SUSTAINABLE DEVELOPMENT OF LAND RECLAMATIONS AND SHORELINES

FULL SCALE EXPERIMENTS AS A DRIVER FOR PUBLIC-PRIVATE INNOVATIONS

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Abstract: With 80% of the world's population living in lowland urban areas by 2050, sea levels gradually rising and societal demands on the quality of living increasing, sustainable development of coastal zones becomes increasingly urgent as well as complex. Modern strategies for the design and implementation of measures for infrastructure development, coastal protection and other functions adopt the concept of Building with Nature to handle these challenges.

Recently, two full scale experiments were implemented to assess the benefits of the this approach for coastal development. The Sand Motor pilot project addresses the potential concentrated nourishments on the basis of a 21 million m3 shore nourishment at the Delfland coast in the Netherlands. This unprecedented experiment aims to protect the hinterland from flooding by letting natural processes distribute sand over shoreface, beach and dunes, thus constituting a climate-robust and environmentally friendly way of coastal protection. The second experiment addresses the concept of seabed landscaping in sand extraction sites, which aims to add ecological value to the sand borrow areas after construction. Both pilots have been monitored since their completion in 2010/2011 and will be monitored extensively in the coming years.

The data available so-far reveal that the morphological evolution of the Sand Motor occurs faster than anticipated. Refined simulations though show that state-of-the-art models do allow for quantitative assessment of concentrated nourishments. Careful analysis of the ecological data sampled from the landscaped extraction site resulted in another key finding: inside the mining pit, 4-5 times more fish was found than outside. At the more strategic level, our findings confirm the key role of full-scale experiments as an effective focal point of (inter-disciplinary) research efforts, and public-private partnering as a successful mechanism to drive innovations in the field of marine infrastructure development.

Key words: Coastal development, Sand Motor, concentrated nourishment, seabed landscaping

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1 INTRODUCTION

With 80% of the world's population living in lowland urban areas by 2050 and societal demands on the quality of living increasing, sustainable development of coastal zones becomes increasingly urgent as well as complex. These trends are reinforced by the ongoing call for coastal protection measures, land reclamations and marine infrastructure, induced by rising sea levels (due to the combined effect of climate change and land subsidence) and further growth of the global energy market. Balancing the sustainable functioning of ecosystems on the one hand with the demand for their development and use on the other, is one of the greatest challenges for the future of humankind.

Implementation of sustainable strategies for the development of land reclamations and shorelines demands a paradigm shift in the approach of project development and design. It is crucial that we learn to design infrastructure that can serve more than just one purpose, that is aligned with natural processes rather than working against them and that is adaptable to cope with changing conditions such as sea level rise and climate change. Traditional approaches focus on minimizing the negative impacts of envisaged infrastructure projects (building *in* nature) and compensating any residual negative effects (building *of* nature). As a next step beyond these 'reactive' approaches, Building *with* Nature aims to be proactive, utilizing natural processes and providing opportunities for nature as part of the process of developing hydraulic infrastructure. This approach is consistent with the Building with Nature concept that originates from the Czech hydraulic engineer J.N. Svašek and was further explored and linked to the field of Integral Coastal Zone Management by Waterman (2008).

Recently, two full scale experiments were implemented to assess the benefits of the Building with Nature approach for coastal development. The Sand Motor pilot project addresses the potential of the concept of concentrated nourishments on the basis of a 21 million m3 shore nourishment at the Delfland coast (NL). This unprecedented experiment aims to protect the hinterland from flooding by letting natural processes distribute sand over shoreface, beach and dunes, thus constituting a climate-robust and environmentally friendly way of coastal protection. The second experiment addresses the concept of seabed landscaping in sand extraction sites, which aims to add ecological value to the sand borrow areas after construction. Both pilots have been monitored since their completion in 2010/2011 and will be monitored extensively in the coming years.

In this paper, we present recent findings from both experiments. For the Sand Motor, the focus is on the development of morphology and nature during the first year of its existence; for the seabed landscaping experiment, attention is being paid to the recolonization of the sand extraction area on the basis of two years of monitoring data. In addition, we also highlight the ingredients for successful innovation in the design and implementation of marine infrastructure: utilization of results as a guiding principle for the research agenda, focus of (interdisciplinary) research efforts through full scale experiments and intense public-private partnering to ensure full coverage of the innovation chain. Most of the work reported here is carried out as part of the Building with Nature innovation program (see intermezzo below).

We are confident this Building with Nature approach will result in improved strategies for sustainable development of land reclamations and shorelines, hence enable us to face near-future challenges in coastal zone management and engineering.

