THE DETERMINATION OF THE BIOLOGICAL VALUE OF THE WANDELAAR AREA BASED ON SEDIMENT PROFILE IMAGING (SPI) AND GRAB SAMPLING.

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INHOUD

1 INTRODUCTION

Biological evaluation of an area, in the sense of its ecological value (e.g. biodiversity) is a pre-requisite for planning human activities in that area. Solid and meaningful biological and ecological information is needed to design a sustainable management plan for a human activity. The assessment of the biological value is not that easy, and is linked to the objectives behind the process of valuation (e.g. conservation, sustainable use, preservation of biodiversity, etc.) (Derous et al., 2007b). Different definitions are found in the literature, mostly linked to the socio-economic value of biodiversity, based on delineating 'hotspot' areas (high number of rare/endemic species or high species richness). Most efforts for the identification of valuable marine areas are initiated at the habitat level, with particular emphasis on structures (bottom topography, wave exposure, depth, substrate type, etc.), because these are the most easily observed features in marine environments and are usually well documented in large databases, which does not hold true for population or community structures (e.g. indicator species, species diversity, functional groups) (Zacharias and Roff, 2001). A well studied ecosystem component is the benthic macro-invertebrates, especially in soft-bottom sediments in the Southern Bight of the North Sea. Moreover, macrobenthos is a good indicator for the status of the ecosystem, due to its direct link with the conditions in and above the sediment surface (Van Hoey et al., 2010). Therefore, it is, combined with the knowledge on substrate type, a good proxy for estimating the biological value or potential of an area.

Nearby the harbor of Zeebrugge, in the Belgian Part of the North Sea (BPNS), the Belgian government aims to re-allocate or install a new site for dredged material disposal (diameter of approximately 2 km²) at the west side of the harbor entrance (Wandelaar area) (Figure 1). Before determining the exact location, they asked to evaluate the biological value of the wider area to minimize ecological conflicts by installing them. Despite the detailed monitoring of the soft-sediment substrates in the BPNS, for the Wandelaar area almost no benthic or sediment data was available (Degrear et al., 2008; Van Hoey et al., 2013). This makes the area an excellent case study to determine the biological value in the light of the design of a sustainable management plan for a human activity (e.g. dredge disposal). To start the actual biological valuation of the area, the necessary information has to be collected and therefore a wide range of monitoring activities are needed. In this case, we focused on the benthic habitat, which is classically monitored by means of grab samples, whereas imaging techniques are also appropriate, but mainly used in deeper, clear waters. One of the video techniques, even applicable in more turbid areas, is the sediment profile imaging tool (SPI), which provides a rapid assessment for evaluating the environment (sediment characteristics and associated fauna) and potential impacts (Rhoads and Germano, 1982, Nilsson and Rosenberg, 2000, Birchenough et al., 2006, Wilson et al., 2009, Germano et al., 2011). The SPI tool seems to have the advantage to be a quick tool to deliver knowledge on mainly sediment characteristics and obvious biota structures (e.g. holes, tubes), with limited time needed for analysis (Germano et al., 2011). Grab samples are quickly taken and delivers mainly biological information (species, densities, biomass), but this is lab intensive. Besides, a sediment core can be taken out of the Van Veen to get quantitative sediment characteristic data. Therefore, each of these techniques can provide a different, yet complementary perspective on benthic community condition (Wilson et al., 2009). The characteristics of sediment and biota gathered with SPI and grabs can be coupled to pre-defined valuation criteria to determine the biological value of that area.

Therefore the objectives of this study, based on information gathered with SPI and grab sampling, are (1) comparing and integrating the quantitative and qualitative information on the sedimentology of the area to get a sediment map of the area, (2) determining the biological (e.g. density, diversity, species composition) and functional (biological traits) characteristics within the area, and (3) applying the valuation criteria and thresholds for the biological valuation to designate an appropriate area for dredge disposal.
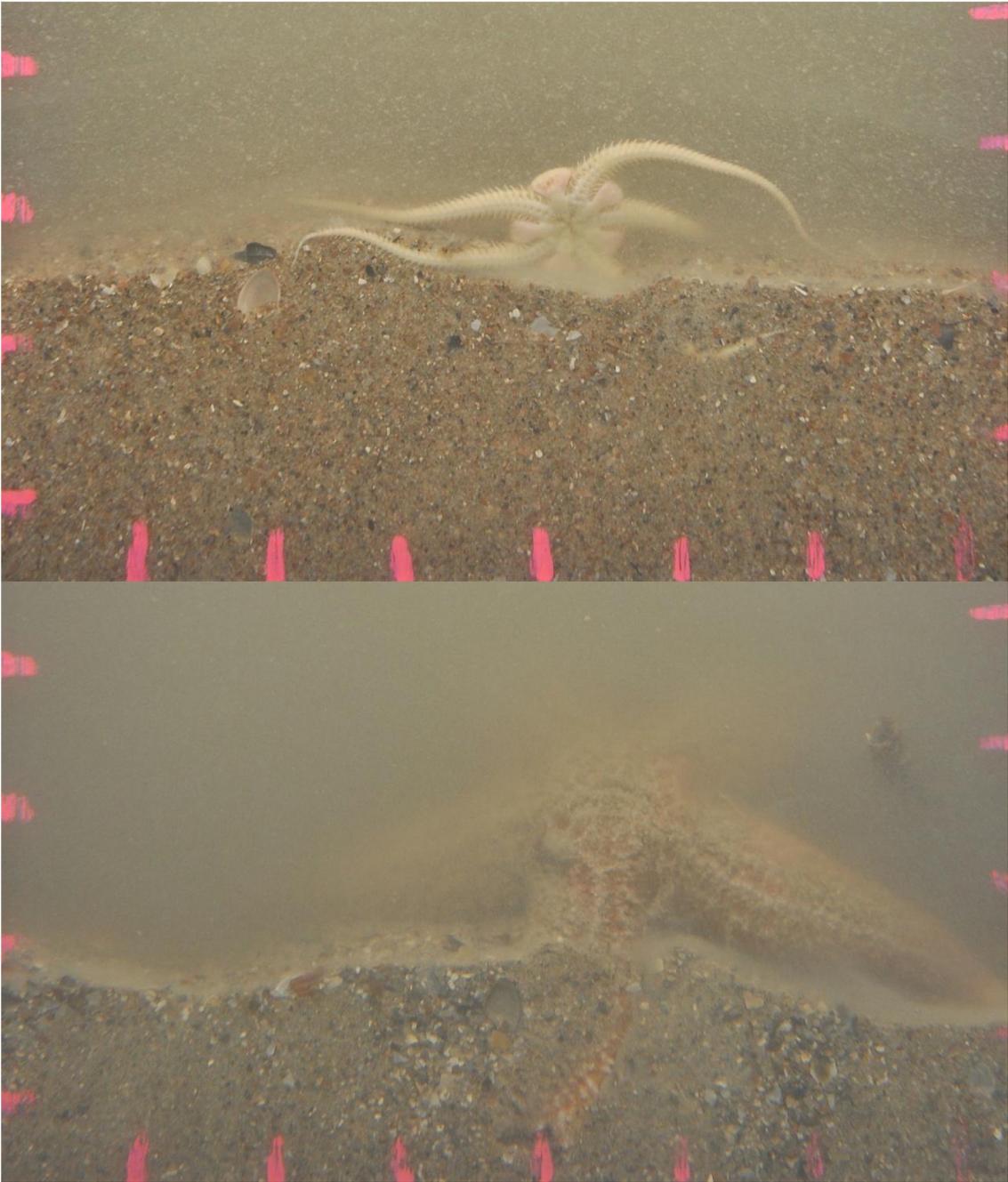
2 MATERIALS AND METHODS

