Above: Using a beam trawl, 4.5-m wide made with 80 mm mesh to monitor for demersal fish – fish living and feeding on or near the seabed; the net filled with fish attracts a variety of gulls. Repetitive monitoring is a critical part of ecologically enriching extraction sites.

D.C. RIJKS, M.F. DE JONG, M.J. BAPTIST AND S.G.J. AARNINKHOF

UTILISING THE FULL POTENTIAL OF DREDGING WORKS: ECOLOGICALLY ENRICHED EXTRACTION SITES

ABSTRACT

Marine extraction sites alter the morphology of the seabed and in doing so offer unique opportunities to create a new environment in these locations. A new physical lay-out means deeper waters and different currents and sediment characteristics, which offer conditions to develop a new ecosystem or a sanctuary for certain fish species. This potential has been tested in a full-scale pilot project in an extraction site in the North Sea within the Building with Nature research programme.

The necessity for this pilot project on utilising the potential of new extraction sites is evident. Rising sea levels and increasing pressure on available coastal lands lead to the need for new land reclamations for ports, cities, nature and recreation, but also sand nourishments for sustainable coastal safety. These are only a few of the many projects that are expected to take place in the future, which will need significant amounts of sand from offshore sources, thus creating extensive extraction sites. These extraction operations should be seen as an opportunity to manage these sites and create an overall increase in natural value of the seabed.

The research done here derived from the premise: Instead of focussing on minimising negative effects let's create opportunities to maximise positive effects. This article describes efforts to do this during the design process, construction and monitoring programme by creating a landscaped extraction site in the North Sea. It provides an overview of the preliminary results, focussing on the added value of landscaped extraction sites. It also describes when they are most effective; it is important to realise that the choice for an ecological landscaping design should be based on both the potential for development of a new ecosystem and the economic workability of the extraction itself (main function of the site).

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INTRODUCTION

Coastal development and management along sandy coasts, such as those in the Netherlands, is heavily based on dynamic sand nourishment programmes, often combined with new (seawards) land development. Depending on the coastline development, expected sea level rise can require an up-scaling of nourishment activities to be able to maintain current safety levels. Ideally, these nourishments are combined with quality enhancement of the coastal living communities, recreational sites and protected nature areas.

In the case of the Netherlands, coastal experts expect that the current 12 million m^3 of sand needed to maintain the coast each year may rise to 40-80 million m^3/year (Aarninkhof et al. 2012). This large amount of sand will be dredged from sand extraction sites in the North Sea (Figure 1). The expected increase in volume demands more and larger extraction sites.

Although in the short term the dredging will affect the local seabed and its inhabitants (they are effectively removed), the increase of the dimensions of the extraction sites offers unique opportunities to develop these sites for more than just extraction of sand.

Figure 1. Coastal replenishment and management along sandy coasts is based on dynamic sand nourishment programmes and demands many millions of cubic metres of sand each year.

The research described here tests the premise that instead of focussing on minimising negative effects, opportunities can be created to maximise positive effects. Using an ecosystem-based approach through an ecological design and using natural processes, the traditional 'ecological threats' can be turned into sustainable opportunities.

This philosophy was tested in the Building with Nature research programme (see box), through a large scale pilot project prepared and carried out in the 240 million m³ sand extraction site for the Maasvlakte 2 Port of Rotterdam expansion project.

INNOVATIVE SAND EXTRACTION

Although traditionally sand extraction in the Netherlands is permitted in the upper 2 metres of the seabed and in designated areas below the 20-metres depth contour (usually at least 12 nautical miles from the coastline), the permit for the sand extraction site for Maasvlakte 2 allowed for deep extraction (20 m below the seabed) reducing the extraction site size, and thus the impact on the seabed, by a factor of ten. In fact, if a (traditional) 2-m deep extraction had been required, the area needed for the extraction of sand for Maasvlakte 2 would have measured about 11 km by 30 km and costs for extraction would have increased as a result of longer sailing distances.

Ecological Landscaping

Building with Nature took this innovative extraction site a step further and designed and constructed landscaped bed forms in the seabed of the extraction site. The design, inspired by locally occurring sand waves, aimed at creating maximum gradients for water depth and current velocities, hence seabed sediments. This yielded a diverse environment for a variety of habitats whilst taking into account that the created slopes and depths would not induce oxygen depletion in the site.

The artist's impressions in Figure 2 summarises this concept: in contrast to extraction areas with a flat seabed (a), which after dredging yield an ecologically poor habitat (b), seabeds with natural bed forms, with landscaped mining areas (c) are hypothesised to encourage re-colonisation and promote higher biodiversity and productivity (d) after completion of the dredging operations.

The subsequent monitoring focussed on determining whether this innovative sand extraction site design with a higher habitat

INNOVATION PROGRAMME '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 programme is an initiative of the Dutch dredging industry, whilst partners represent academia, research institutes, consultancies and public parties.

The programme 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 objectives that were established for the programme:

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 programme is centred on four real-world cases (the Holland Coast, Southwest Delta and the Marker and IJssel Lakes in the Netherlands, plus a case in 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 programme the interaction between disciplines is promoted, involving ecologists, engineers and policy makers. The lessons learnt from these cases are used to formulate generic guidance for the design and implementation of these types of solutions, in the Netherlands as well as abroad. All results of the programme became available through a public wiki as per January 1, 2013. (https://publicwiki.deltares.nl/display/BWN/Building+with+Nature).

