

**Intensive evaluation
of the evolution of a
protected benthic habitat:**

HABITAT

**SUSTAINABLE
MANAGEMENT OF
THE NORTH SEA**



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WATERWAYS AND MARINE AFFAIRS ADMINISTRATION,
COASTAL WATERWAYS

INTENSIVE EVALUATION OF THE EVOLUTION OF A PROTECTED BENTHIC HABITAT

HABITAT



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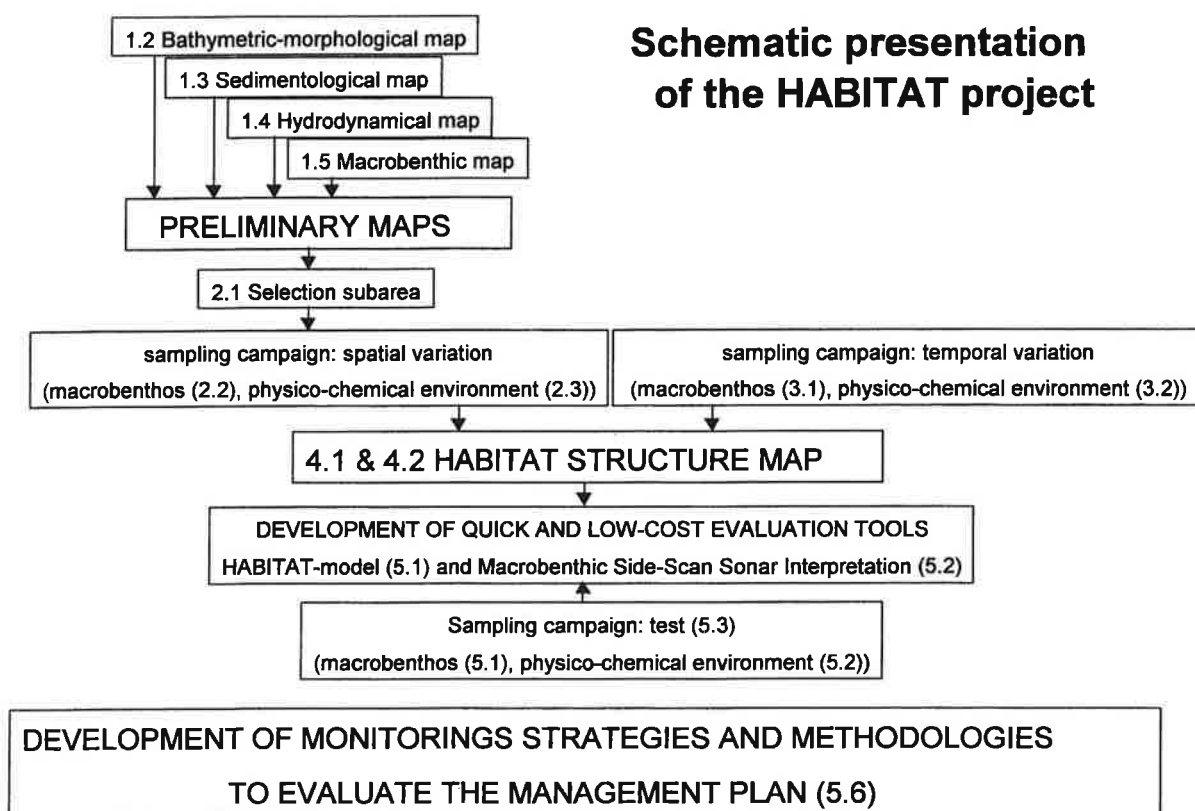
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INTRODUCTORY NOTE

This final report represents the results of the Marine Biology Section, the group Sedimentary Geology and Engineering Geology and the Renard Centre of Marine Geology of Ghent University. The latter group was partner within the framework of the co-financing of the Coastal Waterways of the Ministry of the Flemish Community that since March 2000 also financially supported the research theme associated with the HABITAT project. The consultancy firm Magelas was involved as subcontractor. The Management Unit for the Mathematical Model of the North Sea (MUMM) offered their assistance to gain more insight into the hydrodynamics of the Habitat area.

This project configuration allowed to gather extremely valuable information on the area and has led to the development of powerful tools for the management of the future marine protected areas. The benefice of the co-financing of Coastal Waterways can essentially be translated into a more extensive field campaign enabling more sampling and the enlargement of the area covered by side-scan sonar imagery. Moreover, the results could become more representative and accurate. In this report, the results are presented as a whole as to respect the coherency of the research.

Table I. Schematic presentation of the project.



Reference to this report:

Degraer, S., Van Lancker, V., Moerkerke, G., Van Hoey, G., Vincx, M., Jacobs, P. & Henriët, J.-P. (2002). Intensive evaluation of the evolution of a protected benthic habitat: HABITAT. Final report. Federal Office for Scientific, Technical and Cultural Affairs (OSTC) – Ministry of the Flemish Community, Environment and Infrastructure. Department. Waterways and Marine Affairs Administration, Coastal Waterways, 124 p.

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ABSTRACT

Introduction

The area of the western Coastal Banks includes some Coastal Banks (Trapegeer, Broersbank, and Den Oever), as well as two swales (Potje and Westdiep) and is characterised by water depths of -15 m to 0 m MLLWS. Because of the geomorphological diversity in combination with the presence of several shallow sites (Broersbank), the area has been proposed as a special area within the EC-Habitat Directive. The geomorphological structure, being the most diverse along the Belgian coast, is directly responsible for the high biological diversity and richness of the area. Being a food resource for several seabird and demersal fish species, the macrobenthos is an important component within the ecosystem functioning of the western Coastal Banks.

