Impact assessment of sand extraction on subtidal sandbanks using macrobenthos

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1 Introduction

Remane (1933) assumed that meiofauna includes more stenotopic species than macrofauna and that meiofauna communities are more suitable to characterize subtidal sandy habitats. Por (1964b), Coull & Herman (1970), Fenchel (1978), McLachlan *et al.* (1981) and Hicks & Coull (1983) demonstrated that sandy sediments harbour the most diverse and heterogeneous meiofauna communities. Small environmental changes in these habitats will be rapidly reflected in the meiofauna community structure, because a lot of species have a rapid turn over rate. Schratzberger *et al.*, 2000) clarified that the inclusion of meiofauna in applied monitoring programmes offers the potential for improving the resolution of the spatial extent of anthropogenic impacts over that achievable from macrofauna investigations alone. Nevertheless, impact studies of anthropogenic alterations of the environment have mainly focused on macrobenthos, because they are readily counted and identified. Impacts of dredging activities on the macrobenthos are well documented and describe changes in density, diversity and community structure (see Newell *et al.*, 1998; Boyd *et al.*, 2003 for references). When areas are depopulated through sand extraction operations, recolonization of the disturbed area will depend largely on settlement of larvae and immigration of mobile species (van Dalfsen *et al.*, 2000). This gives opportunistic species a good chance of building up large populations in such open spaces (Grassle & Sanders, 1973). During the initial recovery after dredging benthic communities closely corresponded in structure with those found in advanced stages of organic pollution (Pagliai *et al.*, 1985; Pearson & Rosenberg, 1978). An increase in opportunistic species after sand extraction was observed in the Mediterranean (van Dalfsen *et al.*, 2000). Pagliai *et al.* (1985) found that the distribution of the individuals among species also departs from the log-normal model in the same way as found in many cases of organic pollution (Gray & Mirza, 1979; Bonsdorff & Koivisto, 1982). This convergence in community structure, following such different environmental disturbances is probably determined by a general rule occurring any time after many of the niches became suddenly unoccupied (Pagliai *et al.*, 1985).

Biotic indices have been proposed to provide useful tools to measure ecological quality in the marine environment, mainly as a response to organic enrichment (Hily, 1984; Majeed, 1987; Grall & Glémarec, 1997; Weisberg *et al.*, 1997). Hence, Borja *et al.* (2000) proposed that different anthropogenically changes in the environment, including alterations to the natural system such as dredging, engineering works, sewerage plans and the dumping of polluted waters, can be detected through the use of the Biotic Coefficient. The Biotic Coefficient as defined by Borja *et al.* (2000)

was applied to the macrobenthic data of an intensively exploited sandbank in order to assess the applicability of this kind of biotic indicators to reveal changes in the macrobenthic community as a result of sand extraction. A comparison of macrobenthic density and diversity measurements as well as community analyses were performed on a spatial and temporal scale and compared with the results of an impact study on harpacticoid copepods on the same sandbank.

2 Material & methods

2.1 Sampling stations

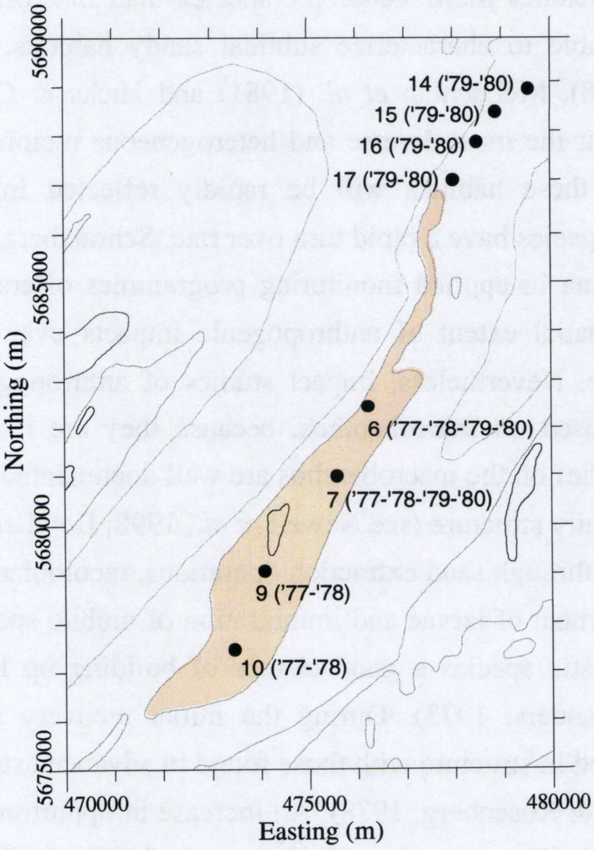

Fig.IV.1: Stations on the Kwintebank sampled for the macrobenthos in the late seventies (1977, 1978, 1979 and 1980)

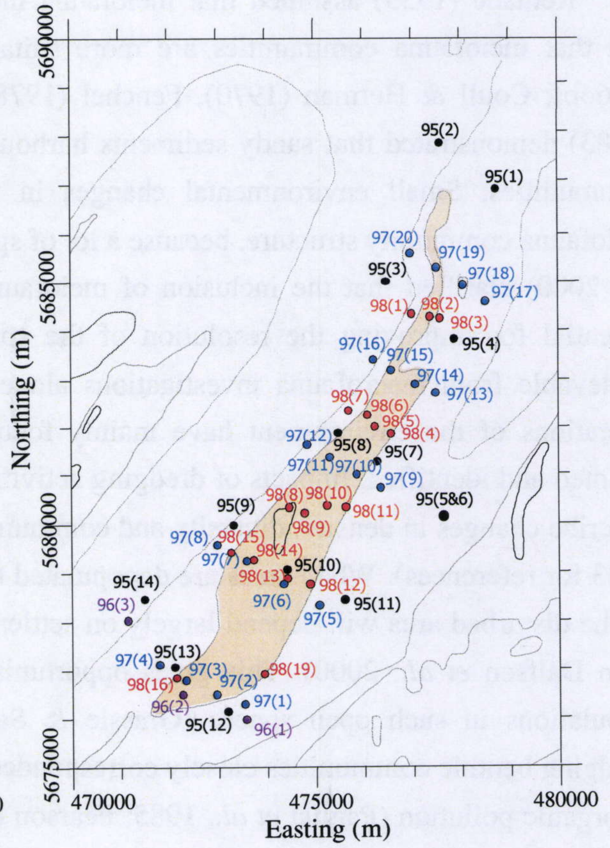

Fig.IV.2: Stations on the Kwintebank sampled for the macrobenthos in the mid nineties (1995, 1996, 1997 and 1998)

Within the framework of different studies (Rappé, 1978; Vanosmael *et al.*, 1979; Waeterschoot, 1984; Vanosmael *et al.*, 1982; Willems *et al.*, 1982a; Coenjaerts, 1997; Cattrijsse & Vincx, 2001; Philips, 1998; Taverniers, 2000), the Kwintebank has been repeatedly sampled for macrobenthos between 1977 and 2001. A total of 144 samples were collected on the sandbank top, slope and in the gullies next to the bank. The time span of macrobenthos sampling on the Kwintebank covers three major periods: late seventies, mid nineties and 2001. No samples were taken in between these periods.

The sampling strategy differs a lot between the late seventies and the nineties, since the data were gathered within the frame of different research projects. In the late seventies (1977, 1978, 1979, 1980) three replicates were taken at different stations on the sandbank top (Fig.IV.1). In 1979 and 1980 the stations were sampled twice a year (in spring and autumn). In the mid nineties single samples were taken along different transverse transects covering the whole sandbank and including some gully stations (Fig.IV.2). In December 2001 five replicates were taken at stations 1, 6 and 9, corresponding with the stations sampled for meiofauna. Stations 6 and 9 were taken at the same location as in the seventies, whereas station 1 is situated near to station 16 sampled in the seventies.

2.2 Sampling and processing

Samples were taken with a Van Veen grab (sampling surface area: 0.1 m² or 0.12 m² and weight: ± 50 kg). A subsample taken with a small tube was used for sediment analysis. In the seventies sieving over a 0.87 mm mesh-sized sieve was done after fixation in a 7 % formaldehyde seawater solution. Very coarse samples were rinsed in a gutter. The lighter organisms were washed towards the end of the gutter and caught on a sieve of 250 µm mesh size, while the heaviest organisms like *Spisula* were picked out of the sediment directly. In the nineties the samples were sieved alive over a 1 mm mesh-sized sieve. After staining with Rose Bengal, macrobenthic organisms were picked out. Anthozoa, Oligochaeta and Nemertea were counted as groups and representatives of the Polychaeta, Mollusca, Archiannelida, Crustacea and Echinodermata were identified to species level under a stereoscopic microscope.

