SUSTAINABLE DEVELOPMENT OF NOURISHED SHORELINES

Innovations in project design and realisation

by

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ABSTRACT

Recent years have shown an ongoing need for marine infrastructure, however the development of large-scale infrastructure projects is associated with uncertainties and delays, increased awareness of the environmental effects and extensive demands on environmental management plans and monitoring programs. The combination of these tendencies drives innovations in project design and realisation, which are often characterized by integral, multi-disciplinary approaches, increased contractor involvement and the application of Building with Nature type approaches.

This paper presents two examples of such innovations in project design and realisation, both developed in the context of of sustainable development of nourished coastlines. The examples concern the application of mega-nourishments for coastal development and ecological landscaping in sand mining areas. The work is carried out as part of the Innovation Program Building with Nature, which aims, amongst others, to draft a manual for the ecodynamic design of marine infrastructure.

We believe the use of ecodynamic design strategies for marine infrastructure will inspire ecologists and engineers to maximally explore environmental benefits of projects, thereby adding to the ecological and public appreciation of marine works.

1. INTRODUCTION

With over 80% of the world's large population centres located in vulnerable coastal, delta and river areas, the development challenge in these areas is extraordinary. Trade and industry require new ports and infrastructure, citizens require housing and rivers require space to discharge larger floodwater volumes. This needs to be harmonized with existing natural dynamics whilst accounting for the effects of climate change and sea-level rise. Recent years have shown that the realisation of marine infrastructure in such complex environmental and societal settings can be characterized by the following trends:

- Long-term drivers such as climate change, increasing energy consumption and population growth in coastal and delta areas induce a permanent demand for new marine infrastructure and extension of existing facilities;
- The development of large-scale infrastructure projects is associated with (political) uncertainties and delays. For instance the Maasvlakte-2 land reclamation took over 20 years of preparation;
- Present-day projects require the implementation of thorough Environmental Management Plans prior to the start of the works and the actual project realisation can come with extensive requirements on environmental monitoring programs;

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- Sustainable project development becomes increasingly important for clients as well as society;
- The specialist expertise needed for the development and realisation of large-scale projects in complex environments increasingly shifts from the client to the contractor and her partners.

In addition to the above-mentioned considerations, it is important to acknowledge that coastal areas are naturally dynamic zones that are vulnerable to anthropogenic interventions. The increased pressure for developing these areas means that interventions need to be tuned to the natural situation and dynamics. Nourished shorelines are an excellent example of sustainable method of combining development whilst remaining flexible enough to absorb the natural dynamics of the system.

To be able to design such sustainable interventions, the field of coastal engineering is facing a series of important challenges to ensure that the necessary expertise and knowledge is available in the near-future. These challenges offer contractors, consultants and research institutes excellent opportunities to stand out in the field of sustainable development of marine infrastructure, hence to reinforce their competitive edge. Innovation is needed to develop new, integral approaches towards the design and realisation of marine infrastructure, based on a sound understanding of ecosystem dynamics, construction processes and stakeholder demands.

In this paper we will discuss several of these innovative ideas in the context of sustainable development of nourished coastlines. To that end, we start with a description of the anticipated scale in crease in Dutch Coastal Zone Management, which offers a suitable framework for the development of sustainable strategies for sand mining and coastal nourishments along the Holland Coast, based on the concept of Building with Nature. The potential for the development of innovative, sustainable solutions is then illustrated on the basis two examples: the application of mega-nourishments for coastal development and ecological landscaping in sand mining areas. The work is carried out as part of the Innovation Program Building with Nature, which is also briefly addressed in this paper.

2. SUSTAINABLE DEVELOPMENT OF NOURISHED SHORELINES

2.1 Context: Scale increase in Coastal Zone Management

In 1990 the Dutch Government adopted the national policy of “Dynamic Preservation” (MIN V&W, 1990) which aimed at a sustainable preservation of safety against flooding, as well as values and functions in the dune area. Acknowledging sand as ‘the carrier of all functions’ (NSS, 2006), the principle intervention procedure is nourishment of sand, making optimal use of natural processes and leaving room for natural dynamics (hence *Dynamic* Preservation). Implementation of the policy has been guided by the definition of tactical objectives at different scales, i.e. preservation of the basal coast line at medium scales (order 10 years) and of the coastal foundation at larger scales (see van Koningsveld and Mulder, 2004; Mulder et al, 2006).The yearly-averaged nourishment volume for the entire Dutch coast since 2000 amounts to 12 million m^3 per year.

