Memo

Aan
Rijkswaterstaat Waterdienst

Datum
30 juni 2010
Van
Bas Borsje
Jan van Dalfsen

Kenmerk
1201899-000-ZKS-0026
Doorkiesnummer
Van
Bas Borsje
Jan van Dalfsen

Aantal pagina’s
24
E-mail
bas.borsje@deltasres.nl
jan.vandalfsen@deltasres.nl

Onderwerp
Coastal protection: innovative use of biogeomorphology

Bas Borsje, Jan van Dalfsen

Contents
Part I: Data analysis on distribution & recovery potential of Lanice conchilega, (Owenia fusiformis) and Ensis species. _________________________________________________
1 The Coastal zone _________________________________________________________
2 Habitat preferences _____________________________________________________
   2.1 Lanice conchilega _______________________________________________________
   2.2 Owenia fusiformis _____________________________________________________
   2.3 Ensis directus _________________________________________________________
3 Review of studies ________________________________________________________
   3.1 RIACON project (Van Dalfsen et al. 1993-1997) ____________________________
   3.2 Zonation of macrofauna (Janssen & Mulder 2005) __________________________
   3.3 Annual shellfish monitoring programme (Perdon & Goudswaard 2006) __________
   3.4 Zandige Kust (Van Dalfsen 2006) _________________________________________
   3.5 Zandige Kust II (van Dalfsen 2009) _______________________________________
   3.6 Baseline Petten (Van der Wal 2008) ______________________________________
   3.7 Base line Texel (Bos 2009) _____________________________________________
   3.8 Macrobenthos Monitoring Program (MWTL) ________________________________
   3.9 Systematic Beach Monitoring (SMP, Gmelig Meyling & de Bruyne, 2009) ______
   3.10 Effects of Beach Nourishment on the Infauna (Menn et al. 2003) ____________
   3.11 Lanice conchilega recolonization pattern (Strasser, M. and U. Pieloth, 2001)___
4 Conclusions part I ________________________________________________________
Part II: Modeling bio-physical interactions by a polychaete tube lawn ____________
1 Introduction _____________________________________________________________
2 Modeling approach _____________________________________________________
3 Results _________________________________________________________________
4 Discussion _____________________________________________________________
5 Conclusions part II _____________________________________________________

Literature: ________________________________________________________________

1 Deltares, Marine and Coastal Systems, Rotterdamseweg 185, P.O. Box 177, 2600 MH Delft, The Netherlands
2 Water Engineering and Management, University of Twente, P.O. Box 217, 7500 AE Enschede, The Netherlands
Part I: Data analysis on distribution & recovery potential of Lanice conchilega, (Owenia fusiformis) and Ensis species.

Jan van Dalfsen

1 The Coastal zone

The Dutch coast is characterised by sandy shores and is part of the sandy coastal ecosystem of the North Sea. The Dutch coast can be divided into three physically different parts: the Wadden Sea islands in the north, the Schelde delta in the south, and in between, the central and western coasts, a sand barrier system fronted by beach and surf zones containing 2 or 3 breaker bars (Janssen & Mulder 2005). The Dutch beaches display a geographical trend in beach types. Those of the Wadden Sea islands in the northern part of the Netherlands are dissipative, flat, fine-grained, and host high densities of many species of benthic macrofauna. The beaches along the western Dutch coast are less dissipative, steeper, with a higher mean grain size; the species diversity and abundance there are lower. Species diversity and abundance on the beaches increase from the high- to the low-water line. A similar pattern is found in shallow subtidal zone where species diversity and abundance are low in the surf zone and increase towards deeper water.

Although differences are found in the geomorphology and the macrobenthic community of the surf zone of the coasts of Wadden islands such as Schiermonnikoog and Ameland, and the central Holland coast, e.g. at Egmond and Castricum, parallels can be drawn as well. The macrobenthic community of the shallow zone differs from that in the deeper coastal zone. Relations exist between the benthic community and the geomorphology and sediment composition. Differences are related to the occurrence of the breaker banks and the presence of the trough in between. A zoning in the benthic community is described existing both at Schiermonnikoog and Egmond: a first community is characterized located at the first breaker bank. The shallow locations including the through form a second community, and the second breaker bank and the deeper seaward locations form a third community.

