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Reefs, sand and reef-like sand: A comparison of the benthic biodiversity of habitats in the Dutch Borkum Reef Grounds

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A B S T R A C T

Reefs play an important role in the distribution of species associated with hard substrates and are of value for biodiversity conservation. High densities of the habitat building annelid *Lanice conchilega* also increase local biodiversity. This study describes the benthic biodiversity of a rocky reef and its surrounding sand bottom with dense *L. conchilega* beds in the Borkum Reef Grounds, north of the island of Schiermonnikoog in the Dutch North Sea. A side-scan sonar survey revealed distinct seabed areas with high acoustic reflections, indicating the presence of hard substrate on the sandy seafloor. To ground truth the side-scan sonar data and make an inventory of the biodiversity of the observed habitats, a multi-method sampling approach (box corer, SCUBA air-lift sampler and visual transects, drop-down camera) was used. This revealed (1) rocky reefs: a combination of gravel, stones and rocks; (2) individual rocks in a sandy environment; (3) sand with dense *L. conchilega* beds (>1500 ind$\cdot$m^{-2}) and (4) sand bottom habitat. A total of 193 taxa were found with many unique species per habitat. Species richness was significantly higher on sand when compared to the rocky reef (NB-GLM; $p = 0.006$), caused by the presence of dense *L. conchilega* beds (Poisson GLM; $p < 0.001$). Including dense *L. conchilega* beds as an additional habitat showed that these held a higher species richness than the rocky reefs (NB-GLM; $p = 0.002$), while sand without dense *L. conchilega* beds did not (NB-GLM; $p = 0.14$). Since the rocky reefs were present on a sandy bottom, the local biodiversity more than doubled with the presence of rocky reefs. The nMDS plot clearly separated the sand and rocky reef communities and also showed a clustering of dense *L. conchilega* beds within the sand samples. Each method detected unique species, demonstrating the value of a multi-method approach compared to e.g. box coring alone. This study identified several species previously unknown to the Borkum Reefs Grounds area. The total area of rocky reefs in the southern part of the Dutch Borkum Reef area is estimated to be 9.8 km^2 and of *L. conchilega* beds with densities >1500 ind$\cdot$m^{-2} to be 74 km^2. Further research should focus on the possible function of *L. conchilega* as an ecosystem engineer creating intermediate sand-reef systems. For mapping these *L. conchilega* beds, we advise using side-scan sonar imaging combined with ground truthing by drop-down cameras.

1. Introduction

Reefs in temperate waters are important to local biodiversity and can host long-lived species (Fariñas-Franco et al., 2014; Sheehan et al., 2013). Such reefs can be of abiotic origin, such as gravel fields, boulder clay or rocky outcrops, or biogenic origin, formed by organisms such as shellfish (e.g. *Modiolus modiolus*), corals (e.g. *Lophelia pertusa*) or annelids (e.g. *Sabellaria spinulosa*) (Davis, 2009; Fariñas-Franco et al., 2014). Around the British Isles, reefs are extensively present but they are rare in the south eastern part of the North Sea, where they are only found on the Hinder Banks, the Cleaver Bank and the Texel Rough (Veenstra, 1969), and the Borkum Reef Grounds (Dörjes, 1977). Further east, reefs are present around Helgoland (de Kluijver, 1991).

Maps by Olsen (1883) show a vast area of reefs present in the southern North Sea. *Ostrea edulis* reefs were found south of the Dogger Bank, in the Wadden Sea, the Dutch 'Zuiderzee' and around Helgoland (Caspers, 1950; Jeffreys, 1862; Korringa, 1952; Möbius, 1877; Olsen, 1883). The *O. edulis* reefs have since disappeared from the Dutch continental shelf (Beck et al., 2011). Olsen (1883) also mapped 'Stones and Rocks' on the Cleaver Bank, Dogger Bank and the Borkum Reef Grounds, and locations with 'Moorlog', a peat deposit, west of the Dutch coast and on the Dogger Bank.

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These reefs may have played an important role in the distribution across the North Sea of species associated with hard substrates. It is therefore of importance to document the remaining reefs as they form the last remnants of a once more extensive reef community in the North Sea. Furthermore, the fauna associated with these reefs is of importance for biodiversity conservation. In Europe, reefs are protected under the EU Habitats Directive, which defines reefs as "*either biogenic concretions or of geogenic origin. They are hard compact substrata on solid and soft bottoms, which arise from the sea floor in the sublittoral and littoral zone*." (habitat code 1170; European Commission, 1992, 2013).

Rabaut et al. (2009) concluded that high densities of the tube-dwelling annelid *Lanice conchilega* also meet the criteria to be defined as reefs, following the 'reefiness' evaluation of *S. spinulosa* by Hendrick and Foster-Smith (2006). Furthermore, *L. conchilega* influences benthic biodiversity by modifying the available habitat and creating attachment surfaces for other species (Rabaut et al., 2007). It increases the species richness in low structured sand habitats (Zühlke, 2001). Dense *L. conchilega* beds were previously observed in the Borkum Reef Ground area (Lindeboom et al., 2008) and may be relevant for the evaluation of the area for protection under the EU Habitats Directive.

Limited information on the biodiversity of reefs in the southern North Sea is available, and most of it is published in reports and other non-peer reviewed publications. Houziaux et al. (2008) made an inventory of the rocky reefs on the Belgian Hinder Banks, and van Moorsel (1994) and Schrieken et al. (2013) investigated the Cleaver Bank. The fauna of the German part of the Borkum Reef Grounds was studied by Dörjes (1977), who focussed on reef species, but did not record many common bryozoan and hydrozoan species. The Dutch part was previously investigated by Bergman et al. (1991, 1992), who focussed on soft-sediment species.