Water depth at each sampling station was recorded *in situ* and standardized to the mean low water spring level (MLWS) using the M2 reduction model (AWK). Sediment subsamples were dried in the oven and sieved in the lab over a set of sieves of different mesh size in the seventies. In the nineties and in 2001 they were analysed with a LS Coulter particle size analyser (measuring range: 0.4 – 850 µm). The median grain size and mud content (volume percentage < 64 µm) were used as granulometric parameters. Sediment classification was defined according to the Wenthworth scale (Buchanan, 1984).

2.3 Statistics

The extensive dataset of the nineties was used separately for macrobenthic community analysis in order to reveal spatially structured variation. The community structure was investigated by means of classification and ordination techniques. Two-Way Indicator Species Analysis (TWINSPAN, cutlevels 0, 1.682, 2.115, 2.660, 3.122, 8.409) (Hill, 1979a; Gauch & Whittaker, 1981) and CA (Hill, 1974) were conducted on fourth root transformed data. A separate TWINSPAN (cutlevels 0, 1.682, 2.000, 2.237, 2.660, 8.409) was performed on the data of one community. The program TWINDEND (Gauch & Whittaker, 1981) was used to define the TWINSPAN groups worth retaining.

Temporal changes were studied by selecting and comparing specific stations from the different datasets. From the dataset of the seventies station 16, station 6 and station 9 were selected and compared with the results of 2001 at stations 1, 6 and 9 respectively. Station 6 could also be compared with station 6 sampled in 1998 and station 9 was compared with stations 6 and 7 sampled in 1997 and stations 13 and 14 sampled in 1998. Two of the three replicates at station 6 in October 1977 were not taken into account as the very high values were obtained from the gully next to the bank (22 m depth) since the ship drifted off a lot while sampling (Rappé, 1978). Grain size and density values at station 1 in September 1978 were taken from Vanosmael *et al.* (1982). Species richness of Vanosmael *et al.* (1982) was not included, since the total number of species per station was listed instead of the mean number of species per station. In this way station 1 in the intensively exploited northern part, station 6 in the intensively exploited central part and station 9 in the relatively undisturbed southern part of the Kwintebank could be compared over time. Mean densities, species richness and grain size were analysed by means of ANOVA or Kruskall-Wallis ANOVA by Ranks, using STATISTICA^{TM} software (Microsoft, StatSoft, Inc., 2000). Overall significant differences were compared pairwise using the planned comparison option in ANOVA for parametric data or following Conover (1971) for non-parametric data.

The continuous Biotic Coefficient was calculated for stations 1, 6 and 9 for each sampling event, according to the formula Biotic Coefficient (BC) = {(0 x % GI) + (1.5 x % GII) + (3 x % GIII) + (4.5 x % GIV) + (6 x % GV)}/100, based upon the percentages of abundance of each ecological group (Borja *et al.*, 2000). The classification of the ecological groups is based upon Hily's model (Hily, 1984; Hily *et al.*, 1986; Majeed, 1987): GI stands for ecological Group I: species very sensitive to pollution, GII = Group II: species indifferent to pollution, GIII = Group III: tolerant species, GIV = Group IV: second-order opportunistic species and GV = Group V: first-order opportunistic species. The species encountered on the Kwintebank were assigned to the different ecological groups according to the species lists given in Borja *et al.* (2000). For stations 1, 6 and 9 the BC was calculated based on all species present, whereas for the different communities on the Kwintebank, the BC was calculated for the 12 most abundant species only, comprising at least 80 % of the total community density. Temporal changes were also tracked by TWINSPAN (cutlevels 0, 1.627, 1.733, 2.237, 2.784, 8.409) and CA for the total dataset of seventies, nineties and 2001 (fourth root transformed data). The ordination analyses were performed with CANOCO for Windows (ter Braak & Smilauer, 1998).

3 Results

3.1 Comparison between harpacticoids and macrobenthos

3.1.1 Macrobenthic communities on the Kwintebank

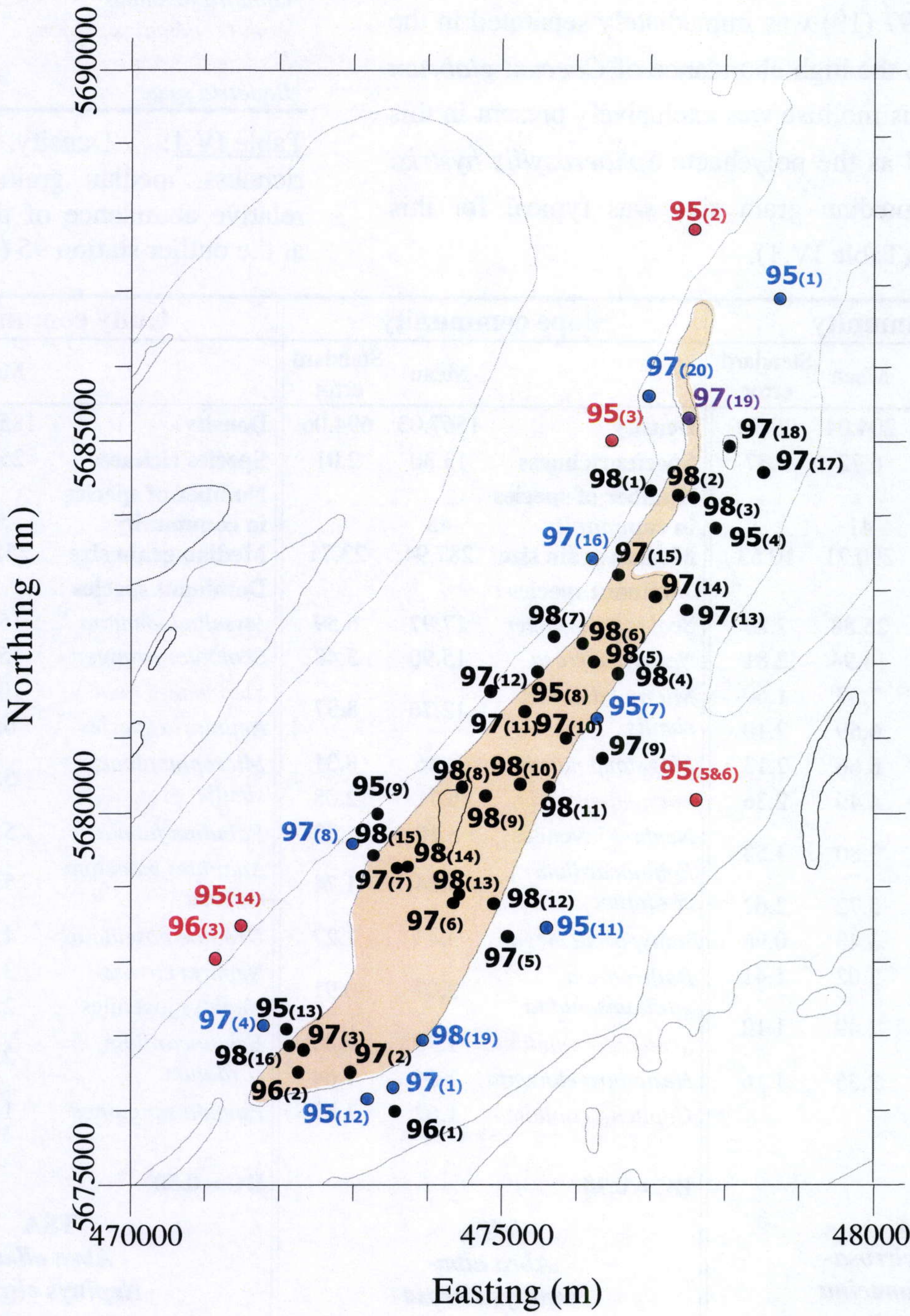

Fig.IV.3: Communities on the Kwintebank, based on the macrobenthos dataset of the mid nineties

TWINSPAN and CA of the dataset of the mid nineties revealed three different communities on the Kwintebank (Fig IV.3). A bank community covering the whole sandbank from north to south (36 stations), a slope community including 10 stations on the slopes and a gully community consisting of 5 gully stations. The outlier station 97 (19) was immediately separated in the analyses due to the high abundance of *Caecum glabrum* (Mollusca). This mollusc was exclusively present in this station, as well as the polychaete *Sphaerosyllis hystrix*. A very high median grain size was typical for this station as well (Table IV.1).