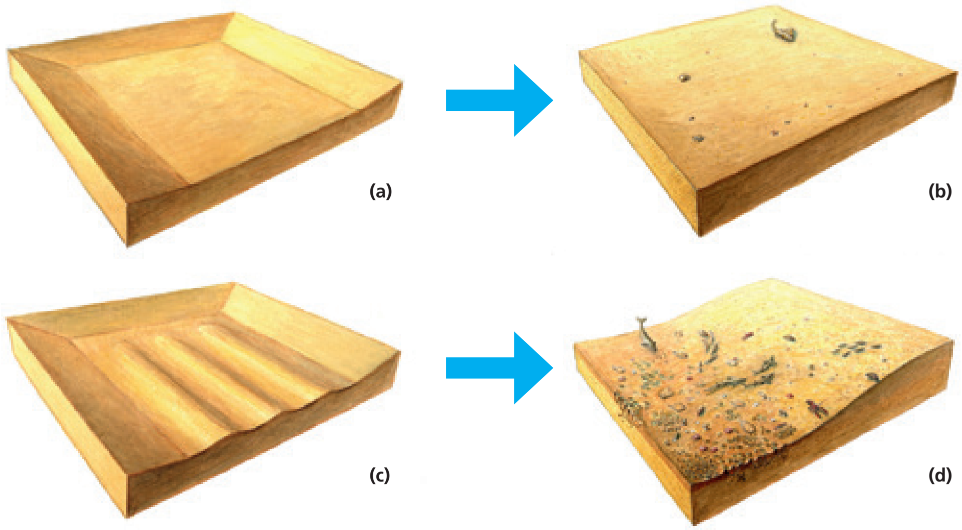

Figure 2. Artist's impression of the concept of seabed landscaping in extraction sites: (a) traditional extraction areas with a flat seabed yield poor habitats (b), whereas the BwN landscaped areas (c) encourage biodiversity (d). https://publicwiki.deltares.nl/display/BWN/Case+-+Ecosystem-oriented+Landscaping+of+Sand+Extraction+Sites

heterogeneity results in a faster re-colonisation, higher biodiversity, higher productivity of benthic and demersal fauna and overall economic benefits.

Mutual Benefits

The ultimate goal of the pilot was to prove the added value of combining ecology (nature) and economy thereby creating mutual benefit. The project searched for the best ways to design and construct landscaped bed forms to study the potential of the ecological development (increase in biodiversity) when extraction is finished and therefore, the ecosystem can optimally benefit from the resultant underwater landscape. By actually creating the landscaped forms and monitoring the ecological development, the theory and design could be tested in a real-life situation, thus ensuring that the final Building with Nature design guidelines are realistic and technically feasible. Based on involvement of stakeholder with ecologists, morphologists, permitting authorities, port representatives and contractors, requirements and technical parameters needed for the design, construction and monitoring were determined and listed. This process created understanding and awareness, thereby contributing to acceptance of the innovation (combining ecology and economy) by all parties involved (Figure 3).

Figure 3. Involvement of stakeholders and international experts was an integral part of the project's initial phase and continued through the planning and design phase.

DAAN RIJKS
works at Hydronamics bv., the in-house engineering department of Boskalis as an engineering manager and marine environment and morphological expert in international projects on Dredging, Ports, Waterways and Navigation. At Boskalis he is member of the corporate Taskforces Eco-Engineering and Energy Management (Emissions). He is also actively involved as a Board member of the Central Dredging Association CEDA and secretary of the PIANC EnviCom WG150 on Sustainable Ports.

MAARTEN DE JONG
is a marine ecologist and currently finishing his PhD project "Modelling the ecological potential of sand extraction". The project is part of the EcoShape / Building with Nature programme and focusses on the short-term impacts of large-scale and deep sand extraction and ecological landscaping on organisms on the seabed, bottom fish and the change of sediment characteristics, bathymetry and hydrodynamics.

MARTIN BAPTIST
is a marine ecologist with a PhD in hydraulic engineering. He has extensive experience with hydrodynamic and morphodynamic models, as well as biological measurements and statistical models. He is a member of the programme committee of the EcoShape/Building with Nature programme as well as a researcher at IMARES Wageningen UR, Professor at Van Hall Larenstein University of Applied Sciences and Senior Research Associate at Waddenacademie.

STEFAN AARNINKHOF
received both his degree as a civil engineer in 1996 and later his PhD from Delft University of Technology. After 10 years at Delft Hydraulics (now Deltares), he joined Hydronamic's Marine Environment and Morphology group in 2006, where he is now Deputy Manager. Until recently, he was in the Management Team of the EcoShape/Building with Nature programme and is presently responsible for the Environmental Engineering Group amongst other things.

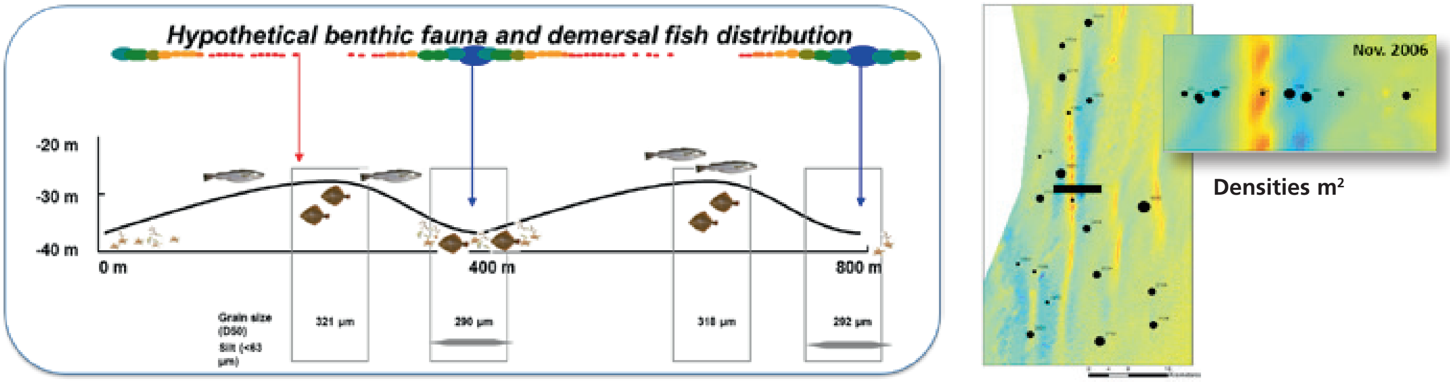

Figure 4. Relationship between the number of species and densities of macrobenthic organisms in the trenches and on the tidal bars (Van Dijk et al. 2012).