Figure 1: Delta Commission (2008) report 'Working together with water' (a) and proposed measures (b) under the Delta programme to adapt to climate change over the next century

On the basis of this national policy of "Dynamic Preservation", the Dutch Delta Commission 2008 adopted the concept of beach and shoreface nourishments as the primary measure to guarantee long-term safety and development of the coast (Figure 1). The Commission was appointed by the Dutch Government to address the long-term threats of climate change on the Netherlands. In the light of accelerated sea level rise, the Commission recommended an increase of the annual coastline nourishments to 40-85 million m^3/year. Nourishment of another 40 million m^3/year would enable seaward extension of the shoreline over about 1000m in the next 100 years. The Commission attributes large benefits for nature and society to such extension, explicitly stating that this approach allows for the application of Building with Nature type concepts. Moreover, the scale increase in annual nourishment volumes opens the door towards innovations in the design of nourishment strategies and associated sand mining pits.

2.2 Towards sustainable strategies for sand mining and coastal nourishments

Implementation of sustainable strategies for sand mining and coastal nourishments demands a paradigm shift in the approach of project development and design: away from a defensive approach, aiming at the minimization of impacts and – if necessary – effect mitigation and compensation, towards a pro-active approach, aiming at the optimization of system opportunities including benefits for nature and society. This approach is consistent with the concept of 'Building with Nature', which 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). Building with Nature type solutions aim to create added value through integral consideration of all functions and values of a coastal system. We adhere to the concept of Building with Nature by adopting three guiding principles towards the design of sustainable strategies for sand mining and coastal nourishments:

1. Make optimal use of natural processes.
2. Explore opportunities for nature development as an integral component of project design.
3. Reserve space to accommodate for natural system dynamics.

Concretisation of these guiding principles by means of so-called ecodynamic design strategies can result in project designs that fundamentally differ from traditional designs. The development of ecodynamic design strategies is the central theme of the Innovation Program Building with Nature, which is presently carried out by the Foundation EcoShape (see intermezzo below). Two examples are discussed in this paper, namely the use of mega nourishments (order 20 million m^3) for coastal development along the Holland Coast (Section 3) and Ecological Landscaping of sand mining areas (Section 4).

Intermezzo: 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. Develop scientifically sound design rules and norms
3. Develop expertise to apply the BwN concept
4. Make the concept tangible using practical BwN-examples
5. Establish how to bring the BwN-concept forward in society and make it happen

The core of the program is centered 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 20 PhD researchers. Throughout the program the interaction between disciplines is promoted, involving ecologists, engineers and policy makers. The work comes together in a work package called "ecodynamic design", which aims to draft a manual with guidelines for ecodynamic design of marine infrastructure. Results will become publicly available throughout the course of the program, with completion of the design manual envisaged for December 2012.

3. MEGA-NOURISHMENTS ALONG THE HOLLAND COAST

3.1 Concept and pilot project Sand Engine

Inspired by the proposed scale increase in annual nourishment volumes (Delta Commission, 2008), Dutch coastal authorities presently explore a variety of innovative sand nourishment strategies. One of these is based on the implementation of mega-nourishments. This concept involves the recurrent realisation of large-scale nourishments along the Holland Coast (each typically in the order of 20 million m^3). A surplus of sand is put into the natural system and expected to be re-distributed alongshore and into the dunes, through the continuous natural action of waves, tides and wind. In this way mega-nourishments gradually induce dune formation along a larger stretch of coastline over a period of one or more decades, thus contributing to the preservation or increase of safety against flooding over a longer period. Before being fully dissipated into the coastal system, the surplus sand volume temporarily creates added value for nature and recreation; amongst others by providing shoals as rest areas for sea mammals, wide beaches for daily tourism and challenging surf conditions for the local surf community.

