Building with Nature

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Abstract

In this thesis, a literature study is presented about Building with Nature and its applications. Building with nature is about combining the protection of the coast and the improvement of the recreational area and the ecosystem in a multifunctional application. This is achieved by using the natural dynamics of the area to redistribute sand over a large area. Three nourishments are investigated that all lie in different environments; a sandy beach, an estuary and a lake. These nourishments, the Zandmotor, the Galgeplaat and the Workumer Buitenwaarden nourishment, all have similarities and differences. Model studies to predict the behavior of all three nourishment are used in this thesis to explain the dynamics and changes and to point out significant differences and similarities between the three nourishments. To conclude, a 'zandmotor-like' nourishment is proposed at the coast of Lincolnshire in the UK. Nowadays, this coast is strengthened by annual nourishments. These annual nourishments may be replaced by a mega-nourishment to protect the coast, increase the recreational area, stimulate the ecosystem and biodiversity, but also work together with nature, which is a win-win situation for both humans and nature.

1. Introduction

Very many people on Earth live in coastal areas. These areas are favorable because of the many opportunities, like, for instance, easy transport methods and recreation. Development of these areas, together with sea level rise and subsidence, creates problems. The amount of space available remains the same, or even decreases, as the population grows. In this way, the sea becomes a significant threat. To keep the sea out of the inhabited areas, good coastal management and protection is needed. Formerly, this coastal protection was achieved by building solid structures, like seawalls, groynes, breakwaters and rock armors. These solid structures protect the coast, but have some significant downsides. The construction and maintenance costs are very high, and it causes extra erosion in places where there is no solid protection structure. The structures are also preventing the natural accumulation of sediment at the coast, thereby compromising the natural adaptive capacity of shorelines to keep up with a relative sea-level rise. To diminish these downsides, a new concept came up that protects the coast in a different way. Instead of 'fighting' against nature, this concept uses nature to protect the coast. This concept is conceived by a company called Svašek Hydraulics, and later developed by Ronald Waterman (Waterman, 2008). The idea came up during the planning of the construction of the Maasvlakte 1, an extension of the Port of Rotterdam. Rocks had to be transported from Norway to construct the harbor. This was however very expensive so another solution was wanted. J.N. Svašek came up with the idea to construct most of the port with sand, and use concrete blocks, which are less expensive and can be made locally, for the steeper parts (Stive, private conversation).

The aim of this concept is to create a (semi-)natural and dynamic environment that adapts to the ever imminent threat of climate change. This (semi-)natural and dynamic environment can be created in several ways, like by 'mega-nourishments', oyster-reefs and dunes. It uses the dynamics of the local nature to protect and/or improve the environment. Wind, currents and waves can be used to redistribute sand. Certain animals, like oysters and mussels, can stop erosion at the side of banks and flats and encourage the development of the biodiversity (de Vriend, et al., 2014). Vegetation can improve the conditions at the coast so that the ecosystem is more suitable for certain species and at the same time increase the strength of the coast. Building with nature aims for multifunctional applications, to combine the protecting the coast and the improvement of the ecosystem, and thereby use the local dynamics of nature. Formerly, we could not afford to think like this. Monofunctional applications were the only way to protect the coast. Multifunctional applications need perfect collaboration between different parties, a long-term view on how the application will react to the environment and vise versa and it requires a lot of money for monitoring and gaining knowledge. It depends on the development of the country, if building with nature applications can be applied (Stive, private conversation).

In this thesis, a literature study is performed to investigate the ways building with nature is applied, where is it nowadays applied and where building with nature may be applied in the future. An overview is made to show which applications are performed at beaches, in estuaries and/or in lakes. This overview is then used to explain the applications investigated in the case studies in chapter 3. These case studies are: the 'Zandmotor' near the south west coast of the Netherlands, the 'Galgeplaat' in the Oosterschelde in the south of the Netherlands, and the 'Workumerwaard nourishment' in the 'IJsselmeer' in the north of the Netherlands. These case studies are all located in a different kind of environment; the 'Zandmotor' is located at a beach, the Oosterschelde is an estuary and the 'IJsselmeer' is a lake. All three case studies are nourishments, but in a different environment.

To start off, the first question asked is: What is Building with Nature? Second, This is explained by the use of different applications in different environments. Third, another question is asked; what are the differences and similarities between nourishments at the coast, in estuaries and in lakes? Fourth, the analysis of the nourishments is used to find a location on Earth, where a nourishment can solve coastal safety problems and/or improve habitats for the local ecosystem.

2. Building with nature applications

Here, several applications are described that are used in different environments.

2.1 Beaches

2.1.1 Mega-nourishments

The most common way to maintain the coastline is to nourish the coast with regular sand nourishments. These nourishments are large volumes of sand that are deposited at the beach or at the shoreface to keep the height of the beach relatively constant and to protect the coast from too much erosion. The main downsides of this method are the steepening of the beach profile (Svašek, 1979), the plants and animals on the seafloor are regularly buried under a load of sand, which prevents the growth of biodiversity and brings the ecosystem to a more or less constant state of disturbance (de Vriend, 2014), and the nourishments are relatively costly. The typical recurrence time of these nourishments is about 5 years, but this depends strongly on the position. The nourishing of only the upper part of the shoreface tends to lead to an over-steepening of the coastal profile, hence to a more offshore directed sediment transport, and, in the long run, the necessity to nourish more frequently. This over-steepening can also lead to an increase susceptibility to coastal erosion when the nourishments stop (Stive et al., 1991). These nourishments have, however, contributed significantly to the coastal safety today, but since these nourishments have many downsides, a solution was sought-after to decrease the negative effects and maintain, or even increase, the positive effects of the nourishments. The solution that was found was a mega-nourishment, like the one seen in figure 2.1. The idea of a mega-nourishment is to deposit a large load of sand at once, instead of regularly nourishing the coast with small deposits. It is thought that this causes less disturbance at the bed and plants and animals will not be buried under a load of sand. This allows plants and animals to grow normally, and is less costly in the long run. The mega-nourishment will eventually spread out along the coast due to the energy released on the bed by waves, tides and wind. Waves stir the sand when the wave base touches the bed. Currents generated by waves, wind or tides then transport this sediment. When sand is exposed to the air, wind can pick small particles up and transport them onto the beach or into the dune area.

This mega-nourishment provides protection to a large stretch of coastline. Not only the shoreface profits from this nourishment. The sand is not only distributed along the coastline, but sand also ends up in the dunes and on the beach. The construction of a mega-nourishment may lead to a decrease in disturbance at the bed in the long run, causing the ecosystem to have move time to recover and thrive. This can lead to pilot vegetation and juvenile dunes on the mega-nourishment, which may cause the mega-nourishment to be more stable. The growth of the dunes, due to an increase in sediment supply, has, aside from protection of the coast, another function. Beneath the surface of the dunes, a groundwater lens develops and when the dunes grow, this lens grows. This is favorable for the economy of the area.

Sand nourishments can be applied in several different environments. This versatility is very useful. Nourishments may behave slightly different in different environments, but the main principle remains the same. Most of the research done on nourishments at beaches is also applicable in lakes and estuaries.

