SCIENTIFIC SUPPORT PLAN FOR A SUSTAINABLE DEVELOPMENT POLICY

SPSD II

STUDY OF POST-EXTRACTION ECOLOGICAL EFFECTS IN THE KWINTEBANK SAND DREDGING AREA (SPEEK)

M. VINCX

PART 2

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Part 2:
Global change, Ecosystems and Biodiversity

FINAL REPORT

STUDY OF POST-EXTRACTION ECOLOGICAL EFFECTS IN THE KWINTEBANK SAND DREDGING AREA
(SPEEK)

EV/38

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This study investigated (1) the long-term changes in benthic metazoan organims of different size classes (macrobenthos and meiobenthos) and different taxa within a size class (nematodes and harpacticoid copepods within the meiobenthos) on the Kwintebank where sand was extracted at high rates and (2) the possible sedimentological and biological recovery of the central depression of the Kwintebank after its closure for extraction in February 2003.

The long term trends were assessed by integrating available historical data on the different benthic taxa. Baseline data, describing the characteristics of the benthic communities before sand extraction was initiated were absent, since the first sampling on the Kwintebank was performed in 1978, whereas sand was already extracted since 1976. However, the extraction rates during the first years of exploitation were very low compared to the amount extracted at the end of the 1990's and the beginning of the 21st century. Therefore we compared community characteristics from low-extraction periods with those obtained during intense extraction.

Results on the macrobenthos suggest that macrobenthic life was indeed impacted in the areas where intense extraction occurred. However, this impact was not dramatic since the main species living on the Kwintebank are adapted to a highly dynamical environment (eg. a sandbank) .

Nematode communities did change drastically since 1978 and were unstable during the extraction period. Larger predatory nematodes disappeared in favour of more opportunistic deposit feeding species. Nematode biomass spectra revealed a shift towards smaller nematodes. These changes are likely due to physical disturbances induced by the exploitation of the sandbank, but the absence of long-term data from an undisturbed area prevents to deduce definitive conclusions.

Harpacticoid copepods in the central depression were affected by the extraction activities when analysed at the species level whereas the use of an ecotype approach remains problematic due to the high spatial variation in copepod distribution since the relative abundance of large species fluctuates and can increase in the sand extraction disturbance situations as well. In addition, the spatial variation of the big epi- and endobenthic species is naturally high in the sandbanks sediments.

The spatial concentration of the extraction activities on the Kwintebank has clearly impacted the morphological, sedimentological and biological characteristics of the sandbank. Biological assessment should be primarily done by assessing changes at the species level, but our results suggest that nematode biomass spectra could be a valuable tool as well. However, this should be confirmed by more research on a global scale.

Baseline data on the original characteristics and data providing information on the natural evolution of non-impacted communities are absolutely necessary to deduce sound evidence on the possible impacts of extraction activities on the benthic environment.

Short-term recovery of the central depression after its closure for extraction activities was not observed. The area evolved into a new environment with sediment characteristics and an evolution in mean grain size similar to the trends observed in the adjacent swale.

The poor macrobenthic community which was present in the central depression during the exploitation evolved to a community with higher densities, species richness and diversity comparable to the communities encountered at other sandbanks on the Belgian Continental Shelf with similar grain size characteristics.

Nematode communities were very different from the communities present during the extraction period and showed a higher stability. This stability was not observed at the northern part of the sandbank were extraction is still ongoing. In addition, nematode biomass spectra revealed that larger nematodes were again present in the absence of dredging activities. However, the nematode communities were very different from the communities observed in 1978, when only small volumes of sand were extracted from the Kwintebank.

It cannot be concluded that recovery has taken place for the copepod ecotype distribution in the central depression after cessation of dredging, since temporal and spatial variability may make the observation of recovery at ecotype level quite difficult and because as an additional problem, the ecotype distribution not consistently reflected a disturbance situation as was presumed. A general increase in harpacticoid copepod densities after the cessation of the exploitation of the central area was observed only in autumn. This trend was absent in the winter situation.

Some general recommendations towards the assessment of the effects of sand extraction activities on the benthic environment include amongst others:

- assessment of the natural situation before the start of the exploitation
- sampling a reference site on a regular basis to deduce natural trends
- incorporating all benthic groups in monitoring programmes since they reveal different aspects of the disturbance effects

key words: sand extraction, Kwintebank, Belgian Continental Shelf, macrobenthos, nematodes, harpacticoid copepods, grain size evolution, recovery

1. INTRODUCTION

Due to an increasing demand for suitable sands needed for construction works, in combination with increasing costs involved with sand extraction at the main land, subtidal sandbanks located at the Belgian Continental Shelf (BCS) offered a valuable alternative source for this material. The exploitation started in 1976 with an annual exploitation of about 29 000 m³ (Degrendele et al. in press). In 1977, exploitation increased by about one order of magnitude (220 000 m³ yr^{-1}) and became more and more important. In the mid of the 1990's already 1 700 000m³ yr^{-1} was extracted, reaching a maximum value of more than 1 900 000 m³ yr^{-1} in 2001. During the last two years, subtidal sand extraction yielded about 1 600 000 m³ y^{r-1} (Degrendele et al. in press).

The Federal Government of Belgium initiated almost from the start of the exploitation, a monitoring programme to asses the impact of sand extraction on the marine environment, although only in 1996 extraction vessels were operated with a black-box system (Degrendele et al. in press) registering the activities and location of the vessels. Since 1999, the Fund for Sand Extraction is monitoring very closely the geomorphology of extraction areas with a multibeam echosounder.

Extraction activities at the BCS are mainly concentrated on the Kwintebank, due to the presence of suitable sand and its close location to the harbour; enabling a cost-effective exploitation. Analysis of the historical registers and recent black box data revealed that at least 75% of all marine sand extraction activities were located on the Kwintebank, more specific on the northern and central part of the sandbank (Degrendele et al. in press). Investigating the bathymetric and the morphological evolution of the Kwintebank by single beam profiles, Degrendele et al. (in press) observed in 2000 the formation of a depression in the central Kwintebank since 1992. Since federal legislation prohibits further exploitation when a deepening of > 5m with respect to the most recent hydrographical charts occurs, this area had to be closed for extraction activities in February 2003.

This report deals with two aspects related to the sand extraction activities on the Kwintebank. As a first goal, we aim at clarifying the impact of the long-term extraction activities on the benthic life. So far, no real focused studies existed in which the possible impacts of sand extraction activities were investigated. Only Bonne (2003), Vanaverbeke et al. (2002) and Vanaverbeke et al. (2004) gave evidence that meiobenthic life (benthic organisms passing a 1mm sieve and being retained on a 38 µm-sieve) was negatively impacted. These studies were limited to a single sampling campaign in 1997 and showed that both harpacticoid communities and nematode communities changed since the early extraction period in 1978. For both taxa, a decrease in vulnerable large organisms was observed as well. However, repeated sampling campaigns were needed to fully understand the effects of sand extraction on the benthos in order to avoid possible bias due to sampling an exceptional situation. For the macrobenthos (benthic organisms retained at a 1 mm-sieve), no paper on long-term effects of sand extraction on the BCS was published in the scientific literature at the start of SPEEK. We therefore analysed historical data available on three benthic components of the Kwintebank, often only available in grey literature. In addition, samples obtained near the end of the extraction period were elaborated. This resulted in a very extensive and probably unique dataset, comprising data on different benthic size groups from an extraction site. Analysis of this dataset allowed for (1) assessing the impact of sand extraction on the different benthic groups and (2) estimating the vulnerability of these size groups for sand extraction activities.

A second goal within SPEEK was to assess the possible short-term sedimentological and biological recovery of the central depression of the Kwintebank after its closure for exploitation in February 2003. Therefore, the central depression was sampled intensively by an international team of geologists (RCMG, Ghent Universiy, Belgium), and benthic ecologists (Marine Biology Section, Ghent University, Belgium; AZTI Foundation, Spain and ILVO, Belgium) and joint sampling campaigns with the EU funded FP5 research training network EUMARSAND European sand and gravel resources: evaluation and environmental impact of extraction, HPRN-CT-2002-00222) and the Belspo funded Marebasse project were organised in the first two years after the closure of the depression for exploitation activities. The latter projects integrated knowledge on geological, geomorphological, sedimentological, hydrodynamical, ecological and engineering–based aspects related to sand extraction. The project SPEEK has focussed on the detailed analysis of the short-term sedimentological and biological trends in the depression and the formulation of a number of recommendations that can be used by policy makers and stakeholders to guarantee a sustainable use of the marine aggregates at the Belgian Continental Shelf.

2. EVALUATION OF THE CONSEQUENCES OF LONG TERM SAND EXTRACTION ON THE STRUCTURAL CHARACTERISTICS OF THE MACROBENTHOS COMMUNITIES

INTRODUCTION

Several studies investigated the effects of marine aggregate extraction on the benthic fauna (for reviews see Newell et al. 1998; Boyd et al. 2004; ASFL 2005). However, most of these studies are limited to the initial effects of extraction and thus do not address the effects of dredging over the life-time of a typical commercial extraction licence.

Most serious physical impacts of sand extraction are related to substratum removal, alteration of the bottom topography and sediment composition, changes in depth and current strength and the creation of plumes through the disturbance by the drag head and from screening (Newell et al. 1998; Boyd et al. 2003; Hacking 2003). The direct removal of species and individuals is considered as the main biological impact. In most cases dredging caused an initial reduction in abundance, species diversity and biomass of the benthic community in the extraction area (Kenny & Rees 1994; Desprez 2000; van Dalfsen et al. 2000; Sardá et al. 2000; van Dalfsen and Essink, 2001; Guerra-Garcia et al. 2003; Newell et al. 2004b; Sanchez-Moyano et al. 2004; Simonini et al. 2005). However the impact of sand extraction is not limited to these short-term effects, but also causes long-term changes in the structure of the benthic community due to habitat changes (Desprez 2000). Increased sedimentation and re-suspension due to dredging of clean (mobile) sand are generally thought to be of less concern, as the fauna inhabiting such deposit areas tend to be adapted to naturally high levels of suspended sediments caused by wave and tidal current action (Newell et al. 2004b).

For this study on the long term impact of sand extraction on the Kwintebank and surrounding areas, different locations on the Kwintebank and on the Oostdyck with different intensities of extraction are considered. The comparison of historical and recent data gives an idea of the evolution of the macrobenthos on a heavily extracted sandbank on the Belgian Continental Shelf.

COMPILATION OF HISTORICAL DATA

Data gathered by ILVO-Fisheries

Macrobenthic samples have been collected at different locations on the Belgian Continental Shelf since 1979. Some of these stations are located on the Kwintebank and the Oostdyck in the area licensed for sand extraction (Figure 1). Samples from the north of the Kwintebank (ZG01) have been collected since 1978, although not continuously. Only few of the old samples were well preserved. A new location (ZG11) was sampled in the newly formed depression in the north since 2004. In the central part of the Kwintebank samples have been collected since 1998 just south of the central depression (ZG04) and since 2003 in the central depression (ZG05-10). Only the samples from 2003 of the central depression will be used for comparison as later samples have higher densities due to the process of 'recovery' (see Chapter 6). According to the black box data analyses all these sampling stations on the Kwintebank were located in the most intensively extracted areas. In the northern part of the Oostdyck, sampling has been conducted since 1978 (ZG02), although the macrobenthos samples have only been processed from 1996 onwards.

At every location, four Van Veen grabs were collected twice a year (February/March and September/October). Three samples served for research on the macrobenthos while the remaining sample was used for sediment analysis. Sampling and processing technique (Van Veen grab, fixation before sieving and a 1 mm sieve) remained the same throughout these 25 years.

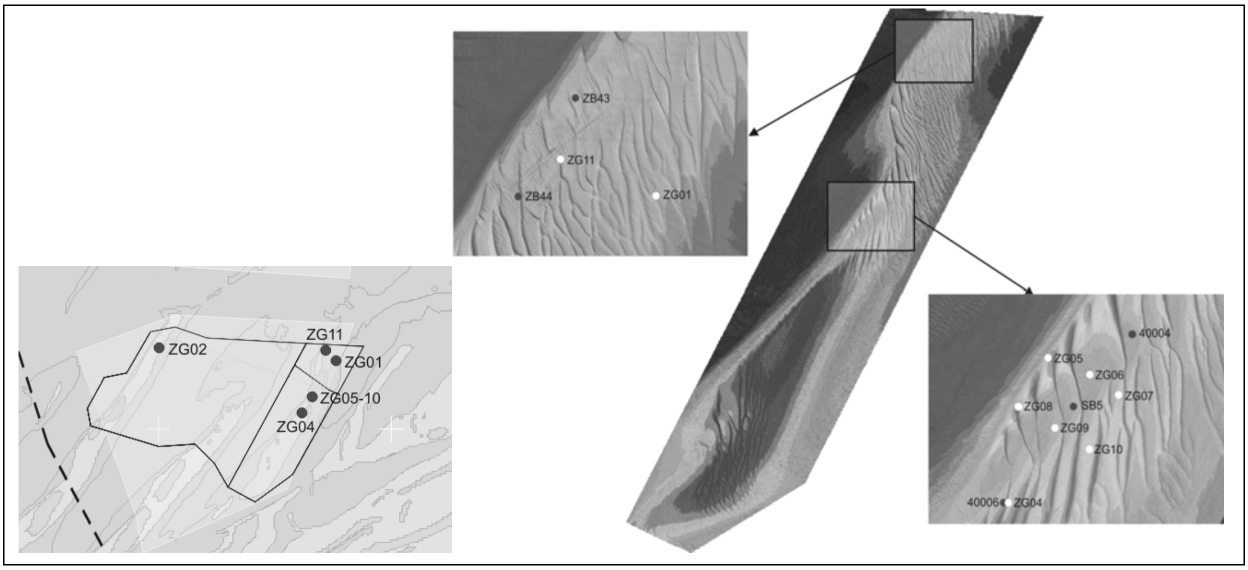

Figure 1: Map of the sand extraction zone 2 with sampling locations (left) and a detailed map of the Kwintebank with sampling locations (right). White dots: ILVO locations; black dots: locations of the historical records from UGent/Marine Biology. (Background Multibeam images: Fund for Sand Extraction)

Data gathered by UGent/Marine Biology

Only few locations have been sampled by ILVO-Fisheries in the early stages of sand extraction activities and, as mentioned above, the historical samples from only one location on the Kwintebank have yet been processed. Therefore some historical data from the Kwintebank and surrounding areas, sampled in the framework of other studies were used for comparison with more recent data (see Table 1).

		sampling year	mesh size	station	comparable to
Kwintebank	Vanosmael & Heip, 1986	1980-1984	1 mm	40004	ZG06 & ZG09
	Waterschoot, 1980	1979-1980	870 µm	40006	ZG04
	Vanosmael *et al.* , 1982	1978	250 µm	SB05	ZG06 & ZG09
	Macrobel databank	1979-1980	?	ZB43-44	ZG11
Oostdyck	Meheus, 1981	1980	870 µm	ZS2	ZG02
	Macrobel databank	1980-1981	?	ZS2	ZG02

Table 1: Overview of the historical data records used from the Marine Biology Section of Ghent University.

Data analyses

The different sediment fractions and median grain sizes were used for comparison of the sediment. For the macrobenthos the different parameters like density (ind/m²), species number (# species / 0.3m²) and the Shannon-wiener diversity index were used. The number of species is presented per 0.3 m² (the content of 3 Van Veen grabs) as for some historical data only a sum of the 3 replicates was available.

Multivariate ordination techniques were used to evaluate changes in the community over time. A wide array of multivariate statistical techniques exists, all with there own pros and cons (James & McCulloch 1990). In this study we used the Correspondence Analysis (CA) approach, a widely used method in community ecology (Jongman et al. 1995). The CA was performed using square root transformed abundance data, after elimination of rare species (present in less than 3 replicates) by means of the statistical package PcOrd (McCune & Mefford 1999) Only data from one season were used in order to eliminate any seasonal variation.

RESULTS

Northern part of the Kwintebank

▪ Intensively extracted eastern zone: ZG01, 1978-2005

The long term sediment data series revealed no major changes in the past 27 years although a high variation between the different sampling periods could be noticed (225-390 µm). Samples from the late 1970's and the beginning of the 1980's showed less variance than samples from the last 10-15 years.

No major evolution could be found in any of the different macrobenthic community parameters, i.e. density, diversity or number of species over the last 25 years (Figure 2). Samples from 1985 and 1988 as well as for the period 2000-2001 showed the highest variation between seasons. Autumn density values were twice as high compared to the stable values during the other periods.

Polychaetes were the most important taxonomic group. In most seasons they represented more than 60% of the total density. Sometimes crustaceans (mainly amphipods) also had an important share in density. Bivalves were never of much importance for the macrobenthic density of this area. In autumn of 2001 there was a sudden increase of echinoderms.

The Correspondence Analysis of the autumn samples indicated a small shift in species composition over the years from long living, more sessile species towards smaller species that prefer coarser sediment. Total inertia amounted to 1.67 and the eigenvalues for the first two ordination axes were 0.32 and 0.15.

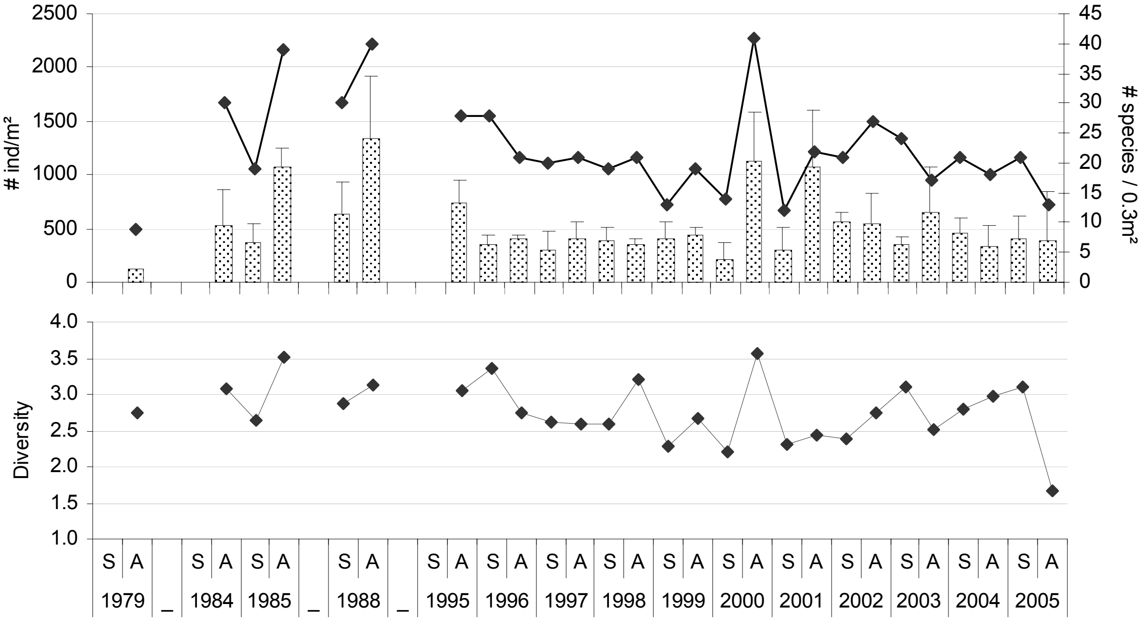

Figure 2: Average number of individuals per m² (+ standard deviation) and total number of species per season for the intensively extracted northern Kwintebank area for the period 1979-2005.

- **Very intensively extracted western zone: Station ZB43 en ZB44, 1979-1980 vs. station ZG11, 2004-2005**

No historical sediment data were available from ZB43 and ZB44. Historical samples from 1979 showed a higher macrobenthic density, diversity and species number compared to the samples from 1980, 2004 and spring 2005 (Figure 3). Highest density and species richness were found in autumn 2005. The macrobenthic species composition remained relatively stable except for some bivalves and bigger sessile bristle worms that were replaced by mobile and interstitial species. *Ophelia limacina, Scoloplos armiger, Spio* spp. and *Spisula* spp. were more abundant in the historical samples, whereas *Polygordius appendiculatus* and *Microphthalmus* spp. were more abundant in the recent samples.

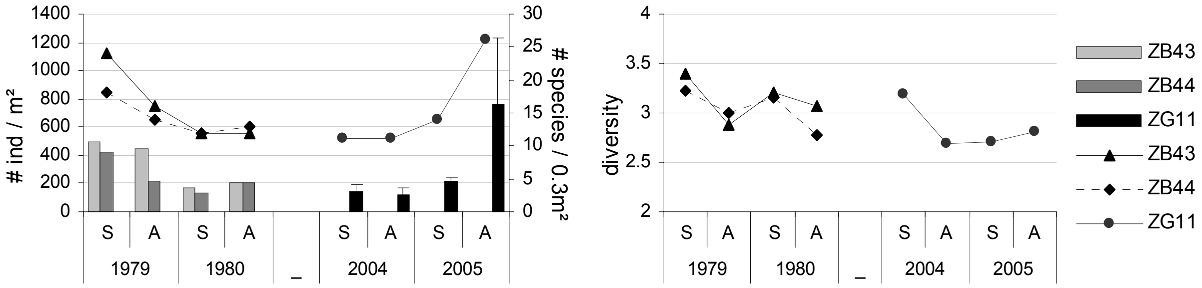

Figure 3: Historical and recent records of density, species number and diversity for the very intensively extracted northern Kwintebank area.

Central part of the Kwintebank

- **intensively extracted zone: Station 40006, 1979-1980 vs. station ZG04, 1998-2005.**

The data from 1979 and 1980 were sampled very close to the location of the more recent samples. Historical samples had a slightly coarser grain size and smaller percentage of silt. Sediment data did indicate a small increase in median grain size from 1998 to 2005, except for 2004 and spring 2005.

Density, species richness and diversity of the macrobenthos were lower in 1979-80 compared to 1998-2001 (Figure 4). In autumn 2001 a peak in density, diversity and species richness was recorded, but since then all values decreased. In 2005 the values were low and comparable to the historical samples.

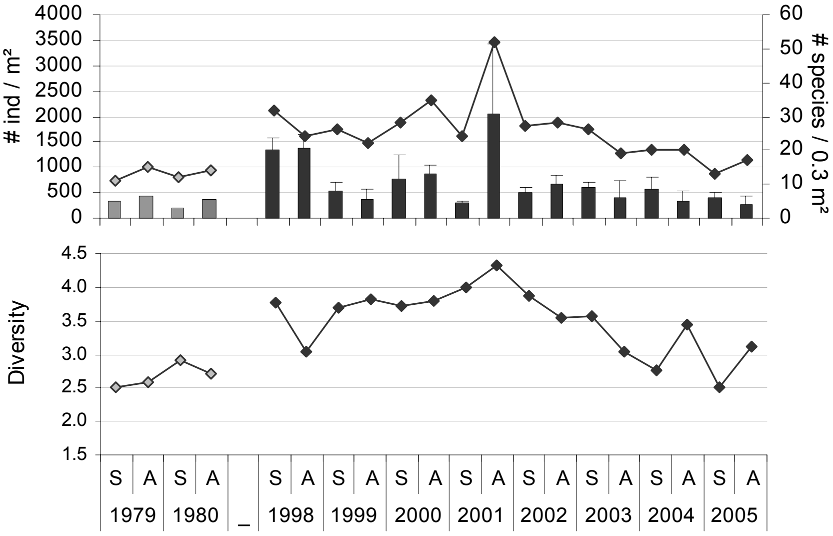

Figure 4: Average number of individuals per m² (+ standard deviation, bars), total number of species (lines) and Shannon-wiener diversity per season for the intensively extracted central Kwintebank area.

