

Biogeomorphology in the field: bedforms and species, a mystic relationship

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Abstract

Fine-scale seabed mapping (<5 m resolution) (e.g. surficial sediments, morphology and benthos) was conducted along the ebb-tidal delta of the Westerschelde estuary, Belgian and Dutch part of the North Sea. To understand variations in habitat and species distributions, mapping was combined with measurements of currents and turbidity throughout 13-hrs cycles and with sediment transport modelling results.

Results showed that highest abundances of some ecosystem engineering species (e.g. the tubeworm *Owenia fusiformis*, and the razor clam *Ensis directus*) occur near bedload convergence zones resulting from a mutually evasive flood- and ebb-dominant channel system. Such zones are at the end of the channels, hence also fine-grained sediments, food and larvae are trapped. The combination of the coarser-grained bedload with the deposition of fines is indeed the optimum for a lot of suspension and detritus feeders. Still, highest abundances occur at the fringes of such a system where stress levels are intermediate. Hypotheses were successfully tested along the Dutch coastal zone. Those insights are important to assess changes in seafloor integrity and hydrographic conditions, two descriptors to define Good Environmental Status within Europe's Marine Strategy Framework Directive.

1. INTRODUCTION

Biogeomorphology is a field in which the understanding of benthic species in relation to their surrounding landscape is critical. In the marine environment, observations of both components remain relatively scarce, but increase steadily as multibeam technology allows capturing, visualizing and quantifying benthic and terrain variables on both small- and large-scales (e.g. Van Lancker et al. 2012). However, feedback mechanisms between geomorphology and benthos are not always clear. Complexity increases where also humans affect the benthos-landscape relationship. This is the case along the ebb-tidal delta of the Westerschelde estuary ('Vlakte van de Raan'), where disposal of dredged material is regular practice for already 30 yrs. This paper

discusses the relative occurrences of macrobenthic species in this area in relation to its driving forces.

2. STUDY AREA

Measurements and observations have been made along the Belgian and Dutch part of the North Sea, a siliciclastic macro-tidal environment (tidal range of 4.5 m), comprising several groups of sandbanks (Fig. 1). Sediment transport is mainly driven by tidal currents (max. 1.2 m/s), though wind-induced currents may have a direct effect on sediment resuspension and bedform morphology. Along the Vlakte van de Raan sediment dynamics become more complex. Increased sediment fluxes arise from the disposal activities, but along its delta front, and more offshore, bedform patterns are very complex with varying rates and directions of migrating sand dunes (Fig. 1). Also on the disposal

ground itself a series of large sand dunes is present (Du Four & Van Lancker 2008) (Fig. 1). On this location, biodiversity is low, but regional observations of macrobenthos (species larger than 1 mm) did show higher abundances in this area (Fig. 2).

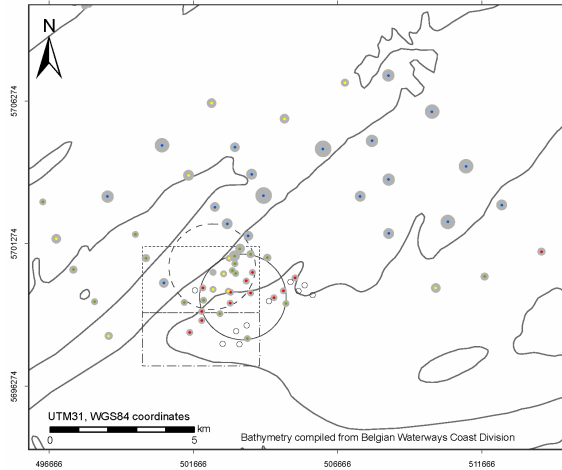


Figure 2. Macrobenthos densities and communities along the western part and delta front of the Vlakte van de Raan (Belgian part). Low species densities to no fauna (open circles) characterize the disposal ground; densities (sized circles) amount up to more than 25.000 ind. m⁻² with up to 43 species per 0.1 m² (Macrodat@UGent, Degraer et al. 2006). Along the delta front the *Abra alba* community thrives, being the most rich and diverse macrobenthic community on the Belgian part of the North Sea. Location see Fig. 1.

Also, the razor clam *Ensis directus*, being the most important invasive species on the Belgian part of the North Sea thrives in this area (Houziaux et al. 2011). This species is commercially exploited in the Dutch part of the North Sea. Yearly stock assessments take place, though the monitoring would benefit from a revised survey design based on the habitat preferences of the species (Troost et al. 2012).