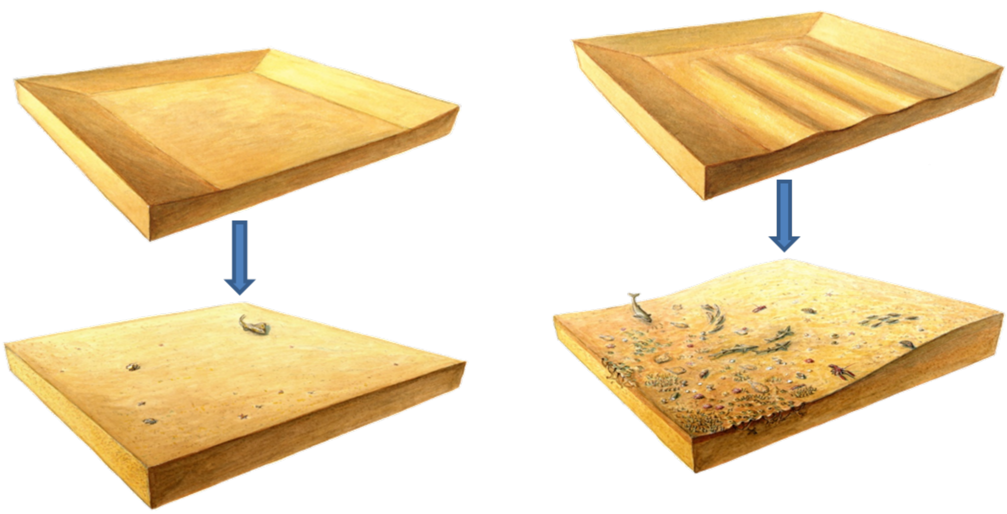
Figure 2.1, Mega-nourishment the Zandmotor at the coast of the Netherlands.
Figure from Ecoshape

2.1.2 Dunes

During storms, dunes can erode heavily. If the beach and dunes are narrow, the probability of flooding during a storm increases. If the beach and/or the dunes are wider, this risk decreases. This is why governments sometimes choose to construct new, additional dune areas. In the Netherlands, this is done just in front of the Delfland coast in the southwest. The new dune area, called 'Spanjaards Duin', with a surface area of about 35 ha, was constructed between 2008 and 2009, using sand extracted from the North Sea floor. The initiative to construct this area came from the construction of the Maasvlakte 1. The amount of habitat taken to build the Maasvlakte 1, needed to be replaced elsewhere. The new dunes of Spanjaards Duin had to be as natural as possible. Groundwater, soil and the basic landscape elements of geomorphology had to be of a quality that would blend in with the local environmental conditions. The grain size of the sand used in the nourishment had to be smaller than the normal nourishments in the area to stimulate aeolian transport and thereby the formation of dunes. The shape of the dune area was planned in advance. An elevated ridge of about 5-7 meters above Mean Sea Level (MSL), a flat depression of about 2.5 meters above MSL and a dune valley were formed in the new dune area. All the higher parts were partly stabilized with Marram grass (van der Meulen et al., 2014). After construction, the area soon began to remodel due to aeolian transport. The salt/brackish sand material gradually desalinated by precipitation and a fresh water lens developed in the subsoil of the area. The spontaneous colonization of plants stabilized the area. The sand is mainly transported from the beach and valley bottom, to the old fore dunes. This strengthens the dunes and thereby protects the hinterland.

2.1.3 Sand mining/sea floor landscaping

In the Netherlands, about 12 million cubic meters of sand is extracted from the sea floor each year. Due to rising sea levels and construction sites at the coast, the demand for sand has multiplied, and will continue to do so in the future. To prevent the water from becoming stratified and depriving plant and animals that live on or near the seabed from oxygen, it was not allowed to dig deeper than 2 meters below the seabed. To keep up with the increasing demand for sand, this depth has been extended to 20 meters below the seabed. These extraction pits are often left relatively flat, as seen in figure 2.2. A flat seascape, however, does not encourage biodiversity. A series of tests was executed to study the effect of artificial bedforms on the biodiversity and productivity. Selective dredging was implemented in 2010. This created an artificial bedform of about 700 meters long and 100 meters wide with crests of 10 meters high, which is similar to natural sand waves (Figure 2.2). Recent monitoring shows an increase in the amount of fish found in the extraction pits relative to outside of the pits. The largest assemblages of fish are found near the artificially formed bedforms, which may indicate the success of the tests. Other tests are executed and hypotheses' are made on what the artificial bedforms should look like, and if they should be parallel to the dominant current or not. Monitoring should determine the best shape of the artificial bedforms (Baptist, ecoshape).



2.1.4 Mangrove restoration
About 35% of all the mangrove forests in the world have disappeared in the last two decades of the 20th century (Kamali et al., 2011). There are several reasons why mangroves forests shrink. For instance, the building of fishponds, deforestation for wood production, the damming of rivers etc. that block the supply of mangrove seeds and subsidence of the land and/or sea level rise. To successfully restore the mangrove forests, it is vital to reproduce the conditions that are favorable for the growth of mangrove forests. If these conditions cannot be achieved, chances are that mangroves will not settle or will disappear again after settling. Breakwaters of some sort are commonly used to create a low-energy environment. This is often done by building permeable brushwood dams in shallow areas (see figure 2.3). This causes sediment to settle, which lifts the land and creates a suitable habitat for mangroves. Seeds are transported by rivers and currents, and end up in the low-energy area. Here, the seeds will settle and, if the conditions are favorable, will eventually grow (Kamali et al., 2011). Mangrove forests provide important ecosystem services, such as fisheries, room for aquaculture, opportunities for recreation and provision of timber products. In addition to that, they shelter the area behind then from the sea, thus protecting the area. Mangrove forests can adapt to sea level rise and protect the coast from the rising water (de Vriend, 2014). However, many mangrove restoration projects fail completely or fail to reach the goal set up beforehand (Kamali et al., 2011). This is often caused by the amount of chemicals used in the fishponds. That pollutes the water, which reduces the waterquality below the threshold for mangroves to grow.

Figure 2.3, Permeable brushwood dams in Java.
Figure from dutchwatersector.com

2.2 Estuaries

2.2.1 Oyster reefs
Oyster reefs are used to prevent erosion from intertidal shoals. Intertidal shoals are very susceptible to erosion when the conditions change, by, for instance, damming of a river. If the tidal amplitude and prism change, wave action becomes more prominent. This wave action erodes the tops of the shoals, flattening them. These changes to the shoals have a negative effect on the populations of residential and migratory birds, which use the area for feeding and resting (de Vriend et al., 2014). To interrupt the sediment transport from the shoals, oyster reefs can be created along the edges of the shoal. Oyster

shells are put into a cages, which are placed at several locations along the shoal edges (Figure 2.4). Empty oyster shells are the perfect substrate for juvenile oysters to settle. This leads to a living oyster reef after a few years. These reefs catch sediment and strengthens the edges of the shoal, thereby reducing the amount of erosion. The major benefit over methods, which do not fall within the regime of building with nature, is that if the oyster reefs are viable in the long run, they will be able to adapt to a changing sea level. This is a capability that does not count for the 'traditional' methods (de Vriend et al., 2014). Oyster reefs also catch very fine grained sediment, which causes the shoal to build up. Oyster reefs are bio-feeders, which means that they catch sediment and filter the eatable materials out. This causes the shoals to adapt to the predicted sea level rise.

Figure 2.4, Artificial oyster reefs are being fabricated.
Figure from Ecoshape

2.2.2 Sand nourishments

Sand nourishments in estuaries can be used to restore tidal flats and protect the low-lying areas near the estuaries. Changes in tidal prism and tidal amplitude can severely change the appearance of tidal flats in estuaries. To maintain these tidal flats, sand nourishments can be implemented to restore the tidal flats. These nourishments work generally in the same way as the mega-nourishments at beaches, mentioned earlier. The wave-activity is, however, less and wind-blown dunes do not form.

2.3 Lakes

2.3.1 Nourishments

Since the coasts of lakes are often very densely inhabited, the risk of a catastrophic flooding is large and the available space for recreation and safety decreases. To protect the dikes around the lake, nourishments can be implemented. In the Netherlands, several projects are running to investigate the best way to implement the nourishments. In the IJsselmeer, two different sand nourishments are applied, which both have different shapes. One nourishment is constructed as a sand ridge, parallel to the coast, where another is a hook-shaped nourishment perpendicular to the coast. Both nourishments are closely monitored and will be monitored until at least 2017. These nourishments have a similar way of protecting the coast as the mega-nourishments at beaches. Wind and waves redistribute the sand from the nourishment gradually over a large area (van Slobbe, 2013).

