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Macrobenthos characteristics and distribution, following intensive sand extraction from a subtidal sandbank

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ABSTRACT

Macrobenthic fauna are investigated, to establish the nature and vulnerability of benthic communities to aggregate mining on a subtidal sandbank, the Kwinte Bank, in the Southern Bight of the North Sea. Within the central part of this sandbank, a depression (5 m deep) has been created, as a result of 20 years of dredging over the same small area (1 km long and 700 m wide). Three stations were sampled within this central depression; two on the western border; and two to the east of the depression. Another station was sampled in a "non-exploited" area to the north of the depression. Four stations were sampled outside of the concession area, on the adjacent Middelkerke Bank. The hypothesis is tested as to whether or not the density, species richness, taxon and community composition do not differ, between the depression and the adjacent sites (with similar sediment composition) on top of the sandbank. In addition, it is examined whether these parameters differ between the depression and reference sites, at the adjacent undisturbed sandbank. Differences in density and species richness could not be detected, between the different locations. Compared to the reference stations at the Middelkerke Bank and locations next to the depression, crustaceans (amphipods and in particular *Bathyporeia* spp.) and echinoderms (*Ophiura* spp. and *Echinocardium cordatum*) were more abundant in the area of the depression, suggesting a higher similarity to the swale environment, than was the case previously. The observed trends were similar, for both of the sampling periods, February and November 2004. However, the species composition difference has been observed within the context of the wide range of species assemblages described earlier for the Kwinte Bank, together with other Belgian subtidal sandbanks. Sand extraction has created small-scale habitat differences on the Kwinte Bank, to which the benthic fauna have adjusted; however, this is not significant on a true larger scale of the sandbank system, one year after cessation of the intensive disturbance.

ADDITIONAL INDEX WORDS: *ecological impact, human disturbance, sand extraction, recovery, Kwinte Bank, Middelkerke Bank, North Sea.*

INTRODUCTION

The investigation of the ecological impact of sand extraction has a long history (ICES, 1992, 2001). This observation applies also to the Kwinte Bank in the Belgian sector of the North Sea, where the first impact assessment of sand extraction was undertaken in the late 1970s (VANOSMAEL *et al.*, 1979; VANOSMAEL *et al.*, 1982). In spite of the fact that sand extraction from sandbanks in Belgian marine waters has been monitored for more than 30 years, the effect on macrobenthic communities has not been detected, before the present investigation. The spatial variation in extraction intensity was not analysed in detail before 2000, as an essential prerequisite to characterising the environmental impact. BONNE (2003) attempted to relate benthic copepod communities of different areas at the Kwinte Bank to sand extraction intensity, for each sampling station, from the "black-box" records of the extraction vessels. The benthic copepod communities identified in 1997, in high extraction intensity areas, varied from those observed in 1976, from the same area. A central depression on the Kwinte Bank was detected, in multibeam imagery, in 2000; this was characterised by intensive sand extraction activities and an impoverishment of the copepod communities. However, a preliminary analysis of available macrobenthos data (from the University of Ghent) did not reveal the same pattern. Based upon these data, any differences in density or species number could not be detected, since the commencement of sand extraction on the Kwinte Bank. However, a deviation in species composition was observed (BONNE, 2003) and confirmed by VANAVERBEKE *et al.* (2007). The extraction of sand from the Kwinte Bank accounted always for more than 95 % of the total volume extracted from Belgian subtidal sandbanks, up to 2003. Until this time the effect of sand extraction on the Kwinte Bank has not been assessed with more than two sampling stations, for monitoring purposes. Hence, an appropriate macrobenthos dataset and an assessment of sand extraction on this intensively (commercially) targeted sandbank, were lacking. Within this context, macrobenthos is accepted widely as an appropriate tool to investigate and detect changes, caused by human dis-

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turbances. In general, most studies undertaken into the impacts of marine sand and gravel extraction have focused upon macrofauna (Boyd *et al.*, 2005; Kenny and Rees, 1996; Newell, Seiderer, and Hitchcock, 1998; Sarda *et al.*, 2000; van Dalfsen *et al.*, 2000). The present investigation attempts to characterise this faunal grouping, for the central depression of the Kwinte Bank; likewise, to compared them with adjacent sites and an unexploited (reference) part of a sandbank. The central depression of the Kwinte Bank was closed for sand extraction, in February 2003. In February and November 2004, the fauna was sampled, to establish any short-term recovery. The hypothesis is tested here that density, species richness, taxon and community composition do not differ between the depression and adjacent sites, with a similar sediment composition on top of the sandbank. In addition, whether these parameters differ between the depression and reference sites, on an adjacent undisturbed sandbank.

SITE DESCRIPTION

The Kwinte Bank and the Middelkerke Bank belong to the Flemish Banks, a group of (7) linear subtidal sandbanks, located to the west of Oostende, at 10 to 30 km off the Belgian coast (Figure 1.). These sandbanks are SW-NE oriented and are separated by swales, which dip to the northeast (Lanckneus, De Moor, and Stolk, 1994).