Polychaetes were the major taxonomic group present, but their proportion was smaller than in the north of the Kwintebank. Bivalves, amphipods and echinoderms were almost absent from the historical samples and were clearly more important in the samples from 1998 to 2003. Bivalves and echinoderms almost disappeared again since autumn 2003. Since then polychaetes and amphipods remained the major taxonomic groups. *Nephtys cirrosa* (adult and juvenile individuals) increased in density and became the most important species. *Spio* spp., *Ophelia limacina* and *Hesionura elongata* were more abundant in the historical samples, whereas *Urothoe poseidonis, Spiophanes bombyx* and *Scoloplos armiger* were absent from the historical samples.

- **Very intensively extracted zone: Station SB5, 1978 vs. station ZG09, 2003 (only sediment data) and Station 40004, 1980-1984 vs. station ZG06, 2003**

Historical data from stations SB5 and 40004 were compared with data from 2003 for stations ZG09 and ZG06, respectively. There was a large difference in median grain size and depth between SB5 sampled in 1978 and ZG09 sampled in 2003 (see Table 2). The macrobenthos data were not compared as a much smaller sieving mesh size was used in 1978.

Also for stations 40004 and ZG06 a much smaller median grain size was noted when comparing the 1980's with 2003. This coarser median grain size might be due to higher shell abundance, which can be locally (Table 2). Macrobenthic density, species number and diversity were lower in 2003. Historical samples were mainly characterised by a high percentage of interstitial species. Some interstitial species (*Hesionura elongata, Polygordius appendiculatus, Thia scutellata*) still occurred in the 2003 samples, although at lower densities. Several species (*Pisione remota, Streptosyllis arenae, Sphaerosyllis bulbosa*) were no longer found after many years of intensive extraction in the area.

	1978 (SB5)	2003 (ZG09)	1980-1984 (40004)	2003 (ZG06)
depth (m)	13.5	17.5	--	17.5
median grain size (μm)	517	272	516	329
mud content (%)	0	0.79	0.55	0.75
gravel content (%)	0.24	1.16	7.19	4.16
organic material (%)	2.92	0.62	--	0.99
skewness	-0.11	-0.01	--	-0.14
average density (ind/m^2)	--	--	780 ±236	143
average number of species (#/0.3m^2)	--	--	21 ±3	13
average diversity	--	--	2.95 ±0.31	1.75

Table 2: Comparison of different parameters between historical and recent data in the intensively extracted central Kwintebank area.

Northern part of the Oostdyck

- **Low intensively extracted zone: Station ZS2, 1980-1981 vs. station ZG02, 1996-2005**

The long term sediment data from the northern part of the Oostdyck showed a comparable pattern. No clear increase or decrease of the median grain size was recorded over the last 30 years, except for 2004. During the 1980's sediment data was relatively stable, whereas in the last decade more variation was found in median grain size.

In both historical and recent samples, the community found was extremely poor with low densities, diversity and species number (Figure 5). Only in the spring of 1980 a higher density was found, due to the presence of the interstitial species *Hesionura elongata,* which represented more than 80% of the total number of individuals. As a smaller mesh size was used in these historical samples, no further conclusions can be made from the higher abundance of this species. On the other hand, the interstitial species *Polygordius appendiculatus* was not found in the historical samples. *Hesionura elongata, Polygordius appendiculatus, Protodrilus* spp.*, Ophelia limacina* and *Nephtys cirrosa* were the most important species present in the northern part of the Oostdyck in the last years.

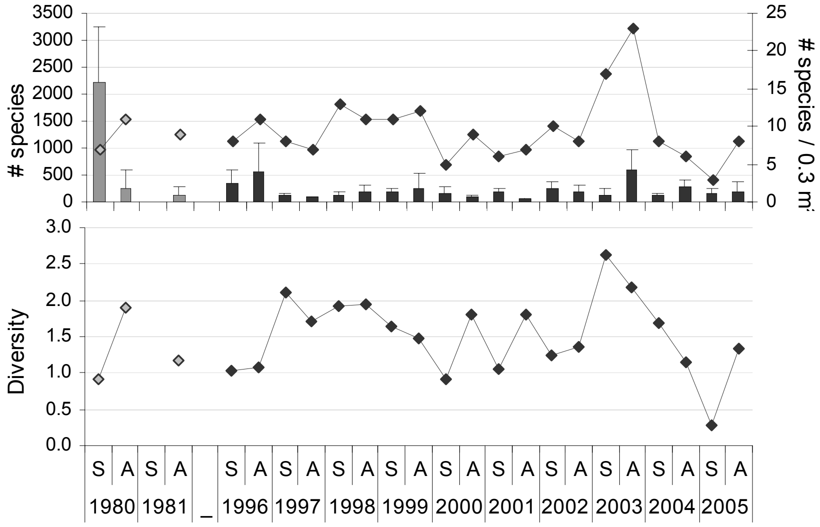

Figure 5: Average number of individuals (+ standard deviation, bars), total number of species (lines) and average Shannon-wiener diversity index per season for the low intensively extracted northern Oostdyck area.

DISCUSSION

When comparing historical with recent data or when using long-term biological data records, many aspects have to be taken into account. Apart from differences in sampling locations, sampling techniques and sample processing, there is also natural variation. To investigate the variation caused by anthropogenic impacts, reference data is needed to distinguish naturally caused changes from anthropogenic ones. A good reference area should be determined through a base line study, before any dredging activities have taken place (Boyd et al. 2003). The Kwintebank has been a sand extraction area for 30 years. Although some historical data on the macrobenthos from the early years of extraction exist, no base line data from before that period are available.

Both short term studies and models emphasize the importance of the initial period in relation to the main changes in the community structure of the macrobenthos (for reviews see Newell et al. 1998 and Boyd et al. 2004). The initial impact of sand extraction on the macrobenthos of the Kwintebank will remain unknown.

Due to differences in sampling techniques and sample processing, caution is needed when interpreting the data from different datasets of the Kwintebank. It is shown that higher densities of smaller species are found when using a smaller mesh size (James et al. 1995). Also the difference in sampling during day and night time might result in variability in the results. The change in the exact position of the samplings might also hamper the long term interpretation as sampling on top of the bank or on the slope can have different results in the sediment characteristics as well as in the macrobenthic community.

The impact of sand extraction on macrobenthic communities depends on numerous factors: extraction method and intensity, sediment type and mobility, bottom topography and current strength. The impact is also dependent on the type of the original macrobenthic community present and is thus site specific (Newell et al. 1998; Desprez, 2000; van Dalfsen et al. 2000; Boyd et al. 2004). Results from the sediment analysis indicated a high variation between samples and seasons and this is likely due to the higher sediment dynamics in the area. Such environments are typically occupied by macrobenthic communities composed of species that are mobile, have a short life span and are adapted to living in dynamic areas. Bigger, long living species are seldom found on the top of the sandbanks. A species typically found in both historical and recent samples, on all sandbank stations was *Nephtys cirrosa*. This rapid swimming bristle worm does not make definite burrows and lives in wave and current exposed locations (Budd 2005). Also the interstitial species *Hesionura elongata* is a typical inhabitant of these sandbank systems. The question here remains whether these species were the inhabitants of the pristine sandbank or whether they became more abundant with increasing sand extraction? According to Hiscock et al. (2005) *Nephtys cirrosa* and *Hesionura elongata* are both tolerant to extraction activities. Boyd et al. (2003) also found higher abundances of *Hesionura elongata, Spiophanes bombyx* and juvenile *Nephtys* spp. in highly dredged

sediments compared to the reference areas. But even on non-dredged sandbanks on the BCS, these species occur in high numbers (Moulaert in prep.).
Results from the comparison of the historical and recent sediment data of the central depression of the Kwintebank indicated that at least locally, the median grain size became finer. This was not found for the area just south of the depression, nor in the north of the Kwintebank. Sediment data from the north of the Kwintebank showed a high variation in median grain size. This is mainly due to the highly dynamic character of the area but also the different position of the ship relative to the sampling point added to this variation. Samples from the late 1970's and the beginning of the 1980's showed less variance than samples from the last 10 years. The same results were found for the north of the Oostdyck. As positioning was probably more correct in the last decade, the latter variation might be solely attributed to an increased disturbance of the area. Whether this disturbance is caused by increasing sand extraction activities which disturb the bottom and create a less stable environment, or by natural variation remains unclear.

In the very intensively extracted zone in the north of the Kwintebank, a clear depression is being formed. This is mainly due to the fact that most of the extraction activities have taken place in this area since the closure of the central part of the Kwintebank (Degrendele et al. 2005). This probably has its repercussions on the local hydrodynamics, the grain size distribution and the benthic community. A clear difference is found between the very intensively extracted western zone and the less intensively extracted eastern zone of the northern part of the Kwintebank. In the former a coarser grain size was found and macrobenthic density and species richness were much lower. Diversity on the other hand did not differ much. Interstitial species (*Hesionura elongata, Polygordius appendiculatus* and *Microphthalmus* spp.) represented a more important proportion of the density in the very intensively extracted western part. Macrobenthic density and species number were higher in 1979 and also in autumn 2005, whereas samples from 1980 were lower and comparable to the samples from 2004 and spring 2005. The change in species composition (more interstitial species) indicated a little coarsening of the sediment. In 1978 a smaller median grain size was found in the north of the Kwintebank (Vanosmael et al. 1982). In the same study high numbers of interstitial species were found as well but mainly because a 250 µm sieve was used. Long term macrobenthic data from the less intensively extracted eastern part of the north of the Kwintebank, showed no negative evolution in density or diversity. According to the sediment data, the environment was less stable in the last decade; the macrobenthos community remained more or less the same. Some peaks in density occurred (1985, 1988, 2000 and 2001), but most likely these were not a result of the extraction activities as comparable peaks were found for other locations on the BCS, which are not influenced by sand extraction.

For the intensively extracted central depression of the Kwintebank, the comparison of historical data with data from 2003 (only one month after closure of that area for sand extraction) indicated, at least locally, a decrease in median grain size. Also the macrobenthic density decreased mainly due to the reduction or even disappearance of interstitial species. This decrease is not related to different processing techniques, as for both historical and recent samples, a 1 mm sieve was used after fixation of the samples. In a following chapter the results from the recovery of the macrobenthic community in that area will be presented.

The area south of the central depression did not show any changes between 1979-1980 and 2004-2005 (comparable univariate indices and species composition), but in between both periods, a higher number of species and a higher diversity were found. The peak in 2001 of density, diversity and species number was also found for other, non extracted, areas on the BCS. The negative evolution from 2001 to 2005 might be due to an increase in extraction activities in this area as a result of the closure of the central depression.

On the Oostdyck only sporadically extraction activities took place probably due to the further offshore location and a less suitable grain size for the extraction industry. The Oostdyck has always hosted a relatively poor macrobenthic community as a result of the coarser grain size. Little changes were found between the historical and the recent data.

CONCLUSIONS

In many cases scientific studies suffer from the fact that in the past monitoring of anthropogenic impacts started after the impact had already begun. As such no real base line data are available to compare with. Secondly one of the main problems when using different data sets, for example to compare historical with more recent data, is the fact that the sampling and processing techniques were not standardised. Therefore one should always be cautious when making conclusions.

After 30 years of extraction on the Kwintebank some changes in sediment and depth occurred, with consequently some changes in the macrobenthic communities. The results from the sediment analyses indicated that the effects of extraction on the sediment composition are site specific and depend mainly on the composition of the sandbank, the grain size of the sediment that is being extracted and the intensity of extraction. As such the effects of extraction can not be generalised.

The very intensively extracted zones of the Kwintebank accommodated little benthic life with a small biomass.

These zones only offer a small food supply for other organisms. For the less intensively extracted areas of the Kwintebank, the density values were slightly higher. Long-term data series from the less intensively extracted area in the northern part of the Kwintebank indicated no major changes in species composition, density and diversity for the last 25 years. Data series from the area just south of the central depression, where extraction activities increased, showed a decrease in macrobenthic number of species and diversity during the last 4 years. These results might indicate that sand extraction has an effect on the macrobenthic community. However *Nephtys cirrosa, Hesionura elongata, Polygordius appendiculatus, Spiophanes bombyx, Urothoe brevicornis, Urothoe poseidonis* and *Bathyporeia* spp., the main species present on the Kwintebank, are able to survive in dynamic areas, and are probably less influenced by the disturbance of sand extraction activities.

3. LONG-TERM TRENDS IN THE NEMATODE COMMUNITIES OF THE KWINTEBANK IN RELATION TO SAND EXTRATION

INTRODUCTION

Since nematodes are considered to be a very good tool for assessing impacts on the benthic habitat (Heip et al. 1985, Kennedy & Jacoby 1999), we investigated possible changes in diversity and composition of nematode communities since 1978. At that moment, sand extraction was already ongoing, but the intensity of sand extraction activities was negligible compared to intense exploitation later on. In this chapter, we use different approaches (multivariate analyses, diversity indices based on species richness and newly proposed indices based on taxonomic relatedness) to assess possible changes in the nematode communities as a consequence of intense sand extraction activities.

MATERIAL AND METHODS

Collection and treatment of samples

The analyses presented in this report are based on historical data from sampling campaigns conducted in June-September 1978 (Vincx 1986), February 1997 (Vanaverbeke et al. 2002) and December 2001 (analysed during the SPEEK project). The samples collected in 1978 are considered as samples from the period before the intense sand extraction activities, while the samples obtained in 1997 and 2001 reflect the situation during intense extraction activities.

Collection and treatment of meiobentic samples was identical during all sampling campaigns: 10 stations along the crest of the Kwintebank were sampled using a Reineck box corer (Fig. 6). From each box corer, subsamples for meiofaunal and sediment analysis were obtained using a perspex core (10cm²). Meiobenthic samples were fixed with a hot (70°c) neutral formaldehyde tap-water solution (final concentration: 4%). Metazoan meiobenthic organisms were extracted from the sediment by centrifugion? with Ludox (Heip et al. 1985). Macrofauna was excluded by means of a 1 mm sieve and all animals retained on a 38µm sieve were stained with Rose Bengal, counted and classified to the taxon level. A fixed amount of nematodes were picked ad random, transferred to glycerin and mounted on slides for species identification. Nematodes from two replicates were identified for the 1997 and 2001 sampling campaigns; in 1978 nematodes from only one replicate were identified. All nematode species were assigned to a feeding type according to Wieser (1953).

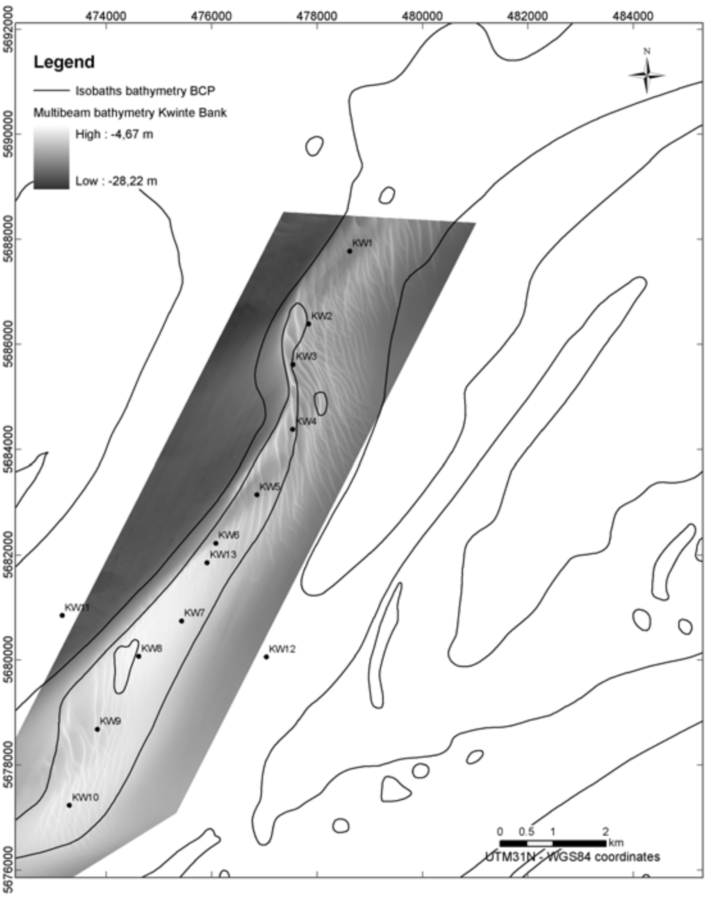

Figure 6: Location of sampling stations for meiobenthic sampling on the Kwintebank. (Map from UGent-RCMG)

Sediment samples obtained in 1978 were analysed using a dry-sieving procedure (Wentworth 1972) and were obtained from Bonne (2003). In 1997, sediments were analysed using both the dry-sieving method (data in Bonne 2003) and a Coulter LS100 Particle Size Analyser (data in Vanaverbeke et al. 2000, 2002). Grain size analysis for the sampling event in 2001 was only performed using the Coulter LS 100 Particle Size Analyser. For the latter method, sediment fractions up to 1000µm are expressed as volume percentages, while the fraction between 1000 and 2000 µm and > 2000 µm are mass percentages. For all sampling years, sediment fractions are defined according to the Wenthworth scale (Buchanan 1984).

Data analysis

Stations were clustered according to their sand extraction history in 1997 (Bonne 2003). Stations Kw1, Kw2, Kw5 and Kw6 were grouped together ("Very High" group) since 5000-8300 m³ of sediment per month were removed. A second group consisted of stations Kw3, Kw7, Kw8, Kw9 and Kw10 ("High" group). Sand extraction in those stations ranged between 150 and 1380 m³ per month. The "Very Low" group contained only station Kw4, since maximum extraction reached only 28 m³ per month.

Data were analysed with non-parametric multivariate methods (Clarke & Gorley 2001) using Primer 5.

Differences in methodology do not allow for a comparison of the grain size data between sampling dates. Therefore, the comparison between 1978 and 1997 is based on Bonne (2003) using the results of the dry-sieving method. Principal Component Analysis using normalised Euclidean distance was applied to show spatial and timely differences in the grain size variables of the sampling campaigns from 1997 and 2001. 2-way crossed ANOSIM was performed to test for differences between years (allowing possible differences between stations) and vice versa (Clarke & Gorley 2001).

General multivariate differences in nematode community composition between the different years were analysed using non-metric Multidimensional Scaling (MDS) on square root transformed nematode data (all species from all replicates) based on the Bray-Curtis similarity measure. 1-way Analysis of Similarity (ANOSIM) was used to test for significant differences in community composition between years. In a second step differences between years per "intensity group" were analysed using MDS followed by a 2-way crossed ANOSIM, allowing to test for differences between years while allowing for differences between stations and vice versa. Species accounting for the similarity between samples within the different years were identified using the SIMPER routine within the PRIMER package. A cut-off of 50% was applied.

Nematode diversity was analysed by calculating a wide array of diversity indices available in PRIMER 5, including total species (S), Margalef species richness (d), Pielou's eveness (J), Shannon Wiener (H', log e based), Simpson Index ($1-\lambda'$) and Hill numbers N_1, N_2 and N_∞. Differences between years were analysed using 1-way ANOVA after testing for the assumptions for ANOVA. Values were subjected to a double square root transformation when needed to meet the assumptions. When the assumptions were not met, the non-parametric Kruskal Wallis analysis by ranks was applied. When significant differences were observed in the ANOVA approach, Tukey's HSD for unequal N was used to test for pairwise differences between years.

In addition, Average Taxonomic Distinctness (AvTD Δ^+) and Variation in Taxonomic Distinctness (VarTD Λ^+) based on presence/absence data were calculated following Warwick & Clarke (2001). Basically, Δ^+ is a measure of the degree to which species in an assemblage are related taxonomically to each other while the degree to which species from the regional species pool are over- or under-represented is reflected in the variation in taxonomic distinctness (Λ^+). The latter can be seen as the 'evenness' of the distribution of taxa across the nematode taxonomical tree.

For the calculation of the taxonomic indices equal step-lengths between each taxonomic level were assumed. In total 7 taxonomical levels were used. Calculation of Δ^+ from simulated sub-samples of different numbers of species m from the master list (based on all nematode species ever found on the Kwintebank) were used to produce probability funnels against which distinctness values for all zones were checked. This formally addresses the question whether these zones have a lower than expected taxonomic spread, assuming a null hypothesis that each sample is a random selection from the regional species pool (Warwick & Clarke, 2001). The same procedure was applied to Λ^+. Actual values falling below the lower probability part of the funnel indicate disturbed communities.

RESULTS

Sediment characteristics

At a station level, sediment characteristics seem to changed since 1978 (Fig. 7). In 1978, the median grain size increased from Station Kw1 to Kw3 and decreased further south (Willems et al. 1982). From Kw7 onwards, the median grain size was about 200 µm.

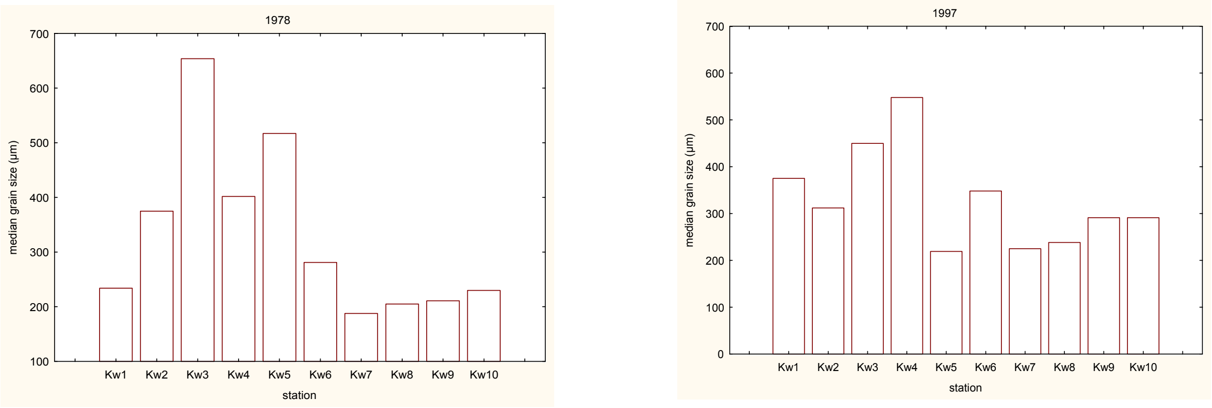

Figure 7. Median grain size at the Kwintebank stations from 1978 and 1997 (data from Bonne 2003).

A general coarsening of the sediment was observed in 1997, although it is not clear whether this is event determined. Only at Kw3 and Kw5, considerable lower values were recorded in comparison with 1978 (Bonne 2003). In general, the coarsening of the sediment was due to an increase of the relative amount of the medium sand fraction (mean value of 33% in 1978 to 50% in 1997), while the proportion of fine sands decreased from 44% to 35%. At Kw3 and Kw5, a refinement of the sediment has occurred. At Kw3, the medium sand fraction partly replaced the coarse sand fraction, while at Kw5 the proportion of coarse sand was replaced with a fine sand fraction. Even at the least impacted station Kw4 coarsening was observed (median grain size of 402 µm in 1978, 548 µm in 1997) due to the partial replacement of fine sand with a very coarse sand (1-2 mm) fraction. Grain size variables of 1997 and 2001 (Coulter Counter data) were compared using PCA (Fig. 8).

