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Relationships between spatial patterns of macrofauna communities, sediments and hydroacoustic backscatter data in a highly heterogeneous and anthropogenic altered environment

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ABSTRACT

A survey was conducted in the Inner Jade tidal channel, the connection between the Jade Bay and the southern North Sea, to investigate the relationships between macrofauna community structure and environmental variables in a highly heterogeneous human disturbed environment. A manual expertise based classification of sidescan sonar records was successful in confirming the general relationship between backscatter intensity and sediment grain size in weakly disturbed environments. In highly disturbed environments, instead, the classification showed the influence of the topographic roughness over the sediment roughness in backscatter intensity. Low, but significant relationships between hydroacoustic classification and macrofauna community structure, as well as sediment distribution and the macrofaunal communities were identified. The most important impact on spatial community structure was the number of days after dredging/dumping activity for the JadeWeserPort, followed by sediment characteristics. Sand dominated western stations that were dredged for the JWP exhibited a characteristic macrofaunal community. Another distinct community occurred in stations with elevated mud content within the regularly dredged old navigation channel and in the undisturbed south eastern area. The macrofaunal communities in the north eastern undisturbed area coincided with elevated gravel and shell contents. This study stresses the problems of benthic habitat mapping in such a heterogeneous area.

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1. Introduction

Patterns in macrofaunal community structure integrate temporal and spatial changes in marine habitats (Johnson, 1972) and are often used to evaluate the status of ecosystems for environmental impact assessments (Warwick, 1993; Borja et al., 2013). Biodiversity in a benthic habitat is influenced by biological and physical oceanographic factors such as oxygen, temperature, salinity and load of organic material (Robert et al., 2014). Furthermore, benthic community structure depends on hydrodynamically mediated food resources (Wieking and Kröncke, 2005; Kröncke, 2006) and, at least to some degree, on substrate type (Gray, 1974; Rhoads, 1974; Snelgrove and Butman, 1994). Anthropogenic physical disturbance, e.g. fishing (Auster and Langton, 1998) and dredging (Newell et al., 1998; Van Dalfsen et al., 2000; Simonini et al., 2007) can also have a strong impact on the composition and abundance of taxa.

The influences of dredging and dumping on the seabed and the associated macrofauna have been widely reviewed (Boyd et al., 2003; ICES, 1992, 2001; Newell et al., 1998). Initial effects of dredging include a 30–70% reduction of species diversity and a 40–90% reduction in population density within the boundaries of dredged areas (Newell et al., 1998). Adjacent areas can also be affected by the redeposition of material mobilised during dredging and transported outside the boundaries of the dredge site (Newell et al., 2002; Hitchcock and Bell, 2004). Macrofaunal community recovery rates are highly site specific (Boyd et al., 2004; Cooper et al., 2005; Kenny and Rees, 1994, 1996; Kenny et al., 1998) and vary between 2 and 10 years (Newell et al., 1998). When dredging activities remove the surface layers of sediments, the remaining substrate may be altered and become unsuitable for re-colonisation by the species that previously inhabited that particular area (Kenny and Rees, 1996; Boyd et al., 2005).

Specific tools are needed to catch and document such rapid changes (and the related processes), both spatially and temporally. Many studies have shown the effectiveness of hydroacoustic systems (i.e. single-beam echo sounder SBES, sidescan sonar SSS, multi-beam echo sounder MBES) in benthic habitat mapping (e.g. Brown et al., 2002; Brown et al., 2004b; Freitas et al., 2003a, b; Freitas et al., 2005). Recent studies focus on spatially continuous sampling, since this low cost, efficient method allows 100% coverage of the seafloor (Brown et al., 2004b). In heterogeneous areas with a patchy distribution of sediments and/or biological communities full coverage is extremely useful for mapping the diversity of habitats. Acoustic backscatter reflects abiotic surficial seabed characteristics (Collier and Brown, 2005; Markert et al., 2013), such as seafloor

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topography, sediment grain size and bed roughness. In addition, biological assemblies, such as seaweed meadows (Preston, 2006), blue mussel beds (Van Overmeeren et al., 2009), coral reefs (Gleason et al., 2006; Gleason, 2009), oyster beds (QuesterTangentCorporation, 2003) or aggregations of tube building worms (e.g., *Lanice conchilega*: Degraer et al., 2008) or brittle star arms (e.g., *Amphiura filiformis*: Markert, 2015) can also be successfully detected and mapped using acoustic backscatter. Although high-resolution SSS images can show decimetre-size features (Kenny et al., 2003), individual macrofaunal organisms are difficult to detect and ground-truthing of the backscatter data is needed to acquire a comprehensive dataset (Kenny et al., 2003). Many field studies first map the seabed with hydroacoustic tools, segmenting the images in regions, and then take only a few samples for each of them (Eastwood et al., 2006). This leads to interpolations, which may neglect habitat complexity (Diaz et al., 2004). Even with a dense ground-truth sampling grid, uncertainties are often detected in many study areas. For example, Markert et al. (2013) noted sharp boundaries between habitats of sorted bedforms, yet the hydroacoustic classification failed to detect a transition in the macrofaunal community. Similarly, Freitas et al. (2006) described three acoustic classes, yet four biological affinity groups were found along the acoustic gradient. In contrast, distinct communities occurring in multiple habitats have been reported using acoustic techniques (Kostylev et al., 2001, Freitas et al., 2003a, b). Often, soft-sediment environments show gradational habitat changes, which are difficult to contour (Holler et al., 2016). Moreover, the coexistence of different communities on the same substrate and/or the presence of the same community in different substrates make the habitat classification of such environments not straightforward (Shumchenia and King, 2010).

