it's kinda hard to say it's either good or bad because it's very context-dependent. If your focus is the natural development of the coastal system of Oostvoorne and Rockanje, well that is lost. Building this of course there are other opportunities, for example, I'm an favour of opening the Haringvliet again and making it brackish tidal system again. The problem with all this things is, I cannot give a good answer on this because I'm not a complete expert, so I don't know all the plan and I don't know everything in details. I know some of these islands in the Haringvliet that are very important for bird breeding there and a lot of these functions are lost as well which has to do with the fact if there are no disturbances, that also means the vegetation succession goes very rapidly making this island very unfavorable again for the birds, so you need constantly have active management to take away all the vegetation, for example putting more dynamics into the system can be beneficial for this. But of course, the Maasvlakte when it was built, they used to be the Beer, this nature area, that was like one of the best nature area as that point of the Netherlands that is lost. In the Netherlands, it is always man-made nature. I mean the Waddensea that is said a natural system but it is not, it's constantly used by humans, that doesn't mean that has no function and that it has no ecological value. So, I think this could be catasthropic and it could also be an opportunity depending on how people implement it and what they do exactly. In the end, the focus should not be on the specific area, should not be on the last dunes in the Oostvoorne and Rockanje, but that could be on the total system. So is it the plus or is it the minus, it depends on where you go and look at all the systems separately and the one big assessment and then it can be positive. But of course the most important thing with the Delta21 is the coastal safety

and the energy lake, the freshwater storage. Yeah, I think that is the prime focus than the secondary. It's always nature development but it does opportunities to try and get the best possible way.

T: You said something in the beginning about natural dynamic would be gone from coast near Rockanje and Westvoorne. But, one of the argumentations in favor of the plan, is indeed the collaboration of the Hinderplaat with the island. We heard those arguments the natural dynamic will be lost either way. **If the Hinderplaat collapsed, or even the energy storage lake will be there, we are a bit in doubt to what extent this would be true** because there is new dynamics, when a big sandbank joins the beach

I: Yeah, so I saw the Hinderplaat, it's the sandbank in front of the Rockanje, right? I think it's a natural nourishment, so constantly we are spending millions of money trying to keep our coastline where it is by applying this nourishments. But sometimes it's the natural dynamic of the coast that these sandbanks that they wash on shore which also give opportunities because it gives new sediments, gives new space. So, I don't see why this is should be hindering the natural dynamic. It just means that the area can stand a little bit further to the west and that's the thing with the dunes, I mean they meander per time (13:27). So, everytime they are progressing towards the sea until the one point when the sea become, you know, sea level rises, or we have storms, etc, and they are put backwards and they can migrate again. But, we don't like that, right? We want it to be exactly where it is and I don't see that the Hinderplaat, that it hinders or obstacle. It's an opportunity.

T: Interesting. I also think it's very much the difference between ecologist and engineers, yeah to let dynamics be

I: I think in the Wadden we have this much more. So, we have for example we have Texel (you have one point, the onrust (14:26), one of the big sandbank that gain on the south point, then the ? developed, and everyone was like whoa.. such a beautiful dune area. Then, we had that also the Noordvaarder and Terschelling (14:35) it was also one of these sandbanks. This happens constantly because there you have this deltas where you have constantly the sand moving and aggregating and then it washes on the island. And well, our delta is not a natural functioning delta anymore, right? But yeah, sometimes you have these sandbanks, I think it's interesting, it's an opportunity, it's good. So, I wouldn't say it's an obstacle, it would change the current position of the dunes of Rockanje, but it means it migrates forward so you have new dune development. In this case, dune development would be completely gone from Oostvoorne and Rockanje but it will be, I don't know how many hundred kilometers to the west where we build artificial new coast. And in that case, we need to be sure the area between the lake and the shore that it is sufficient in space, right. So what is the space dimension that need to be there if you want to have, for example, a dune barrier, a developing there, or you just want to add embryonic dunes there, or what kind of system do you want? I mean space is very important

T: Yeah, that's something need to consider. When we are creating a design of the new dunes system. **What other factors do you think are the most important? The types perhaps of dunes?**

I: I think the slope is important as well. Naturally, our beaches are called "wide beaches" (16:22), so they're like gentle slope and they are wide, because of the dynamic we have on our system. It's much different if you compare to the US where you have for example, micro-tidal system, you can have storm surges, hurricanes there. And our system are generally wide and gentle slope. So, I think that's important to take into account that space is there sufficient and need to be sure that if you want to have a large dune developing there. Well, that also means you need a large beach there, so you have the sand being dried out, being taken up for the aeolian transport so the higher the dunes, the wider the beach needs to be, because the sand need to travel all the way up. Once you have a dune, and you have this large area, those mean you have freshwater storage because dunes also hold on freshwater which will change the dynamic of the ecosystem as well cause it gives the opportunities for other species to growing to it as well. So, I don't know what is the current dimension that we are talking about?

