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Factors influencing the spatial variation in fish and macrocrustacean communities in the surf zone of sandy beaches in Belgium

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An inventory of fish and epibenthic macrocrustaceans of the surf zones of sandy beaches along the Belgian coast was constructed. The surf zones were sampled intensively with a 2-m beam trawl in April–May 1996 (12 stations) and 26 species were recorded belonging to caridean shrimps (4), brachyuran crabs (5), cephalopods (1) and fish (16). The brown shrimp *Crangon crangon* dominated almost all samples (>80%). Total densities exceeded several times 250 ind 100 m^{-2} and 10 ind 100 m^{-2} if *C. crangon* was excluded. An east–west distinction as found in other (epi)benthic studies in deeper waters of the Belgian coast, was not found in the surf zone during this study. Spatial variation was mainly correlated with local characteristics such as turbidity of the water and the morphodynamic features of both the beach and the adjacent subtidal area.

INTRODUCTION

Although several aspects of the ecology of surf zone fish (e.g. Macer, 1967; Gibson et al., 1996) and macrocrustaceans (Salvat, 1962; Dexter, 1990; Gibson et al., 1993) have received considerable attention, comparatively few studies have dealt with spatial variability in the composition and abundance of epibenthic surf zone assemblages of sandy beaches (Clark et al., 1996a). Despite the structurally homogeneous environment, several authors suggest that fluctuations in physical variables (e.g. wave exposure, sediment particle size and turbidity) have a strong influence on the relative abundance of certain species and may alter the composition and species richness (Blaber & Blaber, 1980; Pihl, 1986; Romer, 1990; Pihl & van der Veer, 1992; Clark et al., 1996a). Adjacent subtidal habitat heterogeneity and the presence of rocky substrates and estuarine habitats may also contribute significantly to spatial variability (Robertson & Lenanton, 1984; Wright, 1989; Romer, 1990).

Little information is available on epibenthic communities of the Belgian surf zones, which contrasts with the shallow subtidal epibenthic communities of the Belgian coast. Within these communities clear east–west differences exist (Cattrijsse, in press). Highest diversity and total density is found on the west coast compared to the east side. The negative influence of the polluted water of the Westerschelde estuary causes the eastern coast to be 'poorer' both in terms of diversity and abundance compared to the western end of the Belgian coast (Cattrijsse & Vincx, in press). In this paper, the hypotheses that these east–west differences also exist in the surf zone assemblages, will be evaluated. The aim of this study is therefore to investigate if spatial heterogeneity along the coastline results in the presence of different epibenthic communities and to determine which factors influence the occurrence of these communities.

MATERIALS AND METHODS

Study area

The study area comprises the surf zone of sandy beaches of the Belgian coast (Figure 1), which is situated in the Southern Bight of the North Sea. One additional sample was taken from the coast of northern France. The Belgian coastline is 67 km long and characterized by built-on dykes that are interrupted by dune areas and sporadic groynes on the beaches. In some parts these groynes are less than 300 m apart, while elsewhere they are absent for several kilometres. Three major harbours, Zeebrugge, Oostende and Nieuwpoort are situated in the eastern, middle and western part of the coast respectively. A smaller harbour is present in Blankenberge. The mouth of the Ijzer estuary is situated in the western part, while the large Westerschelde estuary opens just over the Belgian–Dutch border. A strong semi-diurnal tidal regime and a net tidal current running north-east parallel to the coastline are characteristic. All beaches could be classified into two types according to the morphodynamic classification scheme of Masselink & Short (1993): seven low-tide bar/rip (LTBR) and six ultra-dissipative (UD) beaches were studied. The main characteristics of each site are given in Table 1.

Sampling

A sampling campaign in April–May 1996 covered 11 stations along the Belgian coast and one additional station in France (Bray-Dunes). All samples were taken with a 2-m beam trawl during daytime and around ebb tide. The fishing net was 3 m long, had a mesh size of 5×5 mm and was equipped with a tickler-chain in the ground rope. It was pulled by two persons in the surf zone parallel to the coastline at a depth of ~1 m. One haul lasted 15 min and covered a distance of 450–500 m.

