

Long-term effects of subaqueous sand extraction north of the island of Terschelling

27 mei 1999

Report nr RIKZ-98.034



Ministerie van Verkeer en Waterstaat

Directoraat-Generaal Rijkswaterstaat

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38579

Long-term effects of subaqueous sand extraction north of the island of Terschelling

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Project: RIACON*2

Commissioned by: Rijkswaterstaat,
North Sea Directorate

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1 Introduction

In The Netherlands the use of marine sand for coastal nourishment and landfill has increased from 2-3 million m³ per year in the 1970s to ca. 20 million m³ per year since 1990. Future reclamation's projects will require up to 25 times the present yearly amount of marine sand extracted.

The exploitation of sediments from the sea bed in The Netherlands is regulated by the Regional Extraction Plan for the North Sea (RON) (RIJKSWATERSTAAT, 1991). A revision of the RON is necessary because large scale extractions are not included in the present policy. Also new developments in extraction techniques are not foreseen in the RON. The RON does not allow extraction of surface aggregates from the sea bed inshore of the 20 m - NAP depth contour (NAP \approx MSL), except for maintenance dredging of shipping fairways to Dutch ports (RIJKSWATERSTAAT, 1991). Presently, the extraction depth allowed is defined at 2 m below the sea bed in order to facilitate recolonisation of the benthic community and because of fisheries interest.

In the North Sea, several studies were made to evaluate the environmental effects of sand and gravel extraction. (VAN MOORSEL, 1994; KENNY & REES, 1994; VAN DALFSEN & ESSINK, 1997; NEWELL *et al.*, 1998). Studies carried out at sand borrow sites in the Wadden Sea had shown that filling in and recovery of the benthic community was fast at locations with relatively high water and sediment dynamics, such as in tidal channels, but could last over 15 years at intertidal flats where dynamics are low (VAN DER VEER *et al.*, 1985).

In 1994 under auspices of the Commission of the European Community program MAST (Marine Science & Technology) the RIACON project was started to evaluate the risks for the marine benthic community of shoreface nourishment and subaqueous sand extraction (ESSINK, 1997). Within this project studies were undertaken at borrow sites in Denmark, The Netherlands and Spain (BIRKLUND *et al.*, 1997; MANZANERA *et al.*, 1997; VAN DALFSEN & ESSINK, 1997). In all three borrow areas the extraction of sand resulted in an immediate reduction of the macrobenthic fauna in terms of abundance and biomass. After two years the benthic communities in Denmark and The Netherlands had largely recovered except for long living species, such as bivalves and sea urchins. For these long living species, recovery of a diverse composition of age groups was expected to take two to five years. In Spain recovery of the benthic community was expected to take five to ten years (MANZANERA *et al.*, 1997). Bathymetric surveys at the borrow site in The Netherlands showed no filling in of the borrow pit after 2 years, The borrow pit had even extended and showed a further erosion with circa 0.1 m.

In The Netherlands, the borrow area used for a shoreface nourishment off Terschelling was located just below the 20 m -NAP (NAP \approx MSL) depth contour. Around 20 m depth in the North Sea, the dynamics of the sea-bed and also the composition of the benthic community is rather different from that more close to the coast (*cf.* HOLTSMANN *et al.*, 1996). Therefore, actual information on the effects of sand extraction at this borrow site in the North Sea is considered to be relevant to the new RON as well as to the North Sea policy of the Ministry of Transport, Public Works and Water Management.

To investigate the long-term development of the extraction pit North off the island of Terschelling and to determine the rate of recovery of the macrofauna community, the North Sea Directorate of the Ministry of Transport, Public Works and Water Management commissioned the National Institute for Coastal and Marine Management/RIKZ to carry out the RIACON*2 project in 1997 as a continuation of the RIACON project under MAST. The purpose of this study was to assess the long-term effects of sand extraction and to verify the prediction of the recovery process of the macrobenthic fauna taking two to five years after cessation of the extraction.

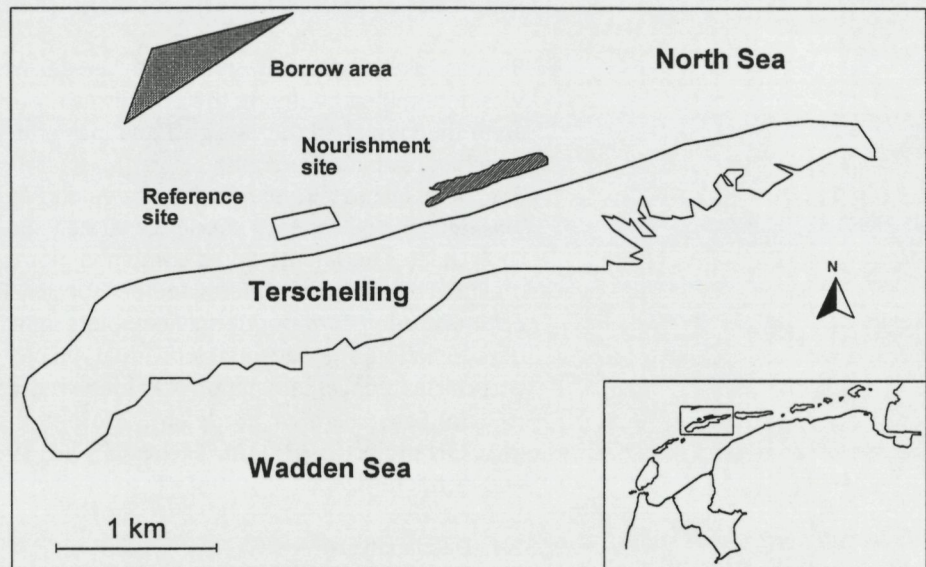
2 Methods

2.1 Study area

The RIACON *2 project studied the former borrow area which is situated approximately 8 km North of Terschelling at a depth between 20 m and 23 m below Dutch Ordnance Level (= NAP \approx MSL) (Fig. 1). From this area a total volume of 2.5 million m³ of sand was extracted with split-hull trailing hopper suction dredgers in the period April - November 1993 (HOEKSTRA *et al.*, 1994). Before extraction the median grain size of the sediment varied between 183 and 213 μ m, with a sorting parameter D80/D20 of 1.32 - 1.40 (maximum 1.67). The D70/D30 ratio varied between 1.17 and 1.23 (maximum 1.35) (BIEGEL *et al.*, 1994).

Eastward flood currents are somewhat stronger than the westward ebb currents. Although in this coastal area of the North Sea the residual current runs from (south)west to (north)east (GOEDECKE, 1968) a reverse residual water transport occurs at times of north-easterly wind stress (BACKHAUS, 1984; RIEPMA, 1980; VAN DE KAMP, 1983; ESSINK, 1985).

Figure 1
Location of the borrow area North off
Terschelling surveyed in November 1997.



2.2 Bathymetry and sampling of macrozoobenthos and sediment

A bathymetric survey of the former borrow site was made in November 1997 by the ms. Holland of the Rijkswaterstaat North Sea Directorate using a Echo sounder (type Atlas Deso 20).

Samples for macrozoobenthos and sediment were taken following the procedures used in the RIACON project (VAN DALFSEN & ESSINK, 1997) to make a comparison possible between the data of the surveys undertaken from 1993 - 1995 and the survey in 1997.

In September/October 1997 a total of 30 samples were taken, randomly distributed over the borrow area. The positions where the samples were taken are listed in Appendix 1. Samples were taken with a Reineck boxcorer (0.078 m²) with a minimum core length of the sample of 0.15 m. After taking a small subsample for sediment analysis each sample was washed over a 1 mm mesh sieve on board of the ship and the remaining fraction was preserved with 4% formalin in sea water and stored in a freezer. In the laboratory the samples were stored at -20°C till further analysis to reduce loss of biomass (SALONEN & SARVALA, 1985).

Sediment samples were analysed for mud content (fraction <53 µm), CaCO₃ and organic matter (% weight of dried sample) at the Middelburg laboratory of Rijkswaterstaat/RIKZ using standard procedures.

2.3 Treatment of macrozoobenthos samples

Analyses of macrozoobenthos samples followed the procedures used in the RIACON project (VAN DALFSEN & ESSINK, 1997). Frozen samples were thawed and rinsed with tap water to remove formaldehyde using a 0.5 mm mesh sieve. The samples were then sorted with the aid of a low-power stereomicroscope.

Density (ind/m²) was recorded at species level for as much as possible, or otherwise at a higher taxonomic level. In *Nephtys* species and *Echinocardium cordatum*, juveniles and adults were enumerated separately. In none of the other species such a discrimination was made. Bivalves were separated into length classes of 0.5 cm except for the small sized *Montacuta ferruginosa*.

Biomass was measured in grams ashfree dry weight (AFDW) per m². AFDW was determined by drying the organisms for 65 hours at 65°C. The animals were then weighed (dry weight) and incinerated at 570°C for two hours and weighed again (ash weight).

For the polychaetes *Nephtys hombergii* and *Magelona papillicornis* the biomass was determined for each species separately. For all remaining worms (polychaetes and nemertini) a combined biomass was determined. In bivalve molluscs biomass was determined per species. For echinoderms (mostly *Echinocardium cordatum*), only complete individuals were used for determination of an average individual AFDW, from which the biomass per m² was calculated. Discrimination was made between juvenile (<2 cm) and adult (>2 cm) *Echinocardium cordatum*. Conform the methodology used in the RIACON project (VAN DALFSEN & ESSINK, 1997) the biomass of Crustacea was not determined.

2.4 Data analysis

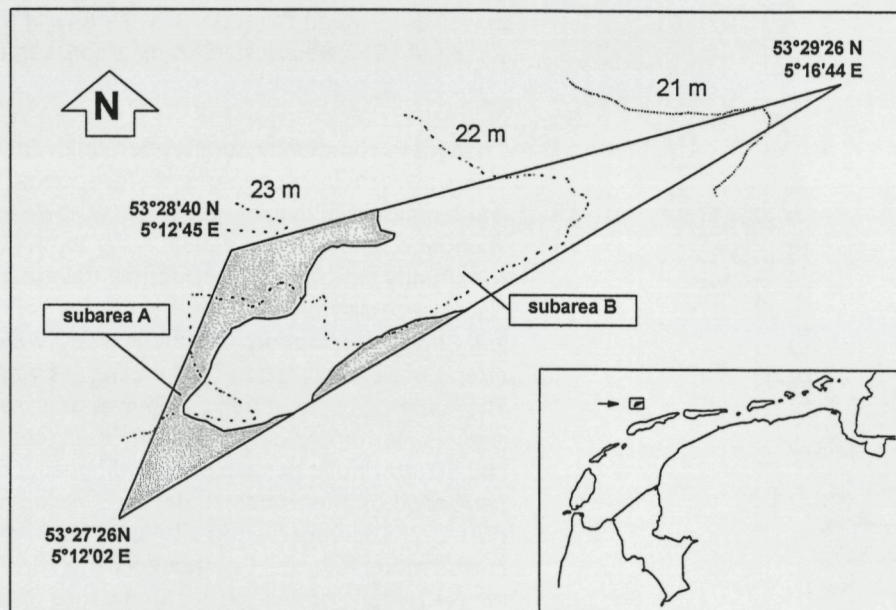
In the RIACON project two subareas were identified within the borrow area on the base of depth changes between February 1993 and May 1994 as the result of sand extraction (VAN DALFSEN & ESSINK, 1997). These subareas A and B having different levels of impact were used to follow the development of the benthic community. The bathymetric survey made in September 1997 revealed no great changes in dimension and position of the borrow pit since the last survey in 1995.

Although no certainty was given whether subarea A could be considered as a fully undisturbed reference area and subarea B as being affected by the extraction of sand (VAN DALFSEN & ESSINK, 1997), it was decided to use this distinction also in the data analysis of the 1997 survey (Table 1; Fig. 2).