2.1 STUDY AREA

The Belgian Part of the North Sea is a small area (3600km²) (BPNS) within the Southern Bight of the North Sea, which is characterized by a complex system of sand banks. It contains four principal benthic habitat types, as the *Macoma balthica* habitat, *Abra alba* habitat, *Nephtys cirrosa* habitat and *Ophelia borealis* habitat (Van Hoey et al., 2004; Degraer et al., 2008). The area at the west side of the harbor of Zeebrugge (Wandelaar area) (Figure 1) is one of the least known areas qua benthos and sedimentology in the coastal area of the BPNS.
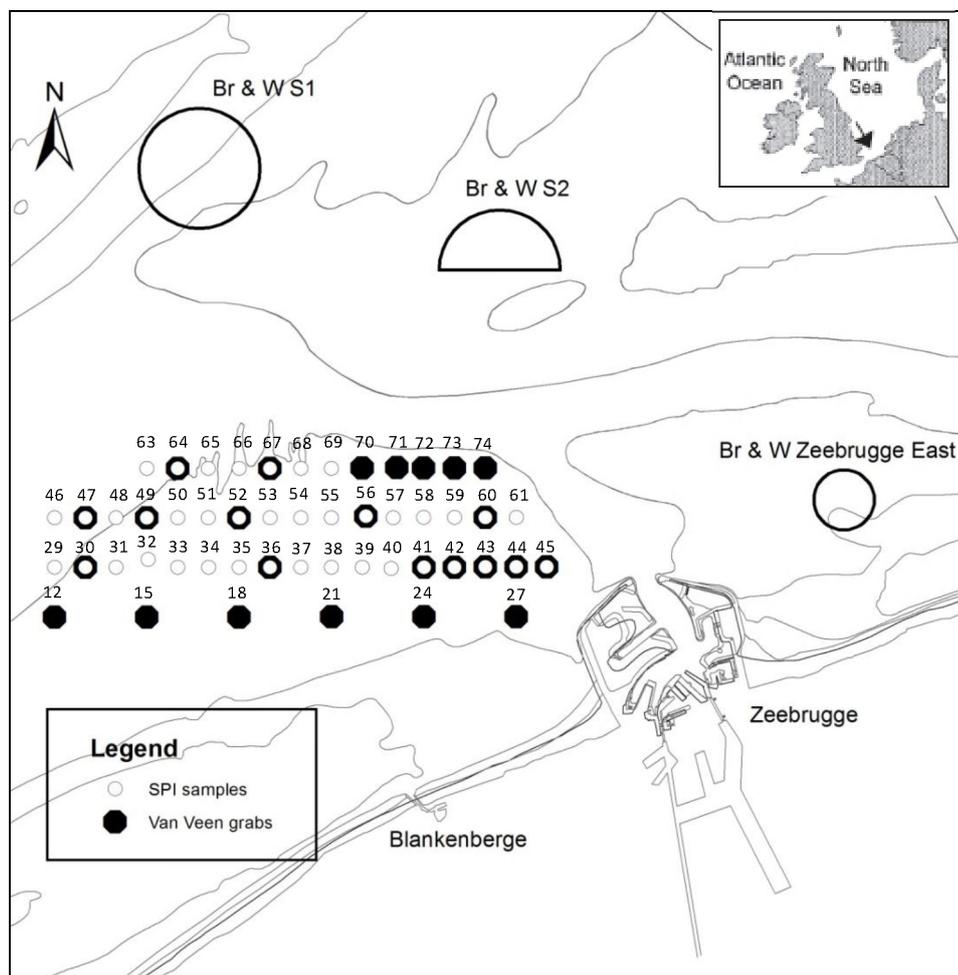

Figure 1. Study area, with indication of the sampling points (numbers are the station names), where SPI samples and Van Veen grab samples are taken. The three current dumping areas for the harbor of Zeebrugge are indicated.

2.2 SAMPLING

2.2.1 SPI SAMPLING

Sediment profile imaging (SPI) provides an in situ view of the sediment-water interface and subsurface sediments, typically as much as 25 to 30 cm from the sediment surface, providing both quantitative and qualitative data on the biological, chemical and physical character of the sediments (Rhoads and Germano, 1982, Germano et al., 2011). The SPI camera works like an inverted periscope, which has a wedge-shaped prism with a plexi-glass faceplate and an internal light provided by a flash strobe. The back of the prism has a mirror mounted at a 45° angle which reflects the image of the sediment-water interface at the faceplate up to the camera (Nikon D90 digital SLR, 11 Megapixel resolution). The wedge-shaped prism enters the bottom and is driven into the sediment by its weight (250 kg). A "passive" hydraulic piston ensures that the prism enters the bottom slowly and does not disturb the sediment-water interface. On impact with the bottom, a trigger activates a time-delay on the camera shutter release and a photograph is taken when the prism comes to rest. For this survey, the initial delay was set to 15 seconds with a second photo being taken after a further 15 seconds. Three replicate samples per station were taken. The SPI camera used for this study is provided by Cefas and manufactured by Ocean Imaging Systems Inc. (Massachusetts, USA). The SPI sampling was executed at 40 stations with the RV Belgica on 6-7 March 2012 (Figure 1).
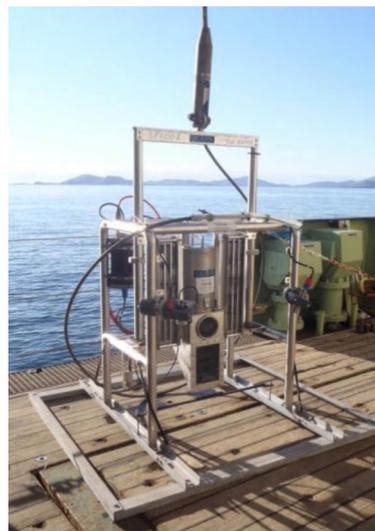
2.2.2 VAN VEEN SAMPLING

To get complementary and additional information, Van Veen grab samples are taken at some similar locations as the SPI samples (regular distributed over the SPI grid) and at stations where the SPI images have shown poor visibility (Figure 1). This sampling was executed with the RV Zeeleeuw on 5 April 2012. The following parameters were collected: species composition, their abundance and biomass, and quantitative sediment characteristics (median grain size, sediment composition). Therefore, at each station, one Van Veen grab (0.1 m²) was taken (Figure 1), sieved on board on a 1mm sieve and fixated with 8% formaldehyde. Of each Van Veen grab a picture was taken to make a visual description of the sediment characteristics. After sieving, all organisms are identified to the lowest possible taxonomic level (species level), counted and weighed (Wet Weight). Of each Van Veen grab, a sediment core sample (3.6 cm diameter) was taken for sedimentological analysis.

2.3   SEDIMENTOLOGICAL AND BIOLOGICAL ANALYSES

2.3.1   SEDIMENTOLOGY

Based on the SPI and grab sample analyses, we give a description of the following physical parameters: sediment composition, surface boundary roughness and a-RPD. For the parameter sediment composition, we also compare these characteristics, deduced from the visual sediment descriptions (SPI and Van Veen picture) with the sediment categories of the detailed sediment analysis for a selection of the stations. Based on a compilation of the sedimentological information, we were able to visualize the distribution of the different sediment categories within the area. This pattern was visualized in ArcGIS10.0.

The following parameters were obtained from the SPI image analyses:

1) Penetration info: minimum and maximum penetration depth (cm), average penetration depth ((max pen + min pen)/2)
2) Surface relief or boundary roughness (cm) is determined based on the penetration info (max pen – min pen) and is an indication of the unevenness of the sediment, which can be a result of faunal activity in the sediment (bioturbation) or from physical disturbance.
3) The apparent redox discontinuity layer (aRPD) was measured by assessing color and reflectance boundaries within the images and is the visible line between the oxygenated and reduced sediments. The a-RPD depth increases when biological activity is high; when it is low or absent, the a-RPD depth decreases.
4) Grain size type and sediment description, sediment color, sediment class
5) Surface and subsurface faunal features: tubes, epifauna, infauna, burrows

These SPI analyses were done completely for 24 of the SPI stations, for another 13 it was only analyzed for their sediment description and for 3 stations it failed (Table 1 in appendix). The penetration depth of the SPI prism was sufficient at most stations (between 7.4 cm and 24.4 cm), but was lower at stations with more coarse sandy sediments compared to stations where the sediments were predominately soft with high silt and clay content and fine sands (Table 1 in appendix). Detailed analyses were not done for all pictures, because a part of them showed a poor visibility. This poor visibility was caused by the very high turbidity within the study area, which caused obscuration within the prism, despite the tight sealing. The Wandelaar area is located in the zone of the BPNS where the maximum turbidity zone is located.

The five sediment class categories, which were determined for the visual sediment description of the SPI and Van Veen pictures was based on rather subjective criteria: (1) Mud (mud dominates); (2) Muddy fine sand (mud with sand), (3) Medium sand (no mud, sand dominates), (4) Coarse sand (sand and a lot of shell material) and (5) Mixed sediments (substantial mud, sand and shells present).

The quantitative sediment information was obtained by drying the sediment sample from the Van Veen at 60° C and analyze it with a Malvern Mastersizer (0.02-2000 microns) (laser diffraction method). The obtained sediment composition and median grain size results were used to assign the samples to one of the five sediment categories, with more objective criteria:

(1) mud (<63 μm more than 20%, no high % of coarse sand or shells, D(50)<125 μm); (2) muddy fine sand (dominance of 125-250 μm class, mud present < 25%, 125<D(50)<230 μm), (3) Medium sand (dominance of 125-250 μm and 250-500 μm class, 230<D(50)<350 μm), (4) Coarse sand (high percentage of 500-1000 μm class and D(50)>350 μm) and (5) Mixed sediments (substantial mud, sand and shells (>1600 μm class) present).

