Long-term changes (1979-89) in the intertidal macrozoobenthos of the Oosterschelde estuary: are patterns in total density, biomass and diversity indaced by the construction of the storm-surge harrier?

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Abstract

To evaluate the effects of the construction of a storm surge barrier in the Oosterschelde, long-term pattems (1979-89) in abundance and biomass of the intertidal macrozoobenthos were studied at 14 permanent stations. Additionally, data of a large-scale survey in late summer 1985 and 1989 were analysed. In this paper, patterns in general parameters are discussed.

Late summer values of total biomass, total density, species richness, diversity and abundance- and biomass ratio show no overall significant trend during the study period. The changes in the hydrodynamics and the morphology of the Oosterschelde after the completion of the storm surge harrier do not seem to have infiuenced the normal patterns in benthic populations. The observed patterns are determined by the occurrence of severe versus mild winters, rather than by hydrodynamic changes caused by the construction of the harrier. Low biomasses, high densities (particularly of opportunistic species) and higher 'stress-values" (abundance- and biomass ratio) in 1985(-87) indicate a temporal disturbance by severe winter weather. At the elevated COST-station 27, total biomass decreased sharply in 1985, due to a short-term increase in exposure time, caused by the manipulation of the storm surge harrier.

Introduction

When the decision was made to build a storm surge barrier in the mouth of the Oosterschelde estuary, an ecological monitoring program was developed to assess the impact of these engineering works. The interest in biomonitoring programs has been widely recognised. This seems to be part of a maturation process in ecology, resulting from the need for integration on a larger temporal and spatial scale (Reise, 1989). The recent success of ecological monitoring has different reasons. First of all, it improves our understanding of natural patterns and processes; by statistical modelling, long-term data sets can be used to assess the appropriateness of sampling schedules (spatial and tempora!) and as a predictor of future trends (Coull, 1986; Gray & Christie, 1983). Secondly, departures from a common pattern may indicate local effects of pollutants or other factors of disturbance (Gray & Christie, 1983; Beukema & Essink, 1986). It is a necessary precondition for translating the principle of anticipatory action into practical policy (Reise, 1989). With an increasing anthropogenic impact on the natura! environment, the development of biomonitoring studies is necessary.

Because of the crucial importance of the intertidal macrozoobenthos in the food-web of the intertidal system (as consumers of plankton, detritus; as prey for higher trophic levels: birds, fish), intensive studies on this group were started as part of the monitoring program in the Oosterschelde (Nienhuis & Smaal, 1994).

In this paper, trends and patterns of some genera!characteristics (total biomass, density, species richness, diversity, abundance- and biomass ratio) of the macrozoobenthos at 14 permanent stations during the period 1979-89 and at 300 stations in late summer 1985 and 1989 are presented and the effects of the changed environmental conditions in the Oosterschelde (cf Nienhuis & Smaal, 1994) on the macrozoobenthic system is discussed. Structural aspects and changes in the distribution and biomass of some important macrobenthic species are treated respectively in Meire *et al.* (1994) and Coosen *et al.* (1994).

Material and metbods

Sampling methods and -stations

Three data-sets were available for the analysis presented in this paper. For all of them, core-samples were taken and sieved on a 1mm-mesh size. All animals were identified, counted and the ash-free dry weight (AFDW) was determined by drying, weighing and ashing. For more details on sampling and laboratory methods, we refer to [1]Meire *et al.* (1991a & b; 1994), [2] Seys *et al.* (1993b) and [2]Craeymeersch *et al.* (1988) and [3]Meire et Dereu (1989) for the INTERECOS-1, COST-[2] and VIANEN-[3] dataset respectively.

The INTERECOS data-set consists of a survey in late summer 1985 (pre-harrier situation) and 1989 (post-harrier situation) at 305 (resp. 300) sampling stations distributed over three tidal flats, *i.e.* in the western, central and northern part of the estuary (Fig. 1).

The COST data-set comes from a monitoring program in the period 1983-1989 based on two stations from the Roggenplaat in the west of the Oosterschelde, one from the Galgeplaat (central part) and five at the eastern tidal flats (Verdronken Land van Zuid-Beveland; Fig. 1). Samples were initially (1983 and 1984) taken 4 times a year, and twice since then (1985-1989). No data were available from station 14 in 1983 and 1986, from station 26 in 1988 and from station 30 in 1985-1986. For two of the stations (3 and 27), all species were picked out and identified; for the other six stations, only data for the 11 biomass-dominant species (*Arenicola marina* L., *Cerastoderma edule* L., *Heteromastus filiformis* Claparède, *Hydrobia ulvae* Pennant, *Lanice conchilega* Pallas, *Macoma balthica* L., *Mya arenaria* L., *Nephtys hombergi* Savigny, *Nereis diversicolor* O. F. Müller, *Scoloplos armiger* O. F. Müller and *Scrobicularia plana* Da Costa) were available. For these stations, 'total biomass' means the sum of biomass of these 11 species. Total density, species richness, diversity, and abundance- and biomass ratio were not calculated for these stations.

The VIANEN-dataset comes from a monitoring program at 6 stations on the 'Slikken van Vianen' (Meire & Dereu, 1989), a tidal flat in the northern branch of the Oosterschelde (Fig. 1). Samples were taken annually in late summer 1981, 1982 and 1984-1989. Additional samples of late summer 1979 were taken at station 60, 10 and 13.