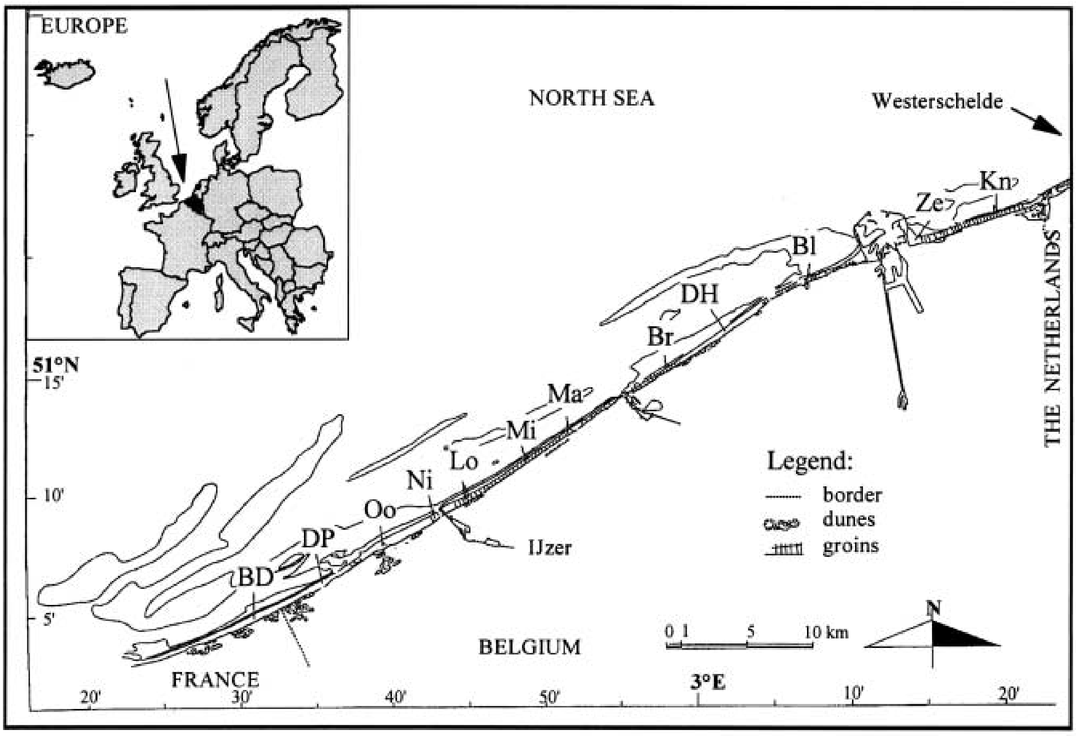

Figure 1. Study area with indication of sampling sites.

Table 1. *Main characteristics of the sandy beaches studied.*

Site	D (μm)	MSR (m)	beach type	beach width (m)	slope IT	slope ST	groynes	bar/rip IT	bar/rip ST
BD	214	5.03	UD	348	1:79	1:71		+	+
DP	246	4.97	UD	317	1:118	1:45		+	
Oo	269	4.92	LTBR	390	1:128	1:210		+	+
Ni	203	4.86	UD	275	1:70	1:117			
Lo	321	4.78	LTBR	180	1:55	1:108	+	+	+
Mi	268	4.74	LTBR	226	1:44	1:73	+		+
Ma	285	4.68	LTBR	214	1:35	1:49	+		+
Br	243	4.57	UD	220	1:49	1:75	+	+	+
DH	333	4.51	LTBR	232	1:61	1:155		+	+
Bl	236	4.38	UD	195	1:54	1:86	+		+
Ze	242	4.34	UD	225	1:79	1:216			
Kn	391	4.28	LTBR	174	1:57	1:41	+	+	

D, mean high tide beach sediment grain size; MSR, mean spring tide range; IT, intertidal; ST, first 300 m of shallow subtidal; UD, ultra-dissipative; LTBR, low tide bar/rip.

Only one haul was taken at each occasion due to practical reasons. When groynes were present, the net was lifted over the obstacle. The catch was anaesthetized in a dilute solution of benzocaine (ethylamino-4-benzoate) and then preserved in an 8% formalin solution. In the laboratory, all animals were identified to species level, measured and counted.

