The impact of marine sand extraction on benthic copepod communities of a subtidal sandbank

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1 Introduction

Sand extraction and dredging in general is one of the most important human impacts on the marine benthic environment (Rumohr & Krost, 1991). Dredges directly impact species that live on or near the seafloor, as the tubes of the extraction ship physically disturb the habitat when they are dragged across the seafloor. Indirect changes in benthic communities, which are strongly determined by sediment structure (Sanders, 1968, 1969; Sanders & Hessler, 1969; Coull, 1972, 1985; Giere, 1993), may result from sediment removal through erosion and changing sediment characteristics causing habitat modifications. The spatial extent and frequency of habitat disturbance influences the degree of ecological impact, but it is a difficult task to detect specific ecological effects due to sand extraction. Dredging statistics are usually not appropriate to determine the dredging intensity at specific sites because the available information is collected over much too broad a scale. Dredgers effectively target sand quality and exploit the habitat in a patchy manner, causing a great deal of spatial variation in dredging effort. Also it is very difficult to detect the effect of human-induced physical disturbance in areas exposed to extreme natural disturbances (Hall *et al.*, 1990; Kaiser & Spencer, 1996). Additionally adequate knowledge of baseline pre-disturbance conditions is often lacking, in order to evaluate the extent of change caused by human-induced disturbance. The assessment of the impact of anthropogenic disturbances on the marine environment depends on the possibility of prediction by the analysis of changes in suitable biological communities. Soft-bottom benthic infauna is most frequently used to monitor the biological effects of environmental change. As a group they are largely sedentary and so must withstand the extremes of their local environment or perish. (Schratzberger *et al.*, 2000) Most studies on the impacts of marine sand and gravel extraction focused on macrofauna (Kenny & Rees, 1996; Newell *et al.*, 1998; van Dalfsen *et al.*, 2000; Sarda *et al.*, 2000; Boyd *et al.*, 2003), which can readily be counted and identified, whereas no studies have been conducted yet on the impacts on the meiobenthos. Meiofauna and in particular harpacticoid copepods react quickly on changes in the environment, making them suitable for ecological monitoring (Heip, 1980; van Damme *et al.*, 1984; Vincx & Heip, 1987; Moore & Bett, 1989).

Marine aggregate extraction is a growing industry. Sand and gravel extraction on the Belgian Continental Shelf increased fivefold from 0.37 million m³ sand in 1979 to 1.69 million m³ in 1999. 95 % of the sand mined in the Belgian waters originates from the Kwintebank, because of its location near the coast, the appropriate grain size and low calcium content of the sand. This intense mining activity makes the Kwintebank a valuable but also a potentially threatened area. The communities of sandbanks and sandwaves in areas with a high amount of exposure, as is the case for the Kwintebank, are adapted to continuous changing conditions. Such communities of high-stress areas are more adept to readjustement to the impact of dredging operations than communities of more stable environments (Desprez, 2000). When stress becomes too severe, however, physical disturbances may decrease community complexity and increase the abundance of opportunistic species (Rzonzef, 1993). Relating the structure of the different harpacticoid communities of the Kwintebank to environmental factors necessitates data on dredging intensity, as this may be an important structuring factor. Since 1978 the Kwintebank has been the subject of several benthic research projects, making it possible to compare the present day communities with the situation of the seventies (Claeys, 1979; Willems *et al.*, 1982b).

In this chapter the following hypothesis has been put forward: sand extraction activities can be associated with changes in sediment characteristics and harpacticoid communities observed between 1978 and 1997. In order to test this hypothesis the different harpacticoid communities on the Kwintebank have been determined and the importance of dredging pressure has been assessed in accounting for variation in community composition across a number of sites that differ in a variety of environmental characteristics. The possible impact of the extraction activities is discussed by comparing the results of 1997 with species distribution data collected in 1978 prior to intensive sand extraction.

2 Material & Methods

2.1 Sand extraction

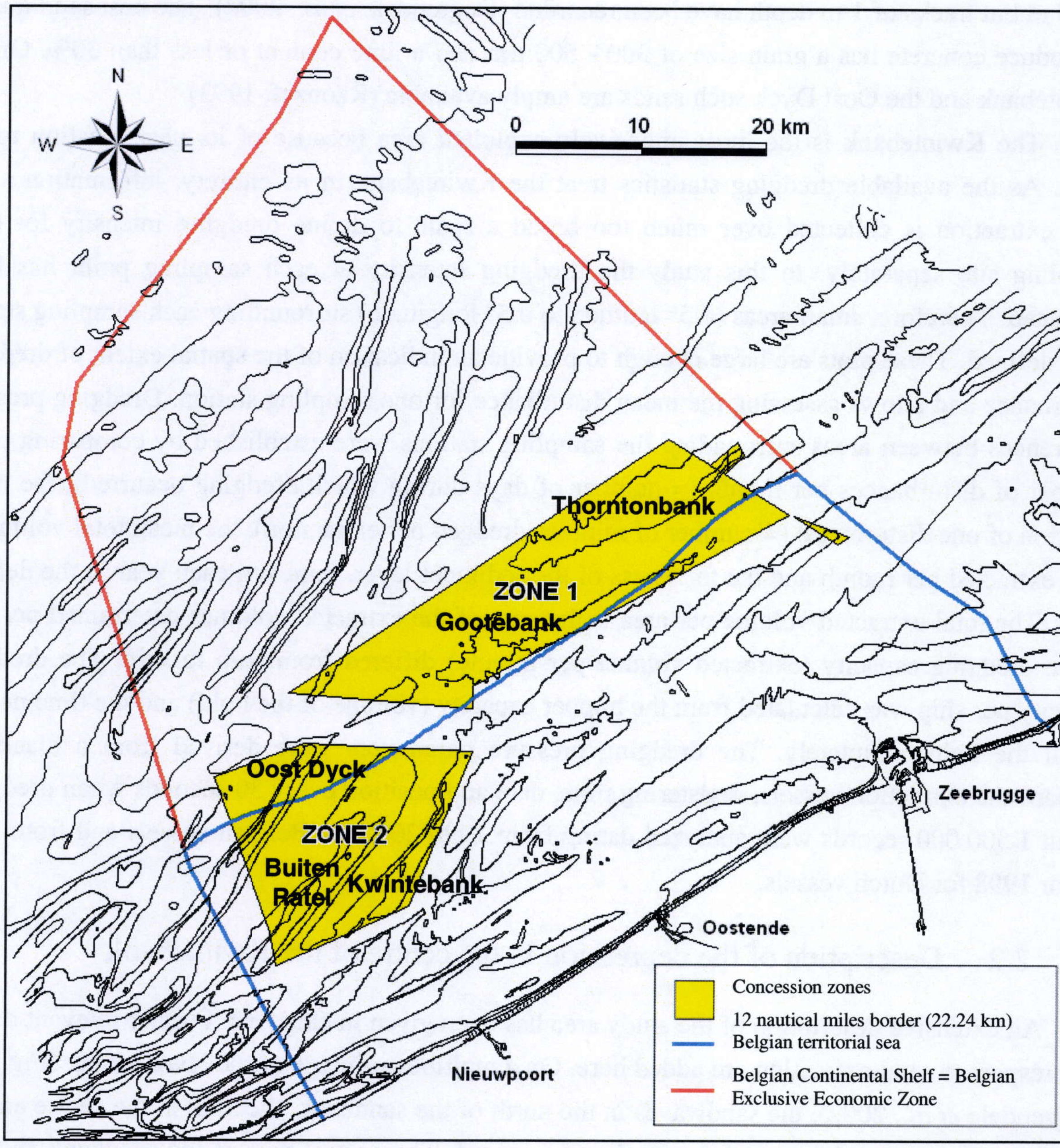

Fig.III.1: Sand extraction concession zones on the Belgian Continental Shelf (Fund For Sand Extraction)

In Belgium marine dredging activities started in 1976 to provide sand for the building industry, for road construction, for beach supplements to slow down erosion of the Belgian coast and exceptionally for land reclamation (Rzonzef, 1993). Two concession zones for sand extraction exist on the Belgian Continental Shelf: concession zone I comprises the Gootebank and the Thorntonbank and is reserved for exploitation in favour of public works. Consession zone II is open to exploitation by private companies and includes the Kwintebank, the Buiten Ratel and the Oost Dyck (Fig.III.1). Since 1996 anchor dredging is banned and trailer suction hopper dredging is the only allowed method in the concession areas of the Belgian Continental Shelf. During trailer suction hopper dredging, a tube at both sides of the extraction vessel is dragged across the seafloor, creating two tracks of 2 m wide and 20 to 30 cm deep (Rzonzef, 1993). The maximum depth is set at 0.5 m but tracks of 1 m depth have been recorded (Degrendele *et al.*, 2002). The best sand quality to produce concrete has a grain size of 300 - 500 µm and a lime content of less than 30%. On the Kwintebank and the Oost Dyck such sands are amply available (Rzonzef, 1993).

The Kwintebank is the most intensively exploited area because of its near location to the coast. As the available dredging statistics treat the Kwintebank in its entirety, information about sand extraction is collected over much too broad a scale to define dredging intensity for each sampling site separately. In this study the dredging intensity at each sampling point has been estimated. Therefore, small areas (0.5° latitude to 0.5° longitude) surrounding each sampling station were defined. These plots are large enough to provide an indication of the spatial extent of dredging disturbance and allows assessing the mean disturbance for one sampling station. Dredging pressure differences between areas surrounding the sampling stations were established by comparing mean number of disturbances per month (= number of days during which dredging occurred), the mean duration of one disturbance (= number of minutes dredged per extraction), the mean total volume of sand extracted per month and the thickness of the sediment layer, removed each year in the defined areas. The total extracted volume per area is the sum of the extracted volumes determined per ship as the dredging capacity (extracted volume per minute) differed from ship to ship. The dredging capacity per ship was calculated from the hopper capacity (volume of the hold) and the time needed to fill the hold completely. The dredging pressure parameters were derived from a black-box onboard the extraction vessels, registering time, date and position every 30 seconds when dredging. About 1 500 000 records were analyzed dating from 1996-2000 for Belgian vessels and from 1997 and/or 1998 for Dutch vessels.

2.2 Description of the depression in the centre of the Kwintebank

An extensive description of the study area has been given in chapter I. Further relevant details with respect to sand extraction are added here. On a multibeam-image of the Kwintebank (Fig.III.2) (Degrendele *et al.*, 2002), the sandwaves in the north of the sandbank, the kink in the centre and the flat elevated plateau of the south are easily recognized. The central part of the sandbank shows a disturbed topography. A depression is formed in the centre beneath the kink in the longitudinal profile of the sandbank. The southern tip of the depression shows a gap in the steep slope of the western flank. The depression runs parallel to the western flank of the centre of the sandbank while the eastern side of the depression forms a continuation of the western flank of the southern plateau. The crests of the large sand dunes situated in the central part of the sandbank display a less pronounced elevation when traversing the depression. The height of the sandwaves is remarkably lower than in the surrounding area.

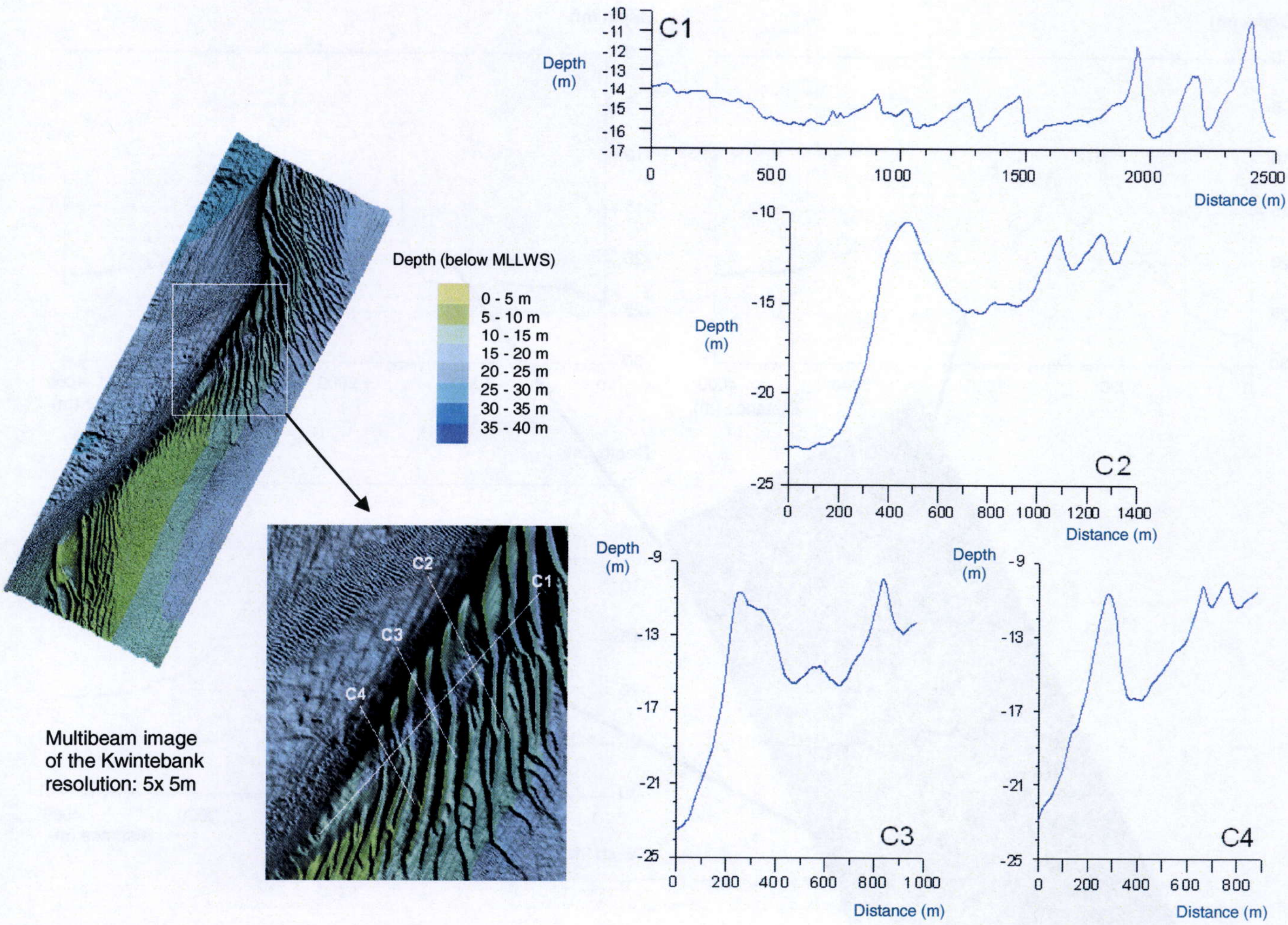

Fig.III.2: Multibeam image of the Kwintebank and cross-sections through the depression in the central part (Degrendele *et al.*, 2002)

Cross-sections through the sandbank were derived from a singlebeam-recording of 1994 and multibeam-pictures of 2000 in order to compare depth profiles (Fig.III.3). By comparing the same cross-section (situated between the meiofauna sampling stations 5 and 6 in the centre) between 1994 and 2000, it was estimated that over a five-year period depth had increased by approximately 5 m in the depression. Cross-sections at most other places along the sandbank did not show such depth differences but only natural oscillations. One cross-section beneath the depression at the centre indicated a decrease of 1 m depth at the eastern side of the sandbank. This decrease is also interpreted to be a result of sand extraction. The depression in the centre is very obvious on the multibeam-image but in the northern top of the sandbank a weaker deepening can also be distinguished in between the sandwaves.

