

On the parameterization of biological influences on offshore sand wave dynamics

BAS W. BORSJE^{1,2}, SUZANNE J.M.H. HULSCHER³,
PETER M.J. HERMAN⁴, MINDERT B. DE VRIES^{1,2}

1. Water Engineering and Management, University of Twente, P.O. Box 217, 7500 AE Enschede, The Netherlands. email: b.w.borsje@utwente.nl
2. Deltares, Rotterdamseweg 185, P.O. Box 177, 2600 MH Delft, The Netherlands. email: mindert.devries@deltares.nl
3. Water Engineering and Management, University of Twente, P.O. Box 217, 7500 AE Enschede, The Netherlands. email: s.j.m.h.hulscher@utwente.nl
4. Centre for Estuarine and Marine Ecology, Netherlands Institute of Ecology (NIOO-KNAW), P.O. Box 140, 4400 AC Yerseke, The Netherlands. email: p.herman@nioo.knaw.nl

Keywords: benthos, sediment dynamics, bedforms, modeling, North Sea

ABSTRACT

JOURNAL OF MARINE SYSTEMS! ARTICLES IN PRESS EN MET NAME FRIEDRICHS EN DIE ANDERE DUITSE GAST!

On the bed of the North Sea sand waves are present, which grow up to 25% of the water depth and migrate with a speed of tens of meters per year. These sand waves can pose a hazard to offshore constructions, navigation, pipelines and telecommunication cables.

The bed of the North Sea is also covered by a great number of organisms, living in and on the bed of the sea, which are known to have significant influence on the stability of the bed. This paper proposes a parameterization of these bio-geomorphological interactions, in order to model the inherent dynamics in offshore seabed patterns.

Three species are included in the parameterization, which influence the stability of the bed in opposite modes. First, the bivalve *Tellina fabula* is known for its destabilizing effect on the bed during its burrowing and feeding activities. On the other hand, the tube building worm *Lanice conchilega* reduces the near-bottom flow around and across the tube fields. Finally, the sea urchin *Echinocardium cordatum* influences the vertical sediment distribution by filtering the finer particles from the sediment surface to the deeper sediment.

T. fabula is found to be responsible for a reduction of the critical bed shear stress up to a factor 0.6, while *L. conchilega* reduces the ripple height with a factor 0.5, due to the deceleration of the near bottom flow. These ripples are present on top of the sand waves, and are the main origin of the bottom roughness. Finally, *E. cordatum* is able to increase the medium grain size at the bed-water interface with a factor 2.

Given the measured biomass of *T. fabula*, *L. conchilega* and *E. cordatum* on the Dutch Continental Shelf, the predicted occurrence of sand waves, in which the parameterization is included, shows significantly better results, compared to the prediction for the default case. This means that inclusion of biological activity is important to predict the occurrence of sand waves.

Introduction

The interaction between benthos and sediment dynamics in the intertidal area has been exhaustively documented (e.g. Widdows and Brinsley, 2002, and references therein). They show that benthos are able to influence the strength of the bed by several orders of magnitude, and thereby have a significant influence

on the sediment dynamics on a large spatial and temporal scale (Borsje et al., in press). However, benthos are also present in shallow self sea, for which the North Sea is an example. At the bed of these shallow seas, sand waves are present, which can grow up to 25% of the waterdepth and migrate with a speed of a couple of meters per year.

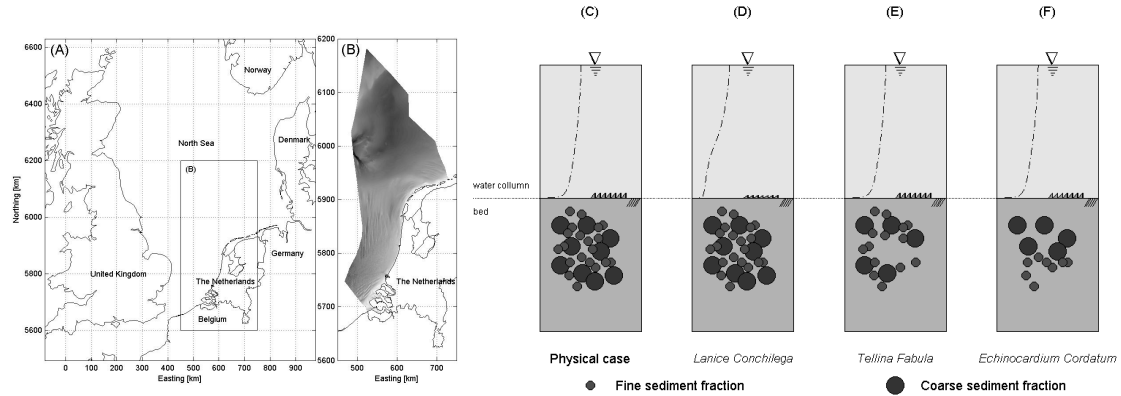


Figure 1. Overview of bedforms in the Dutch part of the North Sea (A-B) and a schematization of the biological influences on the fluid and sediment dynamics (D-F) compared to the physical case (C).