Finally, the linking of these sedimentological categories with potential benthic communities was based on the following habitat description: (1) mud = *Macoma balthica* habitat; (2) fine muddy sand = *Alba alba* habitat; (3) clean medium sand = *Nephtys cirrosa* habitat; (4) coarse sand = *Ophelia borealis* habitat (Van Hoey *et al.*, 2004; Degraer *et al.*, 2008).

2.3.2 BIOLOGY

The biological parameters used in this study are abundance (ind/m²), biomass (Wet Weight/m²), species richness (S/0.1m²), the exponential form of the Shannon-Wiener index (exp H#) (log base e) and the reciprocal of Simpson's index (1/Simpson) (Whittaker, 1972; Magurran, 1988). S is the number of all species regardless of abundance, exp H# is most affected by species in the middle of the species rank sequence, whereas 1/Simpson is primarily a measure of dominance (Whittaker, 1972). The biological patterns were visualized in ArcGIS10.0.

Community patterns within the biological data were obtained by multivariate analysis (cluster analyses, MDS) on a fourth-rout transformed abundance dataset. The cluster groups were defined, based on a SIMPROF analysis and the typical species of each cluster group using SIMPER analysis. The significance in biological characteristics between the groups was tested with a permutational manova, with Monto Carlo correction on a Euclidian distance resemblance matrix. These analyses are accomplished using the PRIMER-E V6/PERMANOVA 5 package.

Furthermore, the biological traits of the 43 species were collected from the Biological Traits Information Catalogue (BIOTIC) of MarLIN (MarLIN, 2006) and from best professional judgment. The following traits categories were examined: motility, feeding, habitat structure, sediment transport, size, position in the sediment, reproductive strategy, hypoxia sensitivity and longevity. For each category, different traits were scored between 0 and 1 (fractions) within each traits (all trait groups within a trait will sum to 1 for each taxon) (Table 2). The abundance of each biological trait at a stations was based on the sum of the density data of each taxon within that trait. The difference in biological trait classes is examined between the two main biological cluster groups.

Table 2. Indication of the different biological traits categories, their codes and description.

Category	Trait	code	Description
Motility	Sedentary	Mot.sed	Non-moving
	Limited free movement	Mot.lim	e.g., withdrawal into sediment
	Freely motile in or on sediment	Mot.fre	free-moving, roaming
	Semi-pelagic	Mot.spel	more water-associated, hyperbenthos, demersal nekton
Feeding	Suspension	Feed.sus	Relying on water currents to deliver food particles
	Deposit feeder	Feed.dep	Feeding on refractory detrital material on or in the sediment
	Predator	Feed.pre	Actively hunting for live animals
	Scavenger	Feed.sca	Consuming dead animals
	Grazer	Feed.gra	Consuming algal or plantlike material
	Parasite or commensal	Feed.com	Parasite/commensal
Habitat structure	Permanent burrow	Struc.bur	Permanent burrow
	Hole, pit or non-permanent burrow	Struc.pit	Hole or burrow that's not permanent
	Tube	Struc.tub	Living in tube
	Creating troughs or trampling across sediment surface	Struc.tra	Changing sediment surface for a while
	Forming biogenic epibenthic structures	Struc.epi	The organisms whose body constitute a form above the sediment
Sediment transport	Surface-to-deep	Sed.sd	e.g. head-up conveyer belt feeder (defecate at depth)
	Deep-to-surface	Sed.ds	e.g. head-down conveyor belt feeder (defecate at surface)
	Surface mixing	Sed.sm	surface biodiffusive
	Deep mixing	Sed.dm	deep biodiffusive
Size	Small	Size.s	1-3 mm longest dimension
	Medium	Size.m	3-10 mm longest dimension
	Large	Size.l	>10 mm longest dimension
Position in sediment	Protruding surface	Pos.pro	Through and above sediment surface
	Attached	Pos.att	To other animals or small hard surfaces
	Oxygenated zone	Pos.oxy	Yellow or brown zone in surface sediment
	Below the oxygenated zone	Pos.sox	Dark grey or black and usually sulfidic zone deeper in sediment
Reproductive strategy	Asexual	Sex.asex	Budding, parthenogenesis
	Spawn	Sex.spa	Gonochoristic, both sexes spawn gamters in water column
	Attached eggs	Sex.egg	Gonochoristic, the egges are attached to substracte
	brood	Sex.bro	Gonochoristic, the eggs are kept in or on the body or coelom
Hypoxia sensitivity	Low	Hyp.low	High or long tolerance (e.g. >21 days)
	high	Hyp.hig	Low or short tolerance (e.g. 0-2 days)
Longevity (yr)	<2	Long.2	years
	2-5	Long.5	
	6-10	Long.10	
	>10	Long.10p	

2.1 BIOLOGICAL VALUE

The biological value of the area was evaluated based on the protocol described in Derous et al. (2007 a,b). A comprehensive valuation assessment protocol can be obtained by using a set of possible assessment questions related to different structures and processes of biodiversity, coupled to the proposed valuation criteria (Smith and Theberge, 1986; Derous et al., 2007a,b). When applying this framework to a given study area, experts should select the questions most appropriate for that area (regarding the data availability, the presence of certain structures/processes) and determine the different class boundaries needed to score the questions. We selected some of the questions (Q) as in Derous et al. (2007a), which were related to the determination of the abundance of certain (Q1) and rare species (Q4), the counts of rare species (Q3), the abundance of habitat-forming species (Q5), the abundance of ecologically important species (Q6), the species richness (Q7) and the presence of distinctive communities (Q8) (Table 3). The benthic species classification as certain, rare, habitat-forming and ecologically important is based on the list within Derous et al. (2007a). To these questions, we added 3 extra questions, reflecting on the functioning and structure (sediment) of the system (Table 3). Q2 was based on the biomass of certain species and referring to the productivity at the location. Q9 judged the amount of biological traits present at the location. A structural questions (Q10) was based on the a-RPD, which can be linked to the benthic infaunal successional stage and the degree of the oxygenation of the sediment (Pearson & Rosenberg, 1978; Nilsson & Rosenberg, 2000). The biological value is only be determined for the stations where a Van veen grab was taken, because mainly biological information was necessary to run the procedure. Question 10 was only evaluated at the stations where detailed SPI analysis were available. For all questions, we used the semi-quantitative scoring system, with five classes (very low [1], low [2], medium [3], high [4] and very high [5]) of Derous et al. (2007a). Boundary values are determined for each of these 5 classes and for each question, based on the expected values for each parameter within the BPNS (Table 3) (Van Hoey et al., 2004; Derous et al., 2007a,b; Van Hoey et al., 2013). By this way, the scoring of each station (sub-zone) in the Wandelaar area was done relatively to the biological valuation of the benthic habitats on the entire BPNS. The biological value at a station is based on the average of the question scores. The highly valued areas (score 4 or 5) can then be considered as 'hotspots' that reflect the highest biological value and should be avoided to execute human activities.

Table 3. Questions and criteria for scoring the biological value of the samples within the Wandelaar area.

	Questions	very low (1)	low (2)	medium (3)	high (4)	very high (5)	unit	Remark
Q1	Is the abundance of a certain species very high?	<100	100-500	500-1000	1000-5000	>5000	ind/m²	
Q2	Is the biomass of certain species very high(good productivity)?	<5	5-50	50-100	100-1000	>1000	WW/m²	
Q3	Is the area characterized by the presence of many rare species?	0	<3	3-6	6-9	>9	#/0.1m²	
Q4	Is the abundance of rare species high?	0	<20	21-100	101-500	>500	ind/m²	
Q5	Is the abundance of habitat-forming species high?	0	1-100	101-500	501-1000	>1000	ind/m²	*Lanice conchilega, Owenia fusiformis*
Q6	Is the abundance of ecologically significant species high?	0	1-100	100-500	500-1000	>1000	ind/m²	*Abra alba, Spisula spp*
Q7	Is the species richness high?	<5	5-15	15-25	25-35	>35	#/0.1m²	
Q8	Are there distinctive/unique communities present?	Ophelia	Macoma	Nephtys		Abra		b=Ophelia; d=Macoma
Q9	Are there obvious, unique functional traits?	<15	15-20	20-25	25-30	30-34	#	Mas considered 34.
Q10	The depth of the a-RPD layer?	0	0-2	2.1-3.5	3.6-5	>5	cm	BHQ classes for a-RPD*
	Average biological value score	0-1.8	1.8-2.6	2.6-3.4	3.4-4.2	>4.2		Derous et al., 2007a