Table 1
Change in depth of the sea floor between February 1993 (pre-extraction) and May 1994 (post-extraction) in two subareas of the borrow area North off Terschelling (from: VAN DALFSEN & ESIINK, 1997). See for areas A and B Fig. 2.

Subarea	Change in depth (range)
A ('reference')	+10 to -10 cm
B ('disturbed')	- 10 to -250 cm

Figure 2
Map of the borrow area North off Terschelling, with depth contours (in m below NAP \approx mean sea level). Two subareas are indicated: A= 'reference' and B = 'disturbed' (see also Table 1 and text).



By doing so, the results of the 1997 survey can be directly compared with the results of the previous surveys made during the RIACON project.

Like in the RIACON project mobile epibenthos (e.g. copepods, mysids, shrimps and crabs) were excluded from the analysis, primarily because of inadequate sampling. Some other groups and species, namely Bryozoa, Hydrozoa, Nematoda and the chordate *Branchiostoma lanceolatus*, were also excluded from data analysis. In Appendix 2 an overview is given of all species found in the samples.

Average density, biomass, species diversity and evenness were calculated for the two distinguished subareas separately. The diversity of the macrobenthic fauna is expressed by the Shannon-Wiener index H' and the distribution of the numbers of individuals among the species by Heip's index $E(H)$ of evenness (HEIP, 1974).

$$H' = -\sum_{i=1}^S p_i (\ln p_i) \quad \text{with } p_i = n_i / N$$

where N = Total number of individuals
 n_i = number of individuals of species i
 S = total number of species

$$E(H) = \frac{N_1 - 1}{N_0 - 1}$$

where $N_1 = e^{H'}$
 N_0 = total number of species

The Shannon Wiener index is sensitive both to the numbers of taxa present in a sample, and to the degree of numerical dominance. The evenness index increases as individuals become more evenly distributed among the taxa. Heip's Index $E(H) = 1$ if all species present are equally abundant.

Statistical differences in abiotic parameters, species composition, abundance and biomass between the two subareas A and B in the 1997 survey separately as well as between the successive surveys of the RIACON project and the survey of 1997 were tested, using a non-parametric Mann-Whitney U-test (\approx Wilcoxon signed-rank test).

Changes in community composition following a disturbance are difficult to assess by mere inspection of data for species composition, population density and biomass. Multivariate techniques, however, may integrate diversity, abundance and biomass data in order to make these complex relations between community structure and environmental gradients (natural or as a result of a disturbance) more clear. In this study TWINSpan cluster analysis (HILL, 1979) and Principal Components analysis (PCA) were both used to investigate the effects of sand extraction on the benthic community composition. The community structure in 1997 was analysed using TWINSpan cluster analysis, performed only on density data (cut levels for each species: 1, 2, 5, 10 and 50 individuals per sample). Additionally, a TWINSpan analysis was performed on the combined data sets of the four successive RIACON and RIACON*2 surveys (*i.e.* on a total of 124 samples). Furthermore, Principal Components analysis (PCA) was carried out, using $\log(N+1)$ -transformed species abundance data from all four surveys (124 sampled stations). For this analysis species were combined into higher taxonomic levels *e.g.* classes and families (WARWICK, 1988).

In the RIACON project it was concluded that the extraction of sand had caused a change in the population structure of some long-living species, *e.g.* molluscs and sea urchins (VAN DALFSEN & ESSINK, 1997). The degree of recovery of the population structure in these bivalve species and in the sea urchin *Echinocardium cordatum* was studied by analysing the age composition (based on length measurements).

3 Results

3.1 Seabed morphology and sediment characteristics

Echo sounding of the former borrow area in November 1997 revealed no noteworthy changes when compared with the bathymetrical surveys made in 1994 and 1995, after the extraction of sand had stopped (Fig. 3). The dimension of the borrow pit in 1997 resembles fairly well the area of extraction found in 1994.

In the sedimentation/erosion maps a pattern of large geomorphological elements ("waves") with a maximum height of circa 0.35 cm and a wavelength of 2.5 km seems to be visible in the surveyed area (Fig. 4-2 and 4-3). The dimensions of these "waves" do not support the definition of true sand waves, although the direction is perpendicular to the water currents as sand waves should be. If such a pattern of large "waves" did exist in the area before the extraction of sand it may be concluded that it was interrupted by the extraction of sand in 1993 (Fig. 4-1). In 1994 the formation of a "wave" is visible in the western part of the borrow area, and the pattern of "waves" in the area was completely restored in 1997.

In 1997 the median grain size in the total area was 221 μm and varied from 204 μm to 240 μm . Sorting parameters D80/20 and D70/30 varied between 1.45 - 1.82 and 1.26 - 1.44, respectively. Median grain size in subarea A was found to be almost significantly higher ($p=0.06$) than in subarea B (respectively 231 μm and 210 μm). Comparison of median grain size and sorting parameters between the 1997 survey and the 1993 survey, before extraction (median grain size varied between 183 and 213 μm ; D80/20 varied between 1.32 - 1.40 and D70/30 varied between 1.17 - 1.23; Biegel *et al.*, 1994), reveals a coarsening of the sediment in the area since 1993. Comparison of data between the 1993 and the 1997 survey for the different subareas was not possible as the 1993 data were taken from literature and station co-ordinates were not available.

The results of the sediment analysis are given in Appendix 1. The average percentages of CaCO_3 , mud (< 53 μm) and organic matter in the 1997 survey were 5.4 %, 7.2 % and 0.57 %, respectively.

The percentage of CaCO_3 , mud (< 53 μm) and organic matter showed no differences between the two subareas (Fig. 5). In the subareas A and B no significant changes were found in the CaCO_3 content when compared with previous surveys in 1993, 1994 and 1995 (Fig. 5a).

The percentage of mud (< 53 μm), however, had increased significantly from 0.4 % to 7.2 % in the entire study area since the survey of 1995 (Fig 5.b). The stronger increase of the mud content in subarea B than in subarea A is explained by high contents of mud (> 12%) found at 4 stations in subarea B. For both subareas the percentage of organic matter was still significantly lower than at the survey of 1993 (Fig. 5c). However, when compared with the survey made in 1995 the percentage of organic matter in 1997 had significantly increased from 0.3 % to 0.6 %.

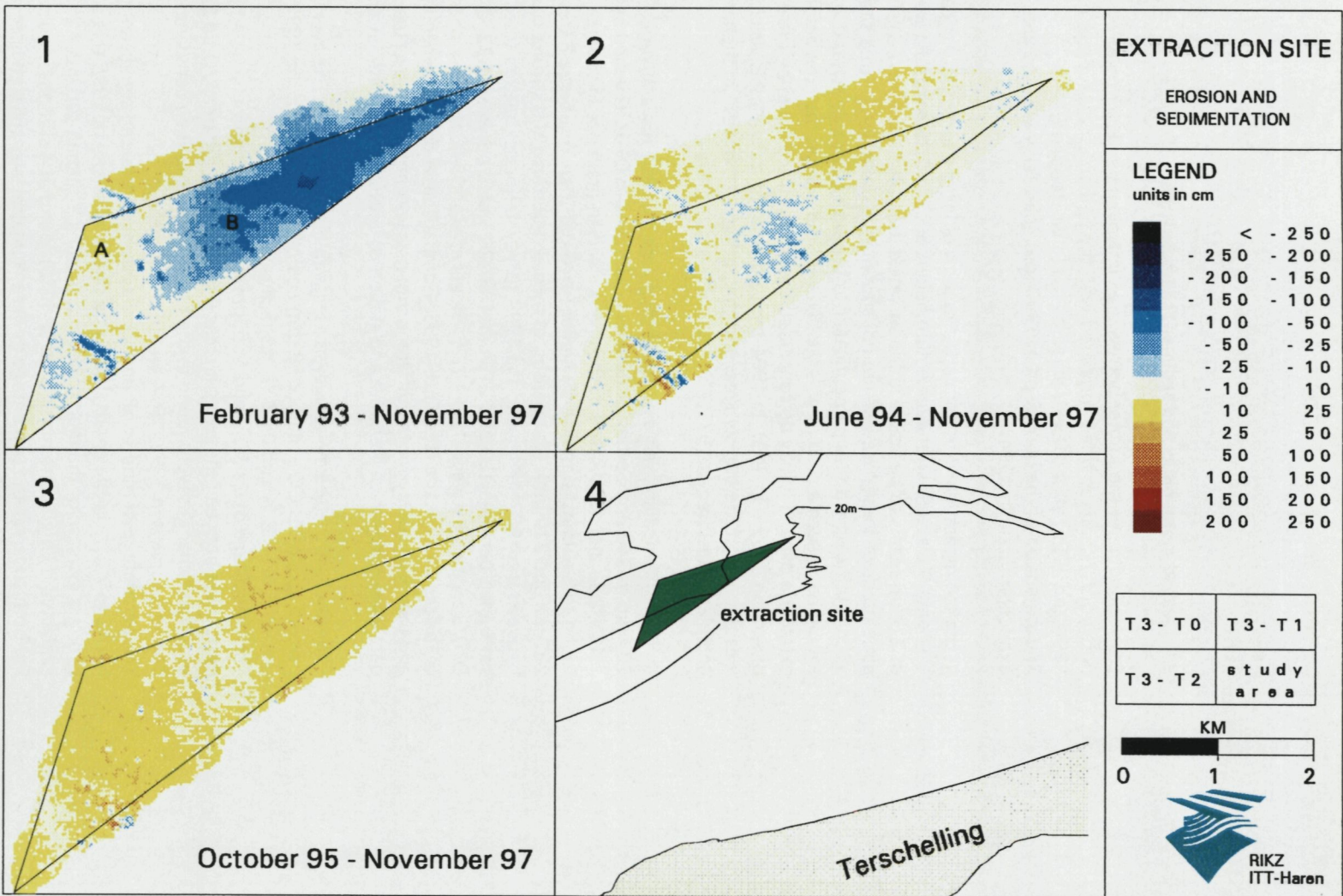


Figure 3
Bathymetric difference maps of the borrow area, showing sedimentation (yellow-brown) and erosion (blue) over the period February 1993 - November 1997 (in comparison to the 1993 survey (T0)).