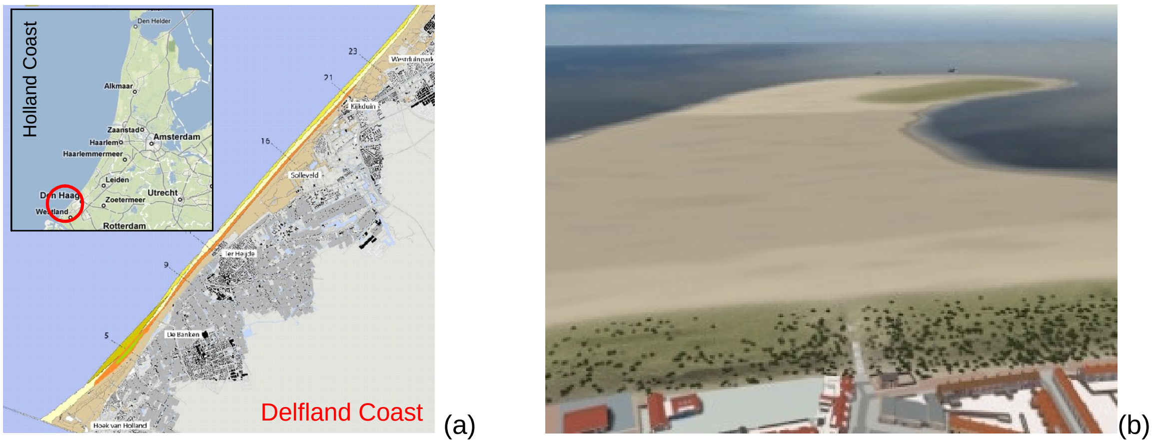

Figure 2: Artist impression of the initial design of the Pilot Sand Engine Delfland, a 20 million m^3 mega nourishment on the Delfland coast. The Delfland coast is located between The Hague and Rotterdam, in the southwest part of the Holland coast. Realization of the Pilot Sand Engine Delfland is anticipated near Ter Heijde. Figure (b) courtesy of Province of South Holland.

To assess the feasibility of mega-nourishments as an innovative measure to create long term safety conditions in combination with extra space for nature and recreation, a pilot project “Sand Engine Delfland” has been initiated (Figure 2). Initiator is the Province of South Holland (PSH), who aims for the realisation of a pilot mega-nourishment at the Delfland coast, south of the city of The Hague, in 2010/2011. PSH is preparing the pilot nourishment in close collaboration with the Ministry of Transport, Public Works and Water Management, local municipalities, the Water Board of Delfland, NGOs and businesses. In preparation of the pilot, several alternative designs of a Sand Engine have been studied and several scenarios for sustainable long-term nourishment strategies evaluated (Mulder et al, 2010). At the moment, the Environmental Impact Assessment is nearly completed (DHV, 2009), indicating the ‘Hook’ as the preferred alternative. At the political level a principle agreement has been reached on implementation from 2010.

3.2 Design aspects of mega nourishments (Building-with-Nature perspective)

The development of ecodynamic design strategies for mega-nourishments along the Holland Coast (following the guiding principles listed in Section 2.2) requires investigation of a variety of issues, including:

- the eco-morphological coupling between surf zone, beach and dune areas;
- eco-morphological dynamics associated with large-scale coastal interventions;
- the transfer of morphological changes to a perspective for nature development;
- swimmer safety on nourished beaches;
- the cumulative effect of multiple mega-nourishments at various locations along the Holland coast;
- development of an evaluation framework that allows for objective assessment of the Building with Nature benefits of a nourishment design, in concert with more traditional evaluation criteria such as the annual maintenance need.

Two aspects, dune formation and meandering tidal channels are described in more detail below.

Dune formation along sandy shorelines

Dune formation is a pre-requisite for sustainable, long-term development of nourished shorelines. Variations in the design of mega-nourishments may affect the rate of dune growth, hence thorough understanding is needed on transport processes driving dune formation and the effect of variations in foreshore and beach topography, sediment characteristics and vegetation on dune evolution.