Additional to the geomorphological information concerning the depression in the centre of the sandbank, a rough estimation could be made of the depth differences over 20 years, concerning the entire sandbank. This very rough analysis was based upon the bathymetric charts of 1980, 1995 and 2000 of the Coastal Waterways Division, the Hydrographic Office of the Flemish Region, Belgium (Addendum III.1, 2 & 3).

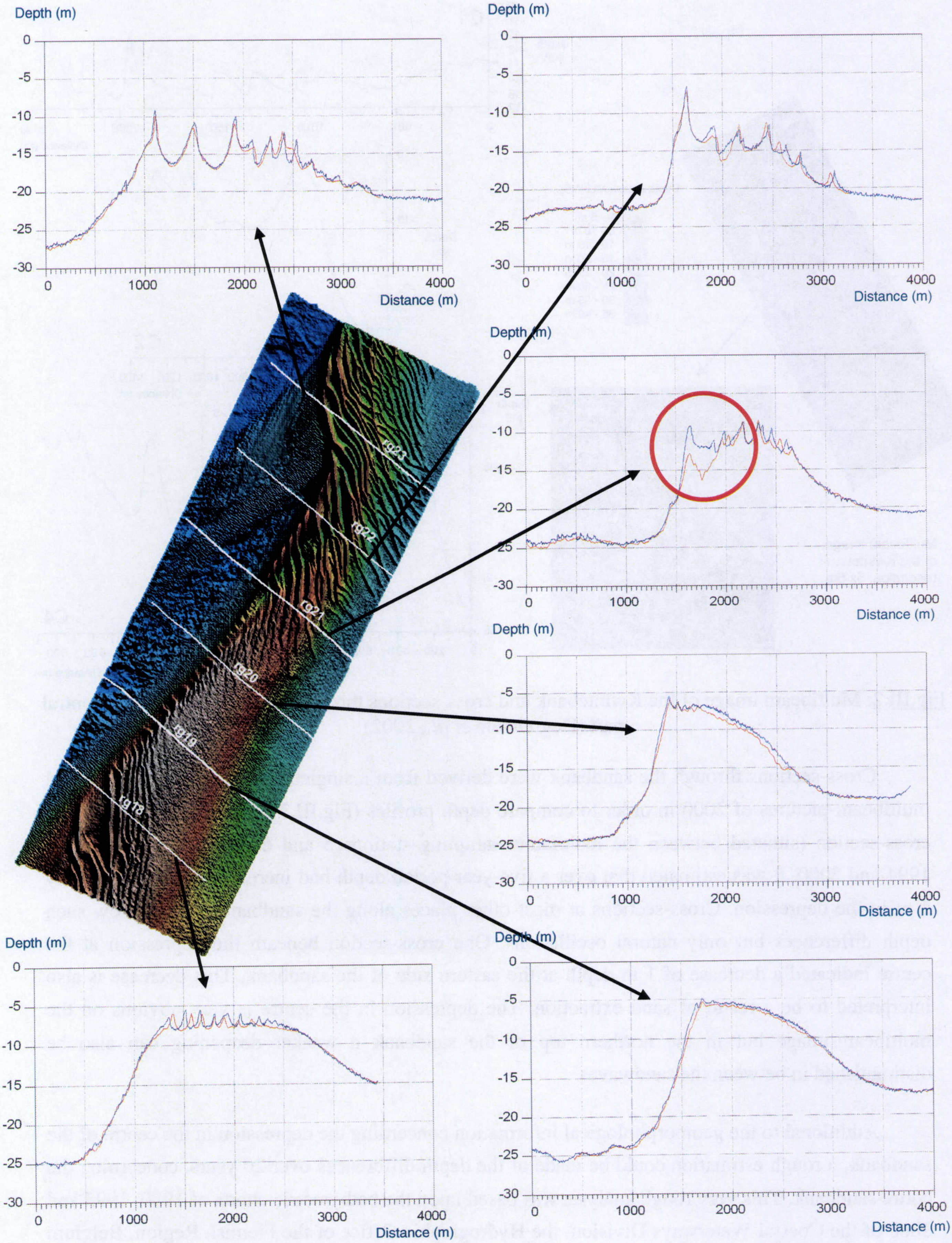

Fig. III.3: Cross-sections through the Kwintebank: singlebeam 12/1994 (red lines) and multibeam 11/1999 – 05/2000 (blue lines), depth below MLLWS (Degrendele *et al.*, 2002)

2.3 Sampling and processing

Meiofauna sampling methods and sample processing are described in chapter I. Additional data used in this chapter originate from a sampling at station 5 on the Kwintebank in 2000 and data of 1978 recalculated and reanalyzed from Claeys (1979). Species richness was also compared with values given in Willems *et al.* (1982b).

In order to compare sediment composition between 1978 and 1997, sediment samples of 1997 had to be submitted to a standard dry-sieving procedure (Wentworth, 1972) for granulometric analysis. Sediment fractions were defined according to the Wenthworth scale (Buchanan, 1984) and expressed as mass percentages.

2.4 Statistics

Hill's numbers (Hill, 1973) were used to calculate diversity. In order to compare densities and diversity indices within 1997 and between 1978 and 1997, ANOVA's were performed on untransformed or log (x+1) transformed data if needed to meet the assumptions for ANOVA. In some cases Kruskall-Wallis ANOVA by Ranks was preferred as relative abundances of some ecotypes and copepodites were still not normally distributed after arcsin (x/100) transformation. A t-test was performed in order to compare a single observation of 1978 with the mean of a sample of 1997 for normally distributed data. If these data were not normally distributed, no comparison could be made because the degrees of freedom were too low to perform a z-test and non-parametric tests are not powerful enough to compare a single observation with a mean. Spearman Rank Order Correlations were used to unravel correlations between densities or diversity indices and granulometric characteristics and Product-moment correlations to search for relationships between sand extraction intensity and total densities or relative copepodite densities. Correlations between individual species presence/absence and parameters of sand extraction intensity were examined by logistic regressions. All univariate analyses (ANOVA, t-tests, Kruskall-Wallis ANOVA by Ranks, Product-moment correlations, Spearman Rank Order Correlations and logistic regressions) were performed with STATISTICA^{TM} software (Microsoft, StatSoft, Inc., 2000).

A Canonical Correspondence Analysis (CCA, Hill, 1974) on fourth root transformed data was applied to describe the structure of the harpacticoid communities of 1997 in relation to environmental factors (granulometric information, depth and sand extraction intensity). The environmental variables retained in the CCA were selected by forward selection using Monte Carlo permutation tests (number of unrestricted permutations set to 999). The harpacticoid community structure of 1978 and 1997 was analyzed by means of multivariate classification and ordination techniques. A Cluster Analysis based on the Bray-Curtis similarity index and Group Average Sorting (Clifford & Stephenson, 1975), a TWINSPAN (TWo-way INdicator SPecies Analysis) (Hill, 1979a) and a Correspondence Analysis (CA, Hill, 1974) were performed on the compiled dataset (fourth root transformed) of the seventies and the nineties. The ordination analyses were performed with CANOCO for Windows (ter Braak & Smilauer, 1998). In order to compare the results of 1997 with the species dataset of 1978, the dataset of 1997 had to be reduced because taxonomical resolution was lower in 1978 and because some representatives of some families (especially Ectinosomatidae and Ameiridae) were not identified down to species level in 1978. In this way, *Kliopsyllus varians* identified in 1978 was lumped with the species *Kliopsyllus* n.spec.2, n.spec.3, n.spec.4 and *Kliopsyllus* spec. defined in 1997. The other species of this genus could be retained. Further taxonomic reductions were performed for the genera *Arenosetella*, *Apodopsyllus*, *Leptopontia*, *Arenopontia*, *Evansula* and *Arenocaris* of which the species identified in 1997 were pooled to genus level.

Different classes of sand extraction intensity were defined using the classification technique Cluster Analysis (Clifford & Stephenson, 1975).

3 Results

3.1 Sand extraction intensity

According to the analysis of sand extraction intensity in the 0.5° latitude x 0.5° longitude (600 x 900m) areas surrounding the sampling stations, three levels of sand extraction intensity can be distinguished (Table III.1): 1) the centre (stations 5 and 6) and the northern top (stations 1 and 2) of the sandbank are very intensively exploited areas, 2) station 3 and the southern part (stations 7 to 10) of the sandbank are exploited much less frequently and 3) at station 4 and the gully stations (almost) no extraction occurs. The centre of the sandbank is disturbed almost every day during the week by the same extraction vessel, for a duration of one hour around station 6 and half an hour around station 5 (Table III.1). In the northern tip sand is extracted every 3 days, during one hour per day around station 1 and three quarters of an hour around station 2. In the centre and the north often two ships or sometimes even three ships visited the same area the same day. Every year an average amount of 62.000 m³ of sand is removed around stations 1, 2 and 5 and 100.000 m³ of sand around station 6. This means that a sediment layer of respectively 12 cm and 19 cm of depth is removed every year of the entire area around the station. The less intensively exploited area (station 3 and the southern part) is disturbed 5 to 6 days a month or about once a week. Stations 8, 9 and 10 are characterized by a disturbance duration of 6 minutes per day, a removal of 4.000 m³ of sand per year or of a sediment layer of 0.3 to 1.3 cm per year. For the stations 3 and 7 these extraction intensity parameters amount to 11 minutes per day, 16.000 m³ of sand per year and 3 cm of sediment per year. In the gully stations no sand is extracted, only one record was registered in station 12. In station 4 no exploitation occurs because the lime content is too high because of the presence of a lot of shell debris. Sand extraction is seasonal: lower values are recorded for December, January and July in comparison with the rest of the year.

Sand extraction intensity	Stations		Frequency (days/month)	Duration (min./day)	Volume of sand removed (m³/month)	Surface removed (cm/year)
1) very high	1 - 2 - 5 - 6	mean ±se	15 ± 2	51.8 ± 6.5	6000 ± 800	13.2 ± 1.7
		range	12 - 19	35.3 - 63.9	5000 - 8300	11.2 - 18.5
2) high	3 - 7	mean ±se	6 ± 1	11.6 ± 1.4	1330 ± 60	2.9 ± 0.1
		range	5 - 7	10.2 - 13.0	1270 - 1380	2.8 - 3.0
2) low	8 - 9 - 10	mean ±se	5 ± 1	6.4 ± 0.5	360 ± 120	0.8 ± 0.3
		range	3 - 6	5.6 - 7.3	150 - 570	0.3 - 1.3
3) very low	4 - 11 - 12	mean ±se	0.2 ± 0.2	0.2 ± 0.2	9 ± 9	0.02 ± 0.02
		range	0.0 - 0.5	0.0 - 0.7	0 - 28	0.00 0.06

Table III.1: Sand extraction intensity on the Kwintebank expressed as mean frequency, mean duration, mean volume of sand removed per month and mean sediment surface layer removed per year

3.2 Sediment characteristics

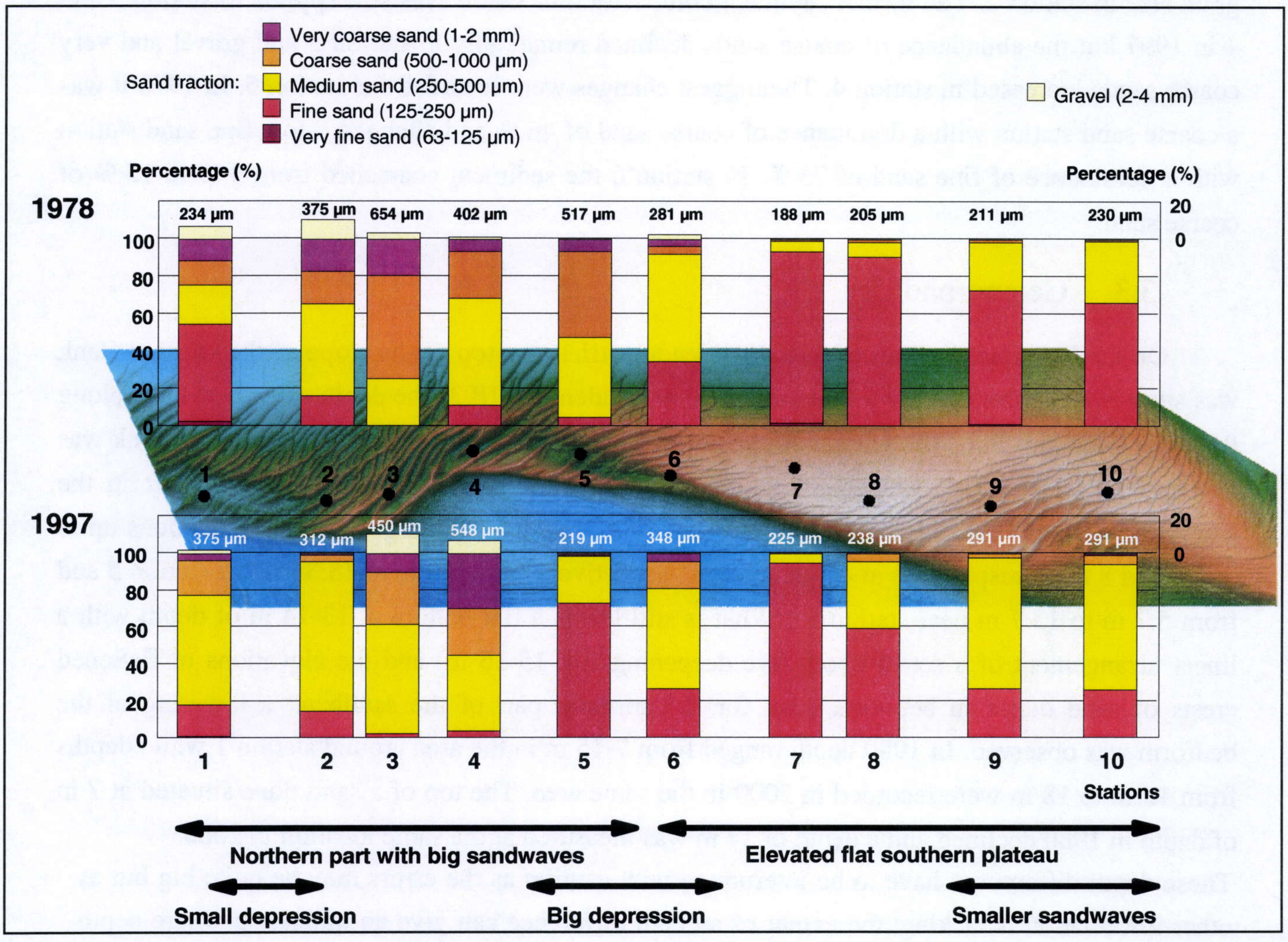

Fig.III.4: Sediment composition on the Kwintebank, the different sediment classes being expressed as mass percentages of the sand fraction and mass percentage of gravel being considered separately. Grain size values are given on top of the bars. Sampling stations are plotted on a multibeam image of the Kwintebank.