DEVELOPMENT PROCESS

This article describes the phases followed from idea to construction:

1. Initiation Phase
   a. Definition of ecological benefits: Based on the idea of landscaping sand extraction sites, brainstorm on aspects/benefits that are considered to be important (biodiversity) and how design and location can be chosen to achieve this;
   b. Literature research on previous studies to be used as reference, lessons learnt and background data in the project;
   c. Study on policy and juridical opportunities and restrictions to determine if and how the landscaping could be implemented in new or existing permits;
   d. Search for a suitable location;
   e. Stakeholder involvement. After the preliminary stages, a workshop was held to involve stakeholders and (international) experts in the project. The chosen aim, location, approach and expected results were discussed and were adapted where necessary based on experiences and expert judgement of the stakeholders.

2. Planning and Design Phase
   a. Selection of extraction site for pilot locations (together with stakeholders);
   b. Determination of design parameters and points of departure;
   c. Design landscape shapes (bed forms) in consultation with ecologists and contractors;
   d. Positioning of chosen designs in extraction site;
   e. Execution of morphological modelling for stability and development through time;
   f. Discussion of results with stakeholders;
   g. Finalisation of design.

3. Construction Phase
   a. Through active involvement, acceptance pilot project in extraction site by permitting authorities;
   b. Integration of final design in contractor dredging plan;
   c. Execution and surveying of construction of bed forms in site;
   d. Lessons learnt in discussion with all stakeholders including contractor and captains of the dredging vessels on workability (practical experiences).

4. Monitoring Phase
   a. Detailed short- and long-term monitoring plan including bathymetric survey, sediment characteristics, density and biomass of benthos and fish;
   b. Execution of monitoring works;
   c. Analysis of results and drafting conclusions and recommendations.

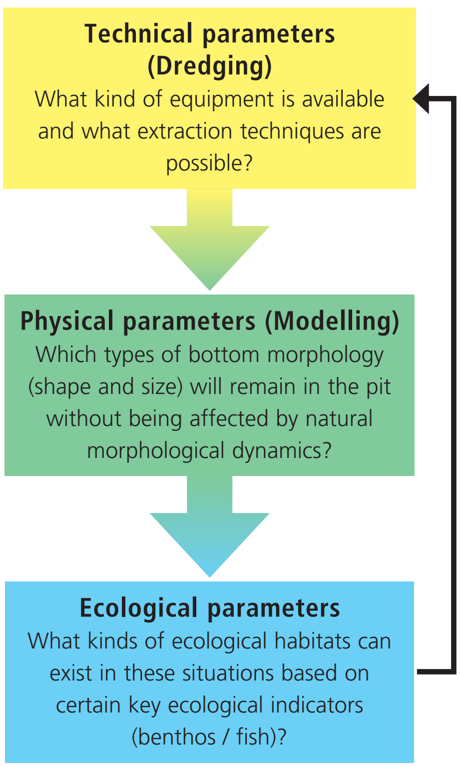

Figure 5. Flow chart showing the process used to accumulate requirements for designing the bed forms at the existing extraction site.

DESIGNING LANDSCAPED EXTRACTION SITES

The combination of dredging and ecological development has been recognised over a longer period of time. In many cases, dredging and managed disposal of dredged material are used as tools to create new environments for nature development. However, these were often dedicated projects that aimed at the actual development of nature. Moreover, never before has an ecologically enriched extraction site of this scale been realised.

Initiation and Concept

In recent years, the perception or design approach of coastal development and water-related infrastructure projects has changed. It started with stakeholders and engineers searching for additional opportunities that could be integrated in a project to enhance the final quality without compromising the main 'function' of the project. Examples are coastal nourishments in combination with natural dune development or harbour expansion projects in combination with beach recreation and fish migration routes. 'Working' or 'Building with Nature' goes a step further. In addition to looking at opportunities to enhance the natural value of the project, it searches for ways to actually build with nature, i.e., use natural processes and organisms in construction and operation to the benefit of the project.

This philosophy led to interesting discussions on the potential of the new physical characteristics of the extraction sites once sand mining was finished. The main discussion concerned the choice for 'rehabilitating' or 'recovering' the original seabed habitat versus developing new habitats after the extraction was finished. The main question is whether or not it is better to return the site to its original situation or to create a potential for a different ecological development with the possibility to enhance local biodiversity and increase biomass.

This pilot was set up to demonstrate that the second option (create a potential for a different ecological development) may be the best option, and that extraction sites can be designed in such a way that they create a new environment for ecological habitat development with potential benefits for a variety of functions:

- Nature/ecology (benthos, fish, birds, sea mammals)
  a. Development of the seabed and its accompanying communities;
  b. Increased biodiversity in the area;
  c. Protection of threatened or endangered species by creating tailor-made resting and spawning areas;
- Social/Recreation
  d. Creating attractive diving or sport fishing sites;
- Economy
  e. Fisheries: creating habitats that attract specific types of commercially interesting fish and shellfish (productive fishing grounds);
  f. Mining: mine only specific pockets containing desired types of sand, gravel, ore, and such and leave behind bed forms containing unusable materials.

Ecological Design and Embedding in Extraction Site

Different habitats exist in a seabed, related to variations in morphology, hydrodynamic conditions, water depth and sediment composition. Ecological research on tidal sand bars and sand waves has shown that there are significant differences in the benthic community composition and macrozoobenthic assemblages of the trough, slope and crest of natural occurring sand waves (Figure 4) (Baptist et al. 2006; Van Dijk et al. 2012).

Resulting from discussions between engineers and marine ecologists, the choice was made to create bed forms with variations of water depth that have a positive effect on the biodiversity and biomass. The gradients should be made large enough to accentuate any potential for differences. This assists in determining the actual effects of the bed forms with a higher level of accuracy and significance.

The design process then started with the accumulation of requirements needed for the bed forms, which were translated into an integrated design. In this project, the design needed to be fitted into an existing extraction site with ongoing dredging works. This asked for flexibility in the design and careful coordination with the contractor, the client and the permit-issuing authority. The requirements for the design were therefore focussed on what was practically possible in the chosen extraction site. The process of accumulating the requirements is shown in the flow chart (Figure 5).