	97(19)
Density	282
Species richness	8
Median grain size	607,1
Dominant species:	
Caecum glabrum	44,33
Sphaerosyllis hystrix	17,73
Glycera convoluta	17,73
Hesionura elongata	8,87
Ophiura juveniles	2,84
Aonides paucibranchiata	2,84
Scolelepis bonnieri	2,84
Bodotria spec.	2,84

Table IV.1: Density, species richness, median grain size and relative abundance of the species at the outlier station 95 (19)

Bank community	Mean	Standard error
Density	204.04	29.90
Species richness	6.72	0.37
Number of species in community	41	
Median grain size	290.71	10.63
Dominant species :		
Nephtys cirrosa	26.88	2.85
Bathyporeia elegans	14.94	2.81
Urothoe brevicornis	7.37	1.60
Magelona mirabilis	6.69	2.10
Scoloplos armiger	6.66	2.13
Urothoe poseidonis	4.49	2.36
Bathyporeia guilliamsoniana	3.80	1.53
Hesionura elongata	3.72	2.62
Scolelepis bonnieri	3.43	0.96
Spio goniocephala	3.02	1.41
Echinocardium cordatum	2.49	1.12
Ophelia limacina	2.35	1.16
BC = 0.65		
TSA *Nephtys cirrosa-Ophelia limacina* community		

Slope community	Mean	Standard error
Density	1567.03	694.06
Species richness	13.30	2.01
Number of species in community	45	
Median grain size	287.94	23.71
Dominant species :		
Scoloplos armiger	17.97	6.59
Nephtys cirrosa	15.90	5.48
Microphthalmus similis	12.76	8.57
Magelona mirabilis	9.86	8.31
Spiophanes bombyx	6.71	2.08
Nephtys juveniles	5.18	1.72
Echinocardium cordatum	3.44	1.74
Bathyporeia elegans	3.43	1.27
Bathyporeia guilliamsoniana	2.07	0.91
Scolelepis bonnieri	1.93	0.80
Hesionura elongata	1.64	1.64
Capitella capitata	1.62	1.57
BC = 0.70		
TSA *Abra alba-Nephtys cirrosa-* community		

Gully community	Mean	Standard error
Density	1850.33	388.95
Species richness	25.17	2.83
Number of species in community	58	
Median grain size	252.58	11.99
Dominant species :		
Mysella bidentata	15.96	4.94
Scoloplos armiger	15.45	7.37
Spiophanes bombyx	10.37	3.85
Actiniaria species	6.41	4.21
Microphthalmus similis	5.83	2.80
Fabulina fabula	5.09	1.70
Anaitides maculata-mucosa	5.05	3.25
Urothoe poseidonis	4.96	4.48
Nephtys cirrosa	3.47	1.81
Nephtys juveniles	2.17	0.75
Echinocardium cordatum	2.06	1.00
Eumida sanguinea	1.83	1.58
BC = 0.50		
TSA *Abra alba-Nephtys cirrosa* community		

Table IV.2: Community characteristics of the bank, slope and gully community on the Kwintebank Ecological groups: species very sensitive to pollution (Group I), species indifferent to pollution (Group II), tolerant species (Group III), second-order opportunistic species (Group IV), first-order opportunistic species (Group V) and species which the ecological group was not available from in black; TSA = Transitional Species Association

In the overall TWINSPAN of the nineties the variance within the bank community was negligible in comparison with the high variance between and among the slope and gully community stations. The similarity among the bank stations was also illustrated by a separate TWINSPAN of the bank community. The TWINSPAN data table with the species arranged in order of their final scores did not reveal a clear gradient in species absence/presence or abundance along the sites. The stations are mainly grouped according to the different years and reflect slight temporal variability but no clear spatial structure on the bank (Fig.IV.4).

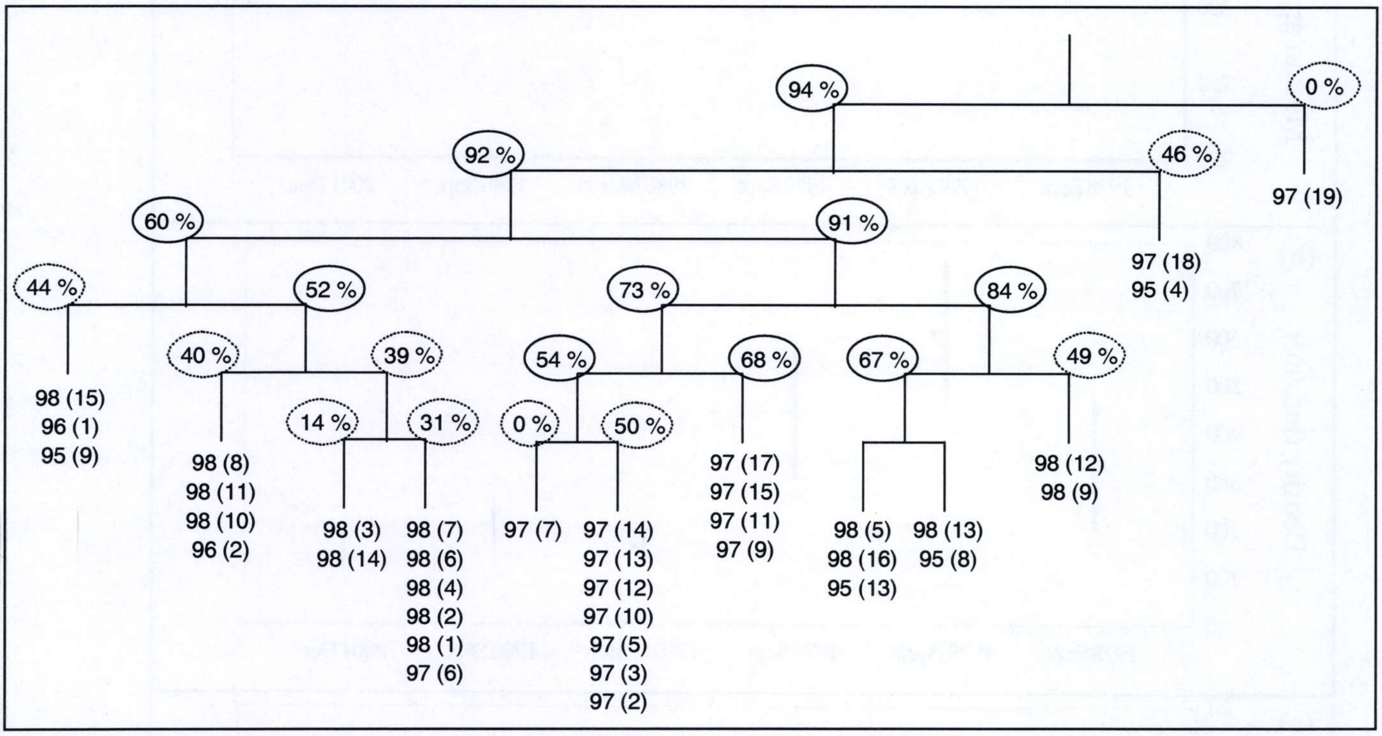

Fig. IV.4: TWINSPAN diagram of the macrobenthic samples belonging to the bank community on the Kwintebank. The percentages listed are the mean within-group variances or dispersions (Dp) expressed as a percentage of the total Dp of the data (Dt). Only the percentages exceeding 50 % indicate that the concerned division can still be subdivided. The percentages within dotted circles indicate that further divisions are not worth retaining.