Given the large biological influences in the intertidal area, strong interactions are also expected in the North Sea area (Borsje et al., 2008), although the biomass in the North Sea area is much smaller compared to the intertidal area. In order to predict the bio-geomorphological interaction in offshore seabed patterns, this paper proposes a parameterization in which biological activity is expressed in physical parameters.

Three benthic species are included in this parameterization on the basis of (i) their abundance in the North Sea, (ii) their strong modification of the environment they are living in, and (iii) their contrasting type of feeding and burrowing, and thereby contrasting influence on the sediment and fluid dynamics. The three species selected are *Lanice conchilega*, *Tellina fabula* and *Echinocardium cordatum*.

The interaction between the selected benthos and the environment is schematized in Figure 1. The tube building worm *L. conchilega* protrudes several centimeters from the sediment in the water column, and thereby influences the near-bottom flow. For dense tube assemblages the near-bottom flow reduces, and consequently lower ripples are present (Figure 1d). Due to the digging and feeding activities of the bivalve *T. fabula* up to 10 cm deep in the sediment, the properties of the surficial sediment are modified and the sediment is more prone to erosion (Figure 1e). Finally, the sea urchin *E. cordatum* lives in the top 20 centimeters of the bed and mixes sediment in vertical direction (Figure 1f), resulting in relatively coarser sediment in the top layer of the bed, compared to the physical case (Figure 1c).

Parameterization of biological activity

While *L. conchilega* reduces the near bottom flow, the ripples on the top of the sand waves will become smaller, as observed in the field by Featherstone and Risk (1977). These ripples are the main origin of bottom roughness. To model the influence of *L. conchilega* on the near bottom flow, a vegetation model (Uittenbogaard, 2003) is adopted with the inclusion of the relevant dimension of *L. conchilega* in the field. The comparison between the model result and flume experiments executed by (Friedrichs et al., 2002) is shown in Figure 2a, for different densities of artificial tube building entities. Given the reduction of the near bottom flow by a factor 0.5, the ripple height will reduce by a factor 0.6, following the empirical relations derived by O'Donoghue et al. (2006).

To parameterize the transport of particles from the sediment surface deeper into the sediment by *E. cordatum*, we adopt an active layer concept. In this concept, the probability of entrainment of a particle is defined in a step function, for which the probability of entrainment of a particle has a constant value in an active layer of thickness l_{bio} near the bed surface, and vanishes below this layer (Hirano, 1971). The layer underneath the active layer is called the substrate, which is physically covered by the active layer. As a result, the grain size distribution in both layers can be assigned differently. By adopting an active layer thickness which is equal to the area of influence by *E. cordatum* the top layer can be modeled as a bio-turbated layer, while the substrate can be modeled as a non bio-turbated layer. Based on an experimental study for *E. cordatum* in New Zealand, Lohrer et al., (2005) found that *E. cordatum* displaces up to 20,000

$\text{cm}^3 \text{m}^{-2} \text{d}^{-1}$, suggesting that surface sediment is reworked about every 3 days at site where *E. cordatum* is abundant.

E. cordatum is regarded as a non-selective deposit feeder (Lohrer et al., 2005). However, due to two reasons, *E. con* (A) will cause a heterogeneous (B) nt distribution in the top centi (C) of the bed.