Due to the crucial role of the macrobenthos within the coastal ecosystem, the distribution of macrobenthic communities in relation to bathymetrical, sedimentological, and hydrodynamical characteristics is determined. This relation is used for the development of time- and cost-efficient evaluation tools, including monitoring strategies for the follow-up of a management plan of the future MPA.

Regional presentation of the macrobenthos and its physico-chemical environment

REVIEW OF THE BENTHIC HABITAT

In a first phase, maps were drawn on the basis of existing data, both from literature and reports. This included a compilation and integration of bathymetrical, morphological, sedimentological, hydrodynamical and macrobenthos data and provided a better characterisation of the benthic habitat of the study area.

Each presentation (map) is the result of a compilation of the available information, structured in a database. Through the possibility to integrate and superpose newly gathered data, a tool is provided to visualize the natural evolution of the area which can be of direct use when defining the present situation of the ecosystem of the western Coastal Banks.

A bathymetrical-morphological map was set-up comprising the occurrences of bedforms and their relative asymmetry. A digital very-high resolution side-scan sonar reconnaissance survey confirmed the presence of those bedforms and gave evidence of the highly diverse and complex nature of the seafloor.

The distribution of the surface sediments was evaluated on the basis of existing sedimentological data. The surface sediments are dominated by fine to medium sands with a coarsening of sediments towards the top of the bathymetric highs. The sand bank areas are generally coarsest, often characterised by coarse shell hash; the surficial sediments of the swales can have high percentages of the silt-clay fraction.

Semi-diurnal tides of macrotidal range (5.4 m) dominate the area. The tidal currents are highly rectilinear with a dominance of the flood current (NE-ENE) that can amount up to 1.32 m/s in the Westdiep swale. Numerical modeling (mu-BCZ) showed the highest current velocities in the Westdiep swale and near the foot of the slope of the Trapegeer. From sediment transport calculations it was shown that the surficial sediments are mainly mobile during Spring and Mid tide, from generally 1 hour before up to 1 hour after High Water. In the Westdiep swale and the Noordpas swale the ebb tidal current is also able to resuspend sediments.

Only little information about the macrobenthos of the Western Coastal Banks from the period before 1999 is available. The historical data are restricted to the Trapegeer, Broersbank, Den Oever and Potje. Almost no information about the Westdiep swale was available. Three macrobenthic communities, spread over the area were distinguished. The macrobenthos-rich *Abra alba* – *Mysella bidentata* community (syn. *Lanice conchilega* community) is mainly found in the deeper parts of the Potje swale and along the northern slope of the sandbank Trapegeer, while the *Ophelia limacina* – *Glycera lapidum* community (syn. *Mytilus edulis* community) prefers the shallowest sites (e.g. top of the Broersbank). On top of the sandbank Trapegeer and in the area of the Broersbank, the *Nephtys cirrosa* community was found. Although these data provide a first view on the community structure and macrobenthic spatial distribution within the area of the Western Coastal Banks, they should be interpreted with caution. For a bathymetric-geomorphological very diversified area as the Western Coastal Banks, the data, derived from only 32 stations, should be regarded as 'point data': spatial extrapolation of any macrobenthic characteristic was impossible.

MACROBENTHIC HABITAT: SPATIAL DISTRIBUTION

To study the spatial variation of the macrobenthic habitat, three subareas, with a maximum geomorphological diversity, were intensively investigated for their physico-chemical habitat and their macrobenthos.

Within the subareas, full-coverage very-high resolution side-scan sonar imagery was obtained that allowed to study the intrinsic nature of the seafloor in relation to the large-scale morphology. The combination of reflectivity, texture and patterns could be translated into specific acoustic facies that could be primarily interpreted in terms of the small-scale morphology and bedform occurrences, distribution of sediments and their relative compaction superimposed with hydrodynamical effects.

Sediment samples confirmed the highly variable nature of the sediments and this often on very short intervals. On the sandbanks, the distribution of the surficial sediments is hydrodynamically determined: the currents are strong enough to distribute the sediments. In the swales, a variety of sediments is deposited. This is mainly due to the high availability of fine-grained sediments that can settle out during slack water. On the contrary, the Westdiep swale is generally characterised by coarser sediments. As confirmed by side-scan sonar imagery, this swale should be regarded a high-energy depositional environment.

Along the foot of the slope of the Trapegeer sandbank, acoustic doppler current meter results confirmed the highly rectilinear nature of the tidal currents with a predominance of the flood current. Yet, the correlation between the high spatial variability and the hydrodynamical numerical model results still needs further investigation.

The knowledge on the macrobenthic community structure, based on historical data (see above), was confirmed by the detailed investigation. Next to one transitional species association (*Magelona mirabilis* transitional species association), three of a total of four subtidal macrobenthic communities discerned at the BCS (Van Hoey *et al.*, in prep.) were found within the area of the Western Coastal Banks: *A. alba* – *M. bidentata*, *N. cirrosa* and *O. limacina* – *G. lapidum* community. Each community or species association is restricted to a very specific physico-chemically defined habitat. Although the communities were spread all over the area, zonation, mainly related to depth, was demonstrated. As already shown by Degraer *et al.* (1999a) and Van Hoey *et al.* (in prep.), the *A. alba* – *M. bidentata* community is an ecologically highly valuable macrobenthic community on the BCS. The community is characterised by the highest macrobenthic densities and diversity. Furthermore, most bivalve

species (e.g. *A. alba*, *Fabulina fabula* and *Spisula subtruncata*) are found in high densities within the community. These bivalves are known to be an important food resource for larger epibenthic predators (e.g. cod *Gadus morus*, and sole *Solea solea*) and benthos-eating diving seaducks (e.g. common scoter *Melanitta nigra*). Primarily within the *A. alba* - *M. bidentata* community, the tube-building polychaete *Lanice conchilega* fulfills an important habitat-structuring role. Both other communities and the transitional species association contribute substantially to the overall macrobenthic diversity of the Western Coastal Banks: 74 % of all macrobenthic species, recently found on the BCS, were detected within the study area.

