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Small scale morphodynamics of shoreface-connected ridges and their impact on benthic macrofauna

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ABSTRACT

The first interdisciplinary analysis (biological and sedimentological) of macrofauna communities influenced by long-term morphodynamics of shoreface-connected ridges in the German Bight on a small scale is presented in this study. The study area covering 4 km^2 was located off the island of Spiekeroog, in an area known as a *Tellina fabula* community. Sediment samples taken at 27 sample sites were coupled with side-scan sonar data to draw a precise sediment map of the area, as well as with high-resolution multi-beam bathymetry data to understand the morphodynamic changes of the seabed between 2003 and 2010. The macrofauna data acquired at the same 27 sites were analysed for community structure using non-metric multidimensional scaling, the ANOSIM and PERMANOVA tests. Correlations between biological and environmental variables were examined with the BIOENV procedure. The study revealed a shore-parallel sediment zonation with clear and sharp borders induced by local morphodynamics, which together with specific local bathymetry affected the formation of three different macrofauna affinity groups. One group was located on the shoreface and in the troughs (dominant species: *Scoloplos armiger*, *Lanice conchilega*, *Notomastus latericeus*), one on the landward flanks of the ridges (dominant species: *Aonides paucibranchiata*, *Goniadella bobretzkii*), and one on the ridge crests (dominant species: *Ophelia* spp. juv., *Spio goniocephala*). The spatial distribution of the affinity groups, their taxa number and abundance of species was dependent on a surface sediment pattern resulting from local hydrodynamics, which in turn is known to influence the food availability. A seaward steepening of ridges took place and was an effect of erosion up to 0.34 m on landward flanks in and accumulation up to 0.29 m on seaward flanks in seven years. The studied shoreface-connected ridges migrated seawards with a pace of 5 m/year for the large ridge and 20 m/year for the small ridge. Elongated mud-pockets were common in the deepest parts of the troughs, but seemed to be unstable in time. The identified general seaward migration of shoreface-connected ridges seemed to be slow enough for the macrofauna communities to migrate with the morphodynamics of the ridges.

1. Introduction

Elongated rhythmic bedforms (typical spacing of several kilometres) called shoreface-connected ridges are shoreline-oblique linear features typically associated with a gently sloping sandy shelf substrate, experiencing recurrent severe storm events at water depths of 5–30 m (Duane et al., 1972; Vis-Star et al., 2009). In general, the length of the crests of shoreface-connected ridges may exceed 30 km, their width 1 km, and their height exceeds 6 m (Antia, 1996; Schwab et al., 2000; Swift et al., 1978; van de Meene and van Rijn, 2000). Shoreface-connected ridges are active under present hydrodynamic conditions (van de Meene et al., 1996) being structured by different factors like tides or storms. Son et al. (2012) presented worldwide examples with similar and dissimilar sedimentary features, which emphasize various controlling mechanisms for different shoreface-connected ridges, but in general numerical models suggest that ridges tend to migrate in the direction of the dominant tidal current with 1–10 m/year (Calvete et al., 2001; de Swart et al., 2008). Shoreface-connected ridges have been studied intensively along the east coast of the United States of America (e.g. Duane et al., 1972; Swift and Field, 1981a,b; Swift et al., 1978), Argentine (Swift et al., 1978), Brazil (Figueiredo et al., 1982), on the central Dutch coast (e.g. van de Meene and van Rijn, 2000), the Flemish Banks (Trentesaux et al., 1994), as well as along the German coast of the southern North Sea (Antia, 1996), but their migration was never confirmed by high-resolution bathymetry data.

The ridges observed in the German Bight off the East Frisian Islands form a westward opening angle of 10–17° with the shoreline (Fig. 1). The coastal morphodynamics is ruled in this area by tidal, wind- and wave-driven hydrodynamics, sediment transport and bed elevation, which causes morphology changes depending on the sediment properties such as grain size, porosity and shear stress (Kösters and Winter, 2014; Zeiler et al., 2008). Along the German coast of the North Sea, storms from north-westerly and westerly directions are able to induce water levels of up to five metres above the mean sea level (Zeiler et al., 2008). The tides in this area are semi-diurnal and the mean tidal

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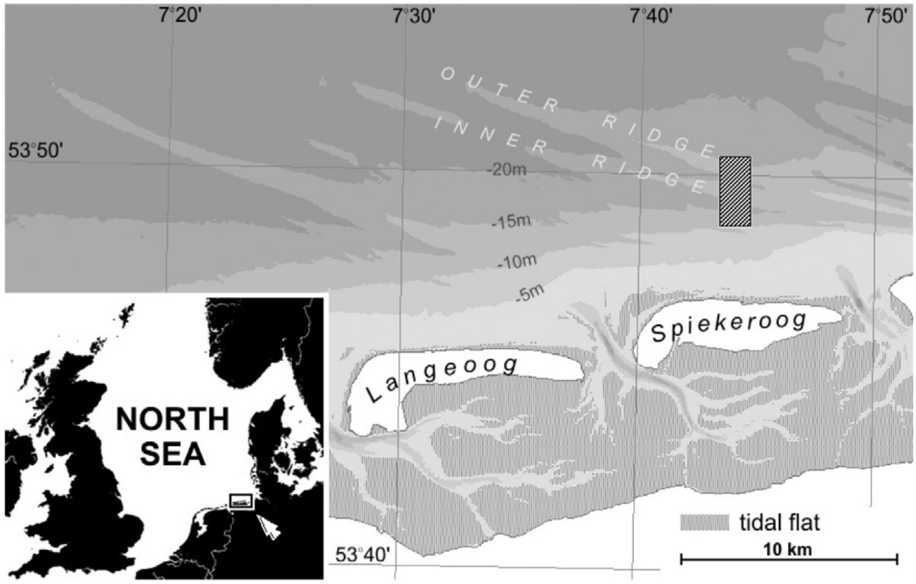