3.1.2 Temporal changes in macrobenthos

3.1.2.1 Station 1

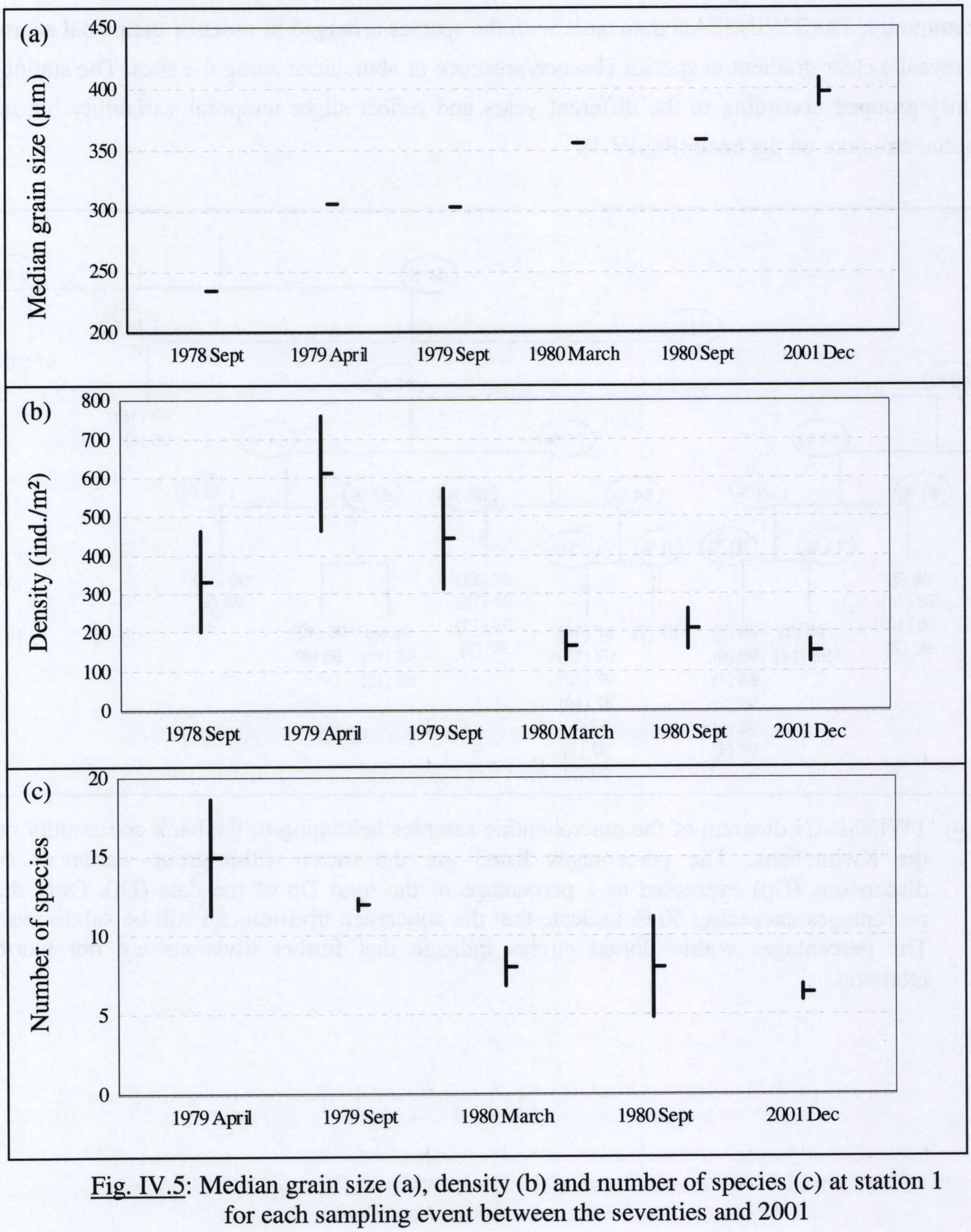

Fig. IV.5: Median grain size (a), density (b) and number of species (c) at station 1 for each sampling event between the seventies and 2001

Median grain size at station 1 significantly ($p < 0.05$) increased between the late seventies and 2001 (Fig.IV.5.a). The increasing trend was already observed in the short time span between 1978 and 1980. The sediment evolved from fine sand in 1978 toward medium sand in 1979-1980. The situation in the eighties and nineties is however unknown.

Density was significantly lower in 2001 in relation to both values of 1979 ($p < 0.05$) (Fig.IV.5.b). Already in March 1980 a significant lower density was recorded in comparison with 1979 ($p < 0.05$). The values in March 1980 were comparable with the densities recorded in 2001.

The number of species dropped between 1979 and 1980 but significant differences could not be detected between the sampling events (Fig.IV.5.c).

3.1.2.2 Station 6

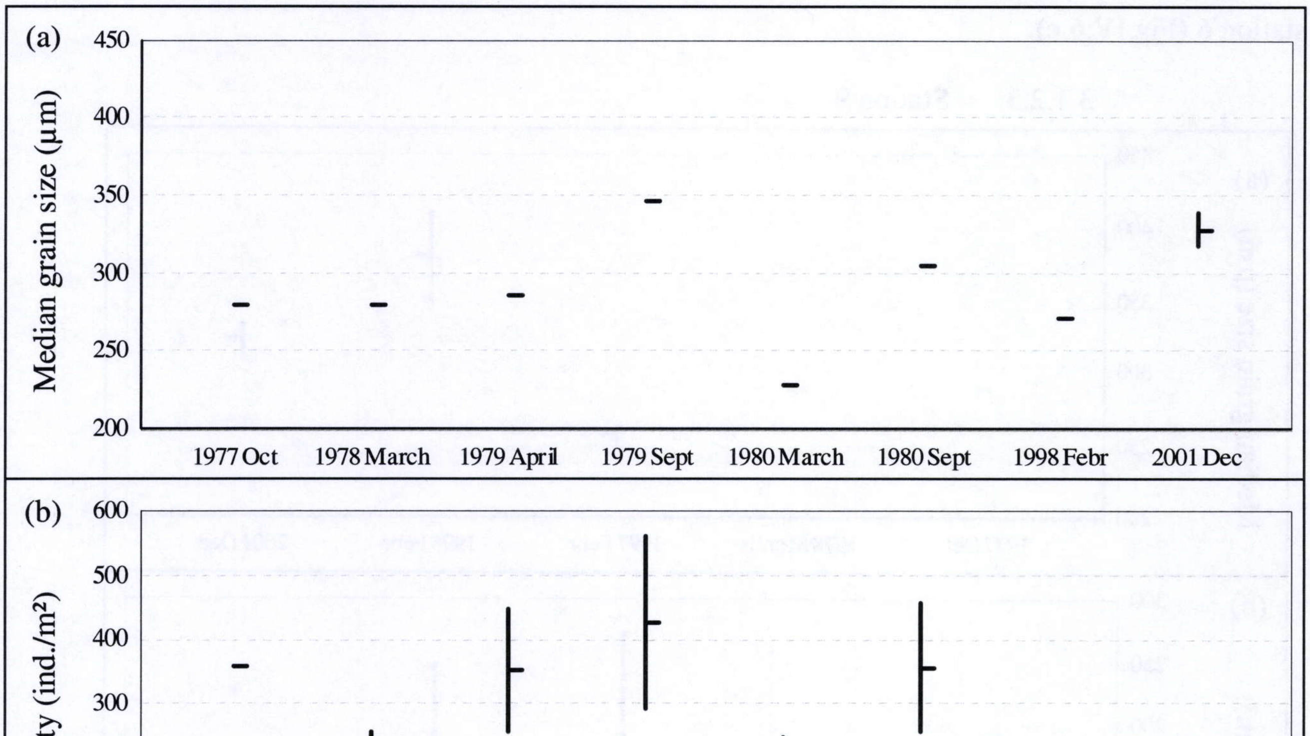

Fig. IV.6: Median grain size (a), density (b) and number of species (c) at station 6 for each sampling event between the seventies and 2001

Median grain size fluctuated around 300 µm through the whole period (Fig.IV.6.a). Slightly higher values were measured in September 1979 and in December 2001, whereas fine sands were sampled in March 1980. The densities of March 1978, March 1980, February 1998 and December 2001 were significantly lower than the densities in September 1979 ($p < 0.01$, $p < 0.05$, $p < 0.05$ and $p < 0.001$ respectively) (Fig.IV.6.b). The values in March 1978 and December 2001 were also lower in relation to September 1980 ($p < 0.05$ and $p < 0.01$). A lower density was also recorded in December 2001 in comparison with April 1979 ($p < 0.05$). Species richness did not reveal any trend at station 6 (Fig.IV.6.c).