3. METHODOLOGY

High resolution multibeam acoustic data were acquired (Kongsberg Simrad EM1002/99 kHz and EM3002/300 kHz) for seabed mapping and habitat characterization (yearly surveys in the period 2006-2011). Depth and backscatter data were processed and data grids were produced at a resolution lower than 5 m. This allowed quantifying fine-scale sediment and terrain variation, as also bioturbation. Some species

indeed alter the acoustic response of the seafloor (e.g. Degraer et al. 2008; Van Lancker et al. 2012), with dense colonies of tubeworms forming mounds of up to 40-50 cm. For the area, these were observed through fine-scale terrain analyses. For the time series analyses, vertical dynamics are quantified from the calculation of a linear trend in time over the available bed levels on a cell-by-cell basis (Van Dijk et al. 2011). Additionally, current and backscatter profiling (Acoustic Doppler Current Profiling, ADCP) was carried out along a transect perpendicular to the delta front, covering periods of 13 hrs tidal cycles. Sediment and macrobenthos samples (> 1 mm) were taken, both in the Belgian and Dutch sector. In this paper, multibeam results will be discussed in more detail.

4. RESULTS

In the area of highest macrobenthos abundances (Fig. 2), a complex of large to very large dunes was revealed (Fig. 3). Bathymetry data showed that the highest dunes occurred where the channel, separating the Vlakte van de Raan from the Akkaert Bank, gradually shallows. The ending of the channel and its higher relief is caused by the interaction of flood and ebb tidal currents, on a residual basis. This is typical in an area where the interaction between the tidal flow and the local or regional bottom topography leads to unequal strengths and duration of the flood and ebb tidal currents. Both currents evade from each other leading to bedload deposition in their interaction zone. This is called a mutually evasive sediment transport system, *sensu* Harris (1988).

In the present case the flood is most dominant and has created a so-called flood channel. ADCP profiling showed strong and rectilinear currents along its axis (Fig. 6). Bedforms are clearly flood-dominated, but become more symmetrical near the end of the channel. Analysis of the morphology, asymmetries and migration rates through time, showed that the northwestern side of the flood channel was merely characterized by ebb-dominated dunes (Fig. 3). A similar evasive system occurs higher up the delta front, though the ebb-dominancy, as also the transport pathway is more difficult to evidence. In any case, currents are weaker here and the tidal ellipse is more rotary (Fig. 6). Generally, the dune area along this side of

the flood channel is more depositional. Figure 4 shows the differences in vertical dynamics along the NW, Central and SE side of the axis of the flood-channel. Note that the dynamics are only high at the end of the flood-channel.

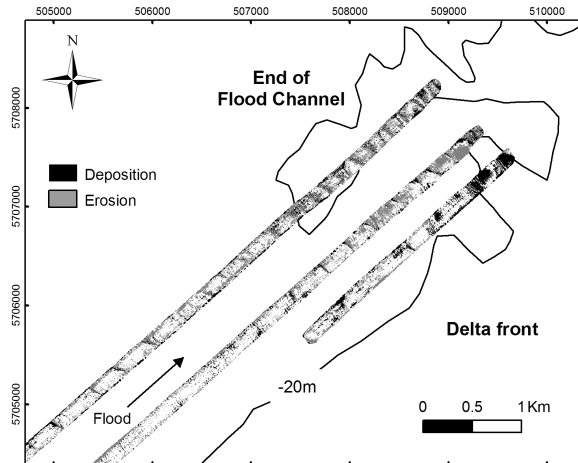


Figure 4. Trends of vertical dynamics based on multibeam time series, here in 2008 and 2009. Along the northern profile erosion and deposition alternate, because of alternating flood and ebb dominance of the dunes; centrally the dunes are mostly erosive; to the southeast, up the delta front, mostly deposition occurs.

Regarding the occurrence of macrobenthos, high resolution multibeam recordings showed extensive small-scale mounds in-between large to very large dunes in water depths around -20 m (Fig. 5). These were related to colonies (up to 6000 ind. m²) of the tube-building polychaet *O. fusiformis* (Fig. 5). They occupy areas of up to 12 km².