Recently, Damsma (2009) carried out a detailed analysis of dune foot dynamics along the Dutch coast, considering a variety of time scales ranging from 5 to 150 years. His analysis was based on statistical investigation of all beach profile data available for the Dutch coast, in combination with model calculations to assess dune erosion during major storm events. On the basis of this work, Damsma hypothesizes that dune growth on the time scale of 5-25 years is dominated by erosion events associated with the occurrence and impact of major storms, rather than the gradual feeding by aeolian transport during mild conditions. The latter is commonly assumed in literature. In addition, Damsma suggests that the maximum rate of dune growth in the absence of any storm impacts (as is the case for specific sections of the Sand Engine) will be in the order of 12-18 m^3/m/year.

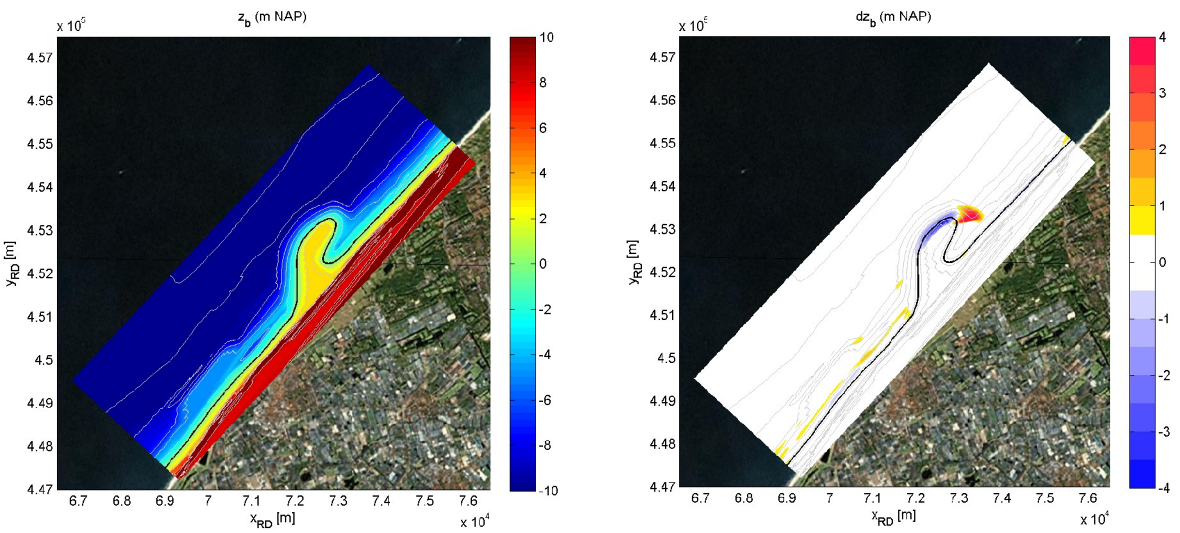

Figure 3: Simulation of morphological changes of the Sand Engine (Alternative 'Hook') during 1/10 year storm event with waves from 270ºN (west). The simulations are made with the state-of-the-art XBeach model (Roelvink et al., 2009). Preliminary results (right panel) reveal erosion near the tip of the mega-nourishment in combination with accretion further north and towards the shoreline (McCall et al., 2009). These results confirm that natural processes are indeed capable of distributing sediments away from the original Sand Engine to nourish neighbouring coastal cells.

On the basis of the findings of Damsma, it is hypothesized that dune formation will be encouraged through appropriate design of beach and shoreface nourishments. For instance, by placing the sediment higher in the beach profile, the nourishment becomes more effective in dissipating wave energy during major storm conditions, hence storm impacts on the dunes are more effectively reduced. This hypothesis is presently validated on the basis storm simulations with the XBeach model (Roelvink et al., 2009). XBeach is a state-of-the-art nearshore numerical model to assess the natural coastal response during time-varying storm and hurricane conditions. The model accounts for wave-group generated surf and swash motions and slumping of sand during dune erosion (avalanching mechanism). The model was used to simulate 1/10 year storm events for four different wave directions, showing realistic patterns of erosion/accretion for each condition (Figure 3). The model results are presently under analysis, with a particular focus on (i) the effect of individual storm events on the predicted long-term evolution of the Sand Engine (which was based on yearly-averaged wave conditions) and (ii) the assessment of dune erosion rates for different nourishment designs (beach versus shoreface nourishment).