Studies on the macrobenthic community of the coastal zone conducted at the Belgian continental shelf show an onshore-offshore gradient with relative poor communities in the very shallow zone and an increase of species numbers and diversity with depth, starting from approximately 6 m. (Van Hoey, 2004; Degraer et al 2003, Speybroeck et al. 2003, Kaag et al. 2005). A maximal diversity was found at a distance of about 5500 m from the shore.

2 Habitat preferences

2.1 Lanice conchilega

Lanice conchilega is found in all soft-bottom sediment types in the North Sea, but with differences in frequency of occurrence and average density. L. conchilega is found in the entire North Sea down to a depth of 180 m (the deepest record in the dataset of Rees at al. (2007) was 380 m). This tube building polychaete is known to live mainly in sandy sediments from
mud to coarse sand (Hartmann-Schröder, 1996). Yet, shallow muddy and fine sands are strongly preferred: L. conchilega shows its highest frequencies of occurrence and densities in these sediments (more than 1000 ind/m² compared with maximally 575 ind/m² in shallow medium sands). In the deeper habitats, L. conchilega is frequently encountered, but only in low abundance (maximally 170 ind/m² in deep fine sand). It can be concluded that L. conchilega has a wide geographical distribution and a low habitat specialization.

L. conchilega influences the density and diversity of macrobenthos in soft-bottom sediments. This effect is most pronounced in shallow fine sand, which is the species' preferred habitat. Although the influence of L. conchilega on species richness difference strongly between strongest correlations are in shallow fine sands (Rees et al. 2007). Changes in benthic characteristics result from the alterations of the habitat by L. conchilega (hydrodynamics, sediment stability, improved oxygen) and the complex interactions between the benthic organisms and the biogenic structures consisting of L. conchilega tubes. Many benthic species can profit from the creation, modification, and maintenance of that habitat by L. conchilega, which results in an increased density and species richness in L. conchilega patches compared with the surrounding soft-bottom sediments. L. conchilega only has an effect on the benthos present in a particular habitat, rather than forming its own association. Consequently, L. conchilega beds can be considered as important habitat-structuring features in the soft-bottom sediments of the North Sea.

The population dynamics of L. conchilega is characterized by conspicuous spatial and temporal heterogeneity. Lanice has been found to establish dense clusters of up to 10,000 ind/m² in the intertidal (Ziegelmeier 1952; Hertweck 1995) and of about 20,000 ind/m² in the subtidal (Buhr 1979).

Despite its wide distribution and the formation of sometimes dense aggregations, the effects of L. conchilega on the surrounding benthic community have received little attention, especially in subtidal areas (Rees et al 2007).

2.2 Owenia fusiformis

Although Owenia fusiformis can be found in fine to coarse sediments (150 to 500 µm) the species only reaches a high relative occurrence in the finer sediments. Sediment has to contain mud to be suitable for O. fusiformis. The highest relative occurrence is reached in sediments with a mud content of 10 to 40%. O. fusiformis does not occur in sediments with a mud content exceeding 40%. O. fusiformis is predominantly found in substrates composed of fine sand with high mud content, such as occur in the Oyster Ground. The distribution of this species is thought to be determined by temperature (Wolff, 1973). O. fusiformis lives in tubes that are partly buried in the sediment and partly extended from the sediment. It is able to live in low oxygen concentrations for a short time.

On Belgian part of the North Sea O. fusiformis has a limited distribution. It was only observed in the near-coastal zone with the exception of eastern coastal zone. Whereas O. fusiformis was only found in low densities in the 1976-1986 period (maximum 15 ind/m²), densities up to 500 ind/m² were recorded in the 1994-2001 period.

2.3 Ensis directus

Ensis directus lives in the sandy bottoms in the intertidal or subtidal zones along the Atlantic coast. E. directus prefers muddy, fine sand with small amounts of silt in the low and subtidal zones in bays and estuaries. It is usually found in colonies. It is not migratory and therefore it remains in its habitat year round. E. directus burrows into the sand using its foot and it only surfaces during high tide. It will climb close to the surface so that only its siphons are exposed.
These two siphons are used for filtering food and water. When low tide occurs, it burrows back down below the surface. E. directus is an extremely fast burrower and is very hard to be caught due to its great speed. It is also a remarkable swimmer. It is able to propel itself through water by expelling water through its shell and drawing in its foot. This action is repeated over and over again allowing it to move through the water (Alexander 1979, Cooper 1960, Pyke 2002). They can actively escape unfavourable conditions e.g. low oxygen or elevated salinity concentrations and leave an area being physically disturbed (Muir 2003) The free-swimming larvae are distributed by currents in spring and secondary dispersal of post-larval stages takes place in summer. The juveniles settle on clean sands in the lower zone of the intertidal areas, where they burrow in the sediment and filter-feed on algae. The life-span is up to 5 years. The maximum sizes 16-17 cm. In periods of physical disturbance as during storms and in winter, Ensis will withdraw deeper in the sediment (Perdon & Goudswaard 2006).