3   RESULTS

3.1   SEDIMENTOLOGY

3.1.1   SEDIMENT COMPOSITION

In this study, the dominant sediment types were soft mud/clay and coarse sandy sediments. A rather good visual correspondence is obtained by the SPI and Van veen images, but with a much better visualization of the layering of the sediment in the profile images (Figure 2). A lot of stations showed on the SPI images a clear indication of added material. This is clearly visible at station SP60, where there are fluid mud layers on top of the coarse sediment, whereas on the Van Veen images, mainly the coarse sediment is visible and the fluid mud limited (Figure 2). Differences in sediment structure were also visible at station SP47 (mud on sand) and SP49 (Black clasts of material), whereas the sediment was mixed on the Van Veen image. When comparing the visual sediment composition classifications, we see that 82% (9/11) of the stations are classified in the same class (Table 4). When comparing the visual classifications with the quantitative sediment analyses, we see only a 60% (15/25) correspondence. For example, the stations SP70 until SP74 were characterized as mixed sediment by the Van Veen images (coarse sand and compact mud), but this mud was not found in the quantitative sediment analysis.
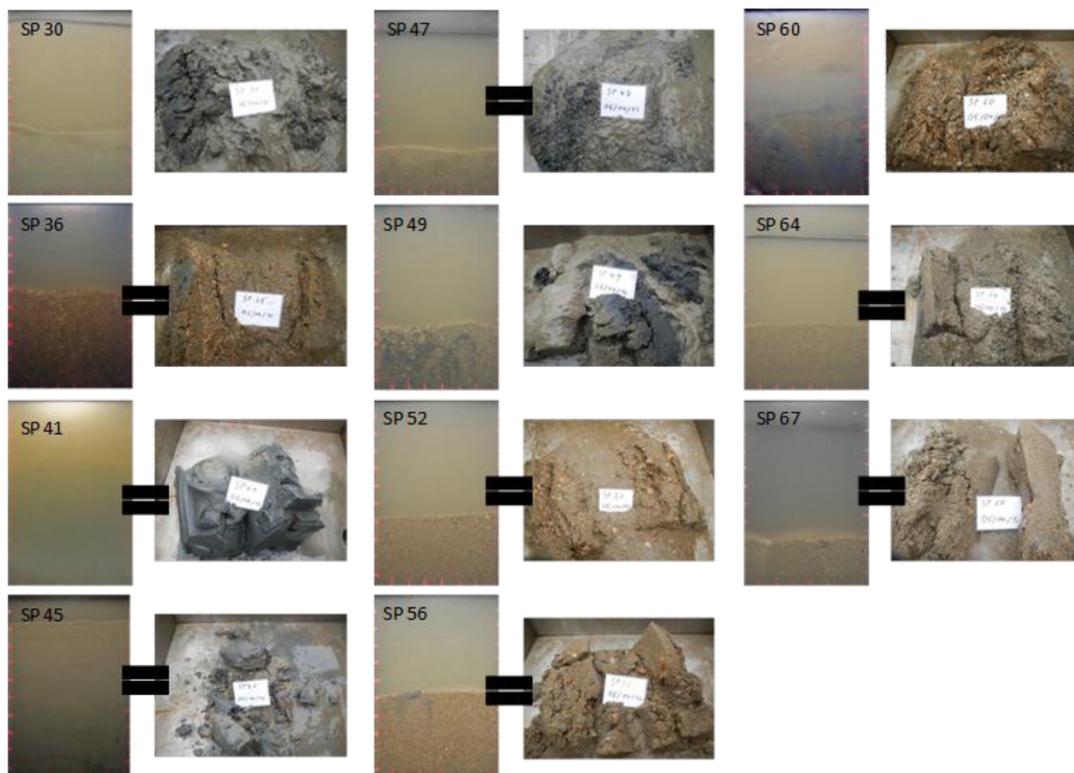

Figure 2. Sediment Profile Images and Van Veen pictures at 11 sampling stations.

Station	SPI images	Van Veen image	Sediment analyse
sp012		**mud**	**mud**
sp015		**mud**	**mud**
sp018		**mixed**	**mixed**
sp021		mud	mixed
sp024		**mud**	**mud**
sp027		mixed	muddy fine sand
sp030	mud	mixed	mixed
sp036	**coarse sand**	**coarse sand**	**coarse sand**
sp041	**mud**	**mud**	**mud**
sp042		muddy fine sand	medium sand
sp043		mud	mixed
sp044		**muddy fine sand**	**muddy fine sand**
sp045	**mud**	**mud**	**mud**
sp047	**mixed**	**mixed**	**mixed**
sp049	medium sand	mixed	mixed
sp052	**coarse sand**	**coarse sand**	**coarse sand**
sp056	**coarse sand**	**coarse sand**	**coarse sand**
sp060	mixed	coarse sand	coarse sand
sp064	medium sand	medium sand	mixed
sp067	medium sand	medium sand	coarse sand
sp070		mixed	coarse sand
sp071		mixed	medium sand
sp072		**mixed**	**mixed**
sp073		mixed	medium sand
sp074		mixed	coarse sand

3.1.2 SURFACE BOUNDARY ROUGHNESS

During the survey, the overall values ranged from 0.1 cm - 4.2 cm and was low in most cases (<1 cm), indicating a flat bottom. In this study, the unevenness of the bottom is in most cases the result of the presence of heterogeneous sediments (some cohesive lumps) (e.g. SP 63, Figure 3), rather than biological activity.

3.1.3 APPARENT REDOX DISCONTINUITY LAYER (A-RPD)

The depth of this a-RPD layer ranged from a depth of 2.1 cm to > 12 cm or fully oxygenated (Table 1). At some stations (e.g. SP57, 59, 63, Figure 3), clear anoxic black layers were visible, whereas at other stations (e.g. SP49, 60, Figure 2) black spots of anoxic

Figure 3. Sediment profile images showing some faunal activity (upper row) and different patterns of the a-RPD layer (lower row).
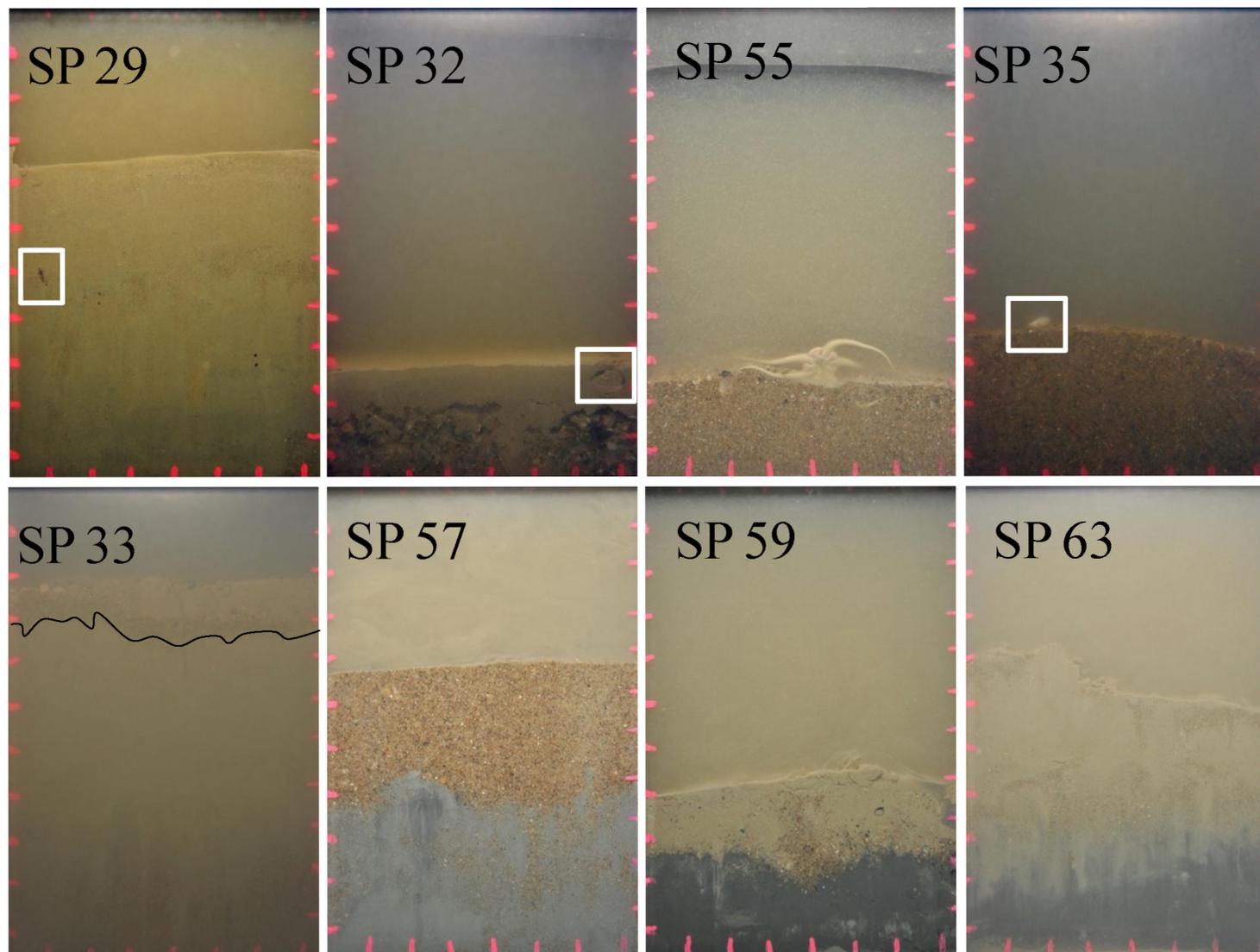
sediment were apparent. At some of these stations, there was also a distinctive thin layer of fine sediments covering deeper layers of added material (station SP59 and 32). In the case of clear presence of fauna (e.g. SP29, 32 and 55, Figure 3), there was a deep and uneven a-RPD layer, which also showed some degree of mixing of the sediment throughout the profile. At stations with indications of sediment disposal, the fauna was restricted to only the surface layers (e.g. SP33), showing a typically shallower a-RPD layer. There are stations where there was newly material added which exhibit the typical a-RPD (solid based on clean material) (e.g. SP 57, 63). The added material at some locations is probably the result of natural sediment processes within the area (wind, waves, storms).

