CHAPTER 8

Building with Nature as Coastal Protection Strategy in the Netherlands

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CONTENTS

8.1 INTRODUCTION

Building with Nature solutions can contribute to the reduction of flood risks and at the same time increases ecological and socioeconomical values in coastal areas (De Vriend et al. 2014). Building with Nature is a Dutch term and many more similar concepts are being introduced worldwide, all focusing on the interplay between physics, ecology, and governance to guarantee safety against flooding: Ecological Engineering (Costanza et al. 2006), Ecosystem-based Management (Barbier et al. 2008), Working with Nature (PIANC 2011), Managed Realignment (French 2006), Nature-based

Flood Protection (Vuik et al. 2016), and Socio-ecological Resilience (Adger et al. 2005). Despite the varying terminology, all approaches are struggling with the implementation of nature-based solutions as innovative flood risk reduction measures, because of the fundamental uncertainties in the stability, efficiency, and especially long-term sustainability of these solutions and the multifunctional nature involving different types of stakeholder coalitions (Borsje et al. 2011).

In this chapter, we aim to draw lessons for managers and scientists involved in the implementation of nature-based solutions for coastal protection by focusing on three Building with Nature case studies within the Netherlands: shoreline nourishments, a mega-nourishment, and vegetated foreshores (salt marshes). Within these case studies, we (1) present a background and motivation, (2) discuss field observations, (3) focus on the lessons learned during and after the implementation phase, and (4) discuss paths forward in which we focus on research needs and strategies for working across different disciplines and overcoming implementation barriers. Next, we discuss the general transition in coastal protection policy in the Netherlands and the main challenges in implementing Building with Nature as a coastal protection strategy in the Netherlands. Finally, some general conclusions are presented.

8.2 DYNAMIC PRESERVATION OF THE COASTLINE: SHORELINE NOURISHMENTS

8.2.1 Background and Motivation

In the Netherlands, the coastal zone largely consists of vegetated dunes, beaches, and a mildly sloping foreshore toward the relatively shallow North Sea (see Figure 8.1 for geographic reference). The almost 120-km-long Holland coastal zone mainly consists of noncohesive sediment. The Holland

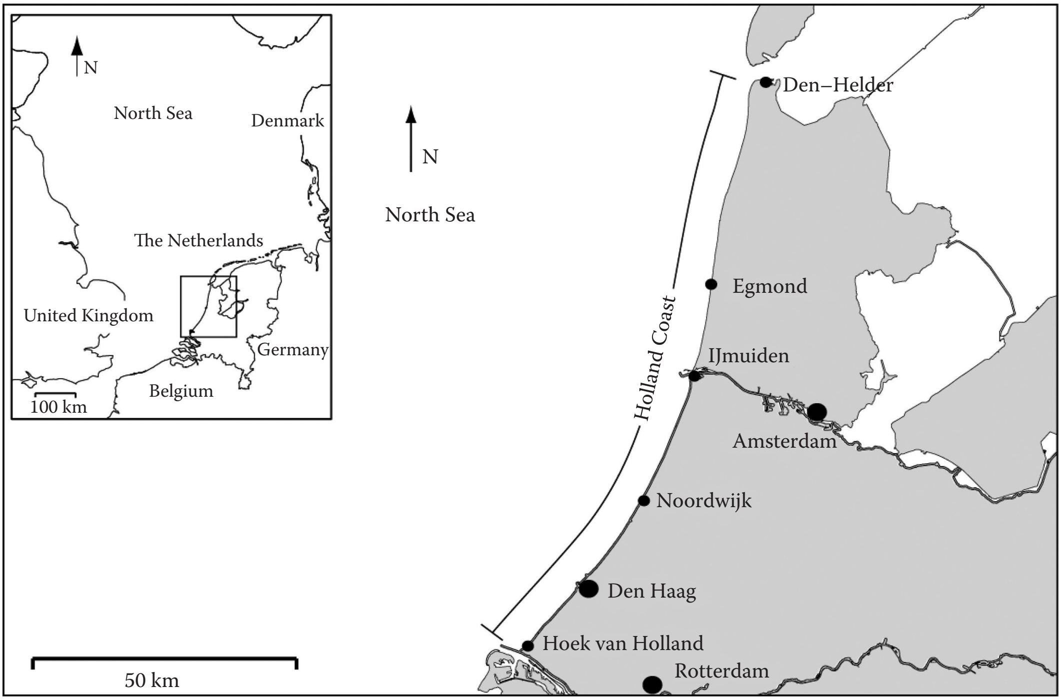

Figure 8.1 Overview of the almost 120-km-long Holland Coast. Nearly the entire Holland Coast consists of sandy beaches and vegetated dunes.

coast forms an important barrier that protects large parts of the Netherlands from flooding. It is in the interest of national safety that this barrier is maintained.

The coastal system of the Holland coast is characterized by an erosive trend. This natural erosion has led to loss of land and infrastructure in the past. Consequently, it has also led to the initiation of significant mitigation measures and maintenance strategies. During the last few decades, a maintenance strategy using sand nourishment has been adopted to compensate for the natural coastal erosion (Davison et al. 1992). This strategy is called *dynamic preservation* and was implemented in national law in 1990. This dynamic preservation strategy is typically a Building with Nature solution and aims to combine safety against floods with sustainable preservation of other services and values (ecological and recreational) of the dunes and beaches (de Ruig 1998). Changes after the implementation of the dynamic conservation policy manifested themselves in a stable or seaward migrating coastline location while allowing for dynamic coastline development. Dynamic preservation requires new methods for evaluating the evolution of the coastal system.