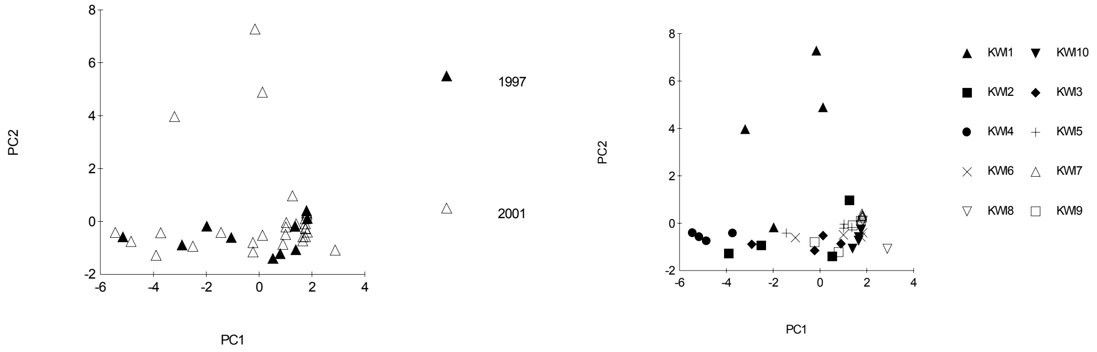

Figure 8 PCA ordination plot of grain size variables of the 10 Kwintebank stations. Left panel: comparison 1997-2001. Right panel: comparison per station

The two first principal components explained 72.6% of the variance. 2-way crossed ANOSIM revealed significant differences between stations (R= 0.479, p=0.001) and years (R= 0.444, p=0.006), indicating a further change in sedimentological characteristics with time.

Nematode communities

Changes in nematode communities with time over the complete sandbank were obvious (Fig. 9). 1–way ANOSIM (R= 0.74, p=0.001) showed significant differences in community composition between the different sampling years. Pairwise tests showed that largest differences occurred between 1978 and 2001 (Table 3)

Differences per intensity group were analysed using MDS (Fig. 9) followed by 2-way crossed ANOSIM. Nematode community composition clearly changed over the years in all groups irrespective of the extraction intensity. 2-way crossed ANOSIM for both the "Very High" and the "High" intensity stations revealed significant differences in nematode communities between the sampling years (R= 0.969; p=0.001 and R=0.9; p=0.001 respectively) and stations (Very High: R= 0.615; p=0.01 and High: R=0.725; p=0.01). Differences between the communities as observed in 1978 showed the largest differences with both the other sampling years (Table 4).

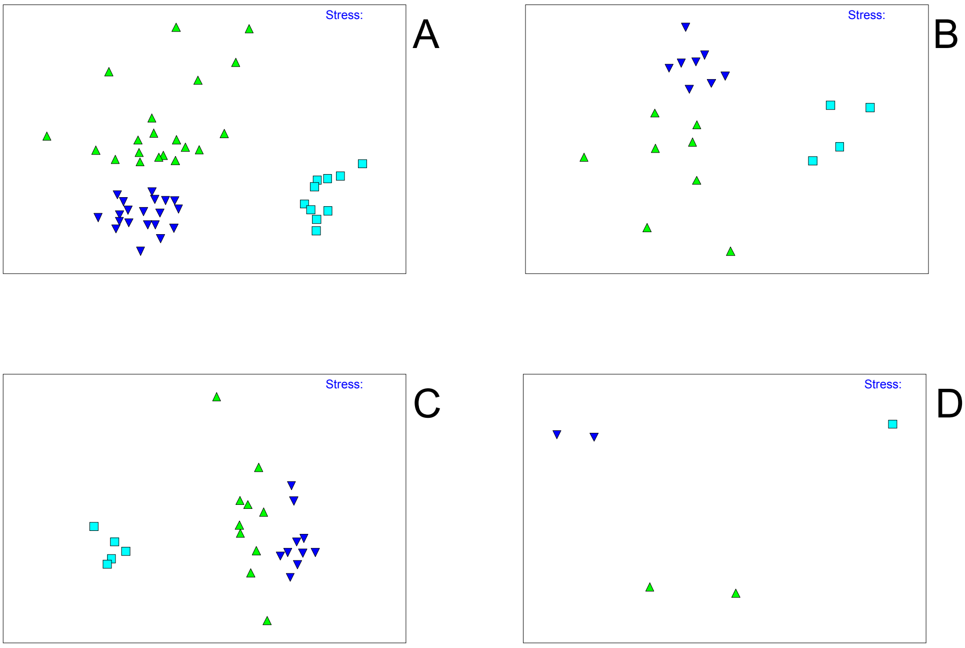

Figure 9 Results of MDS analyses. A: all stations; B: ‘Very High’ group; C: ‘High’ group; D: ‘Very Low’ group. Squares: 1978, Reversed triangles: 1997, Triangles: 2001

Multivariate changes in nematode communities in the “Very Low” intensity group were observed as well (Fig. 8D). Due to the lack of replication during the 1978 sampling event, 1-way ANOSIM was applied, revealing significant differences between the sampling year (R=1; p=0.007).

Years compared	**R**	**p**
1978 – 2001	1	0.001
1978 – 1997	0.829	0.001
1997 – 2001	0.524	0.001

Table 3. Results of pairwise ANOSIM tests on root-transformed species densities from all stations.

SIMPER analyses for the “Very High” and “High” groups revealed clear shifts in feeding type composition over time (Table 5).

	“Very High		**“High”**	
Years compared	**R**	**p**	**R**	**p**
1978 – 1997	1	0.012	1	0.004
1978 – 2001	1	0.012	1	0.004
1997 – 2001	0.94	0.012	0.8	0.004

Table 4. Results of pairwise 2-way crossed ANOSIM tests on root transformed species densities per intensity group.

1978 (35.8)		**1997 (41.84)**		**2001 (24.71)**	
Total %1A	9.86	Total %1A	0	Total %1A	4.24
Total %1B	0	Total %1B	16.86	Total %1B	19.85
Total %2A	6.83	Total %2A	20.47	Total %2A	10.86
Total %2B	37.01	Total %2B	16.25	Total %2B	17.6

Table 5. Results of SIMPER analysis of nematode data from the "Very High" group, listing the total % contribution per feeding type to the similarity within years. A cut off of 50% was used.

In 1978, a substantial amount of the similarity between the stations was due to predatory nematodes (2B). In 1997, epistrate feeders (2A nematodes) and non-selective deposit feeders (1B) were the most important feeding types at the "Very High" and "High" stations. Non-selective deposit feeders were dominant at both intensity groups in 2001 (Table 5 and Table 6).

1978 (48.91)		**1997 (41.84)**		**2001 (24.71)**	
Total %1A	8.08	Total %1A	0	Total %1A	3.54
Total %1B	4.31	Total %1B	22.71	Total %1B	24.6
Total %2A	0	Total %2A	17.14	Total %2A	12.64
Total %2B	36.08	Total %2B	10.54	Total %2B	12.2

Table 6. Results of SIMPER analysis of nematode data from the "High" group, listing the total % contribution per feeding type to the similarity within years. A cut off of 50% was used.

This comparison could not be made for the "Very Low" station, since only 1 replicate is available from 1978. A SIMPER analysis restricted to the comparison of 1997 and 2001 again confirmed the high contribution of epistrate feeders and deposit feeders to the within year similarity, while the nematode abundances in 1978 were largely influenced by epistrate feeders.

Diversity indices (not depicted) for the "Very High" stations were not significantly different between the years (1-way ANOVA or Kruskal-Wallis tests). In contrast, significant differences between years were observed for the "High" group for all indices with the exception of total species (S), species richness and Margalev's species richness. Tukey HSD for unequal N showed for all significantly different indices (except for the Simpson index) that diversity was significantly lower in 1978 compared to 1997. No significant differences between 1978–2001 and 1997-2001 were observed.

Both Δ^+ and Λ^+ values for 1978 were higher than the expected mean value. Values for the Very High Extraction sites were above the 95% confidence intervals. In 1997 and 2001, both indices decreased but values were still within the probability funnels (Fig 10).

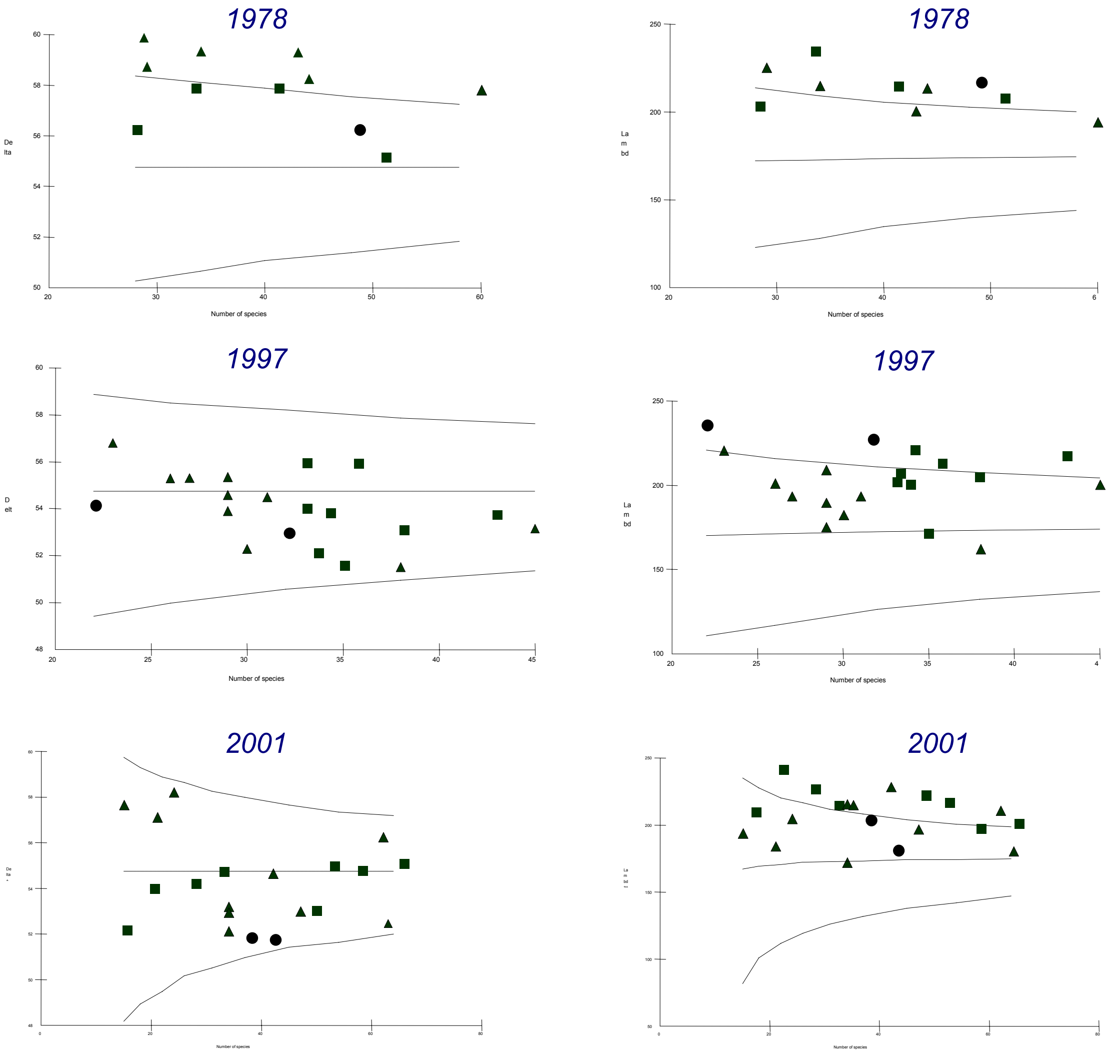

Figure10. The 95% probability funnels (thick line) for Δ+ (left) and Λ+ (right) for 15000 simulations for each subset size of size?? M, drawn randomly from the master list. Dotted line indicates theoretical mean values. Superimposed squares (Very High extraction sites); triangles (High extraction sites) and circles (Very low extraction sites) indicate actual values per station.

For both the "Very High" and "High" group, no significant differences were observed between the years (1-Way ANOVA or Kruskal-Wallis Analysis by Ranks).

DISCUSSION

Limitation of the dataset

Assessing the impact of sand extraction on the nematode communities from the Kwintebank is not an easy task. The earliest data available originate from a sampling campaign conducted in 1978. Extraction activities started already in 1976 and in 1977, 220 000 m^3 was extracted on the BCS and increased to 1 700000 m^3 in the mid of the 90's and 1 900 000 m^3 in 2001 (Degrendele et al. in press). At least 75% of the extraction activities were concentrated on the Kwintebank until 2003. Since the earliest biological samples were retrieved in 1978 there is no real baseline study available. Therefore we compare periods of intense extraction (1997 and 2001) with periods of a very limited exploitation (1978) rather than assessing the effect of sand extraction *sensu strictu*.

During this long period, scientific methods have changed considerably. However, for this study, sampling and treatment of the benthos was identical throughout the study period. Methodology for characterising the sediments did change and therefore a direct comparison of data from 1978 with 2001 was not possible. All samples from 2001 were analysed using the methods currently used, in order to facilitate the follow-up of the effects of cessation of the extraction activities in specific areas of the Kwintebank. Changes in the sediment composition of all stations seemed obvious, but needs further refinement taking into account spatial and seasonal variation. Since meiobenthos in general and nematodes in particular are living in very close contact with the sediment, even minor changes in the grain size variables are responsible for changes in nematode community composition (Vanaverbeke et al. 2002). Therefore, changes in the sediment composition will be inherently reflected in changes in the nematode communities.

Changes in sediment characteristics

Since 1978, considerable changes in sediment characteristics seem to have occurred at the Kwintebank, but a causal relationship with sand extraction has never been proven for the whole area of the sandbank. So far most effort was spent on assessing changes in the morphology of the Kwintebank (Degrendele et al. in press). Results indicate that in areas with high extraction intensity, changes in the morphology are obvious and changes in sedimentological characteristics are most probably related to the exploitation of the sandbank, while changes outside these areas could result from deviations in sedimentation and erosion patterns (Bonne 2003). Next to the above mentioned general long-term changes related to the exploitation activities, the meiobenthos will be influenced by short-term disturbances. The extraction technique creates dredging furrows with a depth of 10-50 cm. In sandbank areas, those furrows remain visible for a maximum of 6 months (Degrendele et al. in press). Likely, the creation and subsequent filling up of these furrows enhance the sediment dynamics

Changes in nematode communities.

Changes in nematode community composition between the different years and for each level of extraction intensity were obvious although no clear and consequent differences in diversity were noted. This holds for both the indices based on species abundances and taxonomic relationship. Heip et al. (1985) and Kennedy & Jacoby (1999) stated that nematode communities are an excellent tool for assessing disturbances to the sediment. One of the reasons for this is the high diversity observed within the nematode communities, with a wide range from species that are very sensitive to disturbance to very tolerant species. Therefore, diversity does not have to change as a consequence of perturbations, but community composition can. Since the impacts of sand extraction are possibly related to changes in grain size variables, a drastic reduction of species diversity is not to be expected. Generally, species diversity is reduced significantly in disturbances causing oxygen stress (Steyaert et al. 1999). Although the calculated diversity indices based on taxonomic relatedness (Δ^+ and Λ^+) are independent to changes in species abundances, they do not reflect the changes in nematode community composition in our study. Both species and genus identity changed over time, but their distribution within the taxonomical tree reflected more or less the same pattern during the successive sampling campaigns. Therefore diversity indices are not suited to assess possible effects of sand extraction activities.

The observed shifts in community structure could be related to natural evolution of the communities, to the exploitation of the sandbank or to the timing of sampling campaigns. Timing of sampling campaigns within a year is probably not important for explaining the observed patterns: Vanaverbeke et al. (2002) showed no difference in community composition or diversity when comparing seasonally different sampling campaigns on sandbanks on the BCS, including the Kwintebank. Moreover, both December and January can be considered winter months. On the other hand, inter-annual differences might have influenced the nematode community composition but the extreme differences between the years (very high R values in pairwise ANOSIM) are most probably not the result of inter-annual variation alone. As the deviations in the topography of the sandbank in the central and northern depression are related to the exploitation of the sandbank (Degrendele et al. in press), it can be logically deduced that the observed changes in grain size are a consequence of this changed sandbank morphology. On the short term, the creation and filling up of the dredging furrows create an extra human disturbance on the nematode populations. We believe that the observed shifts in nematode community composition are a consequence of a combination of changes in the sedimentological environment of the nematode communities and the frequent dynamics induced by the creation and filling of the dredge furrows. Indeed, the medium and very fine sand content and median grain size are known to be the most important sedimentological characteristics structuring nematode communities on sandbanks. Hence, changes in the grain size of the sediment as described above will trigger shifts in nematode community composition. The observed shift coincides with the disappearance of predatory nematodes (2B group) in favour of epistrate feeders (2A) and on the long term deposit feeding nematodes (1A+1B nematodes). It should be noted that in 1978, selective deposit feeders (1A) did contribute about 10% to the within year similarity for both 'Very High' and 'High' station groups. However, this relatively large contribution was due to species belonging to the genus *Trefusia*, which is a rather long nematode genus (length between 2 and 3 mm, Warwick, Platt & Somerfield 1998). Species from this genus are not among the species contributing to the 50% within group similarity in 1997 and 2001. Equally, predatory nematodes are generally large nematodes and become less important in the communities as observed in 1997 and 2001.

Being large in size seems to be a disadvantage when living in an environment where frequent physical disturbances occur as nematodes were generally smaller in the 'Very High' stations compared to the remaining stations (Vanaverbeke et al. 2003). During the 1997 sampling campaign in general, nematodes on the Kwintebank were smaller ompared to other sandbanks were no exploitation was ongoing. Several explanations can be given. Firstly, smaller nematodes have larger growth rates (Peters 1983) and therefore reach adulthood faster, but they also have higher reproduction rates (Kooijman 1986). These nematodes have less difficulty to maintain their populations in a frequent disturbed environment in comparison to larger nematodes. A second reason is given by Gallucci et al. (2005) who showed that predatory nematodes have less success in catching prey (other nematodes) when incubated in sediments deviating from their natural environment. Changing sedimentological conditions might lead to a reduction in predatory nematodes as a consequence of starvation. Moreover, predatory nematodes have a significant top-down impact on nematode prey communities (Moens et al. 2000). The decrease in dominance of 2B nematodes therefore could trigger better survival rates and increased dominance of the other sandbank inhabiting nematodes. This change in ratio between predators and prey might have important consequences for the functioning of the benthic ecosystem (Gallucci et al. 2005).

CONCLUSION

Although possible direct effects of sand extraction activities on the nematode communities cannot be inferred from our results, we suggest that nematode community composition is affected by changes in the sediment composition at the Kwintebank. Whether this is due to the exploitation activities or naturally induced changes needs further investigation. Diversity indices – based on species abundance and taxonomic relationship – do not reflect these changes. However, community composition is markedly changed and characterized by the loss of the vulnerable large predatory nematodes. This, together with the increased dynamics due to furrow creation and filling up, has reshaped the nematode communities in such a way that smaller nematodes belonging to the epistrate feeders and deposit feeders become dominant. This might have important consequences for the functioning of the benthic environment.

4. LONG-TERM EFFECTS OF SAND EXTRACTION ON HARPACTICOID COPEPOD COMMUNITIES FROM THE KWINTEBANK

INTRODUCTION

Since 1978 the copepod communities of the Kwintebank have been surveyed several times through different benthic research projects of the Marine Biology Section of the Ghent University (Willems et al. 1982; Bonne 2003). In the present study three sampling campaigns have been compared in order to reveal the impact of sand extraction on the meiobenthic copepods of the intensively exploited Kwintebank. The data of the samples of September 1978 (situation before the start of intensive sand extraction on the Kwintebank) and February 1997 (disturbance situation during sand extraction) have been used to study long-term effects of sand extraction on the benthic copepod communities and their ecotype distribution. Additional samples of December 2001 were analysed in the present study down to ecotype level only, representing a second disturbance situation during intensive exploitation. The presented evaluation of the long-term effects of sand extraction explains the temporal evolution of the total sandbank and of the different sand extraction intensity areas separately ("Very High", "High" and "Very Low" as explained for the nematode section), comparing data of 1978, 1997 and 2001, and focusing on total copepod densities and the ecotype approach. The high extraction intensity areas, the northern and central depression, have been further investigated in chapter 8 concerning the potential recovery of the benthic communities.

Within the ecotype approach the following hypothesis has been tested: due to sand extraction the bigger species are replaced by smaller interstitial species that can hide deeper in the sediment and can reproduce faster. This hypothesis was based on a preliminary analysis between 1978 and 1997, which showed that the big species were significantly reduced ($p < 0,005$) in the intensively extracted areas in the northern and the central part of the Kwintebank (Bonne 2003).

MATERIAL AND METHODS

Copepods and nematodes have been taken from the same meiobenthos samples. Sampling and sample treatment for the extraction of the meiobenthos from the sediment has been explained before in the nematode section. After staining the meiobenthos with Rose Bengal, all copepods were picked out and counted under a binocular microscope. For the samples of 1978 and 1997 copepods have been identified to species level under a microscope with a 100 X oil immersion lens (Bonne, 2003). One or more specimens were mounted together in glycerol on glass slides in non-permanent toto preparates. Copepodite stages were counted as a single group and identified to species level where possible. Nauplii were disregarded; their identification being too difficult. Identification was based on the descriptions given in Lang (1948, 1965) and Bodin (1997 and references therein) and more recent papers. In order to analyse the trophic structure of communities, four different ecotypes have been discerned for the samples of 1978, 1997 and 2001 (Fig. 11): epibenthic species, endobenthic species, interstitial species and phytal - free-swimming species (Hicks & Coull 1983). Ecotype 1 are epibenthic species that are living on top of the sediment; ecotype 2 are endobenthic species that are digging and living in the upper centimetres of the sediment; both are eating detritus. Ecotype 3 or interstitial species are up to ten times smaller than the former ones and are living in the interstitial spaces between the sand grains, grazing on bacteria. Some harpacticoids are also free-swimming and live close to the sediment; they are defined as ecotype 4.

In order to compare densities among and within different periods, ANOVA's were performed on log (x+1) transformed data. The non-parametric ecotype data are analysed by means of the Kruskall-Wallis ANOVA by Ranks. Overall significant differences were pairwise compared using Tukey's HSD for unequal N for densities and following Conover (1971) for ecotype data. The univariate analyses were performed with STATISTICA (Microsoft, StatSoft, Inc. 2000).

The harpacticoid community structure of 1978 and 1997 has been 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 1979) 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 certain representatives of some families (especially Ectinosomatidae and Ameiridae) have not been 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.