This paper is primarily based on late summer data from the COST- and VIANEN-set, supplemented with INTERECOS-data where necessary. For data on seasonal variability, we refer to Coosen *et al.* (1994) and Seys *et al.* (1993a, b, c). For some stations, data from one or more years are missing. Therefore not all stations could be used in all statistica! analyses. Three different combinations of permanent stations were used for analysis (Table 1). The feuer stations are included in the combination the more year data are available. The CVO-combination includes data from all 14 COST/VIANEN-stations. The

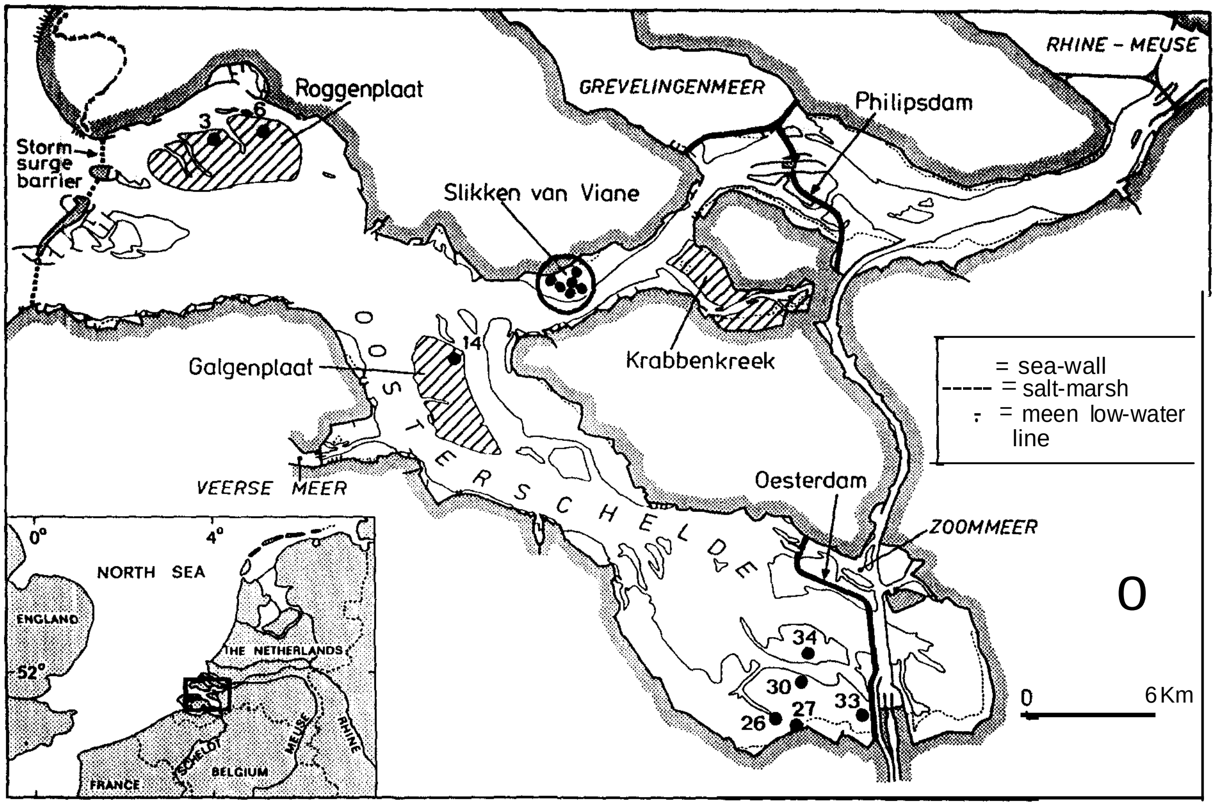


Fig. 1. Study area and sampling stations of macrozoobenthos. The 8 COST-stations (3, 6, 14, 26, 27, 30, 33 and 34) are spread over the Oosterschelde intertidal flats, the 6 VIANEN-stations are enclosed by a circle. The three tidal flats sampled during the INTERECOS-surveys 1985 and 1989 (resp. 305 and 300 sampling points) are shaded.

COST-stations 14, 26 and 30, of which less than 7 late summer data are available are omitted in the CV l-combination. The COST-stations with incomplete data on smaller species (all COST-stations except 3 and 27) were excluded from combination CV2. Calculations of total density, species richness, diversity and abundance – and biomass ratio's were done only with the CV2 combination.

Data-analysis

Biomass was expressed as g ash free dry weight (AFDW) m $^{-2}$ and density as number of individuals m $^{-2}$. The abundance ratio, Abundance/number of species (A/S), and biomass ratio, Biomass/abundance (B/A) were used as stress-indicators (Gray *et al.*, 1988). For the division into feeding guilds, we refer to Seys *et al.* (1993c). Species richness and diversity was expressed as Hill-indices N_0-N_2 (Hill, 1973).

Since the time series available is short and contains gaps for most stations no statistical time series analysis could be performed on the data. To detect if any long term change was present in the data a simple non-parametrical test, the Spearman's rank correlation, was calculated. This test enables us to detect gradual increases or decreases in the selected variables during the study-period, but can not reveal any other pattern.

A Detrended Correspondence Analysis (Hill, 1979) on density and biomass data of all (314) INTERECOS-, COST- and VIANEN sampling stations in 1989, was performed with all species present in more than 5 samples.

