Post-extraction evolution of a macrobenthic community on the intensively extracted Kwintebank site in the Belgian part of the North Sea.

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The Kwintebank, a highly dynamic sandbank in the western Belgian part of the North Sea, is highly extracted, mainly due to the short distance to the coast and the suitability of the sand for construction purposes. After 30 years of exploitation, a depression was formed in the central part of the Kwintebank. To allow the geomorphologic rehabilitation of the area, it was decided to cease extraction in this part of the exploitation zone in 2003. The recovery of the macrobenthos in this depression was monitored for several years through the analysis of Van Veen grab samples taken twice a year at six locations in the depression and at several locations spread over the Kwintebank. The poor macrobenthic community that was found in the central depression directly after the cessation of the extraction activities, clearly evolved to a community with higher densities, species richness and diversity within three years after the sand extraction activities had stopped. The species with the highest increase were the interstitial polychaetes *Hesionura elongata* and *Polygordius appendiculatus*, juvenile and adult *Nephtys cirrosa* and the amphipod *Urothoe brevicornis*. These are characteristic species also for the other highly dynamic sandbanks of the Belgian continental shelf. As the 'central' Kwintebank site will remain closed for another 3 years, there is an opportunity to further investigate the recolonisation/recovery of the macrobenthic community.

Keywords: sand extraction, sandbank, Belgian Continental Shelf, macrobenthos, recolonisation, recovery

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INTRODUCTION

The exploitation of sand on the Belgian Continental Shelf started in 1976 with an annual exploitation of about 29 000 m³. In 1977, exploitation increased by about one order of magnitude and became more and more important. In the mid 1990's already 1700000 $m^3.yr^{-1}$ was extracted, reaching a maximum of more than 1900000 $m^3.yr^{-1}$ in 2001. During the last two years, subtidal sand extraction yielded at about 1600000 $m^3.yr^{-1}$ (Degrendele et al., in press). Extraction activities on the BCS are mainly concentrated on the Kwintebank (> 75%), due to the presence of suitable sand and its close location to the harbour; enabling a cost-effective exploitation (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. Following this decision, the project SPEEK (Study of Post-Extraction Ecological effects in the Kwintebank sand dredging area) was set up, a cooperation between 3 Belgian laboratories (ILVO-Fisheries, University of Gent/Marine Biology and UGent/Renard Centre for Marine Geology) and 1 Spanish institute (AZTI, Department Oceanography and Marine Environment). The main aim of SPEEK was to investigate the possible recovery of the benthic life after cessation of extraction activities in the central part of the Kwintebank. The project focused on the meiobenthos studied by the UGent (Nematoda) and AZTI (Harpacticoida) and the macrobenthos studied by ILVO-Fisheries. All biological data was backed up by geological data, collected by RCMG. (Vanaverbeke et al., 2007) This paper deals with the results of this project of ILVO-Fisheries on the macrobenthos.

The macrobenthos is ideally suited as an indicator for assessing the state of the marine environment and to detect possible changes caused by human and natural impacts. Macrobenthic 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 (Kröncke & Bergfeld, 2001).

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 Newell et al. 1998; Boyd et al. 2004; Birklund & Wijsman, 2005; ALSF 2005). The estimated time required for recovery of the benthic fauna following marine extraction varies, 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 benthos (biomass and structure) after extraction can take up to 10 years or longer (for reviews see Newell et al. 1998; Boyd et al. 2004; Birklund & Wijsman, 2005; ALSF 2005). Some studies (all characterised by mud or fine sand) show re-colonisation after a few months (Pagliai et al., 1985; Guerra-Garcia et al., 2003; Sanchez-Moyano et al., 2004). Most of these studies dealt with the effects of dredging operations that lasted only a short period. Few studies have addressed the consequences of long-term dredging operations on the re-colonization of biota or the composition of sediments following cessation (Desprez, 2000; Newell et al., 2004a; Newell et al., 2004b; Boyd et al., 2005; Cooper et al., 2005).

The central depression of the Kwintebank has been under the influence of intensive extraction for almost 30 years. Although no base line data are available from before the start of the extraction activities or from the last years before the closure of the area, it is assumed that the macrobenthic community on the highly dynamic Kwintebank, must be well adapted to frequent disturbances. Characteristic species are therefore mobile and short-living species that are highly dispersive.

The aim of this study is to see how the area and the associated benthic fauna evolve following cessation of the extraction activities. The outcome of the study should enable us to make some recommendations for policy makers and stakeholders to guarantee a sustainable use of the marine aggregates on the Belgian Continental Shelf.