Intermezzo 1. Innovation program 'Building with Nature'

Innovation program 'Building with Nature'

'Building with Nature' is a five-year innovation and research programme (2008-2012) carried out by the Foundation EcoShape (**www.ecoshape.nl**). This 30 million Euro program is initiated by the Dutch dredging industry, while partners represent academia, research institutes, consultancies and public parties. The program aims to develop knowledge for the sustainable development of coasts, deltas and rivers by combining practical hands-on experience with state-of-the-art technical and scientific knowledge on the functioning of the ecosystem and its interaction with infrastructures. Key is that infrastructure solutions are sought that utilise and at the same time enhance the natural system, such that ecological and economic interests strengthen each other. This approach is reflected in the five program objectives that were established for the program:

1. Develop ecosystem knowledge enabling 'Building with Nature'
2. Establish how to bring the BwN-concept forward in society and make it happen
3. Develop scientifically sound design rules and norms
4. Develop expertise to apply the BwN concept
5. Make the concept tangible using practical BwN-examples

The core of the program is centred around four real-world cases (Holland Coast, Southwest Delta and the Marker- and IJssel Lakes in The Netherlands, plus case Singapore in a tropical environment). Generic research on governance-related topics and nature sciences is carried out by a group of 19 PhD researchers. Throughout the program the interaction between disciplines is promoted, involving ecologists, engineers and policy makers. The lessons learned from these cases are used to formulate generic guidance for the design and implementation of these type of solutions, in The Netherlands as well as abroad. All results of the program become available through a public wiki as per January 1, 2013.

2 CONCENTRATED NOURISHMENTS FOR COASTAL DEVELOPMENT

2.1 The concept: concentrated nourishments

The Netherlands, like several other countries worldwide, have a long tradition of coastal maintenance through shoreline nourishments (e.g. Hamm et al., 2002). The first nourishments, in the sixties and seventies of last century, involved the placement of relatively small volumes of sand on the sub aerial beach and/or dunes. Following the work by Stive et al (1991), a second approach was introduced in the early nineties based on the implementation of sand on the shallow foreshore, just outside or inside the outer breaker bar. Such location typically corresponds to water depths in the order of 5-7 m, depending on the local wave climate, beach profile and operational requirements - most notably the draught of the dredging vessels. Implementation of recurrent foreshore nourishments turned out to be a cost-effective strategy to ensure gradual growth of beaches and dunes. Nowadays being the preferred solution for shoreline maintenance in The Netherlands (e.g. Van Koningsveld et al, 2008), the total sand volume needed to nourish the Dutch coast has steadily increased, from 6 million m3 in 1990 to over 12 million m3 per year since 2001.

In 2008 the Delta Commission, a body set up by the government to consider how to secure long-term flood safety and water supply in times of accelerated sea level rise and climate change, recommended extending the strategy of coastal nourishments. For such schemes, experts anticipate that 40–85 million m3 of sand per year will be needed by 2100, depending on the actual rate of sea level rise. This trend towards increasing volumes of sand has led to questions about how the benefits of such nourishment strategies might be improved in the future, perhaps by creating opportunities for nature and recreation, as well as countering coastal retreat.

Based on the concept of Building with Nature, a new coastal maintenance strategy was developed: concentrated nourishments. The idea is to deposit a significant stock of sand in one location, which is then gradually redistributed across and along the shore by the wind and waves. By making use of natural processes to redistribute the sand, this innovative approach aims to reduce the disturbance of local ecosystems. Traditional schemes foresee in recurrent nourishments – hence coverage of benthic ecosystems – every 4-5 years;

concentrated nourishments, on the other hand, come with either a smaller footprint, or lower frequency of disturbance, or both. While the sediment is being redistributed, there are virtually no indirect effects on coastal ecosystems, as benthic organisms have more time to adapt to the changing seabed topography. In the meantime, the (temporary) presence of surplus sand also creates opportunities for nature and recreation.

Concentrated nourishments may vary in size and shape, depending on site-specific factors such as national coastal policy, established practice and the availability of sand. They may range from relatively small, regular pulse nourishments with the help of permanent infrastructure, to sudden mega-nourishments with a design lifespan of several decades . The largest application of this concept so far is the Sand Motor Delfland on the Holland Coast.

2.2 Pilot Sand Motor Delfland

The Sand Motor Delfland (Figure 1) is a pilot project to assess the effectiveness of concentrated nourishments in protecting the coast of the Netherlands. This unprecedented experiment foresees in the introduction of 21 million m3 of sand rising up to 7 m above mean sea level. Natural processes distribute the sand over the shoreface, beach and dunes, to feed a 20 km coastal cell ranging from The Hook of Holland to The Hague. The initial sand volume was determined from the anticipated rate of erosion along the coast over the project's 20-year design lifespan. The shape of the nourishment was largely inspired by the potential to provide areas for nature and recreation. It was decided to create a hook-shaped peninsula that would provide resting areas for seals at the quiet end of the spit, with a shallow lagoon that would offer habitats for flatfish and other organisms and a dune lake for recreation purposes as well as wet dune habitat. In addition, the Sand Motor should promote the development of pioneer dunes with associated vegetation along the beach.