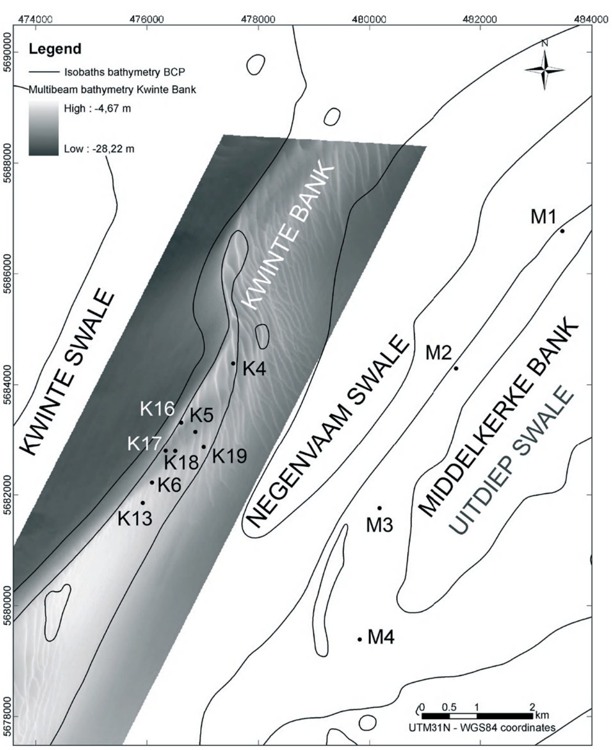


Figure 1. Map showing the location of the sampling stations on the Kwinte and the Middelkerke Banks: The Kwinte Bank crest stations are superimposed onto a multibeam image. The bathymetry and morphology (banks and swales) of the sandbanks are shown including the central depression on the sandbank.

The Kwinte Bank (Figure 1.) is an elongated linear subtidal sandbank, of about 15 km in length, 3 km in width and rising between 10 m (in the north) and 20 m (in the south), above the surrounding seafloor. The mean water depth varies between 6 m over the central part, to over 20 m in the northern and southern edges of the bank (Lanckneus *et al.*, 1992). The characteristics of the depression, together with its creation by sand extraction, are described in detail in Degrendele *et al.* (this volume); it is about 1 km long and 700 m wide, located along the western crest and beneath the "kink" in the central part of the sandbank (Figure 1.). The two swales adjacent to the Kwinte Bank are known, respectively, as the Kwinte (to the northwest) and the Negenvaam (to the southeast). The latter is located between the Kwinte Bank and the Middelkerke Bank.

The Middelkerke Bank (Figure 1.) has a length of 12 km, a mean width of 1,5 km and a height above the surrounding sea floor which varies between 8 m in the northeast, to 15 m in the southwest. The depth (MLLWS) varies between 4 m in the southwest, to 20 m in the northeast (Trentesaux *et al.*, 1994). The swale on the northwestern side is known as the Negenvaam (see above), whilst the southeastern side of the bank borders the Uitdiep.

METHODS

Sampling and Processing

Eight stations were sampled in February and November 2004, over the central part of the Kwinte Bank, together with 4 stations on the adjacent Middelkerke Bank in November 2004 (Figure 1.). The latter sandbank represents a reference area for medium-sized sands; this sandbank lies outside the concession areas, having never been exploited. On the Kwinte Bank, 3 stations were located within the central depression (K5, K18, K6), 2 stations along its western border (K16, K17) and 2 at its eastern border, at the crest of the sandbank (K13, K19). The grouping of these stations is based upon an analysis of the extraction intensity at the different stations, until cessation of extraction in February 2003. The vessel "black-box" records indicated that stations K5, K18 and K6 have been disturbed frequently. One station (K4) was sampled at the crest, in an unexploited part of the bank associated with coarse sediments lying just to the north of the depression on the Kwinte Bank. This station has been sampled to investigate if it can be considered as a reference for the coarse sediments, present over the western flank of the depression.

Macrobenthos samples were collected from each station using a Van Veen grab; for each, 5 replicate grabs were obtained. From each of the grabs, a sub-sample was taken with a 1.5 cm^2 perspex coring tube. These sub-samples were dried immediately at 60°C, for granulometric analysis. The macrobenthic samples were first fixed with formaldehyde, then sieved on-board over a 1 mm mesh-sized sieve. After staining with Rose Bengal, the samples were washed by decantation (repeated 10 times), in the laboratory and over a 300 μm sieve, to retain fragmented organisms. Anthozoa, Oligochaeta and Nemertea were counted as groups and representatives of the Polychaeta, Mollusca, Archiannelida, Crustacea and Echinodermata were identified under a stereoscopic microscope to species level where possible.

Sediment sub-samples were sieved in the laboratory, using a complete column of sieves (4000 to 63 mm). Grain-size parameters have been calculated according to the approach of

Folk and Ward (1957). Sediment classification was defined according to the Wentworth scale (Wentworth, 1922).

Water depth measurements were standardised to Mean Low Water Springs (MLWS), using the M2 reduction model[1].

Statistics

Differences in macrobenthos density (log(x+1) transformed) and species richness (untransformed), between both sampling periods and the different locations distinguished for the Kwinte Bank and the Middelkerke Bank, were analysed by means of a two-way ANOVA. Overall significant differences were pairwise-compared using the Tukey honest significant difference test, for unequal sample sizes. For the non-parametric data, such as the percentages and abundances of particular taxa, the Kruskall-Wallis ANOVA by Ranks was preferred; after this, overall significant differences were further pairwise-analysed, following Conover (1971). All of the univariate statistical analyses were performed with STATISTICA software (Microsoft, StatSoft, Inc., 2000).

An ordination was performed on fourth-root transformed absolute species abundances. A Detrended Correspondence Analysis (DCA, Hill, 1979) and a Canonical Correspondence Analysis (CCA, Hill 1979) were selected as indirect and direct gradient analyses, respectively, to illustrate the (dis)similarities in species composition, between different periods and locations; likewise, to relate them to sediment characteristics.

RESULTS

Sediment Characteristics

A gradient can be discerned over the Kwinte Bank, ranging from very coarse sediment to the north of the depression (station K4), through the slightly less coarse western border and the heterogeneous sediments of the depression, towards the finer sediments at the eastern border of the depression (Figure 2.).