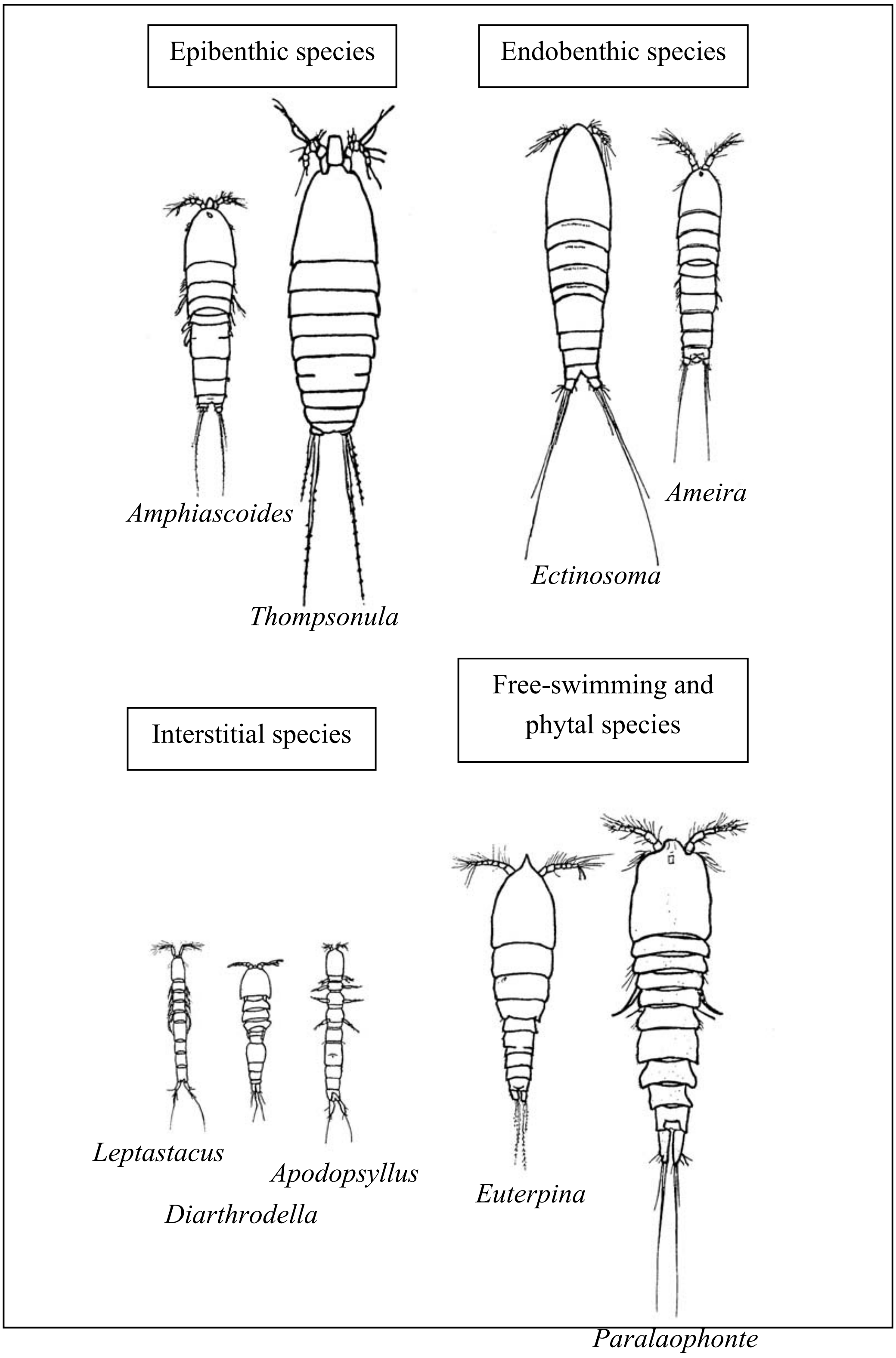

Figure 11. Different ecotypes of harpacticoid copepods, illustrated by means of some typical genera

RESULTS

a. Densities

Total copepod densities differed significantly between the different years 1978, 1997 and 2001 ($p < 0.01$). A significant decrease in densities could be observed between 1978 and 1997 for the whole sandbank (Table 7). During the disturbance situation in 2001 the densities remained the same and as low as in 1997, still significantly different from 1978.

When considering the temporal evolution of the different extraction intensity areas, a significant difference was only found between 1978 and 1997 for the areas with the highest extraction intensity, the northern and the central depression, whereas the copepod densities at the rest of the sandbank remained more similar between the different years (Table 8, Fig. 12).

Years compared	**Total sandbank**
1978 – 1997	$p < 0.005$
1978 – 2001	$p < 0.05$
1997 – 2001	n.s.

Table 7. Results of the comparison of copepod densities from all the bank stations between the different years.

Years compared	**"Very High"**	**"High"**	**"Very Low"**
1978 – 1997	$p < 0.05$	n.s.	n.s.
1978 – 2001	n.s.	n.s.	n.s.
1997 – 2001	n.s.	n.s.	n.s.

Table 8. Results of the comparison of copepod densities between the different years per sand extraction intensity group.

Within the different extraction intensity groups no significant differences could be detected between the stations for copepod densities in 1997 or 2001 (not possible to test for 1978 due to no replication data for 1978).

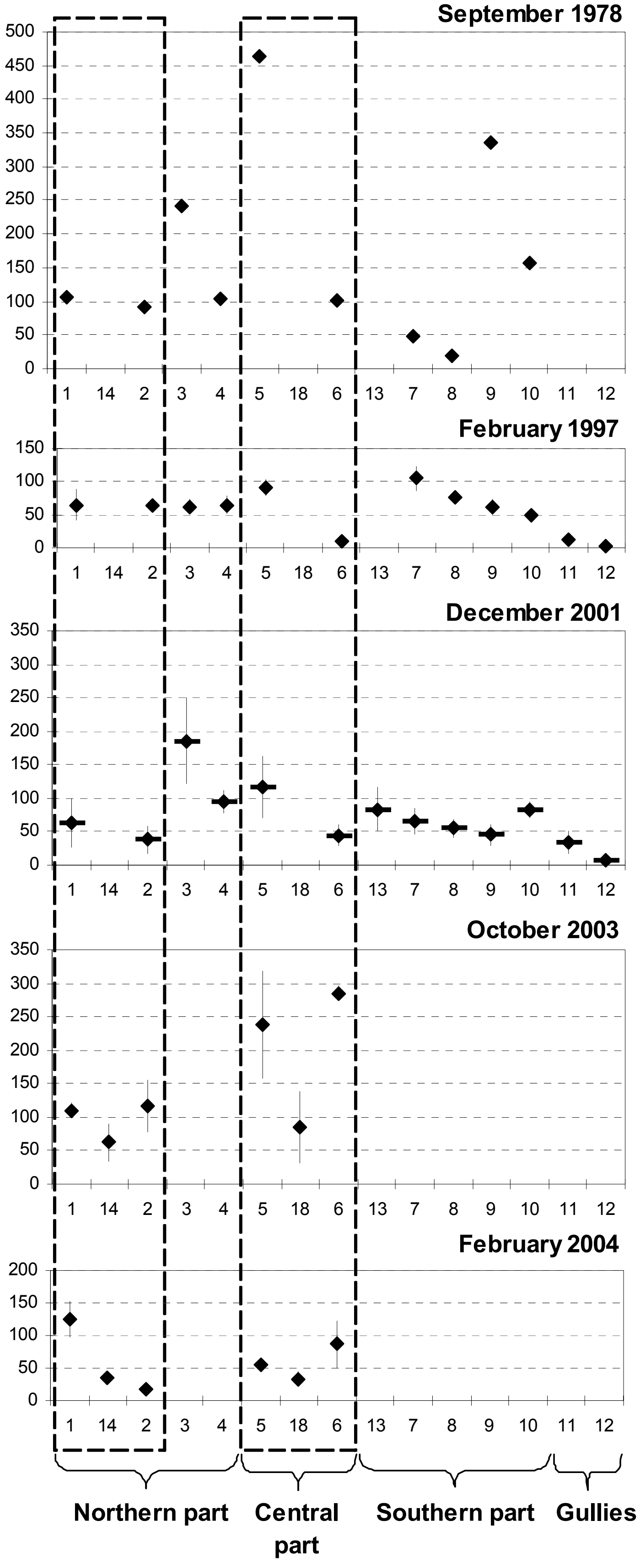

Figure 12:
Mean density (ind./10cm²) of the different sampling campaigns. The dotted frames outline the northern and the central depression on the Kwintebank.

b. Communities species composition

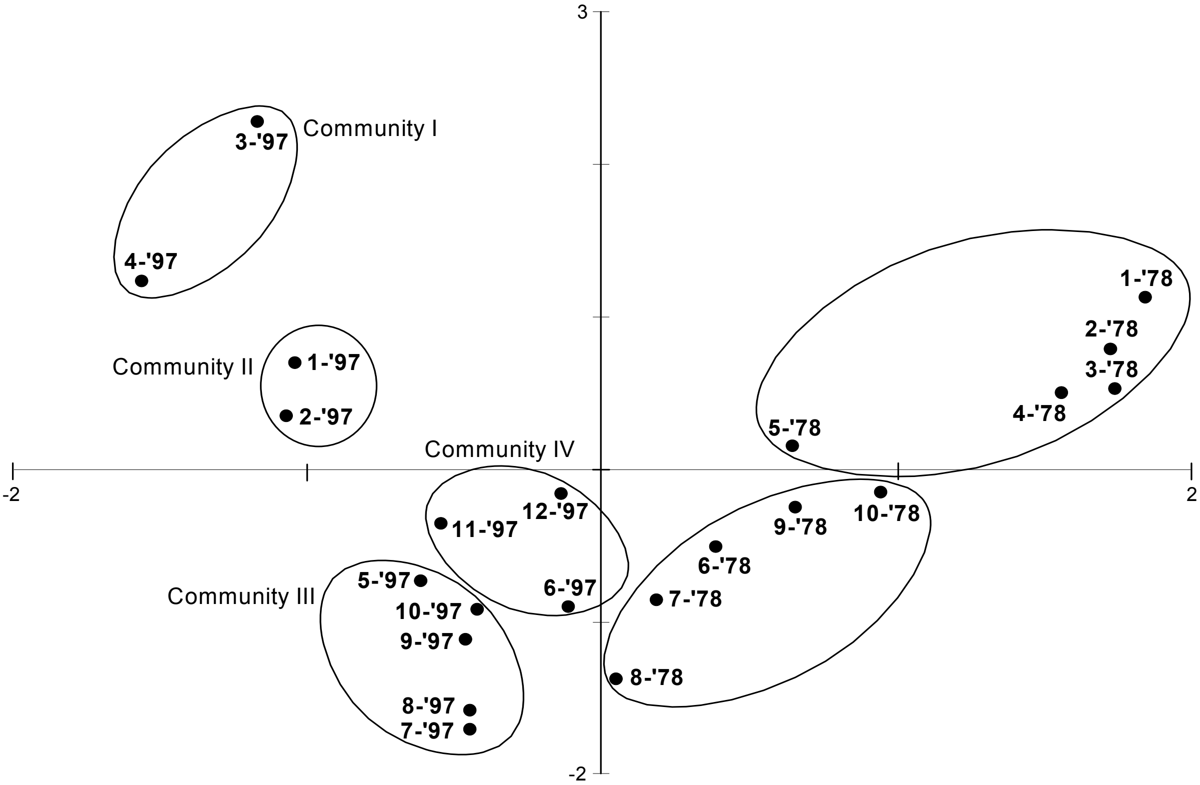

Figure 13 Plot of the stations in a CA, based on absolute species densities of the pooled dataset of 1978 and 1997.

The identified copepod communities of 1997 and 1978 were clearly separated along the first axis in a CA (Fig. 13) of length 3.38 SD, but no environmental gradient was significantly correlated with this pattern. The higher abundance of endobenthic Ameiridae and Ectinosomatidae and the presence of the endobenthic species *Robertgurneya ilievecensis* in 1978 were selected by TWINSPAN as the most important characteristics to distinguish both years, which is also reflected by the ecotype distribution difference between 1978 and 1997 (see next point). 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. In 1978 the northern stations, 1 until 5, were grouped into one highly variable community whereas these stations have been split up in different communities in 1997 (Community I, II and station 5 in Community III). 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. 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. All the species present in 1978 still occurred in 1997. Also the dominant species and the proportional distribution were still comparable. Only the endobenthic 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.

c. Ecotype percentages

The percentages of the four ecotypes of the different periods are shown in Fig. 14. Except for Ecotype 1 significant differences have been found for the different ecotypes between the years (Table 9), Small-sized interstitial species (ecotype 3) increased significantly between 1978 and 1997 due to a decrease of endobenthic species (ecotype 2). Due to an increase in big species again, to a large extent free-swimming species, the interstitial species decreased again between 1997 and 2001 in such a way that 1978 and 2001 had a comparable distribution of small-sized and big ecotypes.

Years compared	Ecotype 2	Ecotype 3	Ecotype 4
1978 – 1997	$p < 0.0005$	$p < 0.005$	n.s.
1978 – 2001	$p < 0.05$	n.s.	n.s.
1997 – 2001	n.s.	$p < 0.01$	$p < 0.001$

Table 9. Results of the comparison of ecotypes from all the bank stations between the different years.

Years compared	"Very High"	"High"	"Very Low"
1978 – 1997	Ecotype 2 $p < 0.01$ Ecotype 3 $p < 0.005$ Ecotype 4 $p < 0.05$	Ecotype 2 $p < 0.05$ Ecotype 3 $p < 0.05$ Ecotype 4 n.s.	Ecotype 2 n.s. Ecotype 3 n.s. Ecotype 4 n.s.
1978 – 2001	Ecotype 2 n.s. Ecotype 3 n.s. Ecotype 4 n.s.	Ecotype 2 $p < 0.05$ Ecotype 3 n.s. Ecotype 4 n.s.	Ecotype 2 n.s. Ecotype 3 n.s. Ecotype 4 n.s.
1997 – 2001	Ecotype 2 n.s. Ecotype 3 $p < 0.0005$ Ecotype 4 $p < 0.0005$	Ecotype 2 n.s. Ecotype 3 n.s. Ecotype 4 n.s.	Ecotype 2 n.s. Ecotype 3 n.s. Ecotype 4 n.s.

Table 10. Results of the comparison of ecotypes between the different years per sand extraction intensity group.

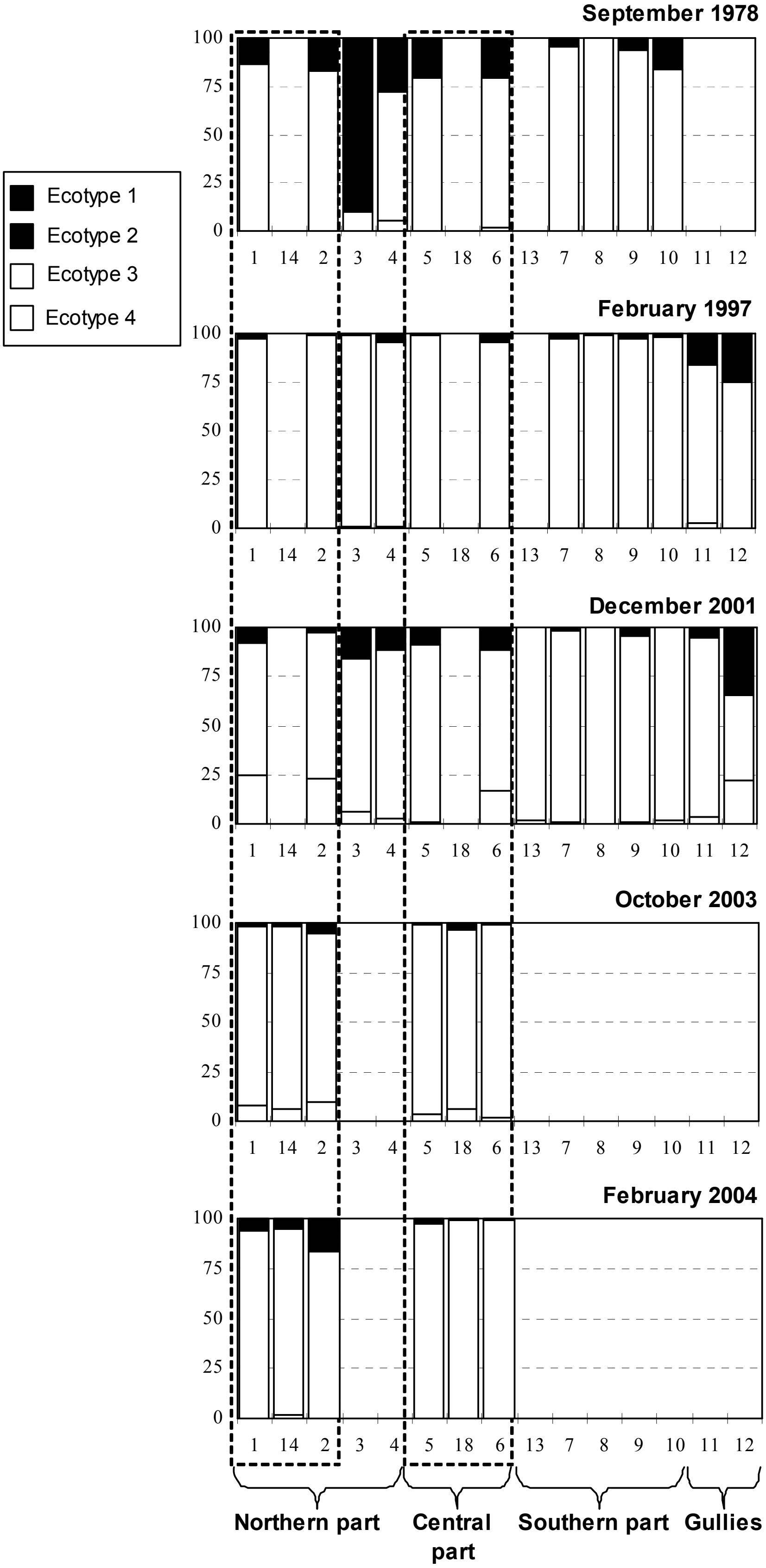

Figure 14:
Mean percentages of the four ecotypes of the different sampling campaigns. The dotted frames outline the northern and the central depression on the Kwintebank

During the dredging situation in 1997 a significantly lower percentage of epibenthic species ($p < 0.01$) was found in the very high extraction intensity area compared to the high extraction intensity area. In 2001 the percentage of epi- and endobenthic species did not differ between the stations with different extraction intensity. However, 2001 was characterized by a significant increase in free-swimming species in comparison with 1997 and this situation differed between the "Very High" extraction area and the "High" extraction area in 2001 (Table 10). The "Very High" extraction area yielded a significantly higher percentage of free-swimming species ($p < 0,05$) and a significantly lower percentage of interstitial species ($p < 0.005$) in comparison with the "High" extraction area.

DISCUSSION

The changes in the species assemblage in the two depressions imply an increased importance of small interstitial species between 1978 and 1997, which may have been related to intensive sand extraction (Bonne 2003). 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. 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). Interstitial harpacticoids are able to hide deeper into the sediment than the bigger epi- and endobenthic species and such behaviour may be more beneficial than the swimming activity of the epi- and endobenthic species when coping with extreme disturbance such as intensive sand extraction. In the present study, however, the small-sized species decreased again between 1997 and 2001 during the extraction disturbance situation. The percentages of the big epi- and endobenthic species in the depressions slightly increased in 2001 and did not show significant differences with the disturbance situation in 1997, but also not with the pre-disturbance situation of 1978. Hence, a clear consistent decrease of epi- and endobenthic species as a result of extraction activities cannot be confirmed. The results also show that it is not easy to distinguish disturbance situations from non-disturbance situations, based on the percentages of ecotypes, because the spatial variation of epi- and endobenthic species can be very high. A difference of 60 % interstitial species existed between two replicates of station 3 in 2001, whereas the sediment characteristics between those replicates were quite similar (Fig.15). This spatial variability may explain the big difference between 1978 and 1997 at station 3, where the decrease in epi- and endobenthic species was even larger than for the "Very High" extraction intensity areas. In muddy and fine sand stations in the coastal area, Herman (1989) has also found extensive oscillations in the proportions of epi- and endobenthic to interstitial species, because of the patchy and momentary high abundance of individual epi- and endobenthic species in this area. This variability seems to occur in communities typical for coarse sand on the Kwintebank as well. If we cannot dedicate the cause of this variability, the ecotype approach will not be very useful to use as a quick monitoring tool to detect effects of sand extraction.

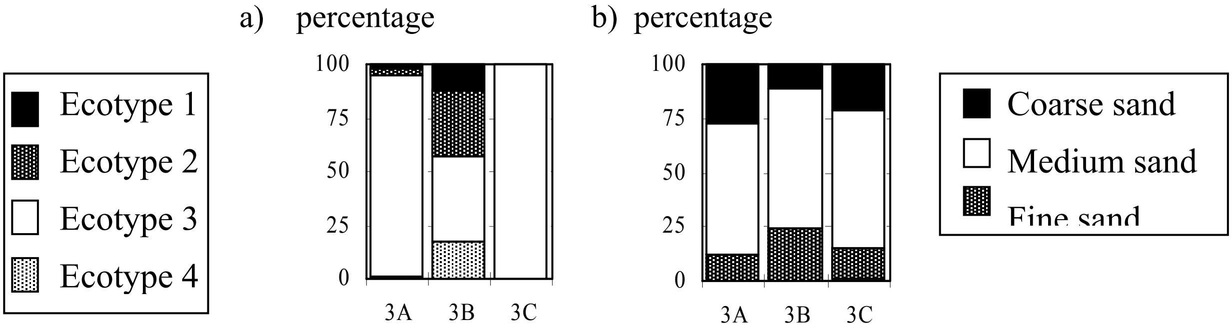

Figure 15

a) Percentages of the four ecotypes of the three replicates of station 3 in 2001.

b) Percentages of coarse, medium and fine sand of the three replicates of station 3 in 2001.

Not only a high variability of copepod ecotypes has been detected between the replicates at very small scale (such as in 2001) but also a high spatial variability of the sediment distribution has been shown at the point-scale (see the section on short-term sedimentological evolution). Yet, at the scale of the extraction intensity areas, some patterns can be observed, since the "very high" extraction areas showed similar characteristics, distinguishable from the rest of the bank in 2001, due to a higher density of free-swimming copepods in the northern and central depression than at the rest of the sandbank. The sedimentological evolution of the central depression has similar characteristics to a gully environment (see the section on short-term sedimentological evolution). Gullies are characterized by a fluctuating abundance of big species, including free-swimming species (Bonne 2003). The higher abundance of free-swimming species in the two depressions may be related to gully-like habitat characteristics that developed due to sand extraction.

CONCLUSIONS

Assessing the long-term effects of sand extraction on the benthic environment using an ecotype approach for harpacticoid copepods seems not straightforward. Densities of larger species were expected to decrease as a consequence of the increased physical disturbance of sediments due to the exploitation activities. However, the obtained results from the harpacticoid copepod study did not confirm this idea and showed that it is not easy to distinguish disturbance situations from non-disturbance situations, based on the percentages of ecotypes. Two reasons have been found in the present study. The first one is that the percentage of big species fluctuates and can increase in the sand extraction disturbance situation, such as the situation for both depressions in 2001. A second reason is that the spatial variation of epi- and endobenthic species can be very high. This variability seems to occur in communities typical for coarse sand on the Kwintebank. As long as we cannot dedicate the cause of this variability, the ecotype approach is not consistently useful as a quick monitoring tool to detect effects of human physical disturbance such as sand extraction, since the decrease in big ecotypes is not always directly related to sand extraction.

5. SHORT-TERM SEDIMENTOLOGICAL EVOLUTION OF THE CENTRAL DEPRESSION OF THE KWINTEBANK AFTER CESSATION OF EXTRACTION ACTIVITIES

INTRODUCTION

The grain-size variation along the central part of the Kwintebank was followed-up after the cessation of sand extraction in February 2003. In order to be able to distinguish between the spatial and temporal variability, a detailed sampling grid was designed with an overall spacing of 300 m and 100 m in the central depression. The temporal variation of the grain-size parameters have been studied in terms of natural processes and anthropogenic influence.

MATERIAL AND METHODS

Four sampling campaigns were conducted between September 2003 and February 2005. The location of the samples for each campaign is indicated on all the figures. During the two first campaigns the samples were taken during flood, whereas during the two last ones, the sediments were sampled both during the ebb and flood tide. For each campaign, 100 grabs were taken along the study area. A Van Veen grab was used of which half of the grab was taken. The sample was subsampled in the laboratory using a splitter. The sediments were sieved on a rack of 4 mm to 75 µm with a ¼ phi interval to allow detailed analysis. The final results were statistically treated to obtain the most relevant sedimentological parameters (Folk and Ward, 1957): mean grain-size, sorting, skewness, and shell content, the latter using a calcimeter. Sediment grain-size fractions were classified according to the Wentworth scale (1922). The parameter results were gridded using the 'natural neighbour' approach.

RESULTS

The area of the central depression is characterised by the following morphological entities: (1) the Kwinte Swale (swale to the NW) with locally very small dunes; (2) the steep slope and the top of the western part with very-large dunes; (3) the central depression with smaller dunes and (4) the gentle slope of the eastern flank with medium to large dunes. Each of these environments shows specific sedimentological parameters; as such, the temporal evolution of the grain-size has been studied per sedimentary environment.

Mean grain-size

The values of the mean grain-size vary from 180 µm to 1250 µm and generally the same pattern was found for the four campaigns (Fig. 16): (1) fine to medium sand in the Kwinte Swale (mean +/- 293 µm); (2) medium to very coarse sand on the steep slope and the top (mean +/- 561 µm); (3) patches of fine to medium sand in the central depression (mean +/- 339 µm) and (4) fine to medium sand on the eastern flank (mean +/- 273 µm).