3.1.2.3 Station 9

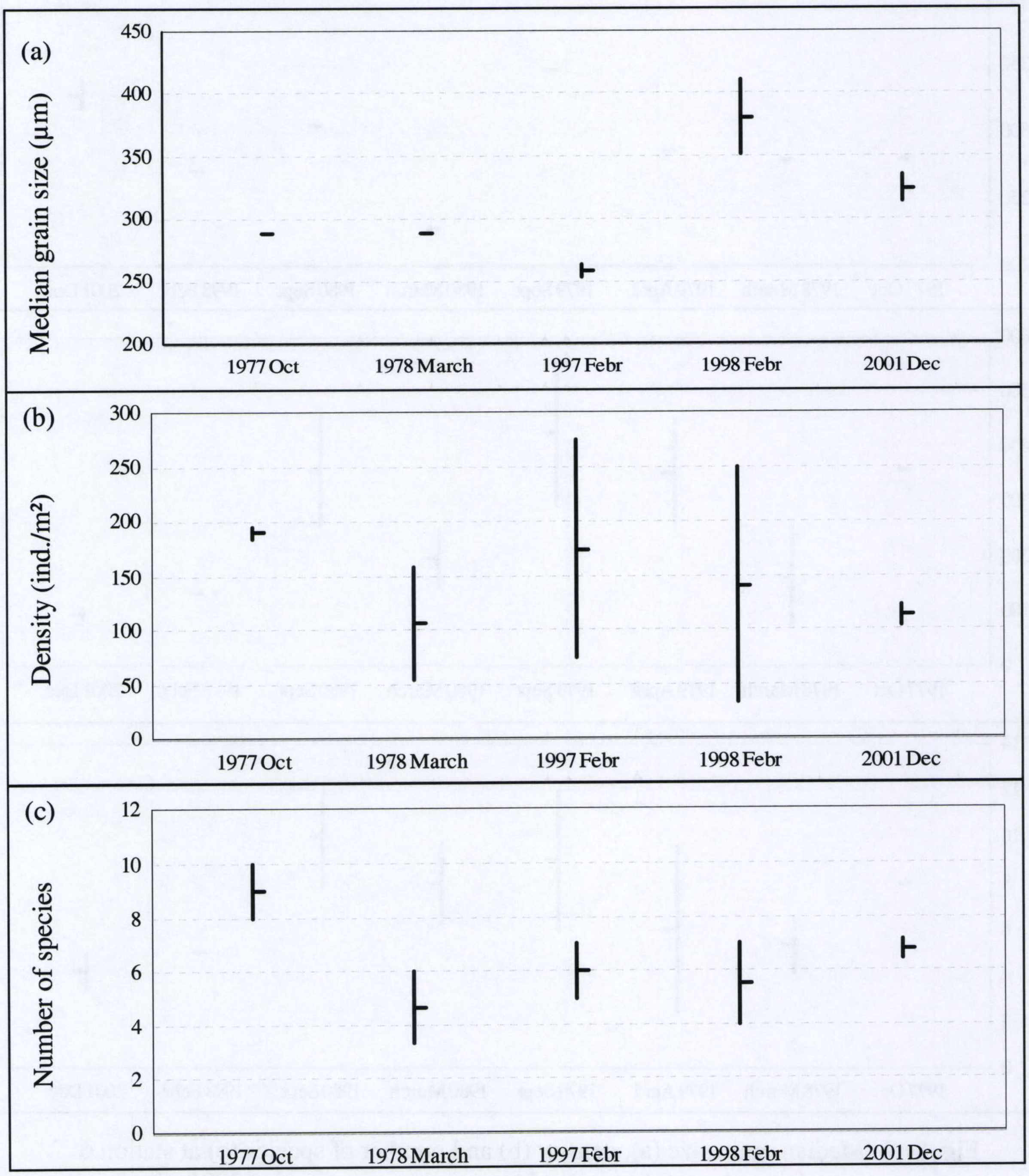

Fig. IV.7: Median grain size (a), density (b) and number of species (c) at station 9 per sampling event between the seventies and 2001

In February 1998 median grain size was significantly higher than at all the other sampling events (Fig.IV.7.a). In February 1997 a slightly lower median grain size was recorded, significantly differing from the measurements in December 2001. In general, however, no clear trend could be derived from the comparison between the seventies, nineties and 2001. Density and species richness did not change through time (Fig.IV.7.a & b).

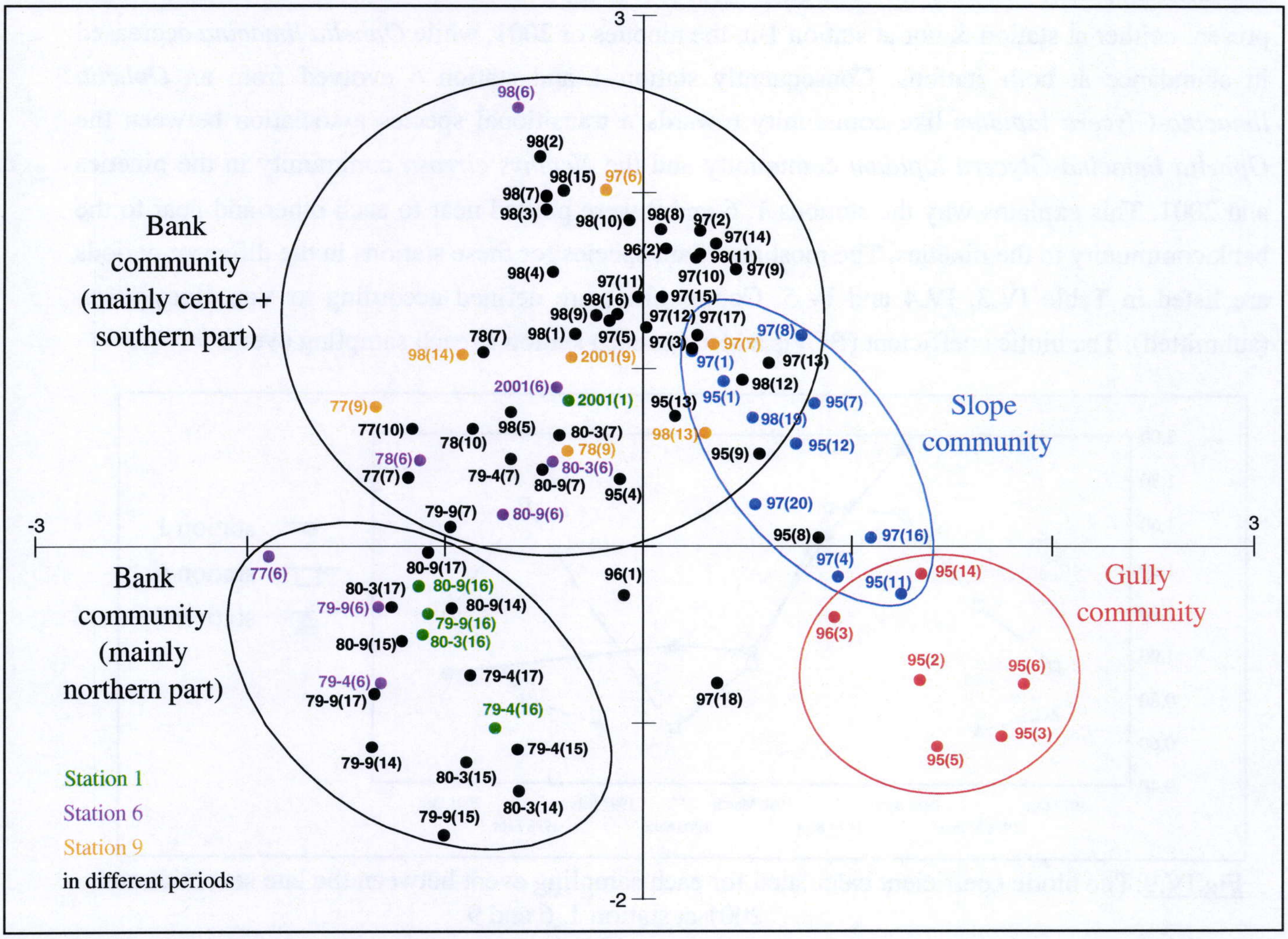

Fig.IV.8: CA plot of the macrobenthic samples taken on the Kwintebank between the late seventies and 2001, based on fourth root transformed absolute species abundances. The sample code includes the year of sampling (+ month if indicated) and the station number between brackets.

In the TWINSPAN (not depicted) and CA (Fig.IV.8) of the total dataset of the different periods, the gully, slope and bank communities were clearly distinguished, as described previously. A distinct difference also existed between the northern part of the Kwintebank (stations 14, 15, 16 and 17) in the seventies and the bank, slope and gully communities in the nineties. This northern part is distinguished due to the high abundances of *Ophelia limacina*, *Spisula solida*, *Spio filicornis* and Oligochaeta. Samples in this northern area are not available from the nineties. In 2001 however, station 1 in the northern part was resampled. This station was not plotted among the other northern stations in the seventies but near to the bank community from the nineties. Moreover, the different stations sampled in 2001 (situated in the northern part (1), as well as the centre (6) and the southern part (9) of the bank) were very similar in the plot. In the seventies similarities were also detected between station 6 and the northern part of the bank, due to the high abundance of the characteristic species *Spio filicornis* and *Ophelia limacina* and the presence of some *Spisula*'s and oligochaetes. In the nineties *Spisula* was only found in some slope and gully stations. *Spio filicornis* and *Spisula* were present neither at station 6, nor at station 1 in the nineties or 2001, while *Ophelia limacina* decreased in abundance at both stations. Consequently station 1 and station 6 evolved from an *Ophelia limacina-Glycera lapidum*-like community towards a transitional species association between the *Ophelia limacina-Glycera lapidum* community and the *Nepthys cirrosa* community in the nineties and 2001. This explains why the stations 1, 6 and 9 were plotted near to each other and near to the bank community in the nineties. The most abundant species for these stations in the different periods are listed in Table IV.3, IV.4 and IV.5. Communities are defined according to Van Hoey *et al.* (submitted). The biotic coefficient (BC) is added for each station at each sampling event.