Environmental variables

After each haul, portable conductivity and oximeters (WTW) were used for *in situ* measurements of water temperature, salinity and oxygen content. Turbidity was measured with a portable microprocessor turbidity metre (HANNA). Water samples were transported to the laboratory in dark bottles and under cold conditions, where they were filtered through Whatman GF/F filters prior to analyses. For the pigments (chlorophyll-*a* and *c* and fucoxanthine), an immediate extraction with acetone (90%) was performed prior to a chromatography, with a Gilson high-performance liquid chromatography chain, following a slightly modified method of Mantoura & Llewellyn (1983). For particulate organic carbon (POC) an automatic CN-analyser (Carlo Erba) was used. The concentrations of nitrate plus nitrite, phosphate, ammonia and silicium were measured with an automatic chain (SAN^{plus} segmented flow analyser, SKALAR). From the sediment sample, median grain size was determined in the laboratory with a Coulter Counter LS particle size analyser. For the measurement of organic matter within the sediment (OM) samples were dried at 110°C for 2 h and subsequently burned at 540°C for another two hours. Beach width was measured from the water line at ebb tide to the high-water mark. Hydrodynamic variables (wave height,

Table 2. *Environmental variables per site.*

	BD	DP	Oo	Ni	Lo	Mi	Ma	Br	DH	Bl	Ze	Kn
33% wave height (cm)	25–50	25–50	25–50	25–50	25	25–50	0–25	0–25	25–50	25–50	100–125	25
wind speed (kn)	5–10	5	10	5–10	5–10	5–10	15	5	5–10	10	15–20	5–10
wind direction (°)	80	290	255	30	270	340	235	235	250	255	25	325
organic material of sediment (g/100g dw)	0.843	2.449	0.799	0.803	0.837	1.128	0.586	0.473	0.880	0.614	0.805	0.661
salinity IT (psu)	32.1	26.4	35.4	34.6	29.6	28.4	28.7	31.8	30.6	30.2	31.0	27.9
salinity ST (psu)	28.5	28.5	29.0	28.5	29.0	29.0	31.8	31.8	29.4	29.5	30.0	29.8
turbidity (ftu)	310	15	76	320	112	49	31	274	80	292	140	27
water temperature IT (°C)	9.5	12.5	14.0	18.0	12.0	12.0	12.5	12.0	11.5	10.0	10.0	14.0
water temperature ST (°C)	9.8	10.0	8.0	10.0	8.0	10.0	7.8	7.8	7.9	7.9	10.0	9.8
POC water column (%C)	0.4	2.3	2.7	3.6	5.2	2.2	4.0	3.9	3.0	5.6	4.6	1.9
oxidized nitrogen-N (μmol/l)	0.591	0.000	0.616	1.009	0.141	0.000	0.527	12.665	10.575	14.446	15.318	3.829
ammonia-N (μmol/l)	2.821	0.190	8.214	2.537	1.980	0.705	46.000	3.852	14.579	2.509	4.591	1.464
phosphate-P (μmol/l)	0.794	0.462	0.569	0.496	0.746	0.429	0.256	0.223	1.298	0.306	0.339	0.543
silicium (μmol/l)	0.978	0.715	1.614	1.338	0.978	0.000	0.000	2.351	1.023	0.000	0.414	0.677
chlorophyll-*a* (μg/l)	48.65	8.38	20.09	23.32	12.88	13.48	72.51	50.07	49.97	25.76	21.58	5.43
chlorophyll-*c* (μg/l)	4.50	1.48	2.70	3.70	1.53	2.06	5.84	3.91	6.11	5.39	1.95	0.80
fucoxanthine (μg/l)	28.23	4.40	11.03	12.81	7.20	6.45	41.72	34.38	25.69	14.70	12.83	2.43
median grain size (low tide) (μm)	179	181	181	180	181	301	304	244	288	246	232	294

dw, dry weight; IT, intertidal; ST, subtidal.

wind speed and direction) at the moment of sampling and slope of the beaches (beach profiles) were obtained from the Coastal Waterways' Division of the Department of Environment and Infrastructure (Ministry of the Flemish Community). Wave height is expressed as the significant wave height H33: the average crest-to-trough height of the 33% highest waves in a wave record (15 min) (Anon, 1996). Wind speed is given as the average speed and wind direction as the scalar average of the measured directions, over a period of 10 min (Gilhousen, 1987).