Table 1. Available data on abiotic characteristics of the CVO-stations in the period 1979-1990 (TL = tidal level; MGS = median grain size (in *rp* units); SC = silt (< 53 µ) content). The classification of stations in the CVO, CV1 and CV2 groups is also indicated. (V = Vianen, C = Cost data set).

CV2		■	■	■	■	■	■
CVl		■	■	■	■	■	■
CVO		■	■	■	■	■	■
Location		V	V	V	V	V	V
Variable/station	Year	10	22	60	13	32	39
TL (MTL + cm)	79	−81		−70	−41		
	84	−78	−78	−82	−51	+63	−10
	85	−68	−69	−78	−57	+59	−13
	86	−92	−94	−98	−80	+43	−18
	87	−91	−94	−97	−79	+42	−18
	88	−93	−88	−85	−72	+47	−15
	89	−97	−92	−88	−83	+42	−19
	90	−97	−94	−90	−96	+42	−20
MGS (rp units)	79	3.17		3.17	3.07		
	81	2.91	2.99	2.89	2.66	3.02	2.83
	84	2.85	2.76	2.95	2.88	2.94	2.96
	85	2.92	2.87	2.84	2.78	2.95	2.89
	86	2.73	2.69	2.69	2.84	2.97	2.93
	87	2.75	2.82	2.74	2.78	2.89	2.95
	88	2.50	2.53	2.55	2.80	2.63	2.61
se (%)	79	8.5		9.2	3.9		
	81	7.6	16.6	6.0	7.0	5.0	6.0
	84	4.5	4.0	10.0	11.0	4.0	7.0
	85	5.7	5.6	5.2	4.5	3.2	6.2
	86	5.6	7.0	5.1	13.6	5.3	5.2
	87	2.0	2.8	[redacted]	2.8	0.8	5.6
	88	3.4	1.54	3.2	4.7	2.1	2.3

CV2		■							
CV!		■							
CVO		■	■	■	■	■	■	■	■
Location		C	C	C	C	C	C	C	C
Variable/station	Year	3	27	6	33	34	14	26	30
TL (MTL + cm)	83	+36	+110	+50	+60	−35	−50	−50	−70
	85					−50			−25
	89			+40		−50	+0	−25	−40
	90	+25		+40				−50	
MGS (cp units)	83	2.65	3.39	2.74	3.47	3.04	3.00	3.09	3.12
	87	2.50	3.03						
	89	2.31	3.22	2.48	3.26	2.73	2.31	2.85	2.82
se (%)	83	4.8	3.9	0.5	12.0	0.7	1.2	2.2	0.5
	87	2.8	7.6						
	89	0.9	2.7	0.1	7.8	0.4	0.3	2.1	1.1

Environmental changes in the Oosterschelde

For a detailed description of the Oosterschelde and the engineering works we refer to Nienhuis & Smaal (1994). The major changes are shortly summarized. Hydrodynamic changes started medio 1985 and resulted, after the completion of the storm surge harrier (October 1986) and the compartmentalization dams (Oesterdam, October 1986; Philipsdam, April 1987) in a reduction of the tidal range (-13%); current velocities were reduced by 30% in the western sector and 70% in the northern sector; tidal volume decreased by 28%, mean fresh water input was 64% less and nitrogen input decreased by 58%. Water residence time increased by 100% and chlorinity by 14%. Primary production has slightly increased (+5 ,) whereas zooplankton is now much more abundant (+60%). In the period end 1986-April 1987, the tidal reduction was more pronounced, caused by the manipulation of the storm surge harrier for the completion of the compartmentalization dams. This resulted in significantly langer exposure periods in the upper part and significantly Jonger immersion periods on the lower part of the intertidal areas (see Nienhuis & Smaal, 1994; Seys *et al"* 1993c).

Results

Representativity of the monitoring stations

The representativity of the COST/VIANEN monitoring stations for the Oosterschelde can be tested by comparing the 1985 and 1989 COST/VIANEN data with the results of the two large scale surveys (INTERECOS) made in both years. The results are summarized in Table 2. The biomass estimates are in close agreement in both years. The biomass of the CV2 combination is higher as the proportion of sampling stations on musselbeds is rather high in this group. The densities are also very comparable, although in 1989 they are higher in the monitoring stations than in the INTERECOS set. In the INTERECOS-survey 1989, 65 species were found. It is not possible to compare this value with the results of 1985 since not all organisms were identified to species level in the INTERECOS survey 1985. In all CV2 stations 57 species were found.

To see whether the benthic communities found at the monitoring stations are representative for the Oosterschelde, a Detrended Correspondence Analysis (Hill, 1979) both on density and biomass data of the COST-, VIANEN-, and INTERECOS stations oflate summer 1989 was done. In both analyses the first two DCA-axes were responsible for most of the variation and all COST/VIANEN monitoring stations are very well spread within the cloud of INTERECOS points as shown in Fig. 2 for the density data. Nearly all main benthic community types found in the INTERECOS-set (Meire *et al.,* 1994) were represented by one or more monitoring stations. The results of the COST/VIANEN stations can therefore be used for further analysis of the tempora!patterns of the Oosterschelde macrozoobenthos.

Changes in environmental parameters

Available data on some environmental parameters of the stations are summarized in Table 1. In the period 1979-83, all stations were situated between Mean Tidal Level (MTL) -80 cm and MTL + 110 cm. In 1988-89, nine stations had eroded with 5-30 cm, while at three stations sedimentation (25-50 cm) occurred. The sediments at all COST/VIANEN-stations, except one, became coarser between 1979-83 and 1987-89: median grain size changed from 2.65-3.47 <p to 2.31-3.26 <p, while the range in silt-content (< 53 µ) shifted from 0.5-16.6% to 0.1-7.8%.