3.1.4 SEDIMENT MAP

The Wandelaar area showed a clear sedimentological pattern with the central area characterised by medium to coarse sediments, with low mud contents (Figure 4). The southeastern and southwestern area is typified by muddy to fine sandy sediments. The northern part is characterised by mixed sediments, where mud and cohesive mud layers are mixed with coarse sand. In general, the area gradually changes from west to east from muddy fine sand over mixed and coarse sand back to muddy or fine sand in the southern part to mixed sediments in the northern part.
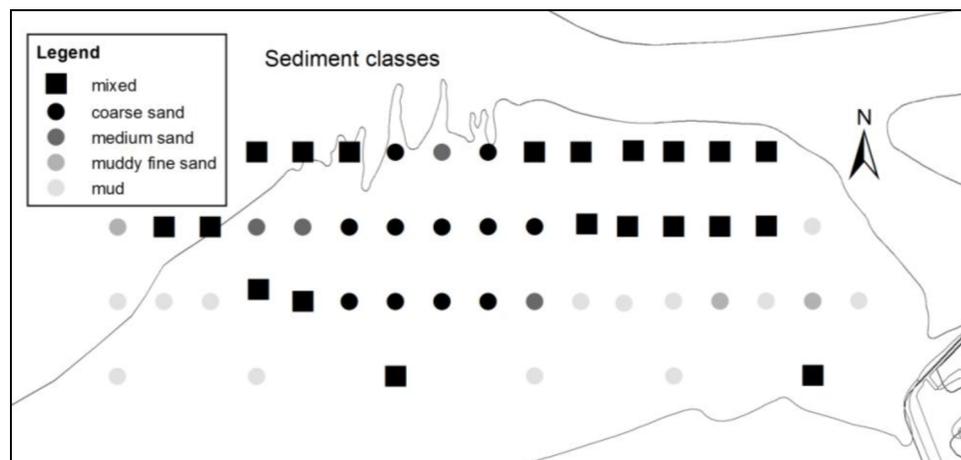
Figure 4. Sediment map of the area, with indication of the 5 sediment classes, based on a combined analysis of the SPI and Van Veen images.

3.2 BIOLOGY

3.2.1 BIOLOGICAL CHARACTERISTICS: SPI ANALYSES

In some of the images, there were clear indications of bioturbation and reworking of the sediment (oxygenation via burrows) (zie table 1). A clear example is the presence of a polychaete (red appearance inside a burrow) at station 29 (Figure 3) and some bivalves at station 35 and 36 (Table 1; Figure 3). At some stations, e.g. station 55, the presence of an ophiuroid (*Ophiura spp.*) was observed (Figure 3). No tube structures or bedforms were

observed in this area. Based on the analysis of the biological activity of the SPI images, we can concluded that there is minor visible biological activity within this area, especially from larger infaunal organisms.

3.2.2 BIOLOGICAL CHARACTERISTICS: VAN VEEN GRAB ANALYSES
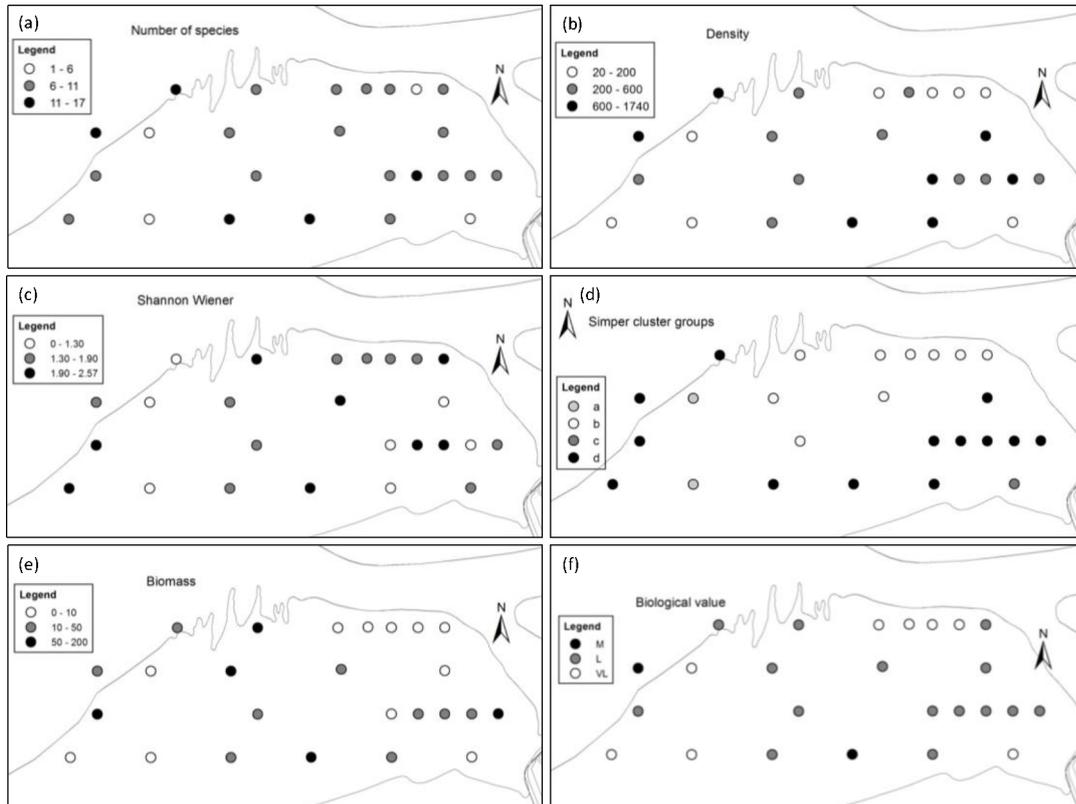
Figure 5. Maps with indication of biological characteristics of the stations. a) the number of species per 0.1m²; b) Density (ind/m²) ; c) Shannon wiener index ; d) Simper cluster groups; e) Biomass (Wet Weight/m²); f) Biological value.

The spatial pattern of the benthic parameters (number of species, density, biomass and Shannon wiener diversity) within the area showed a rather scattered pattern (Figure 5). There were no obvious differences within the area for number of species (#/0.1m²), with in general 6 to 11 species per grab sample (Figure 5a). The two samples at the western border of the Wandelaar area were characterised by the highest densities and number of species, but a low Shannon diversity, due to the dominance of *Scoloplos armiger*. The densities of the benthic species (ind/m²) were lowest in the Northern part of the Wandelaar area and were highest in the Southeastern part (Figure 5b). The Shannon wiener diversity was generally low within this area, and showed a scattered pattern (Figure 5c). The lowest Shannon diversity values were observed in samples, in which *S. armiger* or *Cirratulidae spp* dominated. The biomass (g Wet weight/m²) within the area was generally low, except at some stations with bivalve species (*Macoma balthica*) (Figure 5e). The northeastern area and some spots in the Southwest were characterised by the lowest biomass values.