The pilot location was the sand extraction site for the Port of Rotterdam Maasvlakte 2 port

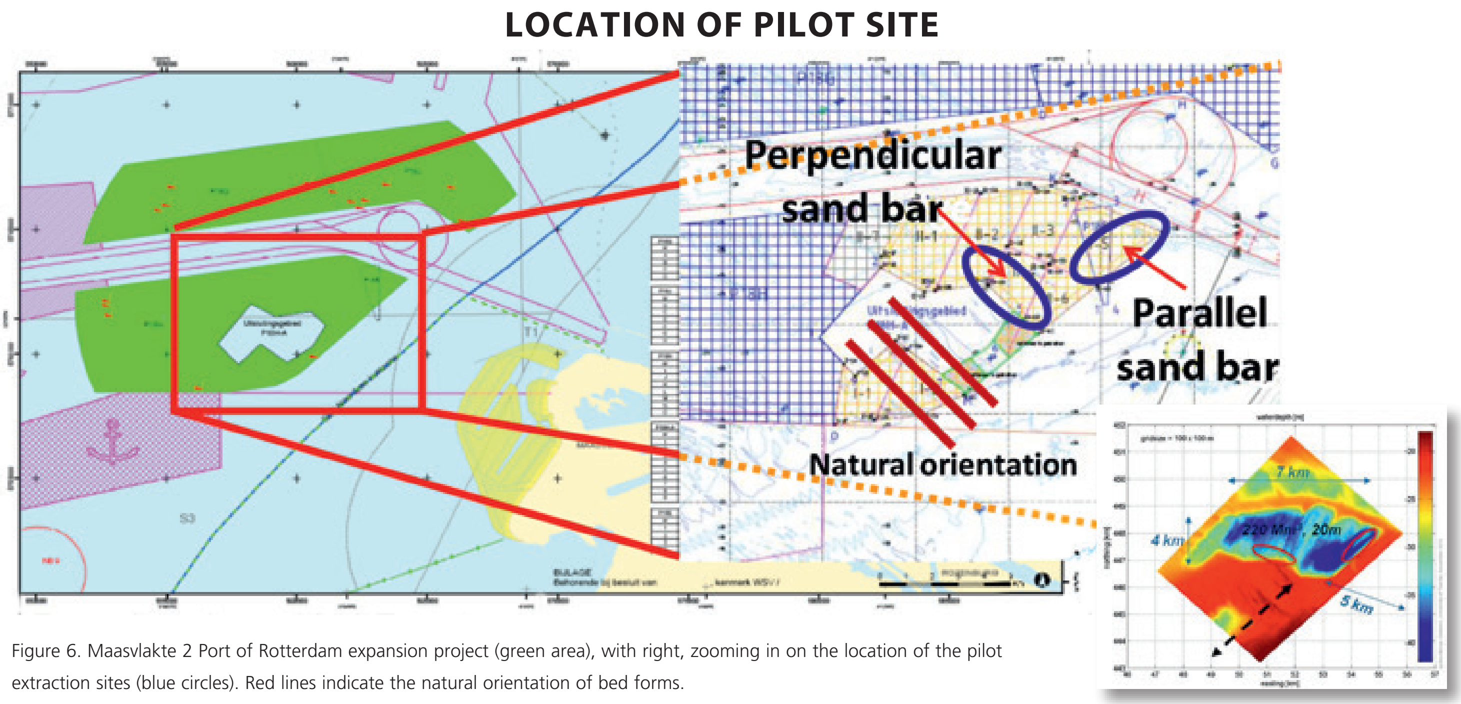

Figure 6. Maasvlakte 2 Port of Rotterdam expansion project (green area), with right, zooming in on the location of the pilot extraction sites (blue circles). Red lines indicate the natural orientation of bed forms.

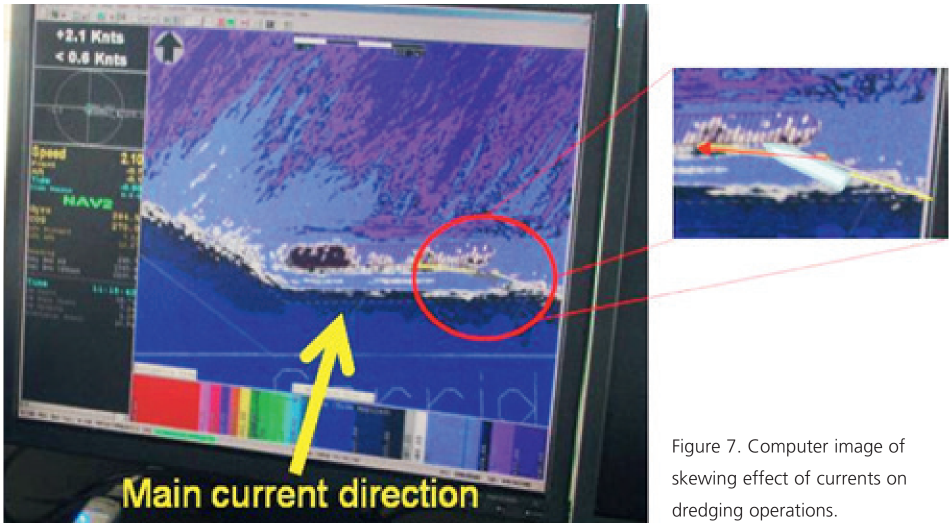

Figure 7. Computer image of skewing effect of currents on dredging operations.

expansion/land reclamation project. The site lies about 20 km offshore from the Port of Rotterdam. It is the largest extraction site along the Dutch Coast. The sides have a minimum slope of ca. 1:7-1:10 and the extraction depth is between NAP -40 and -42m (20 m below seabed). It had sufficient capacity (>250 million m^3) to create two large-scale bed forms.

The choice for large-scale bed forms was made as a result of first order morphological models that showed that they are expected to be morphologically stable long enough for colonisation to take place.

Furthermore, the permit for the extraction site allowed for deep sand mining to an average depth of at least 10 m below the existing seabed. Both the size and depth were important aspects, especially as future extraction sites are expected to increase to similar sizes.

Figure 6 shows the geographical location in the North Sea (green area) of Rotterdam harbour and zooms in on the location of the two pilot areas in the extraction site itself (blue circles). The natural orientation of bed forms in the area, parallel to the tidal current, is shown as a reference (dark red lines).

