Smart and sustainable design for offshore operations in a sandy seabed – the SANDBOX programme

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ABSTRACT: Shallow coastal seas are subject to an increasing pressure by offshore operations, such as sand mining and the construction and operation of offshore infrastructure. The seabed topography, seabed life, sediment dynamics and hydrodynamics form a coupled system. When disturbed, this coupled system needs time to recover. Anthropogenic disturbances will affect the (local) ecosystem, which in turn will affect the sediment-water interaction and the potential of the seabed to store fine sediments. Consequently, the potential of the system for recovery may be affected. This paper poses a research outline focused on a better understanding of the functioning and stability of the coupled system during the lifetime of the offshore operation. This requires integration of knowledge from ecology, geomorphology and fine sediment dynamics, where the authors specifically focus on geomorphology.

1. INTRODUCTION

Coastal seas are highly important both from an economic and ecological perspective, as these areas support a broad variety of offshore activities (Figure 1) and form the habitat for a broad variety of organisms. Offshore activities, such as sand mining and construction and operation of offshore infrastructure, affect sediment dynamics and morphodynamics in coastal waters. Knowledge about these dynamics is also required for conservation and management of the biodiversity of sediment-dwelling (benthic) organisms in the coastal zone. Hence, there is from both an ecological and economical perspective a growing interest in the interactions between human activities, sediment dynamics and the habitat value of sediments for benthos.

The seabed of coastal seas is neither flat nor static (Figure 2). Tides, sediment, organisms and the seabed interact in nonlinear processes that are only partly understood. Previous theoretical explorations (Borsje et al., 2009) have shown that sandy offshore areas, such as found in the Southern Bight of the North Sea, can switch between different types of geomorphological behaviour (tipping points), characterized by the presence or absence of dynamic sand waves, and that small changes to the sediment characteristics (e.g. roughness, storage of fines in the sandy matrix) caused by the activity of benthic organisms may suffice to influence tipping points between the two dynamic regimes.

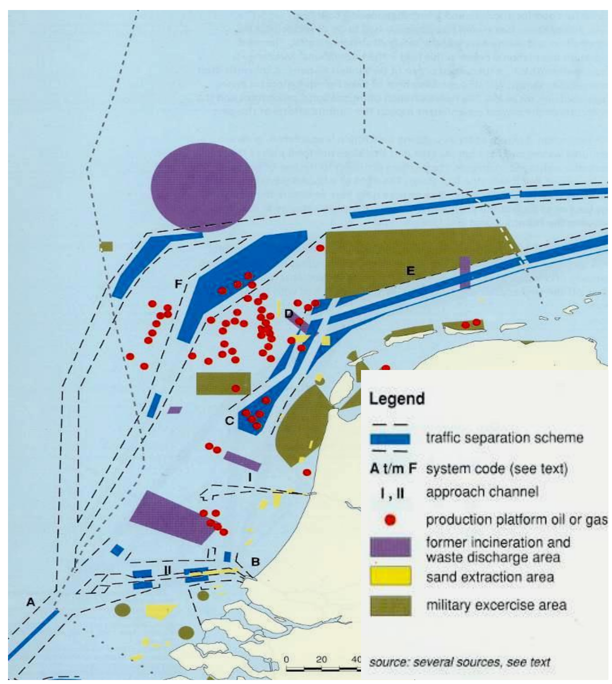

Figure 1: Map of Netherlands Continental Shelf, showing offshore activities (Data courtesy: Rijkswaterstaat).

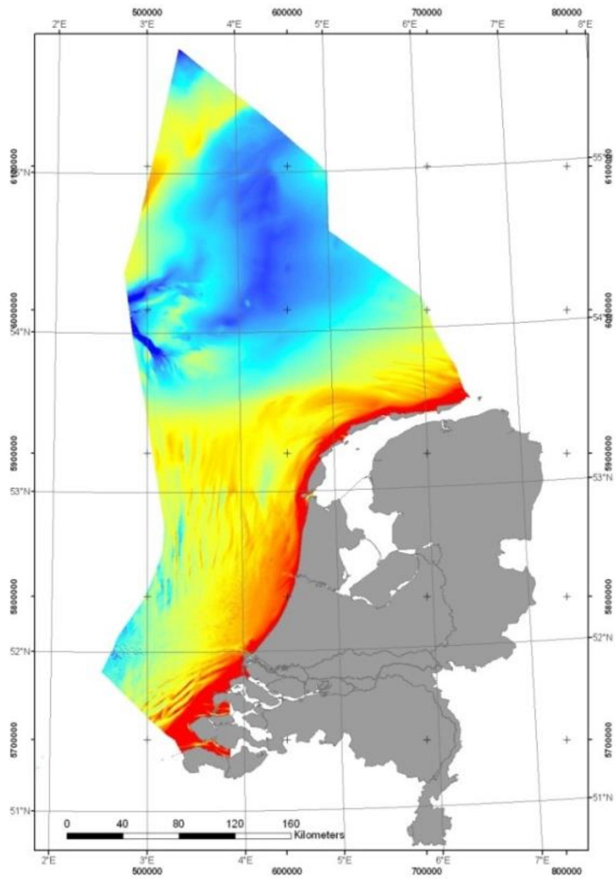

Figure 2. Bathymetric map of the Dutch part of the North Sea, showing large-scale seabed patterns (sand waves). Water depths vary between 0 m (red) up to 71 m (blue). Data courtesy: Deltares.