3 Review of studies

3.1 RIACON project (Van Dalfsen et al. 1993-1997)

To investigate the risk of shore face nourishment to the coastal benthos community the project “Risk Analysis of Coastal Nourishment Techniques (RIACON)” was started in 1993. Six pre- and post nourishment survey (T0 – T5) were conducted at the nourishment site and at a reference site at the island of Terschelling between 1993 and 1995. A total of 2.1 Mm$^3$ of marine sand were deposited on the seabed in front of the beach covering a trough area of circa 1.7 km$^2$, in between two breaker bars. In both nourishment and reference area different strata following the seabed morphology were investigated. In total 90 stations were sampled at the study sites with a van Veen grab samples of 0.06m$^2$ at a water depth between 3 and 7 m – NAP and up to 1000 m from the coastline. Before the nourishment differences in species richness were found between the different geomorphological strata. The highest number of species were found in the North stratum, which is the second breaker bank, lowest diversity was found on the first breaker bank. Short and longer-term effect were observed, showing an impoverishing of the community at the nourishment site, but most effects had disappeared after in 1995. During the successive surveys Lanice was found in low densities (average < 10 ind / m$^2$) and in less than 50% of the stations in all areas. Sometimes higher densities were recorded at single stations indicating the possible presence of patches. Such observations were only made in the Northern strata (second breaker bar) in both reference and nourishment area. Ensis was found also in very low densities before and directly after the nourishment. In 1994 a successful spatfall was recorded which resulted in increased densities at all areas, which were slightly higher at the reference site.

As part of the RIACON project investigations were also made in July 1994 and in March and August 1995 at a beach nourishment site on the North sea coast of the island of Norderney and at a reference site at the island of Spiekeroog. Samples were taken in the lower intertidal and at the upper intertidal. Both Ensis species and Lanice conchilega were mostly absent or found in low densities during these surveys, except for station 1 at Norderney were in the successive surveys Lanice conchilega were found with densities between 1075 – 16240 ind/m$^2$.

Punaise Project (Van Dalfsen et al. 1999, Van Dalfsen & Lewis 2001)

Between 1996 -1997 and in 2001 field surveys were made to investigate recovery and long-term effects of a temporary dredging pit in shallow coastal zone near Heemskerk. The pit was located in the foreshore at a depth between 7-8 m – NAP. The pit was used as a temporary...
borrow site in which a autonomous innovative dredging equipment was used, the “Punaise” (Visser & Bruun 1997). After the dredging activities were stopped the pit was filled in with marine sediment from deeper water. Overall conclusion was that the sediment composition in the top layer of the sea floor had recovered within one year. The macrobenthic community recovered over a period of four years and differences between a reference area and former pit area were only seen temporarily. Detailed analysis of the macrobenthic data showed that before and after the activities densities of both Lanice conchilega and Ensis were very low. Lanice conchilega was found often in over 50% of the stations with densities varying from an average of 1 ind/m$^2$ to 8 ind/m$^2$. From the data it is hypothesised that occasionally patches of the species were found as in individual samples sometimes up to 15 - 32 individuals were found. Densities of Ensis were always very low with a few individuals per sample. The species became more abundant in the area in August 1997.

### 3.2 Zonation of macrofauna (Janssen & Mulder 2005)

Janssen and Mulder studied in 2002 the distribution and diversity of epibenthic macrofauna at different depths in the surf zone along the Dutch coast. Detailed information was obtained from transects sampled in the surf zone on the North Holland coast at Castricum and Egmond. Benthic samples were taken with a 0.2 m$^2$ Van Veen Grab. Species diversity and abundance of epibenthic and benthic animals were found to increase with increasing depth of the water column and especially seawards of the outer breaker bar. Both species Lanice conchilega and Ensis spec were found in more than 50% of the samples and indicated as common.