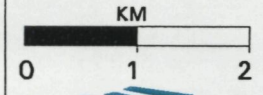
EXTRACTION SITE

EROSION AND SEDIMENTATION

LEGEND
units in cm



T1 - T0	T2 - T0
T3 - T0	study area



overname (hier gecorrigeerd)

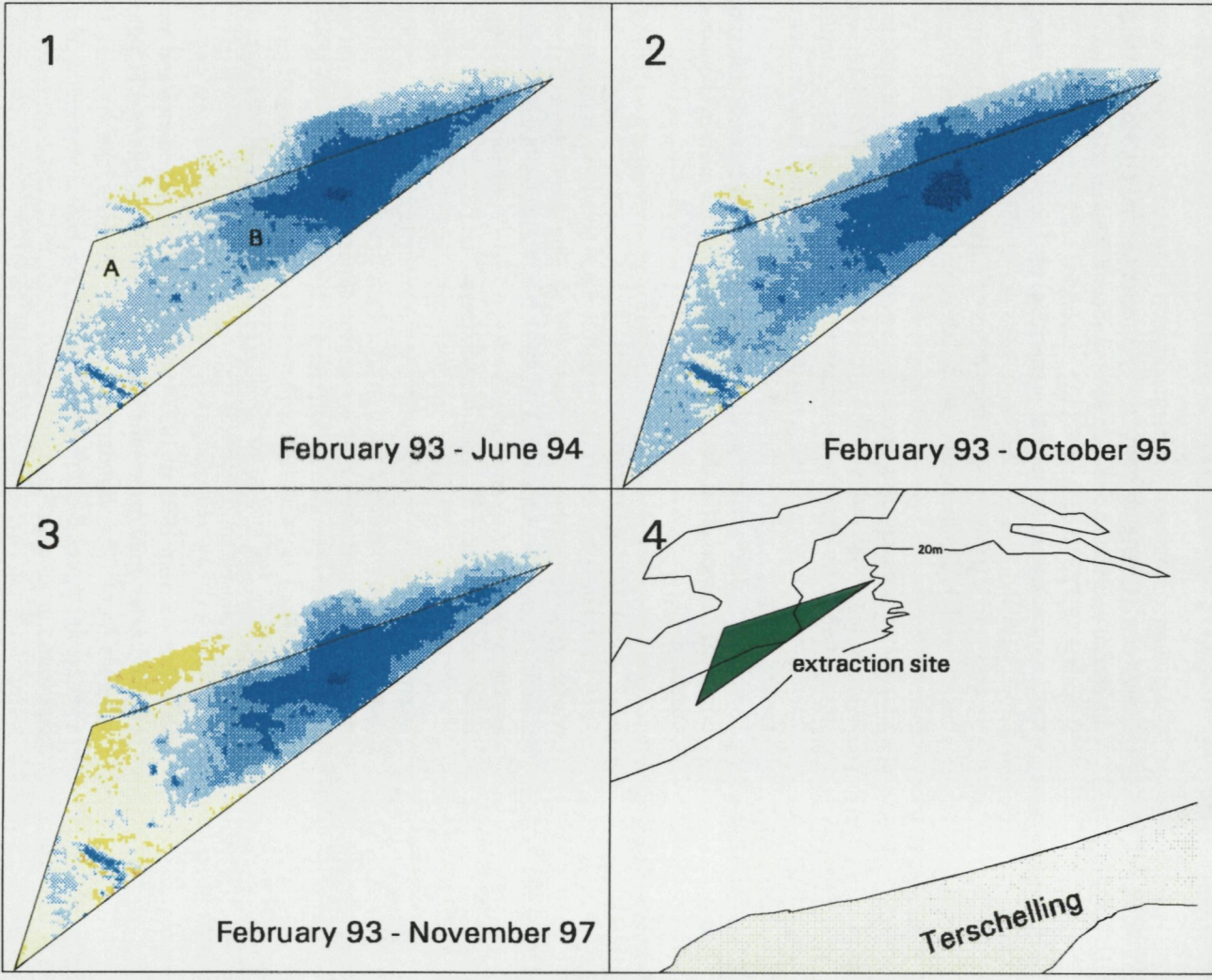


Figure 4
Bathymetric difference maps of the borrow area, showing sedimentation and erosion over the period February 1993 - November 1997 (in comparison to the November 1997 survey).

3.2 Biotic parameters

Comparison of the subareas A and B in the 1997 survey revealed no clearly significant differences in any of the abiotic parameters (see 3.1). In spite of this, reference to both subareas will be made in the results and in the discussion because of differences in the development of the benthic community in these areas during the successive surveys.

3.2.1 Species richness, diversity and evenness

In the September/ October 1997 survey a total of 59 species were identified. Species names and their occurrence are summarised in Appendix 2.

The average number of species per station found at the borrow site in the 1997 survey was 21, ranging from 16 - 29 species per station. No statistical difference was found between the numbers of species in subarea A (avg. nr. species = 19.7) and subarea B (avg. nr. species = 21.9), although in the latter the species numbers are somewhat higher (Fig. 6). The Shannon-Wiener index varied between 1.92 and 2.64 and was significantly higher in subarea B than in subarea A ($p < 0.04$) (Fig. 7). Heips index of evenness varied between 0.36 - 0.62 but showed no significant difference between the two subareas (Fig. 8).

Species numbers, diversity and evenness were all significantly higher in the 1997 survey when compared with the pre-extraction survey in 1993 and the 1995 survey, two years after the extraction had stopped ($p < 0.03$). Compared to the 1994 survey, one year after the extraction had stopped, only the number of species was not higher in the 1997 survey.

The trends in diversity and evenness do match relatively well, indicating a dominant component in the diversity accounting for most of the variability observed.

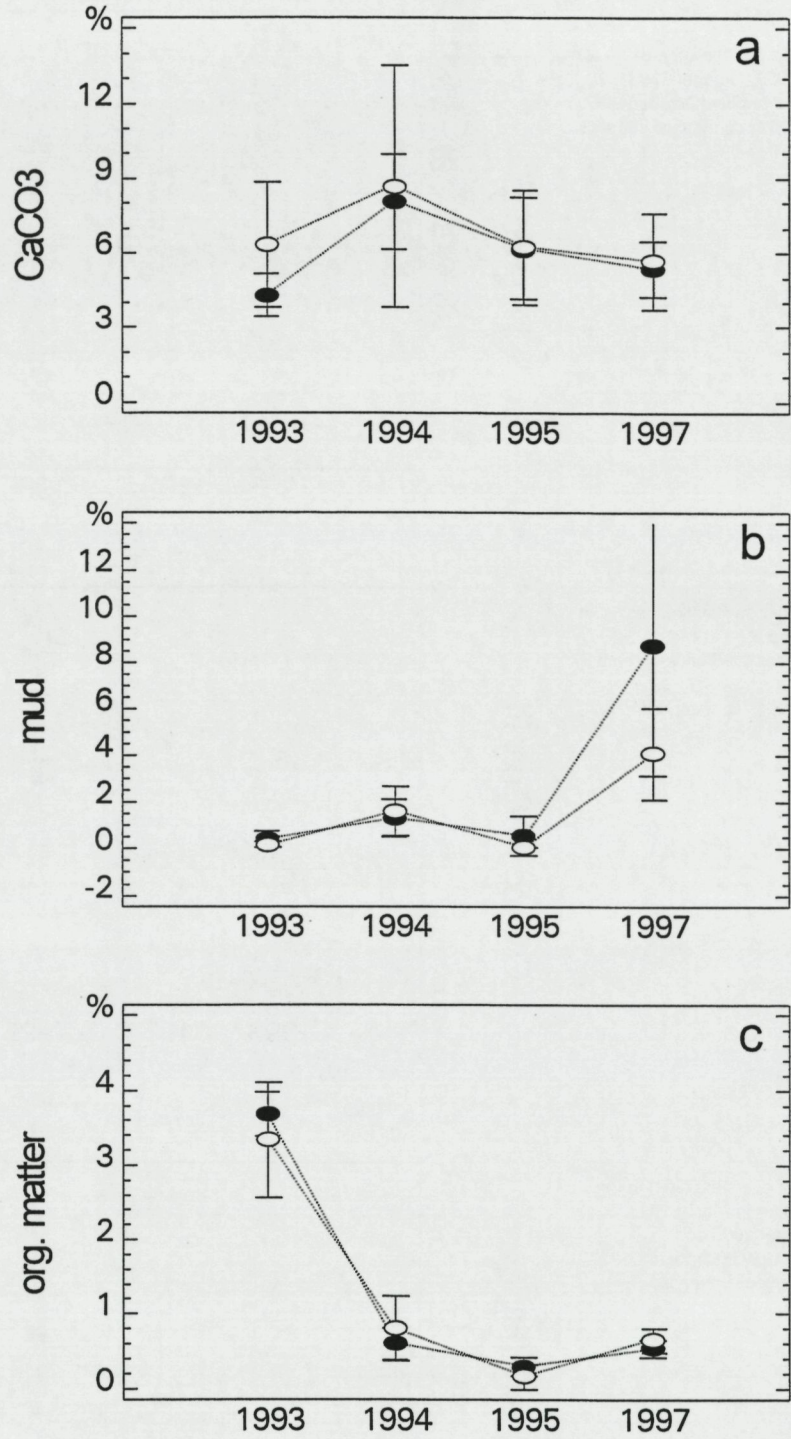
3.2.2 Abundance of macrozoobenthos

Total abundance and abundances of the major taxa (Polychaeta, Crustacea and Mollusca) are presented in Fig. 9 and Fig. 10. The abundances of species per station are given in Appendix 3. In 1997 the total abundance in the borrow area was 1778 ind/m² and varied between 730 - 3667 ind/m². No significant difference was found between the subareas A and B.

From the first survey in 1993 until the survey in 1997 a general decline in total macrofauna abundance is clearly visible in both subareas (Fig. 9). This decreasing trend is also found in the abundance of polychaetes and crustaceans (Fig. 10ab). For the molluscs a decreasing trend in abundance only occurred in subarea B from 1994 till 1997, where the average abundance of molluscs dropped from 236 ind/m² to 137 ind/m² (Fig. 10c). In subarea A no declining trend in mollusc abundance was found.

In the period from 1995 to 1997 total macrofauna abundance and abundance of polychaetes and crustaceans showed no significant changes in either of the subareas A or B. The abundance of molluscs however, still showed a significant decrease in subarea B in this period ($p = 0.02$) whereas no significant change was found in subarea A.

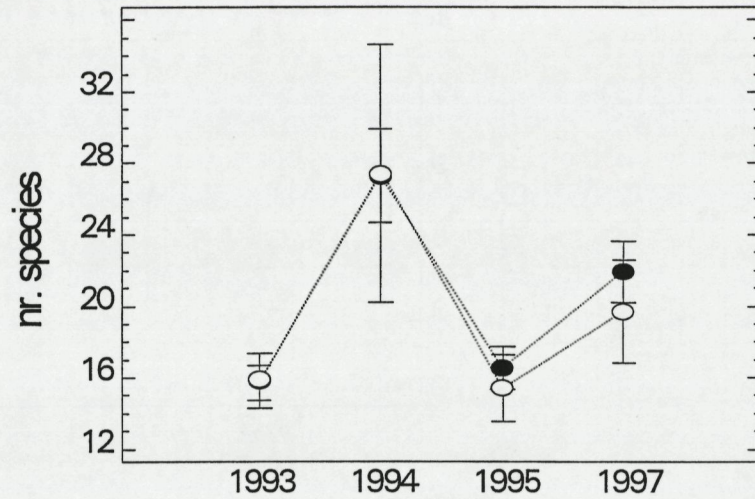
Figure 5
 Mean contents of CaCO₃ (a), mud (fraction < 53 μm; b) and organic matter (c) in the sediment of the subareas A (o) and B (●) in March 1993, October 1994, October 1995 and September/October 1997. Error bars represent 95% confidence intervals.



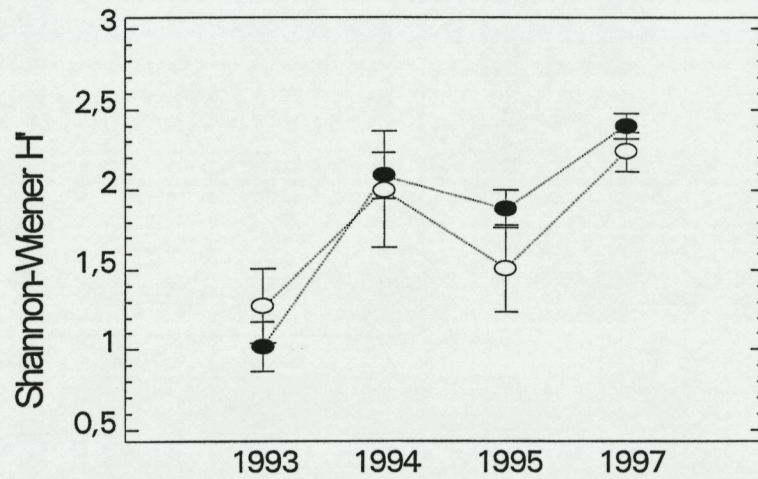
3.2.3 Biomass of macrozoobenthos

The average total biomass in 1997 was 10.8 g/m² and varied between 2.4 and 32.0 g/m². As for the densities no difference exist between the subarea A and B (Fig. 11). The total biomass in subarea B was significantly lower in 1997 than in the 1993 survey in the same area before the extraction of sand (p< 0.01). In subarea A total biomass values between 1993 and 1997 had not significantly changed. From 1995 to 1997 a small but significant (p=0.01) increase from 5.9 g/m² to 10.2 g/m² was found in subarea B, whereas again no significant changes were found in subarea A.