These explorations have large potential consequences for applications. Demands for sand and offshore constructions are increasing, but increasing environmental awareness creates the need to define modes and ranges of operation (the limits of a license to operate) where interventions in the seabed are environmentally safe. In addition, better understanding of the biogeomorphologic interactions may allow designing operations as underwater landscaping, thus combining economic exploitation with the creation of favourable habitats for benthic biodiversity and, linked to that, favourable conditions for demersal fish production.

Ecological landscaping, a well-known concept in terrestrial infrastructure works (e.g. van Bohemen, 2005), is introduced here for submarine operations. Present marine extraction policies aim at quick recovery and restoration of the original habitat, but do not consider the possibility to create habitats designed for target organisms. Developing an ecological landscaping approach for the marine environment may stimulate social and political acceptance of future offshore activities, thus accelerating licensing procedures and project realisation. The definition of potential target communities will be based on indicators of benthic biodiversity integrity, developed in the framework of the Marine Strategy Framework Directive. Using these indicators, the work on this topic will be related to policy-relevant objectives.

The major stumbling blocks for the development of such an approach is the availability of coupled biogeomorphologic models for the dynamic regimes of offshore benthic systems. Such a coupled model must satisfy several requirements:

- The benthic biodiversity (hundreds of species are involved) is suitably summarized to model the effect of geomorphological changes on the community;
- Changes of community are translated into the parameters for the geomorphological dynamics;
- The effect of benthic communities on bed roughness (including the dynamics of fines in the sandy matrix) is properly parameterized.

In addition, application in implementation cases requires that operational models at a scale of a few wavelengths of the sand waves are developed.

2. THE SANDBOX PROGRAMME

The aim of the SANDBOX programme is to unravel the mechanisms behind the coupled seawater-seabed system, as well as the impact of offshore activities on this coupled system. This program will lead to knowledge for smart and sustainable use of the sandy seabed during the life time of the offshore operation and we will use this knowledge to arrive at a design strategy involving ecological landscaping for offshore activities. The expected outcome is an interactive design tool (SANDBOX) which is used to communicate the results of this research with utilization partners and support decision making in implementing sustainable offshore activities.

During the SANDBOX programme, implementation cases are selected in which the results of the program are implemented in the design of new offshore operations (with a focus on ecological landscaping). These implementation cases are selected in close collaboration with Boskalis Westminster N.V. Reversely, field data gathered during these implementation cases (and provided by other consortium partners) are used as validation data for the interactive SANDBOX.

The SANDBOX programme contains three PhD projects and a Post-Doc position. PhD project 1 will focus on the short-term dynamic processes related to ripple formation, incorporation of fines in the bed and structural characteristics (roughness, erodibility) of the sediment surface. PhD project 2 will focus on the generalization of benthic biodiversity and formulation of the mutual interactions between benthic animals and bed characteristics. Effects of benthic communities on bed characteristics will be studied in close co-operation with PhD 1, while the model formulations will be developed in close collaboration with PhD 3. PhD 3 will focus on the modelling of the coupled system, in idealised as well as complex models. The Post-Doc will focus on the usability of the model products. The target application is ecological landscaping in the design of sand extraction operations and offshore constructions.

3. GEOMORPHOLOGY

Within this subproject we aim to come up with an idealised model for sandwaves coupled with benthic organisms giving insight in the dynamics of this system, as well as a more complex numerical model which can be applied in practical cases. These two approaches will be central throughout the whole subproject, where linking these combines insight in the system dynamics through fast computations with realistic results.

The first step is to determine the tipping points in the biogeomorphological system. The idealised modelling approach will be based on Hulscher (1996), where we intend to include biology using the parameterization of Crouzy et al. (2015). This allows for the investigation of the fully coupled system using stability analysis. Also, we will use Delft3D (Lesser et al., (2004)) to model sandwave dynamics (Borsje et al., 2013). Due to its structure, it allows us to incorporate the heterogeneous distribution of benthic organisms in time and space. The empirical data obtained from subproject 2 will be used as input for both modelling approaches.

To further develop the Delft3D sandwave model, an empirical model to predict the roughness of the seabed will be included. This ripple model will be the result of the efforts of subproject 1. Since usually bed roughness is taken constant in morphodynamic models, the outcome of this step may have important implications for other model exercises.

In the next phase we intend to use the models to study the spatial-temporal evolution after anthropogenic interventions in the target areas. In the idealised model approach we can study the effect of e.g. a sand mining pit analogous to Roos and Hulscher (2003). The pit is approached mathematically as an perturbation and the linear reaction of the system can be analysed. The Delft3D model will be used to study interventions in a more realistic way, e.g. the chosen spatial extent of a human intervention within a sandwave field.