In 1978 the median grain size showed a linear trend and decreased from north to south (Willems *et al.*, 1982b). The gradient still existed in 1997 (Fig.III.4) but the difference in grain size between north and south in 1997 was not as pronounced as in 1978, mainly because of dramatic changes at station 5 and because the percentage of medium sand increased to a great extent in the south of the sandbank (from 18 % to 45 %). The domination of this area by fine sands was reduced from 71 % in 1978 to 47 % in 1997. Moreover, the importance of medium sand increased over the entire sandbank from a mean of 33 % in 1978 to 50 % in 1997. The mean percentage of fine sands decreased from 44 % to 35 %. The mean grain size over the entire sandbank, however, did not change at all because the coarsening was counterbalanced by a refining at stations 2, 3 and 5. In 1978 the sandwaves of the north of the Kwintebank consisted mainly of coarse and medium sands (Fig.III.4), while a low content of fine sands was found as well. At the deepest station 1 in the north, fine sands were more abundant in 1978 but also gravel and very coarse material was present, creating a very diverse biotope for meiofaunal organisms. However, the heterogeneous sediment of stations 1 and 2 is much more homogenised in 1997. The gravel, very coarse and fine sands were replaced by medium sands, resulting in a higher median grain size in station 1 and a lower median grain size in station 2. The former sediment composition of sandwaves still applied to station 3 and 4 in 1997 but the abundance of coarse sands declined remarkably in station 3 and gravel and very coarse sands increased in station 4. The biggest changes were recorded for station 5. In 1978 it was a coarse sand station with a dominance of coarse sand of 46 % and changed into a fine sand station with a dominance of fine sand of 73 %. In station 6 the sediment coarsened from 4 % to 15 % of coarse sand.

3.3 Geomorphology

On the bathymetric chart of 1980 (Addendum III.1) the top of the slope of the western flank was situated at approximately 6 m depth, in 2000 (Addendum III.3) the depth measured 14 m along the same boundary line. The bathymetric chart of 1980 shows that the gap in the western flank was not present yet twenty years ago. The large dunes, situated in the western central part in the beginning of the 1980s, were much reduced in 2000. They have undergone height reductions up to 7.4 m and 8 m corresponding to depth changes respectively from 7.9 m to 15.3 m near station 5 and from 5.7 m to 13.7 m near station 6 ! What is still left is a flat bottom at 13-14 m of depth with a linear arrangement of a set of about five deepenings (at 15-16 m) and the elevations of flattened crests of sand dunes in between. Also for the northern part of the sandbank a lowering of the bedform was observed. In 1980 depth ranged from 7-15 m in the area around station 1 while depths from 16 m to 18 m were recorded in 2000 in the same area. The top of a sand dune situated at 7 m of depth in 1980 declined and a depth of 17 m was measured at the same location in 2000.

These depth differences have to be interpreted with caution as the errors may be quite big but as other information is lacking, the extent of a depth difference can give an indication where depth changes really have taken place. The stations for which an increase in depth was found are all situated in the erosion areas as defined by De Moor & Lanckneus (1994) (Fig.III.13.c) while depth didn't change much at the other stations.

3.4 Harpacticoid density and diversity

Densities were significantly lower ($p < 0.001$) in 1997 than in 1978. In 1978 the lowest densities were recorded at the only two stations (7 and 8) with a very high percentage of fine sands (92 %). Density was highest at station 5, characterized by the highest percentage of coarse sand (46 %). Densities at stations 3, 5, 6, 9 and 10 in 1997 were significantly lower than the values of these stations respectively in 1978 (Fig.III.5).

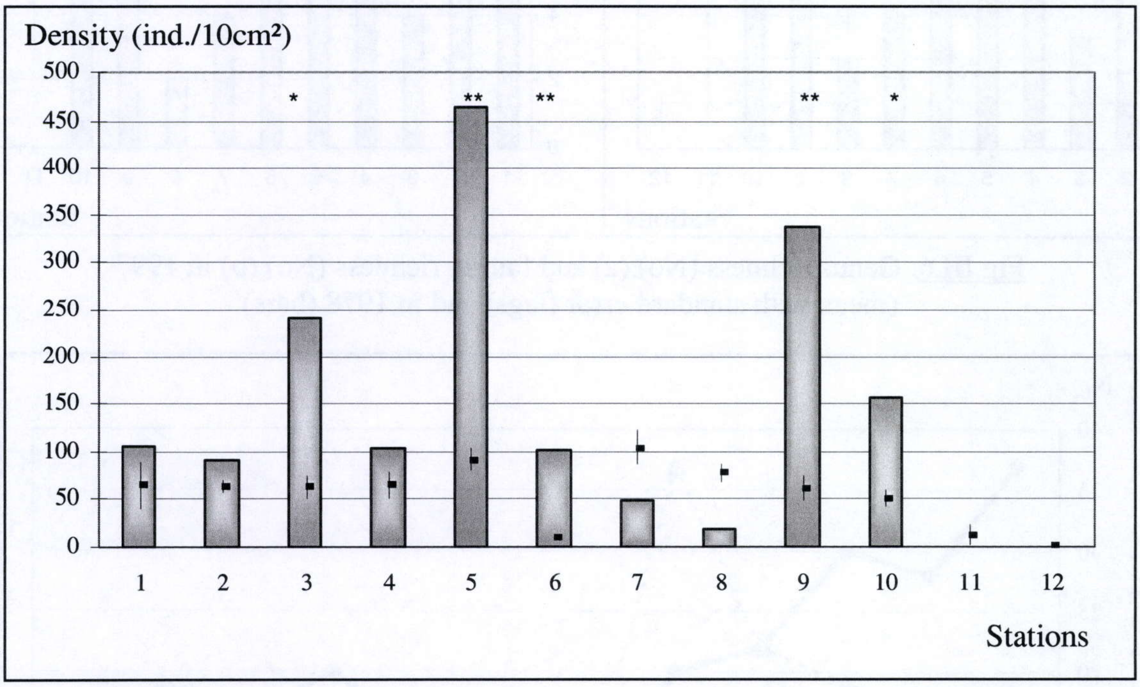

Fig.III.5: Densities in 1997 (mean with standard error flags) and in 1978 (bars), significant differences between 1978 and 1997 at the same station are indicated by *: $p < 0.05$ and **: $p < 0.01$

Although taxonomic resolution was much higher in 1997 than in 1978, species richness was lower near and in the centre of the sandbank (stations 4, 5 and 6) in 1997 than in 1978. Comparing species diversity of 1997 with 1978 accurately was impossible because the bulk of the Ectinosomatidae and Ameiridae were not identified in the available dataset of Claeys (1979). Therefore diversity indices of Hill of both years were compared at genus and family level, although this still resulted in a strong underestimation of genus diversity at station 3 in 1978 because of a high percentage of Ectinosomatidae in this station.

In 1997 genus and family richness were lower in the centre of the sandbank ($p < 0.05$ for station 4 (genus level) and $p < 0.01$ for station 5 (genus and family level)) compared to 1978 (Fig.III.6). Family richness in 1997 was also significantly lower at station 1 ($p < 0.05$).

Between intensively extracted (stations 1, 2, 5 and 6) and not intensively extracted stations a significant decrease ($p < 0.05$) of families was recorded with a loss of 3 families in the north and 4 families in the centre of the bank from 1978 to 1997. In the centre (stations 5 and 6) also the decrease in genera from 1978 to 1997 is significantly different ($p < 0.05$) from the not intensively exploited stations on the bank.

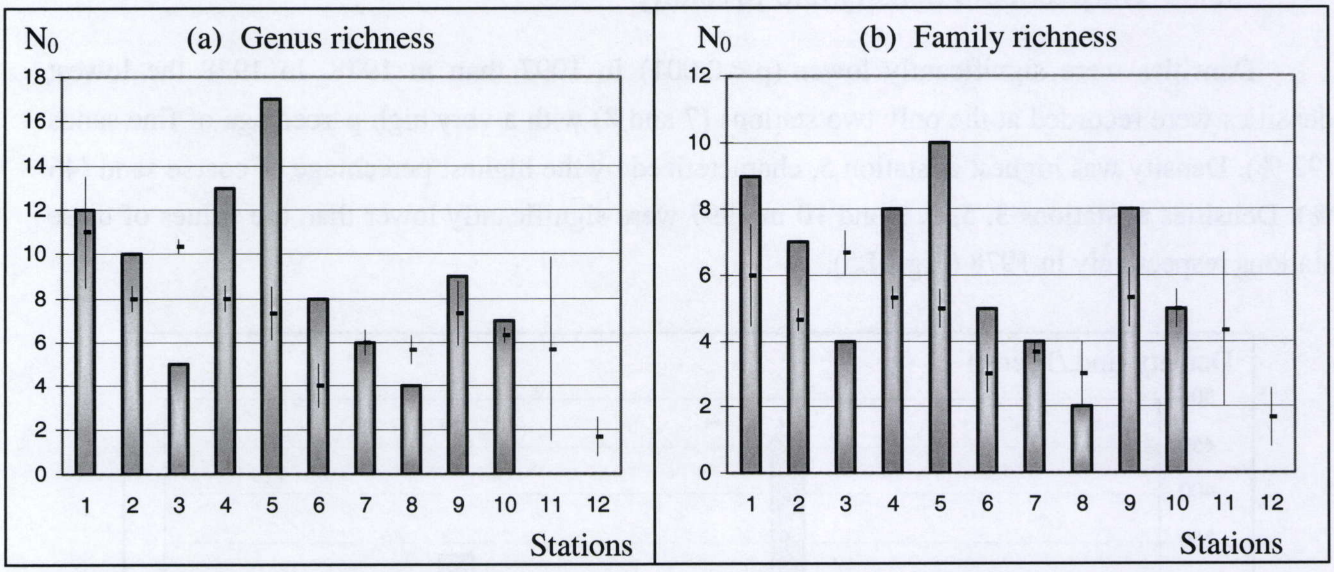

Fig.III.6: Genus richness (No) (a) and family richness (No) (b) in 1997 (mean with standard error flags) and in 1978 (bars)

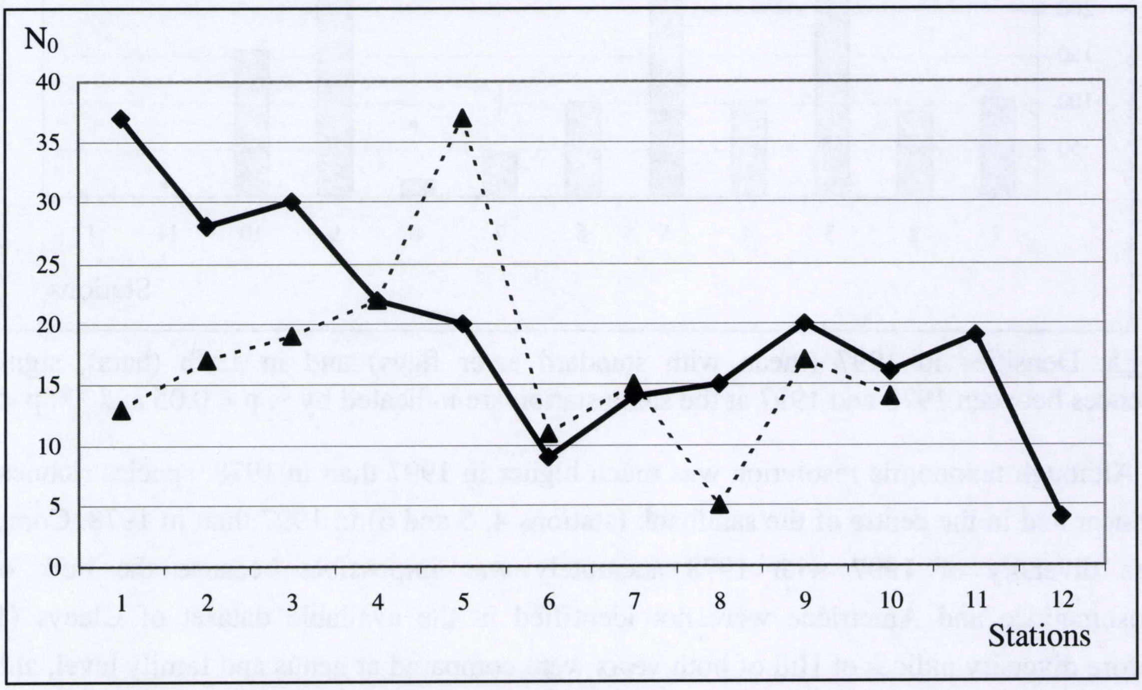

Fig.III.7: Species richness in 1997 (solid line) and in 1978 (dotted line)

In Willems *et al.* (1982b) the total number of species is given for two replicates combined, Ectinosomatidae and Ameiridae also being identified to species level. Comparing these values with the total number of species for three replicates in the nineties, it is clear that stations 1, 2 and 3 yield much more harpacticoid species in the nineties than in the seventies, whereas species richness remained exactly the same at station 4. At station 5 in the centre of the sandbank, the number of species is much lower in the nineties. Species richness at the southern part of the Kwintebank was similar for both periods, except for a rise in the number of species at station 8.

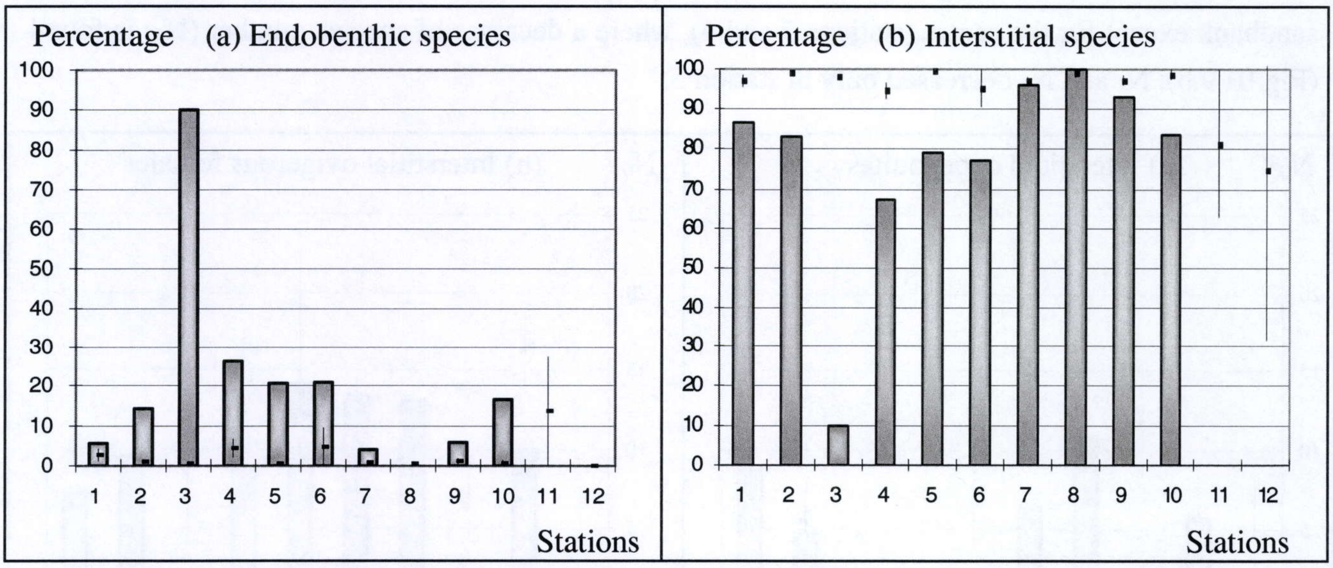

Fig.III.8: Relative abundance of endobenthic (a) and interstitial species (b) in 1997 (mean with standard error flags) and in 1978 (bars)