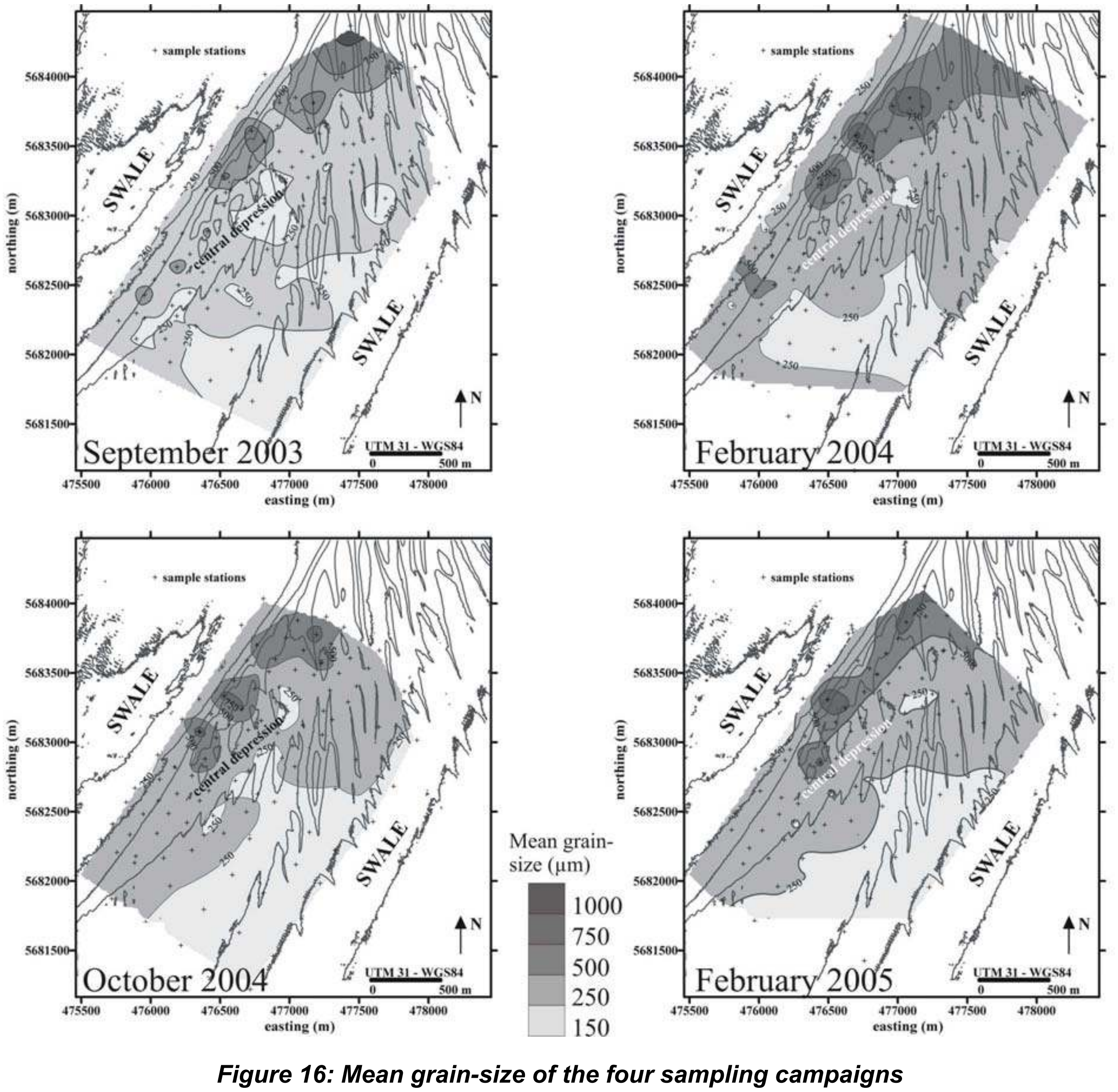

Figure 16: Mean grain-size of the four sampling campaigns

This pattern changes throughout the year (Fig. 16) and the sediment can be coarser (up to +350 µm) or finer (up to –650 µm). A comparison on a sample by sample basis shows that the changes are more important around the steep slope and the top, whereas the gentle slope shows no large differences. However, the differences per environment only vary around +/- 30 µm. When the whole study area is considered, the changes are even lower (+/- 15 µm; Table 11).

Sorting

As for the mean grain-size, the value of the sorting varies according to the location (Fig. 17, Table 11): (1) the swale, the steep slope and the top: moderately sorted to poorly sorted sand (mean around 0.96 ϕ and 1.13 ϕ); (2) the sorting is better into the central depression (mean around 0.80 ϕ) and also somewhat more to the east and (3) the gentle slope shows the best-sorted sand (mean about 0.56 ϕ).

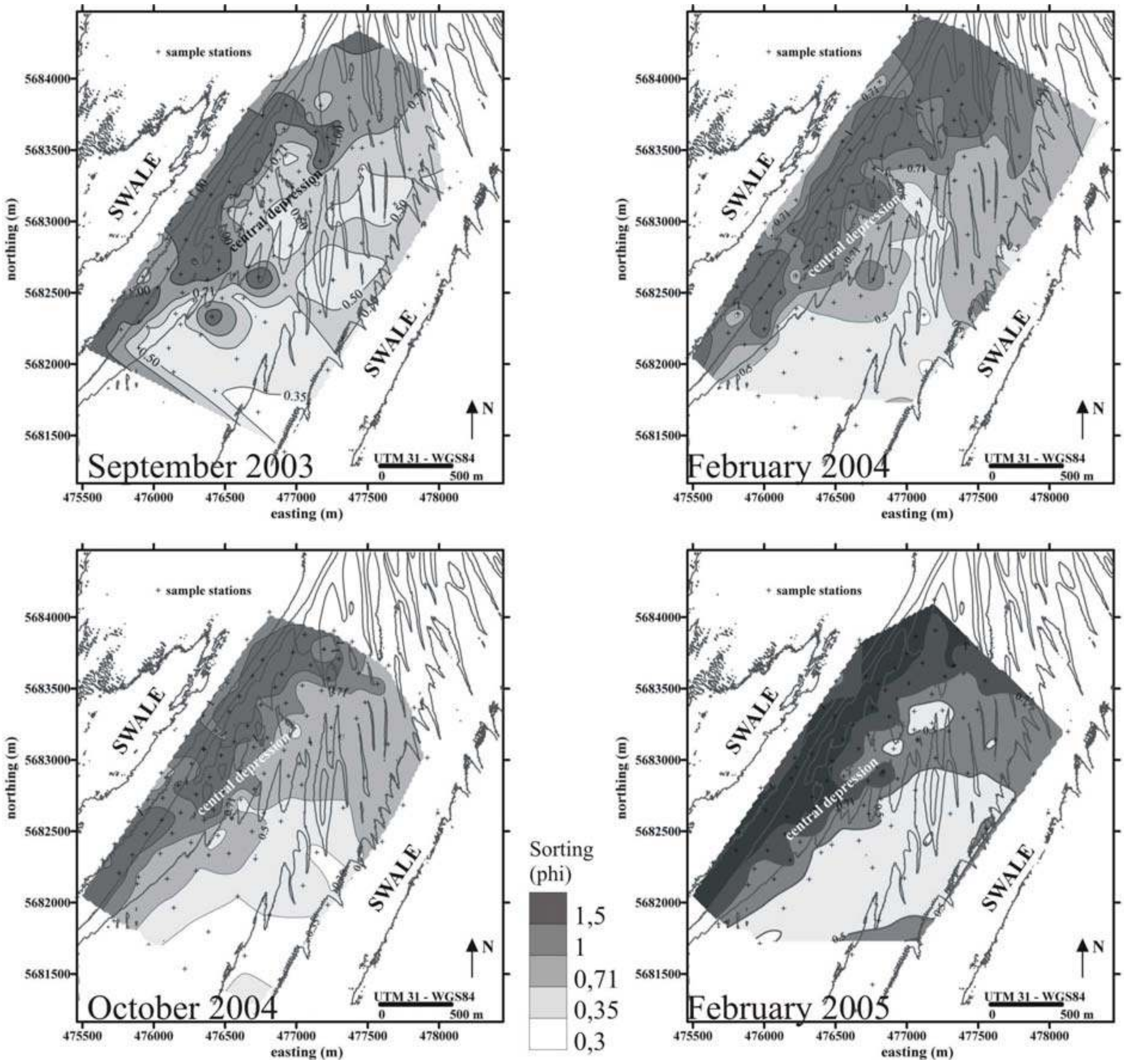

Figure 17: Sorting of the four sampling campaigns

The maximum change of the sorting varied between –0.9 ϕ to +1.1ϕ. The greatest changes are essentially located around the steep slope and the central depression. But similar to the mean grain-size, the evolution for each environment is lower (+/- 0.1 ϕ maximum) and only +/- 0.03 ϕ on the whole study area (Table 11).

Environ.	**Sedimentological parameters**	**September 2003**	**February 2004**	**October 2004**	**February 2005**	***Mean***
Swale	Mean grain-size (µm)	275	294	317	286	293
	Sorting (ϕ)	0.95	0.91	0.98	1.01	0.96
	Skewness	-0.41	-0.42	-0.43	-0.32	-0.39
	CaCO3 content (%)	13	14	15	10	13
Steep slope and top	Mean grain-size (µm)	543	570	533	598	561
	Sorting (ϕ)	1.06	1.14	1.14	1.18	1.13
	Skewness	-0.21	-0.21	-0.25	-0.23	-0.22
	CaCO3 content (%)	29	31	26	37	31
Central depression	Mean grain-size (µm)	299	350	360	348	339
	Sorting (ϕ)	0.71	0.89	0.84	0.77	0.80
	Skewness	-0.26	-0.29	-0.23	-0.18	-0.24
	CaCO3 content (%)	15	17	16	17	16
Gentle slope	Mean grain-size (µm)	271	281	259	282	273
	Sorting (ϕ)	0.55	0.58	0.54	0.59	0.56
	Skewness	-0.17	-0.13	-0.16	-0.12	-0.14
	CaCO3 content (%)	13	13	11	12	12

Table 11. Evolution of the different environments between September 2003 and February 2005.

Skewness

The skewness of the samples varies from -0.75 to +0.25. The positive values correspond to fine-skewed sand (enrichment in fine grains) and the negative values are coarse-skewed sands. Most of the samples are coarse-skewed. Surprisingly, samples with a large amount of shells are often fine-skewed and might be due to a trapping of fine sediment. The repartition of the skewness is less clear than the mean grain-size or the sorting one and is not shown here. Nevertheless the eastern part is stable with generally the closest values to zero in skewness (around –0.14) whereas the western part has alternatively excesses in fine or coarse grains with a tendency towards coarse-skewed sediments (mean around –0.23 for the central depression and the steep slope and –0.39 for the Kwinte Swale). The sample-to-sample evolution of the skewness is important and varies around +/-0.8. The greatest changes are also located in the western part of the bank (central depression, steep slope and swale). The mean changes for each environment are +/-0.05 and for the whole area +/- 0.02 (Tables 11-12).

Sedimentological Parameters		**Sept03-Feb04**	**Feb04-Oct04**	**Oct04-Feb05**
MEAN GRAIN-SIZE EVOLUTION	swale	+	+	-
Coarser: +	Steep slope	+	-	+
Finer: -	Depression	+	+	-
	Gentle slope	+	-	▪ +
Sorting evolution	swale	-	-	-
Worse sorting: -	Steep slope	-	=	-
Better sorting: +	Depression	-	+	+
Similar: =	Gentle slope	-	+	-
Skewness evolution	swale	=	=	-
Coarser-skewed: +	Steep slope	=	+	-
Finer-skewed: -	Depression	+	-	-
Similar: =	Gentle slope	-	+	-

Table 12. Synthesis table of the sedimentological changes between September 2003 and February 2005; Evolution between September 2003 and February 2004, February 2004 and October 2004, October 2004 and February 2005.

CaCO3 content

In general, the CaCO3 content increases from the swale (around 10-20 %) to the top (up to 62 %) and decreases from the top to the gentle slope (down to 5 %). In the swale, the mean values are around 13 %, 31 % on the steep slope, 16 % in the central depression and 12 % on the gentle slope (Table 11). On the sample scale, the changes are between –35 % and +30 %. The variations strongly decrease if an interpretation at a larger scale is done:: only +/- 6 % at the environment scale and +/- 2% on the bank scale (Tables 11 and 12).

DISCUSSION

Changes at the sample scale

Comparing two samples at the "same position" at different time-periods is difficult due to positioning differences, bedform migration and change, bioturbation and hydrodynamic changes. This is clearly the case in an area dominated with large dunes.

Changes at the environment scale

If samples are grouped according to their sedimentary environment, it becomes clear that each environment has particular characteristics: (1) The Kwinte Swale, characterized with moderately sorted medium sand with a very coarse skewed component; (2) The steep slope and the top showing poorly sorted coarse sand with a coarse skewed component; (3) The central depression composed of moderately sorted medium sand with a coarse-skewed component and (4) the gentle slope constituting of moderately well-sorted medium sand with a nearly symmetrical skewness. Seasonal trends become also clearer if the characteristics are studied per environment (Table 12). During the winter, the mean grain-size and the CaCO3 content increase and the sorting is slightly poorer. This is mostly observed along the gentle slope of the sandbank, being a less energetic environment. Along the higher energetic environment of the steep slope, only the mean grain-size follows a seasonal variation. Opposite, the evolution of the mean grain-size of the central depression and the swale shows a similar behaviour and does not reveal seasonal variations at the time-scale of 2 years. Remarkably, the mean grain-size evolution in the central depression differs from the evolution seen along the top and other parts of the bank. Moreover, it is observed that the evolution in grain-size in the depression shows similar trends to the evolution seen in the swales (Table 1). This is likely due to the fact that the central depression has a direct connection with the Kwinte Swale. Moreover, the presence of the central depression allows a local accumulation of shelly material. This gives rise to a more heterogeneous sediment distribution in the depression.

Changes at the bank scale

Although, the seasonal variation may average out when the whole sandbank is considered, there are changes that are spatially important. This can be due to a different surficial sedimentation pattern under different tidal cycles (ebb/flood and, or spring/neap tide). It was shown that under ebb and neap tidal current conditions, a mobile layer of fine sediments (silt and clay) can be deposited in the central depression. Bellec et al. (submitted) argues that, with respect to the ebb current, the central depression acts as a protected area.

CONCLUSIONS

Considering different spatial scales (point location samples, environment or the whole sandbank area), the sedimentological characteristics of the Kwinte Bank change a lot or are very stable at the studied time-scale of 2 years. At the point-scale, the changes are too numerous and important to determine any evolutionary trend. This is imposed by randomness, but is also due to the high spatial variability of the sediment distribution. At the environment-scale, a seasonal variation starts appearing with coarser and more poorly sorted sediments during the winter. This is especially the case along the least disturbed environment of the gentle slope. Remarkably, the central depression on the top of the bank has the same mean grain-size evolution as the swale.

As such, it can be concluded that the human impact is essentially visible at the environment-scale and becomes less important when the whole sandbank is considered. Moreover, it was shown that "perturbed" environments may show a different seasonal variation than environments in equilibrium.

6. RE-COLONISATION AND RECOVERY OF THE MACROBENTHOS AFTER CESSATION OF DREDGING ON THE CENTRAL DEPRESSION OF THE KWINTEBANK

INTRODUCTION

Benthic organisms are closely associated with the bottom of the sea for the major part of their life (Snelgrove & Butman 1994). Most species have a limited mobility and are therefore forced to adapt to seasonal fluctuations and anthropogenic influences (Boyd et al. 2003). Climatologic circumstances (e.g. cold winters, heavy winds...), food supply, predation, as well as human impacts can have serious repercussions on the resident populations (Kröncke & Bergfeld 2001). The macrobenthos is an important link in the marine ecosystem for the re-mineralization and transformation of organic material and as the main food source for demersal fishes. These factors make macrobenthos ideally suited as an indicator for assessing the state of the marine environment and to detect possible changes caused by human and natural impacts (Boyd et al., 2003).

A number of studies deal with the recovery of an area or the rates and processes of macrobenthic re-colonisation upon cessation of dredging activities (for reviews see o.a. Newell et al. 1998; Boyd et al. 2004; ALSF 2005). The estimated time required for recovery of the benthic fauna following marine aggregate extraction may vary, depending on the nature of the habitat, the scale and duration of disturbance, hydrodynamics and associated bed load transport processes, the topography of the area and the degree of similarity of the habitat to that which existed prior to dredging (Newell et al. 1998). In most cases a progress towards full restoration of the fauna and sediments can be expected within a period of approximately 2-3 years following cessation, although a complete re-colonisation of the macrobenthos (biomass and structure) after extraction can take up to 10 years or longer (Kenny & Rees 1994, 1996, Desprez 2000, van Dalfsen et al. 2000, Sarda et al 2000, van Dalfsen & Essink 2001, Boyd et al. 2004; Cooper et al. 2005; Simonini et al. 2005). Some studies (all characterised by mud or fine sand) show re-colonisation after a few months (Guerra-Garcia et al. 2003; Sanchez-Moyano et al. 2004). Most of these studies have been mainly concerned with the effects of dredging operations that last only a short period. Few studies have addressed the consequences of long-term dredging operations on the re-colonization of biota following cessation (Desprez 2000; Newell et al. 2004a; Newell et al. 2004b).

The aim of this study is to see how the area and the associated benthic fauna change following cessation of the extraction activities. The time span considered here is 2-3 years.

MATERIAL AND METHODS

Sample collection and processing

To investigate recovery of benthic life in de central area of the Kwintebank, 6 locations (ZG05 - ZG10) were sampled 7 times between March 2003 and September 2005 from the RV Belgica. (see Chapter 2, Figure 2). At each location 4 Van Veen grabs were taken; 3 for macrobenthos and 1 for sediment analysis. The macrobenthic samples were fixed in a formaldehyde-seawater solution before being washed over a 1 mm sieve in the lab and subsequently coloured with eosine. Using a binocular, macrobenthic specimens were sorted and identified, if possible up to species level.

Data processing

Nemertinea, Nematoda and Oligochaeta species were excluded from the dataset as they were not consistently sorted and identified from each sample. The main community characteristics (total abundance, number of species and Shannon-wiener diversity index) for the six sampling locations were used for spatial and temporal comparisons. Wet weights were measured per species and multiplied with a correction factor for each of the faunal groups to calculate Ash Free Dry Weight (Brey 2001). Biomass data for September 2005 were not yet available.

Multivariate ordination techniques (Correspondence Analysis) were used to evaluate changes in the community over time. No direct gradient analysis could be performed as sediment data were taken from a fourth grab per sampling location, generating only one value per station per season. Therefore it would be statistically incorrect to directly link the sediment values with the macrobenthic data of every single replicate. The CA was performed using the square root transformed abundance data, after elimination of rare species (present in less than 3 replicates) by means of the statistical package PCord (McCune & Mefford 1999).

The biological data of the central depression were also compared with other sampling locations on the Kwintebank. These data were gathered in the same period in the framework of the sand extraction monitoring program of ILVO-Fisheries.

RESULTS

Sediment

Throughout the two year period after cessation of extraction, the median grain size of the area showed no clear evolution. High variations were found between the different sampling periods and locations (Fig. 18). The two sampling stations located in the western part of the study area (ZG05 and ZG08) were characterised by a higher percentage of coarse material (> 2 mm). For the other four sampling stations the most important fractions were 125-250 µm and 250-500 µm. The median grain size for stations ZG08 and ZG09 showed a small increase from 2003 to 2005. The median grain size of station ZG06 was stable around 350 µm.

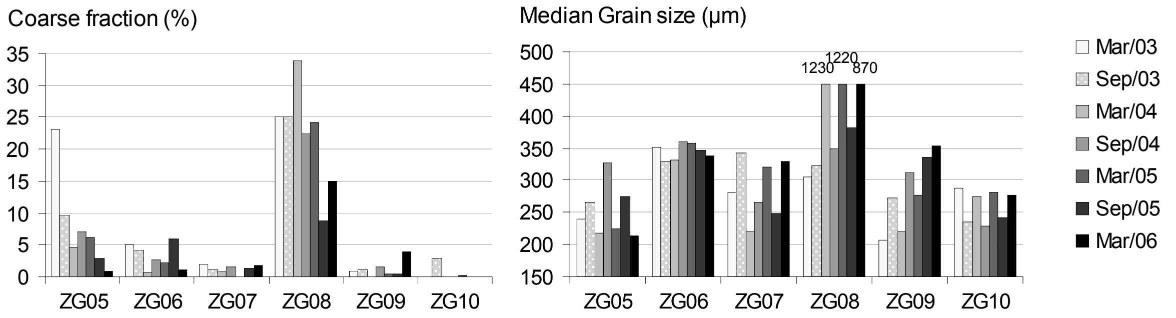

Figure 18: Percentage of coarse fraction and median grain size for all stations for the different sampling periods.

Macrobenthos

1. Species richness

In total 104 different macrobenthic species were found in the period March 2003 - September 2005. Taking the whole sampling period into account, the highest number of different species was counted for station ZG05 (61), the least for station ZG08 (39). Averaging the stations per sampling date and comparing the different sampling periods, the highest species richness was found in September 2005 (67) whereas only 31 different species were counted in March 2003 (Fig. 19). The proportion of the different taxa in the total amount of species did not vary a lot over the different sampling periods. Polychaetes or bristle worms constituted on average 43% of the species composition, crustaceans (mainly amphipods) 30%, molluscs (mainly bivalves) 15%.

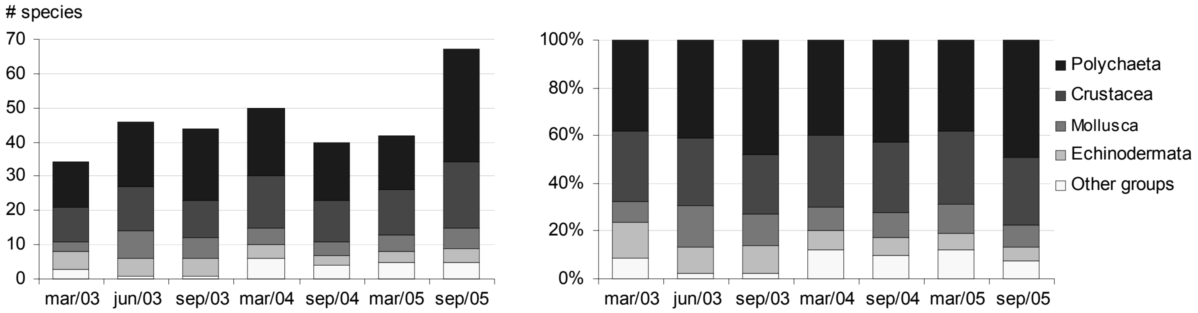

Figure19: Total number of species counted in the central depression per season and the proportion of the major taxonomic groups in density.

2. Diversity

The Shannon-wiener diversity-index was lowest in March 2003, only 1 month after cessation of dredging (Fig. 20). For most stations, the diversity in the other seasons was between 2 and 3. For station ZG05, diversity was not only low in March 2003, but also in September 2003. Station ZG09 showed high values even in March 2003. Station ZG08 had the lowest diversity overall. Diversity of stations ZG06 and ZG07 showed a slightly increasing trend.

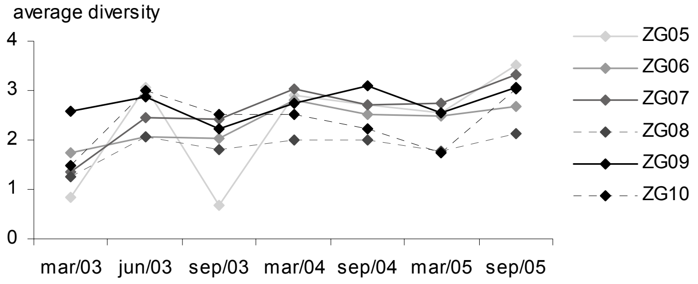

Figure 20: Shannon-wiener diversity index for the different sampling locations for the period March 2003 – September 2005.