Tempora! variations in some genera! parameters

The tempora! pattems of total biomass, biomass of different feeding guilds, density, species richness, diversity and abundance- and biomass ratio's are illustrated in Fig. 3. As most of the patterns observed in the different VIANEN or COST-stations were found to be significantly concordant (based on the Kendall Coefficient

Table 2. Mean biomass, density and number of species from the different data sets in 1985 and 1989 (1 INTERECOS, CVO, CVl and CV2 see Table 1).

Parameter	Data set	1985 Mean	1989 Mean
Biomass		49.3	99.3
(g AFDW m^{-2})	CVO	48.3	88.2
	CV!	52.5	105.8
	CV2	64.1	134.2
Density	1	34715	9673
(numbers m^{-2})	CV2	31838	15254
Number of species	1		65
	CV2		57

of Concordance), average values for the six VIANEN-stations (1979-89) and the eight COST-stations were used to produce Fig. 3. To exclude overruling effects of some individual stations in the figures absolute values per station were transformed to percentages of the long-term average at this station, before different stations were combined. The results of the Spearman Rank correlation coefficient are summarized in Table 3 and 4.

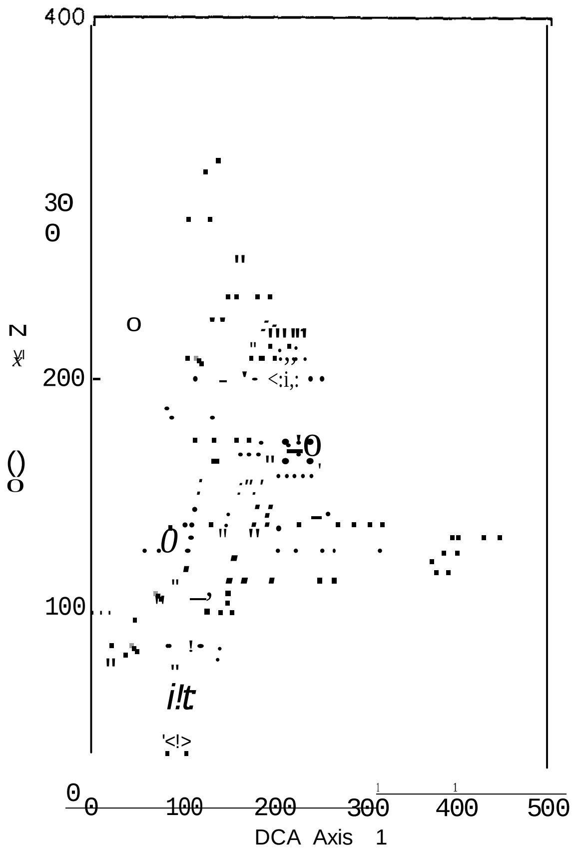


Fig. 2. Detrended Correspondence Analysis on the density data of the INTERECOS- and COST/VIANEN-stations in late Summer 1989 (314 stations). Stations are presented according to their position on the first and second DCA-axis. The CV-stations are encircled.

Biomass

The average total biomass in the INTERECOS-stations changed from 49.3 in 1985 to 99.3 g AFDW m^{-2} and 1989 respectively. For the CVO-stations, total biomass varied between 5.5 and 531 g AFDW m^{-2} with an overall mean value of 76.2 g (Table 5). The highest values occur at the VIANEN-musselbed stations 10, 22 & 60 (Table 5).

Total biomass is dominated by the taxonomically diverse group of deposit feeders and the filter feeders, essentially comprised of *C. edule* and *M. edulis*. Particularly this last group fluctuated rather strongly, with low values in 1985-86 (Fig. 3) and high values in 1987-89 especially at the VIANEN-stations (Fig. 3). The low values are due to mass mortality after the severe winter 1984/85-1985/86, the high values to the abundant spatfall, especially of *C. edule*, after the severe winters and their subsequent survival. Without *C. edule* and *M. edulis*, an overall mean biomass of only 19.3 g AFDW m^{-2} was found with a much smaller range (8.54-28.93 g AFDW

Table Ja. Trends in total biomass (TB), biomass excluding *C. edule/M. edulis* (TE) and biomass of feeding guilds (FF = filter feeders; OF = deposit feeders; OP = omnivores/predators; GR = grazers) at the CVl-stations. The Spearman Rank correlation coefficients are based on late summer values 1979-1989 (station 60, 10, 13), 1981-1989 (station 22, 32, 39) or 1983-1989 (station 3, 6) (*N* = number of cases; $^*p<0.05$; $^{**}p<0.01$; ns = not significant).