2.3.2 Vegetation

Vegetation, like saltmarshes, is an important factor that reduces incoming energy on dikes. Plants reduce the flow velocity as they absorb some energy from the waves and currents passing by. This ability is one of the main factors why vegetation is often used on dikes etc. to protect the inhabited areas behind the dikes. Roots of the plants also stabilize the soil, preventing slumping and other kinds of mass movements on the dike.

3. Case Studies

In this chapter, three case studies are performed. In these case studies, the main focus lies on the problem, plans, construction, monitoring and (expected) outcome.

The first case study that is performed is the Zandmotor, second the Galgeplaat and third the Workumerwaard nourishment. All these cases include a nourishment of some sort in three different environments.

3.1 Zandmotor

The Zandmotor is a mega-nourishment at the coast of Zuid-Holland, in the Netherlands. This nourishment is composed of 21,5 million cubic meters of sand. The southern part of the Zuid-Holland coast is in need for better protection and is lacking room for nature and recreation, therefore, the main reason for the province of Zuid-Holland and the Ministry of Infrastructure and the Environment to build the Zandmotor is to increase the safety inland with more room for nature and recreation (Mulder & Stive, 2011). A second aim is innovation and the development of knowledge. Since, building with nature is a relatively new concept, the amount of knowledge is small. There are nearly no studies performed on projects like the Zandmotor.

After hurricane Katrina struck America in 2005, a ‘New Delta Committee’ was founded in 2007. This committee was primarily implemented to provide advice on the country’s preparation for mitigating flood risk in the near and far future (up to 2200). This committee delivered 12 recommendations for coping with climate and other environmental changes. The main message in all recommendations was to adopt a soft engineering strategy in the form of sand nourishments to mitigate long-term coastal recession instead of hard, concrete coastal protection. One of the recommendations was to increase the yearly sand nourishment volume for the Dutch coast from around 12 to 80 million cubic meters per year. This was the ideal scenario according to Waterman. He wanted to increase the width of the entire Zuid-Holland coast from Hoek van Holland to Scheveningen with nourishments (Stive, Private conversation). This increase caused several problems. The costs became very high and the beach got wider, which is less attractive to the public because the water becomes less accessible. The stakeholders, involved in the process, were also against this idea. Some stakeholders were interested in housing in the area, others were more interested in the ecological aspect of the project. Within this backdrop, the idea of the Zandmotor was born (Stive et al., 2013a). The Zandmotor is supposed to be a spit to the north of Ter Heijde, a small village in the province of Zuid-Holland. This shape is thought to provide the best recreation and development of knowledge and safety. The nourishment is relatively concentrated, so it does not affect the entire coast immediately. The idea is interesting, not only for scientists, but also for the surrounding public. Kitesurfers love to go surfing in the artificial lake, it is a perfect place for a quiet walk and the dynamic nature gives you something new, every time you come there, so it never becomes boring. This idea is much more attractive to the majority of people that have something to do with it. Spatial quality is also important. The spatial quality of the area increases significantly due to the construction of the Zandmotor. All these factors together and the collaboration of all stakeholders provided the opportunity to build a multifunctional application; the Zandmotor.

This spit would extend 1,5 km into the sea and would be about 3 km wide. An addition to the original design, a small lake (7,5 ha) between the base of the spit and the dunes, should moderate the negative effects on the groundwater flow in the dune area where a fresh water lens is situated, which is used for drinking water (van Dijk, 2012). The final version of the Zandmotor is shown in Figure 3.4.

A remarkable fact about the Zandmotor is that one of the main founders of building with nature is against it. Waterman wants to restore the coastline as it was in 1700 and thinks that we should aim for a so called ‘flexible dynamic hollow equilibrium coastline’. The Zandmotor may eventually reach the equilibrium coastline, but, says Waterman, the Zandmotor has not the right shape (van Dijk, 2012). Waterman prefers regular nourishments to Zandmotors. His ideals are to keep the coastline just as it was before, or expand the beach area everywhere with the same amount. No ‘weird’ shapes and other structures, just keep the old coastline we have known for ages. Baptist, another scientist that is committed to Building with Nature, however, pleas for Zandmotors to 'feed' the coastline with sand, because regular nourishments disturb the ecosystem in such a way that it needs at least four years to recover. This means that the ecosystem is not even close to recovered when the next nourishment comes. It is, however, also not clear if the Zandmotor does not disturb the ecosystem. Studies are performed to investigate this (van Dijk, 2012). A row of Zandmotors may not be the ideal solution either. This disturbs the ecosystem and the current at the coast, but may also be dangerous for swimmers. The currents at the coast are very unpredictable, which makes it difficult to protect swimmers from the strong currents that can appear. The coastline may become less attractive, because the natural, straight, seemingly endless coastline is gone.

To realize the Zandmotor, sand needed to be transported from the bottom of the sea, about 10 km offshore, to the site of the new Zandmotor. This required dredging boats, which, fortunately, were close by at the time due to the construction of the Maasvlakte 2, an extension of the Port of Rotterdam (van Dijk, 2012).

The prediction of evolution of the Zandmotor is very difficult due to its unique character. There has no other project been like this one so there is no comparison material. However, with models and the knowledge of experts, predictions have been made on the morphology at 3, 5, 10, 15 and 20 years after construction (see figure 3.1). The models show a gradual reduction in its width (cross-shore) and an increase in length (alongshore) of about 8 km in 20 years time. The approximate beach area gained over this period is thought to be about 200 ha (Stive et al., 2013b).

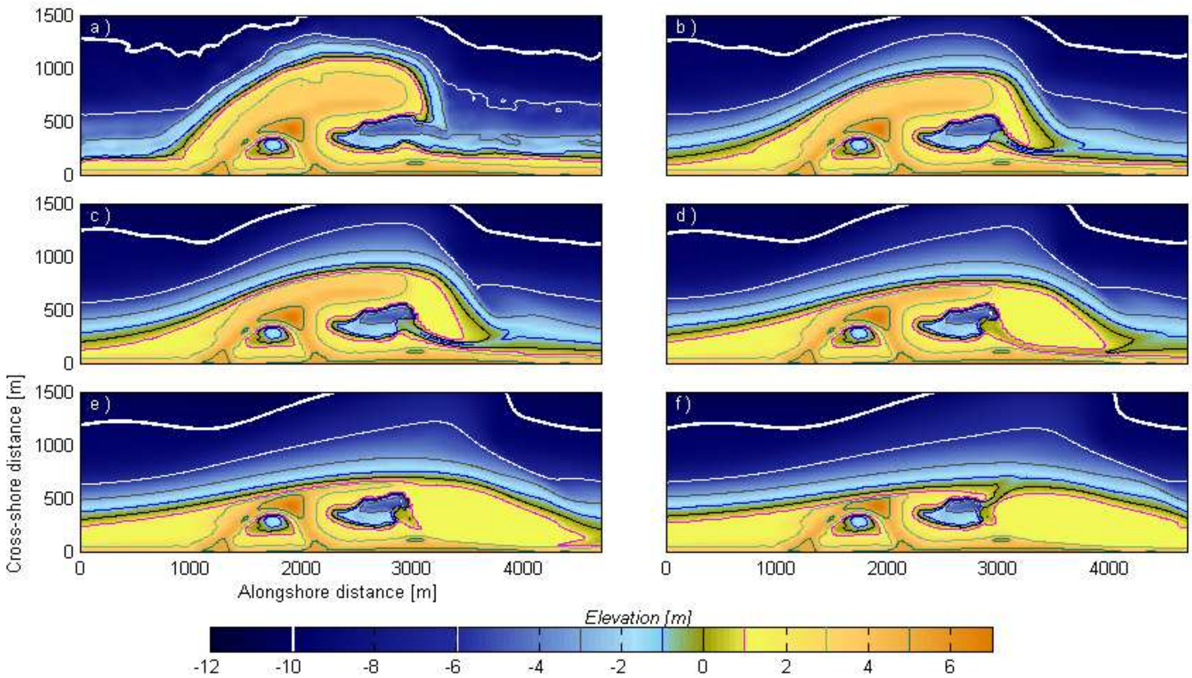


Figure 3.1, Model prediction of how the Zandmotor will evolve over time. Figure a shows the initial shape, b-f show the predicted bathymetric and topographic evolution, 3, 5, 10, 15 and 20 years after construction.
Figure from Stive et al, 2013a