(a)


(b)

Figure 1. Pilot Sand Motor Delfland. Location along the Central Holland Coast (a) and appearance on July 11 (2011), shortly after completion (b). Picture courtesy of Rijkswaterstaat / Joop van Houdt

Work on the Sand Motor was completed in mid-2011, after a construction period of about 20 weeks with production rates in the order of 1 million m3 sand/week. Ever since, the pilot project has been closely monitored, amongst other through permanent collection of wave and current data just seaward of Sand Motor, monthly sampling of nearshore bathymetry at the Sand Motor as well as around, annual sampling of benthos and juvenile fish in the area the organization of bird counting campaigns at three occasions over the last year. The Sand Motor will be the subject of extensive long-term research to document and assess its natural evolution and translate this into generic knowledge applicable elsewhere.

The broad scope of the monitoring program is in line with the inter-disciplinary nature of the Sand Motor project. Similarly, data often serve multiple purposes. Bathymetric data, for instance, are collected on a monthly basis, primarily for coastal safety purposes (understand Sand Motor morphological evolution, improve predictive skills). However, the same data are also provided, on a regular basis, to beach guard organizations in order to help them to make improved assessments of swimmer safety and to guarantee rapid rescue in case of an emergency. An example of the latter is shown in Figure 2.

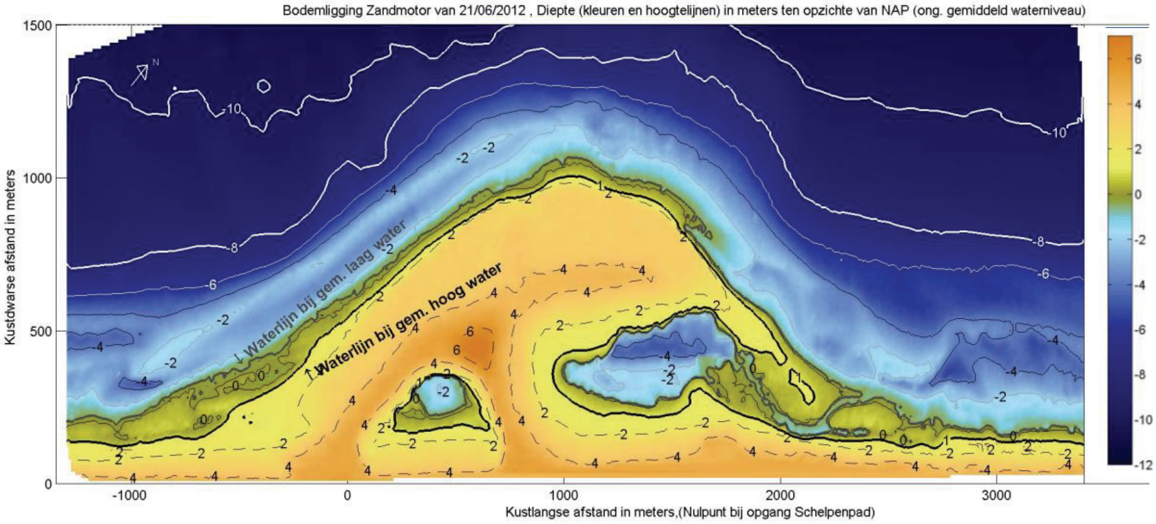


Figure 2. Survey of Sand Motor bathymetry (June 2012) as provided to beach guard organization in support of swimmer safety assessment. Figure courtesy of Shore Monitoring & Research.

2.3 Observations from first-year field monitoring

During the first year of its existence, the Sand Motor has been subject to considerable morphological changes (Figure 3).