Data treatment

Catch densities are expressed as number of individuals per 100 m^2. Small sized crustaceans (e.g. isopods, mysids), early postlarval fish (e.g. clupeids), jellyfish and sedentary animals (e.g. the starfish *Asterias rubens*) were excluded from further analyses. Spatial patterns were examined with the following multivariate statistical techniques: correspondence analysis (CA) and canonical correspondence analysis (CCA) (Ter Braak, 1986, 1988), Two-Way INdicator SPecies ANalysis (TWINSPAN; Hill, 1979) and cluster analysis using group average sorting and the Bray–Curtis dissimilarity index (Bray & Curtis, 1957). Non-parametric multi-response permutation procedures (MRPP) were used for testing multivariate differences among pre-defined groups (Mielke et al., 1976; Whaley, 1983; Zimmerman et al., 1995). A fourth root transformation (Field et al., 1982) was performed on the abundance data prior to the analyses. Differences between the obtained communities were assessed using the non-parametric Kruskal–Wallis test (Sokal & Rohlf, 1981).

In order to assess the importance of the measured variables in structuring the communities, the forward selection option together with the Monte Carlo permutation test in the Canoco package were used prior to CCAs. If variables were significantly correlated (Spearman rank correlations, $P<0.05$), only one of them was retained for further analyses. Since wind direction is a circular variable, it was transformed to a linear variable using the cosine of the angle that the wind made on a set of axes aligned perpendicularly onshore at each site (Clark et al., 1996b). Offshore winds at each site were allocated the greatest values (+1), onshore winds the lowest (−1), while winds with a cross-shore component from either direction received scores between +0.9 and −0.9. For wind speed and wave height values are expressed as arbitrary classes ranging from 0 to 4, with class 4 indicating values of 20 knots and 100 cm respectively.

RESULTS

Environmental variables

With the exception of oxidized nitrogen concentrations, which were higher at the eastern stations, no clear geographical gradients in environmental variables were found along the coast (Table 2). However, variations in intertidal temperature and salinity were higher at the western side. The average water temperature and salinity of the surf zone were higher than in the adjacent subtidal habitat: 12 ±1°C and 31 ±1 psu compared to 9 ±0.3°C and 30 ±0.3 psu respectively. At all sampling occasions 33% of the waves were always lower than 50 cm and wind speed almost never exceeded 10 knots. Only at Ze 33% of the waves varied between 100 and 125 cm and wind speed varied between 15 and 20 knots.

Species composition

During the campaign in spring a total of 26 species was found (Table 3). The number of species per sample varied

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Table 3. *Species list together with their stage, catch densities per station (ind 100 m^{-2}) and total numbers caught (N).*

Taxon		Stage	Catch density per station												N
			BD	DP	Oo	Ni	Lo	Mi	Ma	Br	DH	Bl	Ze	Kn	
Caridea	*Palaemon longirostris*	a										*			3
	Palaemon serratus	a							*			*			2
	Crangon crangon	a	130	153	248	67	262	482	82	95	63	508	69	29	19,443
	Philocheras trispinosus	a		2	2		2	4		*		*	*	*	98
Brachyura	*Cancer pagurus*	a					*								1
	Liocarcinus holsatus	a	3		*			*		*		*			35
	Carcinus maenas	a	*	*			3	*		*		*	2	*	65
	Portumnus latipes	a		*	*		*	*		*	*	*	*		17
	Eriocheir sinensis	a					*								1
Cephalopoda	*Sepiola atlantica*	j						*							3
Pisces	*Clupea harengus*	j						*			*				4
	Sprattus sprattus	j+a				*		*	*	*	*	*			21
	Syngnathus rostellatus	j+a	*									*			6
	Agonus cataphractus	j								*		*			2
	Zoarces viviparus	a						*							1
	Echiichthys vipera	j+a	*												3
	Ammodytes tobianus	j+a				*	*				*			*	10
	Pomatoschistus lozanoi	j+a	9		*				*	11		*			182
	Pomatoschistus microps	j+a			*	*	*		*	*		1		*	19
	Pomatoschistus minutus	j+a	14	*	*					*					131
	Pomatoschistus species	j						*		*					3
	Scophthalmus rhombus	j							*		*			*	3
	Scophthalmus maximus	j	*												3
	Limanda limanda	j	*												1
	Pleuronectes flesus	j						*							1
	Pleuronectes platessa	j	6	*	2	3		*	15	*	*	*	4	*	287
	Solea solea	a	*												1
Total catch density			160	160	250	70	270	490	100	110	60	510	80	30	

*, <1 ind 100m^{-2}; a, adult; j, juvenile.