The first year after construction was highly energetic. The winter of 2011-2012 was very stormy and caused the shape of the Zandmotor to change considerably. The maximum width decreased from 0.96 to 0.84 km and the length increased from 2.4 to 3.6 km, which is both significantly more than expected. The north side of the Zandmotor reveals the largest changes during the first year as shown in figure 3.3. Figure 3.3 shows the interpretation of aerial photos taken between July 2011 and January 2012 (Man, 2012). The tip of the spit curved landward and formed a transverse sand bar. The spit is separated from the shore by an about 100 meter wide shore-parallel channel, forming a lagoon with a surface area of about 20 ha (Stive et al., 2013a). This lagoon turned out to be a perfect nursing home for flatfish and other small animals. The tip of the spit provides shelter from waves, which creates a quiet environment for animals to reproduce and nurse their offspring (Stive et al., 2013b). Recently, seals have been spotted on the Zandmotor.

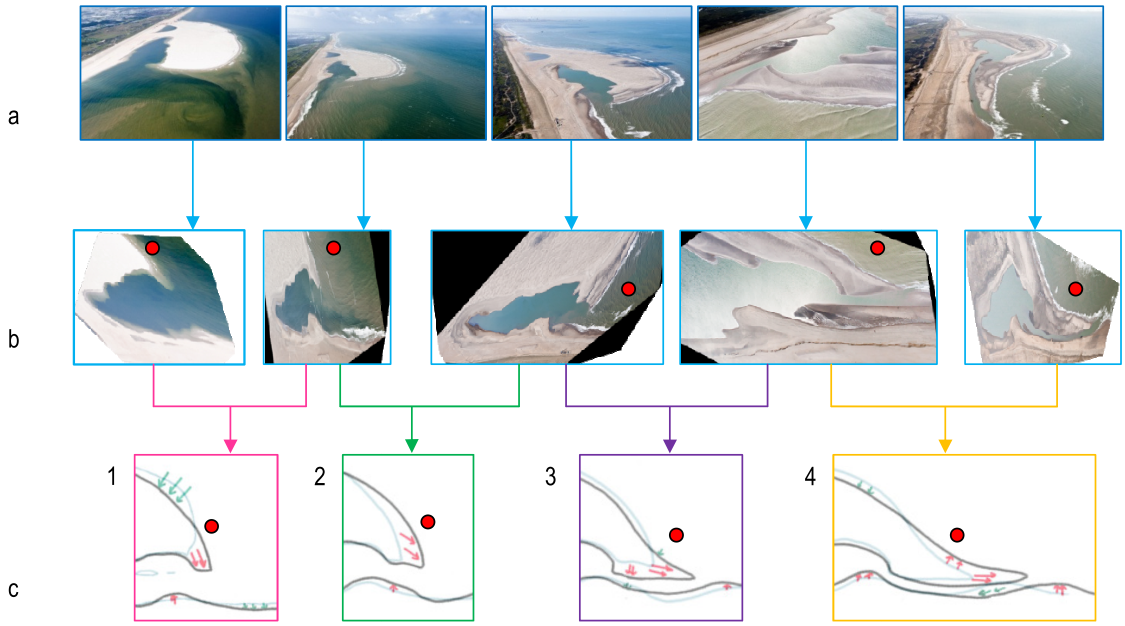


Figure 3.2, A model study performed by Man, 2012. a) aerial photos in the period July 2011 - January 2012 (from Rijkswaterstaat 2012) b) Rectified images of the aerial photos with Adobe Photoshop, focused on the north area of the Zandmotor. c) Illustrations of interpretations of the morphological changes between the aerial photos. Note that the interpretations are subjective and have the purpose to interpret the morphological change qualitatively. No dimensions of the Zandmotor have been incorporated. (According to Man, 2012) *Figure from Man, 2012*

The Zandmotor may have changed a bit faster than expected, but it does confirm the predicted behavior of feeding the surrounding coast. (Stive et al., 2013b)

Two years after the construction, about 2 million cubic meters of sand have moved, of which 0,6 million cubic meters have stayed on the Sand Engine, 0.9 million cubic meters in its immediate surroundings and 0.5 million cubic meters have been transported outside the survey area, either to the dune area or to deeper water. This agrees with earlier predictions (Stive et al., 2013a, b). Small pioneer vegetation has settled, which caused small dunes to develop on top of, and all over the Zandmotor, 2 years after construction (Linnartz, 2013).

According to the 'Beleidsevaluatie Zandmotor 2013', which was released by the Dutch government, the first changes have been positive. Coastal safety, nature and recreation have increased. Unfortunately, due to the young age of the project, there is still too little information available to make assumptions about the future.

Nowadays, 2015, the Zandmotor has changed quite a bit, as seen in figure 3.4. The tip of the hook is almost completely welded to the coast. The Zandmotor has also spread quite a bit. It was constructed off the coast of Ter Heijde, but now it reaches as far as Kijkduin, which is more than a kilometer North.

Figure 3.3, Left, the Zandmotor is shown just after the construction, where on the right, the Zandmotor is shown what it looks like nowadays (May 2015). Sand has accumulated at the southern part of the Zandmotor and the tip of the hook has nearly welded to the coast, creating a lagoon.
Figures from Flickr Zandmotor

3.2 Oosterschelde

The Oosterschelde, located in the southern part of the Netherlands, is a former estuary. In this former estuary, several projects have been carried out, which follow the ‘rules’ of building with nature. One of these projects is the intertidal shoal, the Galgeplaat.

In 1986, a storm surge barrier was built in the mouth of the estuary to protect the land from flooding after a major flooding that struck the province of Zeeland in 1953. This dam is normally open, but can be closed when the water levels get too high. This dam, even though it is open, obstructs the sediment input into the estuary. The construction of the dam caused a significant decrease in tidal prism (25%) and tidal amplitude (20%) (Eelkema et al., 2013). These changes resulted eventually in a decrease in velocity of the tidal current by about 20-40% near the Galgeplaat, as shown in figure 3.5 (van der Hoeven et al., 2006). Because the tidal prism has decreased since the construction of the dam, the channels are too wide for the amount of water flowing through. This disturbance causes sediment to accumulate in the channels, but since the input of sediment has also decreased, a deficit appears. This deficit is compensated by eroding the shoals, which eventually leads to the lowering of the shoals. The decrease of the tidal range leads to the increase of the importance of the wave-activity, which flattens the shoals.