July 11, 2011

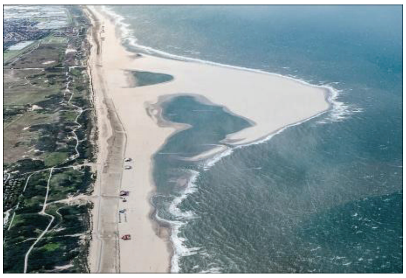

July 18, 2011


September 5, 2011


October 13, 2011


January 10, 2012


March 20, 2012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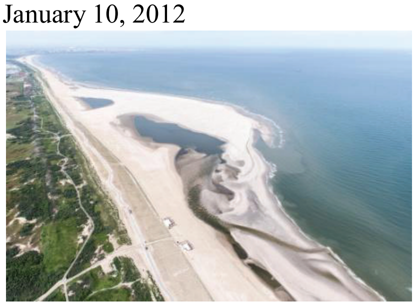
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September 4, 2012

Figure 3. Morphological evolution of Sand Motor since completion early July 2011. Pictures courtesy of Rijkswaterstaat / Joop van Houdt

The most seaward point of the MSL contour, originally extending nearly 1000 m offshore, migrates over 100 m shoreward and the alongshore width of the Sand Motor has increased from approximately 2400 m (initially) to more than 3600 m at present (Stive et al, *subm*). The northern tip of the spit has curved shoreward to form a tranverse bar extending several hundreds of meters northward. At the lee side of this bar, a feeder channel has developed that connects the lagoon to the open sea. The observed morphological behavior is qualitatively consistent with the predicted evolution obtained from model calculations as part of the Environmental Impact Assessment, albeit that measured changes occur faster than predicted. The latter can be attributed to a combination of factors, including the large number of wave events in the stormy winter of 2011-2012, the relatively coarse grid resolution and the actual shape of the Sand Motor immediately after construction. Refined model simulations by Stive et al (*subm*) confirm the capability of present-day models to provide predictions that are in good quantitative agreement with field observations after one year.

Linnartz (2012) provides an overview of the nature that has developed on the Sand Motor during the first year after construction. From the first day on, the Sand Motor was popular amongst birds, fish and mammals. Soon, the Sand Motor became a rest place for cormorants, terns and gulls. Some 500 cormorants used the Sand Motor to fish for lesser sandeel. Local sport fishers were triggered by these groups of birds, as underneath the sandeel mackerel was found. The abundance of fish also attracted larger mammals to the Sand Motor, including seals and porpoises – which were frequently observed. On the sub-aerial beach, the Sand Motor provides room for the development of juvenile dunes, a rare nature type in this part of The Netherlands. At the lee side of these dunes, the sea holly and other rare plants such as the frosted orache can be found. Interestingly, Linnartz (2012) concludes that the massive size of the Sand Motor allows nature development and intense recreational use to go hand in hand.

During the first year of its existence, the Sand Motor also turned out to be a recreational hot spot. It was soon found to be an excellent place for wind, wave and kite surfing. But also sport fishermen were attracted by the large assemblages of fish in the direct neighborhood of the Sand Motor, beach walkers came to enjoy the ever changing landscape and swimmers discovered the place for beach recreation on sunny days. Intensified beach use however also gave rise to some concerns on swimmer safety, especially after development of the long, narrow feeder channel (just before summer 2012) and the associated strong current velocities. These effects were predicted prior to construction and responsible authorities had appropriate management measures in place such as a bathing ban, warning signs and supervisors on the beach. Nevertheless, some incidents occurred which resulted in negative reactions in the media.. It turned out that measures alone were not able to prevent incidents and that continued attention, management of expectations and open communication with stakeholders remains important. It reminded us that the partners must remain involved throughout the project, but especially during the transition phases from project design, to construction, to project operation and maintenance.

3 SEABED LANDSCAPING IN SAND EXTRACTION SITES

3.1 The concept: seabed landscaping

The increasing sand demand for shoreline maintenance and other marine infrastructure such as land reclamations is associated with intensified sand mining operations, that impact the sea bed at the borrow areas. Traditionally, these environmental impacts are considered negative resulting in environmental policies that set restrictions and limitations to the mining operations. The potential post-dredging value of the borrow area is rarely considered as a result of which opportunities that could improve or add to the overall sustainability of the dredging project are missed. Seabed landscaping of sand extraction sites is the Building with Nature response to create added value.

The concept of seabed landscaping is inspired by measurements of benthic species and density in the North Sea. The sandy habitats of the North Sea are home to fish species such as plaice and sole, as well as shellfish, worms and other seabed dwellers that protect themselves by burrowing in the sand. They feed on organic material captured in the sediment or filter their food from the water. Measurements have shown that the diversity and productivity of benthic species in the North Sea depends on the relief of the seabed.

Shallow coastal seas, like the North Sea, often feature a variety of large-scale undulations, or bed forms, up to about 10 metres high. Natural bed forms are associated with gradual changes in terms of water depth, grain size, mud content and surrounding currents, thus providing a variety of habitats for diverse marine species (Baptist et al, 2006, Van Dijk et al, 2012). Whereas traditionally dredging operators were requested to leave a flat bed after mining, the concept of seabed landscaping aims to create such diverse habitat conditions in sand extraction areas by leaving large-scale bed forms on the dredged sea bed after completion of the works (Figure 4). In this way, landscaped mining areas are hypothesized to encourage recolonization and promote higher biodiversity and productivity after completion of the dredging works.