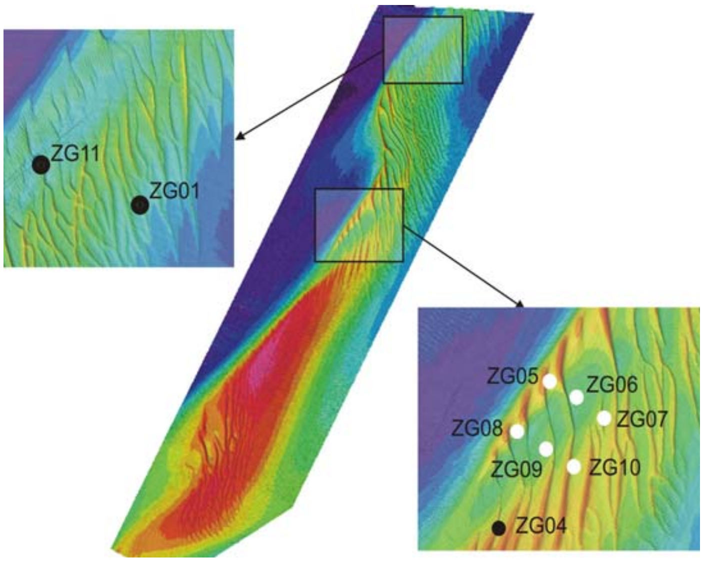

Figure 1: Multibeam image of the central depression of the Kwintebank (FPS Economy) with the locations of the macrobenthos sampling points. (white dots: locations in and near central depression; black dots: reference stations outside closed area)

METHODS

Sample collection and processing

Six locations (ZG05 - ZG10) were sampled 7 times between March 2003 and September 2005 from the RV Belgica (Fig 1). ZG05 and ZG08 were located on the western slope of the depression, ZG09 and ZG06 in the deepest parts of the depression and ZG07 and ZG10 on the eastern slope. At each location 4 Van Veen grabs were taken; 3 for macrobenthos and 1 for sediment analysis. The macrobenthic samples were fixed in a formaldehydeseawater solution before being washed over a 1 mm sieve in the lab and subsequently coloured with eosine. Macrobenthic specimens were sorted and identified, if possible up to species level. Some other stations, sampled within the framework of the national sand extraction monitoring program, were used as reference data. These stations were located south (ZG04) and north (ZG11 and ZG01) of the central depression (Fig 1). Sampling techniques and sample processing were the same for all stations.

Data analysis

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). Correspondence Analysis (CA) was used to evaluate changes in the community structure over time, using the package PCord (v4, McCune and Mefford, 1999). 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). Finally the biological data of the central depression (ZG05 – ZG10) were compared with data from other sampling locations on the Kwintebank (ZG01, ZG11 and ZG04) using the univariate measures (density, number of species, diversity and biomass) and Correspondence Analysis.

RESULTS

Sediment

The variation in sediment characteristics between the different stations as well as the temporal variation per station was high (Fig 2). 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), although a decreasing trend was found. Median grain size of Station ZG08 showed an increase over the last 3 years from 300µm to > 400µm, whereas the median grain size of ZG05 fluctuated around an average of 240µm. The two stations located in the middle of the depression (ZG06 and ZG09) had a similar sediment composition by the end of the study period (350µm), although the temporal evolution found was different. The sediment of station ZG06 was more or less stable (average median grain size of 350µm). A coarsening of the sediment, from 200µm to 350µm, was found for Station ZG09. For the stations of the eastern slope of the depression (ZG07 and ZG10) no in– or decrease of the median grain size was found. ZG07 showed a high variation between the subsequent samplings with an average median grain size of 270µm. The sediment of station ZG10 was relatively stable, with a clear seasonal variation (average median grain size in spring: 275µm; in autumn: 240µm).

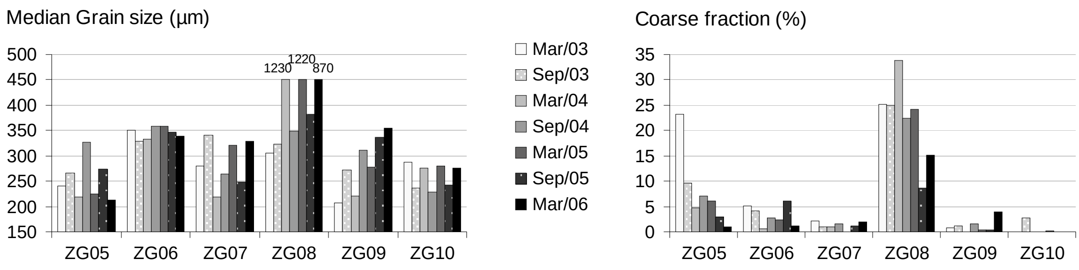

Figure 2: Median grain size and percentage of coarse fraction (> 2mm) for all stations for the different sampling periods.

Macrobenthos - Species richness

In total 104 different macrobenthic species were found in the period March 2003 - September 2005. Each station had a different evolution in the number of species, except for the low number in March 2003 and the high number of species counted in September 2005. Taking all stations together and looking at 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 3). The proportion of the different taxa in the total amount of species did not substantially vary over the different sampling periods. Polychaetes or bristle worms accounted on average for 43% of the species composition, crustaceans (mainly amphipods) 30% and molluscs (mainly bivalves) 15%.