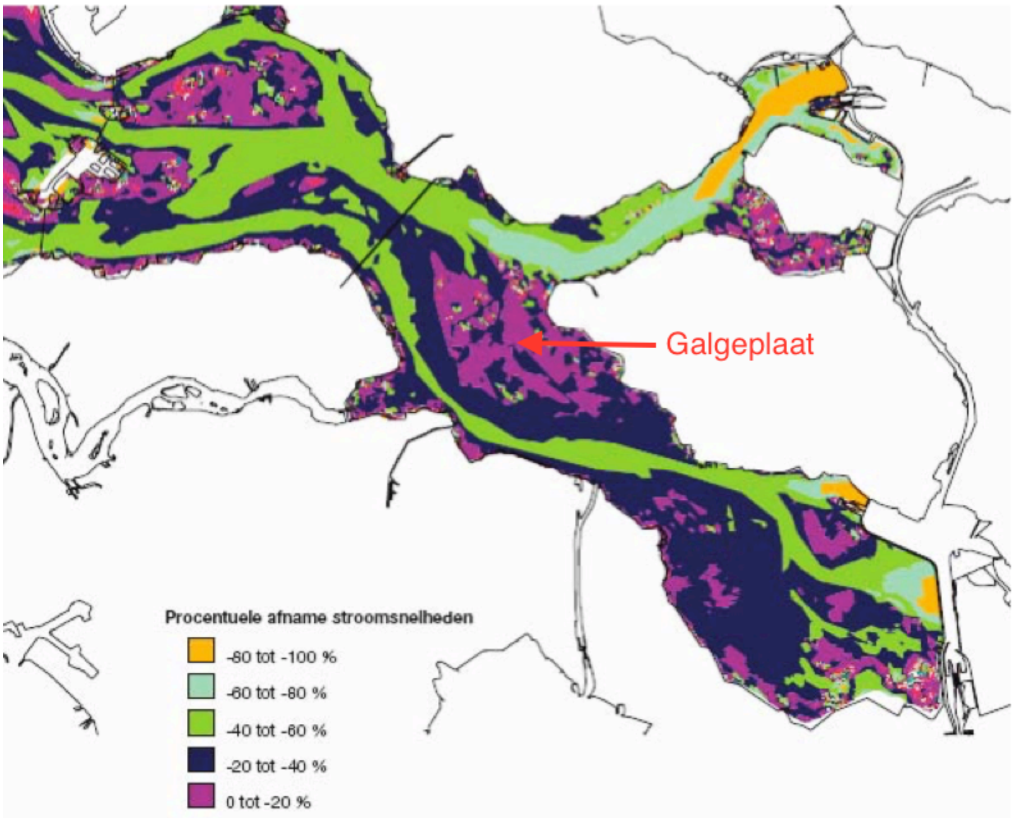


Figure 3.4, velocity reduction of the tidal current in percentages.
Figure from van der Hoeven, 2006

Natura 2000 is a guideline appointed by the European Union, which states that characteristic and endangered habitats should remain and the amount of species should be unchanged. Members of the European Union are required to protect, restore and conserve the flora and fauna of the habitats in their management. This obliges the administrator to take action if there is a reduction in quality or quantity of habitats or populations of animals.

Due to the construction of the barrier, the intertidal shoals are decreasing in height. The prediction is that shoals will decrease about as much as 1.5 m in height before 2045 (figure 3.6) (van Zanten and Adriaanse, 2008). These shoals are often used by birds that feed and rest there (de Vriend et al., 2014). The lowering of these shoals has a negative effect on the habitats and biodiversity. The intertidal area in the Oosterschelde is predicted to decrease by more than 5000 ha in 2045 (van Zanten and Adriaanse, 2008). According to Natura 2000, this effect has to be counteracted. Therefore, action had to be taken to stop the erosion on the shoals. Several measures have been taken to do this. It was, however, not easy to come up with a plan that might actually work in this area. The amount of sand needed to counteract the effects that the storm surge barrier has on the area is about 400-600 million cubic meters. That is 30-50 times the amount of sand used in nourishments on the entire Dutch North Sea coast every year. To put this amount of sand into the system, is logistically and pricewise not achievable (van Zanten and Adriaanse, 2008). A possible solution could be to change the storm surge barrier in such a way, that sediment is able to pass through, but after further investigation, this is also impossible. To keep the changes in the area as little as possible, nourishments are carried out, until a permanent solution has been found. One of these nourishments is located on top of the Galgeplaat. This nourishment consists of 130.000 cubic meters of sand (Wijnhoven et al., 2012) and 150.000 square meters of total area (Borsje et al., 2012).

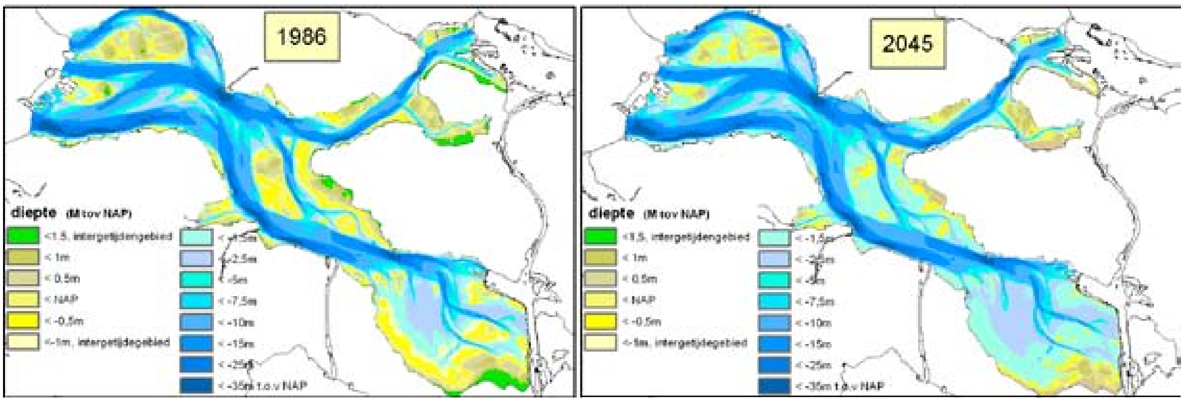


Figure 3.5, the predicted bed height in the Oosterschelde.
Figure from van Zanten and Adriaanse, 2008

The placement of the nourishment was selected carefully. The many mussel plots in the area had to remain (nearly) unaffected by the nourishment, since too much sand in a mussel plot can destroy the plots and thereby the local economy. The nourishment is thought to have a durability of about 30-40 years. The location of the nourishment, the musselplots in the area and the dredging sites are shown in figure 3.7.

The shape and bed heights of the nourishment are shown in Appendix A1. During the construction, a sand wall was first built of approximately 1 m high, forming a ring of 450 m. The ring was filled in with sand during the flood phase of the tidal cycle and spread by bulldozers during the ebb phase. This was done to prevent suspended matter to end up in the mussel plots.

This sand originated from maintenance proceedings in the fairways nearby. The main aim of this nourishment is to investigate if nourishments have a useful effect on the shoals, and if they can temporarily stall the erosion on the shoals (van Zanten and Adriaanse, 2008). The nourishment will not be sufficient to heighten the entire shoal, since it is a pilot project. The predetermined hypothesis was that due to the combined effect of the currents and waves, the nourishment would gradually spread out and heighten the shoal. This would balance the erosion on the tidal shoal, and thereby increase the time when the shoal is above water. The time the shoal is above water, in combination with sufficient food, will benefit the bird colonization in the area (Borsje et al., 2012)

In the years after the construction of the nourishment, careful monitoring showed that after 2 years, only 2% of the original sediment volume has moved outside the nourishment area (Borsje et al., 2012). After 4 years, about 90% of the sand in the nourishment is still within the initial nourishment location. The remaining 10% is distributed over the Galgeplaat. This is visualized in Appendix B. These measurements correspond with the expected durability of 30-40 years (van der Werf et al., 2013).

The placement of the nourishment killed all benthic macrofauna (invertebrates that live on the bed) at the site. Immediately after the nourishment was placed, the recovery started. Monitoring showed that the recolonization was very patchy. On the higher parts of the nourishment, hardly any macrofauna was observed, whereas the lower parts had a relatively rich fauna. The higher parts dried out more during low tide compared to the lower sites. This shows the importance of the shape and height of the nourishment.

After extensive monitoring, lessons are learned regarding the pilot project. These lessons, on how to improve nourishing, include knowledge on nourishments in more dynamic locations, topographical differences in order to speed up recolonization and to minimize the impact on other user functions in the area like commercial mussel beds (Borsje et al., 2012).

To further stimulate the recovery of the shoals and protect the hinterland, wetlands, which were formerly closed off from the estuary, are 'reopened' to enable water to flow into these areas, especially during high high tides and storms (Temmerman et al., 2013). This principle may be applied on other shoals in the Oosterschelde and may be applied in other places, but it needs to be adjusted according to the location and dynamics of the place.