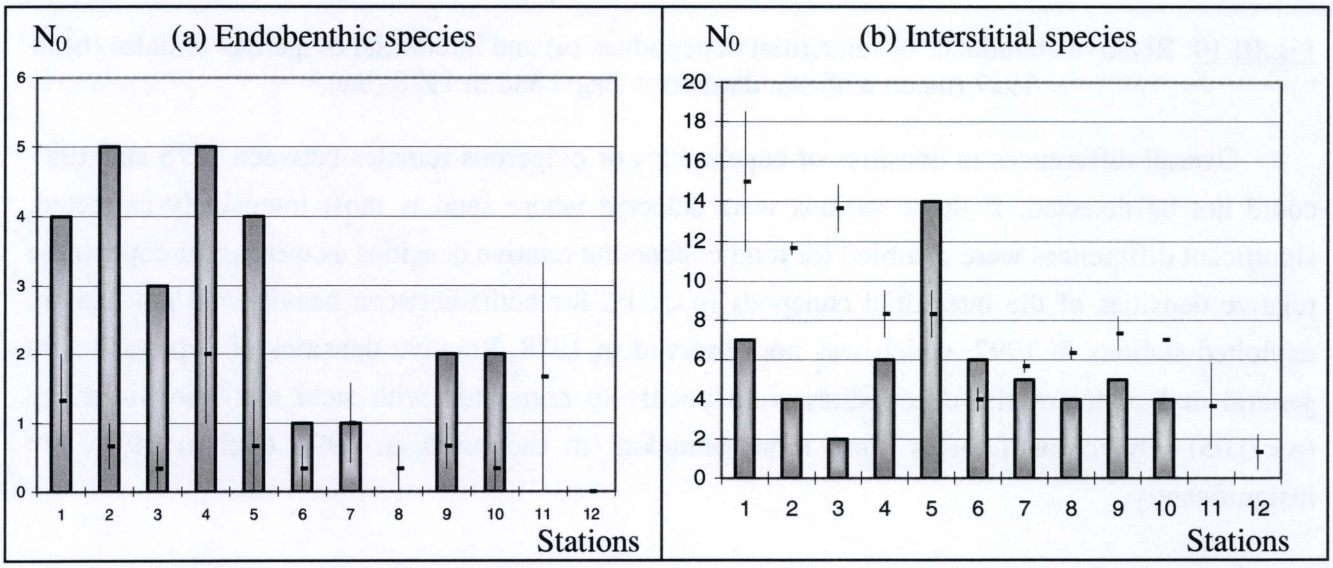

Fig.III.9: Species richness (No) of endobenthic (a) and interstitial species (b) in 1997 (mean with standard error flags) and in 1978 (bars). Species richness of endobenthic species in 1978 is strongly underestimated at station 3.

In the northern tip (station 1) density and species richness of epibenthic copepods were significantly lower in 1997 than in 1978 ($p < 0.01$ and $p < 0.05$ respectively). The decrease in epibenthic species was significant ($p < 0.01$) between the northern most exploited stations and the other categories of stations, grouped by sand extraction intensity. Relative densities (Fig.III.8a), species richness (N_0) (Fig.III.9.a) and N_2 of endobenthic species were significantly lower ($p < 0.001$, $p < 0.05$ and $p < 0.05$ respectively) in 1997 compared to 1978, while the relative densities of interstitial species were significantly higher ($p < 0.001$) in 1997 (Fig.III.8.b). In 1997 the proportion of interstitial species was equal over the entire sandbank with a minimum of 95 %.

Within the interstitial group the diversity indices of Hill increased significantly for the entire sandbank except for the centre (stations 5 and 6), where a decrease of species number (N_0) is found (Fig.III.9.b). N_1 and N_2 decreased only in station 5.

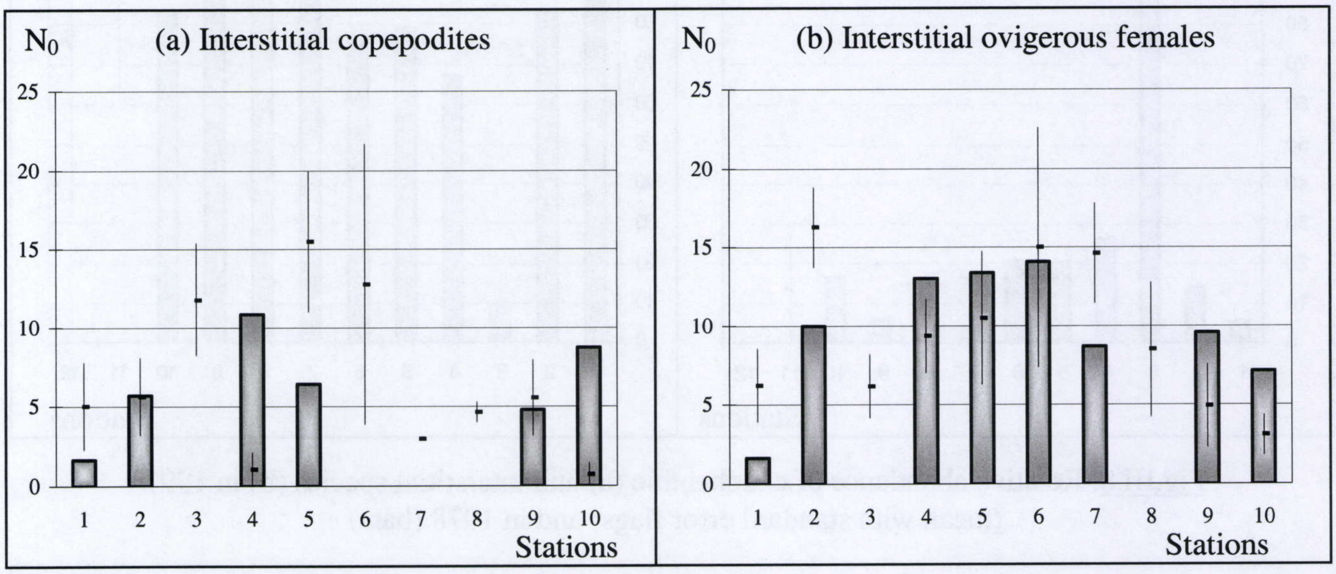

Fig.III.10: Relative abundance of interstitial copepodites (a) and interstitial ovigerous females (b) in 1997 (mean with standard error flags) and in 1978 (bars)

Overall differences in densities of copepodites or ovigerous females between 1978 and 1997 could not be detected. If these stations were selected where sand is most intensively extracted, significant differences were recorded for total copepodite relative densities as well as for copepodite relative densities of the interstitial copepods ($p < 0.05$ for both) between heavily and not heavily exploited stations in 1997, which was not observed in 1978. Relative densities of copepodites in general and of interstitial copepodites were positively correlated with sand extraction intensity ($p < 0.05$). Ovigerous females were more abundant in the north in 1997 than in 1978, but insignificantly.

3.5 Harpacticoid community structure

Fig.III.11 shows that the first axis of the CCA, of length 3.41 SD and explaining 53 % of the variation, is interpreted as a granulometric gradient from coarse to fine sands along the sandbank and the second axis, of length 4.28 SD (eigenvalue 0.39), as a gradient in depth and sand extraction intensity. When the gully stations were excluded, depth was not important anymore but sand extraction intensity was the only important environmental variable with statistical significance ($p < 0.05$) along the second axis.

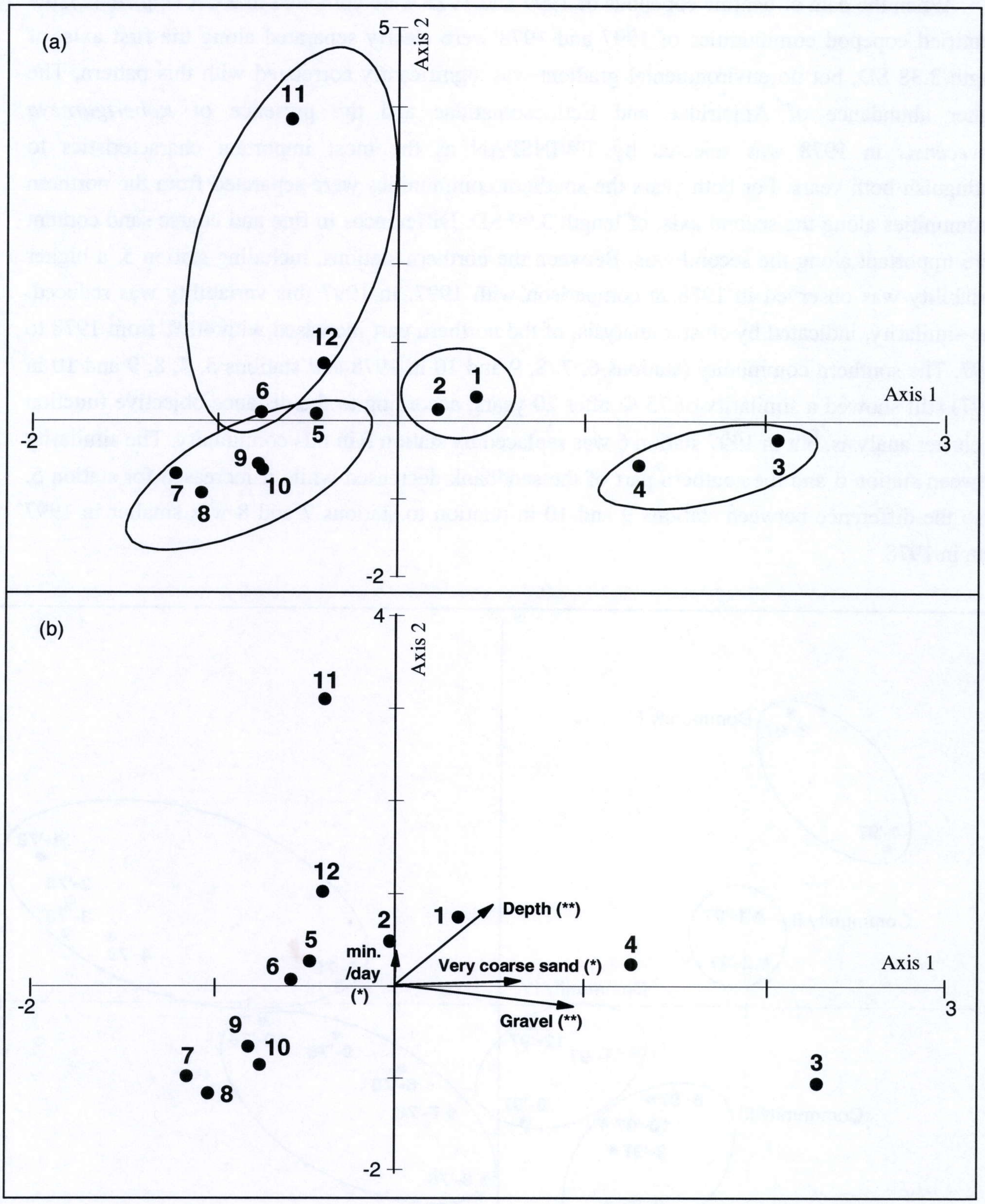

Fig.III.11: Plot of the Kwintebank stations of 1997 in CA (a) and CCA (b) with environmental variables which were selected by Monte Carlo permutation tests as statistically significant (** $p < 0.01$,* $p < 0.05$).

When the data of benthic copepods of 1997 and 1978 were compiled in a CA (Fig.III.12), the identified copepod communities of 1997 and 1978 were clearly separated along the first axis, of length 3.38 SD, but no environmental gradient was significantly correlated with this pattern. The higher abundance of Ameiridae and Ectinosomatidae and the presence of *Robertgurneya ilievecensis* in 1978 was selected by TWINSPAN as the most important characteristics to distinguish both years. For both years the southern communities were separated from the northern communities along the second axis, of length 3.99 SD. Differences in fine and coarse sand content were important along the second axis. Between the northern stations, including station 5, a higher variability was observed in 1978 in comparison with 1997. In 1997 this variability was reduced. The similarity, indicated by cluster analysis, of the northern part increased with 40 % from 1978 to 1997. The southern community (stations 6, 7, 8, 9 and 10 in 1978 and stations 5, 7, 8, 9 and 10 in 1997) still showed a similarity of 75 % after 20 years, according to the distance objective function of cluster analysis, but in 1997 station 6 was replaced by station 5 in this community. The similarity between station 6 and the southern part of the sandbank decreased while it increased for station 5. Also the difference between stations 9 and 10 in relation to stations 7 and 8 was smaller in 1997 than in 1978.

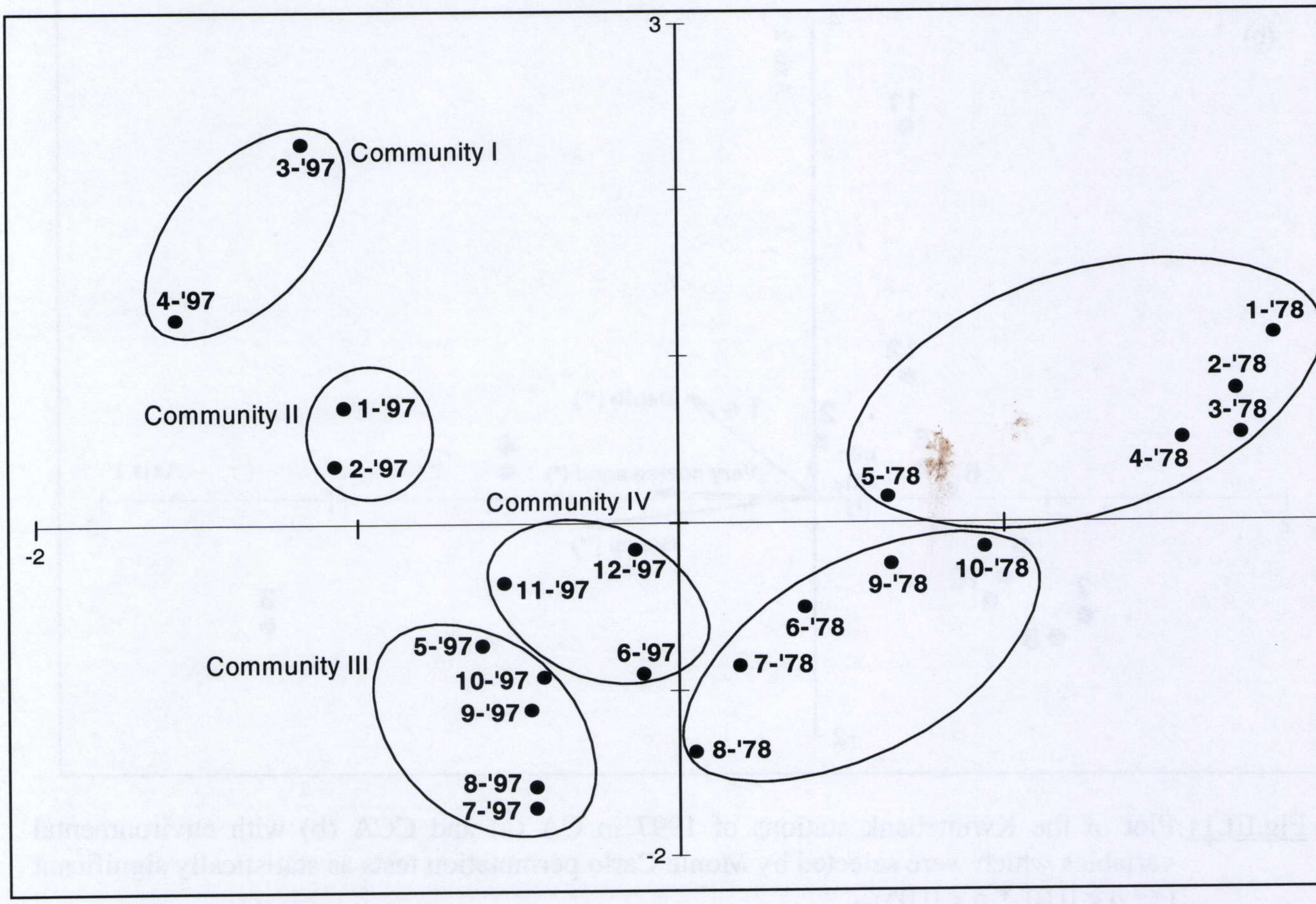

Fig.III.12: Plot of the stations in a CA, based on absolute species densities of the pooled dataset of 1978 and 1997