The presence of the Borkum Reef Grounds was already documented in the 18th century by Guitet (1710), who noted the 'Borkomer Riff' north of the island of Rottum. Further accounts of the presence of the reefs are found throughout the years (Dörjes, 1977; Olsen, 1883) but the reported area occupied by them varies broadly and often lacks mention of reefs west of the German-Dutch border (in Dutch waters). Therefore, the extent of the reefs in the Dutch part of the Borkum Reef Grounds remained uncertain.

The aim of this paper is to provide an inventory of the benthic fauna of the Dutch part of the Borkum Reef Grounds and to map the presence of rocky reefs in the area in order to evaluate the need to protect the reefs under the EU Habitats Directive. We report on the locations of gravel fields and large rocks (henceforth named 'rocky reefs'), the surrounding sandy habitats (sand) and *L. conchilega* beds which had densities of $>1500\ \text{ind}\cdot\text{m}^{-2}$. Furthermore, a species list and a comparison between the different communities is given.

2. Materials and methods

2.1. Study area

The Borkum Reef Grounds are situated in the North Sea north of the Wadden Sea island of Schiermonnikoog (Fig. 1). The area is characterised by water depths between 10 and 40 m, maximum currents between 0.4 and 1.0 ms^{-1} and water temperatures varying between 3 and 19 °C (Joschko et al., 2008). The seafloor has previously been described as a 'rough ground', containing coarse sand, gravel and stone fields (Olsen, 1883; Tesch, 1910). This study focuses on the Dutch part of Borkum Reef Grounds which has an area of approximately 600 km^2.

2.2. Side-scan sonar survey

From 17 to 22 September 2009, a side-scan sonar survey was conducted following methods modified from Lafferty et al. (2006) using a Klein 3900 500/950 kHz side-scan sonar set at 500 kHz frequency. The sonar fish was towed at a speed of 4.0 to 4.6 ms^{-1} along parallel northwest–southeast transects 1500 m apart, covering a strip of 100 m width. Positioning was performed with a C-NAV GPS. Acoustic units identified on the side-scan sonar data were characterised as sand bottom, gravel and stone fields and crust-like structures, or single larger rocks (>30 cm). Extra transects were conducted where hard substrate appeared to be present. During acquisition, data quality was assessed continuously by a side-scan sonar technician. In total, approximately 63 km^2 of side-scan sonar data were obtained, covering approximately 7.4% of the surveyed area.

2.3. Sediment and biodiversity survey

From 12 to 17 August 2013, the side-scan sonar survey was ground truthed. Due to safety limitations on SCUBA diving (depths < 30 m), a main method for the ground truthing, only the southern part of the area was studied. Selection of sample locations (Fig. 1) was based on the acoustic units identified by the 2009 survey, realising a maximum spread over the area with representative sampling of the expected sand and rocky reef habitats (gravel and rock).

To characterise the sediment type, sediment sub-samples were obtained from a Van Veen grab and box corer samples, by sub-sampling with a 5.5 $\text{cm}^2 \times 11$ cm deep corer. Further sediment cores were obtained by SCUBA divers sampling directly from the seafloor. Divers also recorded the dimensions of observed large rocks. All sediment samples were freeze-dried for 96 h. Sub-samples of the sediments (0.5–5 ml) were dry sieved over a 2-mm mesh sieve after which grain size and silt content were determined using a Coulter LS 13 320 particle analyser and auto-sampler. In total, 20 sediment samples were analysed.

The fauna in the sand and on the rocky reefs was inventoried using a combination of four methods:

1) The sand and gravel fields were sampled using a box corer (0.076 m^2). Samples with less than 15 cm penetration depth were rejected and the seafloor was resampled. Before processing on board a photo was taken of each sample. From each sample, the top 2.5 cm layer was removed and stored for later processing, the remaining fraction was sieved over a 1 mm mesh sieve. The residue was then transferred to a plastic storage container. Epifauna were relaxed in an oversaturated seawater menthol solution for a minimum of 2 h. All samples were finally fixed in a borax-buffered formaldehyde-seawater solution (6%). In total, eight box corer samples were taken (seven in sand and one from the rocky reef, containing gravel).
2) Epifauna on large rocks were sampled using a SCUBA diver operated, airlift sampler. Although airlift samplers are not routinely employed for benthic inventories in the Netherlands, they have been used successfully in a number of studies in temperate waters (e.g. Barnett and Hardy, 1967; Benson, 1989). The airlift used in this study resembled that of Chess (1978) and was constructed of 50 mm PVC tubing ending in a net of 500 μm mesh positioned in a downward, vertical angle, from the tube end. It was fed by compressed air from a cylinder attached to the divers harness. Samples were collected by placing a metal frame (0.050 m^2) on a rock and removing all growth in the frame with a putty knife attached to the airlift. During removal the sample was sucked into the airlift and deposited in the net. The net was replaced between samples and sealed with a lid. All sampling activities were filmed by a camera system (GoPro HERO3 Black with 2 Metalsub VL1242 LED video lights) mounted on the diver's head. In total 11 airlift samples were taken from nine rocks (with duplicates at two rocks). Following collection, airlift samples were processed in the same manner as the box corer samples.
3) Demersal megafauna were surveyed by SCUBA divers using line transect observations. Methods by Holt and Sanderson (2001) were adjusted to local circumstances, i.e. a decreased pole length of 2 m operated by a single diver, as low visibility and strong currents were