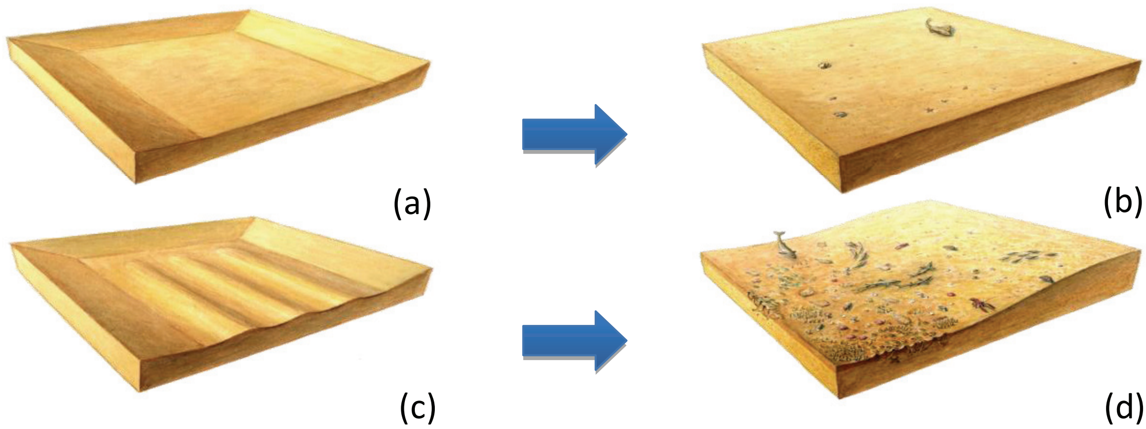

Figure 4. Concept of seabed landscaping in sand extraction areas. In analogy to sea beds with natural bed forms, landscaped mining areas (c) are hypothesized to encourage recolonization and promote higher biodiversity and productivity (d) after completion of the dredging operations; in contrast to extraction areas with a flat bed (a), which yield an ecologically poor habitat (b) after dredging.

3.2 Pilot experiment: Landscaping of Maasvlakte-2 sand extraction site

To explore the ecological benefits of seabed landscaping in sand extraction sites, a full-scale pilot experiment was carried out as part of the sand mining works for the Maasvlakte-2 land reclamation (Figure 5). The experiment involved selective dredging, leaving behind two sand ridges in the designated borrow area. These artificial bed forms are about 700 metres long and 100 metres wide; the vertical difference between the crest and trough level measures 10 m. As regular Maasvlakte-2 mining foresees in a seabed deepening from (roughly) -20m to -40m below MSL, the ridges are located at water depths of 30 to 40 m. Each ridge mimics a sand wave with a wave length in the order of 300-400 m, which is very similar to the scales found in nature. The first ridge was created in 2010 in the eastern part of the borrow area, and the second in 2011 in the southern part..

Within the Maasvlakte 2 project, an important aspect of the experiment with seabed landscaping concerned the alignment of the artificial ridges and troughs. The crest of one of the ridges is aligned east–west, perpendicular to the direction of the tidal current in the North Sea – and consistent with the natural orientation of sand waves. The second ridge runs parallel to tidal current, which is perhaps less natural but easier and cheaper to create with Trailing Suction Hopper Dredgers. By considering the impacts of both orientations in the experiment, it will be possible to assess how to combine the environmental benefits of seabed landscaping with the most cost-effective construction methods.