The multivariate pattern revealed the presence of two main cluster groups b (similarity 32%) and d (similarity 30%) and two small 'outlier' groups a (similarity 48%) and c (similarity 23%). These two main groups did not differ that much in number of species (8 for group b and 11 for group d), but significantly (p=0.028) (Table 5). The difference was not significantly for Shannon diversity (1.78 for group b and 1.65 for group d) (p=0.461) and Simpson diversity (0.79 for group b and 0.67 for group d) (p=0.097). The density was significantly different (p=0.011) between the two groups and highest for group d (685 ind/m² versus 455.1 ind/m²). The species composition differed also clearly between the two groups (SIMPER). Group b was characterised by *Cirratulidae spp*, *Oligochaeta spp* and *Heteromastus filiformis*, typical for muddy sediments. Group d was dominated by *Macoma balthica*, *Scoloplos armiger* and *Gastrosaccus spinifer*, the last two species more typical for sandy sediments. The two stations of group a were characterised by only one species (*H. filiformis*) and a very low density (25 ind/m²). The station of group C was characterised by a low species richness (6/0.1m²) and density (110 ind/m²). The dominant species were *Bathyporeia spp* and *Nephtys spp*. juveniles.

Table 5. Biological and sedimentological characteristics of the simper cluster groups.

	a		b		c		d	
	average	stdev	average	stdev	average	stdev	average	stdev
d (05) (µm)	35.1	17.7	455.1	152.8	215.0		163.1	139.4
<63µm	68.9	29.2	2.8	6.3	0.0		36.8	30.0
63µm-125µm	8.8	1.7	0.5	0.9	1.0		7.6	4.7
125µm-250µm	4.6	5.8	11.3	8.6	68.0		19.7	13.4
250µm-500µm	6.7	9.4	41.4	14.9	26.3		17.5	11.2
500µm-1000µm	3.5	4.9	28.4	10.8	0.0		5.8	8.6
1000µm-1600µm	0.3	0.4	6.0	7.9	0.0		1.4	2.8
>1600µm	7.3	10.4	9.6	5.8	4.7		11.2	8.7
S (0.1m²)	2	1	8	2	6		11	3
N (ind/m²)	25	7	251	144	110		685	450
H'	0.55	0.78	1.78	0.21	1.59		1.65	0.51
Simpson	0.34	0.49	0.79	0.07	0.77		0.67	0.19
SIMPER species	*Heteromastus filiformis*		*Macoma balthica*		*Bathyporeia spp*		*Cirratulidae spp*	
			Scoloplos armiger		*Nephtys juv*		*Oligochaeta spp*	
			Gastrosaccus spinifer				*Heteromastus filiformis*	
			Spiophanes bombyx				*Mesopodopsis slaberii*	
			Mesopodopsis slaberii				*Abra alba*	
			Nephtys juv				*Nephtys hombergii*	
							Nephtys juv	

The biological differences in the cluster groups can be partly related to a difference in sedimentology (DistLM: r²=0.478). The stations within group d were characterised by a relative high mud content (%<63µm=36.8) or muddy fine sands (median grain size= 163.1), whereas the stations within group b were characterised by coarser sediment (median grain size=455.1) and low mud contents (%<63µm=2.8) (Table 5). The stations in group a were characterised by a high mud content (%<63µm=68.9), whereas the station in group c was characterised by a high percentage of fine sand (%125-250µm=68).

The spatial pattern of these cluster groups showed that samples of group b were situated in the central and northeastern part of the area (Figure 5d). The samples of group d were

located in the south-southeastern part and the western border of the area. The station of group c was located in the southeast, nearby the Zeebrugge harbor wall, whereas the two stations of group a in the western part.

3.2.3 BIOLOGICAL TRAITS

For motility, we see that group d was dominated by sedentary organisms together with organisms with a limited motility (Figure 6). In group b, free-moving species and organisms with a limited motility dominated. The same pattern was found in the habitat structure types, where group b contained organisms making mainly holes, pits or non-permanent burrows. In group d, 50% of the organisms living in permanent burrows. Such differences had its consequence on the organisms function, regarding the sediment transport: species in group d were mainly head-up conveyer belt feeders and those in group b were mainly surface bio-diffusers. Another difference between both cluster groups was observed towards their sensitivity to hypoxia, where more organisms showed a higher tolerance to hypoxia in group d. Nevertheless, the organisms in both groups preferred to live in the oxygenated zone of the sediment. The organisms in group b were generally from a smaller size category and had a short living time. Regarding, the feeding types, there was almost no difference, with a dominance of deposit feeders in both groups. The same was observed regarding their preferable reproductive strategy (mainly gonochoristic, with both sexes spawning gametes in the water column).

3.3 BIOLOGICAL VALUE

The biological value of all samples was catalogued as low (1.8-2.6) to very low (<1.8), except for station 21 and 47 (moderate). The difference in biological value between the samples could be attributed to difference in the biomass of species, the abundances of rare species and presence/absence of ecological significant species. The question on the a-RPD was responsible for a slight increase in biological value, especially in sandy environment (mostly well oxygenated). The western, southern and eastern boundaries of the investigated area showed the highest biological value, and the northern and central area the lowest (Figure 5f). The stations located in a more muddy environment seemed to have a slightly higher biological value than those in a sandy environment.

Figure 6. Proportional occurrence of the different biological traits within the two main cluster groups (biological communities).
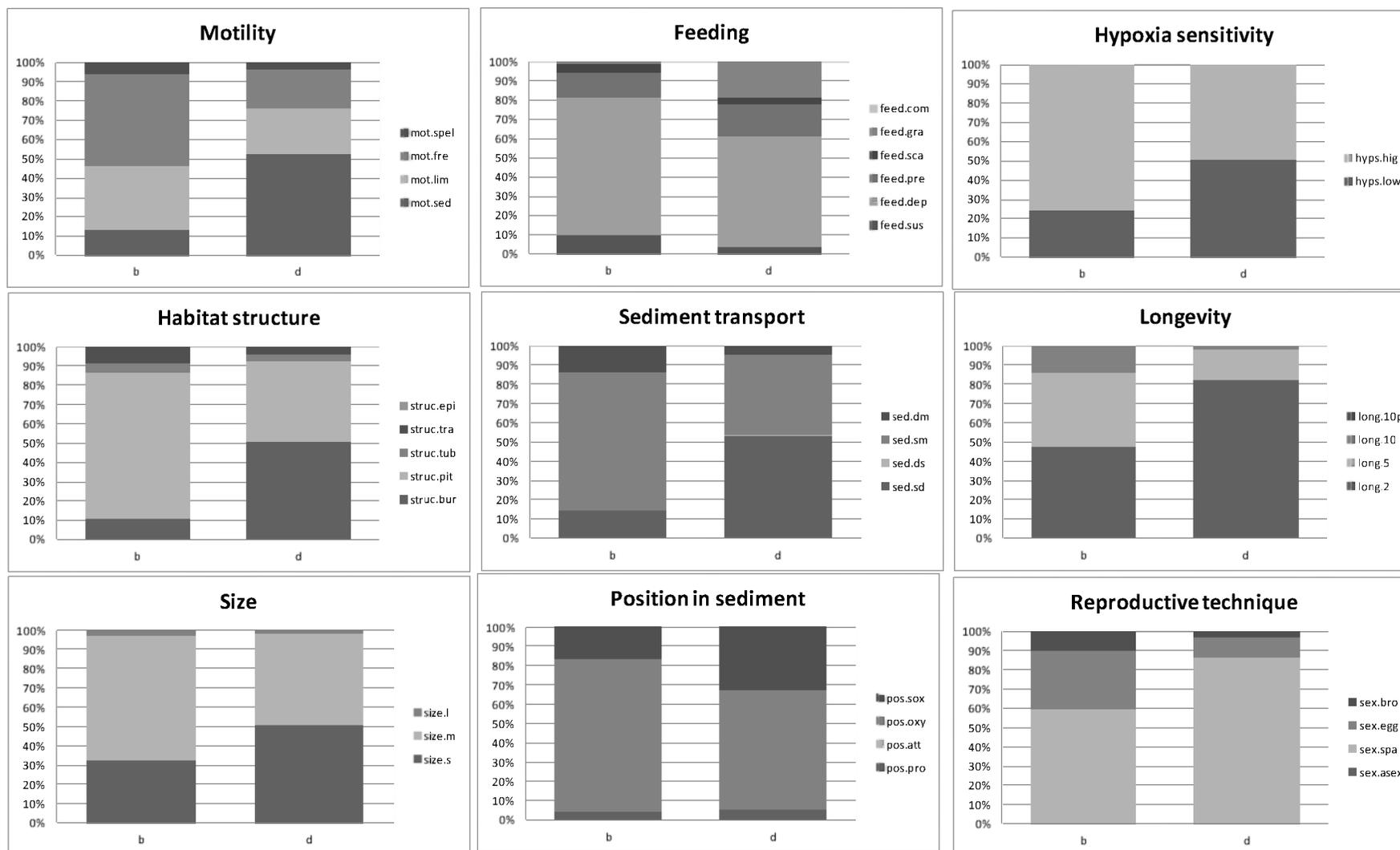
4 DISCUSSION