T: I'm not really sure. It's gonna quite big and long

I: But in a way I think it's quiet narrow. So, we have this natural barrier, these Wadden islands, now you have to till on it. And they kind of similar, this case you have tidal system in the back. And here

you don't have it, you expect freshwater lake. It gives a little bit of an idea how much space is needed to develop dune system there. I think you need more space than you think you would need in advance

T: W**ill it be the kind of the width of the beach?**

I: Yeah

T: Yeah, because in their plan they expect the beach development possibilities there but what we expected was also quite deep because it's the Voordelta and that is deep

I: Yeah exactly, so how much do you need to nourish? How much of sand do you need to get and then another thing that is maybe important for you guys to remember as well so have sands and dunes project, right. So we have that mega-nourishment close to Den Haag, amongst there. I want to think so, because they need a lot of sand there as well. You have to go deep, as a result you have to take out this sand, the patio sand, pretty old one, but there's also a lot of shells in it. So, you got a very armed layer (19:34) and they expect a lot of dynamics because there are so many shells in it and the grain size is so large. It means that hardly any dynamics because the winds cannot pick it up.

T: Oh then that is quite challenging then..

I: Well, you see, building nature, as humans, we don't do it as well nature does it, right. So, we always think were gonna do it like this and then we have something that's very Dutch and that's called bestemmingsplan (20:14). So everything, every square meter in the Netherlands it has a purpose. So we always says this should be nature, this should be a cycling path, this should be this. But that doesn't always work the way that we want. Sometimes they are certain dynamic that we don't take it into account because, for example, it's designed by engineers. Let's say for example the Marker Wadden (20:41) they build these dunes there, and then they're complaining that the sands blown away. What do you expect? I mean it is what it does. So, I think it's one of the challenges to identifying all these bottlenecks because there things you can think of but there's also things you can't think of beforehand

T: Yeah, indeed. One of the most important bottlenecks, the measurse should be the width of the beach then

I: Yeah, and the materials that being used. So if you want to have a large dune barrier, then you need certain processes, you need certain width of the beach. And there are dimension calculations. If you say, well we don't want that, you just want to have a little bit of a embryonic dune development, that is all. Then, it's fine. You should also be aware of whether this freshwater storage behind it, if it stays fresh or it's gonna be saline at one point as well. I don't know, I'm not an engineer. I do see bottlenecks here, it sounds challenging to be honest, that is natural working but you don't have all these problems with the saltwater going into this freshwater lake

T: **Would you expect natural succession would be possible, to let natural dunes come or will it take super long?**

I: Yeah, it will take super long and it depends on what you want. If you wanta dune the same as it was in Oostvoorne, that will not happen. Those dunes are old and those dunes have been developing since the Holocene, they're remnants of the past as well and you will not have that. You will have probably embryonic or small dunes development there. But, like I said it depends on a lot of things, for example, if you have this armed layer beach again, you can look at the sand engine dimension that are there. Then, after, it's been 11 years now, there's some micro dunes developing there. That's probably what you will look at.

T: Something really good to keep in mind

I: Yeah, that could be an important nature area as well. Depending where do you allow people to be on that probably they do, but if you don't allow people on that, it could be the important breeding habitat for little terns or little gull species. Yeah, I guess it will be opened for the public

T: Yeah, we talk about that. Now, the plan is that we will do the most upward part for the recreation. And the more southward will be more in the birding, so that more of recreation also. Perhaps, plant

somewhere a bird watching spot. And in the southern part, that will be inaccessible to tourism. No recreation there

I: Yeah, so that helps species to come if you say

T: Yeah, or else we expect there will be much of disturbance and now it's Natura2000 that protect the area, the Voordelta

I: And it's not doing really well, right? I think it was on NOS this week I mean people complaining about the nature that developed in the Maasvlakte

T: Yeah, and the seafloor is also very much damaged by the fishing that still occurs there. It is kinda "gedoogd". It's very challenging area with the local people who are very… they rely on it

I: Yeah, and it's close to the Europe's biggest harbour town, I mean it's nice that they say it's nature protected area but mostly it's economic area and then like they.. like I said nature is secondary is here. And that's why I always get a little bit ergh about this project, they often sell it as nature project but actually it's just economics or protection or whatever. And secondary, they want to implement some nature in it. I mean it's important that they do this, but don't sell it as nature development area project. Say we want to make sure that nature doesn't suffer too much

T: Yeah, It would be more open indeed

I: I mean we don't build this for the nature.

T:That is true indeed and it is still dredged, the bottom, so it's a bit crooked.