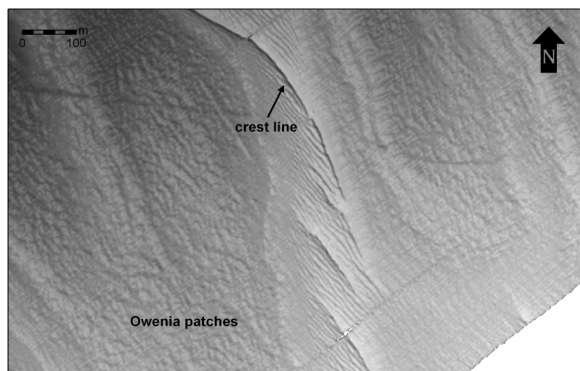


Figure 5. Detailed shaded relief map of an area with very large dunes; in the troughs extensive fields of *O. fusiformis* are present (rectangle on Fig. 3). The Owenia mounds are up to 40-50 cm high.

However, higher up the delta front densities increased with a maximum of macrobenthos abundance along the upper slope, from -16 m onwards (Fig. 6). This is the fringe area, where flood and ebb residual currents mutually evade. Up to 11881 ind. m² were found of *O. fusiformis* and more than 500 ind. m² of *E. directus*. ADCP-derived backscatter profiling showed that this zone is regularly affected by transient turbidity plumes descending the delta front during the ebbing phase of the tide. Dispersion modelling showed that the fine-grained material could originate from the disposal activities, though any fines, whether naturally-, or anthropogenically-induced, would be transported downwards.

Hypotheses were tested along the Dutch Voordelta where it was aimed at predicting highest abundances of *E. directus* from multibeam bathymetry. From the observations described above, an area with a similar setting was chosen for time- and cost-efficient monitoring: from large-scale bathymetry the end of a flood channel was selected (Fig. 1) and surveyed using high resolution multibeam technology. Again a complex of large to very large dunes was revealed with macrobenthos sampling results showing highest abundances (a so-called Ensis bed) at the southeast fringe of the dune system (Fig. 7).

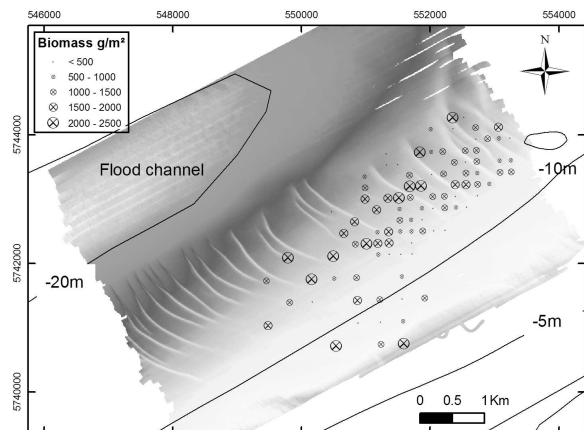


Figure 7. Distribution of biomasses of large Ensis (width > 16 mm), sampled by boxcores (IMARES monitoring Autumn 2012), projected on a multibeam-derived digital terrain model. Note the ebb-shape of the dunes, regardless the overall flood-dominancy of the area. Location see Fig. 1.

Results are important in the framework of Europe's Marine Strategy Framework Directive requiring Good Environmental Status (GES) of its marine waters by 2020. Related to physico-chemical seabed attributes, descriptor 6 on seafloor integrity and descriptor 7 on hydrographic conditions are relevant here. GES for seafloor integrity refers to the structure and functions of the ecosystems that need safeguarding, without adversely affecting benthic ecosystems, whilst GES for hydrographic conditions means that permanent alteration of hydrographical conditions does not adversely affect marine ecosystems. Given the benthos-landscape relationship major changes to flood- and ebb tidal channel systems will undoubtedly affect the benthic ecosystem. Results also indicate that the deposition of fine-grained material, e.g. as resulting from increased human activities, is not necessarily adverse to the structure and function of the ecosystem. Definition of allowable ranges is a challenge for all disciplines.