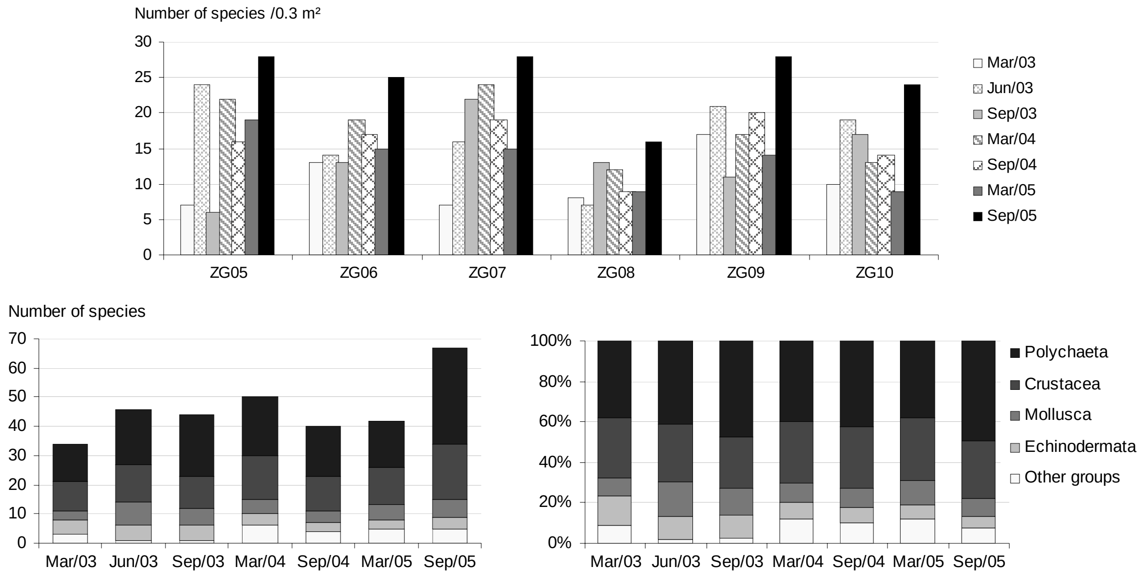

Figure 3: Number of species (/0.3m²) counted per station per season (top) and Total number of species per season with indication of the different relative proportion of the major taxonomic groups in density (bottom).

Macrobenthos - Diversity

The Shannon-wiener diversity-index showed a similar slightly increasing trend, from < 2 in March 2003 to > 2 in September 2005 (Fig 4), except for station ZG09 where diversity was already higher in the first month after the closing of the area. For station ZG05, diversity was not only low in March 2003, but also in September 2003. Station ZG08 had the lowest diversity overall. The diversity of stations ZG06 and ZG07 showed a slightly increasing trend over the whole study period. Diversity of the macrobenthos at station ZG10 initially increased, but decreased again towards spring 2005.

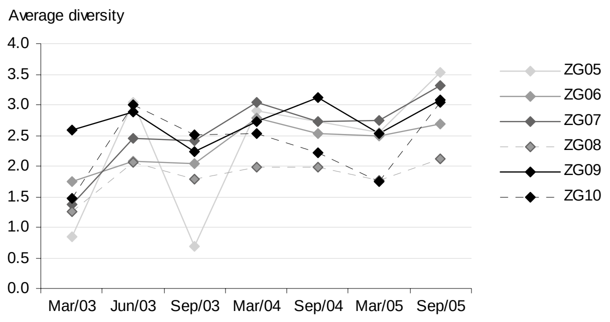

Figure 4: Shannon-wiener diversity index for the different sampling locations for the period March 2003 – September 2005.

Macrobenthos - Density

For all stations an increasing trend was found: extremely low densities in March 2003 and the highest densities in September 2005 (except for ZG10, were the highest density was recorded in June 2003) (Fig 5). 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. The stations of the western slope of the depression, ZG05 and ZG08, had overall the lowest densities The highest densities, especially in September 2005, were recorded in the centre of the depression (ZG06 and ZG09) and for ZG07. Total density of station ZG10 initially increased, but decreased again with another minimum in March 2005.

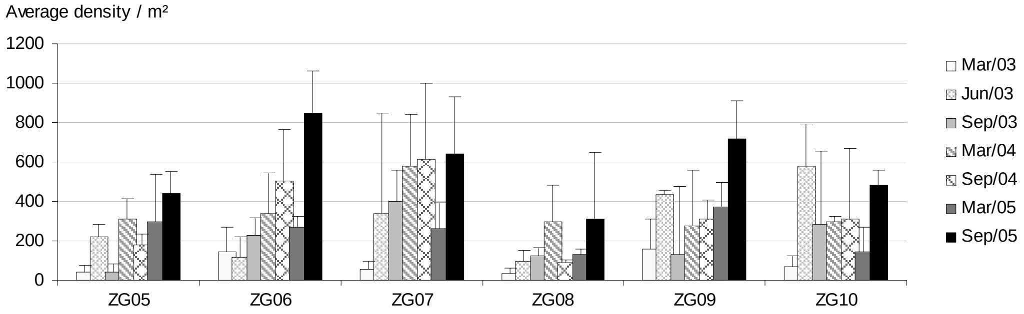

Figure 5: Average number of individuals (+ st. dev. on replicates) for all sampling periods for all locations separately.