Station	*N*	TB	TE	FF	DF	OP	GR
C3	7	-0.679 ns	−0.750 ns	−0.679 ns	−0.357 ns	−0.750 ns	+0.099 ns
C6	7	-0.821 *	−0.786 *	−0.714 ns	−0.786 *	+0.179 ns	+0.408 ns
C27	7	-0.571 ns	−0.571 ns	+0.107 ns	−0.500 ns	+0.321 ns	+0.089 ns
C33	7	+0.143 ns	+0.071 ns	−0.000 ns	+0.214 ns	−0.143 ns	+0.408 ns
C34	7	+0.107 ns	+0.214 ns	+0.179 ns	+0.143 ns	+0.321 ns	+0.450 ns
V60	9	-0.133 ns	−0.333 ns	−0.133 ns	−0.400 ns	−0.400 ns	+0.367 ns
V1O	9	+0.150 ns	+0.033 ns	+0.150 ns	+0.183 ns	+0.233 ns	+0.500 ns
V13	9	+0.950 **	+0.583 ns	+0.950 **	+0.433 ns	+0.283 ns	+0.800 *
V22	8	-0.381 ns	-0.690 ns	−0.333 ns	−0.952 **	−0.119 ns	+0.071 ns
V32	8	+0.667 ns	−0.000 ns	−0.714 ns	−0.167 ns	+0.571 ns	+0.910 **
V39	8	+0.667 ns	-0.190 ns	−0.667 ns	−0.286 ns	−0.310 ns	+0.333 ns

m $^{-2}$). In the INTERECOS-surveys 1985 and 1989 biomass without *C. edule* and *M. edulis* was 17.0 and 14.9 g AFDW m $^{-2}$ respectively. The temporal pattern of biomass excluding *C. edule* and *M. edulis,* is rather stable, with slightly lower values in 1985, mainly due to a decrease of deposit feeders and omnivores/predators.

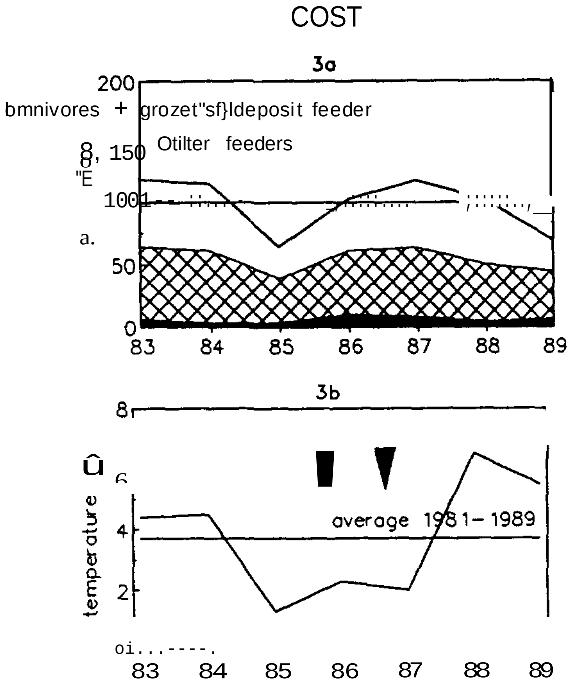
No significant trend was found at 9 of the 11 CVl stations (Table 3a). The positive trend at station 13 (due to a re-establishment of filter feeders – in casu *C. edule* – in the second half of the study period) disappeared if *C. edule* and *M. edulis* were omitted. The decrease in biomass at station 6 resulted from lower biomasses of deposit feeders. Also station 22 had lower biomasses of deposit feeders at the end of the study period {Table 3b). Although no overall trend in total biomass was found at station 13 and 39, the grazers, which were of minor importance for total biomass, showed a negative trend.

Density

The average density at the INTERECOS stations in 1985 was 34 715 m $^{-2}$ (29094 m $^{-2}$ excluding *C. edule/M. edulis),* while in 1989 much lower values were found (resp. 9673 and 9409 m $^{-2}$). The average value for the CV2-stations in the period 1984-89 was 21 426 m $^{-2}$ (without

Table 3b. Trends in total density (DT), density excluding *C. edule/M. edulis* (DE) and diversity (Hili numbers N_0, N_1, N_2) at the CV2-stat1ons. The Spearman Rank correlation coefficients calculated for these variables are based on available late summer values of the period 1979-1989 (stations 60, 10, 13, 22, 32, 39) or 1983-1989 (stations 3, *27)(* *N* = number of cases; $^*p<0.05$; $^{**}p<0.01$; ns = not significant).

Station	*N*	DT	DE	No	N1	*N1*
C3	7	−0.786 *	−0.857 *	−0.673 ns	+0.321 ns	+0.321 ns
C27	7	−0.857 *	−0.857 *	−0.611 ns	+0.536 ns	+0.429 ns
V60	9	+0.017 ns	−0.033 ns	−0.600 ns	−0.533 ns	−0.517 ns
VlO	9	+0.267 ns	+0.333 ns	−0.641 ns	-0.883 **	−0.817 *
V13	9	+0.650 ns	+0.600 ns	−0.025 ns	−0.283 ns	−0.250 ns
V22	8	−0.524 ns	−0.524 ns	+0.036 ns	+0.714 ns	+0.286 ns
V32	8	−0.571 ns	−0.690 ns	−0.626 ns	+0.881 **	+0.786 *
V39	8	−0.429 ns	−0.476 ns	−0.182 ns	−0.190 ns	−0.595 ns