In the nineties the northern part of the Kwintebank was split up in two easily distinguished communities while in the seventies strong affinities existed neither between station 1 and 2 nor between stations 3 and 4. In the seventies only a high variable northern part was defined with the biggest differences between station 1 and the other northern stations. In 1997 stations 1 and 2 were very similar. In 1978 *Apodopsyllus* n.spec.1 (47 %) and *Stenocaris pontica* (22 %) predominated at station 1 while *Leptastacus laticaudatus s.str.* (18 %), *Paraleptastacus moorei* (10 %) and *Apodopsyllus* n.spec.1 (7 %) were the most abundant species in 1997 (Addendum III.4). *Leptastacus laticaudatus s.str.* (43 %) and *Kliopsyllus holsaticus varians* (25 %) were the two codominant species at station 2 in 1978 while the relative abundance of *Leptastacus laticaudatus s.str.* (11 %) decreased and *Paraleptastacus moorei* (34 %) was dominant in 1997. The latter species was not present at all in the seventies, the lower taxonomical resolution taken into account. In 1997 *Paraleptastacus moorei* was the dominant species and an indicator species of the most northern community but it was not restricted to the community in the northern top, it occurred in station 5 as well. The presence of *Paraleptastacus moorei* was not correlated with any sediment characteristics but positively correlated with all sand extraction intensity parameters ($p < 0.05$).

The southern community was stable in time as for stations 7, 8, 9 and 10 still a uniform species composition was found after 20 years (Addendum III.5). All the species present in 1978 still occurred in 1997. Also the dominant species and the proportional distribution were still comparable. Only Ectinosomatidae and Ameiridae, which were important in 1978 at stations 9 and 10 respectively, were represented in a less extent at these stations in 1997. Of all the stations on the Kwintebank, the species assemblage of station 8 in 1997 showed the highest similarity with its situation in 1978.

3.6 Comparison of the results of 1978 and 1997 (2000) in the depression in the centre of the Kwintebank

	Depression in the centre				
	Station 5			Station 6	
	1978	1997		1978	1997
Very coarse sand (%)	6	0.3		3	4
Coarse sand (%)	46	1		4	14
Medium sand (%)	43	25		57	54
Fine sand (%)	5	73		35	27
Very fine sand (%)	0.1	0.5		0.5	0.2
Sediment change	refining (by accretion of fine sediments in the recently formed depression ?)			coarsening (by erosion ?)	
	1978	1997	2000	1978	1997
Density (ind./10cm²)	463	100	39	101	10
Number of species	20 [(1)]	10	10	8 [(2)]	4
Epi- and endobenthic species (%)	21	1	0	21	5
Interstitial species (%)	79	99	100	77	95
***Paraleptastacus espinulatus*:**					
• abundance (%)	0	64	5	27	25
• copepodites (%)	0	19	0	0	20
	• decreasing density and diversity • community shift • impoverishment			• decreasing density and diversity • impoverishment	

(1) 13 % of individuals were not identified
(2) 21 % of individuals were not identified

Table III.2: Differences in granulometric and biological characteristics between 1978, 1997 and 2000 at stations 5 and 6, situated in the depression in the centre of the Kwintebank

In the central part of the sandbank beneath the kink in the longitudinal profile of the sandbank, a depression was formed, in which stations 5 and 6 were situated and which was not present in the seventies. Station 5 was located in the centre of the depression, while station 6 was situated in the south of the depression near the gap in the steep slope of the western flank of the sandbank. In this area density and diversity decreased dramatically and the abundance of big epi- and endobenthic species decreased in favour of interstitial species.

At station 5 very coarse and coarse sands almost disappeared, the quantity of medium sands halved and fine sands predominated in 1997. As a result of these changes in sediment characteristics a shift was recorded from a species rich northern community to a less divers southern community. This change was reflected by the dominance of *Paraleptastacus espinulatus* and the presence of *Kliopsyllus constrictus s.str.* in 1997, which were typical for the southern community. *Kliopsyllus constrictus s.str.* was absent in 1978 and from *Paraleptastacus espinulatus* only one specimen was found. In 2000 the relative abundance of *Paraleptastacus espinulatus* decreased again but then, *Leptastacus laticaudatus s.str.* reached a relative abundance of 33 %. Yet, the station was still characterized by a southern community fauna since *Paraleptastacus espinulatus, Leptastacus laticaudatus s.str.* and *Kliopsyllus constrictus s.str.* replace each other as most dominant species in this community. *Arenosetella* n.spec.1 increased to a large extent in 1997 and two of the dominant species (*Interleptomesochra eulitoralis* and *Sicameira leptoderma*) in 1978 disappeared in 1997.

At station 6 the sediment coarsened. A big loss of Ectinosomatidae species was observed but there was no clear shift in the dominant interstitial species. Remarkable as well was the increased abundance of juveniles at both stations in 1997, almost exclusively due to the high relative importance of *Paraleptastacus espinulatus* juveniles (20%).

4 Discussion

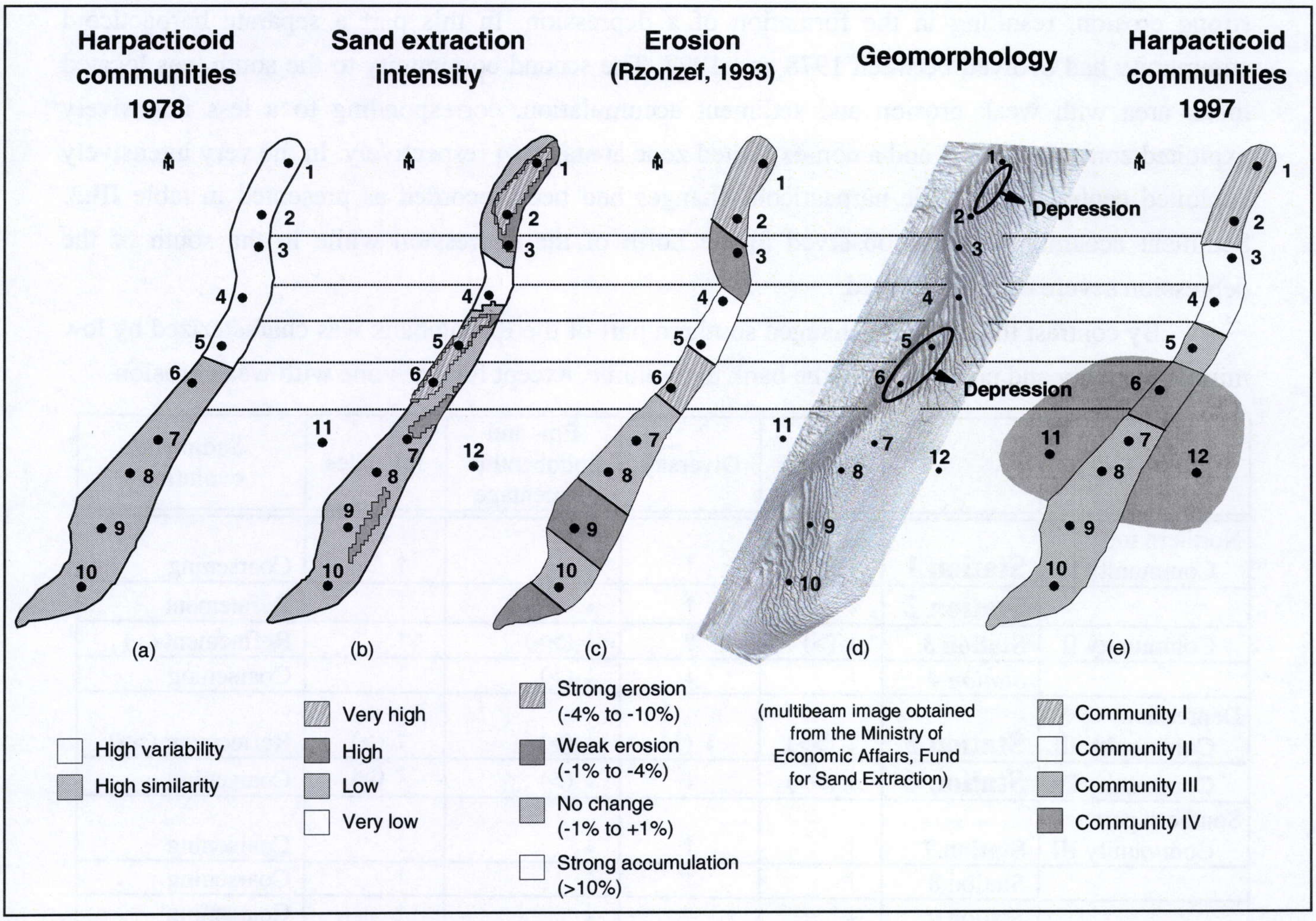

Fig.III.13: Correspondence between sand extraction intensity (b), erosion (c), geomorphology (d) and harpacticoid communities in 1997 (e), compared with harpacticoid communities in 1978 (a) on the Kwintebank

Analogies were found in the occurrence of erosion (Fig.III.13.c) and extraction areas (Fig.III.13.b) and the distribution of harpacticoid communities (Fig.III.13.e) on the Kwintebank. Community analyses of the harpacticoid dataset of the seventies distinguished between a northern part, with a highly variable species composition in the coarser deposits, and a southern community, characterized by a high similarity in the finer sands. This pattern was much different in 1997. The northern part was split up in two communities, while station 5 showed more similarities to the southern community than to the northern part. Station 6 was separated from the southern community due to low densities and the similarities with the gully stations. Stations more to the south remained nearly unchanged.

This community pattern corresponded with different erosion trends and mining intensity patterns. The northern top of the Kwintebank was subject to very intensive sand extraction and strong erosion, resulting in the formation of a depression. In this part a separate harpacticoid community had evolved between 1978 and 1997. The second community to the south was located in an area with weak erosion and sediment accumulation, corresponding to a less intensively exploited zone at station 3 and a non-exploited zone at station 4 respectively. In the very intensively exploited central part drastic harpacticoid changes had been recorded as presented in table III.2. Sediment accumulation was observed in the north of the depression while in the south of the depression severe erosion occured.

By contrast the nearly unchanged southern part of the Kwintebank was characterized by low mining intensity and no changes in the bank top volume, except for one zone with weak erosion.

		Density	Diversity	Epi- and endobenthic percentage	Juveniles	Sediment evolution
Northern top Community I	**Station 1**	↓	↑	↓	↑	Coarsening
	Station 2	↓	↑	↓	↑	Refinement
Community II	**Station 3**	↓ (>)	?	↓ (>>)	↑	Refinement (>)
	Station 4	↓	↓	↓ (>)	↓	Coarsening
Depression Community III	**Station 5**	↓ (>>)	↓ (>)	↓ (>)	↑ (>)	Refinement (>>)
Community IV	**Station 6**	↓ (>>)	↓	↓ (>)	↑ (>)	Coarsening
Southern part Community III	**Station 7**	↑	↑	↓	↑	Coarsening
	Station 8	↑	↑	↑	↑	Coarsening
	Station 9	↓	?	↓	↑	Coarsening
	Station 10	↓	?	↓ (>)	↓	Coarsening

Table III.3: Changes in 1997 relative to 1978 in density, diversity, percentage of epi- and endobenthic species, percentage of juveniles and grain size per station on the Kwintebank; > indicates changes exceeding maximum seasonal differences recorded in other studies along the Belgian coast, >> points to differences exceeding the maximum seasonal fluctuations 1.5 times or more. Sand extraction intensity is expressed as different type fonts of the stations: **Bold 13: very high**; **Bold 11**: **high**; Regular 11: low; *Italic 11: very low*

Although obvious links were observed between the harpacticoid community pattern and sand extraction and erosion zones, table III.3 clearly shows that biological parameters such as density, diversity and ecotype proportion are not closely related to sand extraction intensity nor to sediment evolution. Apart from the percentage of juveniles, correlations could not be detected between biological characteristics and sand extraction intensity. A relationship between sediment evolution and sand extraction intensity was not found either. This does not mean that sand extraction did not impact the fauna because the degree of the impact of extraction activities is site specific and depends on numerous factors, including sediment type and mobility, bottom topography and current strength and the nature of the pre-disturbance community (Desprez, 2000). A similar sand extraction intensity may induce different environmental and biological changes and hence blur an overall analysis of sediment evolution or density and diversity. A lot of observed changes, especially in the centre of the sandbank, clearly surpassed potential seasonal fluctuations and did not clearly correspond to a consistent sediment evolution. These changes will be discussed in detail in relation to sand extraction but attention will also be paid to changes minor to seasonal fluctuations.

4.1 Impacts in the depression in the centre of the Kwintebank

Dredging statistics indicated that a great deal of spatial variation exists in dredging effort on the Kwintebank, as dredgers effectively target sand quality and exploit the habitat in a patchy manner. At the centre and the northern top the most intensive sand extraction was recorded. So far, Vanosmael *et al.* (1979) and De Moor & Lanckneus (1991) considered only the northern top of the Kwintebank to be intensively exploited. This study revealed that the centre of the Kwintebank is even more intensively exploited. In this area, sand extraction affects not only geomorphological and sedimentological but also biological characteristics.