Polychaetes and crustaceans represented the largest fraction of the overall density with respectively 66% and 25% (Fig 6). The relative abundance of the polychaetes increased compared to a decreasing relative abundance of the crustaceans. The most dominant species present in the central depression were, adult and juvenile *Nephtys cirrosa, Urothoe brevicornis*, *Hesionura elongata, Polygordius appendiculatus* and *Spiophanes bombyx* (see Table 1). These species were also responsible for the increase in total density throughout the sampling period (Fig 7). 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 beginning 1 year after the cessation of dredging. Some other 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, due to a low density in March 2005. 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 (Fig 8). 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.

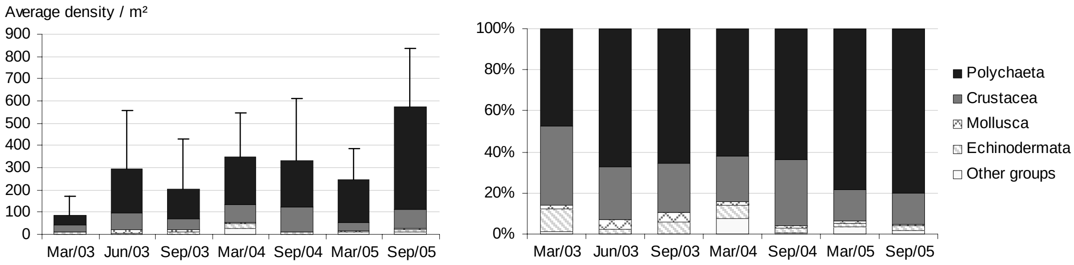

Figure 6: Average number of individuals per m² (+ st. dev.) with indication of the proportion of the major taxonomic groups.

Table 1: Table showing the 6 most abundant species per sampling period, indicating the percentage of total density they represent.

Mar/03		Jun/03		Sep/03		Mar/04	
Nephtys spp.	21.3	*Nephtys spp.*	16.4	*Nephtys spp.*	19.1	*Nephtys spp.*	14.1
Urothoe brevicornis	14.7	*Spiophanes bombyx*	15.1	*Urothoe brevicornis*	15.7	*Urothoe brevicornis*	14.0
Bathyporeia elegans	8.0	*Scoloplos armiger*	10.5	*Spiophanes bombyx*	13.8	*Hesionura elongata*	12.4
Nephtys cirrosa	7.3	*Nephtys cirrosa*	7.9	*Nephtys cirrosa*	10.5	*Nephtys cirrosa*	10.0
Ophelia limacina	6.0	*Bathyporeia elegans*	7.5	*Microphthalmus spp.*	7.2	*Scoloplos armiger*	8.3
Hesionura elongata	2.7	*Ophelia limacina*	3.7	*Hesionura elongata*	6.1	*Spiophanes bombyx*	7.3

Sep/04		Mar/05		Sep/05	
Urothoe brevicornis	20.1	*Nephtys spp.*	20.2	*Hesionura elongata*	16.3
Hesionura elongata	14.0	*Nephtys cirrosa*	15.2	*Polygordius appendiculatus*	14.3
Nephtys spp.	13.6	*Hesionura elongata*	15.0	*Nephtys spp.*	11.9
Nephtys cirrosa	11.8	*Urothoe brevicornis*	8.4	*Nephtys cirrosa*	11.4
Spiophanes bombyx	9.3	*Polygordius appendiculatus*	7.5	*Spiophanes bombyx*	8.4
Polygordius appendiculatus	6.5	*Scoloplos armiger*	5.2	*Urothoe brevicornis*	8.3

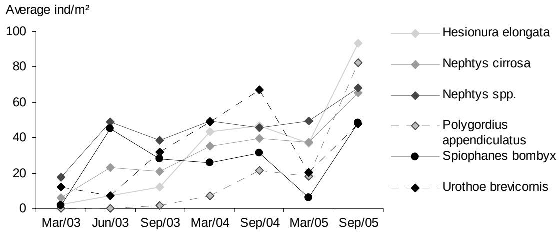

Figure 7: Average number of ind/m² for the 6 most important species for the period March 2003 – September 2005.

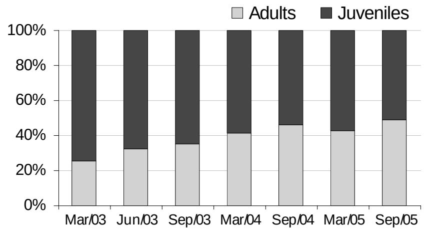

Figure 8: The different proportions of juvenile and adult *Nephtys cirrosa.*

Macrobenthos - Biomass

Average biomass increased from March 2003 to September 2004 due to the high biomass of *Echinocardium cordatum* (Fig 9). Excluding the biomass of *E. cordatum* and *Ensis arcuatus*, an increase in biomass was found, with a peak in March 2004 and September 2005 (Fig 9). The total biomass of polychaetes, crustaceans and molluscs increased, although the average individual body size (biomass/number of individuals) per taxonomic group, did not show a similar trend: the highest value was recorded in March 2003 for polychaetes and in March 2005 for crustaceans and molluscs (Fig 10).