MACROBENTHIC HABITAT: TEMPORAL VARIATION

To study the seasonal variability within the macrobenthic habitat of the Western Coastal Banks, the multi-disciplinary study of October 1999 was repeated in March 2000. On a sedimentological level, the temporal variability was minimal and generally, the differences were within the error imposed by the analysis.

The side-scan sonar imagery shows more variability as it reflects the upper seafloor characteristics. Most striking was the presence of white reflectivity bands in the deepest parts of the swales that could be interpreted as fluid mud layers superimposed on fine sandy sediments. Still, in terms of an interpretation towards an acoustic facies, hardly any differences were apparent which indicates that a standardised side-scan sonar interpretation is valid on a temporal basis.

Although the community structure changed within all macrobenthic communities, the communities, detected in October 1999, were still present in 2000. Because of the relative low temporal variation of the structure of the three communities, the temporal variation does not overrule the "basic" structure of each community. The temporal variation was most obvious in the *A. alba* – *M. bidentata* community, while only minor changes were detected within the *N. cirrosa* and *O. Limacina* – *G. lapidum* community and the *M. mirabilis* species association. Because of the expected stability of the ecologically relevant physico-chemical environment (e.g. sedimentology and depth) at the sampling stations, most of the stations harboured the same community in October 1999 and 2000. A high spatial distributional stability was found within the area of the western Coastal Banks.

Development of methodologies aiming at the creation of time- and cost-efficient monitoring tools for the future mpa

HABITAT MODEL

The HABITAT model, consisting of eight classification function sets derived from multiple discriminant analysis, allows to predict the presence or distribution of macrobenthic communities, based on knowledge of the physico-chemical environment. The model thus allows evaluating the 'macrobenthic potentials' of non-studied places within the protected area on an time- and cost-efficient base. Based on the macrobenthos data of October 1999 and March 2000 (three communities and one transitional species association), 78 % of the classification functions revealed a community specific and overall *a posteriori* and *a priori* accuracy higher than 70 %. These accuracies can be drastically improved if only the three macrobenthic communities are taken into account, rather than using the *M. mirabilis* species association as well. Comparing the community specific accuracy of each classification function set, no set can be put forward as superior to the other sets. Further testing and refinement of the models is advised.

STANDARDIZED MACROBENTHIC INTERPRETATION OF SIDE-SCAN SONAR IMAGES (MSSSI)

Two approaches were followed in the interpretation of side-scan sonar imagery in terms of the occurrence of macrobenthic communities.

The first approach was based on a direct correlation of high abundances of macrobenthos with a specific acoustic facies. A medium to high reflectivity patchy to mottled texture was correlated with the presence of dense fields of the tube-building polychaete *Lanice conchilega*. If the density of this polychaete worm is indeed high enough, local sediment accumulations, detectable by side-scan sonar technology, can be formed. Interestingly, the occurrence of this acoustic facies is highly correlated with slope environments leading to the assumption that these environments have a high input of suspended matter.

Secondly, an indirect link was sought based on the known correlations of the macrobenthos versus sedimentology on the one hand and sedimentology versus side-scan sonar imagery on the other hand. This means that if side-scan sonar imagery can be interpreted in terms of sediment nature, the occurrence of macrobenthic communities can be predicted. To facilitate this process, a standardised interpretation is put forward through the set-up of a table with different criteria and interpretation keys. This table provides a discrimination of acoustic facies into a maximum of classes, which are finally linked to a macrobenthos community preference.

HABITAT STRUCTURE MAP

A Habitat structure was set-up as an integration of the available data and interpretations and reflecting information on the bathymetry, sediment nature, the acoustic facies and the occurrence of the macrobenthic communities. This approach visualises the interactions between the physical environment and the macrobenthos and is a tool for a scientifically sustained evaluation of this unique ecosystem. Together with the other maps, the habitat structure map reflects the situation of the ecosystem before the effectiveness of a support plan. Knowledge on the *t₀*-situation is of primary importance for the evaluation of the effects of the policy decisions.

Implications for future management and monitoring

Both models developed during the project (e.g. HABITAT model and Macrobenthic Side-Scan Sonar Interpretation) allow a time- and cost-efficient, full-coverage spatial extrapolation of point-data. The latter also proved to be useful for the delineation of ecological relevant strata, necessary to set up a stratified random sampling design for the follow-up of a future management plan. Three steps are proposed for the monitoring of the Western Coastal Banks: (1) selection of strata, (2) monitoring of the macrobenthic habitat, following a stratified random sampling design, and (3) full-coverage monitoring of the macrobenthic habitat, using very-high resolution acoustic techniques.

INTRODUCTION

The western Coastal Banks (3400 ha) are situated between the French-Belgian border and Koksijde-bad and from the low-water level to about 5.5 km offshore (Figure 1). The area includes some Coastal Banks (Trapegeer, Broersbank, and Den Oever), as well as two swales (Potje and Westdiep). Because of the geomorphological diversity in combination with the presence of several shallow sites (Broersbank), the area has been proposed as a special area within the EC-Habitat Directive. The geomorphological structure, being the most diverse along the Belgian coast, is directly responsible for the high biological diversity and richness of the area.

