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Differential response of macrozoobenthos to marine sand extraction in the North Sea and the Western Mediterranean

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Sublittoral benthic coastal communities of the North Sea and of the Western Mediterranean were studied before and after sand extraction between 1993 and 1995 at *borrow* sites in Denmark, The Netherlands, and Spain. Recolonization of disturbed areas was fast owing to the rapid increase of opportunistic species. At the North Sea sites, the benthic community largely recovered within 2–4 years, whereas in Spain recovery is expected to take longer. The response of zoobenthos to sand extraction is discussed, taking into account differences in site characteristics, extraction methods, and recovery time of the habitats. The effects on the benthic community appear to be related to the physical impact on the sea floor. Small-scale disturbances in seabed morphology and sediment composition result in short-term effects on the benthic community. However, larger disturbances mainly caused by sediment composition may have a prolonged effect, particularly in low dynamic systems such as those present in the Mediterranean.

Key words: benthic community, macrozoobenthos, Mediterranean, North Sea, recovery, sand extraction.

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Introduction

There is an increasing demand for marine sand for coastal development and coastal protection throughout the world. In the Netherlands and Denmark, plans for coastal development require large-scale sand extractions in the North Sea coastal zone. In Spain, intensive tourist development has resulted in severe erosion all along the Mediterranean coast and has led to an increased need for material for beach recharge (Manzanera *et al.*, 1997). Extraction may interfere with the sand balance of the coast and influence the ecological functions of the seabed, e.g., as a habitat for benthic flora and fauna and feeding grounds for (juvenile) fish and diving seabirds (De Groot, 1979). Also fisheries interests may be negatively affected when commercially exploited species are removed, or their habitats destroyed. The impact of sand extraction varies from short-term effects, related to the immediate removal of fauna, to potential long-term changes in the structure of the benthic community due to habitat changes (Kenny and Rees, 1994, 1996; Newell *et al.*, 1998). Because most of the zoobenthos lives in the top 30 cm of sediment, the amount of benthic life destroyed is directly related to the surface area of the borrow site.

Sediment characteristics have often been cited as a major factor influencing the distribution of macrofaunal communities (Dankers and Beukema, 1981; Salzwedel *et al.*, 1985; Künitzer *et al.*, 1992; Seiderer and Newell, 1999). After sand extraction, borrow areas may fill in with a different sediment type (Van der Veer *et al.*, 1985). Therefore, recovery of a zoobenthic community after a disturbance will depend on the local hydrological and sedimentological conditions. For example, filling in

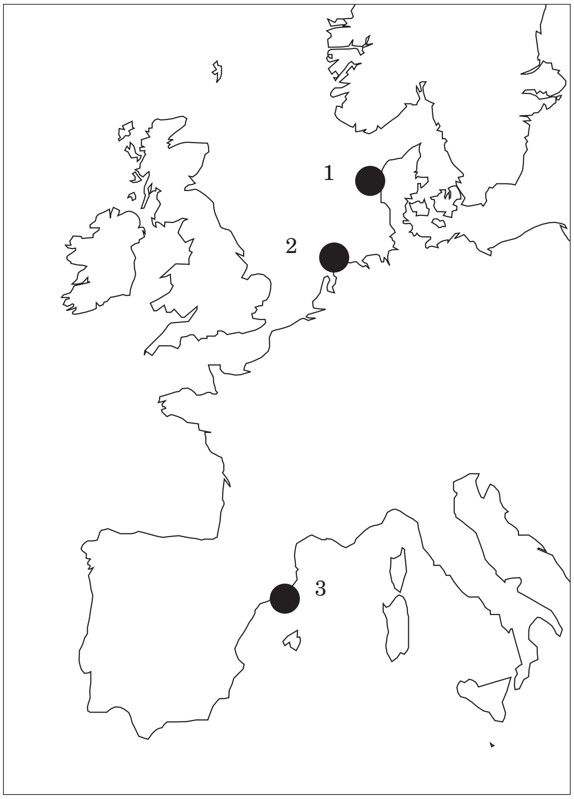

Figure 1. Location of the extraction sites studied within the RIACON-project: 1 – Torsminde (DK); 2 – Terschelling (NL); 3 – Costa Daurada (ES).

with much finer sediment than originally present will lead to the development of a different benthic community (Van der Veer *et al*., 1985), with potential consequences for higher trophic levels.