DESIGN PARAMETERS

Based on detailed discussions between marine ecologists, engineers, permitting authorities and dredging contractors, the following design parameters were identified for use in the design of the landscaped bed forms (Rijks et al. 2011):

Technical parameters

Although dredging contractors can create almost any shape, several aspects have to be taken into account to ensure that no unnecessary high costs and loss of time occur:

- Dredging depth of available dredging vessels;
- Manoeuvrability of the vessels, since sharper or more detailed contours take more time to create;
- Capacity (dredging volume) of the ships: too small or too large shapes increase dredging effort;
- Hydraulic conditions in and around the extraction site, shapes lying oblique to the main tidal current limit dredging capacity of vessels (Figure 7).

Physical parameters

Physical parameters are described here and in Figure 8:

- Orientation and size in relation to morphological (in)stability;
- Grain size distribution: fine sediments in trough, more coarse sediment on the top;
- Currents: bed forms can minimise current speeds for optimal ecological development or enhance hydraulic dynamics and, e.g., related transport of nutrients;

Ecological parameters

When determining the desired ecological habitat, the most important criteria are the basic physical characteristics of the sand extraction site. This includes depth, availability of slopes and of course sediment characteristics after sand extraction has finished. For example, some benthos species appear to prefer quiet environments with higher content of fines, while others are more likely to be found in higher energy environments with moderate to large grain sizes. The first can be found in the troughs of the bed forms, the second at the slopes and crests. Ecological habitats can be chosen on the basis of these parameters, taking into account the natural habitats in the area.
A higher diversity is usually appreciated/valued more, both for benthos and for fish.

Several design requirements and preferences that determine these gradients and subsequent ecological development for the sand bars in this large scale extraction site are:

- Sufficient amplitude, 10 m height difference was chosen;
- Large enough to be able to carry out a monitoring programme;
- Orientation: parallel to the dominant current direction (easy to dredge) and oblique to this current (difficult to dredge);
- Constructed before the spawning season;
- Untouched for a period of about 4-6 years;
- Differences in sediment characteristics.

CONSTRUCTION OF LANDSCAPED EXTRACTION SITES

Construction Preparation

After the design was finalised, dredging of the sand bars started. In this pilot project, the locations of the sand bars were situated within an active sand extraction site. This meant that a special dredging plan had to be made to ensure that the regular work was not hindered.
The following steps were taken:

1. The local bathymetry in the extraction site was studied in more detail together with the contractor to determine exactly where the sand bars could be made;
2. Based on expert judgement concerning hydraulics, morphology and ecology, a choice was made for the preferred locations. In both cases, the sand bars were positioned near the existing slopes of the sand extraction site to ensure an extra slope and trough in the total design;
3. The contractor designated a temporary buffer around the preferred locations

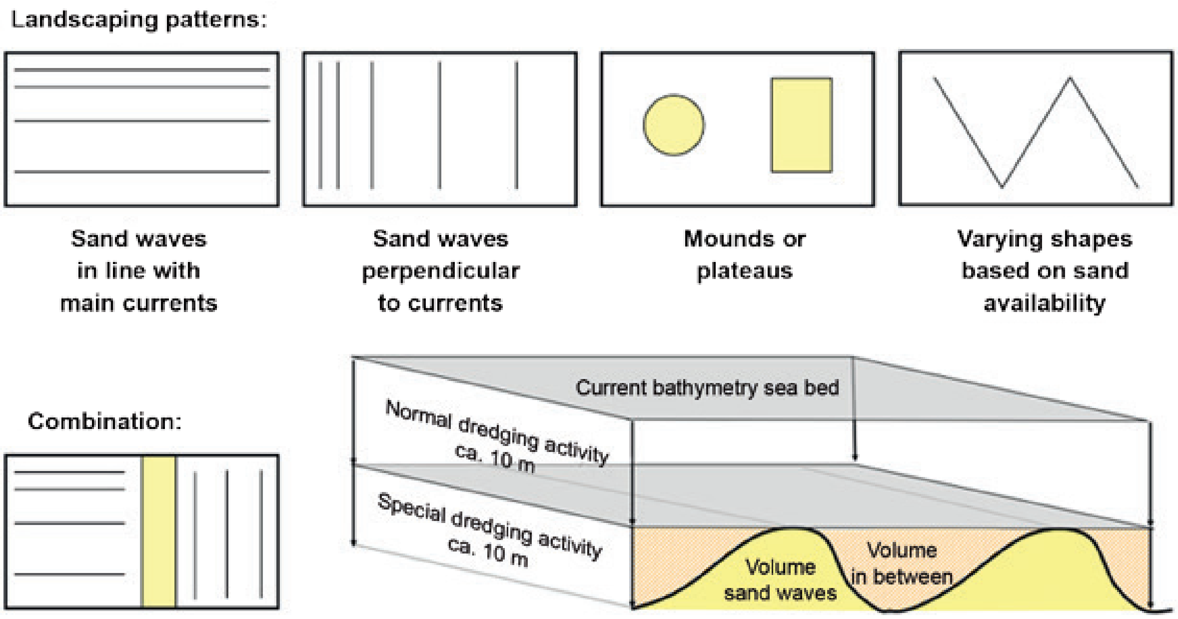

Figure 8. Different alternatives for the design and scheme of dredging volume.

exempting the area from sand extraction until the final position and design was determined;

4. The design was integrated into the existing sand extraction GIS database containing the bathymetry and sediment composition data. Based on a GIS calculation, total dredging volumes and grain size were determined;
5. The designs, volumes and related grain sizes were integrated into the overall contractor dredging plans and the on-board GIS dredging systems (Figure 9). Captains received instructions on how to dredge the sand bars;
6. The temporary exemption areas were removed and the ships were asked to create the sand bars.

Dredging Equipment

The sand bars were constructed using several trailing suction hopper dredgers (TSHDs) that removed sand around the sand bar itself during a period of several months (Figure 10). These ships are able to dredge to large depths with high precision. The TSHDs approached the chosen locations in various ways depending on the currents, waves, presence of other ships and overall dredging plan. In all cases, they aimed to sail a pattern that was as efficient as possible.