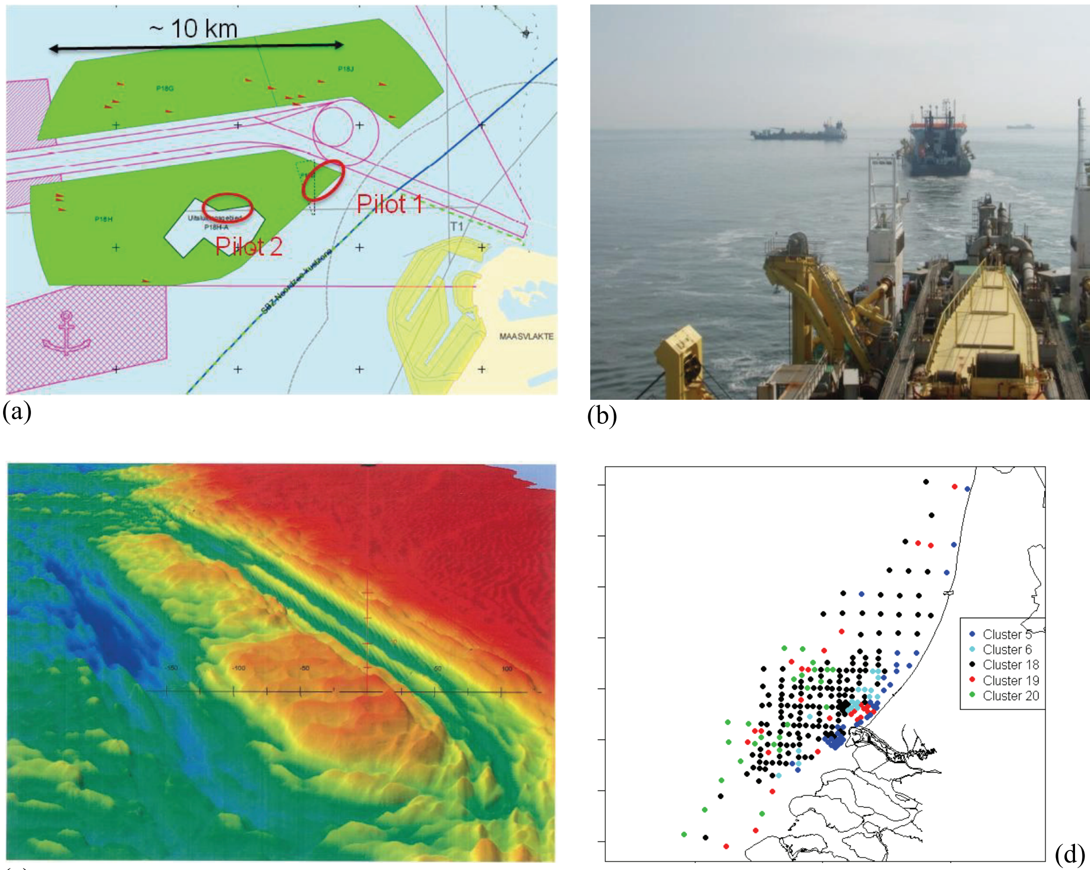

Figure 5. Full-scale pilot experiment on seabed landscaping. Location of pilot sites within designated Maasvlakte-2 borrow area (a), selective dredging for ridge creation Pilot 1 (b), flow-normal ridge Pilot 2 during construction (c) and overview of sample points for recolonization monitoring and sampling of reference data (d).

The recolonization of the borrow area has been monitored since 2010. Table 1 provides an overview of the measurements that we carried out since.

Table 1. Overview of recolonization monitoring nearMaasvlakte-2 landscaping experiment.

Year	2010	2011	2012
Activity			
Boxcore (#)	45	45	63
Bottom dredge (#)	26	26	32
Sediment characteristics	45	45	63
Beam trawl (4.5m – 80 mm)	4 outside / 6 inside	7 outside / 13 inside	4 outside / 10 inside
Side scan sonar	-	-	In- and outside borrow area
Hydrodynamic modelling	Part of NCP	-	MV2 borrow area

The monitoring program foresees in three types of ecological measurements. The boxcore measurements involved sampling of sediment cores from the upper 20-30 cm of the seabed, to assess infauna (animals larger than 1mm) and sediment. The bottom dredge measurements were carried out to sample epifauna (animals in or on the seabed larger than 0.5 cm) with a small dredge (10cm deep, 10 cm wide and 150 m long tracks). Finally, beam trawl measurements were deployed to collect demersal fish (living and feeding on or near the seabed) and in- and epifauna on the seabed. To do so, a 4.5m wide beam trawl was used, with 80 mm mesh size in the net. In addition to these ecological data, supportive data on bed elevation and sediment characteristics throughout the sand extraction area were also collected.

3.3 Observations from two years field monitoring

To assess the potential ecological benefits of seabed landscaping in sand extraction areas, bed samples and fish surveys were carefully analyzed in terms of species density as well as diversity. This is done for a variety of sampling stations, located:

- Within the borrow area, on and near the artificial ridges and troughs
- Within the borrow area, on the flat seabed
- Outside the borrow area (reference locations)

The first and second year of monitoring reveal a consistent pattern, showing four to five times more fish inside the 20 m deepened borrow pit than outside (Figure 6). This is a key outcome of the project, indicating that the environmental impacts of sand extraction areas are not necessarily negative. In fact, the high fish density may yield economic potential for re-development of the pit after dredging as fishing grounds for local communities. Although the data suggest that the largest assemblages of fish are found near the artificially created bed forms, it remains to be investigated whether the high densities can be explained from the applied seabed landscaping, or should be attributed to the presence of the 20m deep pit itself.