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Figure 6
 Mean number of species in the subareas A (o) and B (•) in March 1993, October 1994, October 1995 and September/October 1997. Error bars represent 95% confidence intervals.



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Figure 7
 Mean Shannon-Wiener diversity index (H') in the subareas A (o) and B (•) in March 1993, October 1994, October 1995 and September/October 1997. Error bars represent 95% confidence intervals.



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Figure 8
 Mean Heip's index of evenness (E(H)) in the subareas A (o) and B (•) in March 1993, October 1994, October 1995 and September/October 1997. Error bars represent 95% confidence intervals.

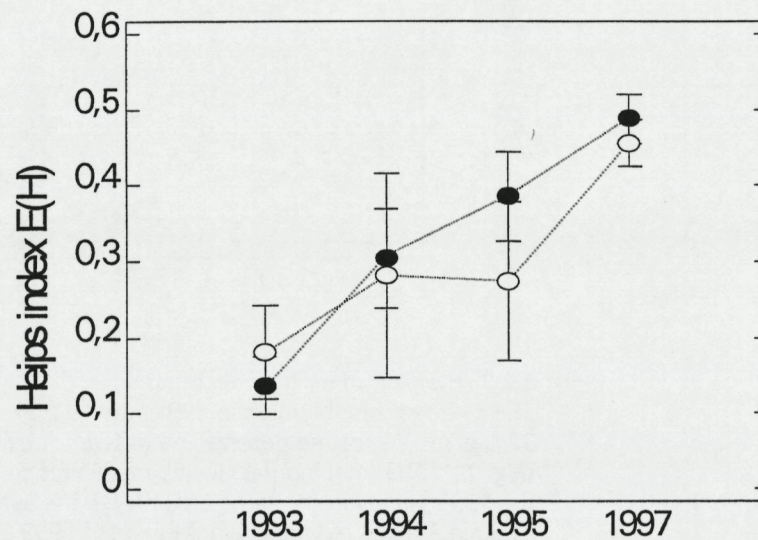
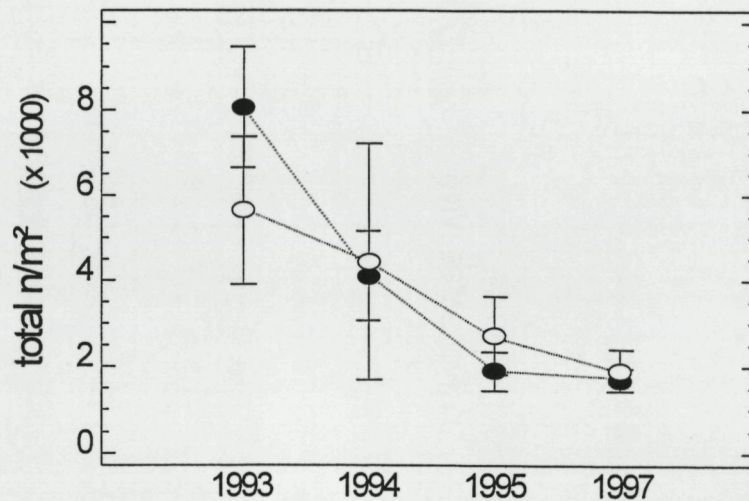


Figure 9
 Mean total abundance of macrozoobenthos (ind./m²) in the subareas A (o) and B (•) in March 1993, October 1994, October 1995 and September/October 1997. Error bars represent 95% confidence intervals.



In 1997 the average biomass of polychaetes and molluscs at the study site was 10.1 g/m² and 0.17 g/m² respectively. The biomass of polychaetes in subarea B had significantly increased ($p=0.01$) from 3.8 g/m² in 1995 to 9.4 g/m² in 1997, but was still significantly lower ($p=0.01$) than the biomass of polychaetes in this area before sand extraction in 1993 (Fig. 12a). The biomass of polychaetes in subarea A in 1997 (11.6 g/m²) shows no significant difference with the biomass of polychaetes in any of the previous surveys.

The biomass of molluscs at the borrow site has decreased from 2.9 g/m² in 1993 to 0.1 g/m² in 1997. This decrease is significant as is the decrease in subareas A ($p < 0.01$) (Fig. 12b). Compared to the 1995 survey no significant changes in mollusc biomass occurred in either of the subareas.

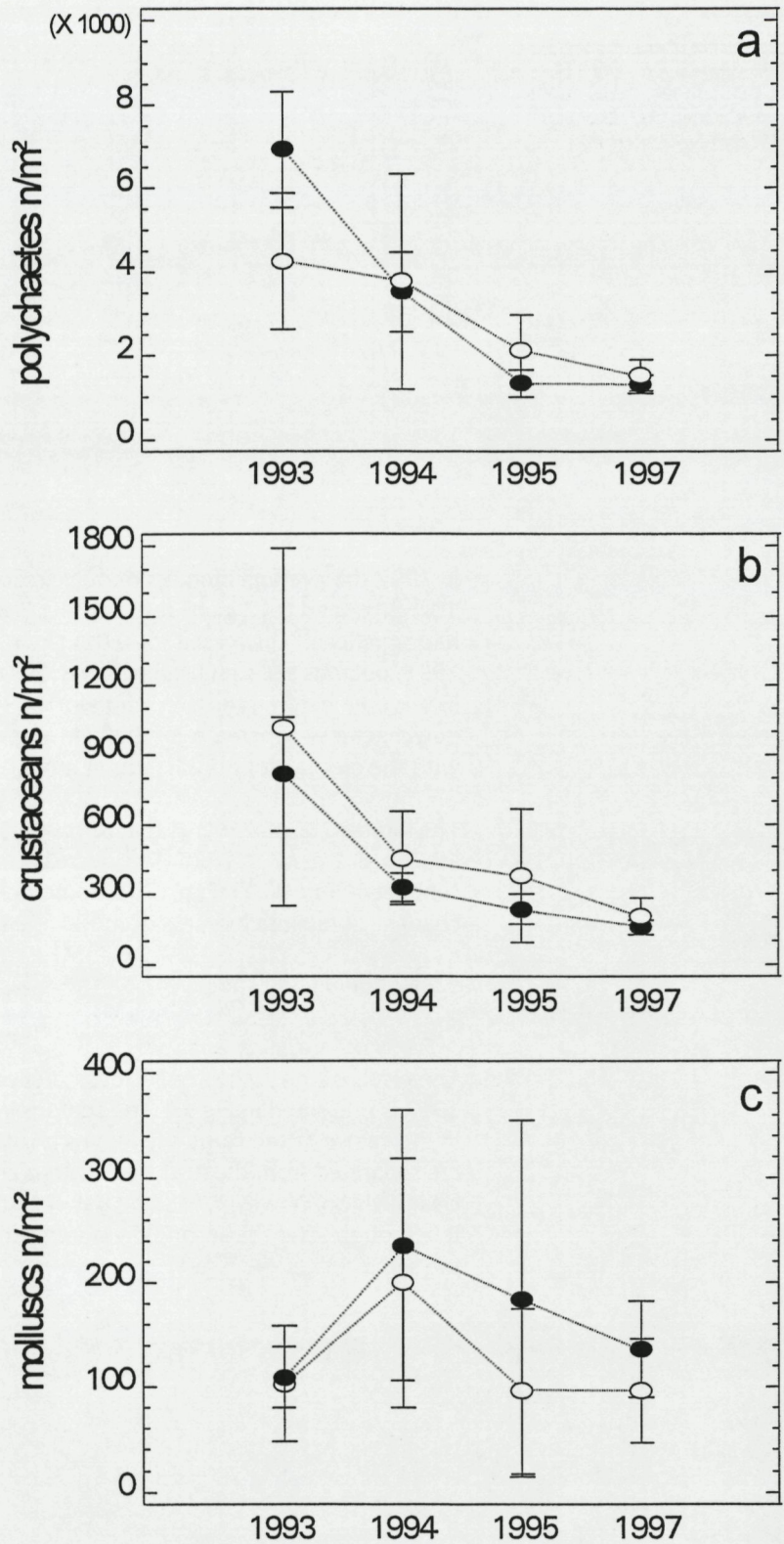
3.2.4 Community structure

* TWINSpan cluster analysis

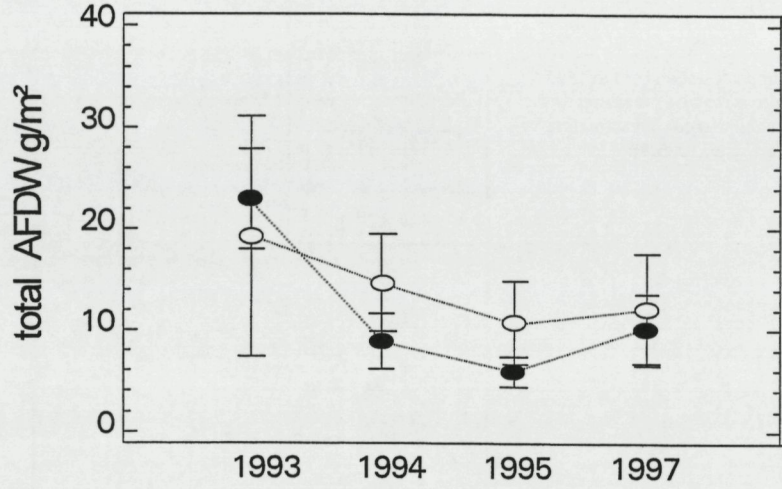
The result of the TWINSpan cluster analysis based on species abundance in 1997 is presented in Fig 13. The stations in clusters 3 and 4, which are located in the centre of the study site in which most of the extraction has taken place, are separated from those at the western and eastern part (clusters 1 and 2). No clear division, however, is made between the stations of subarea A and subarea B, although after the second division most stations of subarea B are grouped in the same cluster (♦)

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Figure 10

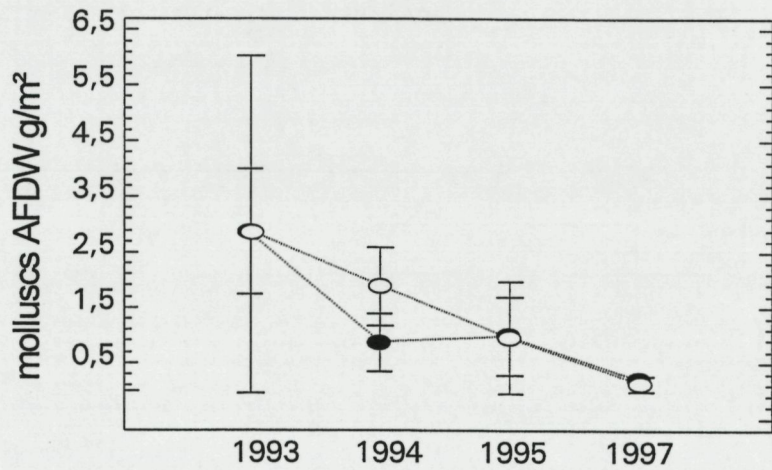
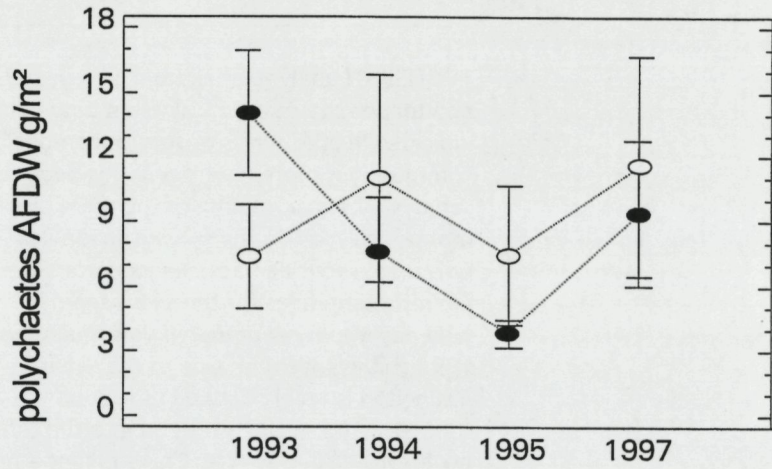
Mean total abundance (n/m²) of polychaetes (a), crustaceans (b) and molluscs (c) in the subareas A (o) and B (•) in March 1993, October 1994, October 1995 and September/October 1997. Error bars represent 95% confidence intervals.