The intended overall result of the programme is to use the Delft3D sandwave-biology model to develop the concept of ecological landscaping in marine environments, which will be implemented in close collaboration with all other subprojects within the SANDBOX programme.

4. ACKNOWLEDGMENT

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5. REFERENCES

Borsje, B.W., Hulscher, S.J.M.H., Herman, P.M.J. and De Vries, M.B., 2009. On the parameterization of biological influences on offshore sandwave dynamics. Ocean Dynamics 59, 659-670.

Borsje, B.W., Roos, P.C., Kranenburg, W.M. and Hulscher, S.J.M.H., 2013. Modelling tidal sand wave formation: the role of turbulence formation, in press for continental shelf research.

Crouzy, B., Baerenbold, F., D'Odorico P. and Perona, P., 2015. Ecomorphodynamic approaches to river anabranching patterns, in Advances in Water Resources.

Hulscher, S.J.M.H., 1996. Tidal induced large-scale regular bed form patterns in a three-dimensional shallow water model. Journal of Geophysical Research C9, 101, 20727-20744.

Lesser, G., Roelvink, J., Van Kester, J. and Stelling, G., 2004. Development and validation of a three-dimensional morphological model. Coastal Engineering 51, 883-915.

Roos, P.J. and Hulscher, S.J.M.H., 2003. Large-scale seabed dynamics in offshore morphology: Modelling human invervention. Reviews of Geophysics 41(2).

Van Bohemen, H., 2005. Ecological Engineering: Bridging Between Ecology and Civil Engineering. AEneas Publishers, Boxtel, Netherlands.

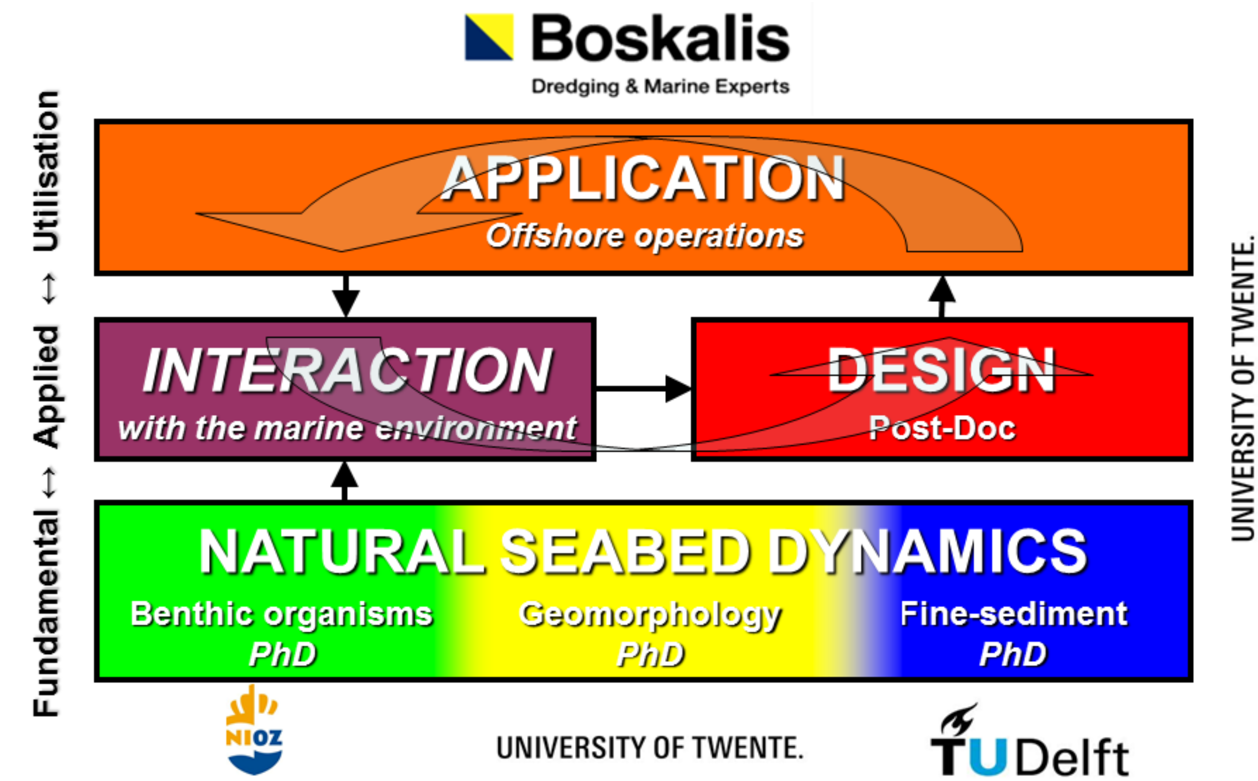

Figure 3. Outline of the consortium of the SANDBOX program and the translation from fundamental research via applied research towards utilization.