The objective of this study was to use two techniques (Van Veen grab, SPI) to deliver suitable and comprehensive information on the sedimentological and biological characteristics of the 'Wandelaar' area in the coastal zone of the BPNS, as input for the re-allocation of a site for dredged material disposal. The ultimate goal was to determine the biological value of that area, so that the future dredge disposal activity can be executed in a sustainable manner. Open water disposal of dredged material is an environmental concern, which is monitored worldwide (Blanchard and Feder, 2003; Fredette and French, 2004; Bolam et al., 2006; Powilleit et al., 2006; Wilber et al., 2007; Dae-In et al., 2010;). The effects of dredged material disposal, like direct burial by dredged material, reduction in community diversity, and a shift in the dominance patterns within the benthic community are well documented (Bolam and Rees, 2003). An essential step in the allocation of a new site for dredged material disposal or other marine activity is gathering detailed ecological and physical knowledge of the wider area. On this manner, the dumping side can be located at a spot within this area, where there is minimal conflict with the natural ecological and physical characteristics. This investigation is ideally followed up by a T0 monitoring of the effective selected side, continued with impact monitoring. T0 monitoring is a regular phenomena for new activities and nowadays regulated by law. A pre-T0 on a wide scale has the advantage that possible conflicts between human activities and the ecology is objectively evaluated on beforehand, which forms the basis for MER studies.

To reach this goal, we analyzed in first instance the sedimentology of the area to reflect on the habitat potential. Secondly, we focused on the biological information, more precisely the species presence, densities and biomass, but also species functions. These two steps had to lead to the determination of the biological value of the area.

4.1 SEDIMENTOLOGY

From a benthic habitat point of view, the sedimentological characteristics are the major determining factors for their distribution (Snelgrove & Buttman, 1994; Van Hoey et al., 2004; Degraer et al., 2008). This study shows that SPI, Van Veen pictures and sediment core analyses give a lot of information on the sedimentological characteristics within an area, but in a different way. The SPI gives a clear view on the sediment characteristics and organization (layering) at a location. Additional, it allows to make quantitative estimates of the a-RPD layer, which can be linked to a potential degree of biological activity at this spot. This a-RPD depth can be used to assess the successional stages of the benthic habitat (Rhoads & Germano, 1986; Nilsson & Rosenberg, 1997). The BHQ index (Benthic-habitat quality) uses this a-RPD depth and classifies it in 6 categories in accordance to the successional stages (from oxidized over reduced to anoxic sediments) (Nilsson & Rosenberg, 1997, 2000). This classification was also used in this study to set the thresholds for question 10 in the biological valuation. Based on the a-RPD information, the 'Wandelaar' area seems to consist of some locations with reduced sediments, whereas the

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majority of the locations consist of well oxidized sediments. This indicates that possible occurrence of species is not directly limited by oxygen within the sediments. This type of information cannot directly be retrieved from the Van Veen pictures, because structure of the sediment is not conserved. A disadvantage of image analyses is that they does not give quantitative data on sediment composition and are rather subjective. This aspect is taken into account by the sediment composition analyses (e.g. laser diffraction method). A comparison shows that there clearly is a discrepancy between the techniques in some case. This is due to the not uniform assessment of the mixed sediment types, especially when they layered, possibly due to an inadequate core sampling. Additionally, mud is sometimes not detected with the laser diffraction method, due to the low analyzed volume, despite the homogeneity of the sample. Thirdly, when using two different sampling technique, there are differences in the positioning of the samples (in this study within 50m range), leading sometimes to the detection of rather different sediment types. Finally, the technique of visual sediment description is subjective. However, all techniques give complementary info in that way that when it is compiled, we get a comprehensive view on the sedimentology of the studied area.

The 'Wandelaar' area is a small area, but it is characterised by a diverse sedimentology, ranging from mud to coarse sediments. The spatial pattern of these sedimentological characteristics show a central coarse sandy area, surrounded by mixed sediments. The southeastern part consist of muddy to muddy fine sands. For the habitat potential of the area (Degraer et al., 2008) this means that a mixture of benthic communities can occur. Previous studies, based on modeling, defined parts of this area as possible *Macoma balthica* habitat (Degraer et al., 2008). Currently, the area seems to have the potential to contain a mixture of *Macoma balthica, Abra alba* and *Ophelia borealis* habitat. However, the SPI images shows that within this area, there is a mixture of sediment types, with frequent incorporation of mud within coarser sediments and anoxic black layers. This is an indication of instability of the sedimentological characteristics at some locations within the Wandelaar area, which undoubtedly have its consequences on the biology.

4.2   BIOLOGY

The SPI analyses showed only a few organisms or their traces, from which we concluded that this area has a low biological activity. This means that, within this area, there are a low amount of organisms, and habitat structuring organisms (e.g. tube building worms) were rare and if organisms were present they were rather small. However, the a-RPD analyses indicate the potential for biological activity, because the top layers are mainly oxic, although clear anoxic (black) deeper sediment layers or spots are present on some locations. The Van veen analyses confirmed the low diversity, the low densities (with some exceptions) and biomass within the area. If a species was present in high densities, it were small opportunistic species (Cirratulidae spp, *Microphthalmus spp, Scoloplos armiger*). Based on a community analysis, we distinguished two main species communities within the area. The first (cluster group b) can be linked with the coarse sand habitat of the BPNS (*Ophelia borealis* habitat) (Van Hoey et al., 2004), but with the dominant presence of some coastal, more mud loving species (e.g. *Macoma balthica, Mesopodopsis slaberii*). The

sediment type was identified as mixed sediments, which is a suitable habitat for the dominant, characterizing species of these samples, *Scoloplos armiger*. *S. armiger* prefers sediments with a median grain size of 200-350µm that are enriched with mud (mud content up to 40%) (Degraer et al., 2006). The biological traits analysis showed that the species present within this group were more or less mobile, deposit feeding, surface bio-diffusive species. These traits are indicative of species with a resilience to frequent changes within their physical environment. Finaly, we catalogued the coarse, (mixed) sandy habitat within the Wandelaar area as an impoverished *Ophelia borealis* habitat, lacking ecologically important species.

The second main cluster (group d) was linked with the muddy habitat (*Macoma balthica* habitat) or muddy fine sand habitat (*Abra alba* habitat) (Van Hoey et al., 2004). The muddy fine sand habitat is mostly characterised by high densities and diversity, but this was not really present within the Wandelaar area. The samples within this group were rather characterised by opportunistic species (Cirratulidae spp, Oligochaeta spp and *Hetermomastus filiformis*). The biological trait analysis showed that mainly small, sedentary, deposit feeding species inhabit the area. They have a higher tolerance to temporary anoxic conditions. Therefore, we considered the southeastern area and the western part of the Wandelaar area as *Macoma balthica* habitat.

Within the Wandelaar area, most of the species are short living and opportunistic, which is probably due to the physically instable environment. Therefore, it is expected that those species show some tolerance and resilience to dredge disposal.

4.3 BIOLOGICAL VALUE

Local and worldwide research indicates that the disposal of dredged material has minimal environmental impact when carefully managed, because disposal typically has near-field and short-term impacts (Fredette & French, 2004; Bolam et al., 2004; Lauwaert et al., 2011). Of course, dredge disposal should not be executed in valuable areas (e.g. seagrass, coral reefs, high diversity areas), because of the risk of a severe impact. The Wandelaar area can be characterised as an area with a low biological value relative to other areas within the BPNS area. This is mainly due to the lack of habitat structuring species, absence of the diverse and dense *Abra alba* habitat and a low presence of rare benthic species. This is what we expected based on previous studies (Derous et al., 2007a). The locations which scores relative good is mainly due to the relative high density and biomass of certain species and the presence of a few rare benthic species. The locations with a higher biological value belongs mainly to cluster d. Based on this information, it can be decided that a sub-area within the Wandelaar area is suited as dredge disposal site.

Different options:

1) The northern area of the Wandelaar area (blue circle, Figure 7) is most appropriate, from a biological value point of view (lowest values there). Due to the instability of the physical characteristics within that area, a modelling test has to be runed to determine how newly added material and in which quantity it will be incorporated within the current sediments.

2) Another possibility is to use the central area (red circle, Figure 7), characterised by coarse sand and a low biological value. But in this case, muddy sediments will be disposed on coarse sand, which is not natural there and will possible lead to changes in the sediment and the ecology within this area.