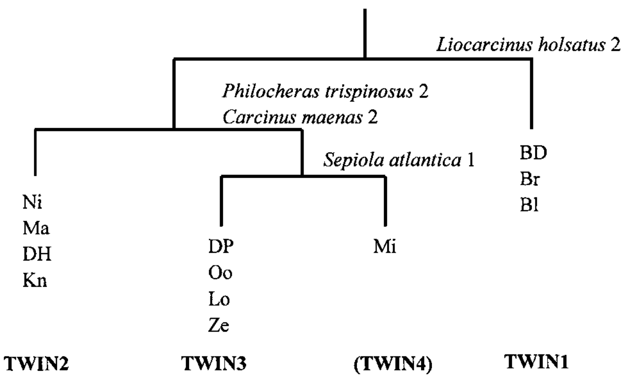

Figure 2. TWINSPAN dendrogram with indication of 'indicator species' and cutlevel (cutlevels used: 0; 0.6; 1.0; 2.0; 5.0).

between four and 12. Only the brown shrimp *Crangon crangon* and plaice *Pleuronectes platessa* were found along the whole coast and four other species were present in more than half of the stations: the shrimp *Philocheras trispinosus*, the crabs *Carcinus maenas* and *Portumnus latipes* and the common goby *Pomatoschistus microps*. Several species were only caught in one station.

Multivariate analyses

Multivariate analyses divided the stations into four groups with TWIN4 being a single station group (only TWINSPAN depicted; Figure 2). If the single station group was excluded, MRPP was highly significant ($P<0.001$), indicating that the three groups were significantly different. Total catch density, diversity and relative species composition differed substantially between the four communities (Table 4). The number of species and the densities of *Crangon crangon*, *Liocarcinus holstatus*, *P. lozanoi* and *Scophthalmus rhombus* differed significantly ($P<0.05$) between the first three TWIN groups according to Kruskal–Wallis tests: most being much higher in TWIN1 (and TWIN3 for *C. crangon*) and only *S. rhombus* being more abundant in TWIN2. TWIN4 was mainly characterized by a high number of species (12) and a high total catch density (489 ind 100 m^{-2}). This division of stations did not reflect an east–west (or other) gradient along the coastline, nor could the absence or presence of groynes or harbours directly explain the distinction.

The forward selection option together with the Monte Carlo permutation test in the Canoco package identified turbidity and to a lesser extent POC (and/or correlated variables) as only significant variables correlated with the variation in epibenthic community structure. Together,

Table 4. *Main characteristics of TWIN groups of spatial campaign (SE, standard error).*

	TWIN1		TWIN2		TWIN3		TWIN4
Mean N0 (SE < 1)	12		7		7		12
Mean total density ±SE	260 ±130		70 ±10		190 ±50		489
Mean total density without *Crangon crangon* ±SE	17 ±9		6 ±3		5 ±1		16
Relative community composition (%)							
C. crangon	93.4		90.8		97.4		98.6
Excluding *C. crangon* (%)							
Pomatoschistus lozanoi	39.1	*P. platessa*	76.2	*P. trispinosus*	33.9	*P. trispinosus*	52.5
Pomatoschistus minutus	27.0	*Sprattus sprattus*	7.6	*P. platessa*	30.5	*C. maenas*	11.5
Pleuronectes platessa	13.5	*Ammodytes tobianus*	4.2	*C. maenas*	24.9	*P. platessa*	9.8
Liocarcinus holsatus	7.4	Clupeidae species	3.5	*P. minutus*	3.4	*Sepiola atlantica*	4.9
Pomatoschistus microps	2.9	*Portumnus latipes*	3.0	*P. latipes*	2.8	Clupeidae species	4.9
Carcinus maenas	2.9	*P. microps*	1.8	*P. microps*	1.1	*Clupea harengus*	4.9
Syngnathus rostellatus	1.3	*Scophthalmus rhombus*	1.4	*Cancer pagurus*	0.6	*P. latipes*	3.3
Philocheras trispinosus	1.1	*P. trispinosus*	0.5	*L. holsatus*	0.6	*L. holsatus*	1.6