Figure 4: Erosion hotspots at the shoreline due to the formation of a meandering tidal channel at the Bornrif (Ameland, The Netherlands). Figure courtesy of Ministry of Public Works, Rijkswaterstaat (The Netherlands)

Meandering tidal channels

A second design aspect that needs consideration in the case of mega-nourishments, is the possible formation of a meandering tidal channel by the time that the mega-nourishment is welding to the shoreline. An analogy of this behaviour is found in nature, on the Wadden Islands in the north of The Netherlands. The morphodynamic behaviour of the ebb-tidal delta is dominated by cyclic behaviour of channel-shoal systems, which migrate in north-east direction with a cycle time in the order of 60 years (Israel, 1998). At the end of a cycle, the tidal shoal welds to the shoreline (Figure 4), leaving a massive sand volume directly in front of the coast. In the case of the Bornrif (Ameland, The Netherlands), the tidal flow filling and emptying the lagoon that was formed between the original shoreline and the welding shoal, developed into a strongly meandering current. The latter was responsible for two erosion hotspots at the original shoreline, which posed a direct threat to a beach house on the dunes. At the moment, a scale analysis is carried out (based on the comparison of tidal prisms, differences in tidal levels, sensitivity for meandering flows and sediment characteristics) to assess whether similar effects can be expected for mega-nourishments on the Holland coast, and if so what mitigating measures should be taken into account.

4. ECOLOGICAL SAND MINING PIT

4.1 Background

Another innovative design strategy relates to the design of borrow areas for sand mining. Mega-nourishments are associated with large-scale 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.

The concept of ecological landscaping in sand mining pits is inspired by terrestrial infrastructure projects, where ecological engineering has almost become a standard component of licensing procedures for sand and gravel mining operations. Developing a similar approach in the marine environment may facilitate social and political acceptance of future dredging works, thus accelerating licensing procedures and project realisation. The overall aim of the landscaping is to make the pit attractive to a variety of benthos and flora that in turn attract fish, mammals and birds. This is done by creating ideal settlement and habitat circumstances by way of different bed forms and/or combinations of sediment characteristics. This will ensure an increase the biodiversity (volume and type) in the borrow area.

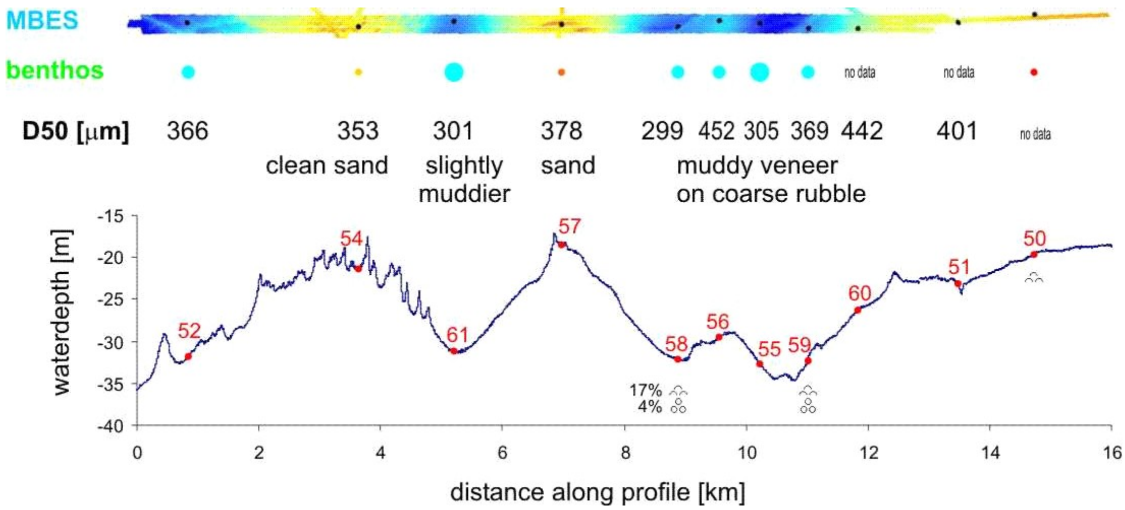

Figure 5: Seabed profile, surface sediment description and benthos community type and density found across tidal ridges in the North Sea. The figure shows (from top to bottom) respectively water depth, benthos density and sediment grain size for a total of 11 sample locations denoted by the red numbers. Figure courtesy of Van Dijk et al. (2007), taken from Van Dalfsen and Aarninkhof (2009).