Dutch national government relies on engineering tools such as numerical models, field data analysis, and expert judgment for assessing coastal safety and designing mitigation measures for coastal erosion. These assessments and mitigation measures are adapted to the latest scientific knowledge. In parallel, there has been significant scientific development for predicting coastal evolution along the Holland coast on different time scales.

8.2.2 Field Observations

Scientific evidence considering different time scales helps explain and quantify the natural erosion along the Holland coast. Regarding geological time scales, Beets and Van der Spek (2000) explained the ongoing erosion by studying changes in sea level rise and sediment budgets in the Holocene period. They showed that in the current interglacial period, sediment supply to the coastal system has decreased significantly, resulting in a shift from long-term sediment accumulation in the coastal system to long-term erosion. On shorter time scales, the erosion of the coastal system is visible where a yearly sediment deficit at many locations along the Holland coast is measured (see, for instance, van Rijn 1997).

The awareness of the erosion problem of the Holland coast led to an increasing interest in measuring and predicting the evolution of the coastal system under natural and anthropogenic forcing. Such knowledge development is partly facilitated by a government-funded large measurement program called JARKUS (JAaRlijkse KUStmeting; yearly coastal measurement). JARKUS provides yearly measurements of the coastal morphology covering the subaqueous and aeolian coastal zones since 1965. Before JARKUS and since the 1860s, the coastline location with respect to a reference was measured at 1-km alongshore intervals. These long-term data sets are unique in the world and allow for studies on sediment budgets as well as geomorphology of the Dutch coastal system. By using these data, the development and behavior of the Holland coast are described in detail and sediment budgets are estimated and related to environmental conditions (see, for instance, van Rijn 1997).

When describing the Holland coastal system, the development of the coast owing to hydrodynamic forcing is often separated from development owing to aeolian forcing. The problem of coastal erosion is mainly driven by hydrodynamic forcing. Moreover, sediment budgets attributable to hydrodynamic forcing are relatively large with respect to aeolian forcing. Therefore, the subaqueous development of the coastal system has received much more attention compared to the aeolian development of the coastal system. For instance, significant variability in the behavior of the subaqueous system of sandbars is described comprehensively using the JARKUS data set (e.g., Wijnberg and Terwindt 1995). However, the specific effects of bar behavior on sediment budgets of the coastal systems and the link between foreshore, beach, and dune development remain unclear (de Vries et al. 2012; Ruessink and Jeuken 2002).

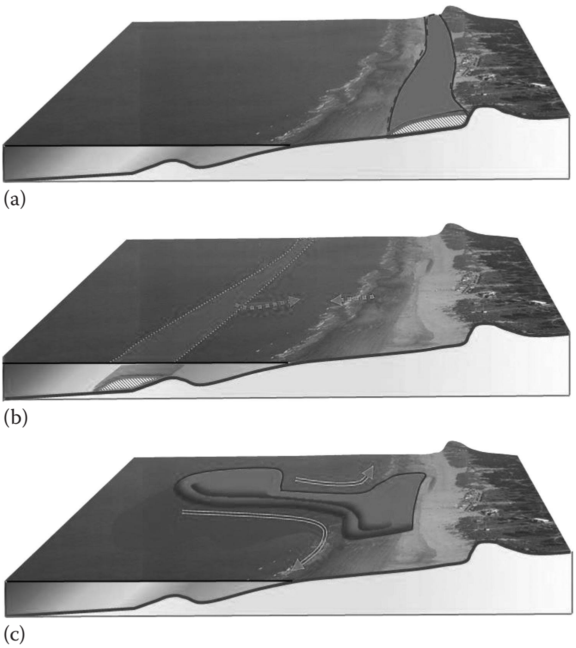

Figure 8.2 Change in nourishment strategies from (a) traditional beach and dune nourishments to (b) shoreface nourishments, and (c) localized mega-nourishments. (After Stive, M. J. F., De Schipper, M. A., Luijendijk, A. P., Aarninkhof, S. G. J., Van Gelder-Maas, C., Van Thiel de Vries, J. S. M., De Vries, S., Henriquez, M., Marx, S., and Ranasinghe, R. (2013). A new alternative to saving our beaches from sea-level rise: The sand engine. *Journal of Coastal Research*, 29.)

While gaining knowledge, experience, insights, and associated tools with respect to coastal systems and nourishments in combination with increasing technological possibilities in the dredging industry, nourishment strategies at the Dutch coast have changed over time. An overview is given in Figure 8.2. Traditionally, relatively small amounts of sand were placed on the beach and the dunes after an erosive event such as a storm. With the introduction of dynamic preservation in the 1990s, the policy has changed from a reactive to a proactive strategy to mitigate erosion. Consequently, nourishment volumes increased and foreshore nourishments were introduced as a measure to protect the coast from erosion attributed to future sea level rise (Stive et al. 1991). Foreshore nourishments are applied outside the breaker zone with the expectation that natural processes will cause the sediment to spread over the full cross-shore profile. Typically, a shoreface nourishment consists of approximately 1–2 × 10^6 m^3 of sand and has a lifetime of approximately 3–5 years (Hamm et al. 2002). It is expected that the nourishment volumes required will increase in the near future because of accelerated relative sea level rise and increasing storminess. To accommodate larger nourishment volumes and to experiment with a more sustainable approach to nourishing the coastline, the sand motor pilot project was implemented in 2011 (Stive et al. 2013). The sand motor pilot project is discussed in detail in Section 8.3.

8.2.3 Lessons Learned

The dynamic preservation policy is considered successful from different points of view. Coastal erosion is halted while dynamics and functions of the coastal system are maintained. It has also proven to be affordable, and the use of coastal nourishments to facilitate a seaward migrating coastline has been suggested and sporadically explored.