In the trough between the two breaker bars at a distance of approximately 300 m from the beach, spots were observed of high diversity and abundance of macrobenthos. In the troughs, dense fields (patches) of juveniles of the Sand mason Lanice conchilega were found. Although at both sites Castricum and Egmond, these observations were made only in one sample.

### 3.3 Annual shellfish monitoring programme (Perdon & Goudswaard 2006)

Since 1995 the Ministry of Agriculture, Nature and Food Quality annually monitors the stocks of a number of shellfish species in the Dutch coastal waters. In the summer of 2006 Wageningen IMARES estimated the stock again but with particular attention to Ensis directus. Samples are taken with a benthic dredge. More than 37 billion individuals for Ensis directus was found, indicating the ecological importance of this species. From this total more than 22 billion individuals were found in the ‘Bird and Habitat Directive Areas’; 17 billion individuals in the ‘Voordelta’ (VHR71) and 6 billion individuals in the protection area ‘Waddeneilanden/ Noordzeekustzone/ Breebaart’ (VHR 39). Most Ensis directus were found in the ‘Voordelta’, but 75% of these animals were small.

The monitoring programme clearly shows the growing population of this species since its introduction in the Dutch coastal waters since 1982. However, the sampling stations are not in the vicinity of the shallow coast.

No recent data or detailed location data available yet
3.4 **Zandige Kust (Van Dalisen 2006)**

To investigate the ecological value of the shallow coastal zone a field survey was conducted in October 2005 at Schiermonnikoog and Egmond. The study was conducted to describe the macrobenthos communities in relation to the morphological structure and sediment composition. Water depth in the studies areas ranged from -1.5 m to -7 m at Schiermonnikoog and from -1.5 to 12 m at Egmond. At Schiermonnikoog the near shore morphology showed the existence of a two breaker bank system with sandwaves to be present at Schiermonnikoog. At Egmond two breaker banks are present, running parallel to the coast. Silt content is generally low (<1%) and increased with depth, but elevated levels were found in the through between the breaker banks. In the trough at Schiermonnikoog relative high concentrations of shell fragments were found.

Both at Schiermonnikoog and Egmond the razor clam *Ensis directus* (synonym used: *Ensis americanus*) is indicated as a common species present in more than 50% of the sampled stations, respectively at 14 and 19 stations of the 21 analysed for Egmond and Schiermonnikoog. At Schiermonnikoog *Ensis* is an important species, especially at the
sampling stations in deeper water, including the through. At Egmond Ensis is also present at the first breaker bank. Densities ranged from 0 - 2800 ind/ m² at Egmond to 0 - 16000 ind/ m² at Schiermonnikoog. The stations with high densities were all found seaward of the second breaker bank.

Lanice conchilega was found at 8 of the 21 analysed sampling stations at Egmond and in only at 3 of the 21 stations taken at Schiermonnikoog. At some stations high numbers of Lanice tubes were found in the samples, although these do not were not always occupied, as the number of individuals fund was far lower that the number of tubes. densities ranged from 0 - 100 ind/ m² at Egmond with higher densities at three station seaward of the second breaker bank where densities up to 500 ind/ m² were found. At Schiermonnikoog densities were low ranging from 0 - 40 ind/ m².

Concluded was that the macrofauna communities showed some differences between the two sides but had similarities as well. For instance, species numbers were higher at Egmond than at Schiermonnikoog. Ensis concentrations were especially high at the deeper stations seaward of the second breaker bank. Concentrations of Lanice conchilega were only found at some stations seaward of the second breaker bank at Egmond.