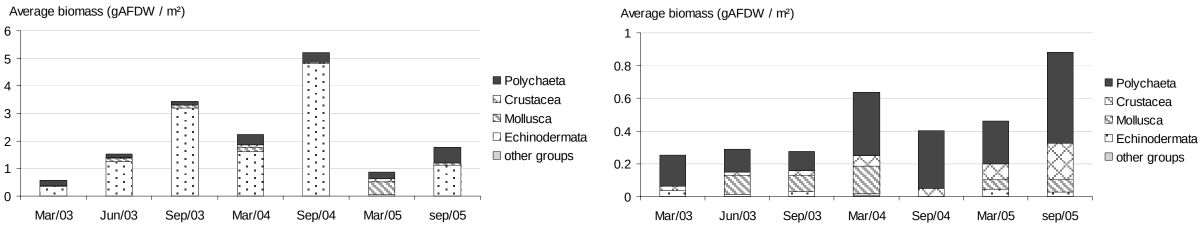

Figure 9: Average biomass / m² (wet weight corrected to AFDW) for the different sampling periods. Left: all species included; right: excluding *Echinocardium cordatum* and *Ensis arcuatus*

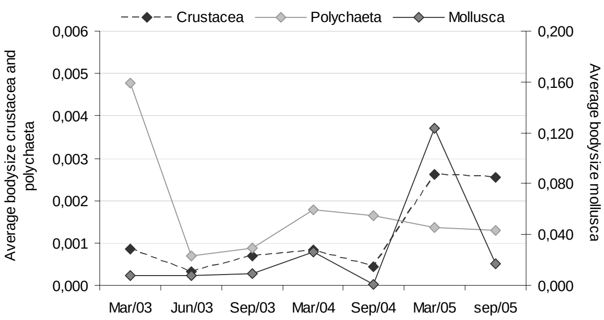

Figure 10: Average body size of the 3 major taxonomic groups.

Community analysis

Correspondence Analysis, using data from all six stations, indicated that both ZG08 and ZG05 had a different faunal pattern, possibly caused by the different sediment composition (higher proportion of coarse material). To have better insight into the temporal evolution in the community structure after the cessation of extraction, both stations were analysed separate from the other 4 stations of the central depression. For location ZG05, clear changes were found between the samples of 2003, the samples from 2004 and spring 2005 and the samples from autumn 2005. The first year was characterised by few species and a high dissimilarity between the samples. The samples taken in 2004 and spring 2005 were characterised by mainly interstitial, opportunistic and fast predator species. The similarity between the samples of autumn 2005 was the clearly higher than for all other seasons and some species, absent form the previous seasons, occurred (e.g. *Magelona johnstoni*, *Heteromastus filiformis*, *Eteone longa*). The community structure of station ZG08 was clearly different in 2003, but samples from 2004 and 2005 clustered more or less together. The species that were more abundant in the samples of 2003 were mainly

Ophiura albida, Urothoe brevicornis and *Aonides paucibranchiata.* The dissimilarity was also highest for the samples of 2003.

The CA of the other four stations together also indicated a shift in community structure, although no clear separation of the different years was found (Fig 11). For both seasons, the 2003 and 2004 samples were partly separated from the 2005 samples due to the higher abundance of *Bathyporeia* spp. (in 2003) and *Urothoe brevicornis* (in 2003 and 2004). More polychaetes were found in the 2005 samples. The interstitial species *Polygordius appendiculatus*, *Microphthalmus* spp. and *Hesionura elongata* and the juvenile *Glycera* spp. were more abundant in the spring samples of 2004 and 2005. The autumn samples of 2005 were separated from the other years due to the presence of a high number of less abundant species (e.g. *Eteone longa, Phyllodoce rosea, Ophiura albida, Magelona johnstoni*).