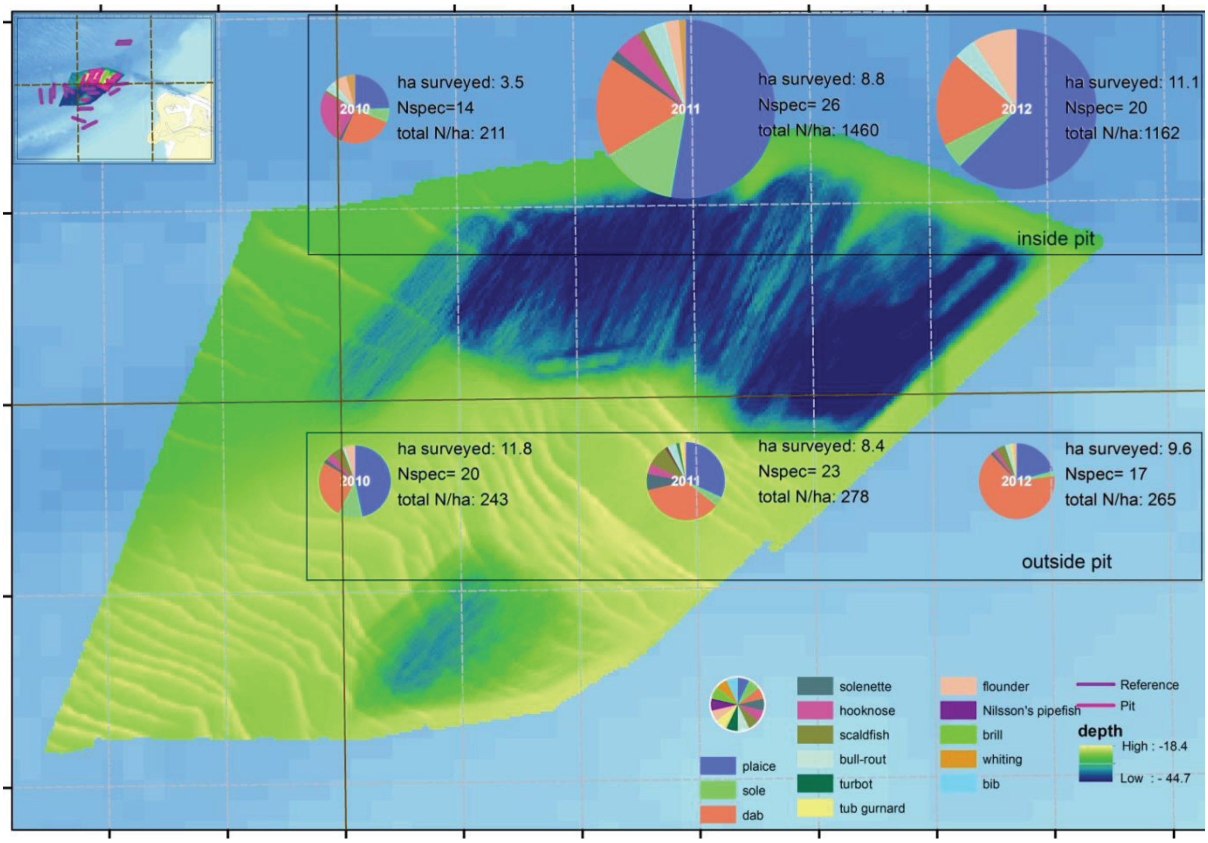

Figure 6. Summary of finding from ecological monitoring campaigns 2010-2012, to assess recolonization in landscaped sand extraction sites. Data reveal fish densities inside the pit are 4-5 times higher than outside. Figure courtesy of Maarten de Jong and Martin Baptist (Wageningen IMARES)

4 FULL SCALE EXPERIMENTS AS A DRIVER FOR PUBLIC-PRIVATE INNOVATIONS

In any infrastructure project, the complexity of the governance framework is often proportional to the number of stakeholders involved. This rule of thumb certainly applies to coastal waters where there are many different, sometimes conflicting interests, ranging from nature and fisheries conservation, to coastal protection, recreational demands and the need for open shipping lanes. From the work carried out as part of the Building with Nature program, we have learned that major innovations in the field of marine infrastructure development can only be realized on the basis of well-established, open networks between public parties, private companies and research institutes. In addition, we found that full scale experiments have the unique capacity to focus multi-disciplinary research efforts and end-user interests, hence act as an important driver for public-private innovations.