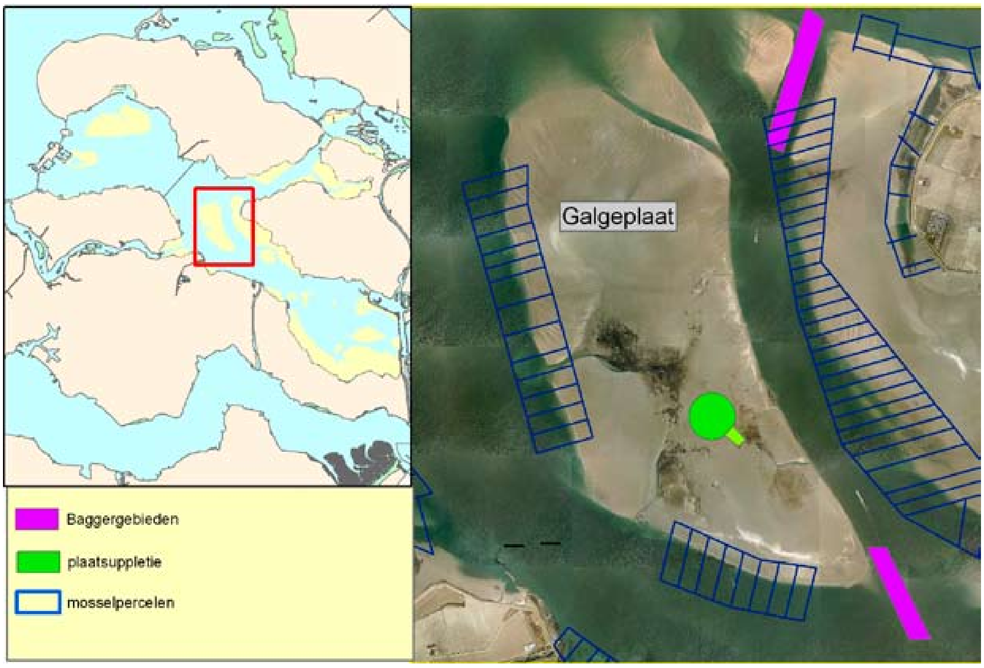


Figure 3.6, nourishments (green), dredging sites (purple) and mussel plots (blue) near the Galgeplaat.
Figure from van Zanten and Adriaanse, 2008

3.3 Workumer Buitenwaarden

The IJsselmeer is a lake in the Netherlands. Formerly called the 'Zuiderzee', this lake had an open connection with the 'Waddenzee' to the north. In 1932, a dam was constructed to close off the lake. This closure caused major changes in the dynamics of the lake. The tidal current was gone and the lake became increasingly less salty. Salt marshes and sand banks soon started to disappear, because the main driving forces had vanished. The waterlevels stabilized and the coastline got fixed. However, since the construction of the dam and the fixing of the coastline, the situation has not changed much afterwards. In 2007, an end came to a relatively quiet period. Policies announced they wanted to change the management of the waterlevels in the IJsselmeer. Their main reasons to change it was the predicted sea level rise in the Waddenzee and to increase the fresh water budget of the lake. In 2008, the Delta Committee proposed to let the water levels in the IJsselmeer rise with the sea level. This would mean that the quasi-intertidal area, about 100 hectares of land, along the Frisian coast would drown and disappear. This quasi-intertidal area originates from the time the Ijsselmeer still had a tidal current and is still preserved due to the small water level fluctuations still present in the lake. To prevent this, adaptation strategies needed to be implemented along the coast. This was the opportunity for building with nature to play a role in the IJsselmeer (van Slobbe et al., 2013). Three 'zachte zandmotors' were proposed at three different locations after a study done by Folmer (Folmer et al, 2010). The aim of this project is mainly the gaining of knowledge and increase of spatial quality (van Slobbe et al., 2013).

At one of the sites, the Workumer Buitenwaarden, a project has started to protect the coast by using building with nature measures. The project consists of a nourishment of about 25000-30000 cubic meters of sand 200 meters off the coast, a line of poles to the north of the nourishment and a glass fiber grid for monitoring (see figure 3.8). The nourishment lies at the edge of the shallow plateau where the waves break. The nourishment is meant to erode within several years and distribute its sand along the Frisian coast. It is predicted that the sand will mostly move towards the northeast where the line of poles break the waves and encourage sedimentation. The 4 km long glass fiber cable measures the temperature every 2 hours. Since sediment has a different temperature than the water, it is possible to detect moving sediment over the cable. Apart from these measurements, water depth, bed height, vegetation and other ecological parameters are measured (van Slobbe et al., 2013).

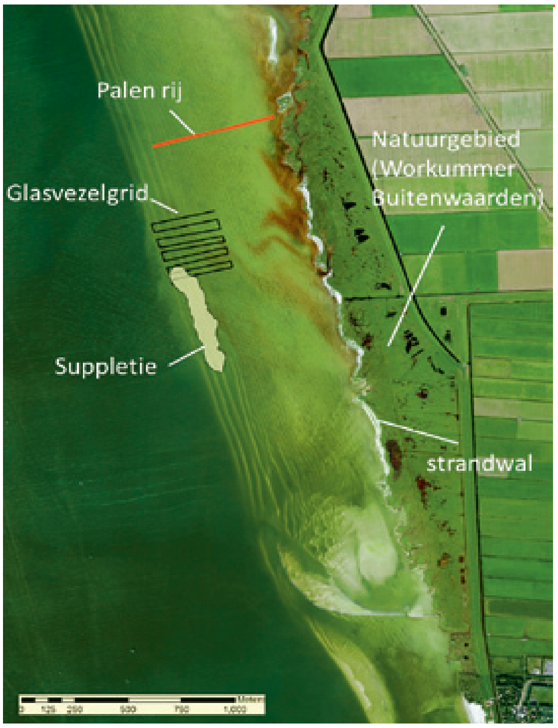


Figure 3.7, an experiment with a nourishment, glass fiber grid for monitoring and a line of poles.
Figure from van Slobbe et al., 2013

Monitoring started in 2011 and will continue until 2018. The morphological changes that already occurred in the system are promising. In 2013, after two major storms in 2012, the nourishment has already taken the original shape of the bed and has lowered in height, which indicates that sand has been redistributed. The nourishment has moved more than 100 m to the north and several tens of meters to the east (see Figure 3.9). The conclusion that can be drawn from these measurements is that the sedimentation of sand is to the north and towards the coast, but the sedimentation rate is lower than expected (van Slobbe et al., 2013).

It is predicted that the coast of the 'Workumer Buitenwaarden' will erode if the water levels in the IJsselmeer will increase. This prediction is made on the basis of measurements done on the beach barrier before and after the winter of 2011-2012. The beach barrier moved landwards by about 20 meters, after exceptionally high waters in January, which indicates a landward movement of the coastline (van Slobbe et al., 2013). Since the project is still very young, definite conclusions cannot be drawn yet.

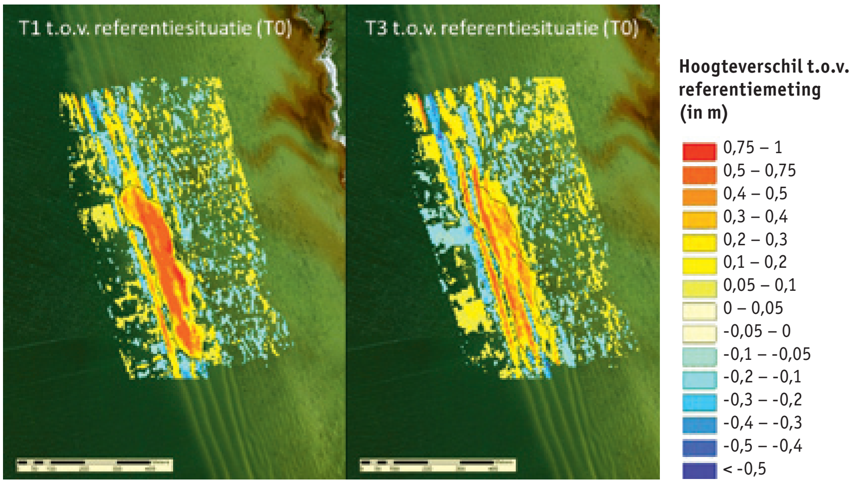


Figure 3.8, Evolution of the nourishment near the Workumer Buitenwaarden, Bed height difference relative to a reference situation before nourishment placement. Left: October 2011, Right: October 2012
Figure from van Slobbe et al., 2013

3.4 The nourishments

The three case studies projected here, all have similar ways of working together with nature. They all use the natural conditions to redistribute their sand over a large area. The ways all nourishments are monitored are different in all locations. The Zandmotor is closely monitored, using photographs and videos, depth measurements, samples and other methods, where in the IJsselmeer, the nourishment is monitored by the use of a glass fiber grid and the Galgeplaat nourishment is monitored by strategic sampling and sightings of birds and other animals.