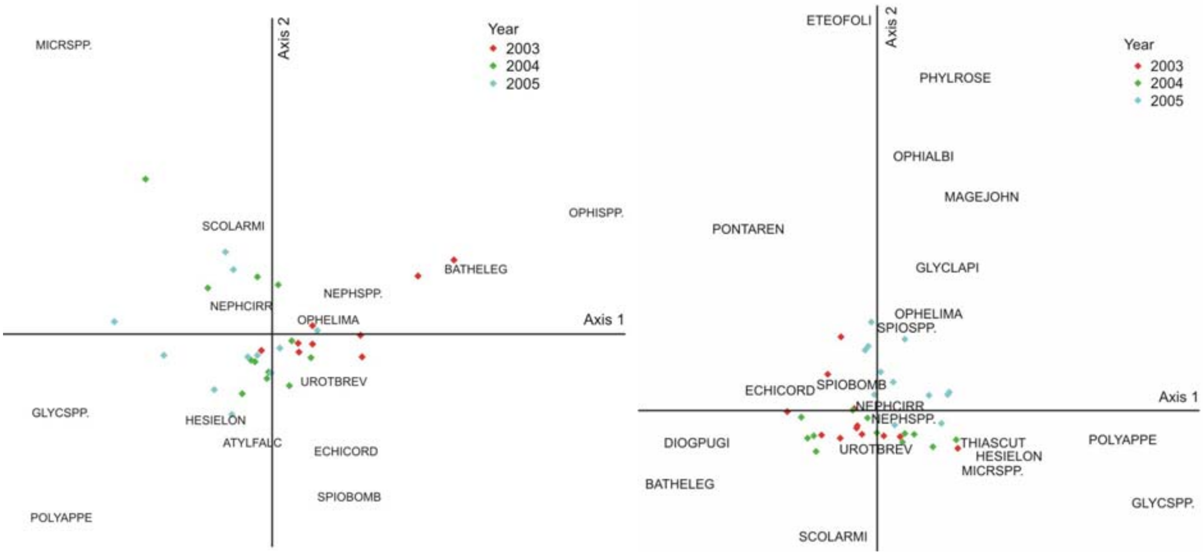

Figure 11: CA of spring (left) and autumn (right) samples from the central depression projected in the plain of the first two ordination axes.

When analysing the sampling stations separately, similar results were found. The difference in similarity between the samples of 2003 and the samples of 2004 and 2005 was more pronounced. The dissimilarity among the samples of the 2003 samples was greater than for the different samples of the other seasons.

Comparison with other sampling locations

Density, number of species and diversity of the six stations from the central depression were compared to three stations, equally located on the Kwintebank (Fig 12). 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. On the other hand, 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 of the macrobenthos in the depression (ZG05-ZG10) was not found for the macrobenthos of the stations from outside the depression. 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 March 2003 in the central depression.

The 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 of 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*. CA indicated 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. 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 13.

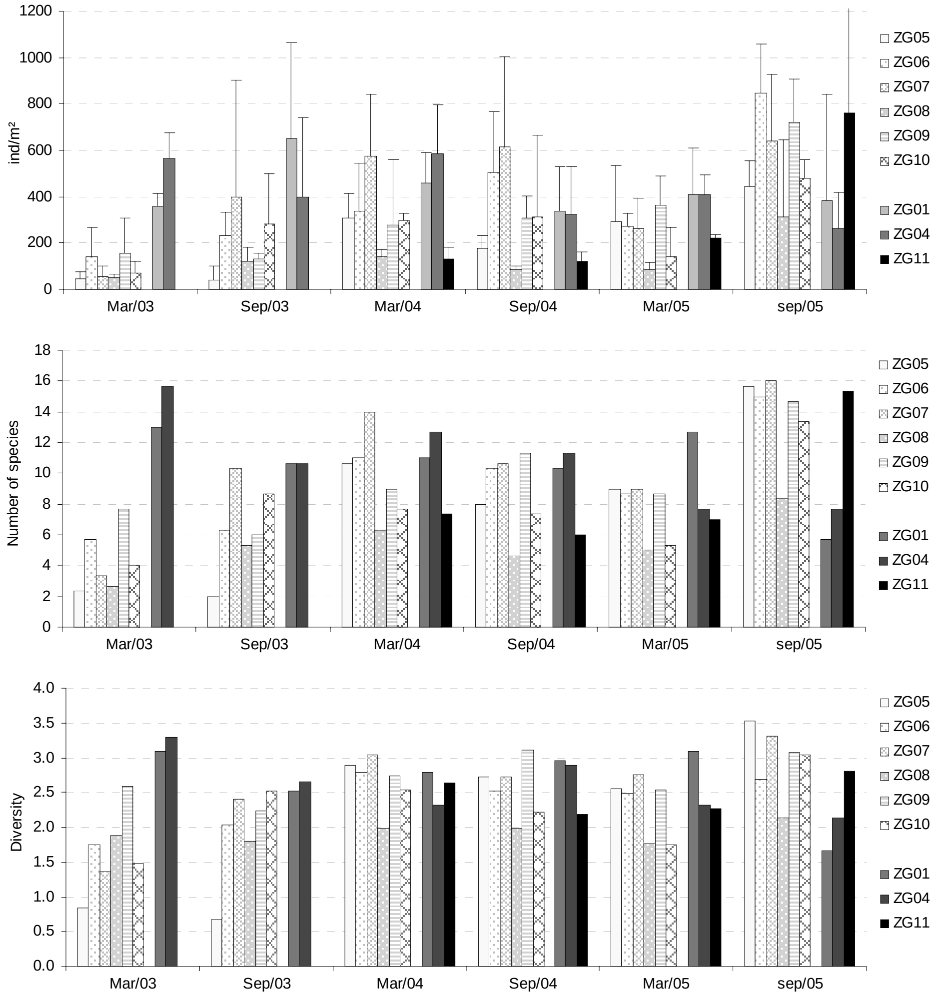

Figure 12: Density, diversity and number of species for different locations on the Kwintebank for the period March 2003-September 2005.