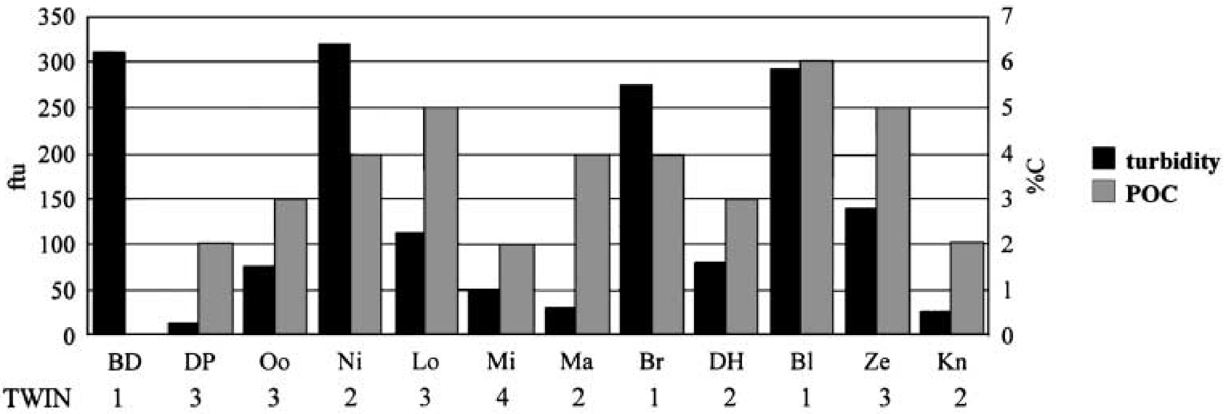

Figure 3. Turbidity (ftu) and POC (%C) per station with indication of TWIN groups.

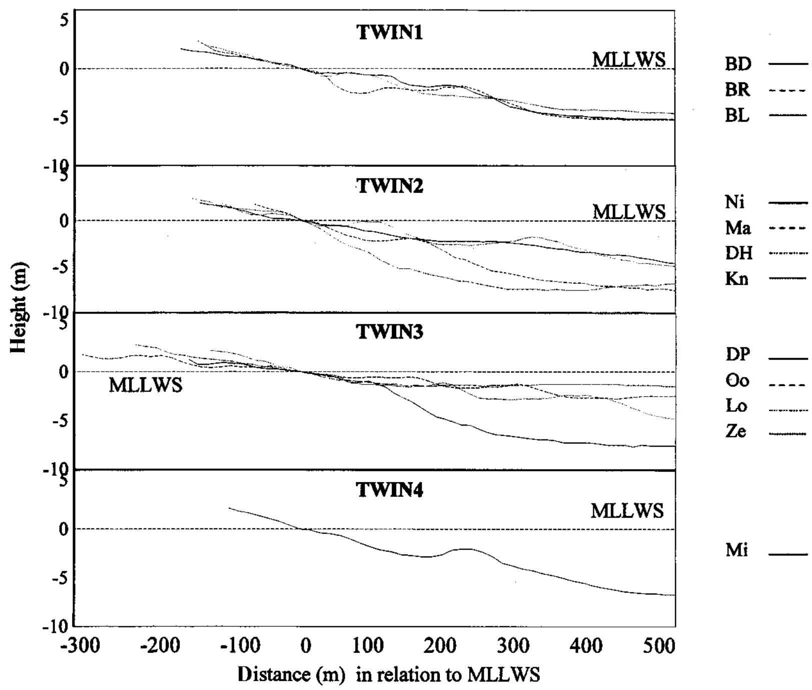

Figure 4. Site profiles per TWIN group (MLLWS, mean low water spring).