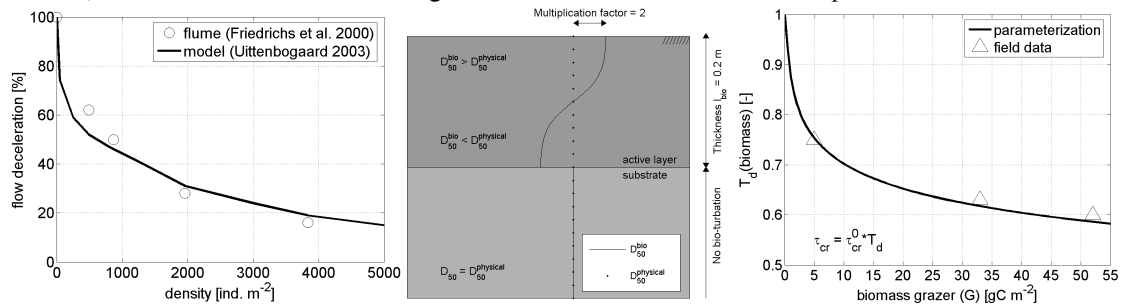


Figure 2. Parameterization for the relation between (A) density *L. conchilega* and reduction of the near-bottom flow, (B) *E. cordatum* and increase in medium grain size at the sediment water interface and (C) biomass *T. fabula* and the multiplication-factor for the critical bed shear stress.

Firstly, because finer particles have a relative larger surface area and have therefore a larger chance to get ingested and brought downward. Secondly, fine sediment is richer in organic matter compared to coarse sediment, and therefore *E. cordatum* moves to another spot, while relative larger particles are not ingested and are still at their original position. The heterogeneous vertical sediment distribution is shown in Figure 2b, in which the thickness of the bio-turbated layer (l_{bio}) and the multiplication factor for the medium grain size needs to be imposed. Based on measurements of *Arenicola marina* (Baumfalk, 1979), which is a comparable non-selective deposit feeders, the multiplication factor could reach values up to 2, meaning a medium grain size twice as large, compared to the default case. The thickness of the bio-turbated layer could reach values up to 0.2 m (Holtmann et al., 1996)

Data on the bio-engineer capacity of the bivalve *T. fabula* are scarce, but the sediment modification by the bivalve *Macoma balthica* is much better known. Both bivalves have comparable feeding strategies (selective deposit as well suspension feeding). However, *M. balthica* is mostly found in muddy sediments, while *T. fabula* prefers fine sediments. Therefore, the distribution of *M. balthica* is much more bordered close to the coast, in contrast to *T. fabula* which can be found in all other parts of the North Sea. Nevertheless, the relation used for *M. balthica* is a good alternative to model the bio-sediment interactions for *T. fabula*. The biomass of the bivalve is related to the critical bed shear stress by a destabilizing factor (T_d), as shown in Figure 2c, where τ_{cr} is the critical bed shear stress for erosion. The superscript '0' for the critical shear stress represents the values without the influence of biological activity. The destabilizing factor is defined by Borsje et al. (in press) and quantitatively shown in Figure 2c.

Model results

In order to show the significance of bio-geomorphological interactions in the occurrence of sandwaves, the proposed parameterization is included in a idealized sand wave occurrence model (Van der Veen et al. 2006). In this model, sand waves are seen as free instabilities of the bed, which are preserved by the tidal current, and own their dimensions to the strength of the tidal current, the grain size of the bed material and the local waterdepth. This type of model is shown to fairly predict the occurrence of sandwaves for the North Sea in both a qualitative (Hulscher and Van den Brink, 2001) and quantitative way (Cherlet et al., 2007). The interested reader is referred to Dodd et al. (2003) for more details on the theoretical approach in idealized sand wave models and to Van der Veen et al. (2006) for the specific model set-up. The spatial distribution of the three benthic species and their biomass or density is based on data provided by Holtmann et al. (1996).

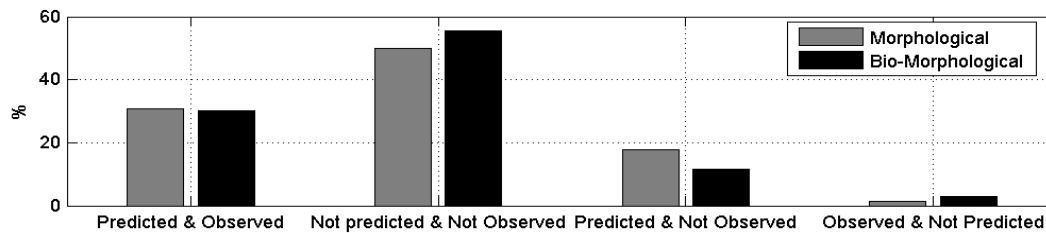


Figure 3. Results for the Morphological (default) and Bio-Morphological model, evaluated against observed sandwave occurrence in the Dutch part of the North Sea. The overall correct prediction increases with almost 4000 km² by including the proposed parameterization in the model (Van der Veen et al., 2006). The case in which both sandwaves are predicted by the model and observed in the field, is not much influenced by the included biological activity. However, the quite large over-prediction (column predicted & not observed) in the model of Van der Veen et al. (2006) is partly restricted by *L. conchilega* and *E. cordatum*. Both species are able to preserve a flat bed for almost 4,000 km² in the Dutch part of the North, while the physical parameters suggest sand waves.