5. CONCLUSIONS

Extensive fine-scale seabed mapping (e.g. surficial sediments, morphology and benthos), in combination with current and turbidity profiling, was carried out along the delta front of the ebb tidal delta of the Westerschelde, Belgian and Dutch part of the North Sea. It was shown that highest abundances of macrobenthos occurred in areas where fine-grained material naturally deposits on top of relatively coarser substrates. This combination is most favourable for suspension feeders (e.g. ecosystem-engineering tube worms and clams) that profit from the stable substrate, of which its coarseness is favourable for detritus trapping and for better oxygenation. In addition, the passing to deposition of fines provides ample opportunities for filtering food resources. Such zones are found: (1) Near bedload convergence zones, at the end of mutually evasive flood- and ebb-dominant channels. Higher dynamics results in the combination of relatively coarser sediments that are enriched with fine-grained material that is, together with food and larvae, transported through the channel systems. Species that can withstand the overall higher dynamics will be sheltered in the troughs of the large to very large dunes. Though, highest abundances are found at intermediate stresses at

the edge of such systems. (2) Up-slope delta fronts, abundances are higher since the edge zones are also enriched with fines that are deposited from turbidity plumes. Whether naturally or anthropogenically-driven (e.g. from disposal activities) these are transported downwards the slope during the ebbing phase of the tide. High abundances of macrobenthos were found in similar settings along the Dutch Voordelta area.

6. ACKNOWLEDGMENT

Data were acquired in the framework of the Belgian Science Policy projects QUEST4D (SD/NS/06B) and EnSIS (SD/NS/09A). Ghent University, Renard Centre of Marine Geology is thanked for the use of multibeam processing software Sonarscope (Ifremer). Ifremer granted the use of the CARAIBES software in the framework of the EU-FP7 Geo-Seas project. Officers and crew of RV Belgica are particularly acknowledged.

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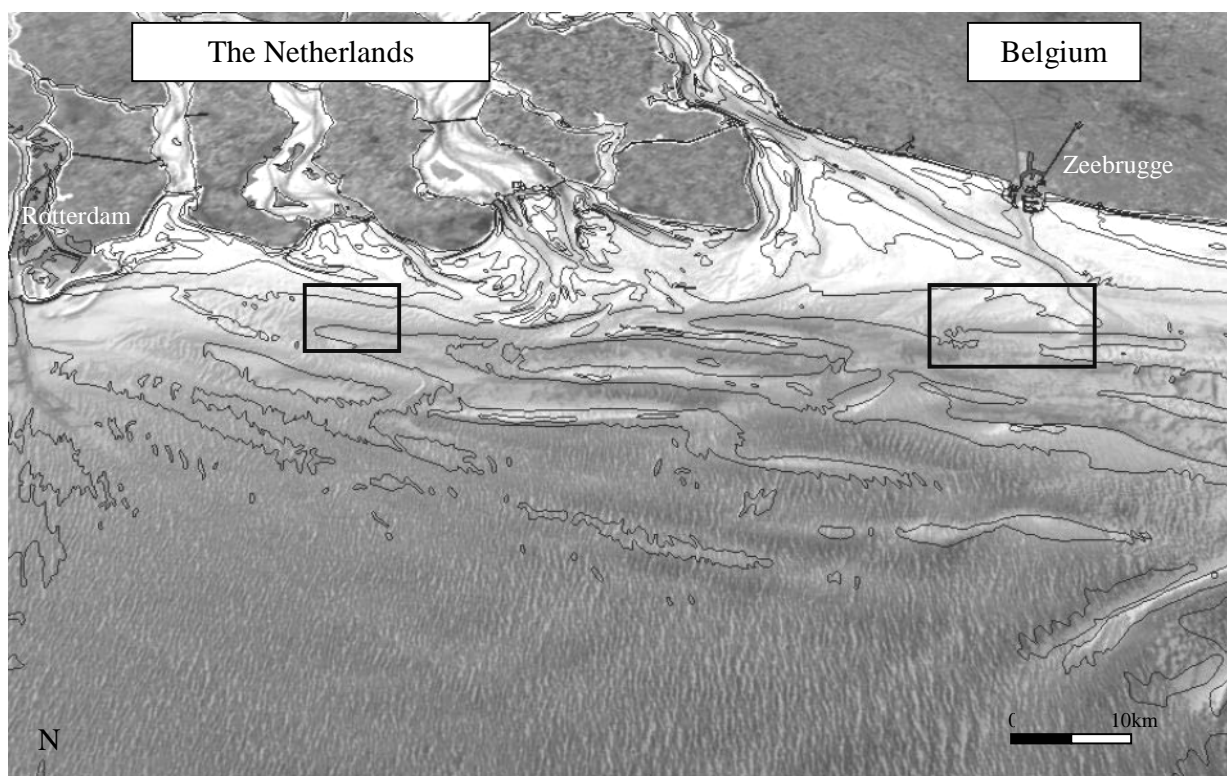


Figure 1. Deltas from the rivers Rhine, Meuse and Scheldt impacting on the Belgian-Dutch coastal zone. Note the complex offshore bathymetry with sandbanks and gullies. Bathymetric data compiled from Flemish Hydrography and Deltares 2011 (Nederlandse Hydrografische Dienst & Rijkswaterstaat Dienst Noordzee). Rectangles indicate the study areas of the Vlake van de Raan (Belgium) and along the Dutch Voordelta (The Netherlands).