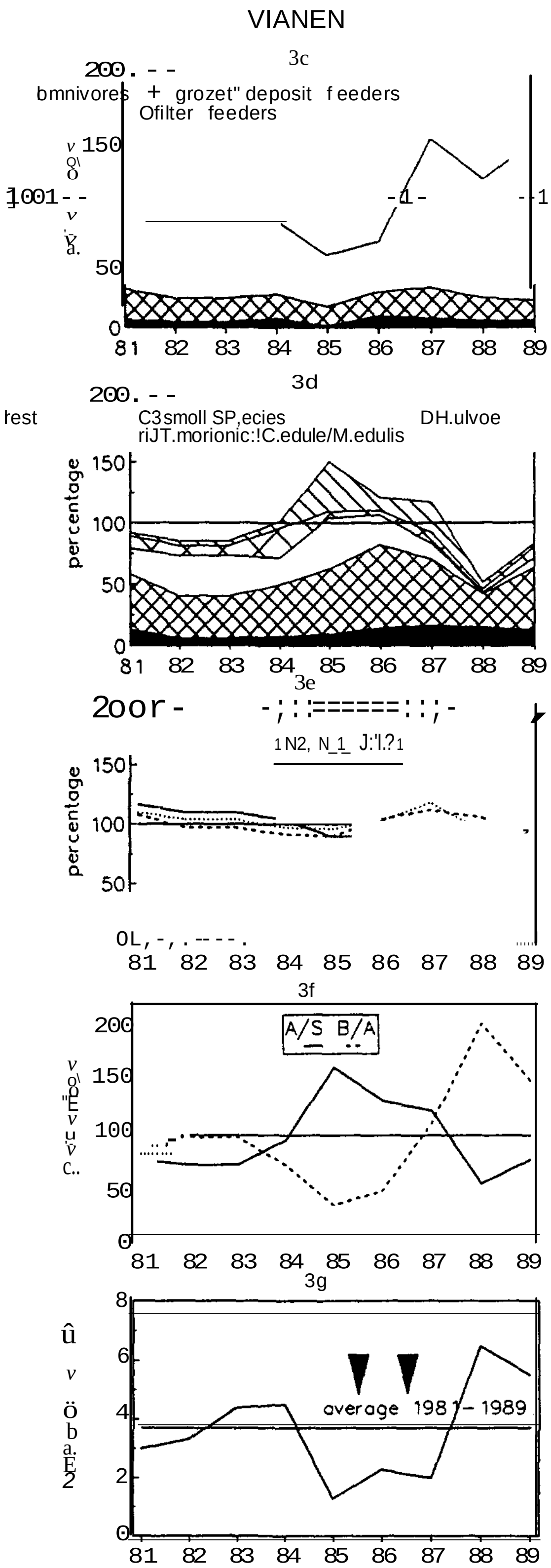


Fig. 3. Change in total biomass (3a, c), total density (3d), diversity ($N_0 N_1$ and N_2)(3e) and abundance- (A/S) and biomass ratio (B/A) (3f) at 8 COST-, resp. 6 VIANEN-stations in the period 1983-1989, resp. 1981-1989. Values are converted to percentages of the long-term average, *i.e.* the average of the whole study period. For the COST-stations, total biomass is the biomass of the 11 biomass-dominant species and density, diversity and A/S, B/A are not calculated (not all species sorted at 6 of the 8 stations). The 'small species' in 3d are: *Anaitides* spec., *Bathyporeia* spec., *Boccardia redeki, Capitella capitata, Corophium* spec., *Eteone* spec., *Heteromastus fi/iformis,* Oligochaeta, *Po/ydora* spec. and *Pygospio e/egans.* In 3b, g, the average winter air temperature (average of mean monthly temperature December-February) and the period of maxima! manipulation of the storm surge harrier (arrows) are indicated.

Table 4. Trends in abundance ratio (A/S) and biomass ratio (B/A) at the CV2-stations. The Spearman Rank correlation coefficients calculated for these variables are based on available late summer values of the period 1979-1989 (station 60, IO, 13. 22, 32, 39) or 1983-1989 (station 3, 27) (N = number of cases; *$p<0.05$;* **$p < 0.01$; ns = not significant).

Station	*N*	A/S	B/A
3	7	-0.857 *	+ 0.357 ns
27	7	-0.893 **	+ 0.714 ns
60	9	+ 0.533 ns	-0.283 ns
10	9	+ 0.333 ns	-0.233 ns
13	9	+ 0.683 *	+ 0.750 *
22	8	-0.571 ns	+ 0.286 ns
32	8	-0.357 ns	+ 0.643 ns
39	8	-0.500 ns	+ 0.690 ns

C. *edule* and *M. edulis:* 19317 m^{-2}). The absolute values of total density were quite different between these stations: they ranged from 6058 m^{-2} at station 13 to 38 256 m^{-2} at station 39 (Table 5).

No significant trend was found in 6 of the 8 CV2 stations, a decrease in 2 stations (Table 3b). Peak values (= more than average) were found in 1985-87 (Fig. 3b). These values are caused by an increase in the abundance of (small) C. *edule/ M. edulis* and of a number of other small species *(Anaitides mucosa, Bathyporeia pi/osa/sarsi, Boccardia redeki, Capitella capitata, Corophium volutator/arenarium, Eteone longa, Heteromastus filiformis, Oligochaeta, Polydora ligni, Pygospio e/egans).* For all these invertebrates, 1988 showed low abundances. Two species with high densities in the first half of the study period *(Tharyx marioni* and *Hydrobia ulvae)* became less common after 1985-86. The overall density of the other species was more or less stable.

Diversiy

In the INTERECOS-survey 1989, 65 species were found. Although it was not possible to compare this value with the results of 1985 (not all organisms were identified to species level in the INTERECOS survey 1985), no species seemed to have (dis)appeared. For all CV2 stations an average value of 22 species per station was found, with a range of 18-26 species (Table 5).