Ecological landscaping in sand mining areas involves the realisation of bed level gradients and other morphological features in newly dredged pits (Van Dalfsen and Aarninkhof, 2009). Whereas present mining policies aim at rapid recovery and restoration of the original habitat on a flat sea bed, the concept of ecological landscaping aims to promote opportunities for nature and economy through development of new, enriched habitats in landscaped mining pits. The feasibility of this concept is derived from recent measurements on the North Sea which reveal a relation between local habitat characteristics and the geomorphology of the sea bed (Baptist et al. 2006). Results show that tidal ridges accommodate different benthic habitats, which are important to both benthic and pelagic organisms (Figure 5). More generally, a zoning exists within geomorphological features (such as tidal ridges), where the crests give home to poor benthic communities and the adjacent slopes and troughs host benthic communities of higher density and diversity (Figure 6). On the basis of these observations, the application of ecological landscaping in sand mining pits is expected to promote the development of valuable habitats at places where these would naturally not occur, or only on the very long term.

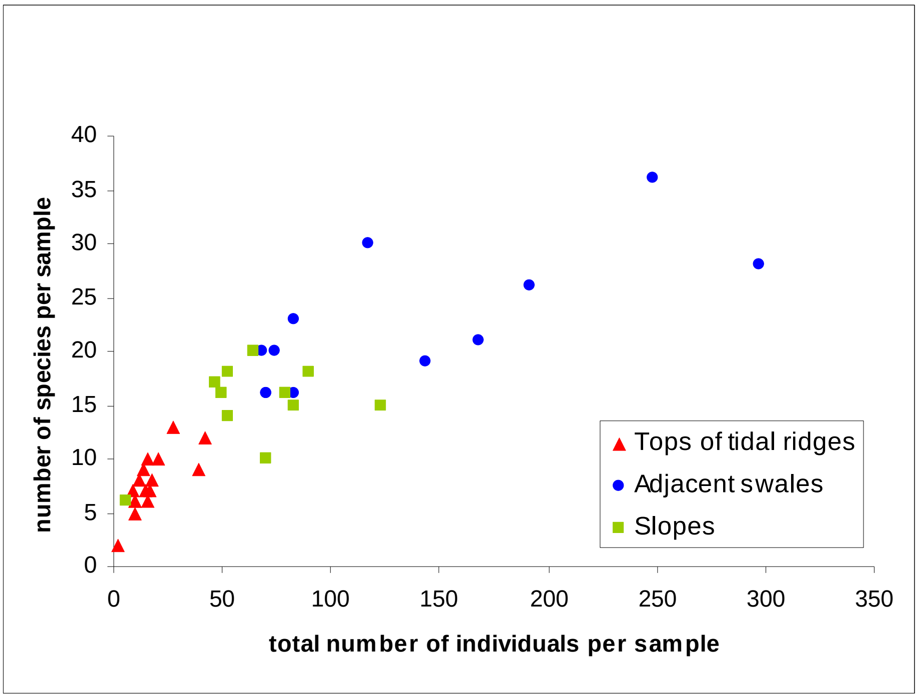

Figure 6: Variation of benthos density and diversity across two tidal sand banks in the North Sea. Maximum benthos density and diversity are found in the trough regions, the bar crest regions give home to poor benthic communities. Figure courtesy of Van Dijk et al. (2007), taken from Van Dalfsen and Aarninkhof (2009).

Application of ecological landscaping in mining pits implies the exchange of the existing habitat into a new habitat, which is not foreseen in current legislation. Assessment of post-dredging ecological benefits and their inclusion in evaluation frameworks thus requires a mind shift in current policies, permit requirements as well as our approach towards the design and realisation of sand mining pits.