3.5 Zandige Kust II (van Dalfsen 2009)

In 2007 a second survey wars initiated to describe the macrobenthos community in the shallow coastal zone and to investigate possible impacts of nourishments. Field surveys were conducted at Ameland, Schiermonnikoog and at 3 sites at Egmond. Samples were taken at transects perpendicular to the coast. Water depths ranged from 1 to 13 m -NAP, but at Schiermonnikoog and Ameland the transects run to a maximum of 7 m -NAP. At Ameland and Schiermonnikoog Lanice conchilega was present at respectively at 12 and 17 stations of the respectively 15 and 25 sampled stations. At most stations densities varied between 0 - 140 ind/ m², but reached densities up to 2340 ind/ m² at a some stations, indicating the presence of "patches" or reefs. These stations were all located outside the second breaker bar at distance between 800m and 1100 m from the coast. At the three areas studied at Egmond Lanice conchilega was present in 14 out of a total of 41 stations investigated in the 3 areas, but completely absent in one area (reference site 1). The densities were low as well, except for 3 stations where densities between 1214 ind/ m² and 2570 ind/ m² were found.
At Ameland and Schiermonnikoog juvenile Ensis was found at low densities to a maximum of 100 ind/m² in less than 50% of the stations. The species was almost completely absent at the 3 areas at Egmond, except for 3 stations where 1 individual was found. The study showed that some differences do exist in the macrobenthic community at the areas investigated and higher densities of Lanice conchilega were found at the Wadden Sea islands Ameland and Schiermonnikoog than at the Holland coast near Egmond. High densities of Lanice conchilega were only seen at the deeper sampling stations located outside the breaker bank system. Banks of the razor clam Ensis were not found in this study.

3.6 Baseline Petten (Van der Wal 2008)

In 2008 a baseline survey was conducted at the North Holland Coast from Egmond to Petten. Samples were only taken at proposed foreshore nourishment areas and a reference area. These were all located at the seaward side of the second breaker bank.

3.7 Base line Texel (Bos 2009)

In advance of a foreshore nourishment planned at the north-western part of the coast of the island of Texel a baseline study was conducted in 2009. Samples were taken at three sites up to maximum distance of 1500 m from the LW mark in a depth range between 2.6 and 8.5 m – NAP. In this baseline study no important concentrations (reefs) were found of the Razor knife (Ensis spec.) or the Sand mason L. conchilega. Individuals of Ensis spec. were recorded in low densities of 1-50 per m² in 7 out of the 24 sampling stations. At the proposed nourishment site only 1 individual was recorded. Also L. conchilega was found in low densities varying from 0-50 per m² and only at the 2 reference areas. The sediment composition was fine with an average grain size of 209 to 255 μm, a silt concentration of less than 1% and <1-2% organic material.
3.8 **Macrobenthos Monitoring Program (MWTL)**
During the annual macrofauna monitoring program in the Netherlands data are also collected in the coastal zone. In 2006 *L. conchilega* was found at 6 of the 16 sampled stations whereas *Ensis directus* (synonym used: *Ensis americanus*) was found at 12 stations. However, due to the limited number of samples taken in the coastal zone, the mean depth of 12.6 m and the distance of the coast, starting at an average distance of approximately 4000 m from the shore, the information of this monitoring program is only of limited use.

3.9 **Systematic Beach Monitoring (SMP, Gmelig Meyling & de Bruyne, 2009)**
In 2009 data of the available Systematic Beach Monitoring research were analysed to investigate the possible effects of beach and foreshore nourishments along the Dutch Coast. Data were used of beach findings recorded along 7 transect along the South and North Holland coast, including the island of Texel. These transect were sometimes followed since 1970. Although the study clearly showed changes in the beach findings, the data presented allowed no detailed study of *Ensis* and *Lanice*.

3.10 **Effects of Beach Nourishment on the Infauna (Menn et al. 2003)**
The impact of two nourishment operations on the island of Sylt (Germany) on meio- and macrofauna across a shore on were been studied between 1999 and 2001. Over a beach length of 2 km 159,000 m$^3$ of sand were deposited in 1999 and a further amount of 351,000 m$^3$ was added to the same site in 2000. A nearby undisturbed beach was simultaneously studied for comparison and to assess seasonal effects.

A minor short-term negative impact by the nourishment in 1999 on the macrofauna in the shallow subtidal was indicated by reduced abundances of some species in the first post-nourishment survey, while nine months after the operation no more differences in abundances between nourished and reference site were detected. The in 2000 revealed a longer-term effect on the macrofauna in the deeper subtidal. Polychaete abundances and species density at 7 m depth were still reduced nine months after the operation.
3.11 Lanice conchilega recolonization pattern (Strasser, M. and U. Pieloth, 2001)

The recolonization process of Lanice conchilega was studied on an intertidal sand flat in the northern Wadden Sea after an intertidal population had been wiped out during the severe winter of 1995/96. The population fully recovered in the third year after its destruction with a distribution pattern that closely resembled the pattern before the severe winter. The observed recruitment pattern was suggested to be the consequence of a large-scale decline in the metapopulation in the tidal basin and the onshore coastal subtidal which resulted in insufficient larval supply onto the tidal flats and low recruitment in the first two years following the severe winter. Lanice larvae have been observed to attach preferentially on the tubes of adults. However, the high recruitment in the third year was also seen in areas devoid of adult Lanice, indicating that settlement facilitation by adults was of little importance for the recolonisation process.
4 Conclusions part I