The number of species (N_0) did not change significantly in the study period (Table 3b). The species richness N_0 and the Hîll-indices of diversity N_1 and N_2 (Hili, 1973) were rather constant over time, with a small increase in 1987 (Fig. 3e). No significant trend was found for N_1 and N_2 at six CV2-stations, a negative significant trend at station 10 and a positive, significant trend at station 32. The negative sign of Rs for N_0, in contrast with positive R_s-values for N_1 & N_2 at station 32 illustrates the different rationale bebind these Hili numbers. While there was apparently no significant change in the total number of species (N_0), a significant decrease in numbers of *H. ulvae (cf* Coosen *et al"* 1994) had increased the (N_2)-diversity (expressed as the reciprocal of the probability to take two individuals of the same species, if one samples at random and without replacement).

Abundance/number of species - Biomass/ abundance ratio's

Except for station 13, none of the CV2-stations had increasing A/S values over the study period 1979-89 (Table 4). At stations 3 & 27, A/S decreased significantly, because of lower numbers of *H. u!vae* in the second half of the study period. The biomass ratio B/A showed an increasing trend at station 13, due to significant higher biomasses in the second half of the study period. Lowest values were observed in 1985-86 (less than 50% of the long-term average), and high values (above average) in the period 1987-89. The abundance ratio showed an opposite pattern (Fig. 3t).

Discussion

The monitoring plots on the Slikken van Vianen were selected to represent the major macrobenthic habitats. The selection of the six stations was based on a larger number of plots that were

Tab/e 5. Average late summer values (1984-1989) of total biomass (TB), total density (TD) and diversity (Dl) indices N_0, N_1 and N_2 at the CVO-stations (ineluding overall average), compared to total biomass and -density values of all INTERECOS-samples 1985 and 1989 (IE). For total biomass and -density, 'all' means all species included, 'exel' means all species excluding C. *edule* and *M. edulis.*

	Station	VlO	V22	V60	Vl3	C30	C26	C14	C34	V39
TB	All	184.0	134.7	218.5	88.9	16.4	48.4	43.9	48.7	79.9
	Exel	27.6	28.9	27.7	8.5	12.2	14.7	17.9	13.6	21.5
TD	All	19741	25643	32143	6058					38256
	Exel	15300	25187	28109	3979					34504
Dl	No	25	26	26	18					22
	N1	6.78	4.64	5.57	7.40					4.82
	Nz	4.28	2.47	3.34	4.95					3.10

	Station	C3	C6	V32	C33	C27	Mean CVO	IE 1985	IE 1989
TB	All	102.3	27.2	27.7	30.4	15.4	76.2	49.3	99.3
	Exel	24.8	16.6	16.8	23.5	15.2	19.3	17.0	14.9
TD	All	8033		16884		24651	21426	34715	9673
	Exel	6415		16497		24547	19317	29094	9409
DI	No	24		18		18	22		65
	N1	8.69		3.14		3.25			
	Nz	6.14		1.93		2.18			

sampled in previous years (Meire & Dereu, 1989). The selection of the COST stations is based on a large scale mapping of the major macrobenthic habitats of the Oosterschelde (Coosen *et al"* 1988). The good resemblance between the results of the monitoring stations in late summer 1985 and 1989 and the INTERECOS large scale surveys indicate that the results from the monitoring stations can be seen as representative for the Oosterschelde. Also the changes in the environmental parameters of the different monitoring stations are similar to the observed changes in the rest of the Oosterschelde (Mulder & Louters, 1994; Ten Brinke *et al"* 1994).

The biomass of the Oosterschelde intertidal macrozoobenthos is high, compared to other Dutch estuaries and brackish lakes: in the Dutch Wadden Sea, a very productive area, a year-average biomass of 38.5 g AFDW m^{-2} (28.1 g AFDW m^{-2}, excluding C. *edule/M . edulis)* was found in 1987 (Beukema, 1989). Corrected for the differing sampling period (biomass in late summer is about 20% higher than year-average biomass; Beukema, 1974) and the incalculation of organic matter in bivalve shells (measured by not removing the flesh from the shell in our study compared to Beukema, 1989) (biomass 17% higher if organic matter in shells is included: Beukema, 1974), a late summer biomass of 54 g AFDW m^{-2} for the Dutch Wadden Sea can be calculated. This value is intermediate between the biomass of the INTERECOS-surveys 1985 (49.3 g AFDW m^{-2}) and 1989 (99.3 g AFDW m^{-2}) and lower than the overall CVO biomass for the period 1984-89 (76.2 g AFDW m^{-2}). In the marine part of the estuaries Westerschelde and Ems, lower values have been found: in 1987, a late summer biomass of 33 g AFDW m^{-2} was observed in the Westerschelde and 22 g AFDW m^{-2} in the Ems (Meire *et al.,* 1991c). Wolff & De Wolf (1977) found an average of 37.5 g AFDW m^{-2} for the Grevelingen estuary in September, with minima of 12.2 g AFDW m^{-2} in December. Lower biomasses were also found in the saline lake Grevelingen (24.8-38.6 g AFDW m^{-2} in spring 1985-1989: Fortuin & Altena, 1990) and in the brackish Lake Veere (22.2 g AFDW m^{-2} in late summer 1987: Seys & Meire, 1988).