At first, the ecological importance of the area is illustrated by the high numbers of different species of birds, wintering in the area. Studies revealed that, next to Divers (Gaviidae), Grebes (Podicepidae), Auks (Alcidae), etc., especially Seaducks (Melanitidae) are wintering at the western Coastal Banks (Devos 1990). During some winter periods more than 1% (> 8000 individuals) of the NW-European population of the Common scoter (*Melanitta nigra*) can be found on the western Coastal Banks. Because of the presence of the Common scoter, the area is regarded as an area with international importance for waterfowl (Ramsar convention 1972). Furthermore the area fulfills the demands of the EC-Bird Directive and is proposed as an EC-Habitat Directive area. The Belgian government is planning to give the western Coastal Banks the status of marine protected area (MPA).

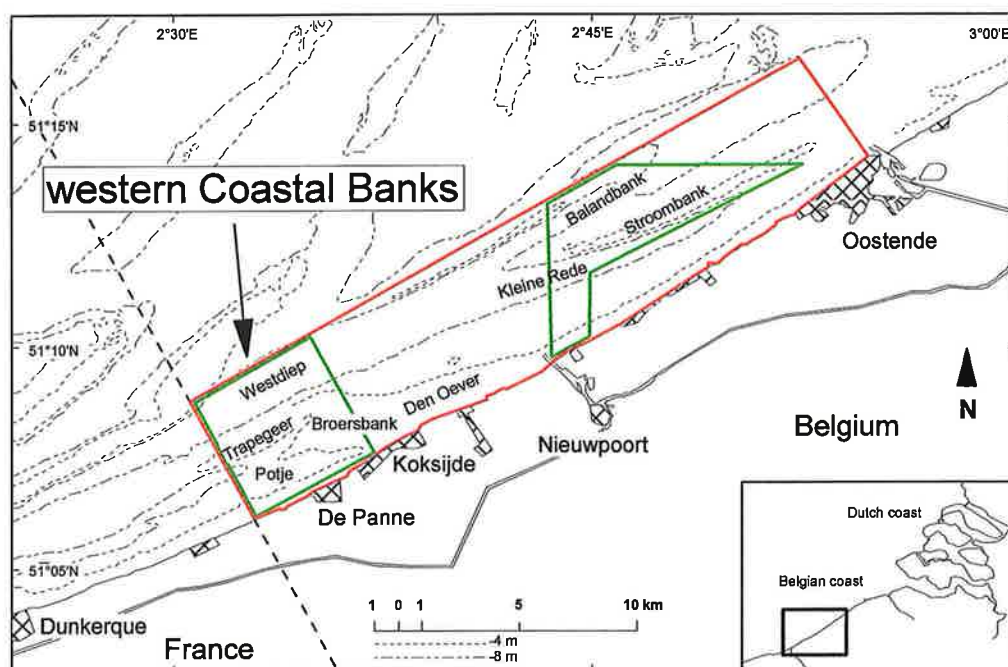


Figure 1. The western Coastal Banks, with indication of the Ramsar area (red line) and the proposed marine protected areas (green line).

The spatial distribution of the wintering Seaducks is defined by several factors, of which food availability and the undisturbed character of the biotope are very important (Kirchoff 1981). The high geomorphological diversity of the area, including intertidal sites, is directly responsible for the restricted access of ships, hence ensuring optimal conditions for the seabirds. Because Seaducks are directly dependent from the macrobenthos, and more specifically the Bivalvia as their food resource (Cramp & Simmons 1977), the presence of high numbers of bivalves (e.g. *Abra alba*, *Tellina fabula* and especially *Spisula subtruncata*) (Degraer *et al.* 1999) is extremely important. Moreover, the macrobenthos is also important as a food resource for several commercial and non-

commercial fishes (e.g. Cod and Gobiids). The macrobenthos is thus an extremely important component within the ecosystem functioning of the western Coastal Banks. Therefore, knowledge of the natural spatial distribution and seasonal variation of the macrobenthos is extremely important when setting up a management plan for the proposed marine protected area (MPA).

The general objective of the project includes the provision of data, necessary for the definition and evaluation of a scientific management plan of the future MPA. Due to the crucial role of the macrobenthos within the coastal ecosystem, especially, the distribution of macrobenthic communities in relation to sedimentological, bathymetrical and hydrodynamical characteristics will be determined. This relation will be used for setting up time- and cost-efficient evaluation tools of the management plan of the future MPA.

The research project is structured as follows:

1. Regional presentation of the macrobenthos and physico-chemical variables

The creation of biological and geological digital maps, based on the existing and newly gathered data, through the setup of an interactive database with future perspectives for the development of a Geographical Information System (GIS). Data, available before the start of the project, is compiled as a review on the benthic habitat (part 1). Two detailed and interdisciplinary macrobenthic, sedimentological and hydrodynamical case-studies of a selected part within the MPA (October 1999 and March 2000) provide information on (1) the community structure, habitat preferences, and spatial distribution of the macrobenthos and (2) the temporal and seasonal variability of the macrobenthic habitat of the Western Coastal Banks (part 2).

2. Development of methodologies aiming at the creation of time- and cost-efficient monitoring tools for the future MPA

Both interdisciplinary case-studies of a selected part also allow the development of time- and cost-efficient tools for the evaluation of the management plan. The latter include (1) a 'modelling' approach of the relation between the macrobenthic spatial distribution and the standardized physico-chemical variables (HABITAT model), (2) a standardized macrobenthic interpretation of side-scan sonar images (MSSSI) and (3) the development of strategies and methodologies aiming at a time- and cost-efficient permanent surveillance of the MPA (cf. monitorings strategy and methodology) (part 3).

All information on the biology and physico-chemical environment within the study area is summarized in a HABITAT map.

STANDARD MATERIALS AND METHODS

Introduction

Within this section, materials and methods are described that were relevant throughout the project. The individual parts also contain such a section, but merely focus on specific approaches and analyses.