Fig. 1. Study area north of Spiekeroog (Germany, North Sea).

range is 2.6 m. Tidal current velocities measured during calm weather conditions range between 0.3 m/s and 0.6 m/s. The dominance of an eastward directed flood current is well documented (Antia et al., 1995).

The study area located ca. 3.5 km north of the island of Spiekeroog (Fig. 1) covered an area of 4 km^2, which included two generations of shoreface-connected ridges at water depths of 9–20 m below chart datum (Normal Null). Previous surface sediment studies based on grab sampling showed that these ridges were composed mainly of a sandy fraction with coarser grains on the landward flanks and in the troughs, and a finer fraction on the steeper seaward flanks (Antia, 1993; Son et al., 2012). No macrofauna studies had been carried out in this area in the past.

The benthic macrofauna plays a vital role for the nutrition cycle, detrital decomposition and as a food source for higher trophic levels, and additionally, the macrofauna species are sensitive indicators for changes in the marine environment (e.g. Kröncke and Reiss, 2010). In this context, many studies in the last years focused on the macrofauna of the North Sea on a large spatial scale (e.g. Dyer et al., 1983; Kröncke et al., 2013; Künitzer et al., 1992; Rachor and Nehmer, 2003; Salzwedel et al., 1985), and on a small spatial scale (e.g. Brown et al., 2002; Kröncke et al., 2011; Weber et al., 2004). On the latter scale the distribution of macrofauna communities is known to be correlated strongly with the sediment composition (e.g. Künitzer et al., 1992; Rachor and Nehmer, 2003; Salzwedel et al., 1985). The hydrodynamic energy influences the sedimentation and re-suspension of the sediment particles (e.g. Rhoads, 1974; Rhoads and Boyer, 1982; Snelgrove and Butman, 1994), as well as the food availability, and organic enrichment of the sediment (e.g. Gray, 1974; Kröncke, 2006; Kröncke and Bergfeld, 2003; Snelgrove and Butman, 1994). Thus, stronger currents and turbulences inhibit the deposition of organic material and result in deposition of coarse sediments (Pearson and Rosenberg, 1978; Rhoads and Boyer, 1982), while muddy sediments occur under calmer hydrodynamic conditions. Govaere et al. (1980) observed a close relation between tidal velocity and direction, the residual currents and the macrofauna distribution. They found that the community structure and its distribution remained stable as long as the currents and the amount of suspended organic material did not change. Morphodynamic processes are important factors for the colonization of habitats by macrofauna (Newell et al., 1998; Olafsson et al., 1994). Weber et al. (2004) studied small-scale (scales of metres) morphological structures in the Southern Bight of the North Sea in areas of shoreface-connected ridges, where they found a higher abundance of the macrofauna in the troughs than on the crests. They found that differences in morphological features matched with differences in the macrofauna communities. Baptist et al. (2006) have been monitoring macrofauna on shoreface-connected ridge off Netherlands for 2 years. They could find differences in communities due to seasonality and sediment composition, but they had no information on seabed changes of the ridges.

For this study we combined hydroacoustic methods for relief and sediment mapping to describe morphodynamics of the shoreface-connected ridges offshore the island of Spiekeroog in the past seven years in combination with macrofauna community studies. With the combined approach of the ground-truthing and hydroacoustic methods we intend to study i) long-term dynamics and the sediment composition of the shoreface-connected ridges, ii) the small-scale spatial distribution of macrofauna communities and iii) to compare sediment and macrofaunal patterns in respect to seabed dynamics in time.

2. Materials and methods

2.1. Seafloor morphology and surficial sediment sampling

The sediment mapping in the area was approached twice. In March 2010 during relatively calm condition the entire area was scanned using the Benthos SIS-1624 side-scan sonar operating at 382 kHz frequency with along- and across-track resolution of better than 0.1 m. The side-scan sonar was set to collect backscatter data from a 200-metre swath. In September 2010 weather conditions allowed covering only a fragment of the pre-designed area and therefore the sediment map from March 2010 was used as a primary source of sediment pattern (Fig. 2).

The backscatter intensity of the sonographs was calibrated by grab samples analysed earlier (Son et al., 2012) as well as by newly taken ones. The latter were taken using a 0.1 m^2 Van Veen type grab-sampler at 27 sampling sites. Sampling took place along two parallel cross-shore transects, and in addition three sites were selected to investigate the deepest part of a trough (Fig. 2). At each site three grabs were taken, of which two were used for studies of benthic macrofauna and one for sedimentological study. The sediment was analysed in a laboratory after desalting and dividing the volumes into gravel, sand and mud fractions (according to Wentworth, 1922). Gravel fractions were sieved mechanically, whereas sand and mud were analysed separately by a MacroGranometer settling tube (Brezina, 1979) and a SediGraph III system, respectively. The results were plotted at quarter-phi intervals