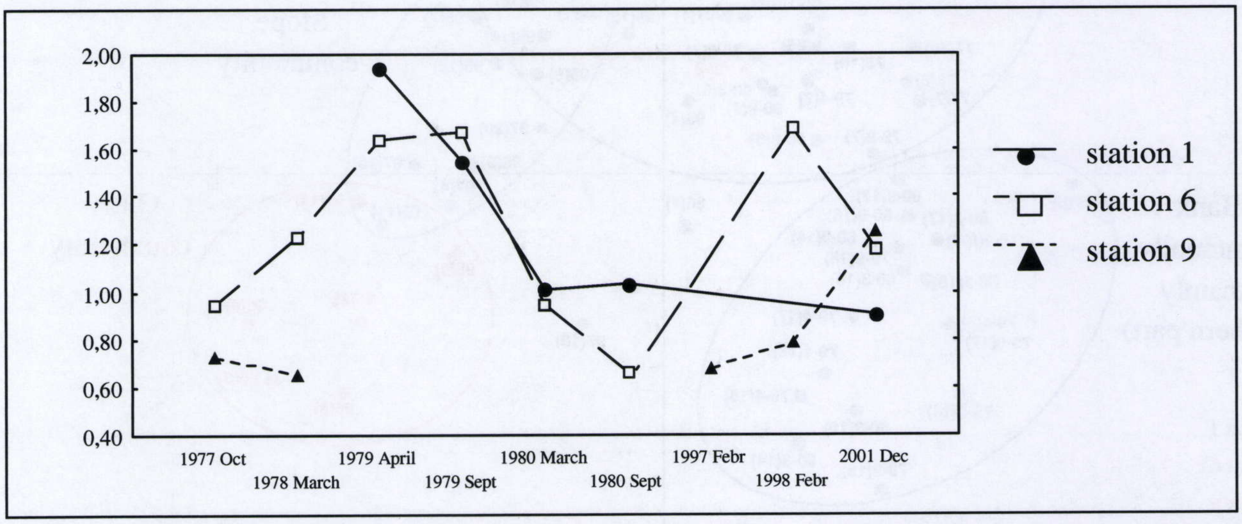

Fig.IV.9: The biotic coefficient calculated for each sampling event between the late seventies and 2001 at station 1, 6 and 9

The biotic coefficient fluctuated between 0.66 and 1.94, corresponding to an impoverished community or to a slightly polluted site (Fig.IV.9).

At station 1 the tolerant species (group III) were most important in April and September 1979, followed by the sensitive species (group I). In March and September 1980 and 2001 the sensitive species accounted for the highest relative abundance, followed by the indifferent species (group II). These changes resulted in a decrease of the BC between 1979 and 1980-2001.

At station 6 indifferent species dominated through the whole period, except in September 1980 when sensitive species were most abundant. Sensitive species were mostly second in abundance, except in September 1979 and February 1998. No clear trend in the BC was discerned through the time series.

At station 9 indifferent species were most abundant in 1977 and 2001, followed by sensitive species, while sensitive species dominated in the other periods with the indifferent species second in abundance. A slight increase of the BC was observed between the nineties and 2001. One second order opportunistic species (group IV) was encountered in the nineties at station 9, i.e. *Cirratulus* spec. in February 1997.

The fluctuations in the BC do not point to an increased abundance of opportunistic species between the seventies and the nineties and 2001 as a result of severe disturbances in the environment. Increasing sand extraction intensity from the late seventies onwards did not result in clear changes of the biotic coefficient. Moreover, the BC did not differ between the stations, characterized by different sand extraction intensity. The BC of the sporadically exploited station 9 was even higher than the two intensively exploited stations in 2001.

Station 1

1979 April		1979 September		1980 March		1980 September		2001 December	
Spio filicornis	27.20	*Spio filicornis*	41.22	*Nephtys cirrosa*	18.07	*Ophelia limacina*	27.14	*Urothoe brevicornis*	22.22
Spiophanes bombyx	21.66	*Ophelia limacina*	15.09	*Ophelia limacina*	16.27	*Spio filicornis*	19.05	*Nephtys cirrosa*	15.41
Scoloplos armiger	12.54	*Bathyporeia elegans*	11.26	*Spio filicornis*	13.86	*Nephtys cirrosa*	14.29	*Ophiura albida*	15.25
Ophelia limacina	8.63	*Glycera capitata*	5.18	*Scoloplos armiger*	12.05	*Spisula solida*	8.10	*Echinocardium cordatum*	11.12
Nephtys cirrosa	5.37	*Nephtys cirrosa*	5.18	*Eteone longa*	12.05	*Hesionura augeneri*	6.19	*Spio goniocephala*	9.38
Spisula elliptica	3.75	*Spisula spec.*	5.18	*Spisula solida*	10.24	*Gastrosaccus spinifer*	6.19	*Scoloplos armiger*	8.75
Heteromastus filiformis	2.77	*Eteone longa*	3.83	*Glycera capitata*	6.02	*Eteone longa*	4.76	*Ophelia limacina*	7.11
Eteone longa	2.12	*Gastrosaccus spinifer*	3.83	*Gastrosaccus spinifer*	4.22	*Atylus falcatus*	3.33	*Glycera capitata*	2.51
Lanice conchilega	2.12	*Hesionura augeneri*	2.93	*Goniadella bobretzkii*	1.81	*Scoloplos armiger*	3.33	*Crepidula fornicata*	2.22
Hesionura augeneri	1.63	*Nephtys spec.*	1.58	*Anaitides mac-muc*	1.81	*Polygordius appendiculatus*	3.33	*Thia scutellata*	1.74
Anaitides maculata-mucosa	1.63	*Microphthalmus similis*	0.68	*Tellina fabula*	1.81	*Bathyporeia guilliamsoniana*	1.43	*Lanice conchilega*	1.38
Anaitides subulifera	1.14	*Anaitides mac-muc*	0.68	*Atylus falcatus*	1.81	*Bathyporeia elegans*	1.43	*Psammechinus miliaris*	1.18
Oligochaeta spec.	1.14	*Spiophanes bombyx*	0.68			*Oligochaeta spec.*	1.43	*Gastrosaccus spinifer*	0.87
Goniadella bobretzkii	1.14	*Spisula elliptica*	0.68					*Eteone longa*	0.87
Spisula solida	1.14	*Brachyura spec.*	0.68						
Aonides paucibranchiata	1.14	*Spisula solida*	0.68						
Pagurus bernnardus	0.49	*Bathyporeia guilliamsoniana*	0.68						
Pariambus typicus	0.49								
Ophiura albida	0.49								
Pholoe minuta	0.49								
Megaluropus agilis	0.49								
Bathyporeia guilliamsoniana	0.49								
Magelona papillicornis	0.49								
Eumida sanguinea	0.49								
Natica alderi	0.49								
Chaetozona setosa	0.49								
BC = 1.94		**BC = 1.55**		**BC = 1.01**		**BC = 1.04**		**BC = 0.91**	
***Ophelia limacina-Glycera lapidum* community**		***Ophelia limacina-Glycera lapidum* community**		***Ophelia limacina-Glycera lapidum* community**		***Ophelia limacina-Glycera lapidum* community**		**TSA *Nephtys cirrosa-Ophelia limacina* community**	

Table IV.3: Community, biotic coefficient and relative abundances of the species assigned to different ecological groups per sampling event at station 1: species very sensitive to pollution, species indifferent to pollution, tolerant species, second-order opportunistic species, first-order opportunistic species and species which the ecological group was not available from in black, TSA = Transitional Species Association

Station 6

1977 October

Species	%
Hesionura augeneri	54.85
Archiannelida	24.86
Gastrosaccus spinifer	9.30
Macrochaeta helgolandica	3.08
Spio filicornis	1.85
Nephtys cirrosa	1.13
Pontocrates altamarinus	0.93
Spisula spec.	0.93
Oligochaeta spec.	0.74
Microphthalmus listensis	0.63
Mysella bidentata	0.47
Glycera capitata	0.43
Spisula solida	0.27
Modiolus modiolus	0.13
Oridia armandi	0.13
Ophelia limacina	0.08
Goniadella bobretzkii	0.08
Streptosyllis arenae	0.08
Notomastus latericeus	0.04

BC = 0.95

TSA
***Nephtys cirrosa*-*Ophelia limacina* community**

1978 March

Species	%
Hesionura augeneri	49.60
Nephtys cirrosa	11.79
Scolelepis bonnieri	9.29
Gastrosaccus spinifer	5.56
Spisula solida	5.56
Bathyporeia elegans	4.17
Pontocrates altamarinus	4.17
Scoloplos armiger	4.17
Archiannelida	1.90
Ophelia limacina	1.90
Paraonis fulgens	0.95
Spiophanes bombyx	0.95