Shiptime, navigation and positioning

Shiptime was granted by Coastal Waterways, Ministry of the Flemish Community. The deeper areas were surveyed with the hydrographic vessel Ter Streep whilst for the shallower areas the campaigns were carried out with the Oostende XI. Table II gives an overview of all the relevant campaigns. In September 1999, a small hydrographic survey boat was used for the side-scan sonar operations, but this seemed not favourable on a longer-term basis. Additional shiptime was provided by the Management Unit of the Mathematical Modelling of the North Sea (MUMM) aboard the R/V Belgica. This allowed the deployment of an acoustical doppler current profiler (ADCP) along the Trapegeer and the use of advanced survey methodologies in the Habitat area.

Crucial to the whole process of data acquisition is the navigation and positioning. The research vessels involved in this project were all equipped with differential global positioning systems (DGPS). (M/V Ter Streep, Ter Streeps' small hydrographic survey boat, R/V Belgica: DGPS Sercel NR 103; M/V Oostende XI: DGPS Sercel NR 109). Tests of the SERCEL NR 103 DGPS on board of the Belgica showed an accuracy of 3 to 5 m (Van Zielegheem 1998). The final processing of all the data was performed in UTM 31N - ED50 coordinates (Hayford 1924 reference plane), as this is the standard for survey work on the Belgian continental shelf.

Table II. Overview of the samplings and side-scan sonar recordings (SSS).

ZONES	SEPT. 1999	OCTOBER 1999		MARCH 2000		OCT.-NOV. 2000	
	SSS	SSS	SAMPLING	SSS	SAMPLING	SSS	SAMPLING
ZONE1A	09,10/09 (1 line)	07/10	06,11/10	20/03	13,16,17/03		
ZONE1A-ZONE2A	09,10/09 (1 line)		06,11/10		13,16,17/03	14/10	15/11
ZONE2A	09,10/09 (1 line)	11,12/10	06,11,15/10	20,21/03	13,16,17/03		
ZONE2A-ZONE3A	09,10/09 (1 line)		06,15/10		13,16,17/03	14/10	15/11
ZONE3A	09,10/09 (2 lines)	14/10	14,15/10	21/03	13,16,17/03		
ZONE1B		29/10	13/10	26/03	24,25/03		
ZONE1B-ZONE2B	10/09 (1 line)		13/10		24,25/03	14/10	15/11
ZONE2B	10/09 (1 line)	12/10	13,22/10	01/04	25/03		
ZONE2B-ZONE3B			13,22/10		24,25/03	14/10	15/11
ZONE3B	10/09 (2 lines)	/	13,22/10	02/04	25/03		

Table III gives a methodological overview of the measurements and samplings performed during the campaigns.

Table III. Methodology

-macrobenthos	Van Veen grab, bulk sample
-sediment (texture)	Van Veen grab, bulk sample and short sediment cores
-sediment (pigment)	Short sediment core from Van Veen grab (5 cm)
-sediment (nutrient)	Short sediment core from Van Veen grab (2 cm)
-water (suspension)	From Niskin bottle and filtration of 500 ml (GF/F filter)
-water (nutrient)	From Niskin bottle and filtration of 500 ml (GF/C filter)
-temperature, salinity and dissolved oxygen	In-situ measurement in Niskin bottle
-depth measurement	Single-beam / multibeam bathymetry
-nature of the seafloor	Very-high resolution digital side-scan sonar

Bathymetrical registrations

Single-beam bathymetry was obtained with M/V Ter Streep and Ter Streeps' small hydrographic survey boat (Atlas Deso 25, 1 sec acquisition). Raw bathymetrical data (at 33 kHz and 210 kHz) were transferred to a TSS 320B heave compensator, so that both the analogue and digital recordings were corrected for the vertical movement of the ship. In the shallow area, surveyed with M/V Oostende XI, multibeam data was recorded (Atlas Fansweep). Additional survey work was performed with R/V Belgica equipped with a Simrad EM1002S Multibeam echosounder. A tidal correction was performed on the basis of the procedures described in Van Cauwenberghe *et al.* (1992).

Side-scan sonar

Side-scan sonar imagery was collected to obtain very-high resolution imagery of the seafloor. The application of this technology is nowadays widely used for seabed habitat mapping as it produces an almost photorealistic picture of the seabed (Kenny *et al.* 2000). Its use is especially favourable in shallow water as the transducers can produce a wide swath regardless of the water depth. Reference is made to Flemming (1976) and Blondel & Murton (1997) for operational procedures and technical constraints.

Side-scan sonar imagery is a reflection of the acoustic energy that is backscattered from the seafloor and as such an image is composed of different grey scales. The differences in backscattering are in decreasing order determined by (1) the geometry of the sensor-target system; (2) the angle of incidence of each beam, local slope, etc.; (3) the physical characteristics of the surface such as the micro-scale roughness and (4) the intrinsic nature of the surface (composition, density, relative importance of volume versus surface diffusion/scattering for the selected frequency) Blondel & Murton (1997). Regarding the acoustic response of the marine sediments themselves, the most important parameters, ranked in order of importance, are (1) porosity; (2) density; (3) overburden stress; (4) the degree and type of lithification and (5) the grain-size and distribution (Stoll 1989).

For the present project, a GeoAcoustics dual frequency side-scan sonar was deployed of which the 410 kHz frequency was preferred during the acquisition. During the surveying, an optimal ship speed of 4 knots was maintained. All the data were recorded digitally using ISIS acquisition software (Triton-ELICS). The processing was performed with ISIS and Delphmap. Corrections for the height of the fish above the seabed (the slant range), lay-back and the vessel speed were taken into account. After the processing of the side-scan sonar data, the images were exported as Geotiffs and eventually as ECW (a wavelet format, highly compressed).