As a result of the dynamic preservation strategy, the behavior of the Dutch coastal system is inseparably connected to anthropogenic forcing. The change from erosion control and stabilizing the coastline toward the policy of dynamic preservation in 1990 has influenced the development of the coast significantly. In the subaqueous domain, the behavior of the subtidal bar systems can be locally disturbed by the nourished sediment (Grunnet and Ruessink 2005; van Duin et al. 2004). In the aeolian domain, it has been reported that the transition from an eroding coast to a stable and accreting coast had significant effects on habitat development of the dune vegetation (Arens et al. 2013).

Nevertheless, the multifunctional nature of shoreline nourishments require broadening of the traditional actor coalitions, since functional integration in Dutch coastal management is limited at the moment (Hermans et al. 2013).

8.2.4 Path Forward

Despite important steps being taken in the prediction of the behavior of the Dutch coastal system and coastal systems in general, there are many unknown processes governing changes in the coastal system. From a reductionist point of view, hydrodynamic modeling has reached a certain maturity. The accurate description of sediment transport processes is however still largely empirical and site specific. Many formulations for sediment transport rely on the extrapolation of empirical knowledge based on laboratory studies or occasional field data. The effects of ecology and the difficulties imposed by the land–water interface that characterizes the coastal system are especially poorly understood and complicate predictions of coastal evolution even more. A general interdisciplinary data set and model approach on coastline evolution as a function of environmental processes is needed to gain knowledge on these topics.

The Netherlands is an example of a society that depends on a safe and healthy coastal system. This societal relevance has resulted in coastal maintenance to be implemented in national law. Moreover, strong knowledge alliances have been established between universities of different disciplines, research institutes, industry, and government. An important organizational platform for this alliance is the Dutch network of coastal science (NCK) that organizes regular thematic days and yearly conferences to discuss collaboration and progress at the different organizations. This alliance plays an important role in facilitating the longevity of the dynamic preservation approach to Dutch coastal maintenance and associated research. Moreover, this alliance is instrumental in establishing innovative and applied research programs regarding coastal development in the Netherlands and beyond, such as the Dutch Building with Nature program (De Vriend et al. 2014).

Pilot projects and field studies are an ideal means to facilitate interdisciplinary coastal research to increase predictability of coastal systems. Shared and open strategies for data collection during pilots and field studies allow for a generic approach to coastal research. This should ideally not be limited to an institutional or even a national level. Modern techniques allow for an international and integrated approach to measure, predict, and manage coastal systems. Therefore, a global approach to knowledge development with respect to coast-related problems and solutions is both desired and possible.

8.3 MEGA-NOURISHMENTS AS AN INNOVATIVE NOURISHMENT STRATEGY: THE PILOT PROJECT SAND ENGINE

8.3.1 Background and Motivation

In 2008, a national committee, the Delta Committee, provided critical advice for protecting the Dutch coast and the low-lying hinterland from the consequences of climate change in the 21st century (Deltacommissie 2008). In line with a key recommendation of the Delta Committee, an innovative pilot project was developed to achieve a more efficient and sustainable nourishment approach: the Sand Engine (Stive et al. 2013). This mega-nourishment, built in 2011 along the Delfland coast (see Figure 8.3a), consists of a total sediment volume of 21 million m^3. The pilot project Sand Engine is a combined beach/shoreface nourishment and consists of a man-made peninsula of approximately 128 ha (see Figure 8.3b). This new coastal maintenance strategy was designed to use the power of winds, waves, tides, and currents to help protect part of the Dutch coast from storms (van Slobbe et al. 2013), while encouraging the development of new dunes and the valuable flora and fauna associated with them and stimulate recreation. It is expected that over the next 20 years, these natural coastal processes will redistribute the sand in the peninsula along the 16-km-long coastal stretch between Hoek van Holland and Scheveningen, leading to an increase of the footprint of the dunes of 33 ha (Mulder and Tonnon 2010).

The Sand Engine pilot consists of a large peninsula of approximately 2 km alongshore while the most seaward position protrudes approximately 1 km into the sea (see Figure 8.4a). The main peninsula part is hook shaped with the outer tip curved toward the north. The crest of the peninsula rises up to 5 m above mean sea level. This design and location best fulfilled the multidisciplinary and multi-stakeholders requirements of safety in combination with recreation, nature development, and scientific innovation (Stive et al. 2013). The cross-shore slope of the peninsula is 1:50, such that the toe of the nourishment is positioned at MSL −8 m and ~1500 m from the original coastline. The northern tip of the peninsula creates a sheltered nurture area for different biotic species. A small lake of approximately 8 ha is intended to prevent the freshwater lens in the dunes from migrating seaward and endangering the groundwater extraction from the existing dune area. Sediment for the nourishment was mined at two borrow sites just beyond the 20-m-depth contour at a distance of approximately 9 km offshore. The sand was mined by Trailing Hopper Suction Dredgers and placed at the location of the Sand Engine by a combination of dumping through the doors in the hull, rain bowing, and pumping onto the beach. The Sand Engine was constructed in a period of approximately 3 months in the summer of 2011.