4.1.1 Geomorphological characteristics

Near station 6 the centre corresponds with an area of strong erosion (Fig.III.13.c) (De Moor & Lanckneus, 1994). A multibeam survey (Fig.III.13.d) showed the existence of a depression in this area that was not present in the seventies (Degrendele *et al.*, 2002). Sandwaves are very stable structures (De Moor, 1985; De Moor & Lanckneus, 1994; Lanckneus & De Moor, 1995) but in the centre of the Kwintebank they were almost entirely destroyed, although evidence for quick recovery exists. In 1992 De Moor & Lanckneus (1994) observed a depression of 6 m depth and 100 m wide in the northern part of the Kwintebank, made by anchor hopper dredging, which is not allowed anymore. After nine months the pit was completely filled, illustrating the potential for recovery by sediment fluxes. De Moor & Lanckneus (1991) stated that dynamic sandbanks can withstand extraction activities because of the residual sediment transport from the gullies towards the top of the sandbanks. Infilling of the pits and furrows depends upon the type of substratum and the ability of local currents to transport the surrounding sediment (Desprez, 2000), but also on the frequency of extraction. Due to the continuous and intensive extraction concentrated in the centre of the Kwintebank, this area had no time to recover from sediment losses. This proofs that sandbanks can be significantly affected by continuous and long-term sand exploitation. Storms may destroy small (max. height of 50 cm) and medium dunes on the summit of a sandbank. Even crests of large dunes (max. 8 m heigh) may be lowered with up to 1.2 m under storm conditions (Houthuys *et al.*, 1994). The original shape of small, medium and large dunes are however reconstructed by the fair-weather tidal flows. Depth differences up to 8 m, as recorded in the centre of the Kwintebank on the bathymetric chart of 2000 in comparison with the one of 1980, are therefore considered unnatural. Probably most of the deepening occurred in the nineties as depth had increased by approximately 5 m in the depression between 1994 and 2000 (Degrendele *et al.*, 2002). Depth may change rapidly due to extraction activities. Kenny & Rees (1996) estimated that over a five-day period depth had increased by approximately 2 m in areas where the draghead had followed the same path several times.

4.1.2 Granulometric characteristics

Not only the morphology of a sandbank but also granulometric characteristics are mainly maintained by tidally induced forces (Stride, 1982). Grain size changes can occur after some rough weather crossed a sandbank (Houthuys *et al.*, 1994) but in general grain size distribution of the Flemish sandbanks is regarded as stable (De Moor & Lanckneus, 1994; M. Roche, pers. comm.). Natural hydrodynamics cannot account for the obvious changes in sediment composition between 1997 and 1978 at station 5. De Moor & Lanckneus (1994) found that near station 5 the centre was characterized by a strong accumulation of sediment (Fig.III.13.c). The altered sediment composition at station 5 may result from an accretion of fine sediments, as a consequence of changed current velocities due to the increased depth in the depression. According to several authors (Kaplan *et al.*, 1975; Hily, 1983; Van der Veer *et al.*, 1985; Desprez & Duhamel, 1993) a further implication of the formation of depressions by dredging is a local drop in current strength associated with the increased water depth, resulting in deposition of finer sediments than those of the surrounding substrate. The fine sediments potentially originate both from overflow and from the large natural tidal transport of sediments in the area. Infilling by sediment transport is the most rapid and dominant process if the dredge site is located in an area of active sand transport (Desprez, 2000), like the Kwintebank. Extraction progressively eliminates the original coarse sand and causes the dredged area to fill in with a different sediment type. Similar observations are reported in the dredging site of Dieppe along the French coast by Desprez (2000) and by Van der Veer *et al.* (1985) in the Dutch Waddensea. Sediments filling dredge tracks are generally finer than the original ones and the fauna colonizing the new substrate may differ from the biota present in the adjacent undredged coarser substrates (Shelton & Rolfe, 1972; Millner *et al.*, 1977). The difference between the fauna is proportional to the refinement of the sediment, which itself is linked to the dredging intensity (Desprez, 2000).

The observed refinement and the continued high extraction intensity seem to contradict each other, since dredgers are looking for coarser sands (300-500 µm). It is however not clear how widespread the refinement at station 5 took place. During three later sampling campaigns fine sediments were encountered again at station 5, whereas at other sampled places in the depression the typical coarser sediments were found. Patches of finer sediments along the dredging tracks probably do not matter as long as the total cargo is coarse enough. At station 6 a coarsening is observed and according to detailed dredging statistics the amount of extracted sand is still higher at this station than at station 5, probably reflecting the intention to get the right mixture of sand.

4.1.3 Biological characteristics

4.1.3.1 Harpacticoid communities

4.1.3.1.1 Station 5

The infilling with much finer sediment than originally present has lead to the development of a different harpacticoid community on the Kwintebank. At station 5 a shift was recorded from a species rich northern community in 1978 to a less diverse southern community with a high dominance of *Paraleptastacus espinulatus* in 1997, the density of which was still negligible in 1978. *Interleptomesochra eulittoralis* was the second most abundant species in September 1978 but absent in January 1997. Along the Belgian coast this species reaches its maximum density in January (Huys *et al.*, 1986a). Low values have been recorded in January on a beach on the North Sea Island Sylt while densities were highest in the preceding months November and December (Mielke, 1975). This decline was the result of a temperature drop down to below zero on the beach. On a sublitoral sandbank such a steep temperature drop will not occur and reproduction of *Interleptomesochra eulittoralis* will not be affected because of this reason. This winter breeder should have been recorded in 1997 if the conditions would have been favourable. Comparison of earlier studies in the Southern Bight (Huys *et al.*, 1986b; Huys *et al.*, 1992) revealed that the interstitial harpacticoid community in sandy habitats is stable in time. Yet, changes in species dominance were only observed when they were related with sediment changes (Huys *et al.*, 1986b).

The community shift in the depression contradict the statement of Van der Veer *et al.* (1985) that on sandbanks, excavated sites are filled with sediment similar to that removed by the dredger and hence the colonizing benthic community is similar in composition to that originally present. Indirect impacts of sand extraction are possible due to habitat modification, changes in sedimentation pattern or benthic algal production and nutrient cycling, as similar to the changes induced by trawling (Thrush *et al.*, 1998). The community shift in station 5 in the northern part of the depression can be clearly defined as mainly an indirect impact of sand extraction, acting through sediment changes. Sand extraction may lead to direct changes in the meiofauna through removal or crushing of individuals. The refinement at station 5 may have induced the shift in species dominance but also the direct effect of the frequent removal of the fauna by the extraction activities may not be overlooked.

4.1.3.1.2 *Station 6*

While an impoverishing community shift was recorded at station 5, even a more extensive impoverishment was observed at station 6. At the border of the depression, near the gap in the steep slope of the western flank, conditions must be too harsh for harpacticoid life to maintain successfully. Surprisingly the lowest density and species richness were recorded here in 1997, although higher values were expected due to the considerable amount of coarse sands (Coull, 1985). The sediment even coarsened from 4 % in 1978 to 15 % coarse sand in 1997. Although sediment characteristics were very similar to the richest station on the bank, station 6 showed more affinities to the poor gully inhabiting community.

The northern part of the central depression has been subject to deposition of fine sediments, while the southern part around station 6 was characterized by strong erosion (Fig.III.13.d). A sediment layer of a minimum depth of 20 cm is removed 4 times a year at exactly the same location, each time eliminating the present fauna. Due to intensive sand extraction a gap may have been created in the western flank. The strong flood stream may have a stronger impact on the southern part of the depression than it had before the gap existed. These currents may carry finer sands more northwards in the depression, where the fine material is deposited as a result of decreasing current velocity. The depression is very sensitive to further erosion because the flood dominant transport in the western gully may cause a residual erosion on the steep bank flank (De Moor & Lanckneus, 1991), reinforcing the erosion due to the intensive sand extraction. Only a poor harpacticoid community is able to sustain, due to the direct impact of the frequent removal of the existing fauna and the indirect impact of strong erosion processes. The changes in the harpacticoid fauna in the depression confirm that biological community composition reflects changes in sediment composition, but is also in equilibrium with seabed disturbance, either from human-induced physical disturbance or from tidal currents and wave action, both of which show spatial variations and interactions with water depth (Newell *et al.*, 1998). Disturbance by currents and agitation of superficial bottom layers have been shown to considerably affect harpacticoids (Giere, 1993). For the Belgian and Dutch Continental Shelf Govaere *et al.* (1980) already clarified the importance of hydrodynamic and related forces, which regulate the distribution of finer sediments, suspended materials and nutrients, and hence the dynamics of the benthic system. We may expect that the basic composition and occurrence of the respective communities will remain stable as long as the currents and the amount of suspended material carried will not drastically change (Govaere *et al.*, 1980). This is not only valid at a large scale, but also on a small scale. Sand extraction may have induced unfavourable habitat changes and hence a mediate to strong impoverishment in the harpacticoid fauna.

4.1.3.2 Harpacticoid densities

The decreased densities in the depression relative to 1978 may be a direct result of the removal of sediment and the inhabiting fauna. Throughout most of the year the harpacticoid community of a sandy station at the Belgian Continental Shelf was concentrated at the sediment surface, with over 70 % present in the upper 6 cm (Huys *et al.*, 1986a). Removing the surface layers by sand extraction up to 20 cm (maximum 50 cm and sporadically 1 m) depth is expected to impact harpacticoid abundances drastically. Indeed, density dropped by 78 % at station 5 in the northern part and by 90 % at station 6 in the southern part of the depression. Seasonal fluctuations may also account for the observed differences. The autumn/winter ratio of harpacticoid densities ranges from 1/1 to 3/1 at the sandy stations investigated in Huys *et al.* (1986a) and in Herman (1989). Ratios of 4.6/1 (for station 5) and 10/1 (for station 6) comparing autumn 1978 with winter 1997 are never recorded as seasonal fluctuations along the Belgian coast. However, in a study along the Dutch coast (Huys *et al.*, 1986b) an interstitial harpacticoid community with very high densities in autumn collapsed totally in spring. Density decreased tenfold but the next autumn the community re-established and density was as high again as the previous autumn. In contrast, densities at station 5 on the Kwintebank were even lower in late autumn 2000 than in January 1997. Also year-to-year variation between September samples amount to ten times (Herman, 1989). This holds for coastal muddy and fine sand stations, which are more subject to density fluctuations than the sandbank communities. The large fluctuations at the coastal stations were mainly caused by *Microarthridion littorale*, an epibenthic copepod which is common along the coast and shows a patchy but dense distribution. Comparison of earlier studies in the Southern Bight (Huys *et al.*, 1986b; Huys *et al.*, 1992) revealed that the community in sandy habitats is stable in time. Furthermore it is very unlikely that a big difference in harpacticoid density due to yearly variation at a specific site would not be recorded in the surrounding area as well, even if it is populated with a different community. Yearly variation is not found to be site-specific. In a study of Herman in 1989 yearly variation was detected at a group of sites, some of which populated with different communities. Nevertheless, the lack of available data on seasonal and yearly variation is definitely a shortcoming in this study to compare 1978 and 1997.

4.1.3.3 Ecotype proportions

The changes in species assemblage in the centre imply an increased importance of small interstitial species between 1978 and 1997. Seasonal fluctuations may account for the observed differences. On the southern part of the Kwintebank and on the Gootebank, endobenthic species showed a seasonal density variation of respectively 5 % and 15 % between winter and summer in 1999 (Chapter II). Comparing autumn 1978 with winter 1997, it's unlikely that a decline of 20 % endobenthic species will only be generated by seasonal fluctuations, all the more since the community at station 5 was completely dominated by interstitial species in late autumn 2000. Additional information on seasonal and year-to-year variation in the proportions of epi- and endobenthic to interstitial species are only available from muddy and fine sand stations in the coastal area (Herman, 1989). These oscillations can be very extensive because of the patchy and momentary high abundance of individual epi- and endobenthic species in this area. The population dynamics of an epi- and endobenthic species assemblage can however not easily be extrapolated to an interstitial sandbank community.

Interstitial harpacticoids are able to hide deeper into the sediment than the bigger epi- and endobenthic species. Harris (1972b) found interstitial species migrating down to a depth of 65 cm on an intertidal sandy beach. Such behaviour may be more beneficial than the swimming activity of the epi- and endobenthic species when coping with extreme disturbance. Epi- and endobenthic species do not hide deeper into the sediment to avoid suspension when exposed to physical reworking of the sediment (Thistle *et al.*, 1995). Being suspended they risk to be damaged, expatriated or exposed to water-column predators (D'Amours, 1988) or their energy stores can become depleted (Thistle *et al.*, 1999). The highly mobile epibenthic species and the endobenthic diggers may be able to withstand sand extractions, as long as they are not too intensive (Rzonzef, 1993). The epi- and endobenthic species were present in 1978 but may have disappeared as the extractions became too intensive. Also Thistle *et al.* (1999) found a reduced proportion of surface-living epi- and endobenthic species and a higher proportion of interstitial harpacticoids, which were distributed deeper into physically reworked sediments, in comparison with more quiescent sites.

4.1.3.4 Juveniles

According to Hall *et al.* (1994) the increased abundance of small opportunistic species is a common response of marine soft-sediment communities to increasing disturbance frequency and intensity. The same holds for an increased abundance of juvenile life-history stages (Hall *et al.*, 1994). In 1997 20 % of the *Paraleptastacus espinulatus* specimens were copepodites while no juveniles of this species were found in 1978. Juveniles of *Arenosetella* n.spec.1 and *Evansula* species were only present in the intensively exploited stations and not encountered at other stations in 1997 or in 1978. Egg carrying females and copepodites of *P. espinulatus* in January are remarkable, since this species was found to have a protracted breeding activity from April to December (Huys *et al.*, 1986a). This indicates that *P. espinulatus* has a prolonged egg bearing period and produces a higher percentage of copepodites in the depression than would be the case in an undisturbed environment. At station 8, a much less disturbed area on the Kwintebank, *P. espinulatus* was also the dominant harpacticoid with a relative density of 55 % (the highest percentage on the Kwintebank) but the juveniles of this species accounted only for 4 % of the total density of this species. The capacity to control output, periodicity, and duration of reproduction in response to a stressful environment would incur great adaptability and might be the basis for marked colonizing abilities of opportunistic species (e.g. Marcotte & Coull, 1974, Castel & Lasserre, 1979; Hicks, 1980, 1982). A high investment in gametes makes evolutionary sense in stressed habitats (Hicks & Coull, 1983). However, no juveniles of the abundant species *Leptastacus* *laticaudatus s.str.* were recorded in 1997. Along the Belgian coast this species was found to breed at the same time as *Paraleptastacus espinulatus* with a seasonal breeding activity lasting up to 7 or 8 months, but spawning was much less pronounced (Huys *et al*., 1986a). In the study of Huys *et al*., (1986a) *Interleptomesochra eulittoralis* had egg production for only 4 months and was the last of the dominant copepods to start breeding in the year, reaching maximum densities in January. The restricted breading season of this species may be the reason why it was not present in 1997, being faced with the frequent removal of the population by sand extraction. Females predominating during periods of low population density are also an adaptation for survival at low densities. This would ensure a sufficiently large number of females in reproductive condition (Hicks & Coull, 1983). A significant increasing trend in ovigere females however was not observed between 1978 and 1997 at the most intensively extracted stations. The significant increase in juveniles in the most exploited stations is remarkable because January is one of the least productive months of the year, falling out of the reproductive period of most interstitial species (Hicks & Coull, 1983). These indications however cannot ensure a clear relationship with sand extraction since the comparison is based on one observation in the nineties.

4.1.3.5 Recolonization

On the eastern flank of the depression, near the northern tip of the southern plateau, a very rich community was present in 2000 (Bonne, unpubl. data). Stephenson *et al*. (1978) and Jones & Candy (1981) both documented the enhanced diversity and abundance of benthic fauna near to dredged channels. Disturbance of sediments by dredging may release sufficient organic matter to enhance species diversity and population density outside the immediate zone of disturbance (Newell *et al*., 1998). The rich communities may recolonize the affected areas on the Kwintebank if sand extraction is ceased to make recovery possible. Due to the detection of the depression, the Ministry of Economic Affairs has decided to close the central part of the Kwintebank for sand extraction in the beginning of 2003 for a period of 5 years.