The purposes of the nourishments are different, but they are all multifunctional. The motive for the Galgeplaat nourishment was to improve the habitat for birds and other small animals that live on and around the shoal. For the Zandmotor and the Workumer Buitenwaarden, the motive was to increase the safety of the coast and improve the ecosystem and habitat.

A cause both the Galgeplaat and the Workumer Buitenwaarden have in common is the man-induced problem. In both cases, a dam of some sort was constructed, which caused the natural conditions in the area to change, with drastic effects, which needed to be addressed.

The shape of the nourishments is also different. The Zandmotor optimally uses the wave and tidal induced currents and the wind to redistribute its sand by a hook shape. The Galgeplaat, which has a circle shape, does not use the wind, because when the shoal is above water, the sand is too wet to be transported by the wind. The tidal current is present but significantly decreased due to the storm surge barrier. The main redistributor is the waves ‘attacking’ the nourishment and stirring the sand, which is then transported by the wave-induced current, and partly by the tidal current. The Workumer Buitenwaarden nourishment has a rectangular shape parallel to the coast. There is no tidal current in the IJsselmeer, so that is disregarded, and since the nourishment is completely under water, wind transport is disregarded too. The only redistributor left is the waves. These waves are locally produced, which means they are not very high due to the short fetch. The nourishment has not the shape like the Zandmotor. This is because of the quasi-intertidal area along the coastline that needed to be preserved. This made it impossible to deposit a large amount of sand at the coast. Therefore, the choice was made to deposit sand near the coast, under water, in a relatively straight line, where it could redistribute its sand slowly along the coastline and not damage the natural environment. The shape of the nourishment is determined by the natural conditions present in the environment.

All three case studies performed in this thesis are pilot projects, which means that it has not been done before, or not on this scale. Knowledge on the subject is scarce and needs to be increased.

4. Discussion

Building with nature is a relatively young concept. This makes making definite conclusions very hard. These projects need time to develop and change due to natural conditions. Knowledge on the subject is scarce and needs to be developed and increased. The only way to do this is by monitoring the projects closely; the learning by doing approach. Different aspects come into play here. Often, the main aim is to provide protection for the coast, but sometimes the main aim is directed to protecting, developing or creating ecosystems.

In the case of the Zandmotor, the main aim was to protect the coast and diminish the amount of work and costs on yearly nourishments. A secondary benefit may be for the ecosystem. Yearly nourishments bury the local ecosystem before it has recovered from the previous nourishment. One mega-nourishment may cause less damage to the ecosystem in that way, and the intertidal pool could provide a nursing home for fishes and other small animals. However, it has not been confirmed yet that the mega-nourishments do not disturb the ecosystem. It may be that the import of sand in nearby areas has been increased to the point that the ecosystem cannot keep up and will still be buried. Monitoring will eventually give the answer.

A downside of building with nature is that it needs a significant amount of space, more than conventional structures. This is a problem, in particular in highly urbanized areas, like New York and Tokyo. The more space between the sea and the urbanized areas at risk, the higher the efficiency of ecosystem-based flood defence. For cities close to the coast, where little space is available, seaward ecosystem creation could be an option. However, one must be aware of the local ecosystem, and not disturb it (Temmerman et al., 2013).

Building with nature is mostly applied in areas that are more developed. To build a Zandmotor in Myanmar, for instance, would make no sense, because the population there would not see any benefits in it. It needs close collaboration with different parties and stakeholders, good planning and a long-term view on the project. Most building with nature projects are relatively expensive at first. There is a need for investigation and research on the site. It is very sensitive to the dynamics in the area. When the final stage of research is complete, the construction can begin. This stage is often also very expensive, but in the long run, the measures pay off.

Most countries in Europe and North-America are developed enough to be able to think about building with nature measures. The UK, for instance, uses a measure called ‘managed retreat’ or ‘managed realignment’ in estuaries, where they remove the first line of coastal protection to create intertidal areas. The benefits of this operation are: 1) lower tidal levels and hence decreased flood risk; 2) reduced pressure on the existing defences; 3) increased area for inter-tidal habitat; 4) additional area for nutrient sequestration; and 5) more space for adjustment to change (Townend and Pethick, 2002). This is not just achieved by breaching the existing sea wall on some spots, because it does not result in the increase of the inter-tidal area of the channel. The entire flood embankment needs to be removed and thereby the inter-tidal area forms an integral part of the estuary (Townend and Pethick, 2002).

Building with nature is implemented in more and more places, all over the world and there are still many places that need to be improved when it comes to coastal protection. Places like, for instance, Lima in Peru, Da Nang in Vietnam, Ystad in Sweden, Poole bay in the UK, Copenhagen in Denmark and Lincolnshire in the UK (Aarninkhof, 2014). Not all these places meet the required level of development, like Peru and Vietnam, but others do, like Sweden and the UK.

One of these places, the Lincolnshire coast in eastern England is discussed here (Figure 4.1). Lincolnshire lies just south of the Humber Estuary and includes part of a nature reserve called ‘the Wash’. The Lincolnshire coast is more than 80 km long. Over 80,000 ha in the area are low-lying agricultural lands, which can be hazardous during floods (Myatt et al., 2003). The ebb-tidal delta in front of the Humber Estuary is predicted to increase in size over the coming years due to the sea-level rise, however, slowly. The ebb-tidal delta is predicted to grow from 16 to 21 square kilometers over the next 100 years (Pethick, 2001). The increasing area of the delta has a positive effect on the safety of the coast. This, however, only accounts for the area where the delta reaches the coast. The exposed shore will continue to erode. For this stretch of coastline, annual nourishments are applied. These nourishments cost much and disturb the ecosystem as mentioned before. Due to the dominantly, wave-induced, southerly current, transportation of sediment is possible. This may also influence the nature reserve ‘the Wash’. In ‘the Wash’, the secondary line of flood defense was strengthened, starting in October 1999. This created more than 70 ha of saltmarshes, which include mudflats and a lagoon for habitats and flood defense purposes. However, most of the Wash still relies on the frontline of defence (Flikweert, private conversation). Saltmarshes are a natural way of protecting the coast, because they reduce wave activity near the coast (Myatt et al., 2003). The vegetation absorbs energy from the waves, reducing them in height. My idea is to replace the annual nourishment with one big mega-nourishment like the one on the Dutch coast. This immediately increases the coastal safety locally, and will increase larger stretches of coastline in the long run. ‘The Wash’ will likely also benefit from this mega-nourishment. Mega-nourishments slowly redistribute its sand over a large area. This mechanism causes the coast to adapt to sea level change. Its slow redistributing nature is beneficial for saltmarshes and other tidal ecosystems. It slowly supplements the area, making it also adapt to climate change and making it able to grow even more, increasing the coastal safety. The British people, however, do not really approve of a Zandmotor-like nourishment at the coast. They think the nourishment poses a threat to the nature reserve. The nature reserve is important for fisheries, which may become smothered by the sand from the nourishment. The proposal to put a ‘zandmotor-like’ nourishment in front of the coast may be a little too straight forward. The area is complex and a lot of parties and environments are involved. It seems like there are three ‘problems’ that need solving. First is the issue of coastal protection. The coastal safety needs to be improved. Second, the Wash should not face any negative affect due to the sand from the nourishment, and third, the Wash needs to be fed with a regular, but slow, input of sand to help it grow. In the Netherlands, there is evidence that nourishments can provide the solution to parts of the problem. Workumer Buitenwaarden nourishment is ‘used’ to slowly feed the intertidal zones at the coast and help it to grow. The nourishment at the Galgeplaat in the Oosterschelde had to deal with important commercial musselbeds in the area that, under no circumstances, could be negatively affected by the sand, and a Zandmotor provides a multifunctional solution for coastal protection and improvement the local ecosystem. A combination between the three kinds of nourishment may provide the answer for the Lincolnshire coast if they are modified to fit the location.