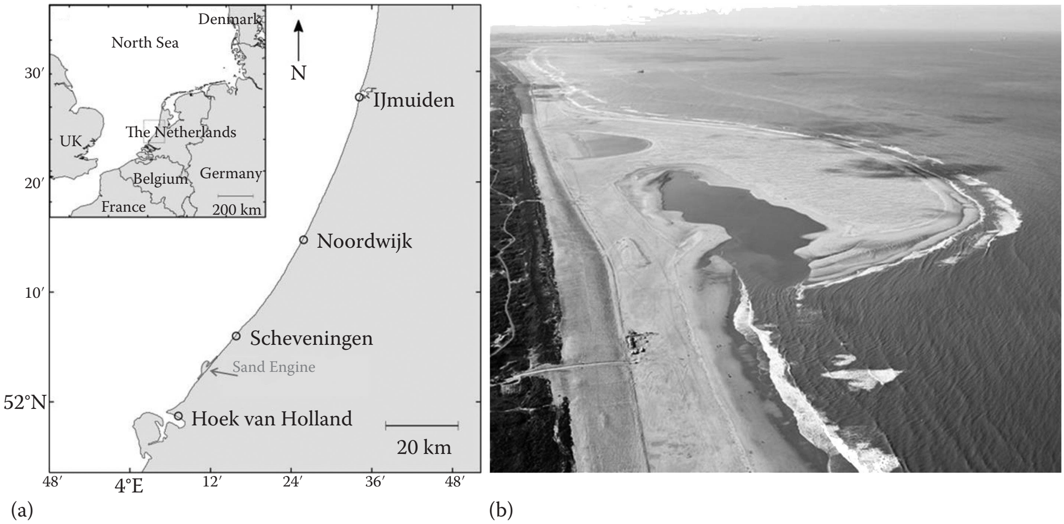

Figure 8.3 (a) Overview of the Dutch coast and the location of the Sand Engine and (b) aerial photograph of the Sand Engine after completion (July 2011).

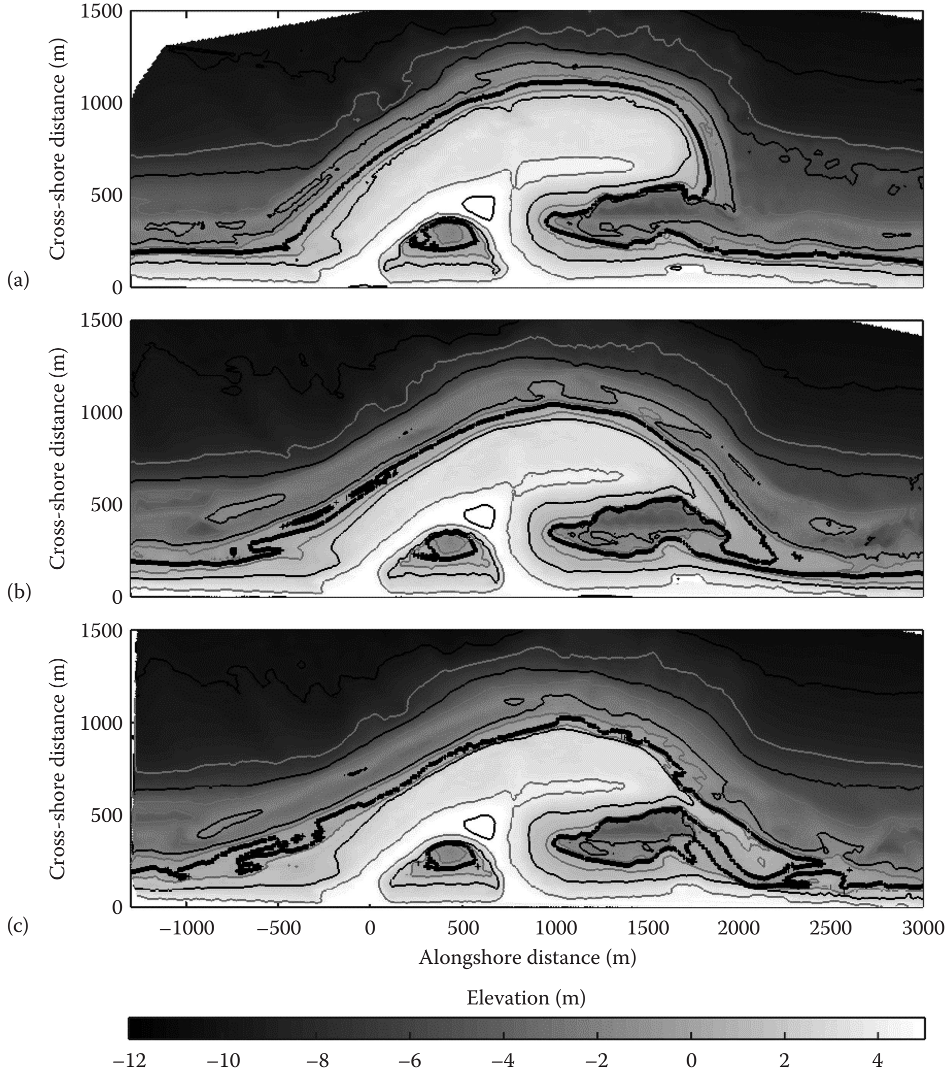

Figure 8.4 Observed bed elevations (in meters); three surveys between August 2011 (a) and August 2012 (c).

8.3.2 Field Observations

Monthly bathymetric surveys show a rapid, predominantly alongshore redistribution of sediment (Figure 8.4). The head of the peninsula eroded rapidly, leading to accretion in both northerly and southerly direction. In the first half-year after implementation, a spit developed from the northerly tip of the peninsula pinching the lagoon entrance. The maximum elevation of the spit and shoal were slightly below the high water level, such that they flooded during high tide (and storms). The channel landward of the shoal discharged the flow into and from the lagoon and strong flow velocities of over 1 m/s were observed here during rising and falling tides in the spring of 2012.

Over time, the transition between the mega-nourishment and the adjacent coast became more gradual (see Figure 8.5). After 2.5 years, approximately 2.5 million m^3 of sand was moved by

Figure 8.5 Aerial photograph of the Sand Engine approximately 4 years after construction (taken in May 2015).

natural forces. Most of the sand (1.14 million m^3) was transported to the north, while approximately 680,000 m^3 accreted south of the original peninsula. The remaining 740,000 m^3 is transported outside the survey area: either cross-shore (to deeper water or into the dunes) or alongshore (past the limits of the survey area). Further analyses and additional monitoring will focus on understanding these sediment fluxes and balance.