4.2 Design aspects ecological mining pit

The key issue towards the use of ecological landscaping in sand mining areas is the assessment of the feasibility of the concept. In other words: Do the desired enriched habitats (as observed across natural tidal sand banks) indeed develop in man-induced mining pits and if so, what type of habitat is being developed, on what time scale, with which benthos density and diversity, etc. These types of questions can only be addressed on the basis of a real-world pilot experiment. Considering the scale of such experiment, this can only be achieved by linking the experiment to a running construction project that involves substantial sand mining. Realisation of such pilot ecological sand mining pit, followed by the evaluation of its ecological benefits is one of the objectives of the Innovation Program Building with Nature.

First step towards the realisation of a pilot ecological mining pit is the identification of a suitable pilot pit location. In this case the borrow area for the construction of the 1000 ha Maasvlakte-2 land reclamation (Port of Rotterdam, The Netherlands) can be used. Discussions were held with all stakeholders including the client Port of Rotterdam, the consortium of dredging contractors (PUMA) and the authorities (Ministry of Transport, Public Works and Water Management). Topics included planning issues (sand balance, timing), dredging operations (feasibility of bed forms), licensing/permits and financial aspects (extra costs for realisation).

The location needs to adhere to several important constraints. It must be located along the sides of the mining site and/or the exclusion zone and should remain untouched for a period of at least 5-6 years after construction to allow for natural recolonisation. Based on these considerations, three possible locations for the realisation of a pilot ecological mining pit were suggested within the overall sand mining site for Maasvlakte-2 (Figure 7). It is stressed that this figure only provides an indication of possible locations. At the time of writing of this paper, no decision has been made yet on the final location of the pilot ecological mining pit.

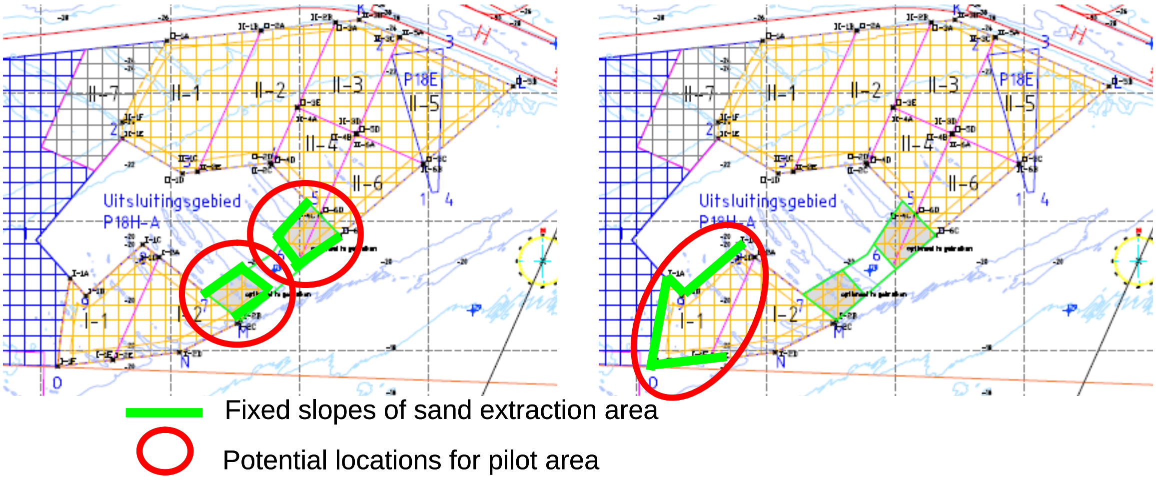

Figure 7: Indication of possible locations for pilot ecological mining pit within overall sand mining area for Maasvlakte-2. The figure shows the appointed sand mining areas as far as located south of the entrance channel of Port of Rotterdam and seaward of the -20 m depth contour. It is emphasized that the figures denote possible locations, at the time of writing of this paper no decision has been made yet on the final location of the pilot pit.

After the location has been determined, the design of the interior of the mining site can be made. The design depends on the available area, depth, volume of sand that can be left behind in the bed forms and the orientation of the fixed slopes. Within these constraints, the design is governed by:

- Ecological potential (depth, height of bed forms, sediment characteristics),
- Morphological stability (length scale and orientation of bed forms)
- Measurability of effects (minimum number of bed forms, to avoid boundary effects)
- Juridical constraints (realisation should fit within present permit).