The depression is characterised by relatively high percentages of fine sand, compared to the other locations. Within the depression at the Kwinte Bank and within the reference area of the Middelkerke Bank, some differences in sediment composition can be distinguished. In order to take into account sediment composition, when comparing densities of specific taxa and genera between the depression and the reference area at the Middelkerke Bank, K5 will be compared with M1 and M2; K6 with M4; and K18 with M3. However, these "station-to-station" comparisons correspond to a relatively low power of the analysis, to detect significant differences.

[1] (Flemish Hydrography, Division Coast, Agentschap voor Maritieme Dienstverlening en Kust (MDK), of the Flemish Public Administration).

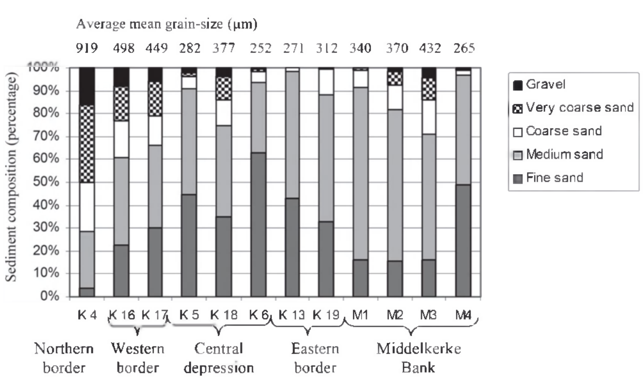


Figure 2. Average sediment composition at the sampling stations of the Kwinte Bank and the Middelkerke Bank. The average mean grain-size is listed for each station, at the top of the column. Note: for station locations, see Figure 1.

Biological Parameters

Density, species number and macrobenthos taxa composition have been compared, between: (a) the western border of the depression; (b) the depression; (c) the eastern border of the depression; (d) the unexploited part to the north of the central depression; (e) and the entire Middelkerke Bank, as an undisturbed reference area. Seasonal differences, between February and November 2004, have been assessed for the Kwinte Bank.

Density and species number

In November 2004, essentially higher densities were recorded than in February 2004 (Figure 3.). However, such seasonal differences were only significant for the eastern border of the depression ($p < 0,05$). Similarly, the species number increased, in general, from February to November 2004, but

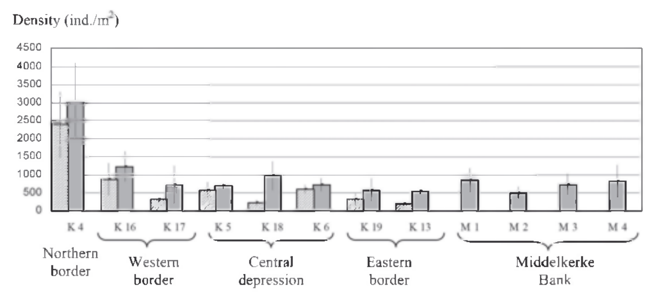


Figure 3. Macrobenthos density per station, at the different locations of the Kwinte Bank and at the Middelkerke Bank, for February 2004 (light grey bars) and November 2004 (darker shaded bars). Note: for station locations, see Figure 1.

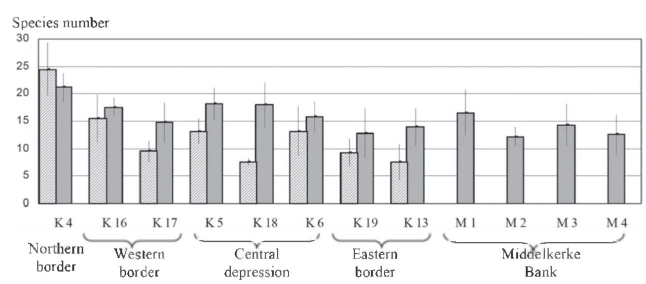


Figure 4. Macrobenthos species richness per station, at the different locations of the Kwinte Bank and at the Middelkerke Bank, for February 2004 (light grey bars) and November 2004 (darker shaded bars). Note: for station locations, see Figure 1.