In spite of the general sensitivity of harpacticoids, also illustrated in the present study, harpacticoids are the most commonly and rapidly recovering taxon due to their active emergence. In contrast, the usually more "sediment-bound" nematodes have a lower potential of recolonization (Giere, 1993). Passive suspension (Bell & Sherman, 1980; Palmer 1988) combined with active emergence (Armonies, 1989) are regular phenomena and lead to rapid dispersal and recolonization of disturbed habitats (Giere, 1993). Mainly diatom-eating species have been recorded to perform excursions in the water column and especially epibenthic harpacticoids are passively transported through suspension by regular tidal currents (Giere, 1993). Recolonization by the interstitial community will last longer, as the vermiform interstitial species are not able to swim (Hicks & Coull, 1983; Bonne, pers. obs.).

The natural communities of gravels and sands contain varying proportions of slow-growing K-selected equilibrium species depending on the degree of disturbance by waves and currents. These communities are held in a transitional state by natural environmental disturbance and are likely to recover within a period of 2-3 years after cessation of dredging. This holds for macrobenthos, meiobenthos will likely recover at a faster rate (Newell *et al.*, 1998). A 9 m² defaunated area of intertidal mud was recolonized by harpacticoids within one day (Sherman & Coull, 1980). The rate of recovery is highly variable depending on the type of community that inhabits the deposits in the dredged area and surrounding deposits, the latitude and the extent to which the community is naturally adapted to high levels of sediment disturbance and suspended particulate load (Newell *et al.*, 1998). The community inhabiting the depression in 1997 is predominated by small interstitial species with a high percentage of juveniles. They are typical r-strategists with a short life cycle so this community will be able to increase densities very rapidly. According to Rees (1987), colonization by a range of infaunal species in soft sediments will occur within weeks or months depending on season, largely through larval recruitment. Also diversity will increase by immigration of the invading species of the rich communities living at the border of the depression. Recolonization by populations of motile epifaunal browsers and predators will depend on the availability of suitable food, but may occur opportunistically through migration of adults into the area or via larval recruitment (Rees, 1987).

The readjustement of the benthic new community after cessation of dredging is not only linked to parameters such as the larval and adult pool of potential colonizers and the nature and intensity of stress usually endured by the community, but also to the nature and stability of the sediment exposed or accumulated at the extraction site (ICES, 1992; Newell *et al.*, 1998). The recovery of the original community depends on the evolution of the sediments present in the depression. It 's unclear whether the original western bank flank in the centre will be restored after cessation of dredging as the current directions and velocities may have changed too much and may hamper the deposition of sediments transported by tidal currents. Natural infill of the dredging site is limited by currents and depends on bottom morphology. In the deepest and narrowest part of a dredging site (dredged to 12 m below original bottom level) in the Seine estuary (France), an acceleration of tidal bottom currents had prevented any restoration, whereas in the larger and shallower part (maximum deepening of 5 m) fine sediments were deposited that were five times more silty than in the reference area (Desprez, 2000). Different levels of recolonization were also observed in the dredging site off Dieppe (France). Recolonization nearly achieved 2 years and 4 months after cessation of dredging in the western part, where intrusion of mobile coarse sands had occurred. Recolonization was in progress in the median sector of the dredging site with increasing number of coarse sand species and decreasing number of fine sand species, whereas the deposition area in the eastern part was still dominated by clean fine sands with the lowest species richness, abundance and biomass (Desprez, 2000). This contrasts with a study at the Catalan coast (Spain), where large quantities of medium to coarse sand were dredged for beach nourishment. After a short period of heterogeneous sediment composition and presence of organic debris, the depressions were gradually replenished by new sand deposits and mean grain size composition reached pre-dredging values in less than one year (Sardá *et al.*, 2000). The recovery of the central part of the Kwintebank is doubtful. Accurate monitoring will have to point out in which direction the area evolves and which further implications are to be expected.

4.2 Impacts in the northern part of the Kwintebank

4.2.1 Geomorphological characteristics

At the northern top of the sandbank (stations 1 and 2) sand extraction intensity is as high as at station 5 in the depression of the sandbank. At station 3 extraction intensity is four times less while at station 4 no extraction activities are taking place (Fig.III.13.b). The northern top is subject to strong erosion, while station 3 is characterized by weak erosion and station 4 is situated in an area of sediment accumulation (Fig.III.13.c) (De Moor & Lanckneus, 1994). Comparing the bathymetric charts of 1980 and 1995 large depth differences could be detected at the northern top. On the multibeam-image a disturbed topography with a depression was observed in this area. Stations 1 and 2 are situated just north and south respectively at the border of this depression. The origin and the dynamics of this depression are not studied yet by geologists but the link with sand extraction is obvious (Fig.III.13), just as in the centre of the sandbank.

4.2.2 Granulometric characteristics

The homogenisation of the sediment at stations 1 and 2 between 1978 and 1997 is confirmed by data gathered by the Ministry of Economic Affairs (Fund For Sand Extraction) from 1989 to 1999 (Degrendele, unpubl. data). The sediment composition (with 68 % medium sand) of a station situated in the depression and about 200 m SE from station 1, was stable in these ten years and very similar to the sediment composition at station 1 in 1997. A second station was located about 100 m NW from station 1 and characterized by much coarser sediment (10 % very coarse and 28 % coarse sand) in 1989. During the following ten years the sediment composition evolved towards that of station 1 in 1997 since the medium sand content increased to 73 %. These evolutions may indicate that medium sand accumulates in the depression and that the depression is probably expanding. In Lanckneus *et al.* (1992a) granulometric data are available from the area around station 1 from 1989-1991, in De Moor & Lanckneus (1994) from 1991-1993 and in Vernemmen (2001) from 1996-1997. Median grain size was defined with the same methodology as in the present study. In September 1978 station 1 had a median grain size of 234 µm while it was roughly assigned to the class of 300-500 µm in November 1989 and in 1991 more precisely to the class of 400-500 µm (in June as well as in December). It is not possible to detect any differences comparing the classifications of 1989 and 1991 but Lanckneus *et al.* (1992a) specified a coarsening in this area not exceeding 200 µm. In May 1993 station 1 was characterized by a mean grain size between 300-

400 µm, reaching a value between 400 and 450 µm in May 1996, while it was assigned to the class of 350-400 µm in 1997. Indeed, the median grain size at station 1 was 375 µm in the present study.

Lanckneus *et al.* (1992a) concluded that grain size parameters on the northern Kwintebank vary through time. Yearly and seasonal variation were clearly detected but the residual difference between 1978 and 1997 was a coarsening of the sediment from fine to medium sand, because in the area of 1 km² surrounding the station a grain size below 300 µm was not recorded anymore since the end of the eighties. The grain size measurements for macrobenthos sampling in seventies and nineties also indicated a significant increase in grain size (Rekecki, 2002, chapter IV).

Conversely, the coarsest patches at 1.5 km northwest of station 1 are subject to a refining. In 1989 these patches had a mean grain size up to 1500 µm. The maximum grain size measured in the same area was 921 µm in June 1991, 870 µm in December 1991, 780 µm in 1993 and 760 µm in 1996. Mean grain size increased again to 847 µm in 1997. In this particular area a grain size decrease up to 600 µm was observed from 1989 to 1991 (Lanckneus *et al.*, 1992a). It was unclear whether the decrease was related to either seasonal processes or to sand dredging operations, because the examined area was located in the northern exploited area and not compared with a non-exploited area. The whole time series indicates that the very coarse patches are more subject to fluctuations than areas with finer sediments and that a residual refinement of the sediment is detected anyhow. The two opposite long-term trends result in a homogenisation of the sediment in the total area, which was already postulated from the increased dominance of medium sand by comparing the samples of 1997 and 1978 at stations 1 and 2 in the present study.

At stations 3 and 4 it's more difficult to distinguish between natural and unnatural sediment changes because the changes are not as abrupt as at station 5 and no extensive additional information is available from other studies as for stations 1 and 2. The observed changes in sediment composition may result from (1) the sampling of small-scale spatial variation proper or from a number of factors inducing sediment changes on sandwaves: seasonal or yearly variation (2), small-scale spatial variation as a result of the movement of the crests of sandwaves (3) and influences by storms (4).

(1) Differences may exist between sandwave tops and depressions because in ripple mark areas crests contain coarser sediments than troughs. In troughs, fine sand and often a flocculent surface layer tend to accumulate, resulting in a higher content of organic material. This varying small-scale sediment pattern represents different microhabitats for meiobenthic animals (Eckman, 1979; Hogue & Miller, 1981; Hicks, 1989). This small-scale difference is not verified yet for sandwave systems but may be responsible for observed differences. Taking replicated samples reveal this spatial variability. The first and third replicate of a station can be 130 m remote from each other and the maximum difference between the mean grain size of 3 replicates at station 3 was 70 µm, the maximum difference of the coarse sand fraction 18 %. Therefore, the difference between 1978 and 1997 at station 3 is higher than this observed small-scale spatial variation.

(2) Coarse sands are subject to considerable seasonal and yearly fluctuations but in the vicinity of station 3 grain size changes recorded in Lanckneus *et al.* (1992a) between 1989 and 1991 were less than 200 µm, while this threshold is exceeded for station 3 in the present study.
(3) The displacement of the crests of large dunes on the Kwintebank has been studied for many years (De Moor, 1985) but no net movement has ever been detected. The positions of the crest lines of the large dunes can however change on a short-term basis. Between February and June 1989 a net movement of 30 m was recorded but in November 1989 the crests were returned to roughly the same positions they had 11 months earlier. The bank always seems to recover from such abrupt changes and the oscillatory movement of the crest lines is probably determined by wind- and swell-induced processes (Lanckneus & De Moor, 1995).
(4) The impact of storm events on the morphology and movement of large dunes was studied by Houthuys (1993). A comparison of the pre- and post-storm results showed that crest lines migrated a maximum distance of 5 m.

A movement of 5 m (due to storms) to 30 m (displacement on short-term basis) of a large dune crest will not be important in inducing differences between 1978 and 1997 as a larger area is covered by taking replicated samples. It is improbable that natural variation induced the sediment changes at station 3. Sand extraction may have reduced the high percentage of coarse sands by homogenising the sediment but this definitely needs more investigation. The changes at station 4 are smaller and may be due to natural variation. An accretion of shell debris may have resulted in the coarsening as the area around station 4 is an accumulation point of material (including shell gravel) coming from the gullies and this process may be enhanced by storm events (Tytgat, 1989).

4.2.3 Biological characteristics

4.2.3.1 Density and diversity

Copepod density dropped by 39 % and 31 % at stations 1 and 2 respectively. The observed sediment changes are not responsible for this decline because two opposite trends in sediment change at stations 1 and 2 both resulted in a decrease in density. Harpacticoids become more abundant as the particle size of the sediment increases (Hicks & Coull, 1983; Huys *et al.*, 1986b). According to this relation, density in station 1 should have increased while the opposite trend had to be observed in station 2, which was not the case. It is unclear whether the decline may be explained by seasonal fluctuations or by the intense extraction activities. The density drop is confined within the range of seasonal variations but extraction activities may also have contributed to the decreasing trend by the removal of fauna, consistent with the results in the depression in the centre. Densities at stations 1 and 2, however, were not as seriously affected by the same frequency of extractions as in the central depression of the Kwintebank.

Also diversity remained high (the highest values of the sandbank in 1997) but the abundance of big epi- and endobenthic species decreased and species composition altered in favour of interstitial species. At station 1 the increase and subsequent predominance of medium sands in the nineties may have caused this trend, since more interstitial species will develop with increasing grain size (from very fine to coarse sand) (Huys *et al.*, 1986b). In contrast, a decrease of coarse sand at station 2 coincided with an increase in interstitial species as well. The observed differences do not exceed seasonal fluctuations already recorded along the Belgian coast, but a link with sand extraction intensity can also be demonstrated. The smaller interstitial species have a shorter life cycle and reproduce much faster. A common response of the northern top and the central depression to the extraction activities is the significant increase of juvenile life-history stages of the small opportunistic interstitial species in both areas. In the northern top, diversity of interstitial species even increased, while it decreased in the central depression. General benthic ecology, but also meiobenthology, could show that disturbance and diversity are not necessarily negatively correlated (Warwick *et al.*, 1986). The natural communities of gravels and sands are held in a transitional state by natural environmental disturbance (Newell *et al.*, 1998). Such a natural ecosystem with its incessant cases of disturbance is never completely stable (Huston, 1979), because disturbances interfere with the established ecological balance and create new niches. Consequently, even in areas with disturbances of predominantly abiotic origin, a considerable meiofauna diversity can be maintained, provided the interferences are not too drastic (Giere, 1993). Due to the high hydrodynamical stress the community in the north is used to frequent physical disturbances and can resist intensive extraction better than the community in the centre in terms of density and diversity. Communities of high stress areas (e.g. shallow areas exposed to strong tidal currents and periodic storm disturbance) are more adept to readjustement to the impact of dredging operations than communities in more stable environments (Desprez, 2000).

4.2.3.2 Harpacticoid communities

Clear changes in harpacticoid communities were detected. Two separate harpacticoid communities I and II have evolved between 1978 and 1997 in the northern part, which was not subdivided in 1978. *Apodopsyllus* n.spec. 1 became less important in the habitat predominated by medium sand in station 1 and a newly appearing species *Paraleptastacus moorei* became dominant in community I whereas it was absent in community II. This species is not restricted to the community in the northern top but occurs in station 5 as well. The presence of *P. moorei* is positively correlated with sand extraction intensity. *Paraleptastacus* species appear to be adapted to different biotopes (Whybrew, 1984). In the intertidal areas of temperate sandy beaches, where they are often important or even dominant (Noodt, 1957; Mielke, 1976; Moore, 1979b), the sympatric occurrence of *Paraleptastacus* species is defined by the conditions of varying exposure (Whybrew, 1984). *P. supralitoralis* was restricted to the upper beach face of high energy beaches. With decreasing exposure its optimal environment and hence the scope of its population becomes increasingly limited. *P. spinicauda* preferred grain sizes between 200 and 450 µm but required more constant environmental conditions for optimal population development than *P. supralitoralis* (Whybrew, 1984). *P. spinicauda* also occurs on the Kwintebank in 1997 being restricted to the coarse sands of community II (stations 3 and 4). *P. moorei* may be the counterpart of *P. supralitoralis* on the Kwintebank. Like *P. supralitoralis,* the fitness and competitive abilities of *P. moorei* may be higher in environments of increasing disturbance (e.g. by sand extraction). As sediment characteristics are appropriate for *P. spinicauda* to occur in community I, it may be restricted to community II because of the elevated sand extraction intensity at stations 1 and 2.

More characteristics reflect the differences between community I and II in 1997. According to Huys *et al.* (1992) the interstitial community of the Southern Bight of the North Sea contains the interstitial families Canthocamptidae, Leptopontiidae, Leptastacidae and Paramesochridae, associated with small Ameiridae and vermiform Diosaccidae and Ectinosomatidae. These associations existed in 1978 and are still more obvious in community II than in community I in 1997. The important species of the northern community in 1978 listed in Willems *et al.* (1982b) are still found in community II. Remarkably the decrease in endobenthic species between 1978 and 1997 is highest at stations 3 and 4 relative to all the other stations on the sandbank. In 1997 the proportion of interstitial species amounted to 98 % and 95 % at stations 3 and 4 respectively.