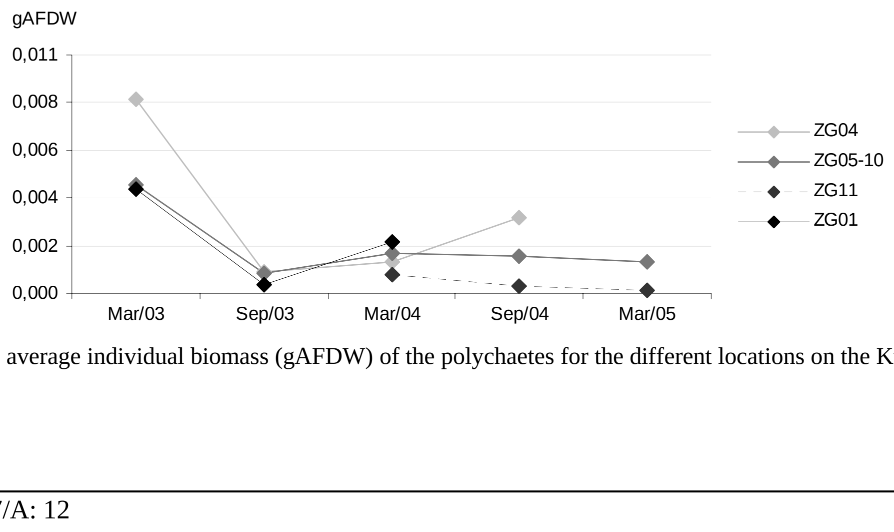

Figure 13: average individual biomass (gAFDW) of the polychaetes for the different locations on the Kwintebank.

DISCUSSION

Samples taken at different intervals after the closure of the central depression showed an increase in macrobenthos density, species number and diversity. For most stations in the central depression, the lowest density was measured directly after the cessation of dredging. After a few months, a higher density was found for all stations. Almost 3 years after the closing of the area, the average density had clearly increased and reached a level comparable to or higher than other locations on the Kwintebank. The species responsible for the general increase in abundance were small interstitial and fast predatory species. These species are responsible for 50% of total density throughout the 3 year study period and are not yet replaced by other species so far in the process of recovery. These species were already found in the early stages of extraction in this area (Waeterschoot, 1980; Meheus, 1981; Vanosmael et al., 1982; Vanosmael and Heip, 1986; Moulaert, 2007) and are the prominent species on other sandbanks of the Belgian Continental Shelf (De Maersschalck et al., 2006; Moulaert et al., 2007). The early settlement of species that are typical for the area and the absence of species belonging to families that were of low abundance or rare before dredging was also found in other studies (Kenny & Rees, 1996; Sanchez-Moyano et al., 2000; Simonini et al., 2005). Long living species like bivalves were not recorded in great numbers in the samples of this study, in contrast to van Dalfsen et al. (2000), who found that bivalve recruitment was favoured at several North Sea extraction sites. It is known that bivalves are not highly abundant on the offshore sandbanks of the BCS (Van Hoey et al., 2004; De Maersschalck et al., 2006; Moulaert, 2007). Even in the early years of extraction on the Kwintebank, only small numbers of bivalves (mainly *Spisula* spp.) were recorded (Waeterschoot, 1980; Meheus, 1981; Vanosmael et al., 1982; Vanosmael and Heip, 1986). The proportion between the total amount of adult and juvenile individuals of *Nephtys cirrosa* changed slightly over the sampling period in favour of the adults. This indicates that the community is re-establishing a state, where juvenile can reach maturity. 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. Results from the Correspondence Analyses showed some 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 showed 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.

A rapid increase in density and species number was found in several studies, although these mainly concerned the recovery after a short term impact of sand extraction (Pagliai et al., 1985; Sarda et al., 2000; Guerra-Garcia et al., 2003; Sanchez-Moyano et al., 2004; Simonini et al., 2005). In contrast to the density and number of species, the biomass and the structure of the community were in most of these studies not yet restored by the end of the sampling period. In some other studies, the ‘recovery’ of an extraction area took several years (Kenny & Rees, 1994, 1996; Kenny et al., 1998; Desprez, 2000; Boyd et al., 2004; van Dalfsen et al., 2000; Cooper et al., 2005; Boyd et al., 2005). Many of these studies concern the effects of dredging operations that lasted only a few months or less. These studies generally have a good BACI (Before/After/Control/Impact) approach that give clear results. A rapid increase of certain species is usually found within one or several months, but a general conclusion is often that the recovery is not fully completed within the time span of the study. A good example is the experimental study off Norfolk, UK that continued for a couple of years and where different conclusions were drawn after each study period (Kenny & Rees, 1994, 1996; Kenny et al., 1998). Few studies have addressed the consequences of long-term dredging operations on the re-colonization of the macrobenthos (Desprez, 2000; Boyd et al., 2004; Newell et al., 2004a; Newell et al., 2004b; Boyd et al., 2005; Cooper et al., 2005). The recovery in areas of prolonged continuous impact (>10 years) is more difficult to study compared to areas with only a short term impact as in a lot of these studies, base line data is not available. The community at the long-term impact site can have evolved to a new structure that is adapted to regular disturbances. These sites may not, in contrast to the short term impact sites, be totally defaunated by the end of the extraction period. Some extra difficulties arising in our study, apart from the absence of a base line study of the area, is the difficulty to find a good reference area, as the area for sand extraction covers the whole Kwintebank. Another difficulty arose from the highly diverse character of the area. The interpretation of our data was clearly hampered by the lack of knowledge of the pre-dredged status of the area and information on the pure natural variation of the area. Data from other locations on the Kwintebank were used as reference locations, 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 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'. This reference area should not be representative of the pre-dredged status, as 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. Kenny et al. (1998) en 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.