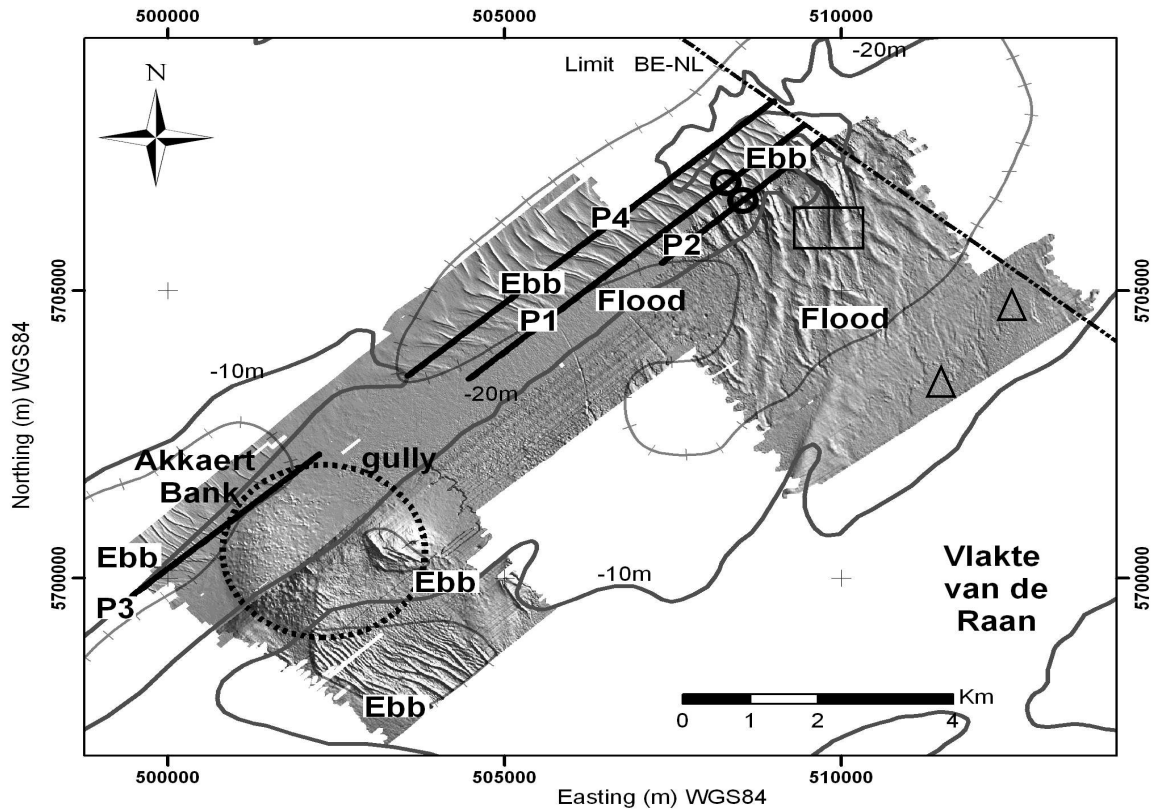


Figure 3. Detailed seabed morphology, as derived from multibeam seabed mapping. Areas with large dunes are observed south and north of the present disposal ground of dredged material (dashed circle). At the northeast extremity of the gully, a series of large complex dunes (up to 4 m) are present. In the axis of the gully and towards the slope their asymmetry is clearly flood-dominated; this gully is a flood-dominated channel. However, in the prolongation of the Akkaert Bank, dunes show an ebb-dominancy. The broad end of the flood channel is a bedload convergence zone, resulting from mutually evasive flood- and ebb-dominated transport zones. Here, colonies of the tube worm *O. fusiformis* occur in the troughs of the dunes (rectangle, see Fig. 6 for a detailed view), as also large quantities of *E. directus* juveniles, American razor blade and most important invasive species along the Belgian part of the North Sea. Higher up the delta front higher densities of *O. fusiformis* and *E. directus* adults occur (triangles). Four profiles (P1 to P4) are indicated along which bedform evolution was followed (see Fig. 5). The circles on profile P1 and P2 indicate where flood- and ebb-dominated dunes converge. The intersected line represents the maximum extent of the bedform area, as derived from broad-scale DTM's.