It is clear that landscaping of extraction sites requires modern equipment; dredgers have to be well instructed and the shapes have to be checked by the contractor beforehand so as to ensure that they can be realised with the equipment at hand.

The parallel sand bar bed form was finished in June 2010 and after a detailed survey, monitoring immediately started to determine the presence of benthos and fish. As the orientation of the sand bar lies in the same direction as the normal/preferred dredging operations, the dredging was carried out without any difficulties.

The oblique sand bar was much more difficult to dredge as the vessels could only dredge along the bar during slack tides when the currents were low. With higher currents, the vessel could be swept over the dredging arm

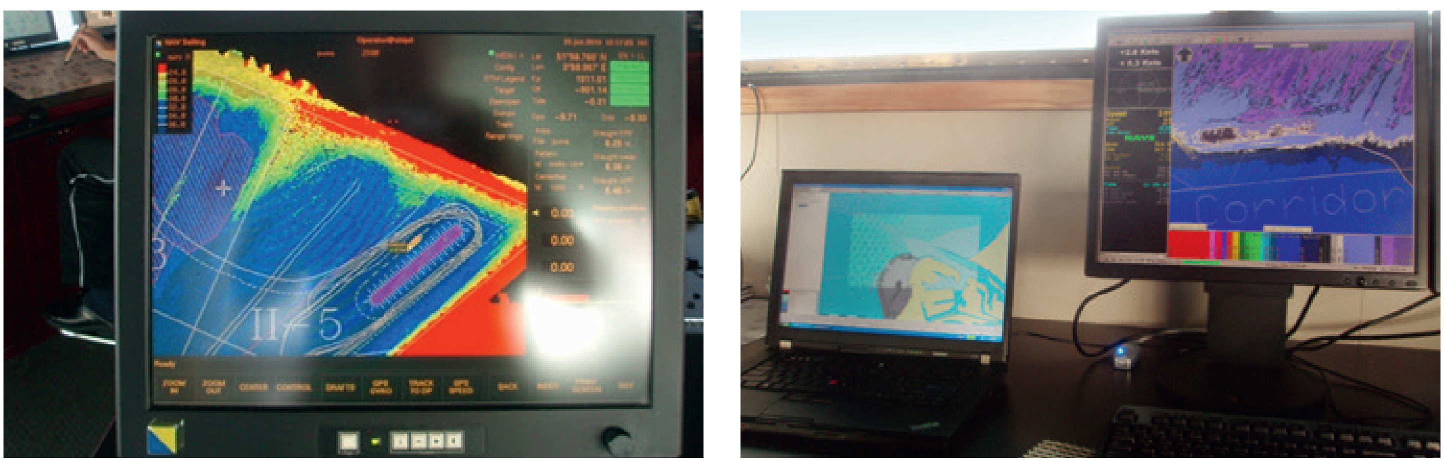

Figure 9. GIS positioning and bathymetric systems (left = oblique, right = parallel).

Figure 10. TSHDs creating the parallel sand bar. In the photo left the sand bar lies to the port side of the vessel.

and cause considerable damage and danger to the vessel.

Integration of Design in Extraction Site

The final design found an optimal combination between the new physical circumstances at the bottom of the extraction site, suitable ecological habitats of species present in the surrounding area and (reasonable) workability of the dredging vessels.

In the pilot project, two large-scale sand bars were created of about 1.25 million m each, 10 m high (from ca. -30 m to ca. -40 m), and 750 m long with slopes of ca. 1:7-1:10 (Figure 8).

One sand bar was created parallel to the main current direction, the other almost perpendicular to the main current in order to study differences, if any, in the alignment.

The sand bar parallel to the main current direction is shown in Figure 11. The first pilot location was chosen in the north-eastern part of the extraction site and lies between the edge of the site and the adjacent plateau (see Figure 6). The second sand bar is oblique to main current direction. This second pilot location lies along the southern edge of the sand extraction site (see also Figure 6) and it has a natural orientation oblique to the main current direction (Figure 12).

MONITORING ECOLOGICAL DEVELOPMENT

An intensive multiyear monitoring programme was set-up to investigate the changes in benthos and fish. Surveys were carried out in the spring of 2010, 2011 and 2012 with the aim to investigate and compare the presence of benthos and fish inside and outside (as a reference) of the extraction site. The analysis of the monitoring results concentrated on the occurrence of biodiversity in relation to water depth, position on the sand bar, median grain size distribution, fraction of fines, silt and organic matter and time for re-colonisation.

The results of the monitoring are used to determine which design parameters are important to take into account; both to achieve higher biodiversity and biomass and to keep the extraction works economically feasible.

Preparation of Monitoring Plan

During the design and preparation phases, a monitoring plan was defined focussing on benthic infauna and epifauna, before and after sand mining, and both inside and outside the ecological extraction site. Analysis was carried out on the 2006 and 2008 surveys for the baseline study of the Environmental Impact Assessment (EIA) for the construction of Maasvlakte 2 to enable