Heterogeneous habitats are even more difficult to map than homogenous environments with clearly definable boundaries (Brown et al., 2004a), or substrates with a distinct gradient. One example of a heterogeneous sea bottom is the Jade channel in the German Bight, a tidal inlet which connects the Jade Bay with the open southern North Sea. Naturally mobile bedforms (Kubicki and Bartholomä, 2011) coupled with dredging activities and construction works have resulted in a dynamic mosaic pattern of substrates in the Inner Jade channel (Capperucci and Bartholomä, 2012). Moreover, the maintenance dredging of a navigational channel and the construction works for a deep-water port have introduced new sources of different sediments, e.g. the old Pleistocene basin clay “Lauenburger Ton” formation.

An initial study carried out in the Inner Jade channel compared sediment characteristics and macrofaunal communities before and during the port construction phases, finding that distinct communities resembled the dredging activities (Gutperlet et al., 2015). The current study expands upon this to i) characterise the habitats in this heterogeneous study area based on manual expert interpretation of the SSS data, sediment distribution and macrofaunal community structure, ii) compare spatial patterns of hydroacoustic classification, sediment composition and macrofaunal communities and test for pattern congruence, and iii) using multivariate statistical approaches, identify the natural and/or anthropogenic environmental factors (including dredging activities and grey values of the backscatter image derived by SSS) related to macrofaunal community compositions.

2. Material and methods

2.1. Study area

The research area lies in the central part of the Jade channel (Inner Jade, Fig. 1a,), a tidal inlet with the deepwater port of the German city Wilhelmshaven, the JadeWeserPort (JWP), within the German Bight (southern North Sea). The study area in front of the JWP is characterised by an upper mesotidal regime. Semi-diurnal tides range from 2.8 m at the northern entrance to 3.8 m in the southern Jade Bay (Kubicki and Bartholomä, 2011). The study was conducted in the subtidal region of the Inner Jade (7.1–14.5 km of the old navigation channel) (Fig. 1b).

Regular dredging of the old navigation channel by the local harbour authority WSA (Wasser- und Schifffahrtsamt Wilhelmshaven) guarantees a width of 300 m and a depth of 20.1 m (refer to the local chart datum, Normalhöhennull (NHN); Kubicki and Bartholomä, 2011). Since March 2008, 46 million m^3 of sand has been used to create the 360 ha terminal area of the new deepwater port. Before piling, fine soft sediment was replaced by coarser material. In the process, sand was deposited both in the terminal area and also in front of the bulkhead (Fig. 1b). The sand was mined from two sites north and south of the JWP, leading to deep depressions (approx. 50 m; Fig. 1b) at both extraction sites. In 2012, land reclamation and the redirection of the navigation channel for access to the JWP were completed.

2.2. Acoustic seafloor classification

In May 2010, a survey was carried out aboard the RV “Senckenberg”. A dual frequency Benthos™ 1624 SSS was deployed to map approx. 10.2 km^2 in front of the JWP construction site (6.1 km in north-south direction and 1.5 km in east-west direction). The north-west sector was not accessible at the time of the acoustic survey, and therefore 88% of the research area is covered with SSS data in this study. The Benthos 1624 SSS operates at two different frequency ranges: 110–130 kHz (low frequency, beam size 0.5° horizontal and 55° vertical) and 370–390 kHz (high frequency, beam size 0.5° horizontal and 35° vertical). A 200 m swath width was used for data coverage. High resolution positioning was achieved by means of RTK-corrected DGPS data.

As the use of high frequency SSS data in such environment is more susceptible to external interferences, like engine noise (Collier and Brown, 2005) or signal lost due to suspended mud (Schrottke et al., 2006), for the present study the low frequency data was processed and analysed. The recording and processing were carried out using SonarWiz™ software. Processing steps included both geometric and radiometric corrections. A final mosaic of the study area was exported (at 0.5 m resolution) and loaded into a GIS software (Global Mapper™ 13) for data analysis, mapping and interpretation.

Automated or semi-automated classification approaches of the Inner Jade SSS data could not entirely reflect the complexity of the sea bottom. In fact, the outputs of such classification tools did not show a segmentation of the SSS image in regions, but rather a fuzzy assemblage of classes with no clear meaningful correspondence to any morphological/sedimentological feature. This may be due to the high variability observed in sediment types and morphologies or the site-specific features (e.g. different generations of dredging marks, in some cases partially reworked by the highly dynamic sediments) leading to misclassifications. Therefore, manual expert classification was applied. Manual analysis and segmentation of the mosaic in regions (classification) was based on backscatter values (i.e. grey scale values) and seabed texture. The mapping process accounted for: intensity of the backscatter, presence/absence of seabed structures (e.g. dredging marks, dunes etc.), and morphological characteristics of such features (e.g. size, orientation, distribution, regularity, etc.). For each acoustic classes the mean grey level value was extracted from the raster image (by means of the QGis2.8 Zone Statistics routine), and used for the identification of threshold values that grouped the classes into high- (HB), medium- (MB), and low- (LB) backscatter. Once defined the acoustic classes, bathymetry data from SBES (Furuno FCV 295) was combined with the backscatter from SSS to characterise the morphological features and to define the seabed roughness within each acoustic region.

2.3. Sampling

Following SSS data collection, 55 stations, with an average distance of approx. 250 m between stations, were sampled along eight west–east transects (A-H; Fig. 1b). Around each JWP dredging and dumping position (midpoint coordinates were provided by the JWP Realization Company) a 100 m buffer was created. Within the 100 m radius around

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