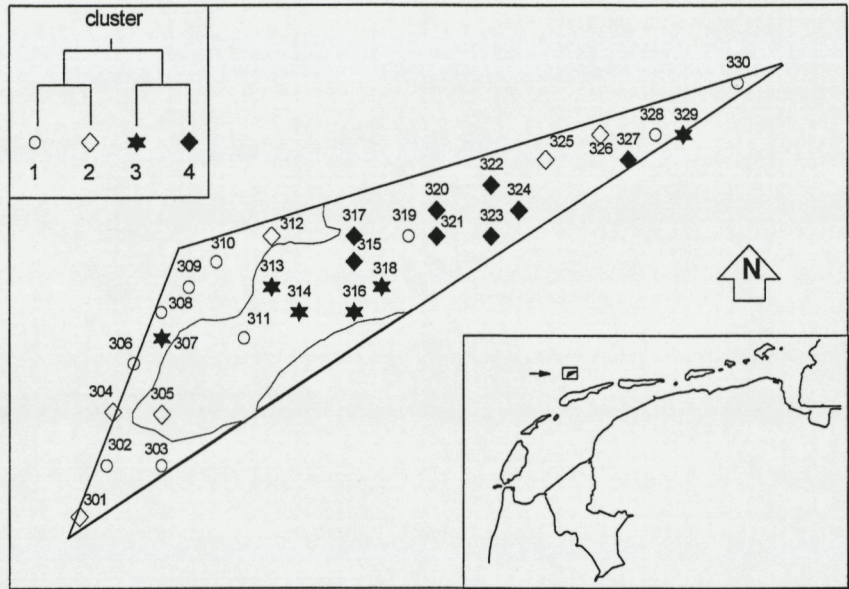
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Figure 11
 Mean total biomass of macrozoobenthos (g AFDW/m²) in the subareas A (o) and B (•) in March 1993, October 1994, October 1995 and September/October 1997. Error bars represent 95% confidence intervals.



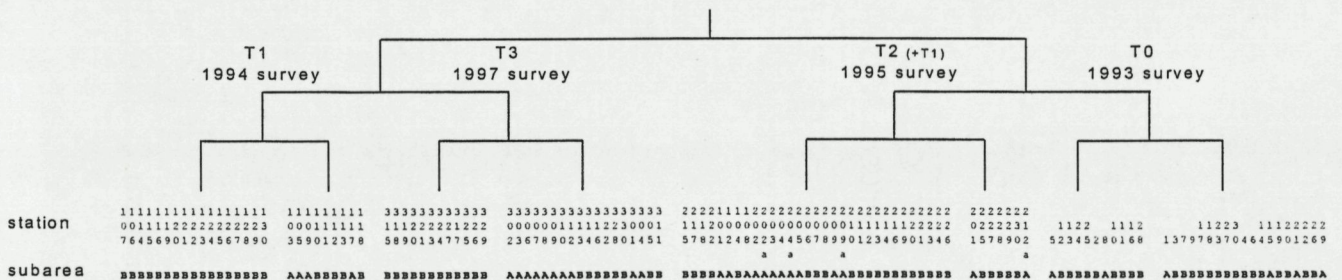
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Figure 12
 Mean biomass (g AFDW m⁻²) of polychaetes (a) and molluscs (b) in the subareas A (o) and B (•) in March 1993, October 1994, October 1995 and September/October 1997. Error bars represent 95% confidence intervals.



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Figure 13
 Distribution of sampling stations of the 1997 survey according to a TWINSpan cluster analysis based on abundance of macrofauna species (cut levels 1, 2, 5, 10, 50/m²).



TWINSpan analysis of all four surveys (1993 - 1997) based on species abundance shows a clear division between the separate surveys (Fig. 14). This indicates that, in terms of species composition and abundance, the benthic community is more heterogeneous between the surveys than within the surveys. The macrofauna of the 1994 and 1997 surveys resemble each other more closely, as do the surveys made in 1993 and 1994. Particularly the polychaete species *Capitella capitata*, *Poecilochaetus serpens* and *Spio filicornis* are representatives for the 1994 and 1997 surveys because of their abundance, whereas *Nephtys hombergii* was much more abundant in the 1993 and the 1995 surveys. Within each of the separate survey related clusters no clear distinction is visible between the subareas A and B, although the stations of subarea A are mostly grouped into the same cluster in the third division, except for the 1993 survey (T0). This signifies a rather weak relationship with the inferred differences in impact of sand extraction (subareas A and B).



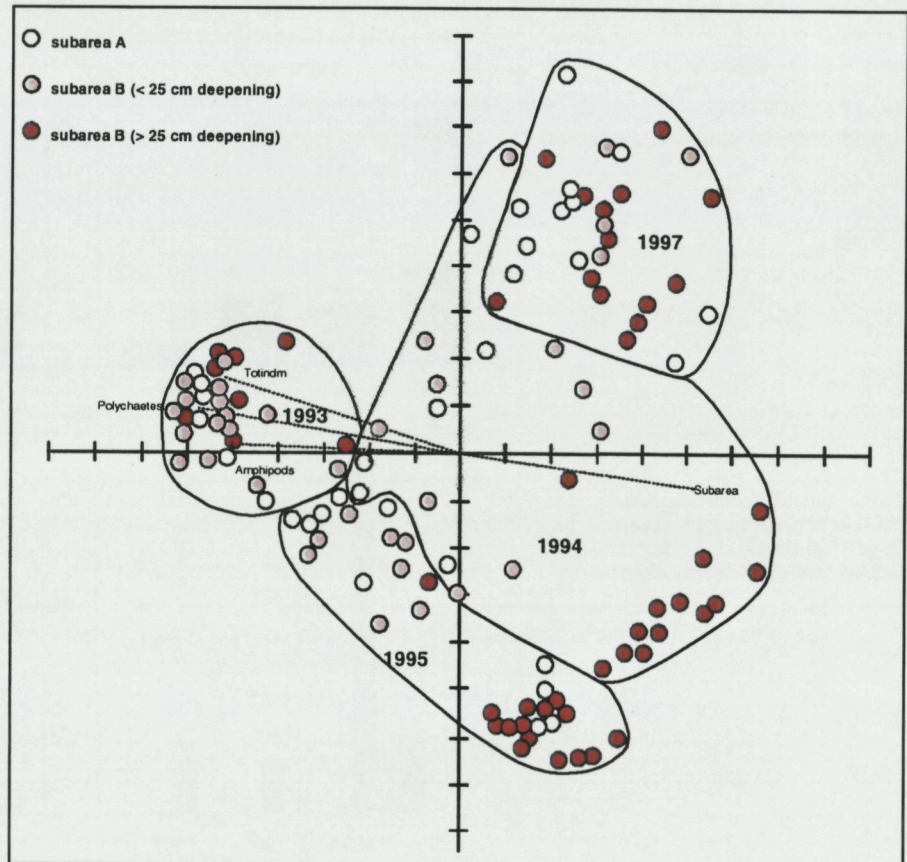
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Figure 14
 TWINSpan generated dichotomy of sampling stations based on abundance of macrofauna species (cut levels 1, 2, 5, 10, 50/m²) found in the successive sampling surveys. Survey and station numbers are indicated. The position of the stations in subareas A and B is indicated in capitals.

** Principal Components analysis (PCA)*

The results of the Principal Components analysis using the abundance data for taxonomic groups from all four surveys (124 sampled stations) are represented by the ordination in Fig. 15. The stations of each survey can be separated in different clusters, but this is not as obvious as with the TWINSpan analysis. The stations of the 1993 survey, before the extraction, form a coherent group, indicating a rather uniform community in terms of species composition and abundance. The stations of the subsequent surveys are much more spatially distributed in the ordination plot. In 1994 stations are widely distributed in the ordination indicating a far more heterogeneous benthic fauna as compared with the fauna present in 1993. In 1995 stations the distances between the stations are somewhat reduced.

Of particular interest is the clustering of the stations of the 1994 and 1995 surveys which were situated within subarea B in the area which was most affected by the extraction (more than 25 cm of deepening, see Fig. 4). This suggests a different development of the benthic community in this part of subarea B. In the 1997 survey no clear separation of stations in subareas or regions is visible, as was the situation in 1993. The benthic community in 1997 has become more homogeneous again. However, the position of the 1997 survey cluster has moved away from that of the 1993 survey cluster. This indicates a general deviation of the benthic community from the original structure and composition present before extraction in 1993. Only the first axis (eigenvalue 0.31) is informative and significantly correlated with changes in depth due to the sand extraction, total macrofauna abundance and abundance of polychaetes and amphipods.

Figure 15
PCA-ordination diagram of the stations of the four successive sampling surveys in the borrow area North of Terschelling. Numerical densities of species were $\log(N+1)$ -transformed. The species data have been aggregated into families. Explaining factors represented by dotted lines: Subarea = subarea A or B, Totindm = total macrofauna density (n/m^2), polychaetes = density of polychaetes (n/m^2), Amphipods = density of amphipods (n/m^2). Envelopes are drawn by hand around stations belonging to the same survey.



*** Age composition of long-lived species**

In the RIACON project, with surveys in 1993, 1994 and 1995, a change was observed in the age composition of long-living species as *Donax vittatus* and *Echinocardium cordatum* towards populations with more juvenile individuals, especially in subarea B. In the 1997 survey *Donax vittatus* has completely disappeared from the study site (Fig. 16). The population of *Echinocardium cordatum* in 1997 has changed towards 16% adults and 84% juveniles in both subareas (Fig.17). There is no evidence for a recovery of the original population structure in *Donax vittatus* and *Echinocardium cordatum* after the reduction of the number of adult specimens as a result of sand extraction. The observed opportunistic settlement of juvenile (< 10 mm) *Tellina tenuis* and *Spisula subtruncata* after the extraction in the 1994 survey did not result in populations which remained in the area in 1995. In 1997 these species were also rare as they were at the 1993 survey before the extraction (Fig. 18 and 19).

Figure 16
Abundance of different size classes (shell length) of *Donax vittatus* in subarea A (left) and subarea B (right) in March 1993, October 1994, October 1995 and September/October 1997.