Figure 4.1, The Lincolnshire coast.
Figure from Google Maps

5. Summary

Building with Nature is a way of thinking, which includes humans to help nature, and in return, nature to help the humans. The main aim is to use the natural dynamics, like wind, tides and/or waves, of the local environment to protect the coast, and improve the habitat for the local ecosystem. Building with nature can be applied in several different environments, like at coasts, in estuaries and in lakes. These different environments also have different applications. At beaches and coastlines, among others, mega-nourishments, artificial dunes, seabed landscaping and mangrove restoration can be applied. Estuaries may be improved by the construction of oyster reefs and nourishments to protect the intertidal shoals, where in lakes, nourishments and vegetation may be implemented. In all three environments, nourishments can be implemented to increase coastal safety, improve habitats and/or increase the recreational area. These nourishments, like the ones done on the Galgeplaat, near the Workumer Buitenwaarden and the Zandmotor, have similarities but also a significant amount of differences.

Because there is a shortage of knowledge on the working and efficiency of mega-nourishments, these projects, pilots, are all closely monitored, but in a different way. The Zandmotor is monitored using photos, depth measurements, samples and other measurements. The Galgeplaat nourishment is mainly monitored by the use of strategic sampling and sightings of birds and other animals. The Workumer Buitenwaarden are monitored by a technique that uses a glass fibre grid that measures temperature changes. The purposes for which the nourishment has been placed are also different. The Zuid-Holland coast and the Workumer Buitenwaarden coast both needed to be strengthened, whereas the shoals in the Oosterschelde were eroding, which decreased habitats. Both the problems at the Workumer Buitenwaarden and the Galgeplaat are human-induced due to a dam-like structure that was built and changes then natural conditions in the area.

To conclude, a new location, at the Lincolnshire coast, has been found, where a 'zandmotor-like' mega-nourishment can be applied, with the applications in the Oosterschelde and the Ijsselmeer in mind, to increase the coastal safety in the area, and improve the local habitat and recreation. The nourishment can not just be copied from the Dutch coast and pasted on the Lincolnshire coast, but it needs to be adjusted to the dynamics of the environment.

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Appendix A

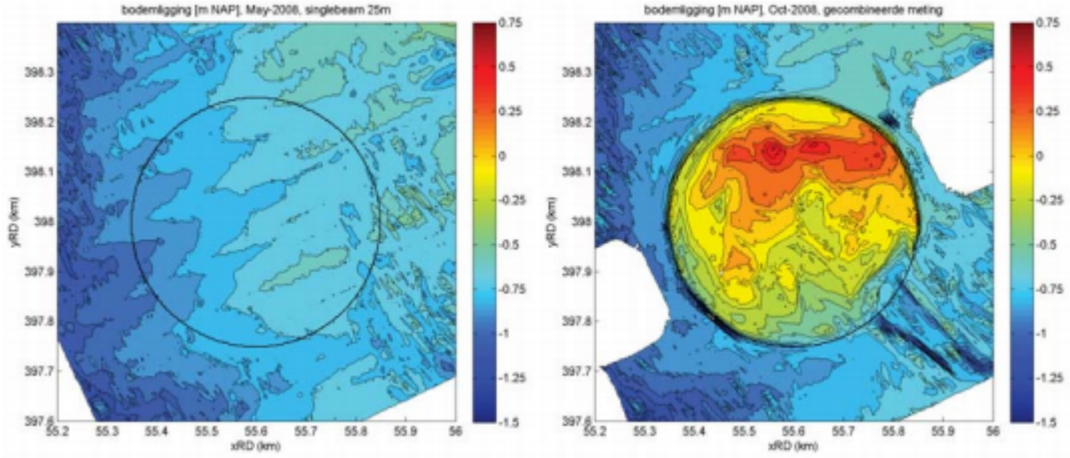

Figure A1, Bed heights before (left) and after construction (right). Figure from van der Werf et al. (2013)

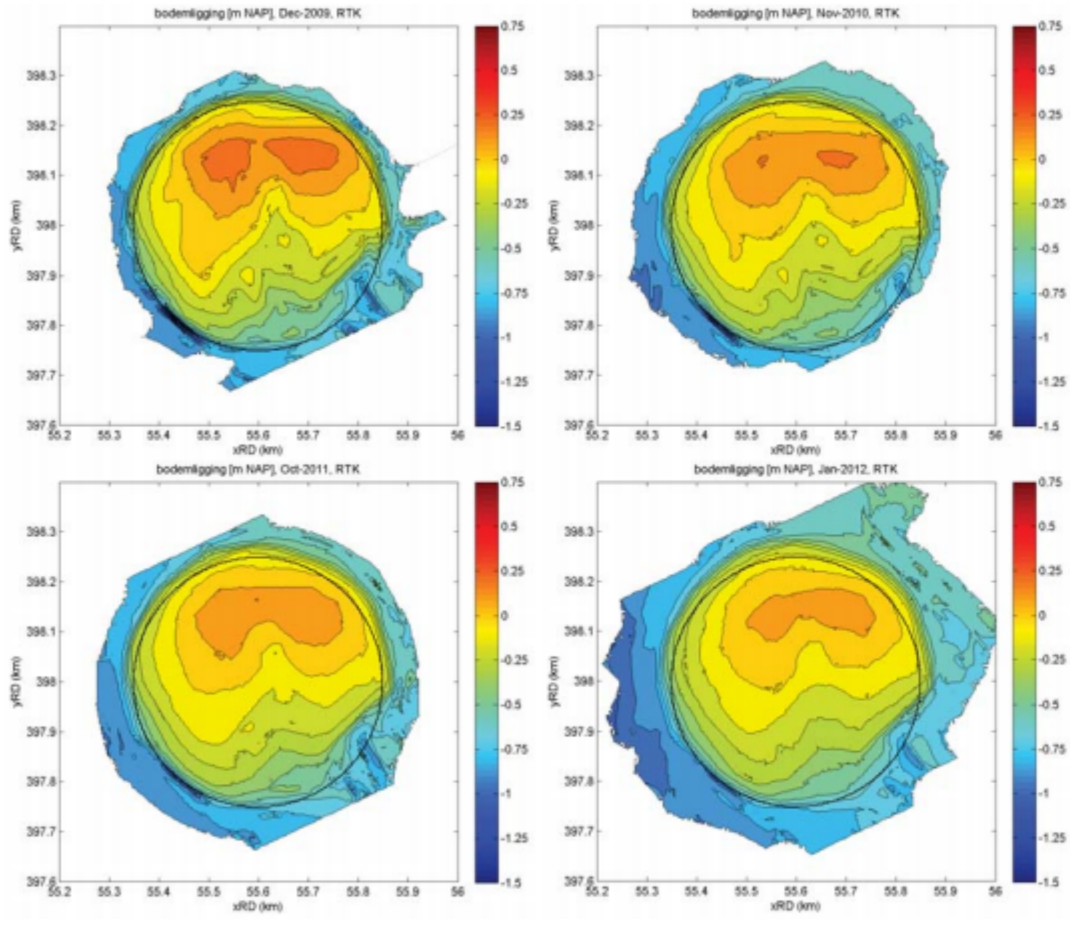

Figure A2, Bed heights in December 2009 (top left), November 2010 (top right), October 2011 (bottom left) and January 2012 (bottom right). Figure from van der Werf, 2013