Sampling and laboratory treatment

To obtain full coverage data on the macrobenthos and its physico-chemical environment, a total of 120 sampling stations were uniformly distributed over the study area with a sampling interval of 500 m. At each station, samples for macrobenthos, sedimentology, suspended particulate matter, nutrient concentrations within the bottom and water column, as well as pigment concentrations in the water column were collected. Water depth at the time of sampling was measured. Sampling was performed in October 1999, March and November 2000.

The macrobenthos was sampled using a Van Veen grab (sampling surface 0.1026 m²). The samples were sieved using a 1 mm mesh-sized sieve and fixated in an 8% formaldehyde-seawater solution. After staining with Bengal rose, all organisms were sorted out and identified to species level, if possible. Densities were expressed as the number of individuals per square meter (ind./m²).

From each Van Veen grab sample, a subsample for sedimentology and bottom nutrients was taken using a core (diameter: 3.6 cm). The subsample was freezed immediately. At the lab, the interstitial water was extracted for bottom nutrient measurements. After sieving the sediments on a 1 mm mesh-sized sieve, the grain size distribution of the remaining sediment was analyzed by means of a LS Coulter counter with a measuring range from 2 to 850 µm. Sediment fractions 2-850 µm are expressed as volume percentages, while sediment fractions coarser than 1 mm are expressed as mass percentages. Median grain size was calculated only using the sediments fraction 2-850 µm.

At each location, an extra sample was taken for standard grain size analysis. The whole Van Veen grab was subsampled to obtain a sample representative for the upper 10 cm of the seafloor. In the laboratory, each sample was photographed. After drying, the bulk sample was first split up to +/- 500 g and sieved on a 710 µm mesh. Subsequently, a subsample of about 25 g was obtained through splitting. After the removal of the organic content with hydrogen peroxide, the sample was wet sieved. After drying, the coarse fraction was treated on a sieve rack with a mesh interval of 0.25 phi. If the fraction less than 53 µm was more than 5 %, the fine fraction was analysed with a Sedigraph (X-ray instrument). The final results were statistically treated to obtain the most relevant sedimentological parameters. Sediment grain size fractions were classified according to the Wentworth scale. Bottom nutrients were measured within the interstitial water of the sediment. The concentrations of nitrite, nitrate, ammonia, phosphate, and silicium were measured trough an automatic chain (SAN^{plus} segmented flow analyser, SKALAR).

To measure the amount of suspended particulate matter (SPM) as well as nutrients and pigments in the water column, bottom water (1 m above the sediment surface) was collected using a Niskin bottle (content: 5l). 2 l of water was filtered through a GF/C filter. The net dry weight of the filter after filtering was measured. SPM was standardized to mg/l. To measure the nutrient concentrations in the water column the same procedure as for the

bottom nutrients was used. For the analyses of pigments (chlorophyll-a, -c and fucoxanthine), water samples were passed through Whatman GF/F filters. An immediate extraction with acetone (90%) was performed prior to chromatography, with a Gilson high-performance liquid chromatography chain using the method of Mantoura & Llewellyn (1983). Pigments and nutrients within the water column were not analysed for the March 2000 samples.

Database

Each of the variables, as well biological as geological, was labelled in a consistent manner including a unique identification and a uniformised timestamp in an UTC format (Universal Time Coordinates). For each campaign, the whole of the variables was clustered in an Excel spreadsheet to be delivered to the IDOD database. These spreadsheets can easily be transformed into databases. Contour maps, exportable in different formats, were produced from the most relevant parameters. The compressed georeferenced side-scan sonar imagery can be imported in a variety of software programmes. The whole of information can easily be imported and treated in a Geographical Information System.

PART 1.
REGIONAL PRESENTATION OF THE PHYSICO-CHEMICAL ENVIRONMENT
AND ITS MACROBENTHOS

REVIEW OF THE BENTHIC HABITAT ALONG THE WESTERN COASTAL BANKS

Introduction

Because of the supposed high ecological value of the area, indicated by the large numbers of seabirds wintering in the area, the benthic habitat of the western Coastal Banks already received some scientific attention. Although most of the data, gathered before the start of the HABITAT project, have to be considered as preliminary information, these studies contribute to the general knowledge of the benthic habitat.

Within this part of the study, a summary of the historical information (data available before 1999) is presented. Special attention is paid to the development of a database and the production of maps, as an orderly tool to present the spatial distribution of different variables.

Materials and methods

DATA GATHERING

In a first phase, maps were drawn on the basis of existing data both from literature and reports. However, to gain more insight into the dynamics of the area, the creation of a detailed *bathymetrical-morphological map* was a necessity. Given the absence of such a base map of the study area and the importance of this map within other parts of the proposed research strategy, existing bathymetrical data (Spring and Autumn of 1997) provided by Coastal Waterways of the Ministry of the Flemish Community was compiled into contour maps. Moreover, the raw bathymetrical data were analysed in terms of the occurrences of bedforms as to give insight into the geomorphological diversity. The heights and approximate positions of bedforms along the survey tracks were extracted from the analogue sounding traces and transferred to a mosaic that provided the basis for bedform height and asymmetry charts. As a first characterisation of the small-scale seafloor structure, a digital side-scan sonar reconnaissance survey was carried out in September 1999 (HA9909). These data led to the selection of three subareas for the two intensive interdisciplinary field campaigns of autumn 1999 (HA9910) and Spring 2000 (HA0003).