The studies conducted in the Netherlands since 1993 give no indication of large concentrations of Lanice conchilega and Ensis directus in the very shallow coastal zone directly in front of the beach. During the RIAON study (1993-1997) no concentrations of either species were recorded in the through between the first and second breaker bank. As Ensis directus is an invasive species first to be recorded in the Netherlands in 1983, the species was not abundant yet, possibly explaining the absence in the troughs of both studied areas. The progress of this invasive species during the last decade is clearly recorded in the annual shellfish monitoring program.

The densities of L. conchilega have increased substantially over the past decade just outside the breaker bank system and further off the coast as is recorded during the annual shellfish monitoring survey, which is conducted in more deeper water at a larger distance from the coast (Perdon & Goudswaart 2006). Observations indicate the preference of the species for slightly deeper water as densities seem to increase from the last breaker bank to deeper water. Lanice concentrations (patches) of different sizes were first observed with an underwater video camera during the “Zandige Kust” study (Van Dalfsen 2009).

The observation of Janssen and Mulder (2005) at Castricum and Egmond of high densities of especially the sand mason L. conchilega in the troughs is not repeated in the data from other studies. Their observation is based, however, upon a limited number of samples only. The studies conducted at Egmond, Ameland and Schiermonnikoog demonstrated that the results of the Janssen and Mulder (2005) found at Castricum and Egmond were not representative for the entire Dutch shallow coast.
Part II: Modeling bio-physical interactions by a polychaete tube lawn

Bas Borsje

1 Introduction

Sediment dynamics in the coastal area are the result of the complex interaction between hydrodynamics and biological activity. Either by stabilizing or destabilizing the sediment, biological activity is able to modify the sediment fluxes by a factor 2 and more, compared to the solely physical case (Graf and Rosenberg, 1997). In the most extreme case, skimming flow may occur, which is a situation in which objects protruding from the bed hinder flow to such a degree that the main body of water passes over them instead of through them, thereby preventing sediment from the bed to erode (Eckman et al., 1981). Tube building worms such as the polychaete Lanice conchilega and Owenia fusiformis protrude partly from the sediment whereas the main part of the animals body is hidden in the seabed. This protrusion will directly influence the near bottom water currents and thereby the sediment dynamics. Indirectly, these biogenic structures can have a profound effect on the structure and functioning of marine ecosystems (Rabaut et al., 2007). For instance, the effect of Lanice conchilega on biodiversity has been described extensively (Carey, 1987; Zühlke et al., 1998; Callaway, 2006). Therefore, understanding the interactions between polychaete tube lawns and the hydrodynamics and sediment dynamics is important from both an engineering and ecological perspective.

Direct effects by tube building worms are extensively discussed in different flume studies (Friedrichs et al., 2000; Bouma et al., 2007; Friedrichs and Graf, 2009; Peine et al., 2009; Friedrichs et al., 2009). From these studies we know that already at low densities (expressed as percentage of area coverage) of 5% skimming flow behavior may occur. However, at smaller densities erosion fluxes are greatly enhanced by the destabilizing effect of the individual tubes. In summary, tube lawns can have both a stabilizing or destabilizing effect on the sediment dynamics, depending on the flow characteristics and the density of tube building worms.

Future research should focus on the up scaling of the flume experiments to field conditions by including tube building worms in a numerical model, as recommend by Friedrichs et al. (2009) and Peine et al. (2009). Few studies are known, where small scale biological activity by tube building worms are included in a large scale model (Bobertz et al., 2009; Borsje et al., 2009a,b). All studies use simplified empirical relations between the density of tube building worms and the critical shear velocity and bed roughness length. These simplifications are justified when studying the large scale sediment dynamics of the whole Baltic Sea (Bobertz et al., 2009) or the Dutch part of the North Sea (Borsje et al., 2009a,b). However, it is a major challenge to understand the interactions between biological activity and physical processes in a process-based way, which asks for a 'bottom-up' approach (van Prooijen and Montserrat, 2009). In this 'bottom-up' approach, the interaction between rigid cylindrical structures (such as tube building worms) on drag and turbulence should be explicitly account for (Bouma et al., 2007).