The Sand Engine is a dynamic geomorphological feature: more than 10% of the sand has been moved in the first 2.5 years. Observations revealed different sediment pathways depending on sediment grain sizes. The most seaward part of the Sand Engine has eroded significantly. In this area, relatively coarse sand has been found, while northeast and southwest of the head of the Sand Engine, fine sand patches are observed owing to deposition of the material eroded from the head. The spatial variation in sediment sizes could, for example, affect the decolonization of benthic species over time. On a longer term, the coarsening of the sediments at the head of the Sand Engine could also affect the overall morphological evolution.

Ecologically speaking, the Sand Engine exhibits interesting developments (Linnartz 2013). Soon after construction of the Sand Engine, pilot vegetation started to grow at the crest combined with the development of embryo dunes (see Figure 8.6). Pioneer plant species have been found such as Sea Rocket (*Cakile maritima*) and Glasswort (*Salicornia maritima*). Even a very rare species, the Frosted Orache (*Atriplex laciniata*), unique for this part of the Dutch coast, has been found. As zonation has not been implemented at the Sand Engine, plants and embryo dunes are regularly affected by human behavior related to recreation and regular safety patrols with 4 × 4 cars. Dune growth has been observed behind the Sand Engine and just north and south of the pilot area, while the crest has become very stable as a result of armoring effects; shells stabilize the bed and prevent it from eroding owing to aeolian transport. The Sand Engine turns out to be a favorite resting area for birds and seals, and the lagoon is full of juvenile fish.

Figure 8.6 Photographs of the Frosted Orache (*Atriplex laciniata*) and embryo dune development at the crest of the Sand Engine.

8.3.3 Lessons Learned

In order to learn from this pilot project, research projects have been implemented to analyze the observations in detail. In the first years, the Sand Engine has changed drastically. The sand has been gradually redistributed by natural processes over the shoreface, beach, and dunes. Bathymetric measurements combined with numerical modeling illustrate the redistribution mechanism of the Sand Engine. After the first 2.5 years, the sand has been redistributed alongshore over a coastal stretch up to 8 km (De Schipper et al. 2016). The erosion of the peninsula is mostly dominated by waves—during large storms and otherwise. Analysis has shown that the 12 largest storm events of the first year were responsible for approximately 60% of the total erosion observed in that year (Luijendijk et al. 2015). The milder wave conditions, with a large probability of occurrence, are therefore almost as important to the erosional behavior of the peninsula as the storm conditions.

The strategy of introducing concentrated nourishments is seen as a climate-robust and eco-friendly means of countering coastal erosion, while the (temporary) presence of surplus sand also creates new areas for nature and recreation. The Sand Engine with its specific dimension forms a unique solution for the Delfland coast and is therefore not easily transferable to other locations in the world. However, the concepts underpinning this multifunctional coastal protection are applicable to other locations and environments, but are highly dependent on the local governance setting and ecological and physical system. An inventory on the relevant ecosystem services and a stakeholder analysis are crucial starting points when exploring sandy strategies at other locations.

8.3.4 Path Forward

After implementation of the Sand Engine, a collaborative effort between public authorities, private companies, and research institutes has resulted in the fact that the Sand Engine has become a focal point for coastal research and an innovative coastal management solution. In the coming years, the Sand Engine will be closely monitored and extensive research programs that will include detailed studies of the evolution of the Sand Engine and the driving mechanisms behind it—physical, ecological, and social–economical—will be defined. An example is the science project NatureCoast (www.naturecoast.nl), in which 15 PhD students and 6 postdocs are studying the temporal behavior of this mega-intervention along six different disciplines: coastal safety, marine and terrestrial ecology, hydrology, geochemistry, and governance. The new knowledge will be beneficial for future nourishment strategies and design. This research will enable an integral evaluation of the effectiveness of local mega-nourishments as a countermeasure for the anticipated enhanced coastal recession caused by accelerated sea level rise in the 21st century.

8.4 ADOPTING SALT MARSHES AS COASTAL PROTECTION MEASURE

8.4.1 Background and Motivation

Salt marshes are coastal ecosystems in the upper coastal intertidal zone between land and water that are regularly flooded by tides and surges. They are covered with dense stands of salt-tolerant plants, such as herbs and grasses. Salt marshes can exist in areas that roughly comply with two criteria. First, the hydrodynamic forcing by waves and currents should be limited to facilitate the settlement and accumulation of fine sediments and the establishment of pioneer vegetation. Second, there should be a sufficient supply of sediment, to allow the surface of the salt marsh to rise during high tides and storm surges (Van Loon-Steensma 2015). Vegetation plays a key role in the development of salt marshes. The presence of the canopy accelerates the sediment settlement by reducing the wave forces on the bed material. Additionally, the root systems of the plants stabilize the accumulated sediments and amplify the process of subsoil drainage, consolidation, and compaction (Deegan et al. 2012). Salt marshes and the neighboring intertidal flats form a coherent system with many mutual dependencies.

Salt marshes occur worldwide, particularly in middle to high latitudes (Figure 8.7). They are a common habitat in estuaries and barrier coasts. For example, extensive salt marsh systems can be found in the Dutch, German, and Danish Wadden Sea and along the Gulf Coast of the United States.