3) A last suggestions is to use the southeastern area (green circle, Figure 7), naturally characterised by muddy sediment and a relative low biological value. A disadvantage of this location is the fact that it is situated in a Bird Directive area and very close to the harbour of Zeebrugge. This can be negative for the flow back of the dredged material towards the harbour.
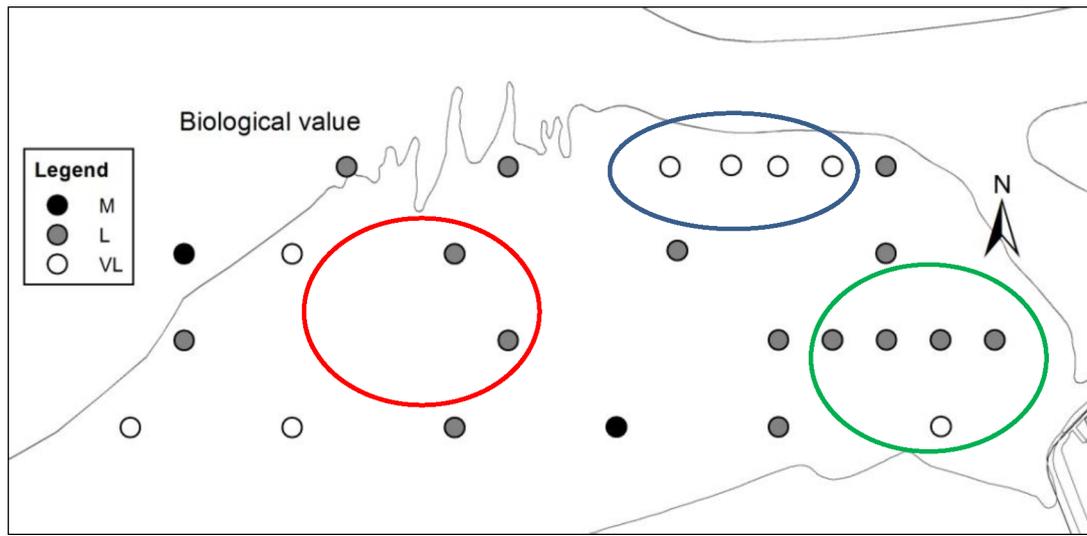

Figure 7: Different options for locating a new site for dredged material disposal within the Wandelaar area.

Next to modelling and detailed bathymetrical survey`s, the SPI technology can give appropriate information on the layering and incorporation of the dredged sediments.

5 CONCLUSION

This study shows and confirms that with complementary techniques, suitable sedimentological and biological information can be gathered for determining the biological potential and value of an area. In the 'Wandelaar' area, physical factors strongly determine the occurrence of the benthic species. The sediments are well oxygenated, but show a high small-scale variability between locations and with sediment depth. These characteristics are best displayed by using the SPI technology. The biological information in this study is mainly obtained by the Van veen grab analyses, because it is not obvious to detect biological activity with the SPI technology in poor benthic environments.

Information on biological value can be gathered, based on a set of assessment questions and related criteria. This area has a low biological value and the benthic system is adapted to changing conditions, due to the dominance of mobile, short living and opportunistic species types. In conclusion the study showed that: (1) SPI and grab sampling are complementary and they provide a detailed assessment of physical and biological characteristics; (2) the biological valuation protocol is very suited for an ecological evaluation of an area in the light of planning marine activities.

6 APPENDIX

Station	Analyse class	min Pen	max pen	Ave Pen	Sur. Rel.	RPD	sediment characteristics (SPI)	Max GrSz (SPI)	Sed. Category	Color	Fauna, tubes or burrows
sp029	OK	23.9	24.9	24.4	1.0	3.9	mud and added layers of other material below	mud	mud	brown grey	
sp030	OK	12.4	14.1	13.2	1.7	2.1	mud and thin layer of fine sand	mud	mud	brown grey	
sp031	poor visibility						mud on medium sand	mud	mud		
sp032	OK	8.3	8.6	8.4	0.4	3.4	Layer of soft mud and mixed corase sand and shells	coarse gravely sand	mixed	brown	1 burrow
sp033	OK	28.5	29.5	29.0	1.0	3.7	clay and some superficial sandy layer covered by clay sediments, bottom of the image coarse sand	mud	mixed	brown and grey	1 burrow
sp034	poor visibility						medium to coarse sand and shell fragements	medium sand	coarse sand		
sp035	OK	9.8	11.8	10.8	2.0	4.1	coarse and medium sand	medium sand	coarse sand	brown grey	1- bivalve M. balthica
sp036	OK	18.1	19.6	18.9	1.5		coarse shelly sand and some patches of fine sand	coarse sand	coarse sand	yellow	1- bivalve M. balthica
sp037	OK	15.3	18.1	16.7	2.8	4.2	medium sand with some small stones and some patches of fine sand	coarse sand	coarse sand	yellow/brown	
sp038	poor visibility						medium sand with very small amout of shells	medium sand	medium sand		
sp039	poor visibility						soft sand over dark material (dredged material)	mud	mud	brown/black	
sp040	poor visibility						fine sandy mud	fine muddy sand	mud	not vissible	
sp041	poor visibility						muddy, fine sand	muddy fine sand	mud	not vissible	
sp042	failed										

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Station	Analyse class	min Pen	max pen	Ave Pen	Sur. Rel.	RPD	sediment characteristics (SPI)	Max GrSz (SPI)	Sed. Category	Color	Fauna, tubes or burrows
sp043	failed										
sp044	failed										
sp045	OK	30.8	31.4	31.1	0.6	3.1	mud, with fine sand	mud	mud	brown	1 burrow
sp046	OK	16.7	17.5	17.1	0.9	5.1	mud and fine sand	mud	muddy fine sand	brown	1-Ophiura albida, 1 burrow
sp047	OK	7.9	8.8	8.4	0.8	6.4	medium to fine sand and a lump of soft clay sediment	coarse sand	mixed	brown/black	
sp048	OK	10.4	11.7	11.0	1.3	6.3	fine and medium sand mixed with broken shells. Layer underneath with a patch of mud	medium sand	mixed	brown	
sp049	OK	10.9	13.3	12.1	2.5	3.5	fine and coarse shelly sand with black clasts of material	fine and medium sand	medium sand	brown	
sp050	limited penetratrion and image 51 analysed in the proximity						medium shelly sand and some patches of fine sand, mud	medium sand	medium sand		
sp051	OK	11.3	11.5	11.4	0.1	8.3	medium shelly sand and some patches of fine sand	coarse sand	coarse sand	brown and black	
sp052	OK	16.5	17.3	16.9	0.8	6.7	top of a clean fine sand and some medium sand underneath	fine sand	coarse sand	yellow	
sp053	OK	5.7	9.1	7.4	3.4	3.9	medium and coarse sand with broken and empty shells in surface	coarse sand	coarse sand	yellow	
sp054	OK	22.7	23.2	22.9	0.5	5.8	medium and fine sand with broken and empty shells in surface	fine sand	coarse sand	yellow	
sp055	OK	7.1	8.4	7.8	1.3	6.4	fine and medium sand with some small shells	fine sand	coarse sand	yellow	1-Ophiurida sp.

Station	Analyse class	min Pen	max pen	Ave Pen	Sur. Rel.	RPD	sediment characteristics (SPI)	Max GrSz (SPI)	Sed. Category	Color	Fauna, tubes or burrows
sp056	sediment in the face plate and suspension of mud						coarse sand with shells	coarse sand	coarse sand		
sp057	OK	22.2	22.9	22.6	0.7	9.7	Fine clean sand and soft grey back clay material under sand	fine sand and added grey material	mixed	yellow and grey	
sp058	OK	13.9	15.5	14.7	1.6		coarse sand with thin veneer of silt material discarded on top	fine and medium sand	mixed	yellow and grey	
sp059	OK	12.7	14.6	13.6	1.8	6.1	mud and fine sand layers and added back-dredged marerial. There is traces of coarse sand under the black material	mud	mixed	grey and black	1 burrow?
sp060	poor visibility						mud, coarse sand, anoxix bottom	mud, coarse sand	mixed		
sp061	limit penetration, poor visibility						mud layer on fine, medium sand	mud	mud		
sp063	OK	19.3	23.5	21.4	4.2	12.0	mud and fine sand over anoxic mud.	mud	mixed	grey/brow and black	1 burrow
sp064	sames as sp065						mud on coarse, medium sand	mud, coarse sand	medium sand		
sp065	limited penetration						medium, coarse sand, with some mud	coarse sand	mixed		
sp066	OK	16.4	17.6	17.0	1.2		coarse sand mixed with newly and old broken shells	coarse sand	coarse sand	brown black	
sp067	OK	9.0	9.9	9.5	0.9	7.6	fine and medium sand mixed with broken shells.	medium sand	medium sand	brown	1-Abra alba?
sp068	sames as sp069						coarse sand with shell fragments, some small mud spots	coarse sand	coarse sand		
sp069	OK	13.0	13.9	13.5	0.9	4.6	fine sand with some small broken shells	fine sand with some black lumps	mixed	yellow brown	

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