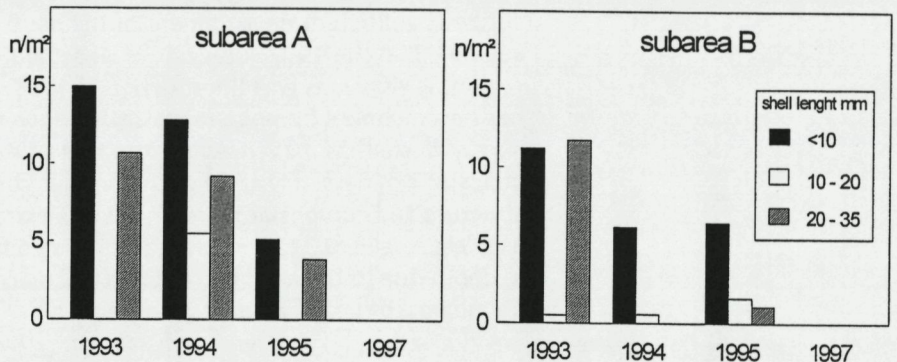


Figure 17
Abundance of adults and juveniles of *Echinocardium cordatum* in subarea A (left) and subarea B (right) in March 1993, October 1994, October 1995 and September/October 1997.

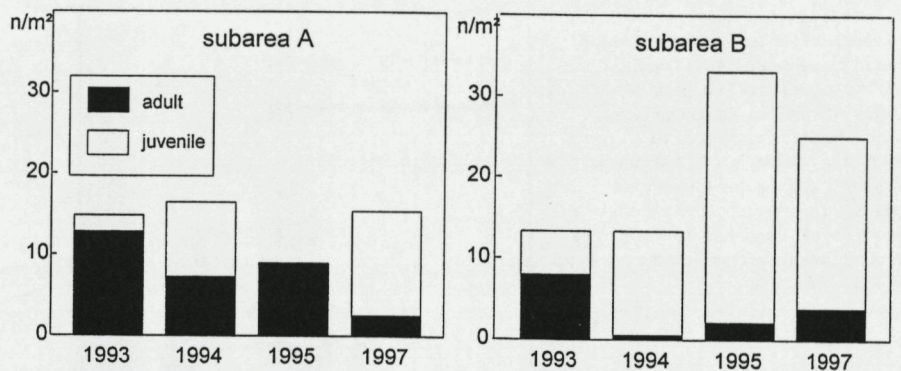


Figure 18
Abundance of different size classes (shell length) of *Tellina tenuis* in subarea A (left) and subarea B (right) in March 1993, October 1994, October 1995 and September/October 1997.

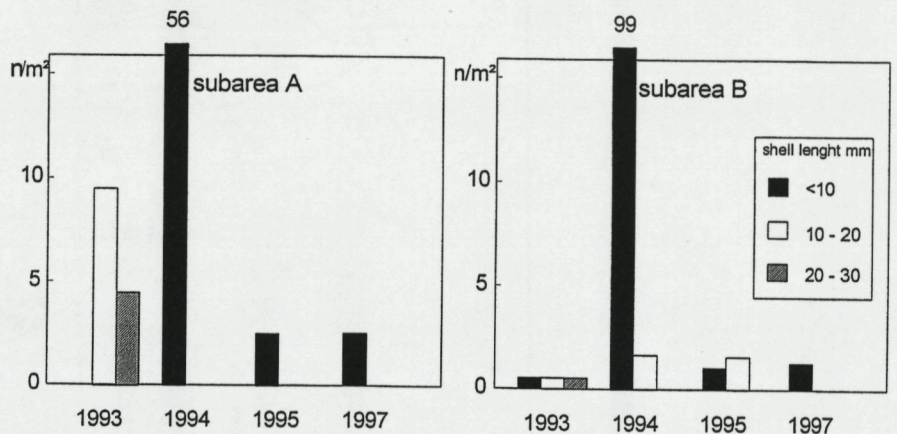
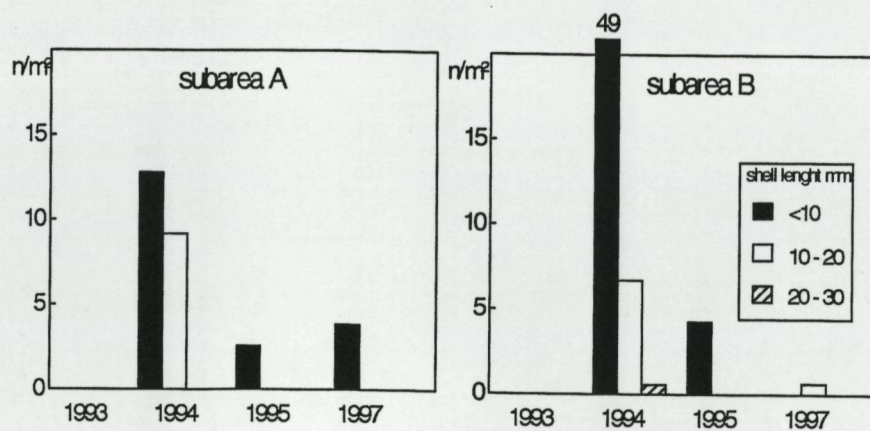


Figure 19
 Abundance of different size classes (shell length) of *Spisula subtruncata* in subarea A (left) and subarea B (right) in March 1993, October 1994, October 1995 and September/October 1997.



4 Discussion

4.1 Seabed morphology

In November 1997, four years after cessation of the sand extraction, no significant changes were observed in comparison with the dimensions and position of the borrow pit seven months after the extraction (June 1994). The enlargement of the borrow pit observed between June 1994 and October 1995 was not visible any more in 1997. This temporary increase of the borrow pit may be explained by a scouring effect on the seabed by bottom currents before a new equilibrium between sedimentation or erosion was reached. From the erosion/sedimentation maps it was concluded that some sedimentation took place between 1995 and 1997, but not exclusively in the extraction area (subarea B) but also in the surrounding area (subarea A). The sedimentation resulted in a pattern of large geomorphological elements, "waves", which may have been already present in the borrow area before the sand extraction. This natural pattern of "waves" may have been interrupted by the extraction of sand and subsequently restored in time, to be completed in 1997. The formation of these "waves" may also have been the result of sediment transport caused by the disturbance of the seabed morphology and controlled by tidal currents. Future bathymetric surveys may give further information on these geomorphological elements and may lead to an explanation of their origin.

No evidence was found for a filling-in of the borrow pit itself as the dimensions and position of the borrow pit in 1997 are comparable to the extraction area in 1994. At this depth in the Dutch coastal zone bottom currents are still relatively high and may negatively influence sedimentation of sands. Also the shape and position of the borrow pit, which was parallel to the residual currents (running south-west to north-east), may have prevented the filling-in of the extraction area due to natural sedimentation processes. The persistence of the borrow pit suggests that in this area the restoration of the seabed morphology as a result of sediment disturbances by wave action has been limited, although wave action under storm conditions is considered to redistribute sediments down to a depth of 30 m.

The results of the RIACON and RIACON*2 projects indicate that in this part of the North Sea sediment extraction up to 2 m under the original seabed may result in long-term changes of the seabed morphology. However, these changes do not seem to interfere with the natural processes for water and sediment transport. Long term disturbance of the seabed morphology was also found in gravel deposits off the coast of England and France where filling in of the dredge furrows and pits was found to take several years (DICKSON & LEE, 1972; MILLNER *et al*, 1977; DESPREZ, 1992; KENNY & REES, 1996).

4.2 Sediment characteristics

Based on grain size analysis of 8 samples of the September/October 1997 survey there is evidence of a coarsening of the sediment in the borrow area since the extraction in 1993. Median grain size was larger in subarea A than in subarea B. This coarsening of the sediment is in contrast with the results of HOLTSMANN *et al*. (1997) who found a slightly decreasing trend in median

grain size for the coastal zone area (between Hoek van Holland and Borkum) since 1993.

The results of the grain size analysis also showed an increase in sorting of the sediment in the borrow area compared to the 1993 survey. An increase in sorting is mostly accompanied with a fining of the sediment which is supported by the increase of mud content in the sediment, but contradicts the increased median grain size. More grain size analyses are needed to validate the results.

4.3 Changes in the benthic community

From 1995 to 1997 no significant changes were found in total macrofauna abundance and abundance of polychaetes and crustaceans. This may indicate a stabilisation of the benthic community in terms of abundance.

The decreasing trend in mollusc abundance since 1994 can be explained by the settlement of large numbers of juvenile molluscs (*Spisula subtruncata* and *Tellina tenuis*) in 1994, which were not able to survive in the successive years (VAN DALFSEN & ESSINK, 1997) plus recruitment failures in the next years. Monitoring of macrofauna in the coastal area since 1987 revealed in general a decreasing trend in all major taxa (i.e. polychaetes, crustaceans and molluscs). However, polychaetes and crustaceans showed a temporary increase in abundance from 1993 till 1995 (HOLTMANN *et al.*, 1997, 1998).

Whereas the densities showed no changes since the survey in 1995, total macrofauna biomass and biomass of worms have significantly increased. This is caused by a strong increase in the population density of relatively large (and heavy) polychaetes *Lanice conchilega* and *Scoloplos armiger*. Biomass of molluscs has decreased which is in congruence with the trend in mollusc abundance.

The changes in the benthic community as a result of sand extraction were also illustrated by the results of the multivariate analysis (TWINSpan and PCA). The impact of the sand extraction on the macrofauna community was distinctly demonstrated in the PCA ordination. A correlation was found between subareas and the observed changes in the benthic fauna. The changes in the abundance of polychaetes and amphipods were the explaining factors in the change of the community structure. Especially the macrofauna community in the most affected region within subarea B (more than 25 cm of deepening) clearly deviated in 1994 from the rather uniform community present in 1993, before the extraction. In 1995 the community in this region was still well separated in terms of species composition and abundance from the community in subarea A and the less affected region within subarea B (less than 25 cm of deepening). The benthic community in 1997 had become more homogeneous again and a differentiation in subareas or regions was no longer apparent. The presence of relict fauna in between the suction lanes in the less affected region within subarea B may have influenced the assessment of the impact of sand extraction on the benthic community. Whereas in the most affected region of subarea B almost all fauna will have been removed/transported with the sand, relict fauna in small intervening undredged areas may have been sampled and influenced the average macrofauna present in the less affected region within subarea B.

The results of the TWINSpan analysis showed a deviation of the benthic community in the borrow area from the one present before extraction started. However, the TWINSpan analysis also clearly illustrated that natural variation in species composition and abundance between years had a larger effect on the community structure than the variation between stations due to differences in impact of the sand extraction within a year.

4.4 Recovery of the benthic community

It was postulated by VAN DALFSEN & ESSINK (1997), that the tendency of the benthic community in 1995 to move towards the position in the ordination of the community in 1993, could be interpreted as a return of the benthic community towards the initial situation. In 1997, however, the position of 1997 survey cluster in the PCA-ordination has moved away from the position of the 1993 survey cluster. Therefore, it has to be concluded that the community structure in the borrow area in 1997 has not returned to its initial structure and composition in 1993, before the extraction of sand started.

Recovery of a biological community does not always have to lead to a situation similar to the community structure before disturbance. Recent studies on the recovery of benthic communities after dredging operations in the North Sea (VAN MOORSEL, 1994; KENNY, 1998; SEIDERER & NEWELL, 1999) showed changes in community composition in the disturbed as well as in undisturbed areas, sometimes resulting in similar communities in both areas, but dissimilar to their original structure. SEIDERER & NEWELL (1999) suggested to consider a recovery of biological resources in the sea bed as the establishment of a benthic community with a sufficient species diversity including long-lived equilibrium species. In this view the increase of populations of the polychaetes *Lanice conchilega* and *Scoloplos armiger* may indicate a return to a more stable benthic community as these species are referred to as examples of species present in equilibrium communities (NEWELL *et al.*, 1998).

As a result of sand extraction changes were observed in the population structure of long-lived species as molluscs and sea urchins from 1993 to 1995 (VAN DALFSEN & ESSINK, 1997). Older year classes strongly declined and recovery of the population took place by settlement of young recruits. In 1997, however, no recovery in terms of abundance or population structure of these long living species towards the initial situation in 1993 was found. For *Echinocardium cordatum* the number of recruits present in the 1995 survey should have been sufficiently to restore the population structure in 1997 in terms of size classes. Natural fluctuations in reproduction and survival between years are most likely to be responsible for the low number of older specimens found in 1997, as the population structure in both subareas is the same.