Vegetation requires a certain time span for seedling establishment, during which disturbance is low or absent. Such periods, characterized with mild wave conditions and limited flow velocities, are often referred to as windows of opportunity (Balke et al. 2011; Romme et al. 1998). A distinction can be made between salt marshes that have developed in areas where windows of opportunity occur by nature and salt marshes that can only persist because of artificial sheltering from waves and currents. An example of the latter can be found along the Dutch Wadden Sea coast, where an extensive system of earthen dams, brushwood dams (Figure 8.8), and drainage channels has led to the presence of 3000 ha of salt marsh habitat (Figure 8.9). Starting from the 18th century, this technique was initially aimed at land reclamation, but nowadays, it is applied for nature conservation

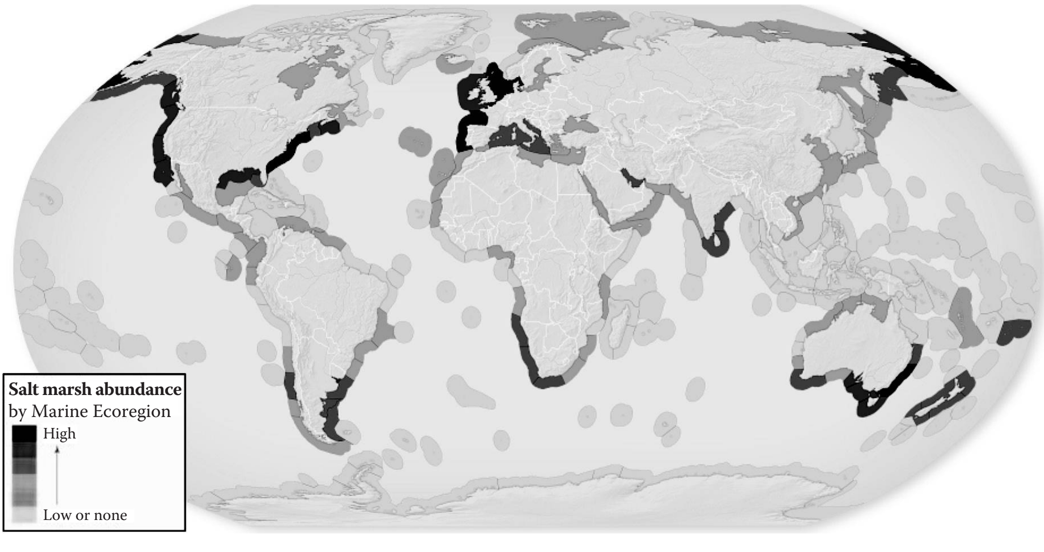

Figure 8.7 Map of global salt marsh abundance. (Taken from http://www.prweb.com/releases/The_Atlas_of/Global_Conservation/prweb3839504.htm.)

Figure 8.8 Brushwood dams to create artificial sheltering of salt marsh vegetation against waves and currents. (Photo courtesy of Vincent Vuik.)

Figure 8.9 Extensive salt marshes with brushwood dams along a dike bordering the Dutch Wadden Sea. (https://beeldbank.rws.nl, Rijkswaterstaat.)

purposes (Dijkema et al. 2011). Such salt marshes are classified as engineered ecosystems according to Van der Nat et al. (2016).

The benefits that ecosystems offer to humankind are known as ecosystem services. The most frequently quoted ecosystem services of salt marshes are storm protection for coastal communities, shoreline stabilization, nutrient removal, carbon sequestration, fisheries, and recreation (Deegan et al. 2012; Temmerman et al. 2013). In the context of this book, we focus on ecosystem services related to nature-based coastal protection. Salt marshes can act as a buffer zone against natural hazards such as floods, cyclones, tidal surges, and storms, by reducing storm waves and storm surges (Gedan et al. 2010; King and Lester 1995). Additionally, salt marshes may protect shorelines from erosion by buffering wave action and trapping sediments (Shepard et al. 2011).

At the moment, in the Netherlands, salt marshes are not explicitly considered as an official part of the flood defense itself. At most, the influence of the salt marshes is implicitly taken into account, when their presence influences the wave conditions at the dike, as computed with numerical wave models with the salt marshes included in the model bathymetry (e.g., the increased bed levels near the dike of Figure 8.9). For this reason, no case study has been elaborated in this section. The focus is on describing the potential of vegetated foreshores for flood protection purposes, and the challenges to overcome.

8.4.2 Field Observations

This section gives an overview of the current knowledge base regarding the ecosystem services storm wave attenuation, surge attenuation, and shoreline stabilization by salt marshes based on field observations.

Energy dissipation of storm waves on salt marshes is predominantly caused by depth-induced wave breaking and wave attenuation by vegetation. Waves, propagating toward shallower water, decelerate and increase in amplitude. Depth-induced wave breaking occurs when the wave height (actually the wave steepness) reaches a critical value. The fraction of breaking waves increases with decreasing depth. Naturally, because of the deposition of sediments by the tide, salt marshes have an elevation around the high tide level. That means that the water depth on top of the salt marsh surface is very low during normal high tides. A significant water depth is only found under storm surge conditions. The corresponding storm waves, approaching the shoreline, will decrease in height because of the process of depth-induced wave breaking.

The second process that plays an important role in dissipating wave energy on salt marshes is wave attenuation by vegetation. Waves propagating through vegetation fields lose energy as a result of the forces exerted by vegetation stems, branches, and leaves (Dalrymple et al. 1984). The decay in wave height increases with vegetation stem density (stems per surface area), stem diameter, vegetation height, and vegetation stiffness (Bouma et al. 2005). Waves with large heights and short periods generate the highest forces on the vegetation and, consequently, experience relatively high energy dissipation (Anderson and Smith 2014). This mechanism has appeared to be very efficient in dissipating wave energy for (nearly) emergent conditions (e.g., Knutson et al. 1982). However, measurements in the field (Möller et al. 1999; Vuik et al. 2016; Yang et al. 2012) and in a large wave flume (Möller et al. 2014) have proven that the vegetation also significantly contributes to wave energy dissipation for water depth of several meters, as can occur during storms.