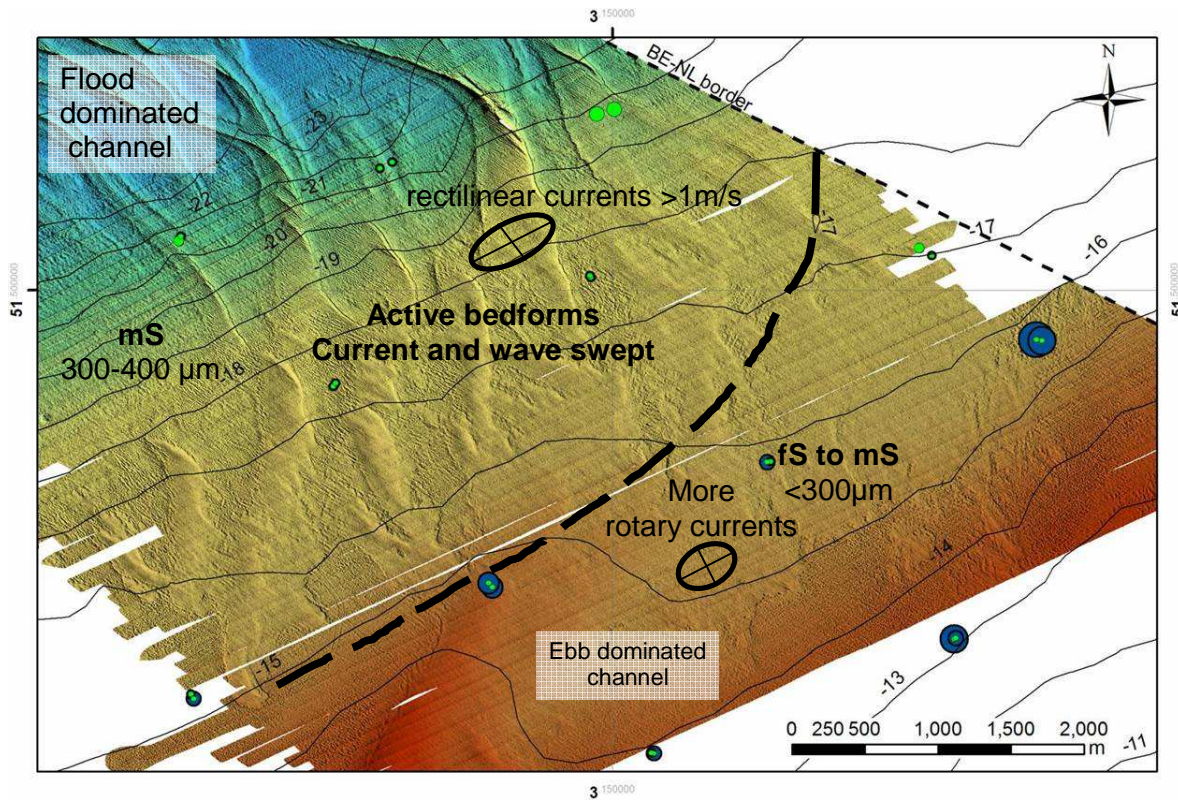


Figure 6. Synthesis figure of sediment dynamics, as derived from acoustic measurements (multibeam and ADCP). Recently reworked sand dunes were observed (without major trawling traces, in contrast to earlier observations that mostly witnessed ripped-up seafloors). In this zone of active transport medium sands (mS) prevail. The dashed line delimits the zone of highest dynamics. Higher up the delta front sediments become finer (fS) and currents became more rotary and less in strength. The ebb current is here important. Highest densities and species richness occur in this upper slope area (e.g. *O. fusiformis* ~ 11.000 ind. m⁻² *E. directus* (dark grey circles) > 500 ind. m⁻²). Light grey circles correspond with the occurrence of *E. directus* juveniles; they are most abundant near the end of the flood-dominant channel. The upper slope area is most frequently subdued to transient turbidity plumes, naturally and anthropogenically-induced. Only, stress-resistant species can survive.