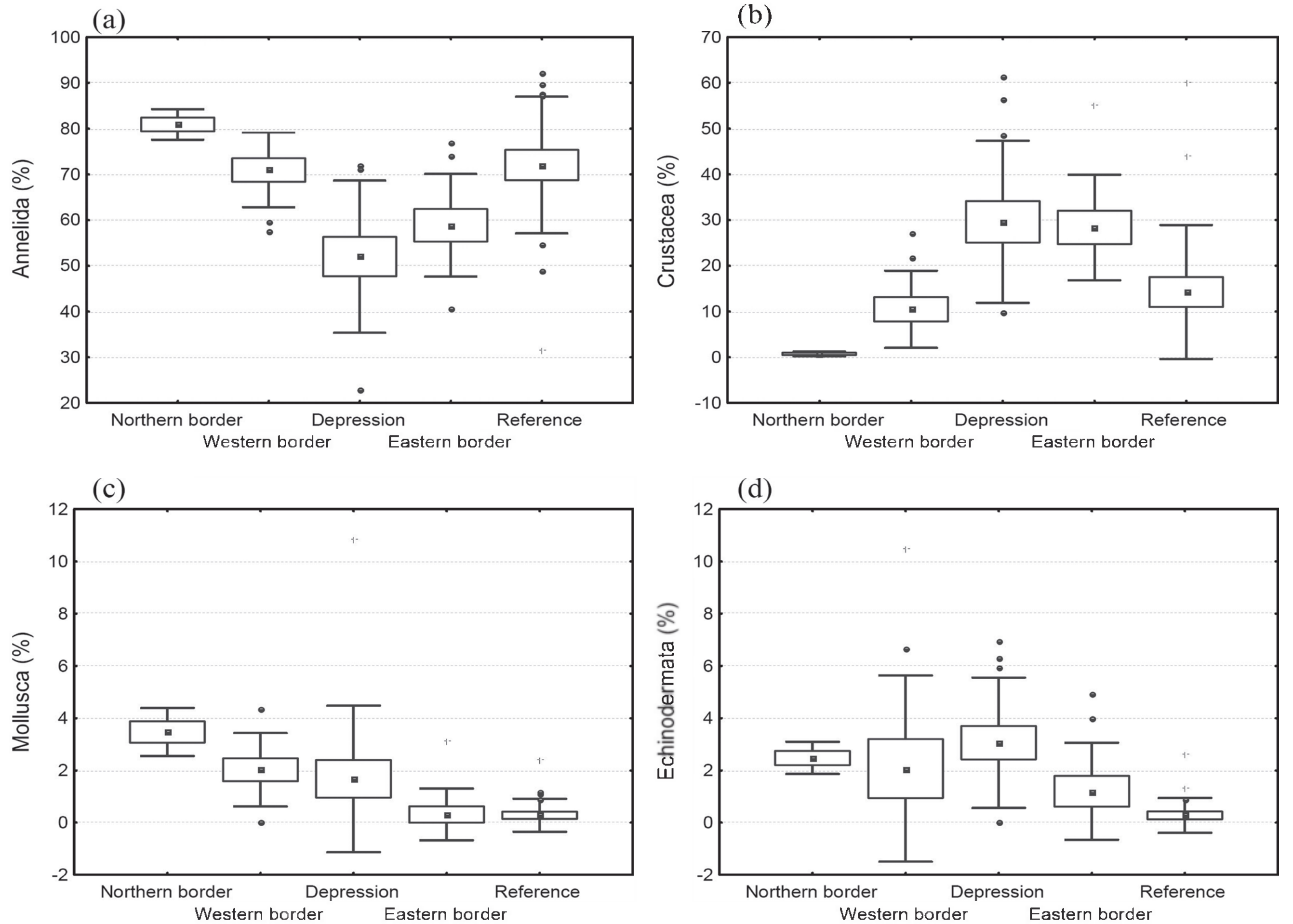


Figure 5. Relative abundance per location at the Kwinte Bank (Northern border, Western border, Depression, Eastern border) and the Middelkerke Bank (reference location) for different macrobenthos taxa: (a) Annelida; (b) Crustacea; (c) Mollusca; and (d) Echinodermata.

Table 1. *Significant differences in the relative abundance of particular macrobenthic taxa, between the different locations on the Kwinte Bank and the Middelkerke Bank. Key: * = p < 0,5; ** = p < 0.01; and *** = p < 0.001. Note: for the station locations and their description, see Figures 1. and 2.*

Taxon				Annelida		
	Location	Station 4	Western border	Depression	Eastern border	Reference area
Crustacea	Station 4		*	***	***	n.s.
	Western border	**		**	n.s.	n.s.
	Depression	***	***		n.s.	***
	Eastern border	***	***	n.s.		**
	Reference area	**	n.s.	***	***	

Taxon				Mollusca		
	Location	Station 4	Western border	Depression	Eastern border	Reference area
Echinodermata	Station 4		n.s.	**	***	***
	Western border	n.s.		n.s.	***	***
	Depression	n.s.	n.s.		*	*
	Eastern border	*	n.s.	*		n.s.
	Reference area	***	*	***	n.s.	

Table 2. *Significant differences in density of particular macrobenthic taxa between the different locations at the Kwinte Bank and the Middelkerke Bank (* = p < 0,5, ** = p < 0.01, *** = p < 0.001).*

	Taxon			Ophiura species		
	Location	Station 4	Western border	Depression	Eastern border	Reference area
Echinocardium cordatum	Station 4		n.s.	n.s.	n.s.	n.s.
	Western border	n.s.		*	n.s.	n.s.
	Depression	*	**		**	***
	Eastern border	n.s.	n.s.	n.s.		n.s.
	Reference area	n.s.	n.s.	*	n.s.	
	Taxon			**Amphipoda**		
	Location	Station 4	Western border	Depression	Eastern border	Reference area
Bathyporeia species	Station 4		*	***	***	*
	Western border	n.s.		**	n.s.	n.s.
	Depression	**	*		n.s.	***
	Eastern border	n.s.	n.s.	n.s.		*
	Reference area	n.s.	n.s.	*	n.s.	
	Taxon			**Tellimya ferruginosa**		
	Location	Station 4	Western border	Depression	Eastern border	Reference area
			n.s.	*	n.s.	n.s.
	Western border			**	n.s.	n.s.
	Depression				n.s.	**
	Eastern border					n.s.

significant only in the depression (p < 0,01). Only to the north of the depression (Station K4), the species number decreased slightly between the two sampling periods.

Density and species number were significantly higher at Station K4 (p < 0,005, p < 0,0005, respectively), in comparison with all the other Kwinte Bank locations, in February 2004. This difference still existed for density in November 2004, but was not observed anymore for the species number, since the species number in November decreased at station 4 and increased at the other stations in comparison with February (Figure 4.). Density and species richness are also significantly higher at station K4, in comparison with the entire Middelkerke Bank (p < 0,0005 and p < 0,05, respectively).

Density or species number data do not permit differentiation of the depression, from its western border or from its eastern border, for neither of the two periods. The depression is characterised by an intermediate density, between those of the western and the eastern borders. The species number was very similar over the entire central part of the Kwinte Bank, without any distinction between the depression and the western or the eastern borders. No differences could be detected, in terms of density or species number, between the central part of the Kwinte Bank and the entire Middelkerke Bank.