3. Density

Stations ZG06, ZG07 and ZG09 showed the highest densities for most seasons, whereas the densities were lowest in most seasons for station ZG08 (Fig. 21). Taking into account all stations, a minimum average of 90 ind/m² was calculated in March 2003 and a maximum of more than 590 ind/m² in September 2005 (Figure 21). The high total density in September 2005 was mainly due to high numbers recorded in the two central stations ZG06 and ZG09 (Fig. 20). Polychaetes and crustaceans represented the largest fraction of the overall density with respectively 66% and 25% (Fig. 22). The relative abundance of the polychaetes increased compared to a decreasing relative abundance of the crustaceans.

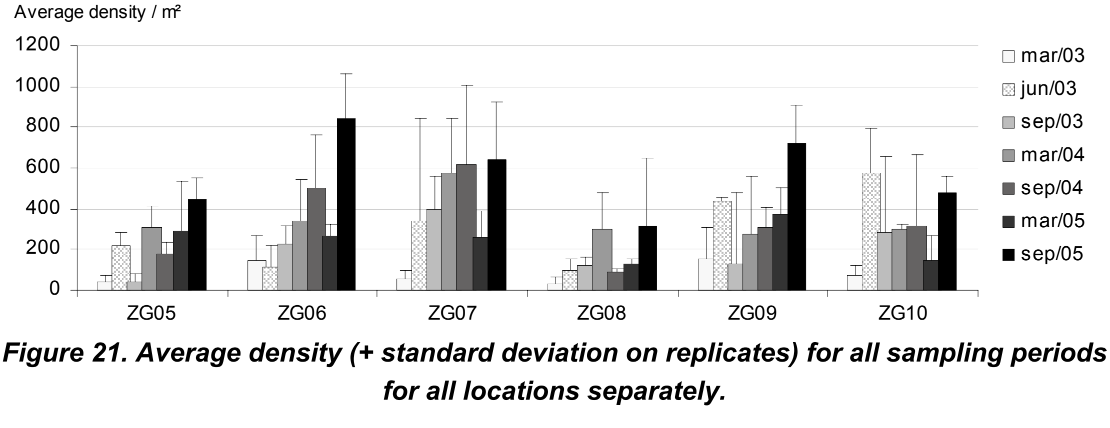

Figure 21. Average density (+ standard deviation on replicates) for all sampling periods for all locations separately.

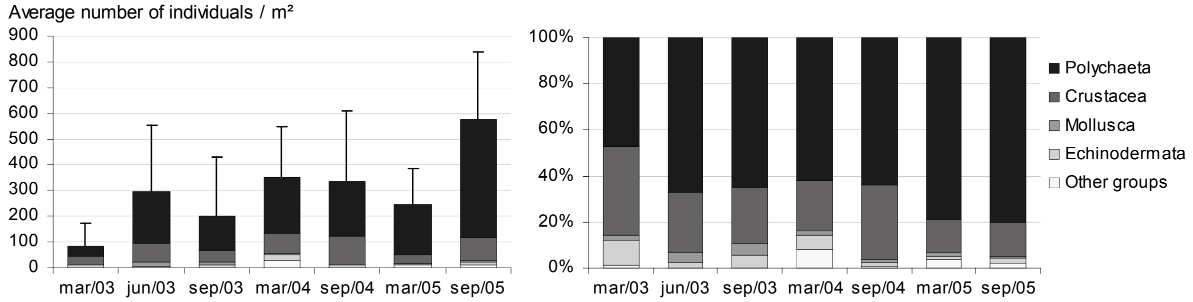

Figure 22: Average number of individuals per m² (+ standard deviation) with indication of the proportion of the major taxonomic groups.

The most dominant species present in the central depression were adult and juvenile *Nephtys cirrosa, Urothoe brevicornis, Hesionura elongata, Polygordius appendiculatus* and *Spiophanes bombyx*. They were also responsible for the major increase in total density throughout the sampling period (Fig. 23). Density of *Nephtys cirrosa* (adult and juvenile species) increased over the whole period. For the interstitial species *Hesionura elongata* and *Polygordius appendiculatus*, density only showed a steady increase from 1 year after cessation of dredging onwards. Some interstitial species like *Pisione remota, Microphthalmus* spp. and other species that prefer coarser sediment (e.g. *Phoronis pallida)* were also present in the samples since 2004, but only in small numbers. The density increase of *Spiophanes bombyx* and *Urothoe brevicornis* was discontinuous. The proportion between the total amount of adult and juvenile individuals of *Nephtys cirrosa* slightly changed over the sampling period in favour of the adults. The main feeding types were predators and deposit feeders. No changes could be found in the proportion of the different feeding types in terms of density.

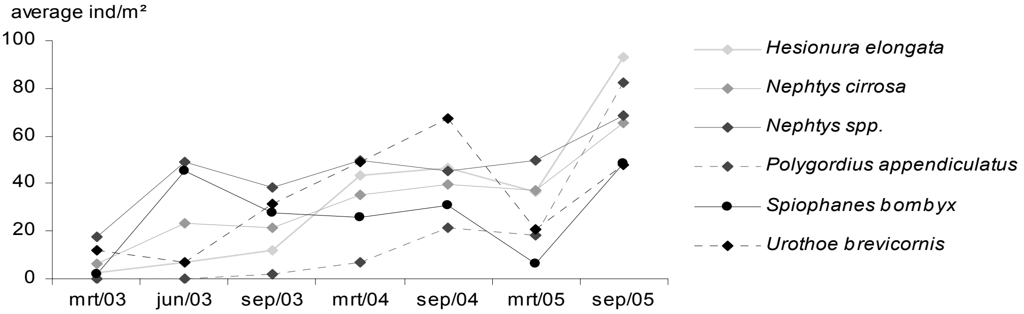

Figure 23: Average number of ind/m² for the 6 most important species for the period March 2003 – September 2005.

4. Biomass

Total biomass, taking into account all species was very variable due to the high biomass of *Echinocardium cordatum* and the single individual of *Ensis arcuatus*. Leaving out both species, a small increase in biomass was found from March 2003 to March 2005 with a peak in March 2004 (Figure 24. The total biomass of polychaetes, crustaceans and molluscs increased, although when looking at the average individual body size (biomass/number of individuals) per taxonomic group, the highest value was recorded in March 2003 for polychaetes and in March 2005 for crustaceans and molluscs.

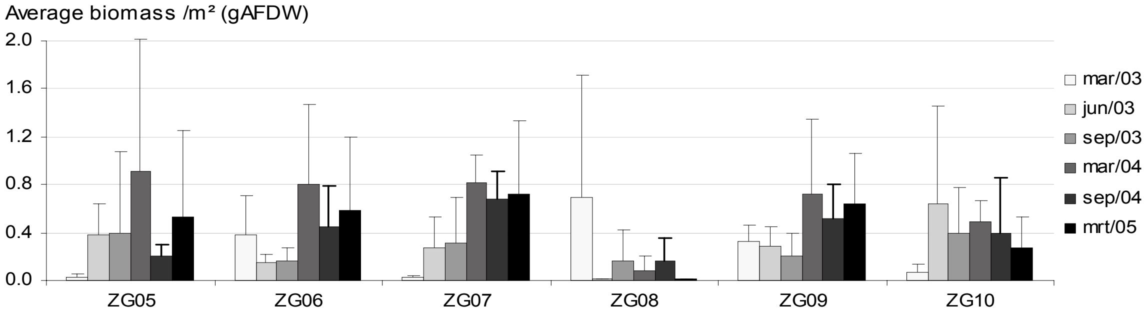

Figure 24: Average biomass / m² (wet weight corrected to gAFDW) for the different sampling periods for all stations separately, excluding Echinocardium cordatum and Ensis arcuatus.

5. Community analysis

It is known that the macrobenthic community is highly dependent on sediment characteristics. The results of the sediment analysis (Fig. 18) showed that stations ZG05 and ZG08 had a different sediment composition compared to the other locations. To obtain a better insight in the possible effects of the cessation of extraction on the community composition of the macrobenthos in the area, the samples of station ZG08 and ZG05 were eliminated from the data matrix. Spring and autumn samples were kept separate to eliminate seasonal variation. Total inertia amounted to 1.14 for the spring analysis and 1.16 for autumn. The eigenvalues for the first two ordination axes were 0.23 and 0.18 for spring and 0.22 and 0.17 for autumn.

For both seasons the samples from 2003, 2004 and 2005 were placed close to each other in the CA, representing a high similarity. Still a change in the proportional presence of species and in species composition over the years could be detected (Fig. 25). For both seasons the 2003 and 2004 samples were partly separated from the 2005 samples due to the higher abundance of *Bathyporeia elegans* (in 2003) and *Urothoe brevicornis* (in 2003 and 2004). On the contrary more polychaetes were found in the 2005 samples. The interstitial species *Polygordius appendiculatus, Microphthalmus* spp. and *Hesionura elongata* and the juvenile *Glycera* spp. were clearly more abundant in the spring samples of 2004 and 2005. The autumn samples of 2005 were separated due to the presence of a high number of less abundant species.

A greater dissimilarity between the samples could be noted for the spring samples of 2003 compared to the 2004 and 2005 samples. This was even more clear when analysing the sampling stations separately, where the variability among the replicates of the 2003 samples was greater than for the different samples of the other seasons. This was mainly so for stations ZG06, ZG07 and ZG09.

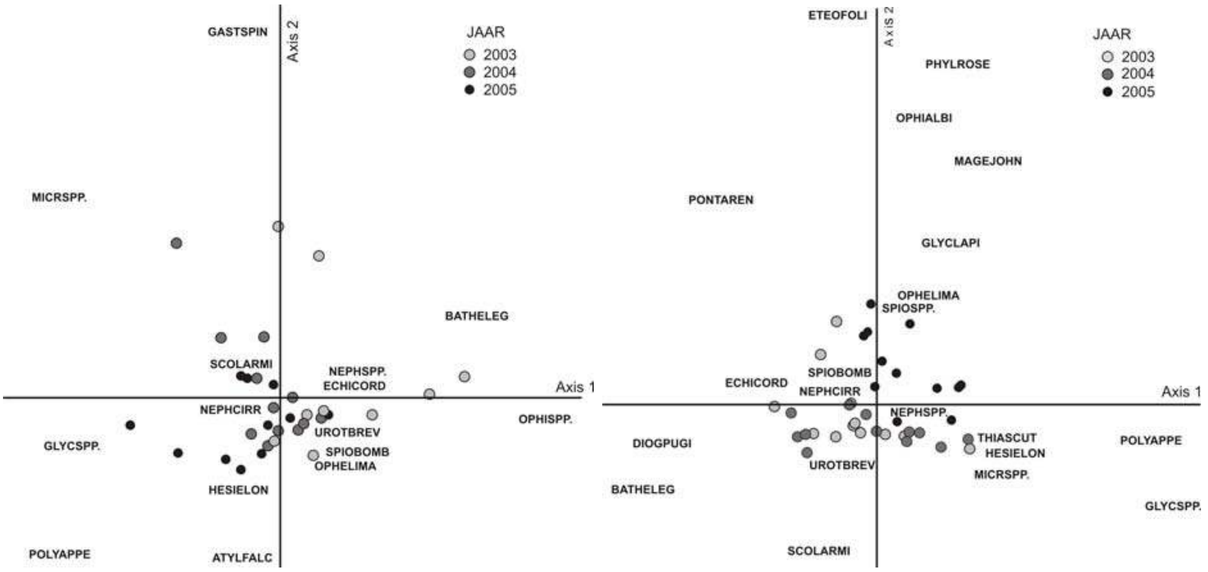

Figure 25: Multivariate analysis of spring (left) and autumn (right) samples from the central depression projected in the plain of the first two ordination axes.

Comparison with other sampling locations

Data from the central depression were compared with three other stations on the Kwintebank (ZG01 and ZG11 on the northern part and ZG04 just south of the depression). Only one month after the cessation of dredging, macrobenthic density, species number and diversity in the central depression were lower than in station ZG01 and ZG04 (Fig. 26). Values recorded in September 2005 in the central depression were higher than in stations ZG01 and ZG04. As such the increase in the biological parameters as found for the central depression was not found for these stations. ZG04 even showed a decrease in species number and diversity. In 2004 and 2005 (except autumn 2005) the densities recorded in station ZG11, situated in the zone of currently highest extraction, were as low as the ones found in the central depression in March 2003 (directly after cessation).

Species composition in the central depression was best comparable to the community found in the north of the Kwintebank (*Nephtys cirrosa, Hesionura elongata, Polygordius appendiculatus* and *Urothoe brevicornis*). In the samples from ZG04 *Nephtys cirrosa* was one of the main species found, but *Hesionura elongata* was almost absent and *Urothoe poseidonis* more or less replaced *Urothoe brevicornis*.

Multivariate analyses with the reference and impacted stations indicate only a small similarity between the samples from the central depression and stations ZG01 and

ZG04. For the period 2003-2005 station ZG06 showed a good similarity with station ZG11. Due to the increase of small polychaetes towards 2005, also several other stations from the central depression were found closer to the ZG11 samples in the CA.

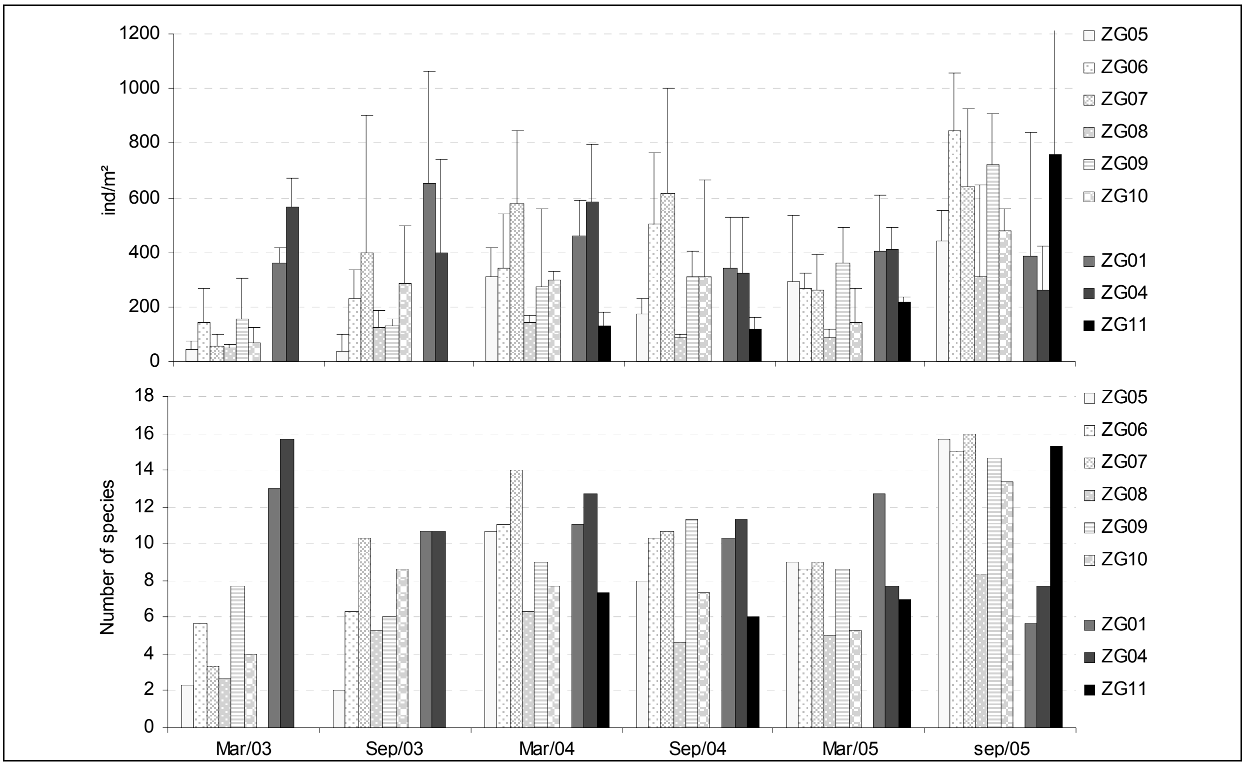

Figure 26: Density and number of species for the different locations on the Kwintebank for the period March 2003-September 2005.

Total biomass of the macrobenthos community in the central depression was smaller than the biomass recorded in the other locations on the Kwintebank, although the average biomass per individual was comparable. An example of the average individual biomass is given for the polychaetes in Fig. 27.

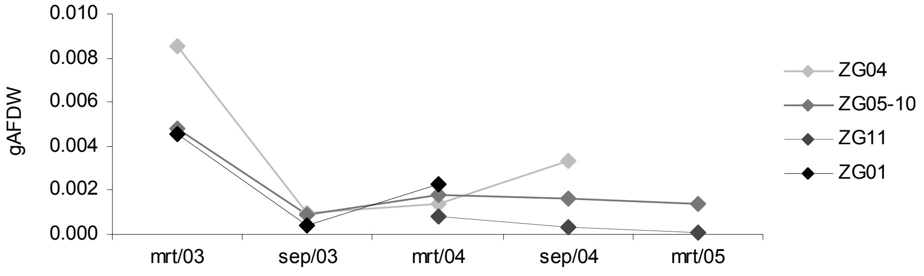

Figure 27: average individual biomass (gAFDW) of the polychaetes for different locations on the Kwintebank.

DISCUSSION

Samples taken at different intervals after the closure of the central depression show an increase in macrobenthos density, species number and diversity. For all stations, the lowest density was measured directly after cessation of dredging. But already a few months later, a higher density was found for most stations. Almost 3 years after the cessation of extraction, the average density per m² had clearly increased and has reached a level comparable to other locations on the Kwintebank.

The interpretation of the data is hampered by the lack of base line data (data of the pristine state of the area before any extraction activities took place). This could be solved by using data from a comparable reference area. Data from other locations on the Kwintebank were used as reference location, but as these other stations were also located in a sand extraction area, their seasonal pattern is probably not only naturally caused. As such these stations can not be used as a reference area according to the following definition by Boyd et al*.* (2003): 'a good reference area should be identical in all respects to the extracted sites, save for the impact of extraction activities'. The question remains if it is necessary to have a reference area that is representative of the pre-dredged status. 'Recovery' of a community does not necessarily have to lead to a situation similar to the one that existed before the disturbance. The environmental conditions on the impact site may have changed irreversibly, leading to a new macrobenthic community which is also stable, but no longer comparable to the pre-dredged status. Also the community of a reference area may change. Van Dalfsen et al*.* (2000) found changes in community composition both in the disturbed and undisturbed areas in the North Sea that were similar to each other, but dissimilar to the original community. For the Kwintebank, no comparison could be made to a pre-dredged status. But after 3 years of cessation of sand extraction the macrobenthic community of the central depression of the Kwintebank did not evolve to a totally different community. Although the species composition on the Kwintebank changed slightly, the abundant species remained the same and were also found on parts of other sandbanks of the BCS (Thorntonbank, Gootebank and Hinderbanken) with the same sediment characteristics.

When assessing 'recovery' rate, it is important to draw a distinction between (1) 're-colonisation', which is the settlement of new recruits from the plankton or immigration of adults from outside the area, and (2) 'restoration', which can be considered as the re-establishment of the community structure. (Boyd et al. 2003). It is not clear whether a full 'recovery', in the sense of restoration, of the Kwintebank central depression has been reached after 3 years, but the process of 're-colonisation' of the area has clearly started. Density, diversity and species number have reached a level that is higher than other locations on the Kwintebank, but it is not clear whether these levels are equal to the pre-extraction level as no base line records from the area are available. Total biomass values have only slightly increased and are smaller compared with other areas on the Kwintebank, but the average individual biomass was stable and comparable with the other stations on the Kwintebank and with stations on other sandbanks on the BCS (De Maersschalck et al. 2006; Moulaert *in prep.*).

Wilson (1998) defined 're-colonisation' as a temporal change in biological variables following a perturbation, and 'recovery' as a lack of difference in the temporal change of biological variables at impact sites relative to reference sites. In other words, 'recovery' is thought to be complete when temporal trends in the benthos of the impact site run parallel with those at the reference sites. According to these definitions, 're-colonisation' did occur, as an increase of the biological variables was found for the central depression, but it can be assumed that 'recovery' has not been fulfilled. Although the temporal trends run parallel with those found for reference station ZG11, it has to be reminded that this station is located in a highly extracted area. For stations ZG01 and ZG04, which are under less influence of the extraction activities, the temporal trend was different from the central depression.

By reviewing the different studies on the recovery of the macrobenthos after dredging, it becomes clear that recovery is site specific, mainly depending on the habitat type of the dredged area, as well as on the scale and duration of disturbance, hydrodynamics, etc. (for review see Newell et al. 1998). The existing benthic communities in highly dynamic areas are well adapted to elevated levels of natural stress, with a high proportion of robust, rapidly colonising, fast-growing, opportunistic species (Newell et al. 2004a). As was shown, the sediment composition of the central depression of the Kwintebank is highly heterogeneous. In this highly dynamic area it is not surprising that a relatively rapid re-colonisation occurs. The recovery of the macrobenthos also depends on the comparability of the extracted area with the surrounding area. If the habitat type is similar rapid recolonisation may occur. Results from the June 2003 samples indicate an increase in the density for some species and species richness, probably due to this migration from close by areas.

The slight increase in the biomass of the macrobenthos is mainly a reflection of the increase in number of individuals as the biomass by growth of individuals did not change significantly. The evolution of the average body size of the major taxonomic groups was comparable to the evolution found for other locations on the Kwintebank.

For this macrobenthos study, multivariate analysis was used as a tool to allocate possible changes in the community structure of the central depression of the Kwintebank. Results from the Correspondence Analyses showed only small differences between the samples taken in the first year after cessation of extraction and samples taken in the second and third year. Samples taken in the first year after extraction ceased on the Kwintebank had a slightly greater variability. Warwick &

Clarke (1993) suggested that a higher variability may be due to perturbations. As such the smaller variability in year 2 and 3 of the study period, might be another sign of improvement.

CONCLUSIONS

Generally it can be concluded that 're-colonisation' of the central depression has occurred. The poor macrobenthic community that was found directly after the cessation of extraction, evolved in 2-3 years to a community with higher densities, number of species and diversity. Moreover, the macrobenthic community was characterised by small interstitial and mobile species, which is typical for other sandbanks on the BCS with a comparable sediment composition.

It remains unclear whether 'recovery' s.s. of the macrobenthos of the central depression has been fulfilled, due to the lack of base line data and the practical problems related to defining a suitable reference area. As such the observed positive trend in the different macrobenthic variables might be related to the cessation of dredging as well as to natural variability.

The area will be closed for another 3 years (until March 2008) which makes it possible to follow up the 'recovery' a few years longer. Sampling will continue to see whether the increased values remain at the same level, increase or decrease and whether the species composition will change or remain stable.

7. EVALUATION OF THE RECOVERY OF NEMATODE COMMUNITIES AFTER CESSATION OF SAND EXTRACTION ACTIVITIES ON THE KWINTEBANK

INTRODUCTION

In this chapter we explore the possible recovery of the nematode communities from the cessation of exploitation activities in the central depression of the Kwintebank. Possible changes in these communities from this area of the sandbank are compared with the possible changes in the northern part of the Kwintebank, where sand extraction is still ongoing. Here, a second depression exists which coincides spatially with extraction efforts in that area (Degrendele et al. in press).

MATERIAL AND METHODS

Samples in the central depression and northern part of the Kwintebank were collected in October 2003 and February 2004. Sampling nematode communities in different times of the year should have no effect on nematode community composition (Vanaverbeke et al. 2002).