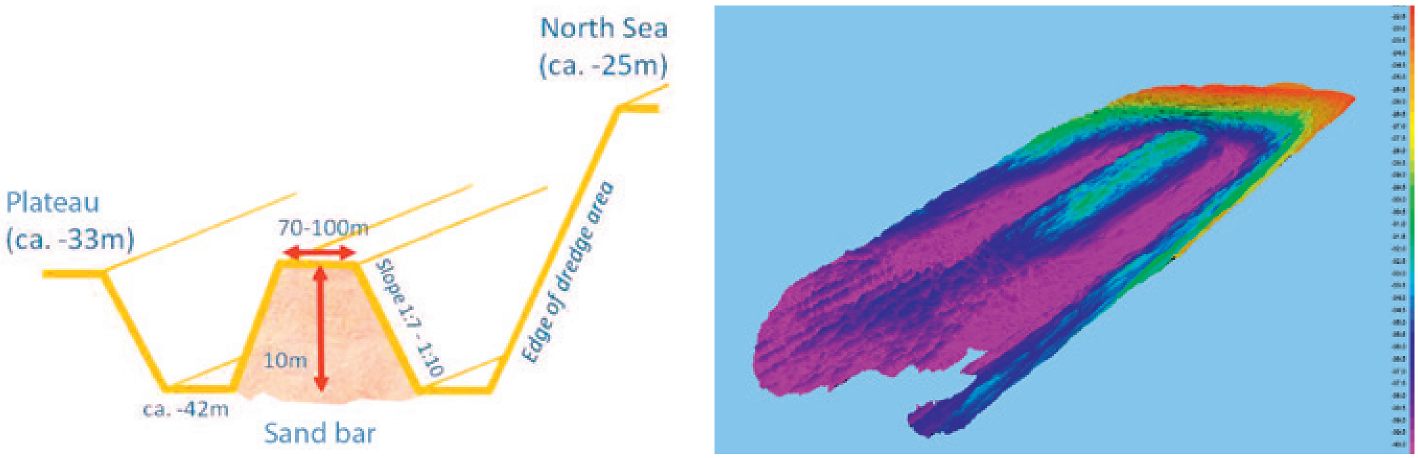

Figure 11. Parallel sand bar profile design (left) and survey of final result (right).

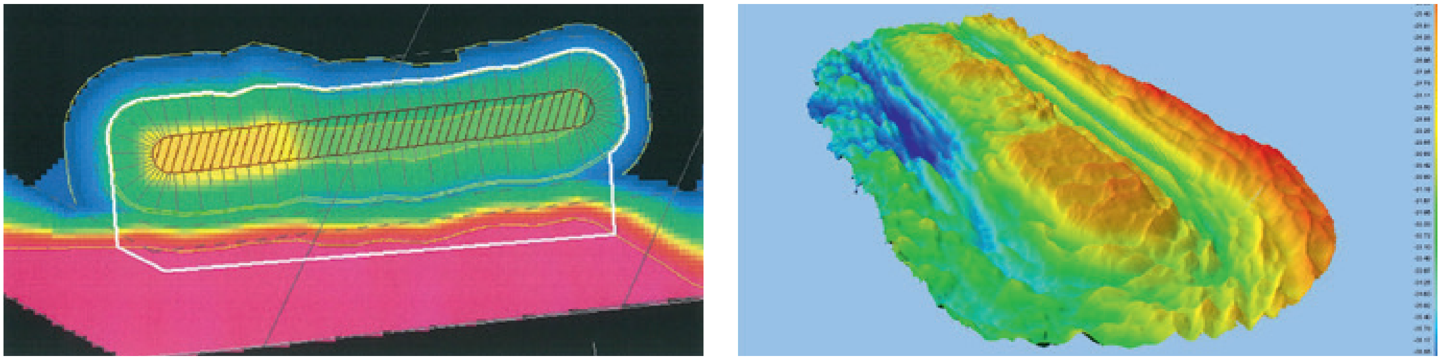

Figure 12. Oblique sand bar profile design (left) and survey of final result (right).

comparisons with the situation prior to the large-scale sand extraction (Kaag and Escaravage, 2007; Craeymeersch and Escaravage, 2010; De Jong et al. in prep. a, Borst et al. 2012).

Finally the monitoring activities were planned in anticipation of the sand extraction activities.

Execution of Monitoring

The monitoring programme consisted of three types of ecological measurements with different equipment (Figure 13):

1. Box core measurements involved sampling with sediment cores of the upper 20-30 cm of the seabed, to assess all infauna (animals living in the seabed) larger than 1 mm, and sediment;
2. Bottom dredge measurements involved sampling for infauna and epifauna (animals living in or on the seabed) larger than 0.5 cm and smaller than 10 cm, using a bottom-cutting dredge over a relatively large sampling area (10 cm deep, 10 cm wide and 150 m long tracks);
3. Beam trawl measurements involved fishing for demersal fish (living and feeding on or near the seabed) and epifauna using a 4.5-m wide trawl with 80 mm mesh size in the net (see opening photo).

In addition to biological data, supportive physical data on bed elevation (multi-beam survey), sediment characteristics, hydrodynamic variables and time after cessation of sand extraction were collected. Table I shows the number of sampling points/ tracks per year during the monitoring campaign.

For benthos and demersal fish sampling, the surveys distinguished between those in the reference area (crests and troughs of sand waves) and in the extraction site the edge, the deep part and the crests and troughs of the sand bars.

Results and Observations of Monitoring

Preliminary monitoring results showed that benthos and pelagic and demersal fish quickly entered the extraction site. The monitoring revealed a four to five time increase of fish density inside the 20 m deepened borrow pit at a comparable species diversity compared to the reference locations (De Jong et al. 2014). Significant differences between the crests and troughs of the sandbars were detected (De Jong et al. 2014).

The increased biomass of demersal fish was closely linked to increased biomass of white furrow shell (*Abra alba*) that flourished in the fine sediments of the extraction site (De Jong et al. 2014; Tonnon et al. 2013).

This increase in fish is a key outcome of the project, indicating that the environmental impacts of sand extraction areas are not necessarily negative. Moreover, the high fish density may yield economic potential for re-development of the pit as fishing grounds for local communities. Although the data show that the highest densities of fish are found near the artificially created bed forms, it remains to be investigated what processes drive this. Can it be explained:

- by the shape of the applied seabed landscaping creating diverse habitats, or
- as a secondary effect of an increase in benthic food in or near the bed forms, or
- is it owing to the fact that the seabed remained untouched after dredging, or
- is it a combination of all three.

Figure 13. Left to right: Monitoring with a box core; box corer sampling in the dredge; sample from the seabed in the reference area with epifauna and fish; and the sample sorted.

Table I. The number of sampling points/tracks per year during the monitoring campaign.

Year	2010	2011	2012
Box core	45	45	63
Bottom dredge	26	26	32
Sediment characteristics	45	45	63
Beam trawl (4.5 m, 80 mm mesh)	4 outside / 6 inside	7 outside / 13 inside	4 outside / 10 inside
Hydrodynamic modelling	First order	-	In- and outside extraction site

The results of the bathymetric multi-beam surveys showed that the ecologically designed sand bars were stable and allowed for longer-term development of ecosystems in the extraction site.