The CEC-funded project "Risk Analysis of Coastal Nourishment Techniques (RIACON)" offered an opportunity to study the effects of sand extraction on the benthic community as well as the recovery process. We describe the response of the macrozoobenthic community to subaqueous sand extraction for three borrow sites in Europe in relation to differences in extraction methods used and in the dynamics of the benthic systems.

Materials and methods

Study areas

Three borrow sites were studied (Figs 1 and 2), two in the North Sea off the coast of Denmark (Torsminde) and the Netherlands (Terschelling), and one in the Mediterranean (Costa Daurada). Table 1A lists the differences between the sites with respect to volume of sand extracted, area directly affected, maximum depth, duration of the extraction, and changes in sediment type. All borrow sites were approximately 20 m deep.

The benthic communities at the sites in Torsminde and Terschelling both represent a typical North Sea coastal assemblage (Künitzer *et al*., 1992; Holtmann *et al*., 1996). Tide and wind-driven currents play an important role in the frequent redistribution of these sediments. The benthic community at the Costa Daurada site, with seagrass meadows and adjacent patches with fine sand, is characteristic for the western Mediterranean infralittoral open sandy coast (Ros *et al*., 1985). Along this coast, waves and wave-induced currents are the main factors controlling sediment transport in the shoreface. However, at depths >15 m sediment transport and morphological changes of the sea floor only occur as a result of wave activity during southern storms (Manzanera *et al*., 1997).

Sampling of benthos and sediment

At each site, a survey of the macrozoobenthos was made prior to extraction as well as one to three years after sand extraction. Samples were taken using a Van Veen grab or Reineck box corer and sieved over 1 mm or 0.5 mm. In Spain, commercially exploited species were also sampled before and after the extraction using commercial dredges.

In Denmark, surveys were conducted in May (1994) and September (1994, 1995) in the extraction area as well as in a nearby reference area. The reference area was chosen at a location where no influence of the dredging activities (deposition of suspended sediment) was expected. In the Netherlands, surveys were conducted in April (1993), October (1994, 1995) and November (1997) within the extraction area only. Based on recorded sailing tracks of the dredgers, as well as on bathymetric changes in the seabed after extraction, two subareas were identified. The subarea where depth had increased <0.1 m was used to represent reference conditions, whereas the subarea where depth had increased >0.1 m was considered to represent the actual extraction area. Sediment analysis from the reference area gave no indication of deposition of fine material discharged during dredging. In Spain, samples were taken before (July 1993) and after extraction (March 1994) in the borrow area. No samples from a reference area were available. The number of samples taken per survey varied per site and survey. Sediment samples were analysed for grain size distribution and/or organic matter content (loss on ignition). Table 1B summarizes the sampling methodology applied. A detailed description of the methods used at the three sites is given by Birklund *et al*. (1997), Manzanera *et al*. (1997), and Van Dalfsen and Essink (1997).