Extensive salt marsh systems have a significant influence on surge propagation and surge levels. The rough salt marsh surface retards the fluid motion. For a rapidly varying wind and a relatively short surge wave, this effect can lead to lower surge levels at the coast behind such large salt marshes. However, the retardation of the fluid motion might lead to higher surge levels at the coastline at the windward side of the marshes. That is why Wamsley et al. (2010) concluded that the magnitude of surge attenuation by salt marsh wetlands is dependent on the surrounding coastal landscape and the strength and duration of the storm forcing. Therefore, the application of a constant attenuation rate (in terms of surge reduction per kilometer salt marsh) is misleading and not appropriate (Resio and Westerink 2008).

The third main ecosystem service of salt marshes is the stabilization of coastlines. First, the presence of vegetation leads to a reduction of wave heights, current velocities, and turbulence and, as a consequence, to an increase of sediment deposition and a decrease of sediment entrainment. Belowground, plant roots increase the shear strength of the substrate, since plant roots tend to enhance the cohesion and tensile strength of their substrate (Gedan et al. 2010). The bottom surface of salt marshes is mostly very stable, according to poststorm observation (Spencer et al. 2015) as well as large-scale wave flume experiments (Möller et al. 2014). All in all, surface erosion of salt marshes is not very likely to occur, even during severe storm surges. However, salt marshes might erode laterally, starting with the formation of a cliff at the salt marsh edge. These then retreat because of the generation of tension cracks in response to the erosive attack of waves and tidal currents, which subsequently leads to toppling failures and rotational slips (Allen 1989; Francalanci et al. 2013). Such cliff erosion is the main mechanism for the retreat of many salt marshes.

8.4.3 Lessons Learned

For coastal protection purposes, stable and static salt marsh characteristics are preferred during the lifetime of the flood defense. However, natural salt marshes inherently have a dynamic character. Conceptual models describe the long-term development of salt marshes as a cyclic process with a time scale of several decades, with alternately a period with expansion and a period with retreat. In the expanding phase, the dynamics on the mudflat in front of the salt marsh are below a certain threshold, and there are windows of opportunity for new vegetation seedlings to settle. Tides and surges supply sediment to the vegetated surface, and the elevated salt marsh platform extends in seaward direction. In systems with sufficient sediment supply, salt marshes are able to adapt to sea level rise by trapping the required volume of sediment to raise the marsh platform with the same rate. As a consequence of the salt marsh expansion, the slope of the mud flat steepens, and the wave and flow dynamics on the mud flat intensify. At a certain moment, a cliff develops: the tipping point from expansion to retreat. Breaking waves and tidal currents exert relatively high stresses on the marsh edge cliff, and usually the cliff height exceeds the rooting depth of the vegetation. The cliff retreats, until the steepness of the mud flat declines to such an extent that seedlings can settle beyond the cliff. In a favorable environment, this cyclic behavior leads to regular rejuvenation of the ecosystem and to relatively high biodiversity (van de Koppel et al. 2005). For that reason, many ecologists detest the construction of stone protections and groins, which aim to fix the position of the salt marsh edge.

Natural developments and human interventions can disrupt the cyclic salt marsh dynamics and can lead to irreversible salt marsh retreat. For example, dredging of shipping channels as well as natural migration of tidal channels can lead to a steepening of the intertidal mud flats, with decreasing windows of opportunity for vegetation seedlings as a result. Another example is the (partial) damming of estuaries, which results in a decline in tidal current velocities. As tidal currents are the main driver of the buildup of intertidal flats, the intertidal landscape might flatten out. During storms, the wind waves can propagate easier over the drowned tidal flats, and higher waves hit the coastline, including the salt marshes bordering the estuary. Such developments can lead to irreversible salt marsh retreat, and nature conservation agencies might consider the protection of these ecosystems with artificial measures, like brushwood dams (Figure 8.8) or stone protections.

The persistence and health of characteristic salt marsh plant species depend on abiotic drivers such as water salinity and water quality, which makes these quantities of crucial importance for the longevity of salt marshes. The dominance of certain plant species is determined on the basis of competition. In salty environments, salt-tolerant species like cordgrass (*Spartina anglica*) dominate, while in brackish environments, they are outcompeted by other species such as grassweed (*Scirpus* *maritimus*) or common reed (*Phragmites australis*) in freshwater. Vegetation properties such as shoot density, stem flexibility, and rooting depth determine the physical properties of the salt marsh to a large extent. Changes in salinity will lead to changes in ecosystem characteristics and, consequently, changes in the ecosystem services they offer. For example, Howes et al. (2010) suggest that the difference in rooting structure between low-salinity wetlands and high-salinity wetlands has led to the preferential erosion of the low-salinity wetlands during hurricanes Katrina and Rita. Another important aspect is coastal eutrophication as a driver of salt marsh loss (Deegan et al. 2012). They found that high nutrient levels lead to rapid growth of vegetation, relatively high aboveground leaf biomass, and limited belowground biomass of stabilizing root systems. Consequently, geomorphic stability is reduced, resulting in collapse of the creek-banks with significant areas of salt marsh converted to areas of bare mudflat.

8.4.4 Path Forward

For the flood protection services of salt marshes to be actually incorporated in flood risk assessments, a thorough reliability assessment should be carried out. There should be empirical or process-based knowledge of the processes that determine the most important characteristics of the salt marsh in view of surge and wave attenuation and shoreline stabilization, such as cliff erosion, seasonal biomass variations, uprooting, and stem breakage attributed to wave impact (Bouma et al. 2014). The inherent dynamic character of ecosystems and the required extrapolation to extreme storm conditions make exact predictions of the functioning of the salt marshes impossible. Quantification of uncertainties is required. Before nature-based flood defenses can be considered as a reliable supplement to conventional flood defenses in densely populated areas, they need to be tested according to engineering standards for probability of failure (Van Wesenbeeck et al. 2014).