BC = 1.23

↑

TSA
***Nephtys cirrosa*-*Ophelia limacina* community** →

1979 April

Species	%
Ophelia limacina	25.50
Hesionura augeneri	25.50
Spio filicornis	18.98
Glycera capitata	11.33
Oligochaeta spec.	6.52
Nephtys cirrosa	5.67
Scoloplos armiger	2.83
Goniadella bobretzkii	1.98
Nephtys caeca	0.85
Polygordius appendiculatus	0.85

BC = 1.64

***Ophelia limacina*-*Glycera lapidum* community**

1979 September

Species	%
Hesionura augeneri	37.38
Spio filicornis	28.74
Gastrosaccus spinifer	9.35
Ophelia limacina	7.71
Nephtys cirrosa	7.01
Scolelepis bonnieri	3.04
Spisula elliptica	1.64
Bathyporeia elegans	1.64
Anaitides maculata	0.70
Spisula spec.	0.70
Chaetozona setosa	0.70
Bodotria scorpioides	0.70
Dyastilis rathkei	0.70

BC = 1.67

1980 March

Species	%
Nephtys cirrosa	32.14
Ophelia limacina	15.31
Bathyporeia elegans	13.78
Scoloplos armiger	10.20
Anaitides maculata	6.63
Eteone longa	6.63
Spio filicornis	3.57
Scolelepis bonnieri	3.57
Nephtys longosetosa	3.57
Tellina fabula	1.53
Dyastilis bradyi	1.53
Bathyporeia guilliamsoniana	1.53

BC = 0.95

TSA
***Nephtys cirrosa*-*Ophelia limacina* community**

1980 September

Species	%
Ophelia limacina	28.93
Nephtys cirrosa	27.25
Bathyporeia elegans	17.70
Gastrosaccus spinifer	6.46
Echinocardium cordatum	4.78
Spio filicornis	3.65
Eteone longa	2.81
Scolelepis bonnieri	1.97
Hesionura augeneri	1.97
Scoloplos armiger	1.97
Pectinaria koreni	0.84
Anaitides maculata	0.84
Oligochaeta spec.	0.84

BC = 0.66

TSA
***Nephtys cirrosa*-*Ophelia limacina* community**

1998 February

Species	%
Nephtys cirrosa	50.00
Spio goniocephala	31.25
Bathyporeia elegans	6.25
Paraonis fulgens	6.25
Urothoe brevicornis	6.25

BC = 1.69

TSA
***Nephtys cirrosa*-*Ophelia limacina* community**

2001 December

Species	%
Nephtys cirrosa	54.03
Urothoe brevicornis	13.82
Gastrosaccus spinifer	10.15
Spiophanes bombyx	5.17
Ophelia limacina	4.00
Echinocardium cordatum	2.67
Thia scutellata	2.50
Scolelepis bonnieri	2.00
Nephtys spec.	2.00
Spio spec.	2.00
Eteone longa	1.67

BC = 1.18

TSA
***Nephtys cirrosa*-*Ophelia limacina* community**

Table IV.4: Community, biotic coefficient and relative abundances of the species assigned to different ecological groups per sampling event at station 6: species very sensitive to pollution, species indifferent to pollution, tolerant species, second-order opportunistic species, first-order opportunistic species and species which the ecological group was not available from in black, TSA = Transitional Species Association

Station 9

1977 October		1978 March		1997 February		1998 February		2001 December	
Nephtys cirrosa	22.39	*Nephtys cirrosa*	21.67	*Bathyporeia elegans*	39.02	*Scoloplos armiger*	31.67	*Nephtys cirrosa*	34.29
Gastrosaccus spinifer	18.32	*Tellina tenuis*	21.67	*Nephtys cirrosa*	20.50	*Nephtys cirrosa*	22.50	*Echinocardium cordatum*	15.03
Tanaissus lilljeborgi	17.31	*Mysella bidentata*	16.67	*Urothoe brevicornis*	11.49	*Spio filicornis*	14.17	*Scolelepis bonnieri*	9.22
Scolelepis bonnieri	6.93	*Scoloplos armiger*	13.33	*Bathyporeia guilliamsoniana*	9.95	*Urothoe brevicornis*	12.50	*Ophelia limacina*	7.13
Bathyporeia spec.	5.26	*Ophelia limacina*	10.00	*Scolelepis bonnieri*	7.64	*Gastrosaccus spinifer*	12.50	*Gastrosaccus spinifer*	6.40
Bathyporeia elegans	5.19	*Spiophanes bombyx*	6.67	*Bathyporeia spec.*	5.41	*Magelona mirabilis*	1.67	*Spiophanes bombyx*	5.54
Ophelia limacina	3.61	*Scolelepis bonnieri*	3.33	*Cirratulus spec.*	3.09	*Nephtys hombergi*	1.67	*Ophiura albida*	5.08
Spio filicornis	3.42	*Bathyporeia elegans*	3.33	*Magelona mirabilis*	1.45	*Urothoe poseidonis*	1.67	*Thia scutellata*	4.21
Bathyporeia guilliamsoniana	1.85	*Paraonis fulgens*	1.67	*Crangon crangon*	1.45	*Bathyporeia guilliamsoniana*	1.67	*Urothoe brevicornis*	4.05
Eteone cfr. flava	1.85	*Eteone longa*	1.67					*Nephtys spec.*	2.00
Scoloplos armiger	1.85							*Spio goniocephala*	2.00
Pontophilus trispinosus	1.75							*Spio spec.*	1.54
Pseudocuma longicornis	1.75							*Nephtys caeca*	1.18
Nototropis swammerdami	1.75							*Hyale nilssoni*	1.18
Megaluropus agilis	1.75							*Bathyporeia guilliamsoniana*	1.18
Hesionura augeneri	1.67								
Paraonis fulgens	1.67								
Magelona papillicornis	1.67								
BC = 0.73		**BC = 0.65**		**BC = 0.68**		**BC = 0.79**		**BC = 1.25**	
TSA *Nephtys cirrosa*-*Ophelia limacina* community		**TSA *Nephtys cirrosa*-*Ophelia limacina* community**		**TSA *Nephtys cirrosa*-*Ophelia limacina* community**		**TSA *Nephtys cirrosa*-*Ophelia limacina* community**		**TSA *Nephtys cirrosa*-*Ophelia limacina* community**	

Table IV.5: Community, biotic coefficient and relative abundances of the species assigned to different ecological groups per sampling event at station 9: species very sensitive to pollution, species indifferent to pollution, tolerant species, second-order opportunistic species, first-order opportunistic species and species which the ecological group was not available from in black, TSA = Transitional Species Association

4 Discussion

4.1 Community structure, density and diversity

The macrobenthic samples in the nineties included the centre and the southern part of the Kwintebank and some stations (‘97(17,18,19, 20)) in the northern part. Station ’97(19) was located in coarse sand and immediately separated from all the other stations in the analyses, due to the high abundance of *Caecum glabrum*, *Sphaerosyllis hystrix* and *Glycera convoluta*. The other stations from fine to medium sand in the centre and the southern part of the bank were defined as one bank community.

Vanosmael *et al.* (1982) discerned two major communities on the Kwintebank: a rich community including stations 2, 3 and 4 in the northern part of the bank (see meiofauna sampling stations on the Kwintebank) and a poorer southern bank community. *Sphaerosyllis* was abundantly present in the northern community and *Caecum glabrum* was exclusively found at station 4 (Willems *et al.*, unpubl. report). Station ’97(19) is situated very near to this station 4, which is devoid of any sand extraction activity because of the high content of shell debris and thus the coarseness of the sediment. The dominant species in this particular area did not change a lot between the seventies and the nineties. However, species richness probably decreased since 47 species were found in three replicates in the seventies (Willems *et al.*, unpubl. report) and only 8 species were encountered in one replicate in the nineties. The difference between sieving the samples alive or after fixation may account for the loss of some interstitial polychaetes in the nineties, but not for the loss of some molluscs. At the undredged station 4 the harpacticoid community of the nineties showed still similarity with the species assemblage of the northern part in the seventies, but the loss of some bigger harpacticoids was also observed (Chapter III). Unfortunately, in the nineties macrobenthic samples were not available from stations 2 or 3, which belonged to the rich northern macrobenthic community in the seventies. These stations are exploited for sand extraction and showed some differences with the seventies according to the harpacticoid species composition (Chapter III).