The aim of this paper is to determine the relevant interactions between polychaete tube lawns and physical processes in the subtidal environment from a 'bottom-up' approach, by including rigid cylindrical structures explicitly in a three dimensional hydrodynamic model (Delft3D). We will achieve this objective by first introducing the model and model set-up (Section 2). Next,
the interaction between biological processes and hydrodynamics (Section 3) are quantified. Finally, the main findings of this study are discussed (Section 4), leading to general important conclusions (Section 5).

2 Modeling approach

To model the influence of L. conchilega on the near bottom flow, we represent the tube building worm by thin piles on the bottom of the seabed. In this way, we are able to include the worms in a vegetation model (Uittenbogaard, 2003). This vegetation model is able to calculate the turbulent flow over and through vegetation (thin piles) in water of limited depth. The vegetation model explicitly accounts for the influence of cylindrical structures on drag and turbulence by an extra source term of friction force in the momentum equation and an extra source term of Total Kinetic Energy (TKE) and turbulent energy dissipation in the $k$-$\varepsilon$ equations respectively. The vegetation model is included in Delft3D-FLOW model, which is a three-dimensional hydrodynamic model (Lesser et al., 2004). The Delft3D-FLOW model computes flow characteristics (flow velocity, turbulence) dynamically in time over a three-dimensional spatial grid. For a detailed mathematical description of the vegetation model see Bouma et al. (2007).

In this study we adopt a grid of $5 \times 5$ km with a grid size of $100 \times 100$ m, resulting in $500 \times 500$ grids. The waterdepth is about 10 m, divided in 10 layers. The tube building worms are characterised by a length of 3.5 cm and a diameter of 0.5 cm. The density is varied for the different model simulations. In order to speed up the calculation time, the patch size is put to $400 \times 400$ m. In reality the patch size is much smaller. However, detailed model simulations show that the patch size not influences the results.

3 Results

Inside the patch, the flow velocity decreases dramatically (Figure 3.1) due to the presence of the tube building worms. For the default case (0 individuals m$^{-2}$) the flow velocity in the lowest bottom layer is around 0.8 m s$^{-1}$, whereas for higher densities this flow velocity is around 0 m s$^{-1}$ in the lowest bottom layer.
Moreover, the flow velocity profile for the run with 1000 individuals per m$^2$ deviates mostly from the default run, indicating that another process is responsible for the increase in flow velocity for higher densities in the layers above the tube building worms. The process is called ‘skimming flow’, a situation in which objects protruding from the bed hinder flow to such a degree that the main body of water passes over them instead of through them. This effectively limits the influence of bed roughness, leading to higher velocities over the tube field. This process is discussed in detail in figure 3.3.
For increasing density the flow velocity is decreased dramatically within the patch (Figure 3.2), however above the patch the flow velocity first decreases and increases again after a given density, as a result of skimming flow. The flow velocity in the top layers all increase due to the presence of the patch. To study the skimming flow behaviour, the depth averaged velocity is plotted against varying density (Figure 3.3). For a coverage around 12% depth averaged flow velocity is increasing again, showing that the damping of turbulence within the patch is maximum and leading to an increase in flow velocity above the patch.
Apart from influencing the flow velocity within in the patch, also the flow velocity in line with the patch is influenced dramatically (Figure 3.4). Before the patch, the flow velocity and bed shear stress are the same for the different densities. However, right in front of the patch, a small increase in bed shear stress is found, which will result in a scour hole in front of the patch. A phenomena which is often found for intertidal tube building worm patches in the field. Within the patch the flow velocity is influenced as discussed before (Figure 3.1). However, the bed shear stress is for all densities going to zero, resulting in no erosion in the tube building worm field and deposition of fine material. This observation is found in the field by Rabaut et al. (2007), where they found larger fine material contents compared to the default case. Moreover, the found larger coarse material contents, which they attribute to the disintegration of the tubes of the died worms. Most interesting is the influence of the patch on the flow velocity and bottom shear stress after the patch. At a location downstream around 3 times the patch size (1 km), the flow velocity and the bed shear stress are still much influenced. The spatial influence of the patch on the flow velocity shows the same trend (Figure 3.5). Remarkable is the large area of influence around the patch, which is much larger than the patch size. Moreover, the large influence after the patch is remarkable. The decrease in area of influence for increasing flow velocity is explained by the skimming flow behaviour: the larger the density the less influence in the water column (except from the bottom layer) and therefore the smallest influence. In conclusion, patch with densities of around 300 individuals per m² have the largest impact on the surrounding area.