I: It's fine, we live here in the Netherlands, we live in the delta. So, we modified the delta which is fine. But, yeah, be aware of it and be honest

T: Another question was: **What plant species that are most important for the new dunes system, so that would be embryonic dunes I think with micro dunes?**

I: I think ___ (27:06) sand couch and ammophila so I don't know if they want to let it just go or want to just plant to kickstart it. I think it's not needed to kickstart it, I think if you don't kickstart it in the beginning, you will have some searocket(27:28) growing in it. And another one point, you will have ___(27:34) annual species. So, every year it dries up and you get the stumble weed but it already start a little bit of a dune development and it can cope really well with salt, so next you probable will get ___ (27:51) in it, it's perennial. Once it is start developing there and it will also kickstart the dune formation. And other possibility, what is possible, because it is depends on the source material that they used. So, if they use sand that a little bit richer in nutrients and if they are going to be a lot of birds on the spot, you get name Leymus arenarius which is sand haver because it's a nitrogen loving species. It's possible you will go into states of these kind of small dunes developing of Leymos (28:32) I think it probably be it and then one point probably ammophila it really needs the sand dynamic, that should be some wind blown sand

T: **Would you prefer giving a kick start or just leave it alone and it will come and let it be?**

I: I would like to let it be but I can imagine because it can take quiet long. But, it depends on what it looks like in the end. Yeah, it's difficult question it depends on what it looks like otherwise you can kickstart a little bit. Another way to do it is also throw in some wreck material, so after storm, after the winter season, like wreck on the beach. And within it, there's a lot of rhizomes and seeds so it maybe a little bit of a natural way than planting all this. The way we plant that we used for the forestry design and the way we plant, it always takes away the dynamic as well , we don't take this spatial organisation of this plant into account. We just plant them in the field on the certain distances from each other. So, I'm not big favour for that

T: **You can copy it a bit it is never how it should be?**

I: We don't do that, we don't copy. If you want to have it at least, I would say it's a nice experiment to see what's happening

T: **Do you think there would be an opportunity for creating habitat for bird species in this new dunes?**

I: I think at the beginning it would be bare sand flat. And if it sufficiently high and there's not a lot vegetation close to it. It means especially for protected species like terns species, it would be an optimal kind of habitat. So the terns, for example, they used to be in great number on a the Beer so the beer was the Maasvlakte became, so it was nature area there is this book "Vogeleiland Beer" I found that last week in the secondhand shop.I bought it, which is cool But, this terns is all around the Netherlands, we create and build artificial islands to accommodate this species. And I think there would be opportunity for this species on this type of island. Well, this sort of nature area here as well. But, again, it depends on the dimension because it's going to be wave-dominated environment, exactly next to the Northsea. So it's also possible that the dynamic in this system is too large for the species to be there comfortably

T: **That would perhaps be an option for the Lachstern?** Because this bird dissapearedis in the red list but now it seems to disappeared

I: Yeah, if it is gone, it's hard to get it back. So, some of these terns, also the "visdiefje"and "zwarte stern" they don't have large nest fidelity, they do need to find the area and I think for the Lachstern maybe harder considering the fact that they don't actually come here.

T: Yeah, would take too long probably. For now, we're working with target species for the different kind of nature types. Now, we had selected the Dunlin because it has disappeared as the breeding species but across it is very common in Waddensea. The Bonte strandloper. I looked a bit into that and said that there was a territory found in the Netherlands in 2015, so it is presence in the Netherlands but it apparently breach anymore because it also the southern of its areaal. But we did select because it seems to be a good target for facilitating, yeah perhaps they return but also improving nature around it. And this dunlins they breed in open area but they also need vegetation. **Would you then think it would be the suitable species for this area?**