Secondly, a *preliminary sedimentological map* was drawn on the basis of existing data and aided by the integration with the bathymetrical-morphological map. For the Westdiep area, detailed sediment data (65 samples) was available from March 1999 (Van Lancker *et al.* 2000), whilst for the shallow area, sediment data was used from the Marine Biology Section (34 samples) (Degraer *et al.* 1999). Other sediment data exists (e.g. Bastin 1974, Nihoul & Gullentops 1976, Belgische Geologische Dienst 1991, Ministry of the Flemish Community), but proved to be too scattered.

A third aspect included the compilation of *hydrodynamical data*, based on existing current meter data and numerical models. Current meter data have been provided by Coastal Waterways, Ministry of the Flemish Community and had been analysed as a first estimate for sediment transport calculations (Van Lancker *et al.* 2000). The "Management Unit for the Mathematical Model of the North Sea and Scheldt Estuary" (MUMM), offered their assistance to gain more insight into the hydrodynamics of the Habitat area and provided numerical model results on a grid resolution of 750 m (mu-BCZ model) for a Spring and Neap tidal cycle. Results on a 250 m grid resolution have also been provided.

Fourthly, the available *macrobenthic data* have been mapped and provide a first indication of the geographical distribution of the macrobenthos. The data, used within this overview of the spatial distribution of the macrobenthos, are originating from a sampling campaign performed in October 1994 (all variables) (Degraer *et al.*, 1999) and September 1977 (only total density) (Van Steen, 1978).

Results

LARGE-SCALE MORPHOLOGY

The area is characterised by a bank – swale topography with water depths of 0 to -15 m MLLWS (Figure 2) (Van Lancker *et al.* 2000). The Westdiep swale separates the Flemish Banks from the Coastal Banks. Its width varies from 1500 m in the east to 600 m at the French-Belgian border. The latter is associated with the vicinity of the Smal Bank, which is here characterised by very steep slopes. The swale itself has no uniform depth distribution. A narrow deeper channel is present running north of a plateau-like morphology that is the transition zone towards the Trapegeer, albeit with a faint depression at the foot of this sandbank. The Trapegeer forms part of a complex system that also comprises the Broersbank and a shallow shoal connected to the shoreface. The water depth of this sandbank complex varies from - 10 m to 0 m MLLWS. The Trapegeer has a parallel orientation to the coastline whilst the Broersbank shows a clear offset. The whole is intersected by the Potje swale (up to - 7 m MLLWS); itself divided into a northern and southern branch. The latter nears the coast under a faint angle and has given rise to coastal erosion problems near Koksijde in the past (Ministry of the Flemish Community 1993).

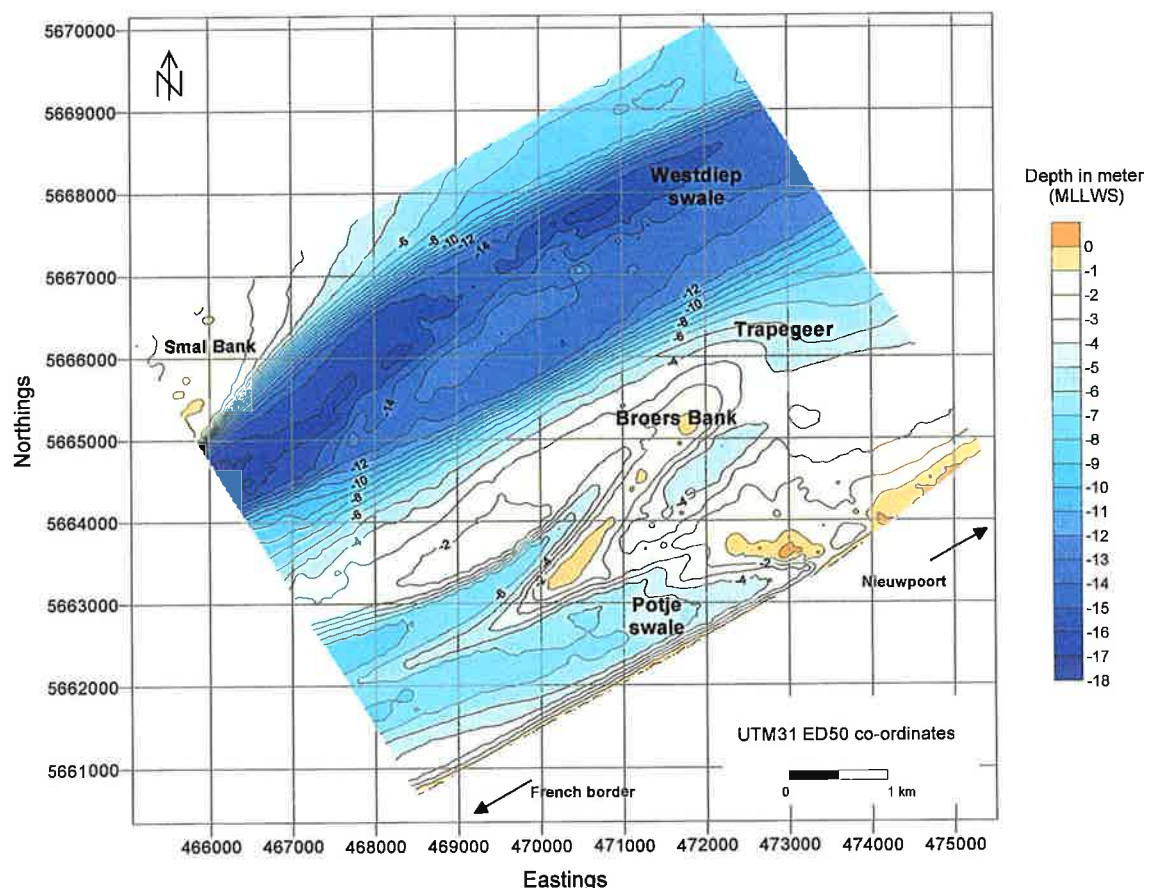


Figure 2. Bathymetrical map of the study area (Data supplied courtesy of the Coastal Waterways, Ministry of the Flemish Community).