Figure 3.3: Depth averaged flow velocity against varying density. Skimming flow behaviour is found at a coverage of around 12%, which is in line with the flume study by Friedrichs et al. (2000).
Figure 3.4: Flow velocity before, inside and after the patch, as well as the bed shear stress along the complete transect. Different colours reflect different densities (Figure 3.1).

Figure 3.5: Change in flow velocity (explained lower right plot) for different densities. Stabilised (blue) and destabilised (red) areas are indicated in the top left.
The spatial change in bottom shear stress (Figure 3.6) shows qualitatively the same patterns as the change in flow velocity (Figure 5), however the area of influence is even larger. For the lowest density (500 individuals m$^{-2}$) the stabilised area and destabilised area are around 10 times larger than the patch size (Table 3.1).

Table 3.1: Stabilised and destabilised area expressed as factor of the patch size (0.4 x 0.4 km). (D)e)stabilisation is defined as an (in)/(de)crease of the bottom shear stress by 1%.

<table>
<thead>
<tr>
<th>density</th>
<th>destabilised</th>
<th>stabilised</th>
</tr>
</thead>
<tbody>
<tr>
<td>500</td>
<td>9,4375</td>
<td>12,375</td>
</tr>
<tr>
<td>1000</td>
<td>4,25</td>
<td>11,625</td>
</tr>
<tr>
<td>1500</td>
<td>2,625</td>
<td>10,375</td>
</tr>
<tr>
<td>2000</td>
<td>2</td>
<td>9,5625</td>
</tr>
<tr>
<td>2500</td>
<td>1,625</td>
<td>8,3125</td>
</tr>
<tr>
<td>3000</td>
<td>1,375</td>
<td>6,25</td>
</tr>
<tr>
<td>3500</td>
<td>1,25</td>
<td>4,625</td>
</tr>
<tr>
<td>4000</td>
<td>1,1875</td>
<td>4,4375</td>
</tr>
</tbody>
</table>
4 Discussion

In this study we elaborated the interaction between tube building worms and hydrodynamics by varying the density. However, much more parameters could be varied, which is a recommendation for future work. First of all, the flow velocity and patch size should be varied, in order to detect the transition from normal flow to skimming flow. The large wake after the patch could result in a spatial pattern of tube building worms found in the field. After the patch, the flow velocities are lower and the sedimentation of sediment and food is flavoured. Side scan sonar in the Western Waddensea shows a comparable pattern (Figure 4.1). Future work should focus on the explanation of the given pattern of tube building worms in the field.

Figure 4.1: Side scan sonar images in the Western Wadden Sea. Ripples indicate the dominant flow direction, and the tube building worms are situated perpendicular to the dominant flow direction. Samples are taken in the red circles.

5 Conclusions part II

Tube building worms are able to modify the flow properties dramatically within the patch, resulting in a bed shear stress of around zero for increasing density. Moreover, the flow properties around the patch are also influenced enormously, resulting in a stabilised area and destabilised area around the patch which is almost ten times larger for an intermediate density (500 individuals m\(^{-2}\)). The stabilised area is situated within the patch and in the wake zone of
the patch, whereas the destabilised area is situated in half circles around the patch. Given the densities found in the Dutch Coastal Zone (part 1), large influences are expected on the coastal sediment transport. Including the influence of tube building worms is therefore important in coastal sediment transport, as the influence is much larger than the patch size itself.
Literature:

Part I.


Rabaut, M., L. Van de Moortel, J. Van Dalsen, M. Vincx, S. Degraer, subm.-b. Importance of ecosystem engineered habitats for juvenile flatfish


Van Dalsen, J.A. 2009. Inventarisatie brandingszone. Wageningen IMARES rapport C0138/07

Van der Wal, J.T. and J.A. van Dalsen 2008. Monitoring kustsuppleties. Wageningen IMARES rapport C014/08

Van Hoey, G. 2006. Spatio-temporal variability within the macrobenthic Abra alba community, with the emphasis on the structuring role of Lanice conchilega. Ghent University (UGent), PhD, 187pp.


Part II.