In 1978 station 3 did not yield a typical interstitial community as endobenthic Ectinosomatidae predominated with 71 % and were associated with 19 % big sized Diosaccidae. Station 3 had an extremely high median grain size of 654 µm in 1978. Especially Ectinosomatidae and Diosaccidae tend to be very abundant in very coarse sands such as Amphioxus sand (Guille & Soyer, 1966). Willems *et al.* (1982b) pointed out that the community of the coarse sands of the Kwintebank contained many coarse sand indicator species previously described from Amphioxus sand (Monard, 1935; Por, 1964a,b; Soyer, 1970). Of these, the ectinosomatids *Ectinosoma reductum*, *Pseudobradya beduina* and *Hastigerella monniotae* were still found in community II in 1997 though not in high numbers anymore, while the abundant diosaccids *Robertgurneya ilievecensis* and *Rhyncholagena* disappeared. Representatives of the following genera in Amphioxus sand were also found in the coarse sands of the Kwintebank in 1978 (but not at stations 3 and 4): *Bulbamphiascus*, *Leptomesochra confluens*, *Phyllopodopsyllus bradyi* and *Pteropsyllus*. They were all absent in 1997. As Ectinosomatidae and Diosaccidae are so typical for very coarse sands, their strong reduction in 1997 may be attributed to the decrease of coarse and very coarse sands at station 3, associated with weak erosion (De Moor & Lanckneus, 1994) and potentially induced by sand extraction. Sand extraction (though not that severe) may have exerted a direct impact by the removal of the fauna as well. The presence of a lot of endobenthic forms in the coarse sands in 1978 implies that organic matter must have been available for this ecotype in 1978, whereas the harpacticoid fauna was dominated by interstitial bacteria-feeders in 1997, because the amount of suspended material was minimal (Govaere *et al.*, 1980). The sediment at station 3 contained 3.5 % organic matter in 1978 (Vanosmael *et al.*, 1982). Food availability is lower in winter than in autumn but the differences in epi-and endobenthic species densities at station 3 clearly exceed the seasonal variation ever recorded in sandy stations with a mean grain size exceeding 250 µm (Herman, 1989). Vanosmael *et al.* (1979) calculated that about 70 500 tons of slib per year were resuspended by the sand extraction activities at that time. A fivefold increase in sand extraction since then results in 352 500 tons of resuspended slib. Physical disturbances such as tidal mixing decrease the incorporation of organic matter into the sediment (Jennes & Duineveld, 1985). Hence sand extraction may have decreased the organic matter content in the dredged area, while silt is deposited in adjacent areas (Newell *et al.*, 1998).

At station 4 sand extraction activities are not taking place, the percentage of very coarse sand and gravel increased and still a decrease of the endobenthic Ectinosomatidae and Diosaccidae was observed. Hence the dynamics of these harpacticoids have to be interpreted with caution in order to draw conclusions on an impact of anthropogenic disturbances. Their decrease in the nineties is remarkable but cannot be defined with certainty to dredging impacts yet. An increase of the smaller and more frequently reproducing interstitial species strongly suggest a relation with enhanced disturbances but the comparison with similar non-dredged areas has to be documented more into detail.

4.2.3.3 Nematode communities

The coarser sediments in the north induced the separation of the Kwintebank nematode assemblages into a northern and a southern group (Vanaverbeke *et al.*, 2002). The presence of the coarser sediments was assigned to the impact of intensive sand extraction activities, whereas no attention was paid to the natural occurrence of coarser sediments in the north (Lanckneus, 1989), previously described as the reason for the existence of two nematode groups on the Kwintebank (Willems *et al.*, 1982b). Evaluating the effect of extraction activities on sediment characteristics and communities necessitates a comparison with the pre-dredging situation, which was not included in the study of Vanaverbeke *et al.* (2002). Coarse sands cover the entire northern part of the Kwintebank while it contains intensively dredged as well as non-dredged areas. The present study revealed that coarsening as well as a refinement is recorded in the exploited areas in the northern part, resulting in a homogenisation of the sediment. These differences, however, have not been assigned yet with absolute certainty to sand extraction activities by geologists. Erosion due to sand extraction may lead to a coarsening of the sediment but important changes also result from the infilling of newly created depressions with finer sediment than those of the surrounding substrate. This is very likely also the case in the depression in the northern top. Moreover, the most extensive coarsening in relation to the seventies took place in a non-dredged area. For such a complex system as the Kwintebank, care has to be taken not to jump to conclusions.

4.3 Impacts in the southern part of the Kwintebank

4.3.1 Geomorphological characteristics

The southern part of the Kwintebank is the least exploited part, in which the same area is disturbed only about once a week. The sand extraction intensity at station 7 is similar as at station 3, removing approximately 3 cm sediment per year. The extracted volume of sand at the stations more to the south is 4 times less than at stations 3 and 7 (Table III.1). This removal is compensated by natural sediment transport as the topography of the southern plateau of the Kwintebank did not show clear abnormalities. No changes were recorded in the top volume of the sandbank between 1987 and 1994 (De Moor & Lanckneus, 1994; Fig.III.13.c), except for the area around station 9, which had been subject to weak erosion. In 2002 weak erosion was also detected SE of the central depression, where the bedform was lowered by 1 m over a time period of 6 years (Fig.III.3). The lowering was linked to sand extraction intensity (Degrendele *et al.*, 2002). Station 7 was situated at the border of this area. The cross-sections south of this area only showed some natural variation in the displacement of sandwaves (Fig.III.3).

4.3.2 Biological characteristics

Harpacticoid communities of the southern plateau of the Kwintebank were stable in time. Dominant species were still the same after twenty years and proportional distribution remained very similar. The species assemblage of station 8 in 1997 showed the highest similarity with the species composition in 1978, relative to all other stations on the Kwintebank. Station 8 is characterized by the weakest sand extraction intensity, station 4 (no exploitation because of the shell debris) not taken into account. Yet, some remarkable differences were recorded between 1997 and 1978 at stations 9 and 10. Density decreased due to a considerable drop of the *Leptastacus laticaudatus s.str.* population and in the second place of a *Kliopsyllus* population. In a sandy station along the Belgian coast *L. laticaudatus s.str.* has repeatedly been recorded in high densities in September/October and always in association with a *Kliopsyllus* species second in dominance (Herman, 1989). Densities in winter from Herman (1989) were similar to the values found in 1997. On an intertidal sandy beach in England *L. laticaudatus s.str.* reached a very high density of 242 ind./10 cm² in September while the lowest value was recorded in January (Harris, 1972b). Also in that habitat *L. laticaudatus s.str.* was accompanied by a *Kliopsyllus* species, alternated with *Psammotopa phyllosetosa*, as second dominant species. These studies proved that reproduction of *L. laticaudatus s.str.* can be very pronounced in autumn, though not every year. The same holds for the accompanying *Kliopsyllus* species. So for these species, the differences on the Kwintebank may be explained by seasonal fluctuations, which is improbable for the decrease in *Interleptomesochra eulitoralis* density in the centre of the sandbank. The density drop at stations 9 and 10 is not clearly associated with a drastic change in an environmental factor. The only change that was measured is a replacement of some fine into medium sand. This change may be the reason why many endobenthic copepods are replaced by interstitial forms at station 10 (Huys *et al.*, 1986b), which cannot be completely explained by seasonal variation. Govaere *et al*. (1980) and Willems *et al*. (1982b) suggested that a stable *Leptastacus laticaudatus* community can be described for well-sorted clean, fine to medium sands of the Southern Bight of the North Sea. The data of 1997 showed that this community in the southern part of the sandbank remained about unchanged and is indeed stable in time. Sand extraction intensity is low in this area and these extraction activities may have washed away some fine sands but this did not affect the species composition in a great extent.

4.4 Comparison between Kwintebank and Middelkerkebank

A very similar interstitial community inhabits the sandwave area, covering a surface of approximately 9 x 1 km on the Middelkerkebank. Outside the area with sandwaves a totally different community is encountered in the fine sands of the southern topographically flat region and in the gullies. The pre-disturbance situation of the Kwintebank in the seventies revealed the same pattern: a 7 x 2 km sized sandwave area was defined as one unit with a variable species assemblage of predominantly interstitial copepods and the southern community was clearly distinguished from the northern part. The occurrence of two distinct groups at the northern and the southern part of the Flemish banks was thus illustrated by the species distributions on the Middelkerkebank as well as on the Kwintebank prior to intensive sand extraction. In the nineties enhanced similarities and dissimilarities between species assemblages subdivided the northern part of the Kwintebank in distinct communities. Environmental disturbance was unevenly distributed on the Kwintebank, which probably lead to a mosaic of communities and partly accounted for the patchiness of the harpacticoid communities (Newell *et al*., 1998).

Not only the general community pattern but also the density pattern showed a striking correspondence between the Middelkerkebank and the Kwintebank prior to intensive sand extraction. Sandwaves yielded significantly higher numbers of copepods while low numbers were typical of flat areas and gullies. In the nineties lower densities were recorded in the northern part of the Kwintebank than in the flat area of the southern part, which yielded least copepods in the seventies. The inversed relation between the northern and the southern part in the nineties may be induced by sand extraction, as densities between pre-dredging and post-dredging situation dropped from 31 % to 90 % in the most intensively exploited stations and clearly surpassed potential seasonal fluctuations at 3 of the 5 impacted stations. Remarkably, density even increased in the southern flat area of the Kwintebank relative to the seventies and was comparable with densities recorded in the sandwave area of the Middelkerkebank. A common feature of the sandwave areas of the Middelkerkebank and the Kwintebank in the seventies is the high proportion of interstitial juveniles, indicating an enhanced productivity in hydrodynamically stressed areas relative to calmer regions. At heavily exploited stations of the Kwintebank the percentage of juveniles is higher in winter 1997 than in autumn 1978 and almost as high as the values in autumn 1997 at the sandwave area of the Middelkerkebank, although a lower productivity is expected in winter (Hicks & Coull, 1983). At the non-exploited station the percentage of juveniles was indeed lower in winter than in autumn.

In contrast with the Middelkerkebank, the sandwave area of the Kwintebank also contained very coarse sediments, harbouring a dense endobenthic species assemblage in the seventies. This typical coarse sand assemblage disappeared in the nineties, potentially extinguished by direct or indirect effects of sand extraction activities.

5 Conclusions

When the harpacticoid data of the Kwintebank are compared with information of sand extraction intensity and erosion, analogies could be found in the occurrence of erosion and extraction areas and the occurrence of harpacticoid communities on the sandbank (Fig.III.13). In the nineties the Kwintebank was split up in four communities while only two parts could be distinguished in the seventies: a high variable northern part and a southern part with a high similarity. The latter community is found to be stable in time, while the northern part was split up in different entities in the nineties. In the central part of the bank, the most intensive exploited area, community structure changed completely and copepod density and diversity decreased dramatically. By contrast, in the northern intensively exploited area, diversity remained high in the nineties but the species composition altered in favour of interstitial species like in the centre. Similar sand extraction intensities (in the centre and the north) induced different environmental changes and hence different harpacticoid community changes, resulting in enhanced community patchiness in 1997 relative to 1978 on the Kwintebank.

In Fig.III.14 conclusions are summarized in a scheme with hypothetical harpacticoid-environment interactions. Natural conditions define which harpacticoid species and communities occur but sand extraction may influence species composition both on a direct and an indirect way. The sand exploitation on the Kwintebank is very patchy and much too intensive in the centre. The northern tip and the centre of the Kwintebank are strongly impacted areas. The extension of the present central depression due to sand extraction can become quite problematic if these human-induced physical disturbances may cause a continuing erosion and impoverishment. Spreading the extraction activities over the different sandbanks in the concession zone will help decreasing disturbance frequency and intensity.

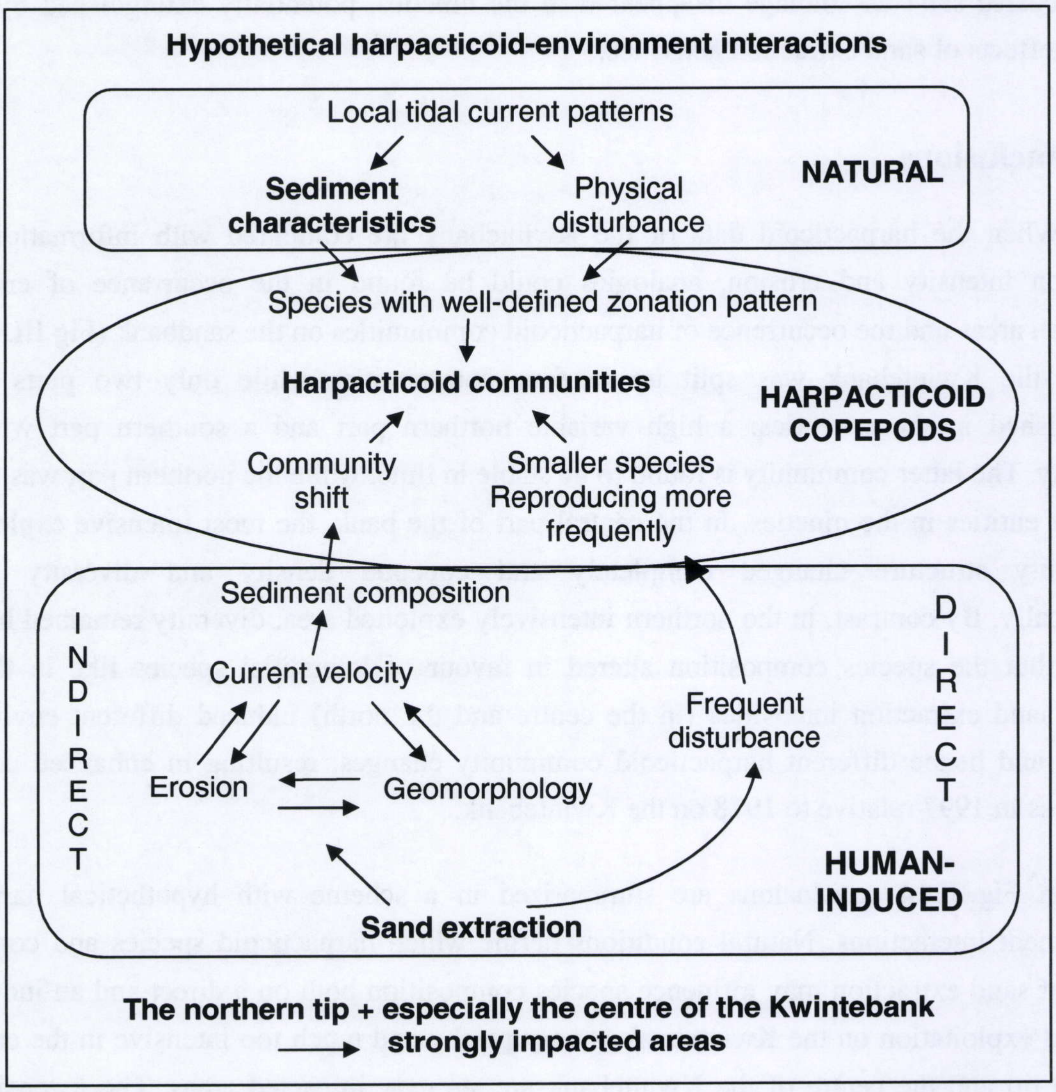

Fig.III.14: hypothetical harpacticoid-environment interactions

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