Figure 14 shows the bathymetry of the sand extraction site in 2010 with superimposed the observed average demersal fish species density and composition in the extraction site and reference area in 2010, 2011 and 2012. The parallel sand bar is visible in the north-western and the oblique sand bar in the southern part of the extraction site. Maximum water depth in 2010 was found in the area around the parallel sand bar.

ACKNOWLEDGEMENTS

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The team would like to thank all parties involved in making the pilot project possible. The positive collaboration and contributions, technical feedback, innovative suggestions and great efforts made by the stakeholders were essential in making this project a success.

The stakeholders involved are:

- The Contractor PUMA (Joint Venture Boskalis and Van Oord) for making the Maasvlakte 2 extraction site available and assisting in making a realistic design for the sand bars and for creating the sand bars. Without their support this pilot project could not have been realised so quickly and on such a scale. A special thanks to the captains of the dredging ships involved in creating the sand bars and for their feedback concerning the workability of the designs and suggestions for improvements;
- The Port of Rotterdam is responsible for the construction of the Maasvlakte 2 and kindly allowed the pilot to take place in their extraction site. They actively took part in the technical and juridical discussions and put their considerable expertise, knowledge and data on the coastal area in and around the extraction site at our disposal;
- The Ministry of Transport, Public Works and Water Management, Directorate-General for Public Works and Water Management (Rijkswaterstaat Dienst Noordzee), the responsible entity for granting the permits in the extraction area. They also made their impressive knowledge on the Dutch coastal and ecological system and (legal) permit requirements available;
- EcoShape for assisting in organising the workshops, inviting stakeholders, making the BwN information available and in providing office support and facilities.

Finally, the many other experts from within and outside the Building with Nature Programme that joined the technical workshops and contributed to the brainstorm sessions must be acknowledged.

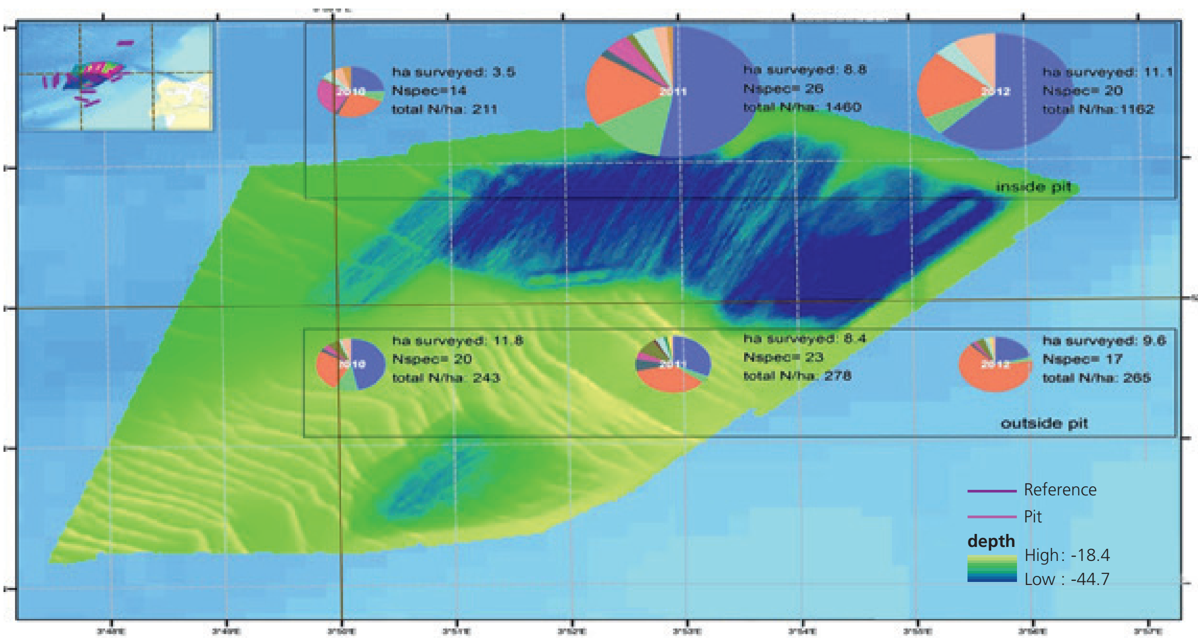

Figure 14. Summary of findings from demersal fish monitoring campaigns 2010-2012.

CONCLUSIONS

This article describes the preparation, design and results of a pilot for an ecologically enriched extraction site. Based on the results of the monitoring programme, it proves that the concept of ecological landscaping has high potential.

Furthermore, the stakeholders involved in the project have changed their perception of extraction sites from being a traditionally negative issue into a positive view on opportunities for ecological development and added value for the local environment. In the case of sand extraction sites, it is therefore advisable to use 'establishment of habitats' instead of 'recovery of habitats'.

In addition, the following conclusions can be drawn:

- Designing an ecologically enriched extraction site should be:
  - Based on existing ecosystem and local physical conditions;
  - Linked to the size and volume of the extraction site;
  - Done in cooperation with ecologists, morpho- and hydrodynamic experts, the fishing industry and dredging contractors;
  - Discussed with permitting authorities beforehand to define requirements (if any);
  - Take place preferably before dredging works start, to allow the contractor to make a cost-efficient dredging work plan.
- Constructing the landscaped seabed:
  - If designed correctly and in consultation with dredging contractor, has no influence on production rates and thus time and cost;
  - Can be beneficial especially if different kinds of sediments/grain sizes are needed within the same extraction area.

This work puts sand mining for land reclamations, coastal safety, port development and other uses in a new perspective. Rather than adopting the traditional focus on negative, direct environmental impacts caused by seabed removal, this work shows the potential and opportunities for ecological and economic benefits of sand extraction.

In fact, data from monitoring surveys show an increased density of demersal fish that can be attributed to the presence of the deepened sand extraction site itself plus additional benefits owing to the realisation of landscaped bed forms within the site. These new insights can make an important contribution to improved (sustainable) designs for marine and navigation infrastructure, hence to reduce lead times of future projects in marine environments through a Working and Building with Nature ecosystem-services approach.

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