The presence of different *Spisula* species was a common characteristic of station 1, station 6 and the northern community in Willems *et al.* (unpubl. report) as well as in the analyses of the seventies in the present study, whereas *Spisula* was absent at station 1 and 6 in the nineties and 2001. In the seventies station 6 even harboured the mollusc *Caecum glabrum* (Willems *et al.*, unpubl. report). Station 1 and station 6 were also characterized by a high abundance of *Ophelia limacina* and *Spio filicornis* in the seventies, while these species clearly decreased in the nineties and 2001. Sieving the samples alive or after fixation cannot account for differences in presence/absence of *Spisula* or *Ophelia* species, whereas *Spio filicornis* may escape alive through the meshes of the 1 mm sieve (Degraer, pers. comm.). Although *Spio filicornis* was still encountered at a few stations in different years in the nineties, indicating that at least some *Spio filicornis* individuals are retained during sieving alive, no conclusions can be drawn from these quantitative differences.

Stations 1 in the northern part and station 6, situated in the depression in the centre of the Kwintebank, are heavily exploited stations, as was revealed in Chapter III. The disappearance of *Spisula* at these stations may be related to the sand extraction activities. *Spisula* was still encountered next to the depression in 2001, at the same station where a rich harpacticoid community was encountered in 2000 (Chapter III). Hence sand extraction may also have affected the macrobenthic fauna on the Kwintebank. Vanosmael *et al.* (1979) already suggested that *Spisula* may be affected by sand extraction activities on the Kwintebank, because this is a slowly growing species with a long life span. This statement was also applied to *Nephtys* species, whereas no indications were found of decreasing *Nephtys* densities in the present study. Sand extraction may initially also favour bivalve recruitment (*Spisula* species and *Tellina* species) (van Dalfsen *et al.*, 2000) but these species may fail to establish lasting populations due to continuous disturbances as on the Kwintebank.

The potential impact of sand extraction on the macrobenthos of the Kwintebank is however not confirmed by clear changes in other biological characteristics. As a result of sand extraction a decrease in macrobenthic density and species richness is expected (Newell *et al.*, 1998; Desprez, 2000). The direct impacts through removal of the fauna are undeniable. Vanosmael *et al.* (1979) studied the removal of macrobenthic organisms by sand extraction *in situ* and followed the dumping of dead and alive organisms by the sand extraction vessel. 45 % of the animals, which were retained on the sieve aboard the vessel and dumped in the sea, were deadly damaged, accounting for 70 % of the biomass. Mainly molluscs contributed to this percentage of deadly damaged fauna. Sampling the extraction site before and after dredging revealed a reduction in macrobenthic abundance by 80 % (Vanosmael *et al.*, 1979).

At station 1 and 6 significant differences were found between densities of different sampling events. Yet, these differences may result from seasonal fluctuations, since the densities in winter (February, December) and early spring (March) differed generally from samples in April or September. The very high macrofauna density in April 1979 at station 1 was attributed to the high abundance of *Spiophanes bombyx* (133 ind./m²) and *Spio filicornis* (167 ind./m²). Very high densities of *Spiophanes bombyx* have been frequently observed, probably as a response on the sedimentation of the spring phytoplankton bloom at the end of April (Van Hoey, unpubl. data and Chapter II). At station 9 densities were very similar, all the samples being taken in winter or early spring.

Species richness did not change through time at station 9 or at station 6, whereas a slight decreasing trend was observed at station 1. Station 1 was also characterized by a decreasing density and a coarsening of the sediment. The latter trend was also deduced from the comparison of meiofauna samples between the nineties and the seventies and from some time series of geologic surveys at this station, as was discussed in Chapter III. Harpacticoid density also showed a decreasing but non-significant trend at station 1, whereas significant changes were recorded for diversity.

Although macrobenthic density and species richness did not change a lot at any station, the species composition at station 1 and station 6 changed and became very similar to the poor macrobenthic bank community. Hence, the extraction activities may have caused a homogenisation of the macrobenthic on the Kwintebank. Except for one coarse station, the macrobenthic community analysis in the nineties did not distinguish between different parts on the sandbank top. Intensively exploited stations in the depression (station 6 as well as other stations in the nineties) or in the north (station 1) of the bank were not distinguished from less disturbed areas on the sandbank, whereas the harpacticoid community analysis clearly showed different communities, corresponding with different erosion and sand extraction areas (Chapter III).

Macrobenthic densities and diversities on the sandbank top are low, which is typical for well-sorted mobile sands (Elliott *et al.*, 1996) and characterized by mobile polychaetes (e.g. *Nephtys cirrosa*) and crustaceans (e.g. *Bathyporeia* spp.). The *Nephtys cirrosa* community is typically found in well-sorted medium sandy sediments and shows a lot of overlap with several transitional species associations (Van Hoey *et al.*, submitted). On the Kwintebank a transitional species association between the *Nepthys cirrosa* and the *Ophelia limacina-Glycera lapidum* community was generally defined. Slight differences between several combinations of transitional species assemblages may be hard to find and may not be detected in an overall community analysis.

4.2 Biotic Coefficient

In order to investigate the changes of macrobenthic species belonging to different ecological groups more accurately, the biotic coefficient was calculated according to Borja *et al.* (2000). This continuous index allows detecting changes in macrobenthic species with different sensitivity to a pollution gradient, giving a different weight to species with a different sensitivity. The biotic coefficient did not change markedly due to increased sand extraction activities since the late seventies. The highest biotic coefficient was recorded in April 1979 at station 1 and in September 1979 at station 6. The high co-dominance of the tolerant species *Spio filicornis* and *Spiophanes bombyx* accounted for the higher value in April 1979 at station 1. These deposit feeders may have increased in abundance due to enhanced food availability after the sedimentation of the spring phytoplankton bloom (Widbom & Frithsen, 1995). Hence the biotic coefficient measured an impact of slight organic enrichment.

The biotic coefficient is widely used in organic pollution assessment, the increase in opportunistic species being mainly related to this kind of environmental change. Borja *et al.* (2000) assumed that the increase in the biotic coefficient in the inner part of an estuary was related to dredging activities. The dredging probably increased the abundance of suspended matter and hence the abundance of opportunistic species. In Spain the increase in fine sands also resulted in an increase in opportunistic species (van Dalfsen *et al.*, 2000). As long as dredging activities cause an increased organic load through resuspension and resettling of organic matter, the biotic coefficient may be used to assess changes as a result of dredging but this study revealed that its applicability should not be overestimated. Reworking organic poor sediments of subtidal sandbanks (Vanosmael *et al.*, 1979; Vanosmael *et al.*, 1982) does not seem to favour typical opportunistic macrobenthic species. The competitive ability of opportunistic species responding to organic enrichment is probably not advantageous in organically poor and naturally physically stressed environments such as subtidal sandbanks. The naturally occurring species may just recruit more frequently to cope with the more intense disturbances but their species composition may not be altered in poor habitats. In Chapter II it was suggested that the impact of tidal mixing is important on the Kwintebank. In this kind of turbulent environment benthic macrofauna are apt to be less abundant and not as diverse as in more stable regions (Jennes & Duineveld, 1985). It is very difficult to detect the effect of human-induced physical disturbance in areas exposed to extreme natural disturbances (Hall *et al.*, 1990; Kaiser & Spencer, 1996) because the communities of high-stress areas are characterized by higher growth rates (Jennes & Duineveld, 1985) and hence more adept to readjustement to the impact of dredging operations (Desprez, 2000).

Some former species-richer areas (such as the northern top of the Kwintebank) may however have impoverished and have become similar to the surrounding area. This homogenisation hampers the distinction between extracted and non-extracted sites at a fixed moment in time. The use of a biotic coefficient, designed for organic pollution assessment, is not appropriate to measure dredging impacts in clean sands. A suggestion might be to modify the classification of the ecological groups used for the biotic coefficient, focusing on differences between the different (interstitial) polychaetes and amphipods prevailing in these habitats or to examine the percentages of juveniles or biomasses. If groups of species are used to characterize a certain degree of enrichment or disturbance, rather than single species, and such groupings are related to other environmental variables then a more useful system must be defined. Analysis of the ecological principles underlying the used model should remain the chief aim of those biologists concerned with the examination of the effects of enrichment or disturbance, and the use of any indicator schemes must be accompanied by a detailed knowledge of both the abundance and range of species in the area concerned (Pearson & Rosenberg, 1978). Swartz (1972) and Eagle & Rees (1973) pointed out that any attempts to use the presence of macrobenthic species in a sample as indicative of the enrichment or disturbance of the area must always be qualified by a consideration of the full species range present and the environmental conditions prevailing at the time of sampling.

Yet, differences in the macrofauna between areas of different levels of human disturbance are not easily detected on the Kwintebank at a fixed moment in time, because of potential homogenisation by the extractions, the poverty and wide niche width of the community and the extent to which the community is adapted to high levels of sediment disturbance in these dynamic systems. The poverty of samples so far is definitely an additional problem and comparisons with the macrofauna of similar undisturbed areas should be made. Hence a clear picture can be given on the presence/absence of the naturally occurring K- and r-strategists against which the community of the Kwintebank can be tested.