Within each area, three stations were sampled. Kw5 and Kw6 with an additional station Kw18 are located in the central depression, whereas Kw1 and Kw2 were sampled in the northern part together with the new station Kw14 (Fig. 28).

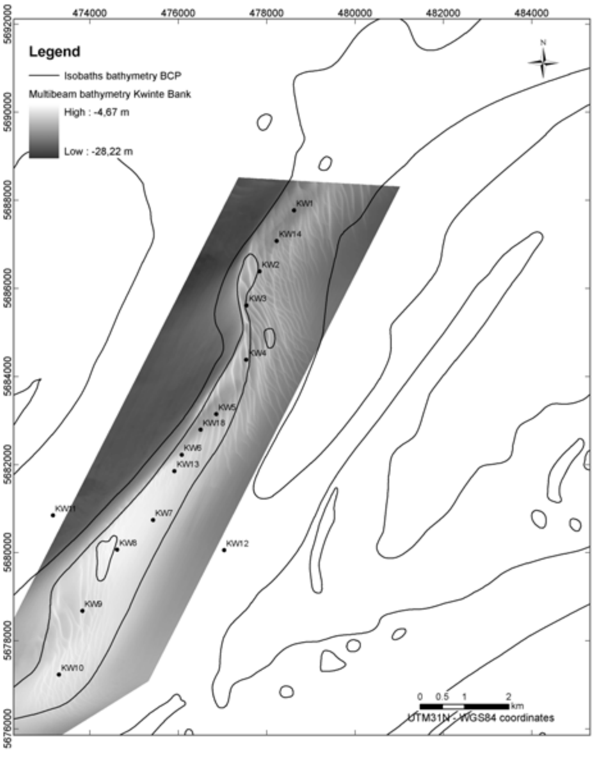

Figure 28 Location of the sampling stations for meiobenthos for the recovery study.

Sampling and treatment of samples for faunal and grain size analyses were performed as described in chapter 3. Methods of multivariate analyses of sedimentological data and nematode communities are described in chapter 3.
In addition, nematode biomass spectra (NBS) for the samples from 2004 were compared with those obtained from 1997 (Vanaverbeke et al. 2003). Construction of NBS was done following Vanaverbeke et al. (2003).

RESULTS

Sediment characteristics

Sedimentological changes were analysed using PCA (Fig. 29) and 2-way crossed ANOSIM (similarity matrix as normalised Euclidean distances). In the central depression, there were no multivariate differences between grain size characteristics of the stations, but sediments during the extraction period were significantly different (R= 0.208; p= 0.05) from the sediments encountered after the closure of the area.

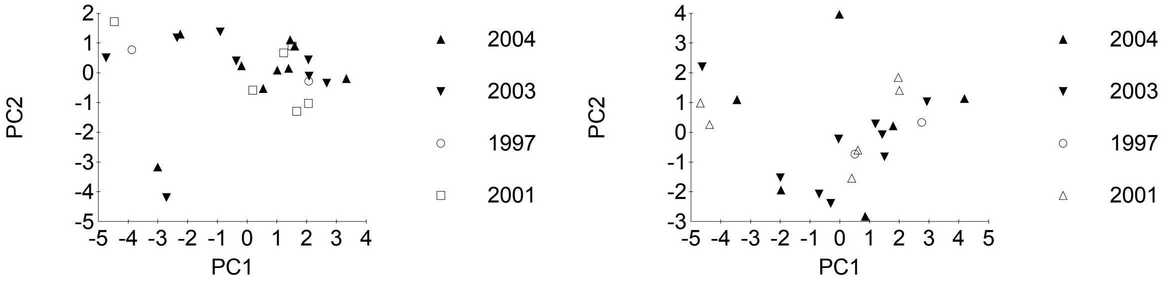

Figure 29: PCA ordination plots of grain size variables. Left panel: Central depression. Right panel:northern area of the Kwintebank.

Two-way crossed ANOSIM for the northern area revealed significant differences in sedimentological variables between stations (R= 0.31; p= 0.01). Pairwise comparisons revealed that the largest differences existed between sediments of station Kw2 and Kw14. Significant differences between years existed as well (R= 0.256; p= 0.024).

Nematode community composition

There were no differences (Two-way crossed ANOSIM: R= 0.927; p=0.08) in nematode community composition from the different stations in the central depression (see Fig. 30). However, differences between the years were obvious (R= 0.719; p=0.001).

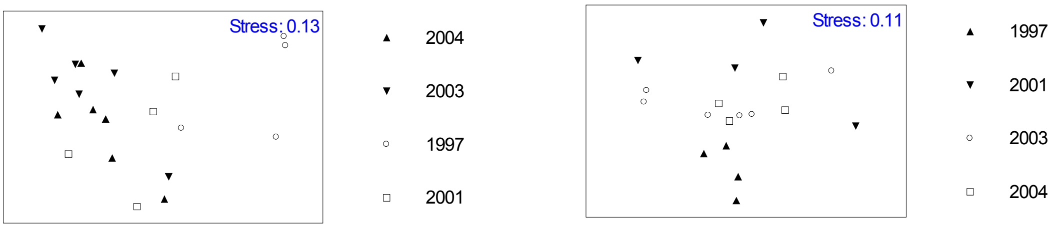

Figure 30: Results of MDS analyses on non-transformed nematode species densities. Left panel: central depression. Right panel: northern area of the Kwintebank.

Strongest differences were observed between 1997 and all other years and between the communities found in 2001 and 2003. Smallest differences were found between 2003 and 2004 (Table 13)

	2001	2003	2004
1997	1	1	1
2001		0.875	0.375
2003			0.25

Table 13: Results of pairwise 2-way crossed ANOSIM on untransformed species densities per year in the central depression on the Kwintebank (all p=0.11)

In the northern area (Fig. 28), significant differences between stations (R= 0.78; p= 0.02) and years (R= 0.67; p= 0.001) were observed in Two-way crossed ANOSIM on untransformed species densities. Nematode communities of subsequent years showed strong differences in the pairwise comparison (Table 14).

	2001	2003	2004
1997	0.625	0.75	1
2001		0.625	0.25
2003			0.75

Table 14 Results of pairwise 2-way crossed ANOSIM test on untransformed species densities per year in the northern area of the Kwintebank

SIMPER analysis (not shown) for the central depression stations indeed showed that within year similarity in 1997, 2001 and 2003 was due to different species, while this was not the case when comparing contributing to the within-year variability of 2003 and 2004. In these years, average within-group similarity was mainly due to the dominance of *Onyx perfectus*, *Mesacanthion hirsitum* and *Enoploides spiculohamatus*. In the northern part, larger differences between years were observed in the nematode species contributing to the within-year similarity.

Nematode diversity

A wide array of diversity indices (see chapter 3) was calculated. One-way ANOVA was used to test for significant differences between years on untransformed or root-root transformed values. When assumptions for ANOVA were not met, the non-parametric Kruskal-Wallis analysis by ranks was used.

In the central depression, no significant differences between years were observed. Only in the northern part, significant differences between years were observed for J' ($F_{3,14}$= 3.93; p<0.05) and Λ^+ ($F_{3,14}$= 3.96; p<0.05). Tukey HSD for unequal N showed that significantly (p<0.05) higher values were observed in 2004 in comparison with 1997. All other pairwise comparisons showed no significant differences. Concerning Λ^+, no significant differences were detected in the pairwise comparisons.

Nematode biomass spectra

Nematode biomass spectra from 1997 were recalculated from Vanaverbeke et al. (2003). New NBS were constructed for the sampling campaign of 2004 (Fig. 31). Both in the depression and the northern part, a general increase in biomass could be noted when compared to 1997. In addition, the spectra at both sites shifted towards higher biomass classes. Comparing both areas within the same year revealed a change since the closing of the central depression. In 1997, the NBS constructed for the central depression showed an irregular pattern with biomass peaks in size class -3 and 0. In the northern area, the NBS had a normal shape with a biomass peak in size class -3, but a high value was observed in size class 3.

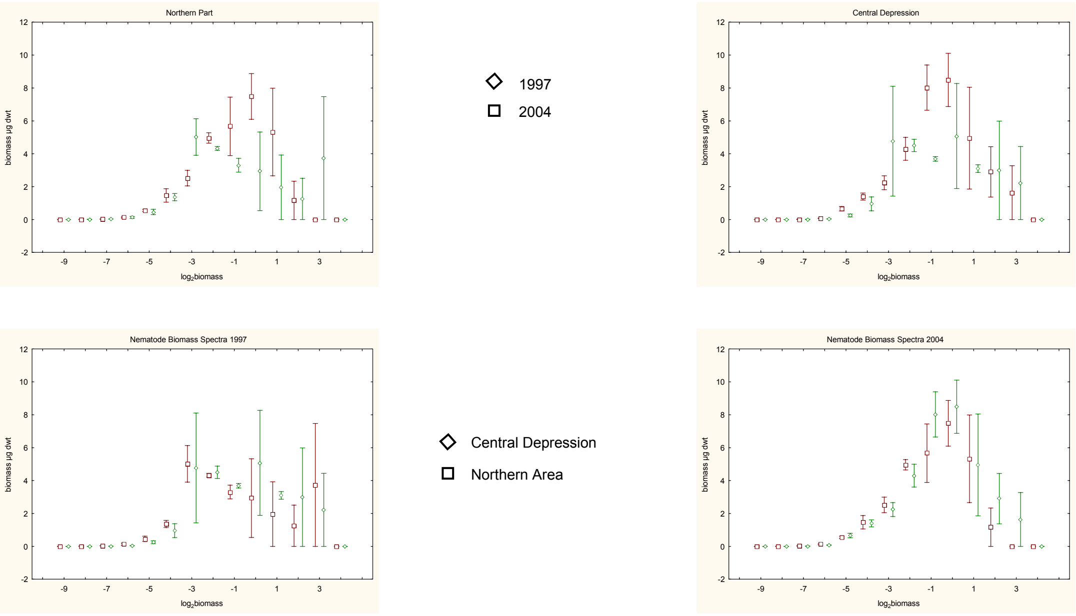

Figure 31: Nematode biomass spectra (NBS).
Upper panels: comparisons of NBS of different years per area.
Lower panels: comparison of NBS of different areas per year.

In 2004, both spectra showed a regular shape, with a consistent higher biomass in the lower size classes in the northern area. From size class -1 onwards, higher biomass was observed for the central depression (with the exception of size class 1). Size class 3 was not occupied in the northern area, whereas this is the case for the central depression.

DISCUSSION

Changes in sedimentological characteristics and nematode communities

Cessation of extraction activities has led to a change in the sedimentological environment in the central depression, but no differences between the stations were detected. In the northern part, differences in grain size variables were detected between both stations and sampling campaigns. This was reflected in changes in the nematode community composition of both areas. The spatial heterogeneity in the northern area was reflected in the nematode communities since multivariate differences were observed between stations and years. Further and intensified extraction in this area probably led to a continuously changing nematode community for reasons described in chapter 3. Differences in the nematode communities in the central area were situated within the extraction years (1997 – 2001) and between the extraction years and the period in which the area was closed (2001 – 2003). After closing of the central depression, a more stable nematode community established.

Diversity, as measured by a wide array of indices did not show significant changes between the years, both in the central depression and the northern area. This again indicates that physical disturbance on sandbank nematode communities can lead to a change in the species composition of the communities without affecting their diversities, as shown in chapter 3. This suggests that the use of diversity indices, both based on species abundance or taxonomic relatedness is not recommended when assessing the impact of sand extraction on the nematode communities.

Nematode biomass spectra

Vanaverbeke et al. (2003) showed that NBS can be used to detect both anthropogenic and natural disturbances to the sea floor. However, that study is based on comparing different nematodes communities sampled within one year. The current results indicate that interannual variation affects both the peaks size class and values. This can be attributed to general changes in nematode communities, due to either cessation or continuation of the extraction activities, or to differences in natural circumstances. However, differences can be observed when comparing both the northern area and the central depression within one year, e.g. 2004. Size classes occupied by medium-sized and larger animals (from size class -1 onwards) show lower biomass values in the area were sand extraction is still ongoing. This indicates that the more stable environment in the central depression allows for survival of larger sized nematodes as already explained in chapter 3.

Recovery of the nematode communities

Benthic recovery from sand extraction usually follows two steps: at first 'recolonisation' occurs which is the settlement of new recruits from the plankton or immigration from outside the area, followed by 'restoration' which is defined as the return of community structure (Boyd et al. 2003).

Although the nematode communities from the central depression evolved into a new, more stable community after the cessation of the extraction activities, they are still very different from the communities observed in 1978 (Fig. 32).

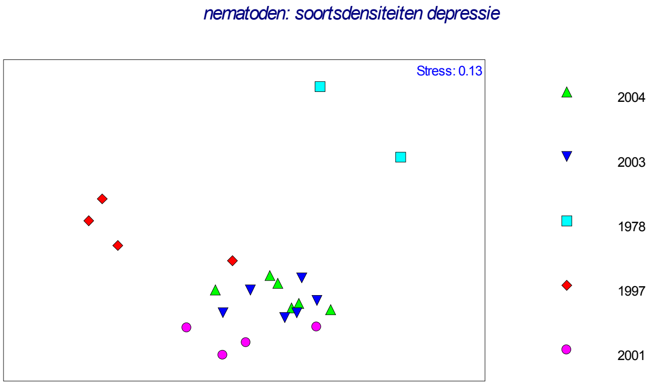

Figure 32: Results of MDS plot on untransformed species densities. All sampling years combined.

There are two possible explanations for this: (1) nematode communities from other sandbanks have changed in a similar way in the absence of sand extraction. Hence, a re-establishment of the communities as found in 1978 is not to be expected. (2) The change in the morphology of the sandbanks and the long lasting extra stress on the sediment (eg. creating and filling up of dredge furrows) changed the nematode communities in such a drastic way that a re-establishment of the naturally occurring communities is prevented by removing the dominant species of the original communities. Recolonisation of a disturbed habitat by nematode communities is not straightforward, given their strictly benthic life cycle. In addition, the sedimentary habitat is still influenced by the connection of the depression with the swale. Since nematode community composition on sandbanks is very much influenced by the sediment composition (Vanaverbeke et al. 2002), a complete restoration is not to be expected as long as the original conditions are not restored. Within the framework of this study, it is impossible to conclusively exclude one of the two possible explanations since no routine monitoring programme was set up to follow the natural evolution of benthic communities in undisturbed habitats. However, given the different response in grain size characteristics and nematode community dynamics in both the northern area and the central depression, we suggest that the newly developed and relatively stable community in the depression established as a result of the cessation of the activities. However, this should be considered as a transitional community given the large difference with the communities observed in 1978.

CONCLUSIONS

1. After closing the central depression on the Kwintebank for sand extraction activities, the nematode communities shifted towards a new and more stable community, in contrast with the continuous changes in the northern area were sand extraction is still ongoing. Since the communities in the central depression are still very different from the communities encountered in 1978 (when sand was extracted at very low intensities), we believe that a restoration of the nematode communities was not established in a 2-years period.
2. Assessing the impact of sand extraction activities on nematode communities is preferably done by identifying nematodes to species level for community analysis, since diversity did not change as a consequence of either sand extraction or cessation of the extraction activities.
3. Nematode biomass spectra can be effective for a preliminary assessment of differences in communities provided that sampling of control and target communities takes place within the same period or at the same site. Since only limited size spectra have been constructed for assessing the impact of sand extraction on nematode communities, analysis of nematode biomass spectra should be accompanied by species identifications in order to guarantee a sound interpretation of the results.

8. EVALUATION OF THE RECOVERY OF THE COPEPOD COMMUNITIES AFTER CESSATION OF DREDGING

INTRODUCTION

In the section on the long-term effects of sand extraction on harpacticoid copepod communities (Chapter 4), the temporal evolution of the total sandbank and of the different sand extraction intensity areas separately ("Very High", "High" and "Very Low" as explained for the nematode section) has been explained for the years 1978, 1997 and 2001, the latter two representing intensive sand extraction situations. In February 2003 the central depression has been closed for exploitation and in the following section the potential recovery of the copepod communities has been studied for October 2003 and February 2004. For this purpose, only the northern and the central depression on the Kwintebank have been sampled to compare with the previous situations. Three stations have been sampled in each depression: two stations were also sampled during the previous studies and an additional third station in each depression, station 14 for the northern depression and station 18 for the central depression.

MATERIAL AND METHODS

The meiobenthic samples of 2003 and 2004 were taken in the same way as for the previous years as explained in the above section on nematode and copepod data. After treatment in the lab, as explained before, and staining the meiobenthos with Rose Bengal, all copepods were picked out and counted under a binocular microscope. Four different ecotypes were discerned, described in Chapter 4 : epibenthic species, endobenthic species, interstitial species and phytal - free-swimming species (Hicks & Coull, 1983).

RESULTS

The ecotype distribution in the northern and the central depression in 2003 and 2004 were included in Fig. 13 in comparison with the data of 1978, 1997 and 2001. For both the intensively extracted depressions, there were significant differences between 1978 and 1997 ($p < 0{,}005$) due to the decrease in the big epi- and endobenthic species in favour of interstitial species. The second disturbance situation in 2001, however, did not confirm the same situation as in 1997. Between 1997 and 2001 ($p < 0{,}005$) the free-swimming species increased significantly in both depressions, and significant differences with 1978 could not be detected anymore in the depressions. After the extraction ceased in February 2003, no increase of big species has been observed. To the contrary, endobenthic species decreased in the central depression between 2001 and 2003 and their abundance is similar again to the values observed in the intensive exploitation situation of 1997. The higher percentage of free-swimming species remained in 2003 and differed still significantly from 1997 (Table 15) but later on, between 2003 and 2004 the big free-swimming species declined significantly in the central depression, whereas in the northern depression, endobenthic species increased between 2003 and 2004. However, this is the place where sand extraction increased during that period, so under an increased disturbance situation some big species have increased.

In contrast with the ecotype distribution that does not seem to recover as expected, the density shows an increase in the central depression after the cessation of dredging. Whereas density did not change a lot in the northern depression through time, not even after the start of the extractions between 1978 and 1997, the density decreased after the start of the extractions in 1978 in the central depression. An increase in density is shown between 1997-2001 and 2003 in the central depression. Significant differences between 2003 and 2004 were also observed for the two depressions (p < 0,05).

ECOTYPES	Northern depression	Central depression
1978 – 1997	**Ecotype 1 (p < 0,05)** **Ecotype 2 (p < 0,05)** **Ecotype 3 (p < 0, 05)** Ecotype 4 n.s.	Ecotype 1 n.s. **Ecotype 2 (p < 0,05)** **Ecotype 3 (p < 0,05)** **Ecotype 4 (p < 0,01)**
1978 – 2001	Ecotype 1 n.s. Ecotype 2 n.s. Ecotype 3 n.s. Ecotype 4 n.s.	Ecotype 1 n.s. Ecotype 2 n.s. Ecotype 3 n.s. Ecotype 4 n.s.
1978 – 2003	Ecotype 1 n.s. Ecotype 2 n.s. Ecotype 3 n.s. Ecotype 4 n.s.	Ecotype 1 n.s. **Ecotype 2 (p < 0,05)** **Ecotype 3 (p < 0,05)** Ecotype 4 n.s.
1978 – 2004	Ecotype 1 n.s. Ecotype 2 n.s. Ecotype 3 n.s. Ecotype 4 n.s.	Ecotype 1 n.s. **Ecotype 2 (p < 0,05)** **Ecotype 3 (p < 0,05)** **Ecotype 4 (p < 0,005)**

ECOTYPES	Northern depression	Central depression
1997 – 2001	Ecotype 1 n.s. Ecotype 2 n.s. **Ecotype 3 (p < 0,05)** **Ecotype 4 (p < 0,01)**	Ecotype 1 n.s. Ecotype 2 n.s. **Ecotype 3 (p < 0,05)** **Ecotype 4 (p < 0,05)**
1997 – 2003	Ecotype 1 n.s. Ecotype 2 n.s. **Ecotype 3 (p < 0,05)** **Ecotype 4 (p < 0,005)**	Ecotype 1 n.s. Ecotype 2 n.s. **Ecotype 3 (p < 0,05)** **Ecotype 4 (p < 0,005)**
1997 – 2004	Ecotype 1 n.s. **Ecotype 2 (p < 0,05)** **Ecotype 3 (p < 0,005)** Ecotype 4 n.s.	Ecotype 1 n.s. Ecotype 2 n.s. Ecotype 3 n.s. Ecotype 4 n.s.
2001 – 2003	Ecotype 1 n.s. Ecotype 2 n.s. Ecotype 3 n.s. Ecotype 4 n.s.	Ecotype 1 n.s. **Ecotype 2 (p < 0,05)** Ecotype 3 n.s. Ecotype 4 n.s.
2001 – 2004	Ecotype 1 n.s. Ecotype 2 n.s. Ecotype 3 n.s. **Ecotype 4 (p < 0,05)**	Ecotype 1 n.s. **Ecotype 2 (p < 0,05)** **Ecotype 3 (p < 0,005)** **Ecotype 4 (p < 0,01)**
2003 – 2004	Ecotype 1 n.s. **Ecotype 2 (p < 0,05)** Ecotype 3 n.s. **Ecotype 4 (p < 0,005)**	Ecotype 1 n.s. Ecotype 2 n.s. **Ecotype 3 (p < 0,005)** **Ecotype 4 (p < 0,0005)**

Table 15: Results of the comparison of ecotypes between the different years for the northern and the central depression.

DISCUSSION

Densities

The community inhabiting the central and the northern depression in the exploitation situation of 1997 was predominated by small interstitial species with a high percentage of juveniles (Bonne 2003). They are typical r-strategists with a short life cycle. Therefore this community would be able to increase densities very rapidly, as indeed shown by the situation of 2003 in the central depression in comparison with the exploitation situation of 1997 and 2001. 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. In the present situation, densities in October 2003, 8 months after the cessation of dredging in February 2003, were similar to the pre-disturbance values of 1978. 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). In February 2004 the density in the central depression has dropped again, probably due to the rough winter conditions. Hence, it may be difficult to distinguish a disturbance from a non-disturbance situation during the winter period, whereas this distinction was clearer in autumn (2003). The higher densities in the central depression in October 2003 may have been a consequence of the phytoplankton bloom that occurred in autumn 2003 (Franco et al. in prep). Previously it has been highlighted that the central depression has similar characteristics to a gully environment (see the section on short-term sedimentological evolution) in which sedimentation during ebb has been observed. Hence, if sedimentation of organic matter originating from the phytoplankton bloom has occurred in the central depression in the absence of sand extraction, the copepod community may have taken advantage of this higher food availability, which may have triggered a higher reproduction, whereas this did not happen in the northern depression. The dominant species in October 2003 was indeed *Apodopsyllus* n. spec. 1, a species that has been proven to be an opportunistic species increasing its densities after a phytoplankton bloom (Bonne 2003).

Ecotypes

Since the percentage of epi- and endobenthic species in the central depression in the post-disturbance situation in 2003 and 2004 was still significantly lower than the pre-disturbance situation of 1978, it can be concluded that no recovery has taken place for the ecotype distribution in the central depression after cessation of dredging. However, the ecotype distribution did not consistently reflect a disturbance situation as was presumed. Namely, a high relative abundance of small interstitial species to be related with sand extraction has not been confirmed for 2001. The ecotype distribution did not show significant differences between the pre-disturbance situation of 1978 and the disturbance situation of 2001 for the depression areas, due to a relatively high abundance of bigger species in 1978 and 2001. Moreover, the depressions behave differently concerning the endobenthic species abundance, which even increased between 2003 and 2004 in the northern depression under increasing sand extraction intensity circumstances, whereas this increase was not observed in the central depression where sand extraction no longer occurred. Hence, this parameter of ecotype distribution is not consistently useful for monitoring of sand extraction since the decrease in big ecotypes is not always directly related to sand extraction.