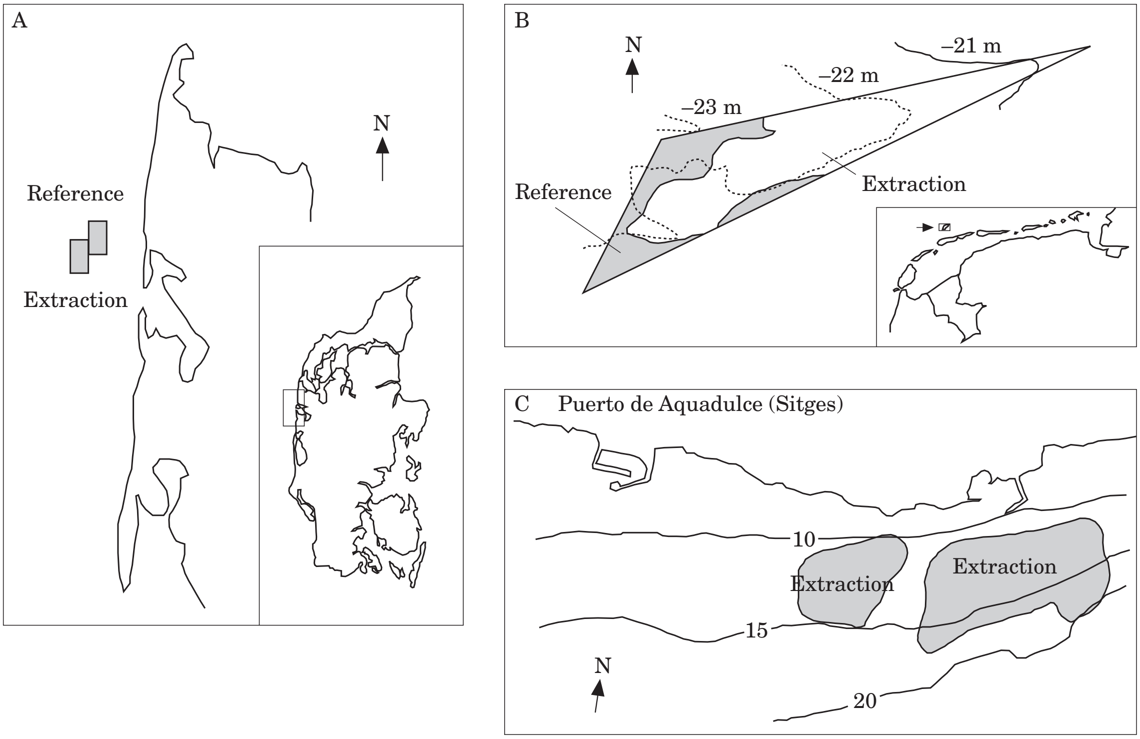

Figure 2. Maps of the study sites at (A) Torsminde (DK), (B) Terschelling (NL), and (C) Costa Daurada (ES), showing extraction and reference areas. Depth contours (m) are indicated.

Table 1. Summary of (A) extraction characteristics (OM, organic matter; FS, fine sand) and (B) sampling methodology (vV, van Veen grab; BC, Box corer) at the three extraction sites.

	Torsminde	Terschelling	Costa Daurada
A. Site			
Volume extracted ($\times 10^3$ m^3)	0.25	2.1	2.6
Area affected (km^2)	0.5	1.4	1.5
Water depth (m)	16–18	20–23	16–20
Max. depth of extraction (m)	0.5	1.5	2.0
Extraction period	May 1994	Apr–Nov 1993	Sep–Dec 1993
Sediment after extraction	No change	Less OM	More FS
B. Methodology			
Sampling device	0.1 m^2 vV	0.08 m^2 BC	0.04 m^2 vV
Reference area	+	+	–
n surveys (before+after)	1+2	1+3	1+1
N samples per survey	24–41	30–34	3+9

Data analysis

Macrozoobenthos was analysed for abundance and biomass (ash-free dry weight) of species and taxa. Shannon-Wiener diversity (H′) was calculated per sample. Mobile epibenthos (e.g., copepods, mysids, shrimps, and crabs) were excluded from the analysis because the samples contained insufficient numbers of these taxa. The benthic community was described using different ordination techniques on log (N+1) transformed species abundance data.

Results

Sediment structure

At the Torsminde site, median grain size of the surficial sediment changed from a predominance of coarse sand

Table 2. Average number of species, diversity (Shannon-Wiener H′), and abundance per sample before and after (number of months in brackets) sand extraction at the three extraction sites.