Salt marshes, bordering a dike, lead to a reduction of wave forces on the dike revetments during periodic storm events, elongating the expected lifetime of the revetments. This leads to a reduction of maintenance efforts and costs. On the other hand, dike managers should spend more time removing organic debris from the dike after storm events. In the end, governmental issues are at least of the same importance as knowledge of the physical functioning of the system, to ensure the official incorporation of salt marshes in flood protection strategies. Interdisciplinary research should facilitate the decision making.

8.5 DISCUSSION: TRANSITION IN COASTAL PROTECTION POLICY IN THE NETHERLANDS

The first coastal protection measures inspired by the Building with Nature philosophy now become visible in the Dutch landscape. A range of pilots has been initiated to test the potential of the Building with Nature solutions in practice as discussed in this chapter. Pilots form an important tool in exploring or evaluating innovations, and the lessons learned from these pilots may form the first step toward actual implementation on the landscape scale. In order to place the lessons learned within the current coastal protection policy, we review the general transition in coastal protection policy in the Netherlands for the last decades.

The Netherlands is worldwide known for its flood protection management. A culture of protecting the land and its inhabitants against floods already emerged in the 13th century (Van Koningsveld et al. 2008). In the 20th century, two iconic projects illustrate this flood protection practice: the damming of the Zuiderzee Sea in the north and the Delta project in the southwestern part of the Netherlands, which closed a number of tidal inlets. These major interventions allow today for safe living in a country where two-thirds is vulnerable for river or sea flooding and approximately 25% lies below sea level. The second Delta committee successfully raised awareness in Dutch society and politics of the potential impacts of climate change (Deltacommissie 2008). Today, protection against flooding is high on the political agenda as ever: a new “delta program” has been initiated to protect the Netherlands against flooding in the future and includes flood protection works for more than 700 km of dikes and dams. The management approach, however, and anticipated solutions have undergone fundamental change over the last decades.

Traditionally, Dutch flood protection management is dominated by a technocratic–scientific regime, which promotes “hard” engineering structures to control and keep out flooding (Lintsen 2002). Since the 1970s, there has been a growing appreciation and understanding of the negative environmental effects of such hard structures (Airoldi et al. 2005; Van Wesenbeeck et al. 2014). In the Netherlands, the construction of the Oosterschelde Dam, which is part of the Delta project, indicates the start of an ecological transformation (Disco 2002). While initially planned to close off the tidal inlet, the dam was designed as a semiopen barrier to allow for tidal dynamics. Over the past 40 years, a fundamental shift has taken place from a technocratic engineering strategy to integral and participatory water management (Van der Brugge et al. 2005). Water management is not just assessed from a flood protection point of view, but other social, ecological, and physical components are valued as well. The integrated approach, increased environmental awareness, and changing climate have enabled a new pathway to emerge in which Building with Nature is the central concept (De Vriend et al. 2014).

Implementation in Dutch mainstream flood protection practice is one of the main challenges of the Building with Nature approach. Even projects with an explicit Building with Nature ambition have failed to be realized in practice (Janssen et al. 2014). The multifunctional nature and inclusion of dynamics structurally differs from conventional hard solutions, which are designed in a static and monofunctional way. Building with Nature solutions introduce uncertainties arising from the inherent unpredictability of natural dynamics and this is at odds with the prevailing idea that flood should be controlled and strict criteria should be employed to assess flood protection solutions. Adaptive management solutions are needed to foster implementation (Borsje et al. 2011; Korbee et al. 2014; Van Wesenbeeck et al. 2014). Building with Nature requires integration among nature and flood protection policy domains, which is a challenge given the dominant nature of the flood protection domain in terms of institutions, resources, and actors (Janssen et al. 2014). Moreover, the multifunctional nature of Building with Nature requires broadening of the traditional participatory actors (Korbee et al. 2014; van Slobbe et al. 2013). Another challenge relates to the assessment of Building with Nature solutions, which should support its multifunctionality. Traditional assessment tools, however, such as those used in cost–benefit analyses or in environmental impact assessments, do not automatically support this integrated nature (De Jonge et al. 2012).

For the three case studies discussed in this chapter, we draw the following general lessons learned for implementation: (1) in order to design Building with Nature solutions, we should not only integrate the different disciplines (physics, ecology, and governance) but also focus on the integrated coastal system (both subaqueous and aeolian); (2) in order to extrapolate the short-term fluctuations in stability of a certain Building with Nature solution into long-term behavior, we should quantify the uncertainties and set up an adaptive management strategy; and (3) in order to successfully implement Building with Nature solutions worldwide, we should set up new actor coalitions within a certain governance setting.

8.6 CONCLUSIONS

The three promising Building with Nature solutions for coastal protection discussed in this chapter inherently have a dynamic nature. Therefore, there is a relatively large degree of uncertainty with respect to their adaptive behavior. Consequently, harnessing the complex and nonlinear dynamics of natural systems is an essential challenge in Building with Nature solutions. Moreover, designing Building with Nature solutions in an interdisciplinary research approach allows for transferring Building with Nature concepts to other locations in the world. Finally, developing adaptive management strategies in close collaboration with local stakeholders, decision makers and scientists are of utmost importance. The three general lessons learned on the Building with Nature pilots discussed in this chapter may form a first step toward actual implementation of these solutions on the landscape scale both in the Netherlands and worldwide.

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