The genera! characteristics of the macrobenthic system in the Oosterschelde did not yet change markedly after the construction of the storm-surge harrier. Notwithstanding some variation, especially in the period 1985-1987, no overall increasing or decreasing trends in biomass, density, species richness, diversity, abundance- or biomass ratio were observed. These results suggest that hydrodynamical (Vroon, 1994) and sedimentological (Ten Brinke *et al"* 1994) changes in the Oosterschelde after the completion of the storm surge harrier (Nienhuis & Smaal, 1994) had, by now, only a small effect on the genera! characteristics of the benthic fauna, compared to the impact of natura} phenomena, like the occurrence of severe winters.

In most long-term data-sets *(Wadden Sea:* Beukema, 1989; Essink & Beukema, 1986; Dörjes *et al.,* 1986; Reise *et al.,* 1989; *Northumberland coast:* Buchanan & Moore, 1986; *Scottish lochs:* Pearson *et al.,* 1986; *Baie de Morlaix:* Dauvin & Ibanez, 1986; Ibanez & Dauvin, 1988; *Ba/tic Sea:* Rosenberg & Loo, 1988; Cederwall & Elmgren, 1980; Persson, 1987; Joseffson & Widbom, 1988) there is quite a large natura} seasonal and year to year variation. This makes it often difficult to separate these fluctuations from effects of gradual man-induced changes in the system, particularly because species react in different ways. Only when the system is affected abruptly and severely (heavy pollution: Dauvin & Ibanez, 1986; Pearson *et al.,* 1986; complete closure of an estuary: Lambeck, 1981; dredging activities: Lopez-Jamar *et al.,* 1986), genera! parameters of the macrozoobenthic community react clearly upon these changes. In two Scottish lochs, Pearson *et al.* (1986) found the organic input from a paper mill to determine the major changes in total density and biomass. However, this input was on average 4-14 times Iarger than the natura! carbon input from planktonic sources. Neither the changes in the sediments of the Oosterschelde nor the change in primary production were so drastic (Wetsteyn & Kromkamp, 1994) although the plankton communities did change (Bakker *et al.,* 1994).

It was shown that the most pronounced changes in some genera! parameters of the benthic system occurred in 1985(-87). This can result from effects of the first (1984-1985) of three successive severe winters (Fig. 3g), but also from the major hydrodynamic changes, started medio 1985. If hydrodynamic changes would have an effect on the genera! characteristics of the Oosterschelde macrozoobenthos, we would expect a gradual change after 1985 when the hydrodynamic changes occurred. Although the time series is rather short no other long-term trend was observed before or after the changes. Secondly, at the COST-stations low biomass- and density values were found already in spring 1985 (Seys *et al.,* 1993b; Craeymeersch *et al.,* 1988), *i.e.* before the major hydrodynamic changes. Moreover, different species known as winter sensitive collapsed immediately after the winter 1984-1985 and/or 1985-1986, 1986-1987 (Coosen *et al.,* 1993; Seys *et al.,* 1993b). Indeed a closer examination of the long-term pattem of 25 important species in the data-set (Seys *et al.,* 1993c) revealed that 17 species were directly or indirectly affected by the severe winter periods: the populations of winter-sensitive species, such as *C. edule, L. conchilega, S. plana* and *N. hombergii,* were decimated during one or more of the severe winters 1984-85, 1985-86 and 1986-87. *C. edule* and some other large species *(A. marina, M. balthica)* may have a good recruitment after severe winters, while others (*S. armiger, H. filiformis*) can benefit from the high mortality in the populations of one of their predators: *N. hombergii* (Beukema, 1989). In the Oosterschelde, there was a good spatfall of *C. edule* after the winter 1984-1985 and *S. armiger* did indeed increase significantly in numbers where *N. hombergii* was decimated (Smaal *et al.,* 1991; Coosen *et al.,* 1993; Seys *et al.,* 1993c). A group of small species with a large ecological spectrum and a short generation time, was particularly abundant immediately after the severe winters 1984-85 and 1985-86. Since these opportunists can recolonise empty niches in any 'stress' situation (after pollution, dredging, severe winters, etc.) they are often used as 'stress' indicators. The rationale bebind the use of the biomass ratio B/A and the abundance ratio A/S (Gray *et al.,* 1988) is based on this mass occurrence of opportunists following any kind of disturbance. In the Oosterschelde, maxima! stress values (high A/S, low B/A) were concentrated in 1985, *i.e.* after the first severe winter (1984/85).

Although there were no clear effects of hydrodynamic changes in the Oosterschelde on the general characteristics of the benthic system, some changes could be observed if we looked in more detail. On a small spatial scale, some stations were clearly influenced by the hydrodynamic changes. At one elevated COST-station (station 27: NAP + 110 cm), total biomass, total density and the abundance of individual species declined sharply between late summer 1986 and spring 1987, due to a considerable temporal decrease in inundation time (Coosen *et al.,* 1994; Seys *et al.,* 1993c). At this tidal level the mudflat was exposed for several successive days, due to the manipulation of the harrier. Experimentally it was demonstrated that most estuarine organisms show a considerable mortality after four days of exposure (Hummel *et al.,* 1994).

Although by now there is not much evidence of major changes in the macrozoobenthic populations of the Oosterschelde this does not mean that on the long run there will be no effects. Indeed changed hydrodynamic conditions may have an impact on the distribution of larvae, on the sedimentation of food particles to the bottom etc. Furthermore the clear erosion of the intertidal flats (Mulder & Louters, 1994) will in the end certainly have an impact on the total benthic populations. Therefore it is of crucial importance to continue the monitoring of the benthic populations in order to detect the long term effect of the construction of the storm surge harrier on the benthos.

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