	Extraction area		Reference area	
	Before	After	Before	After
Species richness				
Torsmide (5)	7.8	16.7	7.2	22.8
Terschelling (10)	15.7	27.3	15.8	27.4
Costa Daurada (3)	20.7	20.3	—	—
Diversity (H′)				
Torsmide (5)	—	—	—	—
Terschelling (10)	1.02	2.09	1.28	2.00
Costa Daurada (3)	3.81	2.42	—	—
Individuals m^{-2}				
Torsmide (5)	3232	8065	315	3612
Terschelling (10)	8050	4105	5670	4454
Costa Daurada (3)	477	1883	—	—

(MD_{50}=0.55 mm) in May 1994 towards medium sand (MD_{50}=0.46 mm) after the extraction in September 1995. A similar trend was observed at the reference area indicating a large-scale change in sediment type in the area that was not directly affected by the sand extraction. At the Terschelling site, organic-matter content of the sediment had declined sharply after extraction, but did not differ between the extraction and the reference subarea. Both subareas showed similar patterns in sediment composition (median grain size and organic-matter content) during successive surveys. Bathymetric surveys revealed no great changes in dimension and position of the pit created by extraction from 1995 till 1997. At the Costa Daurada site, grain size changed considerably after sand extraction as a result of deposition of material from the spillways during the dredging operation. After two months, scuba divers observed a 5–20 cm thick layer of very fine sediment (Md_{50}=16–18 μm) on top of the native sand (Md_{50}=100–150 μm). In 1995, the fine fraction still formed on average 27% of the sediment by weight (Manzanera *et al.*, 1997).

Benthos

At the two North Sea sites, the number of species had increased in September/October 1994 (i.e., five and 10 months after cessation of sand extraction for Torsminde and Terschelling, respectively), in both extraction and reference areas (Table 2). This increase was mainly due to elevated numbers of polychaete species. At Torsminde, the increase was significantly larger in the reference area, whereas at Terschelling the increase in the two subareas was similar. One year later, in 1995, the number of species had decreased in both North Sea sites. In Spain, the number of species before and three months after extraction remained approximately the same. Diversity (H′) at Terschelling approximately doubled after extraction and values were slightly higher within the extraction subarea than in the reference subarea. At the Costa Daurada, diversity had significantly decreased after extraction owing to the development of a few, but abundant, opportunistic polychaete species such as *Capitella capitata* and *Malacoceros* sp.

In terms of macrofaunal abundance (Table 2) and biomass (data not shown), the North Sea sites responded differently to the extraction of sand. Total abundance at Torsminde increased strongly mainly as a result of recruitment of bivalves (*Spissula* sp.). At Terschelling, densities of polychaetes and crustaceans dropped, resulting in an overall decline in abundance. However, an increase in the opportunistic polychaetes *Spio fillicornis* and *Spiophanes bombyx* was observed at both sites. The recruitment of young bivalves resulted in an increase of total biomass at Torsminde. In contrast, biomass at Terschelling was significantly reduced as a result of the elimination of bivalve (*Donax vittatus*, *Tellina* sp.) and echinoderm (*Echinocardium cordatum*) populations in the extraction subarea. A similar effect was observed at the Costa Daurada, where commercially exploited bivalve populations, especially *Callista chione*, were severely reduced after extraction.

At both North Sea sites, community structure after extraction deviated from the initial situation. However, the community response, differed between Terschelling (Fig. 3) and Torsminde (Fig. 4). Before extraction, the benthic community was rather homogeneous in terms of species composition and abundance, according to the close grouping of the stations in the ordination plot (March 1993 in Fig. 3; May 1994 in Fig. 4). After extraction the community became more heterogeneous according to the increased scatter of the points. Stations from borrow and reference areas were also well separated. In later years, the community became more homogeneous again, with a reduction of scatter and more overlap between subareas. This is particularly evident for the Terschelling site in 1997. Yet the communities responded differently. Although at Terschelling a homogeneous community had developed four years after the extraction, the position of the 1997 samples in the PCA plot has moved away from the position of the 1993 cluster (Fig. 3). This suggests an overall change in community structure over a wider area around the extraction site, most likely being a feature of natural dynamics of the benthic system in that part of the North Sea. However, the effect of extraction on long-lived biota may also be partly responsible. Although one year after extraction total abundance of *E. cordatum* had recovered because of recruiting juveniles, it took four years before adult abundance in the two subareas was comparable (Fig. 5). At Torsminde the benthic