Taxon composition

In contrast to the findings concerning total macrobenthic density and species number (see above), clear differences in taxon composition could be detected between different locations on the Kwinte Bank.

The relative abundance of Annelida was clearly lowest in the depression and differed significantly from the coarser sediments of Station K4 (northern border), the western border, and the Middelkerke Bank (Figure 5a. and Table 1.). The lowest relative abundance of Annelida corresponded with the highest relative abundance of Crustacea, within the depression (Figure 5b.).

The contribution of molluscs decreases from the coarsest undisturbed part, over the western border of the depression and the depression, towards the eastern border and the Middelkerke Bank (Figure 5c.). The depression is associated with an intermediate amount of molluscs. Values for

Table 3. *Significant differences in density of particular macrobenthic taxa, between specific stations in the depression of the Kwinte Bank and stations with a similar sediment composition to that at the Middelkerke Bank. (* = p < 0,5, ** = p < 0.01, *** = p < 0.001).*

	K5 compared to M1 - M2	K6 compared to M4	K18 compared to M3 or K16 - K17 (1)
Annelida	*	n.s.	n.s.
Crustacea	*	*	* *
Mollusca	n.s.	*	n.s.
Echinodermata	* *	*	n.s.
Ophiura	* * *	*	n.s.
Echinocardium	n.s.	n.s.	* (1)
Amphipoda	* *	n.s.	*
Bathyporeia	*	n.s.	n.s.
Tellimya	n.s.	n.s.	n.s.

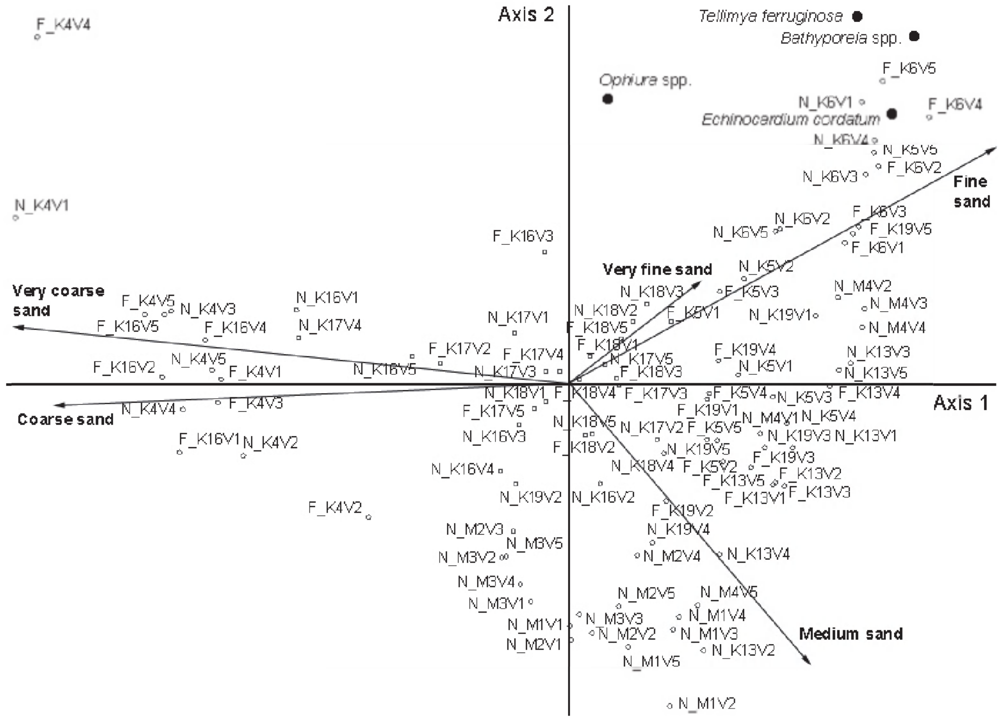


Figure 6. CCA-plot of all of the stations, with some species characterizing the depression. Important sediment characteristics are plotted on the graph. Key: F- February 2004; N- November 2004; K- Kwinte Bank; and M- Middelkere Bank).

the depression are significantly lower than at Station K4; they are significantly higher than the eastern border and on the Middelkerke Bank (Table 1.). A similar decreasing linear trend can be identified for the echinoderms (Figure 5d.). However, for this taxon the depression yields the highest relative abundance;it is slightly greater than at Station K4, and significantly more than over the eastern part and the Middelkerke Bank (Table 1.).

Trends in the distribution of these taxa, over different locations at the Kwinte Bank, could be detected for both periods.

In summary, the depression yields relatively less annelids and more crustaceans and echinoderms, than any of the sites; likewise an intermediate number of molluscs between the coarser sediments, to the west and north, and the sediments of the eastern border and the Middelkerke Bank. The depression shows a somewhat higher similarity to the western border, for the relative abundance of molluscs and echinoderms, and seems more similar to the eastern border in relation to the realtive abundance of annelids and crustaceans.