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 the Kwintebank central depression has reached a full 'recovery', in the sense of restoration, 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 still smaller compared to other areas on the Kwintebank, but the average individual biomass was stable and comparable to the other stations on the Kwintebank and with stations on other sandbanks on the BCS. 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. Also for the Thornton- and Gootebank the seasonal variation was different from the study area (De Maersschalck et al., 2006).

By reviewing the different studies on the recovery of the macrobenthos after dredging, it is 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). In a study on the long term effects of extraction on the Belgian Continental Shelf, a fining of the sediment was found for the central part of the Kwintebank from samples of 1980-1984 compared to 2003 (Moulaert, 2007). The sediment sampled in the area after cessation of dredging showed an increase of the median grain size for most of the sampling locations, although a high variability between locations and sampling periods was found. This large variability in the sediment characteristics are probably a combination of the dynamic character of the sandbank as well as the uneven impact of the extraction. In this highly dynamic area it is not surprising that a relatively rapid re-colonisation occurs. Highly disturbed sediments in dynamic coastal areas and estuaries, which are dominated mainly by opportunistic, rapidly colonising, fast-growing species, have a rapid rate of recovery. The recovery time increases in more stable habitats that are dominated by long-lived components with complex biological interactions controlling community structure (Newell et al., 1998). The recovery of the macrobenthos also depends on the comparability of the extracted area with the surrounding area. If the habitat type of the impact area and the neighbouring areas is similar, a short distance, rapid migration may occur. Results from the June 2003 samples indicate an increase in the density for some species and species richness, probably due to the migration from areas closeby.

CONCLUSIONS AND RECOMMENDATIONS

Within this project, we aimed at assessing the possible biological recovery of the central depression on the Kwintebank, after its closure for extraction activities in February 2003.

In general 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 Belgian Continental Shelf with a comparable sediment composition. So far it remains unclear whether this situation is stable and 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.

We recommend that 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 are 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. Ideally sand extraction areas are should rotate frequently in order not to introduce prolonged disturbances. For the Kwintebank it remains unclear how long the area will need to recover and re-establish an equilibrium state.

We 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.

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LITERATURE CITED

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

Birklund J & Wijsman JWM (2005) Aggregate extraction: a review on the effect on ecological functions. DHI Water and Environment and WL/Delft Hydraulics, report Z3297.10. 56pp

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 & Rees HL (2003) En examination of the spatial scale of impact on the marine benthos arising from marine aggregate extraction in the central English Channel. Est Coast Shelf Sci 57: 1-16

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

Boyd SE, Limpenny DS, Rees HL, Cooper KM (2005) The effects of marine sand and gravel extraction on the macrobenthos at a commercial dredging site (results 6 years post-dredging). ICES J Mar Sci, 62: 145-162

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

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

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

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

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

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

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

Kenny AJ, Rees HL, Greening J, Campbell S (1998) The effects of marine gravel extraction on the macrobenthos at an experimental dredge site off north Norfolk, U.K. (Results 3 years post-dredging). ICES CM 1998/V:14, 1–8

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

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

Moulaert I (2007) Evaluation of the consequences of long term sand extraction on the structural characteristics of the macrobenthos communities. In: Vanaverbeke J, Bellec V, Bonne W, Deprez T, Hostens K, Moulaert I, Van Lancker V & Vincx M (2007) Study of post-extraction ecological effects in the Kwintebank sand dredging area (SPEEK): final report. Belgian Science Policy: Brussels, Belgium. 92pp

Moulaert I, Hostens K, Hillewaert H, Wittoeck J (2007) Spatial variation of the macrobenthos species and communities of the Belgian Continental Shelf and the relation to environmental variation. ICES CM 2007/A

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. 152pp

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

Pagliai AMB, Varriale AMC, Crema R, Galletti MC, Zunarelli RV (1985) Environmental impact of extensive dredging in a coastal marine area. Mar Poll Bull 16(12): 483-488

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 PVR & Butman CA (1994) Animal-sediment relationships revisited: cause versus effect. Oceanogr Mar Biol Ann Rev 32: 111-117

Vanaverbeke J, Bellec V, Bonne W, Deprez T, Hostens K, Moulaert I, Van Lancker V, Vincx M (2007) Study of post-extraction ecological effects in the Kwintebank sand dredging area (SPEEK): final report. Belgian Science Policy: Brussels, Belgium. 92pp

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 Hoey G, Degraer S, Vincx M (2004) Macrobenthic community structure of soft-bottom sediments at the Belgian Continental Shelf. Est Coast Shelf Sci 59: 601-615

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

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. 125-144

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

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