The absence of relict fauna in the most affected region of subarea B may have resulted in a type of recovery which was largely dependent on recruitment, whereas in the less disturbed region recolonisation could take place by recruitment as well as by migration from intervening undredged areas. As the community in 1997 is more or less uniform once again possible differences in the ways of recovery did not result in changes in the community after 4 years. In their review on the impact of dredging on biological resources on the sea bed NEWELL *et al* (1998) summarised rates of recovery of benthic fauna following dredging in various habitats. For the recovery of benthic communities in gravels and sands a period of 2 - 4 years seems to be a realistic estimate of time which is in good congruence with the results of the RIACON 2 project. However examples in which recovery took as much as 10 years also exist (NEWELL *et al*, 1998).

4.5 Implications for sand extraction in the Netherlands

Future coastal development will increase the amount of sand dredged in the Dutch part of the North Sea for many years. Most of these developments are planned in the coastal zone from Hoek van Holland to IJmuiden. For economical reasons the sands for the construction will be dredged from the sea bed as close as possible. The hydrodynamics as well as the sediment composition at the borrow area North of Terschelling are comparable to those off the West coast of the Netherlands at similar depths (HARTHOLT, 1998). The macrobenthic community at the borrow area forms part of a very large benthic assemblage found all along the Dutch coastal area at depths from 20 m -NAP (HOLTMANN *et al*, 1996). General changes in the benthic community observed at the borrow site from 1993 -1997 show concurrence with patterns found in the entire coastal and offshore zone of The Netherlands (HOLTMANN *et al*, 1998). Although biological and physical responses to dredging are site specific, it may be expected for the above mentioned reasons that the morphological and biological effects of the sand extraction off Terschelling observed in the RIACON 2 project will be generally applicable to impact assessment of sand extractions off the West coast of The Netherlands.

5 Conclusions

5.1 Sea bed morphology

The studies in the sand extraction area off the island of Terschelling have shown that a deepening of the seabed less than 2 m may lead to long-term changes in bottom morphology. Four years after cessation of the sand extraction no significant changes were found in the dimensions of the borrow pit. The presence of this pit, however, did not seem to greatly influence the natural transport of sediment.

5.2 Effects of sand extraction on the benthic community

In 1997 no significant differences were found between subarea A (reference area) and subarea B (area impacted) in terms of species composition, macrofauna abundance or biomass.

Between 1995 and In 1997 total macrofauna biomass and biomass of worms had increased significantly whereas no significant changes were found in macrofauna abundance except for a decrease in mollusc abundance. These changes are considered to be caused by natural fluctuations as they were not related to differences in sand dredging impact between subareas.

Long-lived species, as some mollusc species and sea urchins, declined strongly after the extraction of sand and only partly returned. Natural fluctuations in reproduction and survival may explain this yet incomplete recovery.

5.3 Recovery of the benthic community

The effects of sand extraction on the benthic community which were still visible after two years, were not obvious any more after a period of 4 years.

Dredging for sand by removing the top layer of the sea floor by more than 0.25 m over a vast area may lead temporarily to a different benthic community than when less than 0.25 m is removed, possible leaving refuge areas in between the dredged furrows. Differences in colonisation processes between these methods of sand extraction did not affect the recovery of the macrofauna community as after four years a similar community structure was found.

The community structure in the borrow area in 1997 has not returned to its initial structure and composition present in 1993, before the extraction of sand started. This deviation of the benthic community in the borrow area since 1995, however, can not longer be related to the effects of the extraction only, but is also caused by natural fluctuations in the benthic community.

Recovery time of the benthic community in terms of abundance was found to take 2 years, in terms of biomass 2-4 years. Recovery of the population structure of long lived species will take more than four years.

5.4 Exploitation of marine sand deposits

The results of the RIACON 2 project with respect to the morphological and biological effects of sand extraction may prove to be useful in relation to the Dutch policy on future exploitations of marine sand deposits in the coastal zone of The Netherlands.

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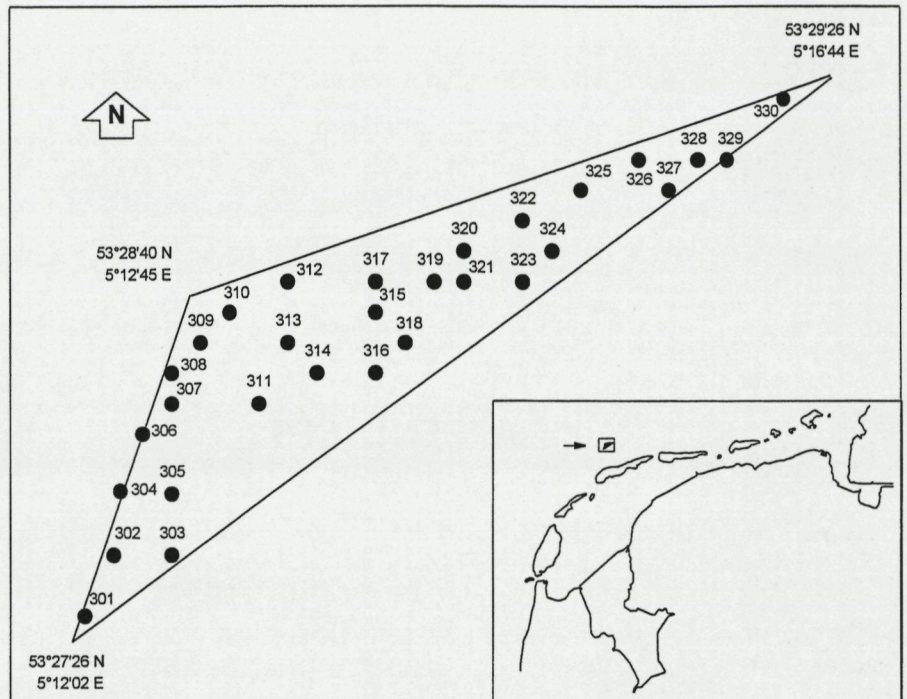
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APPENDICES

Appendix 1
 Location of the sampling stations at the borrow area North of Terschelling in 1997, station coordinates and sediment parameters (% dry weight).



station	N. latitude			E. latitude			CaCO ₃	< 53µm	Org. Material
	degr.	min.	sec.	degr.	min.	sec.			
301	53	27	32	5	12	7	4,1	3,82	0,4
302	53	27	45	5	12	17	3,4	6,71	0,7
303	53	27	45	5	12	39	4,1	6,19	0,7
304	53	27	58	5	12	17	3,3	1,83	0,3
305	53	27	58	5	12	39	3,9	1,81	0,7
306	53	28	11	5	12	28	3,5	5,65	0,8
307	53	28	17	5	12	39	9,6	9,15	0,7
308	53	28	24	5	12	39	10,3	2,22	1,0
309	53	28	30	5	12	50	8,5	1,28	0,3
310	53	28	37	5	13	1	4,5	3,50	0,8
311	53	28	17	5	13	11	7,7	3,31	0,3
312	53	28	43	5	13	22	5,3	0,47	0,7
313	53	28	30	5	13	22	7,6	2,95	0,3
314	53	28	24	5	13	33	9,9	6,97	0,7
315	53	28	37	5	13	55	4,0	5,93	0,3
316	53	28	24	5	13	55	9,3	3,97	0,4
317	53	28	43	5	13	55	5,5	6,59	0,3
318	53	28	30	5	14	6	4,2	9,89	0,7
319	53	28	43	5	14	16	3,5	2,02	0,4
320	53	28	50	5	14	27	5,9	0,47	0,3
321	53	28	43	5	14	27	6,3	1,87	0,4
322	53	28	56	5	14	49	7,7	29,67	1,0
323	53	28	43	5	14	49	8,5	0,00	0,4
324	53	28	50	5	14	60	5,3	12,26	0,4
325	53	29	3	5	15	11	3,0	1,35	0,7
326	53	29	9	5	15	32	2,4	2,42	0,8
327	53	29	3	5	15	43	3,0	7,00	0,9
328	53	29	9	5	15	54	3,6	38,90	1,0
329	53	29	9	5	16	5	3,2	0,80	0,4
330	53	29	22	5	16	26	2,2	36,70	0,3

Appendix 2

List of macrobenthos species collected during the RIACON*2 project in the sand extraction/borrow area off the island of Terschelling in September/October 1997, and the number and percentage of stations where the species were found. Species indicated with an asterisk (*) were excluded from the data analyses (see 2.4).

Phylum codes:

- 1 Mollusca
- 2 Crustacea
- 3 Annelida
- 4 Echinodermata
- 5 Nemertinae

Taxon codes:

- A Amphipoda
- B Bivalva
- D Decapoda
- E Echinoidea
- G Gastropoda
- M Mysidacea
- N Nemertinea
- O Ophiuroidea
- P Polychaeta
- S Asteroidea
- U Cumacea

species	abbreviation	Phylum	Taxon	n stations	% stations
Lunatia poliana	LUNAPOLI	1	G	15	50
Montacuta ferruginosa	MONTFERR	1	B	16	53
Mysella bidentata	MYSEBIDE	1	B	7	23
Spisula subtruncata	SPISSUBT	1	B	5	17
Tellina fabula	TELLFABU	1	B	28	93
Tellina tenuis	TELLTENU	1	B	17	57
Venus striatula	VENUSTRI	1	B	1	3
Atylus falcatus	ATYLFALC	2	A	4	13
Atylus swammerdami	ATYLSWAM	2	A	1	3
Bathyporeia elegans	BATHELEG	2	A	29	97
Bathyporeia guilliamsoniana	BATHGUIL	2	A	19	63
Callianassa subterranea	CALLSUBT	2	D	19	63
Crangon crangon *	CRANCRAN	2	D	2	7
Dexamine thea	DEXETHEA	2	U	1	3
Diastylis bradii	DIASBRAD	2	U	1	3
Diastylis lucifera	DIASLUCI	2	U	10	33
Gastrosaccus spinifer *	GASTSPIN	2	M	5	17
Iphinoe trispinosa	IPHITRIS	2	U	3	10
Jassa falcata	JASSFALC	2	A	1	3
Orchomene nana	ORCHNANA	2	A	1	3
Pariambus typicus	PARITYPI	2	A	1	3
Petalosarsia declives	PETADECL	2	A	1	3
Pontocratus altamarinus	PONTALTA	2	A	2	7
Pontophylus trispinosus *	PONTRIS	2	D	13	43
Processa modica *	PROCMODI	2	D	2	7
Processa novelli sp. holth. *	PROCNouv	2	D	8	26
Processa species *	PROCSPEC	2	D	5	17
Urothoe poseidonis	UROTPOSE	2	A	16	53
Phylodoce mucosa	ANAIMUCO	3	P	9	30
Capitella capitata	CAPICAPI	3	P	24	80
Chaetozone setosa	CHAESETO	3	P	24	80
Eteone foliosa	ETEFOOLI	3	P	13	43
Eteone longa	ETEOLONG	3	P	7	23
Eteone picta	ETEOPICT	3	P	1	3
Eumida sanguinea	EUMISANG	3	P	24	80
Glycinde nordmanni	GLYCNORD	3	P	1	3
Harmothoe lunulata	HARMLUNU	3	P	29	97
Lanice conchilega	LANICONC	3	P	30	100
Magelona mirabilis	MAGEPAPI	3	P	30	100
Microphthalmus scelzcowii	MICRSCZE	3	P	1	3
Microphthalmus species	MICRSPEC	3	P	1	3
Nephtys caeca	NEPHCAEC	3	P	17	57
Nephtys cirrosa	NEPHCIRR	3	P	9	30
Nephtys hombergii	NEPHHOMB	3	P	6	20
Nephtys longosetosa	NEPHLONG	3	P	4	13
Nereis longissima	NERELONG	3	P	7	23
Ophelia limacina	OPHELIMA	3	P	20	67
Pectinaria koreni	PECTKORE	3	P	1	3
Poecilochaetus serpens	POECSERP	3	P	22	73
Scoloplos armiger	SCOLARMI	3	P	30	100
Scolecopsis bonnierii	SCOLBONN	3	P	26	87
Scolecopsis foliosa	SCOLFOLI	3	P	5	17
Spiophanes bombyx	SPIOBOMB	3	P	27	90
Spio filicornis	SPIOFILI	3	P	17	57
Asterias rubens	ASTERUBE	4	S	1	3
Echinocardium cordatum	ECHICORD	4	E	20	67
Echinocyamus pussilus	ECHIPUSS	4	E	1	3
Ophiura albida	OPHIALBI	4	O	2	7
Nemertinae species	NEMERTIN	5	N	30	100

Appendix 3

Number of individuals per station of the macrofauna species found in the September/October 1997 survey.