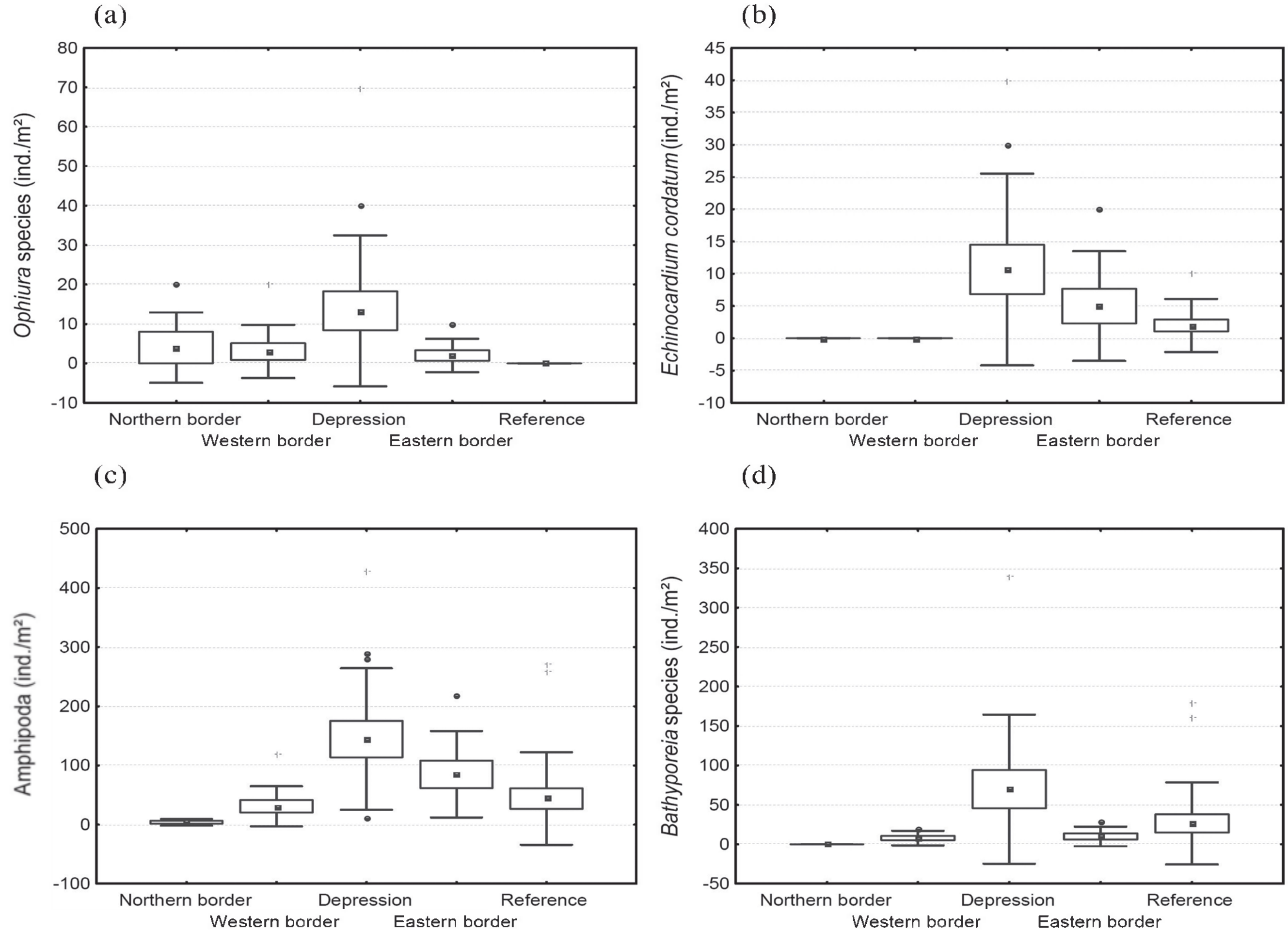
The particular characteristics of the depression were confirmed also by the DCA- and CCA analyses (Figure 6.). Station K4 is separated clearly from the other locations and is related closest to the western border; this, in turn, is characterised by an impoverished coarse sand community. The Middelkerke Bank shows approximately the highest similarity to the western border of the Kwinte Bank, along the first axis, whereas the eastern part and (clearly) the depression are separated along the second axis. On the CCA-plot, some species that can be associated with the differences in species composition of the stations, within the central depression, have been plotted.

Figure 7. illustrates that the depression yields higher mean densities of *Ophiura* species (13 ind./m^2), *Echinocardium cordatum* (11 ind./m^2), *Tellimya ferruginosa* (9 ind./m^2), Amphipoda (145 ind./m^2) and, in particular, *Bathyporeia* species (70 ind./m^2) (see Table 2. for significant differences), than the other locations. These species are important in distinguishing the different areas within the DCA- and CCA analyses. Significant differences for all of these taxa were obtained for both February and November 2004. Comparing each station of the depression, with stations having similar sediment characteristics as at the Middelkerke Bank, thus reducing the power of the analysis, many of the differences remain significant (Table 3.).

DISCUSSION

Density and Species Number

Impacts of dredging activities on macrobenthos are well documented elsewhere and describe changes in density, diversity and community structure (see Boyd *et al.*, 2003; Newell, Seiderer, and Hitchcock, 1998, for references). As a result of sand extraction, a decrease in macrobenthic density and species richness can be expected (Desprez, 2000; Newell, Seiderer, and Hitchcock, 1998). Dredges impact directly upon the species that live on or near the seafloor, as the dredge pipes physically disturb the habitat, when they are dragged across the seafloor.



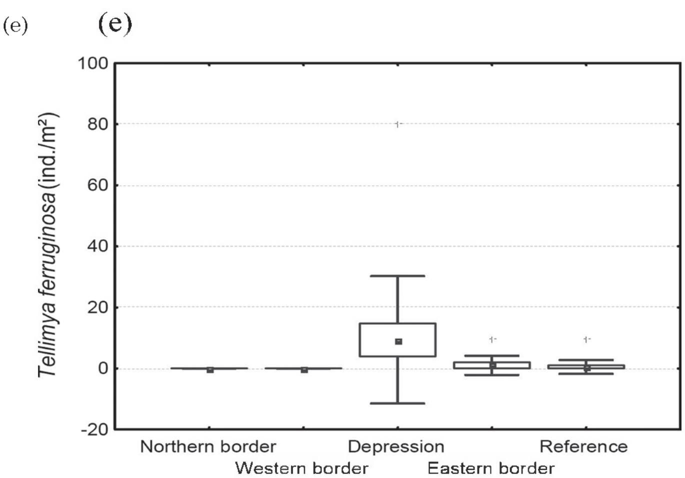


Figure 7. Density per location for the Kwinte Bank (Northern border, Western border, Depression, Eastern border) and the Middelkerke Bank (reference location) for different macrobenthos taxa: (a) Ophiura species; (b) Echinocardium cordatum; (c) Amphipoda; (d) Bathyporeia spp.; and (e) Tellimya ferruginosa.