Conclusion

This paper proposes a parameterization on the interaction between three subtidal benthic species and sediment dynamics. By including this parameterization in an idealized sand-wave model, the occurrence of sand waves is significantly better predicted, compared to the default case. In summary, biota is able to preserve a stable flat bed, while the physical conditions suggest bed patterns. Likewise the opposite effect is induced by destabilizing benthos.

In reality, much more benthos are present in the North Sea, with a much stronger spatial distribution than modeled in this paper, moreover the temporal variation needs to be accounted for by extending the models to predict seabed dynamics. However, the inclusion of the three most relevant bio-engineers in the North Sea already shows the necessity to account for bio-geomorphological interactions in predicting sand wave occurrence in shallow shelf seas.

Acknowledgements

This research is supported by the Dutch Technology Foundation STW, applied science division of NWO and the Technology Program of the Dutch Ministry of Economic Affairs.

References

- Baumfalk, Y.A., 1979. On the pumping activity of *Arenicola Marina*. *Neth. J. of Sea Research* 13, 422-427.
- Borsje, B.W., De Vries, M.B., Hulscher, S.J.M.H., De Boer, G.J., in press. Modeling large-scale cohesive sediment transport affected by small-scale biological activity. *Estuarine, Coastal and Shelf Science*.
- Borsje, B.W., De Vries, M.B., Bouma, T.J., Hulscher, S.J.M.H., Herman, P.M.J., 2008. Bio-geomorphological interactions in offshore seabed patterns. *Proceedings of the 31st International Conference on Coastal Engineering, Hamburg, Germany*.
- Cherlet, J., Besio, G., Blondeaux, P. van Lancker, V., Verfaillie, E., Vittori, G., 2007. Modeling sand wave characteristics on the Belgian Continental Shelf and in the Calais-Dover Strait. *Journal of Geophysical Research*, Vol. 112, C06002, doi:10.1029/2007/JC004089.
- Dodd, N., Blondeaux, P., Calvete, D., De Swart, H., Falques, A., Hulscher, S.J.M.H., Rozynski, G., Vittori, G., 2003. The use of stability methods for understanding the morphodynamical behaviour of coastal systems. *Journal of Coastal Research* 19, 849-865.
- Featherstone, R.P., Risk, M.J., 1977. Effect of tube-building polychaetes on intertidal sediments of the Minas Basin, Bay of Fundy. *Journal of Sedimentary Petrology* 47, 446-450.
- Friedrichs, M., Graf, G., Spring, B., 2000. Skimming flow induced over a simulated polychaete tube lawn at low population densities. *Marine Ecology Progress Series* 192, 219-228.
- Lohrer, A.M., Thrush, S.F., Hunt L., Hancock, N., Lundquist, C., 2005. Rapid reworking of subtidal sediments by burrowing spatangoid urchins. *J. of Exp. Marine Biology and Ecology* 321, 155-169.
- Hirano M., 1971. River bed degradation with armouring. *Proceedings, Jap. Soc. of Civil Eng.* 195, 55-65.
- Holtmann, S.E., et al., 1996. Atlas of the zoobenthos of the Dutch Continental Shelf. Ministry of Transport, Public Works and Water Management, North Sea Directorate, Rijswijk, 1-244 pp.

- Hulscher, S.J.M.H., Van den Brink, G.M. 2001. Comparison between predicted and observed sand waves and sand banks in the North Sea. *Journal of Geophysical Research* C5, 106, 9327-9338.
- O'Donoghue, T., Doucette, J.S., van der Werf, J.J., Ribberink, J.S., 2006. The dimensions of sand ripples in full-scale oscillatory flows. *Coastal Engineering* 53, 997-1012.
- Uittenbogaard, R., 2003. Modelling turbulence in vegetated aquatic flows. *Riparian Forest Vegetated Channels Workshop Trento (Italy)*.
- Van der Veen, H.H., Hulscher, S.J.M.H., Knaapen, M.A.F. 2006. Grain size dependency in the occurrence of sand waves. *Ocean Dynamics* 56, 228-234.
- Widdows, J., Brinsley, M.D., 2002. Impact of biotic and abiotic processes on sediment dynamics and the consequences to the structure and functioning of the intertidal zone. *Journal of Sea Research* 48, 143-156.