From the early days on, the Sand Motor experiment has been designed as an integral development serving multiple objectives: guarantee long-term coastal safety, promote nature development and recreation along the Delfland coast and stimulate innovation in the field of coastal zone management. While the scientific community played a key role in suggesting and promoting the concept, the project itself was initiated by a consortium of public authorities including the *Milieufederatie Zuid-Holland*, an NGO in the field of the conservation of the environment. Parties consolidated their ambitions in a formal document called the 'Ambition Agreement' (2008). Attracted by the potential of this innovative measure and the envisaged full-scale experiment, EcoShape became involved as an independent partner running its own innovation program, inspired though by observations from the real-world pilot case Sand Motor.

The successful collaboration during preparation and implementation of the Sand Motor resulted in a well-established network between public authorities (Ministry of Infrastructure and the Environment, Province of South-Holland), research institutes (Deltares, IMARES, universities) and private companies (both dredging contractors and consultants). The parties of this network shared a common ambition: To explore the Sand Motor Delfland experiment to its full extent, in order to learn from it for the next project either in The Netherlands or abroad. This demands thorough understanding of the evolution of the Sand Motor and the driving mechanisms behind it. To that end, an extended monitoring program was implemented under the guidance of the Ministry of Infrastructure and the Environment Rijkswaterstaat and EcoShape, with substantial co-funding from the European Fund for Regional Development EFRO. The availability of these data inspired a successful application for funding from the Dutch Technology Foundation STW, resulting in a program called NatureCoast that foresees in 12 PhDs and 3 postdocs working on all relevant physical, ecological and social fields as well as their integration. A key element of the program is the high degree of end-user involvement, both in the scoping of the individual research projects as well as the translation of NatureCoast outcome back to practice. With more than ten million euro in place now for inter-disciplinary coastal research and supportive monitoring, it is fair to conclude that the Sand Motor Delfland experiment did indeed manage to become a focal point for coastal research and innovative coastal management, as well as to establish the public-private networks that were necessary to enable all this.

Similar considerations apply to the seabed landscaping experiment that was carried out as part of Maasvlakte-2 land reclamation. Collaboration between public authorities, the project client (Port of Rotterdam), the dredging contractors (PUMA joint venture, consisting of Van Oord and Boskalis) and research institutes (IMARES, Deltares) was a prerequisite to make the experiment feasible at all within the constraints of the existing sand mining permit. Once considered feasible, it required intense interaction with the dredging contractors to enable realization of the experiment in the context of their regular operations and project obligations. Finally, to meet budget constraints, the Building with Nature monitoring program for the landscaped mining pit was set-up complimentary to the large-scale Maasvlakte-2 monitoring program carried out by Port of Rotterdam. It required permanent liaison between both parties to coordinate the monitoring efforts, which was successfully achieved. Again, these observations confirm that the availability of well-established networks and a full scale pilot experiment form the key ingredients for driving successful public private innovations.

The network arrangements described above form a practical illustration of the collaboration in the so-called 'Golden Triangle' of public authorities, research institutes and private companies. It is this sort of collaboration that is actively pursued by the Dutch government as part of its innovation strategy in the framework of the so-called *Top-Sectors*. We share this vision and believe such collaboration will open the door towards near-future innovations on sustainable development of shorelines and land reclamations.

5 CONCLUSIONS

This paper has explored the feasibility of Building with Nature solution for sustainable development of land reclamations and shorelines. Focal point of the research are two full scale pilot experiments, which aim to address the concepts of concentrated nourishments for shoreline development and seabed landscaping in sand extraction sites, respectively. Key findings include:

- Rapid changes of morphology observed during the first year after implementation of the 21 million m3 'Sand Motor' nourishment have inspired the development of a refined morphological model, which shows improved predictive skills.
- Visual observations on the Sand Motor confirm beneficial nature development and recreational use, in all relevant aspects.
- Ecological monitoring data sampled from the landscaped extraction site indicate 4-5 times more fish inside the mining pit, than outside.

At the more strategic level, our findings confirm the key role of full-scale experiments as an effective focal point of (inter-disciplinary) research efforts, and public-private partnering as a successful mechanism to drive innovations in the field of marine infrastructure development.

We envisage the lessons learned from the Building with Nature (2008-2012) program will have an impact on a world-wide scale. The observed abundance of marine life in the sand mining pit puts dredging works in a different perspective: Rather than a threat to the environment, sand mining can have a positive effect. This will positively affect procedures for the approval of sand mining permits world-wide, including the Arabian Gulf where countries show increased awareness of the impact of marine construction works in sensitive environments (e.g. Khalifa Port and Industrial Zone Project in Abu Dhabi, UAE). Within a year after its implementation, the Sand Motor Delfland has already raised international interest from amongst others the US, France, Belgium and China. Although the size, shape and frequency of the nourishment may vary from site to site, the underlying concept is generic and applicable along many shorelines worldwide. The availability of a full-scale prototype Sand Motor to demonstrate the feasibility of the concept was found to be of crucial importance.

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