As study, the direct impacts, through the removal of the fauna, are undeniable. VANOSMAEL *et al.* (1979) studied the removal of macrobenthic organisms by sand extraction *in- situ* in Belgian territorial waters, by following the dumping of dead and live organisms by the sand extraction vessel. 45 % of the animals retained on the sieve aboard the vessel, then dumped into the sea, were fatally damaged; these accounted for 70 % of the biomass. Molluscs contributed mainly to this percentage of fatally damaged fauna. Sampling the extraction site before and after dredging revealed a reduction in the macrobenthic abundance, by 80 % (VANOSMAEL *et al.*, 1979). In the present study, no differences in density and species richness could be detected, between an intensively exploited area and the reference sites on the Middelkerke Bank. The higher density at Station K4 is related mainly to the naturally higher abundance of interstitial polychaetes, within these coarse sediments (VANOSMAEL *et al.*, 1982). Data presented in this study date are characteristic of the depression, after or during ecological recovery, since dredging over this area has been prohibited since February 2003. Hence, post-extraction characteristics are described for an area, topographically and geomorphologically altered by sand extraction; this, in turn, may imply lasting ecological differences with the natural surroundings. Communities inhabiting sandy sediments are maintained in a transitional state by natural environmental disturbance and are likely to recover within a period of 2-3 years, after the cessation of dredging (NEWELL, SEIDERER, and HITCHCOCK, 1998). The rate of recovery is highly variable, depending upon the type of community, the latitude and the extent to which the community adapts naturally to high levels of sediment disturbance and suspended particulate load (NEWELL, SEIDERER, and HITCHCOCK, 1998). According to REES (1987), colonisation by a range of infaunal species will occur in soft sediments within weeks or months, depending upon season, largely through larval recruitment. Also, diversity will increase by the immigration of invading species. According to NEWELL, SEIDERER, and HITCHCOCK, (1998), density is the first community parameter which reaches the pre-disturbance level, one year after the cessation of the disturbance activity. Subsequently, the species richness stabilizes following potential increase during the period over which the community evolves into its final state. Since sampling for the present study has taken place one year after the cessation of dredging, the direct effects of the disturbance are not being detected anymore; as such, the community represents a transitional state. VANAVERBEKE *et al.*, (2007) have ilustrated recently that macrobenthic density and diversity in the Kwinte Bank central depression was low, immediately following the cessation of dredging (March 2003), increasing distinctly one year later.

Species Composition

The depression is distinguished clearly from its surroundings, on the basis of geomorphological and sedimentological characteristics (BELLEC *et al.*; DEGRENDELE *et al.*, this volume). However, the differences in ecological parameters were not as straightforward.

VANOSMAEL *et al.* (1982) described two major communities on the Kwinte Bank, at the end of the 1970s: a rich community over the northern part of the sandbank, including Station K4, together with poorer central and southern communities. These communities correspond to the *Nephtys cirrosa* community and the *Ophelia limacina - Glycera lapidum* community, respectively; or, more particularly, to a transitional species association between these two communities (VAN HOEY, DEGRAER, and VINCX (2004)). In VAN HOEY, DEGRAER, and VINCX (2004) sieving live specimens understimated the mean density of the *Ophelia limacina - Glycera lapidum* community, due to the high loss of interstitial polychaetes. The macrobenthic taxon compositions, detected between the different sites of the present study, all fall within the range of the species compositions described for the typical sandbank communities (VAN HOEY, DEGRAER, and VINCX , 2004). Stations K5 and K6 were sampled previously by VANOSMAEL *et al.* (1982). At that time, Station K6 was classified within the southern Kwinte Bank community, but Station K5 showed a higher similarity to the community found at Station K4, than in the present study. Such a difference may be a consequence of the disappearance of very large dunes at that station, which were present in the 1970´s but have largely disappeared from the present depression (DEGRENDELE *et al.*, this volume). The higher similarity of Station K5 to Station K4, in the 1970´s corresponded also with a higher similarity in sediment characteristics, between both of the stations (VANOSMAEL *et al.*, 1982).