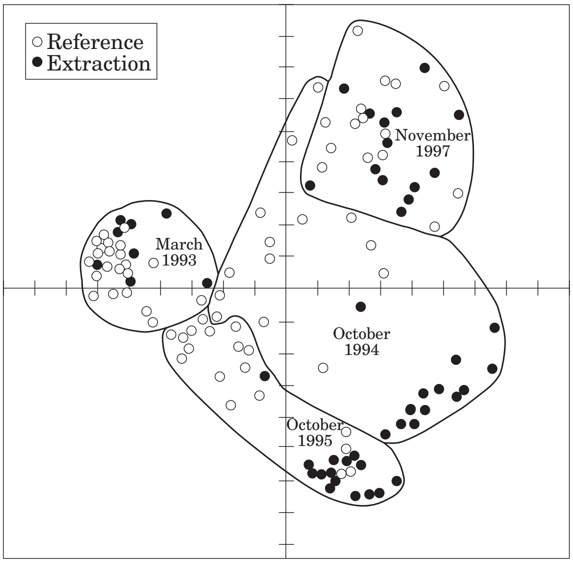

Figure 3. PCA-ordination diagram of community data from four successive sampling surveys of extraction and reference areas before (1993) and after sand extraction (1994–1997) at Terschelling.

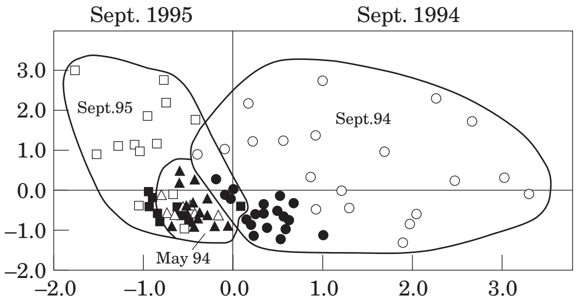

Figure 4. Ordination plot of species abundance data (SAS PROC FACTOR procedure) from sampling stations before (May 1994) and after (September 1994 and 1995) sand extraction at Torsminde (open symbols: reference area; filled symbols: extraction area).

community in the extraction area in 1995 partly overlapped the pre-extraction community in May 1994. The community in the reference area was apparently more dynamic than in the borrow area.

At the Costa Daurada site, the benthic community had changed drastically three months after cessation of sand extraction. Populations of commercially exploited mollusc species (*C. chione*, *Murex* sp., *Cerastoderma edule* and *Ensis siliqua*) were almost completely eliminated, and the study area was densily inhabited by large numbers of opportunistic species such as *Malacoceros* sp. and *C. capitata*.

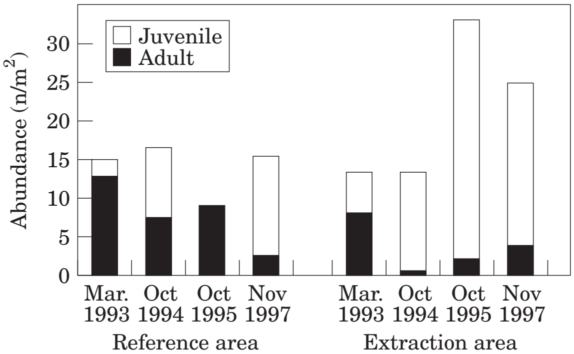

Figure 5. Abundance of adults and juveniles of *Echinocardium cordatum* in the reference and extraction area at Terschelling, 1993–1997.