The stability of bed forms with an orientation perpendicular to the tidal current was addressed with the help idealized stability models (linear and non-linear analysis after Sterlini, 2009), which obtained their tidal boundary conditions from a larger-scale model according to Roos (2008). The morphological calculations revealed that the preferred (stable) wave length of the bed forms is in the order 300-400 m. Owing to the large water depth, the morphological evolution of the bed forms is expected to be very slow.

Taking into account the preferred length scale of the bed forms (300-400 m), ecological demands on preferred bed form height (6-10 m) and requirements on the minimum number of bed forms (2-3, to avoid boundary effects), we anticipate that the dredged volume associated with the realisation of the bed forms will be in the order of 2.5 to 10 million m^3 of sand. Ideally, the pit should feature bed forms both perpendicular and parallel to the tidal currents. Final detailing of the pit design is carried out in consultation the stakeholders mentioned above.

Benefits of ecological landscaping of sand mining pits

Assessment of the benefits of ecological landscaping in mining pits relies on the execution of field measurements which, ideally, should reveal significant, different colonization patterns in the landscaped areas as compared to surrounding flat areas. Over time this should result in areas in which the ecological functions are enhanced. In turn, this could increase the economical potential of the area (e.g. fishing or recreation). The monitoring program is linked to the ongoing monitoring program by Port of Rotterdam related to the realisation of Maasvlakte-2. These monitoring programs should result in a thorough understanding of ecosystem principles and basic morphodynamics in ecological mining pits, which form the key factors to produce effective designs for sustainable landscaping projects.

The lessons learned and results of the design process including the different design parameters will be used as basis for the ecodynamic design manual. The effectiveness of the design will be determined through the monitoring program and also incorporated in the manual.

5. Conclusions

This paper has explored the potential for sustainable development of nourished shorelines through innovations in project design and realisation. The key observations in this work are:

- Climate change, energy consumption and population growth induce an ongoing need for marine infrastructure; however, the realisation of such infrastructure is often associated with uncertainties, delays and extensive requirements on environmental management plans and monitoring programs;
- Innovation is needed to develop new, integral approaches towards the design and realisation of marine infrastructure, based on a sound understanding of ecosystem dynamics, construction processes and stakeholder demands;
- The anticipated scale increase in Dutch Coastal Zone Management offers a suitable framework for the development of sustainable strategies for sand mining and coastal nourishments along the Holland Coast, based on the concept of Building with Nature;
- Case examples on the application of mega-nourishments (20 million m^3) for coastal development and ecological landscaping in sand mining areas illustrate the potential of this approach;
- The development of ecodynamic design strategies in support of sustainable development of nourished shorelines will be further explored as part of the Innovation Program Building with Nature (carried out by the Foundation EcoShape, 2008-2012).

We believe the use of ecodynamic design strategies for marine infrastructure will inspire ecologists and engineers to maximally explore environmental benefits of projects, hence add importantly to the ecological surplus and public appreciation of marine works.

6. ACKNOWLEDGEMENTS

The work presented in this paper is carried out as part of the innovation program Building with Nature. The Building with Nature program is funded from several sources, including the Subsidieregeling Innovatieketen Water (SIW, Staatscourant nrs 953 and 17009) sponsored by the Dutch Ministry of Transport, Public Works and Water Management and partner contributions of the participants to the Foundation EcoShape. The program receives co-funding from the European Fund for Regional Development EFRO and the Municipality of Dordrecht.

This paper is based on the outcome of a series of projects in the context of the Building with Nature case Holland Coast. The dedicated work of Jasper Fiselier (DHV), Kris Lulofs and Pieter Roos (both University of Twente), Martin Baptist and Maarten de Jong (both IMARES), Pieter-Koen Tonnon, Jamie Lescinski, Robert McCall and Rolien van de Mark (all Deltares), Sierd de Vries, Matthieu de Schipper and Thijs Damsma (all Delft University of Technology) on these projects is gratefully acknowledged. Special thanks to the Province of South Holland, The Ministry of Public Works Rijkswaterstaat, Port of Rotterdam and PUMA for their constructive collaboration within the case Holland Coast.

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