Within the present study, significant differences have been detected in the relative abundance of annelids, crustaceans, echinoderms and molluscs and, in particular, *Ophiura* species, *Echinocardium cordatum*, amphipods (*Bathyporeia* species) and the bivalve *Tellimya ferruginosa*, between the different locations. The latter species has a commensal relationship with *E. cordatum* (DAAN, MULDER, and VANLEEUWEN, 1994). *Urothoe poseidonis*, an amphipod living in the burrow of the echinoid *E. cordatum* (GILLAN, RIBESSE, and DE RIDDER, 2004), was observed frequently also in the depression in the present study. *E. cordatum* has been described as a typical species belonging to an equilibrium community and, as such, of the final stage after recovery took place (NEWELL, SEIDERER and HITCHCOCK, 1998). An interesting observation is that the present state of the community in the depression yields more *E. cordatum* individuals, than were found on the eastern border or on the Middelkerke Bank, or during any of the sampling undertaken in the 1970´s or 1990´s (BONNE, 2003; VANOSMAEL *et al.*, 1982). *E. cordatum* has been described as one of the dominant species of the macrobenthic community found within the Belgian Coastal Banks (DEGRAER *et al.*, 1999), where material in suspension is generally higher than over the Flemish Banks (GOVAERE *et al.*, 1980). Since *E. cordatum* is a selective deposit feeder, it may be concluded that the high abundance of *E. cordatum* in the depression (with a mean of 11 ind./m^2), indicates that more organic material may be deposited in the depression than is normally the case on the surrounding sandbank crest. BELLEC *et al.* (this volume), have pointed out that fluid muddy layer is deposited, during the ebb phase of the tide, in the depression. Colonisation depends upon the availability of suitable food, but may occur opportunistically, through migration of adults into the area, or via larval recruitment (REES, 1987). Active migration of adult *E. cordatum* individuals, to their most favorable habitat, has been observed (OZOLIN'SH and NEKRASOVA, 2003). Sedimentation of organic material is considered to permit the development of a dense population of *E. cordatum*. This species reworks the organic matter, into the sediment, which may have caused the bioturbation observed in the cores of the depression (BELLEC *et al.*, this volume). The higher echinoderm density confirms that the depression has similar sedimentological characteristics to these in the swale where, generally, much more organic material is available and denser macrobenthos communities and a higher bioturbation are found (BONNE, 2003; TRENTESAUX *et al.*, 1994; VAN HOEY, DEGRAER, and VINCX, 2004). *Gastrosaccus spinifer* occurred abundantly in the samples within the depression, indicating another similarity with the swale environment. At the Flemish Banks, mysids are significantly more abundant in the swales, than on the sandbank crests (DEWICKE, 2001). At its southern end, the depression connects to the Kwinte Swale and is subject to strong flood tidal currents (BELLEC *et al.*, this volume; DEGRENDELE *et al.*, this volume). Such currents cause erosion over the western part of the Kwinte Bank and induce hydrodynamic characteristics which are similar to the swale environment in the depression (GAREL, this volume).

VANAVERBEKE *et al.*, (2007) did not identify any differences in taxon composition over the central part of the Kwinte Bank related to the lack of any taxon composition analyses, at a small spatial scale. These investigators analysed total proportion of major taxonomic groups incorporating the data from all of the stations, without distinguishing the western and eastern border, from the depression. Moreover, they sampled only the central and the northern part of the depression omitting the southern part of the depression, where the highest densities of *E. cordatum* have been recorded in the present study.

The annelid, crustacean and echinoderm contributions, between the various locations, does not reflect a significant difference with the different communities, as they have been defined for the Kwinte Bank and other Belgian subtidal sandbanks. On the Kwintebank, a transitional species association between the *Nepthys cirrosa* and the *Ophelia limacina - Glycera lapidum* community can be defined in general terms, characterised by mobile polychaetes (e.g. *Nephtys cirrosa*) and crustaceans (e.g. *Bathyporeia* spp.). Species contribution differences, between several combinations of transitional species assemblages, exist but are not distinguished as a separate community on the larger spatial scale. The high mobility of the species, the poverty and the wide niche-width of the community, together with the extent to which the community is adapted to high levels of sediment disturbance in these dynamic systems, makes it difficult to detect the effect of anthoprogenically-induced physical disturbance. Moreover, communities of high-stress areas are characterised by higher growth rates (JENNES and DUINEVELD, 1985) and, hence, more capable of readjustement to the impact of dredging operations (DESPREZ, 2000). Sand extraction has created a different habitat on the Kwinte Bank, to which the benthic fauna has adjusted, within the wide niche width of the community. Such adjustments do not mean that no change has been detected, it is just not significant on the larger spatial scale; it indicates that, locally, a sandbank environment has been created with greater similarity to the swale system (than would naturally be the case). The evolution of the community depends upon that of the sediments and geomorphology and hydrodynamics, within the depression. Nonetheless, it is unlikely that the original western flank will be restored, since the area is subject to erosion (BRIÈRE *et al.* this volume; GAREL, VAN DEN EYNDE *et al.,* this volume). In the longer term, it is anticipated that the sandbank will shift slightly to the east, to establish a new equilibrium (BRIÈRE *et al.*, this volume). In the latter case, the macrobenthic fauna in the depression will develop further towards a typical "swale community". Monitoring the northern depression on the Kwinte Bank, created also by sand extraction, will establish if the evolution in the north, where there is no connection between the depression and an ajoining swale, will differ from the observed trend in the central depression.

CONCLUSIONS

- Macrobenthos density and species richness was similar over the entire central part of the Kwinte Bank and the Middelkerke Bank.
- Seasonal variation was less important, than spatial differences.
- A depression created by sand extraction was characterised by a lower relative abundance of annelids (%), together with a higher relative abundance of crustaceans (%) and echinoderms (%) than its surroundings and an unexploited sandbank as reference location. Higher densities of *Ophiura* species (13 ind./m^2), *Echinocardium cordatum* (11 ind./m^2), *Tellimya ferruginosa* (9 ind./m^2), Amphipoda (145 ind./m^2) and, in particular, *Bathyporeia* species (70 ind./m^2) were responsible for these higher taxon contributions.
- The central depression (which is probably not going to infill under prevailing hydrodynamic conditions) shows similarities to the swale environment, based also upon the macrobenthic fauna.
- The species composition observed in the depression compares to the wide range of species assemblages described earlier for the Kwinte Bank together with other Belgian subtidal sandbanks.
- Sand extraction has created a local-different habitat on the Kwinte Bank, to which the benthic fauna has adjusted. Such small-scale change is not significant, within the context of the larger scale of the sandbank system.

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