Station	301	302	303	304	305	306	307	308	309	310	311	312	313	314	315
Lunatia poliana			1				1			1	1	1			2
Montecuta ferruginosa				6	1		5				1			1	3
Mysella bidentata				2											2
Spisula subtruncata	2		1	1	3						1				
Tellina fabula	4	6	4	1		6	13	2	3	2	4	6	2	3	8
Tellina tenuis				2		1	2		1	1			3	3	
Venus striatula															1
Atylus falcatus											1				
Atylus swammerdami															
Bathyporeia elegans	5	8	1	5	5	4	11	6	2	15	3	2	3	8	1
Bathyporeia guilliamsoniana	2				1	1	2	6	4	5			3	5	
Callianassa subterranea	2		3			1	5			1	1	1	5	2	1
Crangon crangon *															
Dexamine thea							1								
Diastylis bradii															
Diastylis lucifera			1											1	1
Gastrosaccus spinifer *	1		1	2		1									
Iphinoe trispinosa															1
Jassa falcata															
Orchomene nana						1									
Pariambus typicus									1						
Petalosarsia declives															
Pontocratus altamarinus															
Pontophylus trispinosus *			2	1	2	2			2	1					
Processa modica *				1					1						
Processa novelli sp. Holth. *				1	2					1	1		1		
Processa spec. *			1			1									
Urothoe poseidonis	1		6			4	12	2	6	6	1	3	2	1	1
Phylodoce mucosa			1				1								1
Capitella capitata			2	1	1		7	7	2	3	1		74	5	2
Chaetozone setosa	2	5	8	6		6	8	6	7	4	1	6	1	4	3
Eteone foliosa				1						4					1
Eteone longa							2						1	1	
Eteone picta															
Eumida sanguinea		1	2	1		1	2	1			11	3	11	3	1
Glycinde nordmanni		1													
Harmothoe lunulata	3	5	12	3		3	20	6	10	1	19	9	12	17	6
Lanice conchilega	51	19	37	11	1	10	48	17	37	10	19	17	32	35	10
Magelona mirabilis	46	17	17	46	5	34	52	39	18	12	13	29	11	17	10
Microphthalmus scelzcowii															1
Microphthalmus spec.		1													
Nephtys caeca	2		1	2	2		3	2						2	1
Nephtys cirrosa	1			2	1		1	2			1				
Nephtys hombergii	1						3				1				
Nephtys longosetosa															
Nereis longissima							1	1				1			
Ophelia limacina		1	8		2		1	1		1	2			1	2
Pectinaria koreni										1					
Poecilochaetus serpens			1	1	1		4	1			1	1	2		2
Scoloplos armiger	33	32	43	26	23	25	59	37	28	37	22	40	24	53	34
Scolecopsis bonnieri	4	1	1	5	1	4	6	1	1	2	2	3	2	1	1
Scolecopsis foliosa			2						1						
Spiophanes bombyx	3	1	2	6	6	2	2			2	6	1	2	1	1
Spio filicornis					2	2	1	2			1	4	4	2	1
Asterias rubens															
Echinocardium cordatum		1	3	1	1		2		1	1		2		4	3
Echinocyamus pusillus															
Ophiura albida															10
Nemertini	4	4	11	4	1	3	11	4	3	9	4	8	13	10	11
diversity **															
nr. species	17	16	23	21	17	17	29	20	16	20	23	17	19	26	26
H'(S-W)	1,92	2,16	2,38	2,26	2,18	2,17	2,56	2,24	2,1	2,36	2,48	2,22	2,18	2,42	2,58
Evenness	0,68	0,78	0,76	0,74	0,77	0,77	0,76	0,75	0,76	0,79	0,79	0,78	0,74	0,74	0,79
Heip's index	0,36	0,51	0,45	0,43	0,49	0,48	0,43	0,44	0,48	0,5	0,5	0,51	0,44	0,41	0,49
abundance **															
total ind/m ²	2141,026	1384,6	2166,7	1730,8	730,77	1397,4	3666,7	1846,2	1602,6	1512,8	1500	1756,4	2653,8	2359	1384,6
Polychaeta n/m ²	1871,795	1141	1756,4	1423,1	576,92	1115,4	2833,3	1589,7	1333,3	987,18	1282,1	1461,5	2256,4	1833,3	974,36
Crustacea n/m ²	141,0256	102,56	192,31	128,21	141,03	192,31	423,08	179,49	230,77	371,79	89,744	89,744	179,49	269,23	76,923
Mollusca n/m ²	76,92308	76,923	76,923	153,85	51,282	89,744	269,23	25,641	51,282	51,282	89,744	89,744	64,103	128,21	166,67
biomass															
total AFDW g/m ²	7,1692	6,8936	13,769	9,8718	2,4269	7,0538	32,033	12,435	16,191	7,0654	13,017	8,459	17,255	17,621	5,7795
worms AFDW g/m ²	7,0603	6,6397	13,445	9,6154	2,2731	6,9795	30,058	12,382	15,119	6,8167	12,589	8,1051	17,231	16,421	4,9308
molluscs AFDW g/m ²	0,109	0,0526	0,1295	0,159	0,0923	0,0744	0,2551	0,0526	0,0885	0,1615	0,4282	0,1154	0,0244	0,7564	0,3256

* mobile epifauna,

** mobile epifauna excluded

station	316	317	318	319	320	321	322	323	324	325	326	327	328	329	330
Lunatia poliana		2	1	1	1	2		3		1			1	1	
Montecuta ferruginosa	1		2	1		2		7	1	10	10	4			2
Mysella bidentata		4	1					2	1					1	
Spisula subtruncata															
Tellina fabula	2	2	4	6	11	18	2	16	7		18	3	1	6	2
Tellina tenuis		2	1	1	1	1			1	2		1		3	1
Venus striatula															
Atylus falcatus						1			1		1				
Atylus swammerdami														1	
Bathyporeia elegans	5	11	3	9		2	13	6	1	6	8	1	9	11	4
Bathyporeia guilliamsoniana	1	2			6	2	2	2	3		2		1	1	
Callianassa subterranea	4	3	2		7	1	1	3			2		1		
Crangon crangon *						1			1						
Dexaminea thea															
Diastylis bradii				1											
Diastylis lucifera	1	1	1			1	1					1		1	
Gastrosaccus spinifer *											1				
Iphinoe trispinosa	1								1						
Jassa falcata			1												
Orchomene nana															
Pariambus typicus															
Petalosarsia declives					1										
Pontocratus altamarinus				1			1								
Pontophylus trispinosus *	1		1	1					1		1		2		1
Processa modica *														2	
Processa novelli sp. Holth. *			1								2				1
Processa spec. *										1			1		1
Urothoe poseidonis			3			1		1					1		
Phylodoce mucosa				2		1		3	3			1	2		
Capitella capitata	14	1	3		2	3	2	9	4		1	1		3	28
Chaetozone setosa	4	2		7		2	5	3		2	8			2	3
Eteone foliosa	1	1	1		2	2		2	2		1	2			1
Eteone longa		1	3		1			2							
Eteone picta											1				
Eumida sanguinea	7	3	10	1	2	2	4	6	3	1		3	1	4	
Glycinde nordmanni															
Harmothoe lunulata	16	4	5	7	4	11	5	18	9	1	1	9	8	4	5
Lanice conchilega	58	13	22	16	18	12	15	60	14	6	1	9	13	12	7
Magelona mirabilis	4	5	18	26	12	45	4	11	4	2	22	8	7	9	10
Microphthalmus sczelcowii															
Microphthalmus spec.															
Nephtys caeca	1	2				1	1	3		2		2		3	1
Nephtys cirrosa					1	2					1				
Nephtys hombergii		1					1							1	
Nephtys longosetosa		1								1	1				
Nereis longissima			1				1	2	1						
Ophelia limacina	4	2	1			1	2	4		1	4	1	2		3
Pectinaria koreni															
Poecilochaetus serpens	2	1	2	2	5	2	4	3	6			3	1	2	1
Scoloplos armiger	22	34	31	52	39	38	28	39	22	25	19	14	26	30	24
Scolecipis bonnierii	2		1	2	1	1		1		1		2	4	4	1
Scolecipis foliosa	2		5	2											
Spiophanes bombyx	7	37	1	13	1	5	15	5	11	9	3	63	1	6	
Spio filicornis		4			1	1	5	4	2			3		2	
Asterias rubens								1							
Echinocardium cordatum	1		1	2	5	2		7	3	6	3	2		2	
Echinocyamus pussilus						1									
Ophiura albida												1			
Nemertini	14	4	6	6	6	6	7	7	14	5	1	6	2	8	9
diversity **															
nr. species	23	25	26	20	21	29	21	28	22	17	20	22	18	22	16
H'(S-V)	2,37	2,45	2,57	2,24	2,39	2,45	2,53	2,66	2,64	2,31	2,39	2,16	2,24	2,61	2,18
Evenness	0,76	0,76	0,79	0,75	0,79	0,73	0,83	0,8	0,85	0,82	0,8	0,7	0,77	0,84	0,79
Heip's index	0,44	0,44	0,48	0,44	0,5	0,38	0,58	0,49	0,62	0,57	0,52	0,37	0,49	0,6	0,52
abundance **															
total ind/m ²	2230,769	1833,3	1666,7	2012,8	1628,2	2166,7	1525,6	2935,9	1461,5	1038,5	1397,4	1782,1	1051,3	1487,2	1307,7
Polychaeta n/m ²	1846,154	1435,9	1333,3	1666,7	1141	1653,8	1179,5	2243,6	1038,5	653,85	807,69	1551,3	833,33	1051,3	1076,9
Crustacea n/m ²	192,3077	217,95	141,03	153,85	205,13	115,38	243,59	153,85	102,56	102,56	230,77	38,462	205,13	230,77	64,103
Mollusca n/m ²	38,46154	128,21	115,38	115,38	166,67	294,87	25,641	358,97	128,21	166,67	358,97	102,56	25,641	141,03	64,103
biomass															
total AFDW g/m ²	31,3205	5,9333	13,505	8,3385	5,9141	7,8167	9,1718	23,846	7,3846	6,4103	5,2526	6,2859	7,3859	5,1782	3,8962
worms AFDW g/m ²	31,05	5,8013	13,168	7,9974	5,1628	7,3654	9,1551	20,742	6,8167	3,3551	2,2103	5,8308	7,3038	4,9179	3,8538
molluscs AFDW g/m ²	0,1038	0,1321	0,2064	0,1295	0,1885	0,2923	0,0167	0,4128	0,1141	0,1949	0,2897	0,0474	0,0821	0,1667	0,0423

* mobile epifauna,
** mobile epifauna excluded