For the nematode community structure, large differences were detected between 2001 and 2003 (see nematode section) and in 2004 a more normal nematode biomass spectra distribution was found compared to 1997, whereas the copepod ecotype distribution did not indicate a recovery. However, the first phase of recovery may not be characterized by an increase of bigger copepod species, because the opportunistic copepods reproducing after a disturbance may belong to the small-sized interstitial species. The interstitial species *Apodopsyllus* n.spec., for example, has been identified as such an opportunistic species, which may have reproduced even more due to higher organic matter availability as a consequence of an autumn phytoplankton bloom in 2003. This may explain why bigger species may not have become more relatively abundant in 2003. In 2004 however, a higher abundance of bigger species has not been found either, although endo- and epibenthic and free-swimming species are expected even more in the gully-like habitat that has developed due to sand extraction in the central depression, since these bigger species appear in the gullies with high relative abundances, though with a high temporal and spatial variability (Bonne 2003). So this variability may also complicate the detection of recovery at ecotype level.

CONCLUSIONS

The situation of 2001 and 2003 lies in between 1978 and 1997. In the central depression the post-disturbance situation of 2004 is similar to the disturbance situation of 1997.

Since the pre-disturbance situation of 1978 significantly differs from the post-disturbance situation in 2003 and 2004 for the central depression, it cannot be concluded that recovery has taken place for the ecotype distribution in the central depression after cessation of dredging, although temporal and spatial variability may make the observation of recovery at ecotype level quite difficult. However, the ecotype distribution did not consistently reflect a disturbance situation as was presumed.

The percentage of big species fluctuates and can increase in the sand extraction disturbance situation, such as the situation in 2001 and in the northern depression in 2004, where extraction is very much concentrated since the closure of the central depression. In 2004 namely, the endobenthic species showed a higher abundance in the extraction situation than in the central depression where no exploitation is allowed anymore.

The percentage of big species did not increase in 2003 or 2004 after the cessation of dredging, while the percentages have been higher during the disturbance situation in 2001. Hence, this parameter of ecotype distribution is not consistently useful for monitoring of sand extraction since the decrease in big ecotypes is not always directly related to sand extraction.

An increase in density is observed in the central depression after cessation of dredging in 2003, and densities at that moment were very similar to the densities in 1978 in that area. After cessation of dredging the densities are similar to those of the pre-disturbance situation of 1978 but the situation can fluctuate a lot in the winter situation as a result of the natural dynamics such as cold temperatures and storms. Hence, in autumn, differences in density can be detected between the northern still exploited depression and the central depression; however these differences are not detected in winter.

GENERAL CONCLUSIONS AND RECOMMENDATIONS

Within this project, we aimed at assessing (1) the effects of long-term sand extraction activities on sediment inhabiting organisms and (2) investigating the possible sedimentological and biological recovery of the central depression on the Kwintebank, after its closure for extraction activities in February 2003.

The effects of long-term sand extraction and the biological recovery were studied by integrating historical data – when available – and newly collected data on three benthic groups: the macrobenthos, the nematodes and the harpacticoid copepods. All of these groups have their own characteristics and associated pros and cons when it comes to assessing disturbance to the seafloor.

Methodological considerations

As shown in this report, assessing the effect of human activities on the benthos is difficult when no clear baseline data are available. In addition, natural variation in benthic characteristics could not be deduced directly.

When human activities at sea are planned, the natural situation should be assessed before the start of the activities and this should include the study of all benthic groups. Sampling has to be replicated in time in order to guarantee the correct use of standard statistical methods designed for assessment of disturbances (BACI approach).

Parallel to the sampling of the impact area, a reference area on the Belgian Continental Shelf should be sampled at regular intervals allowing an estimation of the natural variation in benthic communities.

The assessment of long-term changes in the benthos was hampered by the fact that new methodological approaches were introduced in sampling and treatment of samples. **It is therefore suggested to produce a protocol for sampling and treatment of samples, based on current sound knowledge. This protocol should be at the basis of all future monitoring efforts and will guarantee a standardised execution of scientific efforts and allow a correct interpretation of the data obtained.**

Long-term effects of sand extraction on the benthos

The intense sand extraction on a limited area of the Kwintebank has created a depression in the central part of the Kwintebank, which can be considered a new environment on the sandbank. Relocation of the intense extraction activities towards the northern part of the sandbank resulted in the formation of a new depression in that area. Apart from the creation of a new habitat, the benthic organisms also have

to deal with increased sediment dynamics as a result of the creation and filling up of dredging furrows.
Although the lack of baseline data and changes in methodologies makes it difficult to assess the effects of the exploitation on benthic communities, some general patterns can be deduced:

- The very intensively extracted zones of the Kwintebank accommodate little macrobenthic life with a small biomass. The less intensively extracted areas of the Kwintebank had a slightly higher density and species richness. For the northern less intensively extracted area, no major changes were found over the last 25 years. The area just south of the central depression, where extraction activities increased, showed a decrease in macrobenthic number of species and diversity during the last 4 years. These results might indicate that sand extraction has an effect on the macrobenthic community. However, the main species present on the Kwintebank, are able to survive in dynamic areas, and are probably less influenced by the disturbance of sand extraction activities.
- Nematode community composition changed drastically since 1978 and our results suggest that nematode communities were unstable during the period of exploitation. Larger, vulnerable predator nematodes disappeared in favour of more opportunistic deposit feeding species. In addition, nematode communities were shifted towards smaller individuals in the central depression. Diversity indices, either based on species richness or species relatedness are not a good tool to assess changes in nematode communities as a consequence of sand extraction. Species identifications are absolutely necessary and the use of nematode biomass spectra also proved to be a useful tool. More research on a global scale is needed to confirm this finding.
- Harpacticoid copepod communities in the central depression were affected by the extraction activities when analysed on the species level (1978-1997). On the other hand, the use of harpacticoid copepod ecotypes as a quick biological tool for assessing impacts on the benthic communities remains difficult.

The concentration of the extraction activities clearly impacts the morphological, sedimentological and biological characteristics of the sandbank. The changing of the environment has repercussions on the benthic communities. Even if no morphological changes in the sandbank occur, the increased dynamics introduced by the creation and filling up of the dredging furrows do affect the benthos. Removal of key species, needed for the establishment or maintenance of the naturally occurring communities, should be avoided in all cases. **Changes in these benthic communities always reflect changes in the**

functioning of sediments (with respect to mineralization processes) that are very important for the processes occurring in the water column in particular for the marine ecosystem in general.

After the closure of the central depression on the Kwintebank, the possible short-term recovery of the depression was assessed by a detailed investigation of the sedimentological and biological characteristics of the area.

- Detailed sedimentological observations showed a high spatial variability of the surficial sediments. The main sediment characteristics group according to the morphological position in the sandbank-swale system. The central depression is clearly a new environment and its sediment characteristics and evolution in mean grain-size is now similar to the trends observed in the adjacent swale. . . Short-term sedimentological recovery was not observed although the shape of the central depression does allow trapping shelly material. Moreover, a deposition of fines during ebb and neap tide was observed, which is rare in dynamic sandbank environments.

Biological observations indicate that a full biological recovery was not achieved within 2 years. The poor macrobenthic community that was found directly after the cessation of extraction, evolved in 2-3 years to a community with higher densities, number of species and diversity. The macrobenthic community in the central depression is characterised by small interstitial and mobile species, which are typical for other sandbanks on the Belgian Continental Shelf with a comparable sediment composition. So far it remains unclear whether this situation is stable. Nematode communities were very different from the communities encountered in 1997 and 2001 and showed a higher stability. This higher stability was absent in the northern part of the Kwintebank, where sand extraction is still ongoing, and can therefore be explained by the absence of dredging activities. In addition, nematode biomass spectra revealed that larger nematodes were again present in the absence of sand extraction. However, communities are still very different from those observed during the start of the extraction period. The ecotype approach for the harpacticoid copepods did not yield consistent results, first of all because the percentage of big species fluctuates and can also increase in the sand extraction disturbance situation and secondly, because spatial variation of epi- and endobenthic species is naturally high in sandbank sediments. An increase in copepod density is observed in the central depression after cessation of dredging, but differences in density between the northern, still exploited depression, and the central depression can only be detected in autumn and not in winter.

The size of the area of impact should be so that the impacted area and the distance for potential re-colonisation from un-impacted areas is small. On the

other hand, the intensity of dredging per unit area increases with decreasing size and higher dredging intensities may eliminate a greater portion of species (Boyd & Rees 2003). Therefore an optimum size of extraction area should be found to reach an equilibrium between the above mentioned factors. Sand extraction areas are ideally rotated frequently in order not to introduce prolonged disturbances. As in the present study no full recovery was yet found after 2 years, it remains unclear how long the area needs to recover and re-establish an equilibrium state.

Short-term recovery of the central depression of the Kwintebank was not observed during a 2 years period. **We therefore recommend to leave this area closed and to continue the scientific observations (morphological, sedimentological and biological) in this area. This will lead to an increased knowledge of the recovery processes of heavily extracted areas on the Belgian Continental Shelf and can lead to recommendations on the best time interval at which the rotation of the dredging operations across different areas should occur.**

Although the present study clearly indicates that the benthic communities were affected by the intense sand extraction in the central depression, literature data indicate that **the magnitude of the effects of sand extraction on the benthos not only depends on the intensity of the extraction activities, but also on the natural site-specific conditions and benthic communities. Conclusions on recolonisation rates produced in the present study are therefore not necessarily valid for other possible extraction sites on the Belgian Continental Shelf.**

Monitoring and assessing the effects of sand extraction to benthic life using simple methods remains difficult. Some of the techniques used in the present study were not suitable to distinguish any effect of sand extraction or to conclude on possible recovery after cessation of extraction. This was the case for the ecotype approach for the harpactoids and the diversity indices, either based on species richness or species relatedness, for the nematodes. These techniques could not be tested for the macrobenthos due to the absence of sound baseline data. **Tools based on community composition seem to be the best technique**. Simple multivariate analyses indicate a change between the period during extraction and the period after cessation of the activities. **Both meiobenthos and macrobenthos should always be identified up to species level. Nematode biomass spectra can be effective for a preliminary assessment of differences in communities provided that sampling of control and target communities takes place within the same period or at the same site.**

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LITERATURE

ALSF (2005) MEPF 04/04 Coupling Physical and Ecological Models: A New Approach to Predicting the Impacts of Aggregate Extraction on Biological Recoverability. Report 2004-5

Bodin P (1997) Catalogue of the new marine harpacticoid copepods (1997 edition). Studiedocumenten van het Koninklijk Belgisch Instituut voor Natuurwetenschappen, Brussels, 89: 304 pp.

Bonne (2003) Benthic copepod communities in relation to natural and anthropogenic influences in the North Sea. Ph.D Thesis, Ghent University, Biology Department, Marine Biology Section, Belgium: 298 pp.

Boyd SE, Limpenny DS, Rees HL, Cooper KM, Campbell S (2003) Preliminary observations of the effects of dredging intensity on the re-colonisation of dredged sediments off the southeast coast of England (Area 222). Est Coas Shelf Sci 57: 209-223

Boyd SE, Cooper KM, Limpenny DS, Kilbride R, Rees HL, Dearnaley MP, Stevenson J, Meadows WJ, Morris CD (2004) Assessment of the rehabilitation of the seabed following marine aggregate dredging. Sci Ser Tech Rep 121, CEFAS Lowestoft, 154pp

Brey T (2001) Population dynamics in benthic invertebrates. A virtual handbook. Version 01.2. Alfred Wegener Institute for Polar and Marine Research, Germany. http://www.awi-bremerhaven.de/Benthic/Ecosystem/FoodWeb/Handbook/main.html

Buchanan JB (1984) Sediment analysis. In Holme NA & McIntyre AD, eds.: Methods for the study of marine benthos. Blackwell Scientific Publications, Oxford an Edingburgh: 41-65

Budd GC (2005) Nephtys cirrosa. White catworm. Marine Life Information Network: Biology and Sensitivity Key Information Sub-programme [on-line]. Plymouth: Mar Biol Ass UK http://www.marlin.ac.uk/species/Nephtyscirrosa.htm

Clarke KR, Gorley RN (2001) Primer v5: User Manueal/Tutorial. PRIMER-E: Plymouth, 91 pp.

Clifford H, Stephenson W (1975) An Introduction to Numerical Classification. Academic Press, London, 229 pp.

Conover WJ (1971) Practical non parametric statistics. John Wiley & Sons, New York, 462 pp.

Cooper KM, Eggleton JD, Vize SJ, Vanstaen K, Smith R, Boyd SE, Ware S, Morris CD, Curtis M, Limpenny DS, Meadows WJ (2005) Assessment of the rehabilitation of the seabed following marine aggregate dredging-part II. Sci Ser Tech Rep 130, CEFAS Lowestoft, 82pp

D'Amours D (1988) Vertical distribution and abundance of natant harpacticoid copepods on a vegetated tidal flat. Neth. J. Sea Res 22, 161-170

Degrendele K, Roche M, Schotte P (2005) Monitoring van de impact van de extracties. in: 2005. Balans van het duurzaam beheer van zand en grindexploitatie op het Belgische Continentaal Plat en toekomstperspectieven. *Studiedag 10 Oktober 2005*

Degrendele K, Roche M, Schotte P, Van Lancker V; Bellec V, Bonne W (in press). Morphological evolution of the Kwinte Bank central depression before and after cessation of affregate extraction. J. Coast. Res

De Maersschalck V, Hostens K, Wittoeck J, Cooreman K, Vincx M, Degraer S (2006) Monitoring van de effecten van het Thornton windmolenpark op de benthische macro-invertebraten en de visfauna van zachte substraten - Referentietoestand. Rapport ILVO-Visserij/Monitoring/2006-01

Desprez M (2000) Physical and biological impact of marine aggregate extraction along the French coast of the Eastern English Channel: short- and long-term post-dredging restoration. ICES J Mar Sci 57: 1428-1438

Galluci F, Steyaert M, Moens T (2005). Can field distributions of marine predacious nematodes be explained by sediment constraints on their foraging succes?. Mar Ecol Prog Ser304 ( ):167-178.

Guerra-Garcia JM, Corzo J, Garcia-Gomez JC (2003) Short-term benthic re-colonisation after dredging in the harbour of Ceuta, North Africa. P.S.Z.N.: Mar Ecol 24(3): 217-229

Hacking N (2003) A review of the ecology of offshore ocean sediments with particular reference to marine aggregate resources for beach nourishment in New South Wales. Centre for Natural Resources. Department of Infrastructure, Planning and Natural Resources

Herman R (1989) De structuur van de meiobenthosgemeenschappen in de Zuidelijke Bocht van de Noordzee - met speciale aandacht voor de Copepoda Harpacticoida. Ph.D. thesis, University Gent, Belgium, 211 pp.

Heip C, Vincx M, Vranken G (1985) The ecology of free-living nematodes. Oceanogr. Mar. Biol. Ann Rev 23: 399-489

Hicks GRF, Coull BC (1983) The ecology of marine meiobenthic harpacticoid copepods. Oceanogr Mar Biol Ann Rev 21: 67-175

Hill MO (1974) Correspondence Analysis: neglected multivariate method. J. R. Stat. Soc. Ser. C-Appl. Stat. 23: 340-354

Hill MO (1979) TWINSPAN - A FORTRAN program for arranging multivariate data in an ordered two-way table by classification of the individuals and the attributes. Ecology and Systematics, Cornell University, Ithaca, New York, 50 pp.

Hiscock K, Langmead O, Warwick R, Smith A (2005) Identification of seabed indicator species to support implementation of the EU Habitats and Water Framework Directives. Second edition. *Report to the Joint Nature Conservation Committee and the Environment Agency from the Marine Biological Association*. Plymouth: Marine Biological Association. JNCC Contract F90-01-705 77 pp

James FC, McCulloch CE (1990) Multivariate analysis in ecology and systematics: panacea or Pandora's box? Ann Rev Ecol Syst 21: 129-166

James RJ, Lincoln Smith MP, Fairweather PG (1995) Sieve mesh-size and taxonomic resolution needed to describe natural spatial variation of marine macrofauna. MEPS 118: 187-198

Jongman RHG, Ter Braak CJF, Van Tongeren OFR (1995) Data analysis in community and landscape ecology. Camebridge University Press, 299 p

Kennedy AD, Jacoby CA (1999) Biological indicators of marine environmental health: meiofauna-a neglected benthic component. Environmental Monitoring an Assessment 54: 47-68

Kenny AJ, Rees HL (1994) The effects of marine gravel extraction on the macrobenthos: early post dredging re-colonisation. Mar Poll Bull 28: 442-447

Kenny AJ, Rees HL (1996) The effects of marine gravel extraction on the macrobenthos: results 2 years post-dredging. Mar Poll Bull 32: 615-622

Kooijman, S.A.L.M. (1986). Energy budgets can explain body size relations. J. theor. Biol.121 ( ):269-282

Lang K (1948) Monographie der Harpacticiden. Håkan Ohlssons Boktryckeri, Lund (Sweden), 1682 pp.

Lang K (1965) Copepoda Harpacticoidea from the Californian Pacific Coast. Kungliga Svenska Vetenskapakademiens 10: 1-560

Kröncke I, Bergfeld C (2001) Review of the current knowledge on North Sea benthos. Berichte aus dem Zentrum für Meeres- und Klimaforschung Z 12: 112 p

MACROBEL Long term trends in the macrobenthos of the Belgian Continental Shelf. Research action SPSD-I. MN/DD2/013 http://www.vliz.be/Vmdcdata/macrobel/index.php

McCune B, Mefford MJ (1999) Multivariate Analysis of Ecological Data Version 4.25 MjM Software, Gleneden Beach, Oregon, U.S.A.

Meheus L, (1981) Vergelijkende studie van het macrobenthos van enkele zandbanken in de zuidelijke bocht van de Noordzee. Lic thesis, University of Gent, Belgium

Moens T, Herman P, Verbeeck L, Steyaert M, Vincx M (2000). Predation rates and prey selectivity in two predacious estuarine nematode species. Mar Ecol Prog Ser 205:185-193.

Newell RC, Seiderer LJ, Hitchcock DR (1998) The impact of dredging works in coastal waters: a review of the sensitivity to disturbance and subsequent recovery of biological resources on the sea bed. Oceanogr Mar Biol 36: 127-178

Newell RC, Seiderer LJ, Robinson JE, Simpson NM, Pearce B, Reeds KA (2004a) Impacts of overboard screening on seabed and associated benthic biological community structure in relation to marine aggregate extraction. Tech Rep to ODPM and MIRO. Project No SAMP.1.022. MES Ltd, St. Ives, Cornwall. 152 pp

Newell RC, Seiderer LJ, Simpson NM, Robinson JE (2004b) Impacts of marine aggregate dredging on benthic macrofauna off the south coast of the U.K. J Coast Res 20: 115-125

Peters RH (1983) The ecological implications of body size. Cambridge University Press, Cambridge

Rees HL (1987) A survey of the benthic fauna inhabiting gravel deposits off Hastings, Southern England. ICES CM 1987/L 19: 9 pp.

Sanchez-Moyano JE, Estacio FJ, Garcia-Adiego EM, Garcia-Gomez JC (2004) Dredging impact on the benthic community of an unaltered inlet in southern Spain. Helg Mar Res 58: 32-39

Sardá R, Pinedo S, Gremare A, Taboada S (2000) Changes in the dynamics of shallow sandy-bottom assemblages due to sand extraction in the Catalan Western Mediterranean Sea. ICES J Mar Sci 57: 1446-1453

Simonini R, Ansaloni I, Bonvicini Pagliai AM, Cavallini F, Iotti M, Mauri M, Montanari G, Preti M, Rinaldi A, Prevedelli D (2005) The effects of sand extraction on the macrobenthos of a relict sands area (northern Adriatic Sea): results 12 months post-extraction. Mar Poll Bull 50: 768-777

Snelgrove P, Butman C (1994) Animal-sediment relationships revisited: cause versus effect. Oceanogr Mar Biol Ann Rev 32: 111-117

Steyaert M, Garner N, Van Gansbeke D, Vincx M. (1999) Nematode communities from the North Sea: environmental controls on species diversity and vertical distribution within the sediment. J Mar Biol Ass UK 79:253-264

ter Braak CJF, Smilauer P (1998) CANOCO Reference Manual and User's Guide to Canoco for Windows: Software for Canonical Community Ordination (version 4). Centre for Biometry Wageningen (Wageningen, NL) and Microcomputer Power (Ithaca, New York, USA), 352 pp.

Thistle D, Levin LA, Gooday AJ, Pfannkuche O, Lambshead PJD (1999) Physical reworking by near-bottom flow alters the metazoan meiofauna of Fieberling Guyot (northeast Pacific). Deep-Sea Res Part I-Oceanogr Res Pap 46: 2041-2052

Thistle D, Weatherly GL, Ertman SC (1995) Shelf harpacticoid copepods do not escape into the seabed during winter storms. J. Mar Res 53: 847-863

Vanaverbeke J, Gheskiere T, Vincx M (2000) The meiobenthos of subtidal sandbanks on the Belgian Continental Shelf (Southern Bight of the North Sea). Est Coast Shelf Sci 51: 637-649

Vanaverbeke J, Gheskiere T, Steyaert M, Vincx M (2002) Nematode assemblages from subtidal sandbanks in the Southern Bight of the North Sea: effect of small sedimentological differences. J Sea Res 48: 197-207

Vanaverbeke J, Steyaert M, Vanreusel A, Vincx M (2003) Nematode biomass spectra as descriptors of functional chages due to human and natural impact. Mar Ecol Prog Ser. 249:157-170

van Dalfsen J, Essink K, Toxvig Madsen H, Birklund J, Romero J, Manzanera M (2000) Differential response of macrozoobenthos to marine sand extraction in the North Sea and the Western Mediterranean. ICES J Mar Sci 57: 1439-1445

van Dalfsen J, Essink K (2001) Benthic community response to sand dredging and shore face nourishment in Dutch coastal waters. Senck marit 31: 329-332

Vanosmael C, Heip C (1986) A comparative study of the macrobenthos of three sandbanks in the Belgian coastal waters in 1980-1984. Has sand exploitation an influence on the macrobenthos? In: Heip C, Coomans A (Ed) (1986) Ecology, ecotoxicology and systematics of marine benthos. pp125-144

Vanosmael C, Willems K A, Claeys D, Vincx M, Heip C (1982) Macrobenthos of a sublittoral sandbank in the southern bight of the north sea. J Mar Biol Ass U.K. 62: 521-534

Vincx M (1986) Free-living marine nematodes from the Southern Bight of the North Sea. PhD tesis, University of Gent, 618 pp

Waeterschoot H (1980) Macrobenthos van de Kwintebank (1979-1980): studie in het kader van de zand- en grindexploitatie voor de Belgische kust. LicThesis University of Gent, Belgium

Warwick RM, Clarke KR (1993) Increased variability as a symptom of stress in marine communities. J Exp Mar Biol Ecol 172: 215-226

Warwick RM, Clarcke KR (2001). Practical measures of marine biodiversity based on relatedness of species. Ocean Mar Biol Ann Rev 39: 207-231.

Warwick RM, Platt HM, Somerfield PJ (1998). Free-living marine nematodes. Part III. Monhysterids. Synopses of the British Fauna (New Series) 296 pp.

Wentwhorth W (1972) A scale of grade and class terms for cladistic sedimiments. J Geol 30: 377-392

Wieser W (1953) Die Beziehung zwischen Mundhöhlengestalt, Ernährungsweise und Vorkommen bei freilebenden marinen Nematoden. Ark. Zool 2: 439-484

Willems KA, Vincx M, Claeys D, Vanosmael C, Heip C (1982) Meiobenthos of a sublittoral sandbank in the Southern Bight of the North Sea. J. Mar Biol Ass UK 62: 535-548

Wilson G (1998) A Post-impact Monitoring Study of Benthic Fauna in Areas Dredged for the Third Parallel Runway in Botany Bay. Australian Museum Marine Invertebrates Section