Discussion

Sand extraction changed seabed morphology in the three areas. At Torsminde, the changes observed were only minor, but at Terschelling and Costa Daurada pits were created with a maximum depth of 1.5 m and 2 m, respectively. Significant differences in sediment structure after extraction were only observed at the Costa Daurada site. Differences in the physical recovery of the seabed between areas are strongly related to differences in hydrodynamic conditions and sediment transport. At the North Sea sites, the relatively high dynamics of the system may explain the minor sediment changes observed after extraction. At Terschelling, bathymetric surveys revealed neither sedimentation nor erosion between 1993 and 1997, implying that large-scale disturbance of the seabed is not quickly restored by natural sediment transport. At the Costa Daurada site, extraction took place at a depth (>15 m) where conditions for regular redistribution of sediment do not exist. Therefore, changes in bottom morphology and sediment type may last much longer. An eventual return towards the undisturbed situation depends entirely on severe storm events that occur irregularly.

When areas are depopulated through sand extraction operations, recolonization of the disturbed area will depend largely on settlement of larvae and immigration of mobile species. This gives opportunistic species a good chance of building up large populations in such open spaces (Grassle and Sanders, 1973). In all three sites, such a short-term change was reflected by the increased abundance of polychaete species that are known to be opportunistic. A similar development after dredging has been reported by López-Jamar and Mejuto (1988). The open space created at the North Sea extraction sites also seem to have favoured bivalve recruitment (*Spisula* sp., *Tellina fabula*, *Tellina tenuis*) in 1994. However, these species failed to establish lasting populations, probably relating to the Terschelling site being at the margin of the more coastal distribution of these species (Wolff, 1973; Holtmann *et al*., 1996). Rapid recovery through migration of adult organisms from refuge areas may have occurred in Torsminde because the extraction took place over a relative large area and dredge tracks did not overlap completely.

Longer-term effects of sand extraction were demonstrated by the changes in community composition and in the age structure of long-lived species. Recovery of these species is dependent on successful recruitment. Good recruitment, however, does usually not take place each year for many species. The departure from the pre-extraction situation of the benthic community structure at the Terschelling site as observed in 1997 cannot be related to the extraction itself because the stations from the extraction and reference subareas were no longer separately clustered in the PCA plot. Natural fluctuations in the community over larger areas of the coastal zone are a more likely explanation. Recovery of a community does not necessarily lead to a situation similar to the one that existed before the disturbance. Recent studies on the recovery of benthic communities after dredging operations in the North Sea (Seiderer and Newell, 1999) also showed changes in community composition in disturbed and undisturbed areas that were sometimes similar but dissimilar to the original community.

The degree and duration of change in sediment composition caused by sand extraction has large implications for the recovery potential of the benthic fauna. The large shift in sediment composition at the Costa Daurada site with a thick layer of muddy sediment may have had a great impact. For instance, a probable consequence was that the formerly abundant bivalve *Callista chione* did not recover. Observations indicating recovery times for this species of at least four years had been made by fishermen at other dredging sites along the Spanish coast (Manzanera *et al*., 1997). Similarly, Van der Veer *et al*. (1985) reported long recovery times (ca. 15 years) for benthos in sand pits in low-dynamic tidal flats in the Dutch Wadden Sea, which were filled in with mud rather than with sand.

Our data suggest a relationship between duration of the impact of sand extraction on the seabed and recovery time of the benthic community. At the North Sea sites, changes in sediment structure were only minor and long-lived macrofauna species abundance recovered within two years, although recovery in terms of population structure took four years at Terschelling. For Torsminde, a four-year recovery time may also be assumed, because the species were comparable. In contrast, the large changes in sediment structure at the Costa Daurada site are expected to lead to a recovery time in excess of four years. Indeed, recovery of commercially exploited bivalve species in this region may take three to 10 years (Strada, 1985). Estimates of the life span of *C. chione* between larval settlement and exploitable adult size range between four (Strada, 1985) and 30 years (Forster, 1981), implying long-term damage to local fisheries caused by sand extraction.

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