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they could explain 31% of the variation present in this data set. Turbidity was correlated with intertidal salinity and POC with no other variables measured. Turbidity was higher in TWIN1 as compared to most other stations (Figure 3). Although separate variables such as slope and beach width could not explain the observed pattern, a combination of these factors might have been of some influence. Figure 4 shows the profiles of the sampled sites for the TWIN groups. TWIN1 contained only UD beaches with intermediate slopes (shallow subtidal slopes between 1:71 and 1:86), with bars and rips in the shallow subtidal (first 500 m). TWIN2 on the other hand contained mainly LTBR beaches with a rather steep intertidal area (1:35–1:70). Both UD and LTBR beaches were present in TWIN3, but at most sites the intertidal area was wider than 225 m and the slopes remained rather flat (<3 m depth 400 m after the mean low water spring level). In TWIN4 Mi had a rather steep intertidal (1:44) and a shallow subtidal area (1:73) with bars and rips. However, all these patterns were rather weak and must be interpreted with care.

DISCUSSION

Three different communities could be distinguished. These appear discontinuously along the coastline. No east–west gradient along the coast was found. This is in contrast to earlier studies of the shallow subtidal areas (5–10 m depth): here a clear distinction could be made between the epibenthic communities of the east and west coasts respectively (Cattrijsse & Vincx, in press). The negative influence of the polluted water of the Westerschelde estuary causes the eastern coast to be 'poorer' both in terms of diversity and abundance as compared to the western end of the Belgian coast. Due to several factors such as run-off from the beach, presence of groynes etc., the intertidal area is less homogenous than deeper water masses. This was also reflected in the environmental variables measured: no geographical gradients could be detected. Each beach site is probably highly influenced by local characteristics, which might be reflected in the variation in epibenthic community structure. Replicate sampling in future research might be necessary to support these results.

Few studies (e.g. Clark, 1997) deal with the effects of exposure on surf zone fauna, and in general only the intertidal slope is considered. Local characteristics of the beaches might however be of major importance. In the present study, highest diversity and high densities were found at sites with intermediate profiles (if both the intertidal and shallow subtidal are considered). High densities were also observed on sites with long flat slopes, but diversity was much lower there. Sites with steep intertidal areas were characterized by low densities and low diversity. While steep slopes increase wave exposure (long-term effect), flat slopes can increase the local fluctuations of several environmental variables, such as water temperature and salinity. A decrease in wave height might result in higher catch efficiency, but with one exception (Ze), weather and wave conditions at the moment of sampling (short-term effect) were comparable and thus not likely to be responsible for these results.

Turbidity (and correlated variables) was identified as an important structuring environmental variable. Together with POC it could explain 31% of the total variation within the catch density data. The stations with the highest turbidity were characterized by the highest number of species and high total densities. However, sampling efficiency might be higher (lower escape response) in turbid water, several studies in both estuarine and marine habitats indicate that fish abundance is usually higher in turbid waters (e.g. Blaber & Blaber, 1980; Clark et al., 1996a; Clark, 1997), while low catches are attributed to the presence of clear waters (e.g. Lasiak, 1982; Ross et al., 1987). The presence of turbid waters in estuaries is generally considered to be advantageous for juvenile fish, as they provide cover from predators and frequently harbour higher densities of invertebrate prey than clear waters (Blaber & Blaber, 1980; Cyrus, 1983; Cyrus & Blaber, 1987a,b). Since the mobile and relatively homogenous nature of the substratum on sandy shores provides few refuges, protection due to higher turbidity might be important.

In conclusion, a lot of variation exists within the epibenthic macrocrustacean and fish assemblages of the Belgian coast. This variation might be linked with sampling efficiency (and intensity), but the correlation with turbidity of the water and the morphodynamic features of both the beach and the adjacent shallow subtidal area, should be investigated further. The mobile and relatively homogenous nature of the substratum on sandy shores means that few refuges are available thus protection due to higher turbidity might be important. Also the protection that organisms gain by occurring on flat, shallow beaches (less predation, less wave exposure) is probably outweighed by increased fluctuations in environmental variables such as salinity and higher risks of retention on the beach by ebb tide, resulting in a higher diversity at intermediate sites.

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