I: I don't know exactly. I must say I'm not a bird ecologist. I do a little bit because I work on one of the project. I work on biogeomorphology, how vegetation influences morphological processes in an environment and its biodiversity then again influences its vegetation . So this is the biogeomorphic feedback we call it. And one on the projects I had with phd students, we look at birds and how they fuel biogeomorphic feedback, so especially in small islands, we have massive amount of birds, so let's say in the …(34:67) we have about in the breeding season, about 3 ton of bird species that is brought to this island and you can see the plant that grow in this island, they use this organic material to grow on, you can look at the ___ (35:12) of vegetation, having the idea that you use the nitrogen from the atmosphere, did you use nitrogen from the sea, or did you use from for example, from other organic sources that you find here. So, we also want to extend this and look at for example, the island in Haringvliet. So, I know a little bit about birds but mostly how they fuel the biogeomorphy. How vice versa this area that develop, how this determine the habitat suitability for these birds. So, indeed, I know the Bonte strandloper needs some vegetation. So, especially in the beginning, it will not be a suitable habitat I think because it's going to be bare. Normally, in this development of this environment, right, you would say that first you have the species that prefer this bare open habitat which can be the terns but that can also then again the area needs to be wide enough so it's not scary for them being too close to the ocean because the ocean is a dangerous place. Then, if at one point, the area starts developing more and more, then, potentially other species can come in. well, this can be of course, the gulls for example if the ___becomes high enough, then the problem, gulls can also predate on smaller species, so then it can also become unavailable for others. Target species, they can work, because you can understand what kind of habitat they require. But, for birds, unfortunately, well you can accommodate but they choose, so I don't know. So, species that are rare, it's hard to get them back, and for the Bonte strandloper that the area in which the forage that close by as well. So, the forage in the intertidal flats, right. And , of course, those are in the Haringvliet, if it's going to completely open, you will have that again. But right now, it's not really so I don't know. So, in the Waddensea, of course, there's a bank of the food close by. So they use it to a stop off place. Yeah, I'm not so sure. They cant fly to a long distances to forage. I think that they eat mostly shells or worms, I'm not so sure. But I know that they eat the benthic species.

T: Yeah, interesting. Something we need to keep in mind. I think we didn't think of the different types of dunes. Of course the micro dunes, the embryonic dunes, they will be there for a quiet long time in the beginning

I: Yeah, potentially, they always stay in this state, potentially doesn't go to the big dunes

T: Okay, so it's not a given that it will become those dunes again.

I: No

T: Okay, I thought it's always a natural succession

I: Well, it can stay in a lower state for a very long time and to go into a very high well developed dune, so it depends on the storm climate as well, right? Because if you have major storms, a small dunes are impacted, sand is taken out of the system again. I'm not saying that it's not possible, but that's why I said it's important the spatial width of the beach. I think it's going to be unlikely to have large dunes. I think they'll probably stay in a lower state. If we leave it natural, so if we don't plant it, it's possible to have these larger things.

T: Yeah, indeed kickstart the succession but…

I: Yeah, but still, I mean these plants they can cope with the sands very well. But let's say that we have 50 centimeters so half a meter of sand deposited every year in a specific area. Then you still need quite some years right to go into a dune that is more than 10 meters and then it's possible so once it's 10 meters, it also means that the sands travel up 10 meters to reach that point to have it growing again. Yeah, and what you will see is that it starts developing more and more on the western side. So, one point, good large dunes that we have, they're also remnants of the past.

T: Yeah they've taken centuries or millenia, so..

I: Yeah, there are some nice opportunities right for dunes developments for example in the Horst you can see how fast it can go. If a big nourishment, natural nourishment, like the sandbanks, if they wash ashore and can go fast, but then it was also a lot, a lot of sands and a large base that was there.

T: **yeah, and what would you think of around a number for the big dunes?**

I: I'm not sure if you notice of the publication of Marinka. she looked a little bit of the embryonic dunes development. So, she looked a little bit at this. She works at VMR, Imares, Wageningen Marine Research. She did some calculations, but keep in mind that all these calculations are based on already existing dunes. And just the development of the embryonic dunes in front of it. This is completely different system right there. So that also means that the processes are different. So, I can't give you a number on this.

T: Yeah, I'll look into it. We have another question. What method can be applied to keep the area of the dynamic dune system. **So just to keep it natural, but perhaps that's now a bit different with the whole uncertainties, yeah, of what type of dunes will be?**

I: yeah exactly. So I think most likely it will stay a little bit lower type of dune system. Well, if that's the case, you also have storms affected there. So you would have constant recovery, rebuilding cycling, because that's normally how it goes. And otherwise there can be potential bottlenecks, so we have a general we have a very high of course, nitrogen deposition. So in general, all around the world, worldwide we have greening of dune systems. So they become too stabilize too green, too much vegetation. And if there's too much vegetation, there's no dynamics. So there's the grassing of the dunes, they become too grassy. There's no natural biogemorphy feedbacks anymore, and it also changes the system, the functions that it has.

T: **so it's very important to also look at the surrounding if there isn't supplus of nitrogen?**

I: I think it's just good to skip all these potential bottlenecks and identify them. Because the developing of the system it's also very much depending on chance. So if we have a large number of storms, it really depends on timescale. You look at the generally, we have a four year timescale matters. Because that's a new government selected. That sometimes we have decadal timescales, but that's pretty much what we can do because then we think in already in a lifetime and a lot of

these natural forming process sometimes they need a bit longer so it's something will develop, might no be on the times that the people wanted

T: interesting. A lot to think about, very intrigued.

2.6 Interview Lies van der Pol – Municipality Westvoorne

This interview could not be included yet because of delayed response from the Interviewee.