Figure 3 is a bathymetrical-morphological map showing the occurrences of bedforms in the study area (Van Lancker *et al.* 2000). From offshore to onshore, bedforms in the range of medium to large dunes (up to 0.75 m in height, terminology according to Ashley 1990) occur within the Westdiep swale, below the -10 m isobath. On the northern and southern slopes of the Westdiep swale, only small sand dunes are found with a maximum height of 0.4 m. However, moving up onto the Trapegeer, the bedforms increase in height and terminate in a line of medium to large sand dunes where water depths are shallower than -2 m MLLWS. On the Broersbank, large sand dunes of more than 1 m occur at the broad summit area, whilst no bedforms were observed on its lower slopes (below the -4 m isobath) and concurrent with the Westdiep and Potje swales. In the latter swale, a few medium sand dunes were still recorded, but no bedforms were evident on the shoreface above the -5 m isobath. Still, at and above the MLLWS level a series of swash bars (up to 0.8 m in height) occurs, running parallel to the shore. Generally, the bedform asymmetries are orientated up the slopes of the banks and other bathymetric features. Within the Westdiep swale, the bedform asymmetries converge corresponding with a rise in the swale. Asymmetry convergence occurs along the crest of the Trapegeer and on the Broersbank summit. Symmetrical dunes occur along these lines of convergence and within the Westdiep swale at the NE end of the raised area.

The reconnaissance digital side-scan sonar survey of September 1999 confirmed the general scheme of bedform distribution of Figure 3 still, the images revealed very sharp delineations of bedform occurrences likely induced by the strong tidal currents. Due to the bank - swale hydrography, the spatial variability is indeed high; hence the bedform dimensions vary from small to large dunes on very short intervals. In the shallowest zones (0 m MLLWS) complex seafloor patterns were observed.

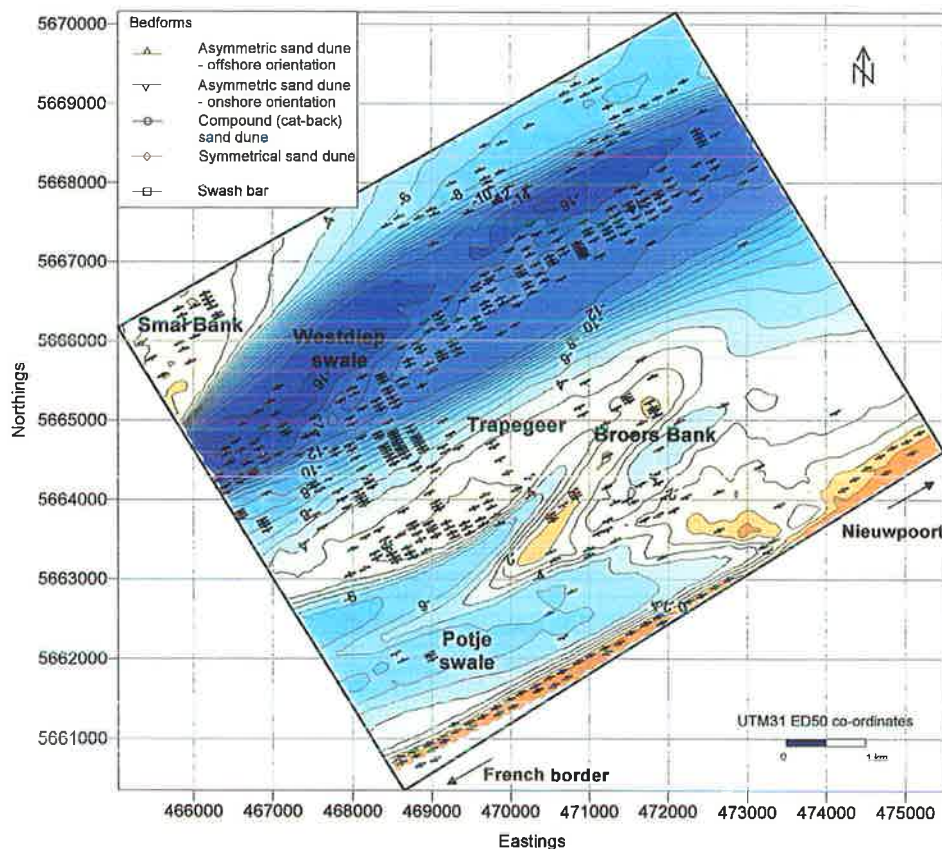


Figure 3. Scheme of the bedform distribution (Depths in m MLLWS) (Honeybun 1999) (Data supplied courtesy of the Coastal Waterways, Ministry of the Flemish Community).

NATURE OF THE SURFICIAL SEDIMENTS

Figure 4 is a contour map of the distribution of the surficial sediments in the area as compiled from existing data. Given the limited density of sampling points south of the Trapegeer, this zone should be treated with more caution.

From the map, it can be shown that the surficial sediments within the Broersbank - Westdiep system are dominated by fine to medium sands (Honeybun 1999; Van Lancker *et al.* 2000). The sediments get coarser towards the top of the bathymetric highs, including a rise in the Westdiep swale. The sand bank areas are generally coarsest, whilst the surficial sediments of the swales can have high percentages of the silt-clay fraction. The shallow Broersbank (up to 0 m MLLWS) is characterised by coarse shell hash. Still, the sorting is, generally, best on the bank summits and poorest in the swales. Throughout the study area, the mean grain-size ranges from fine sands of 2.75 phi ($\sim 150 \mu\text{m}$) up to medium sand of 1 phi ($500 \mu\text{m}$).

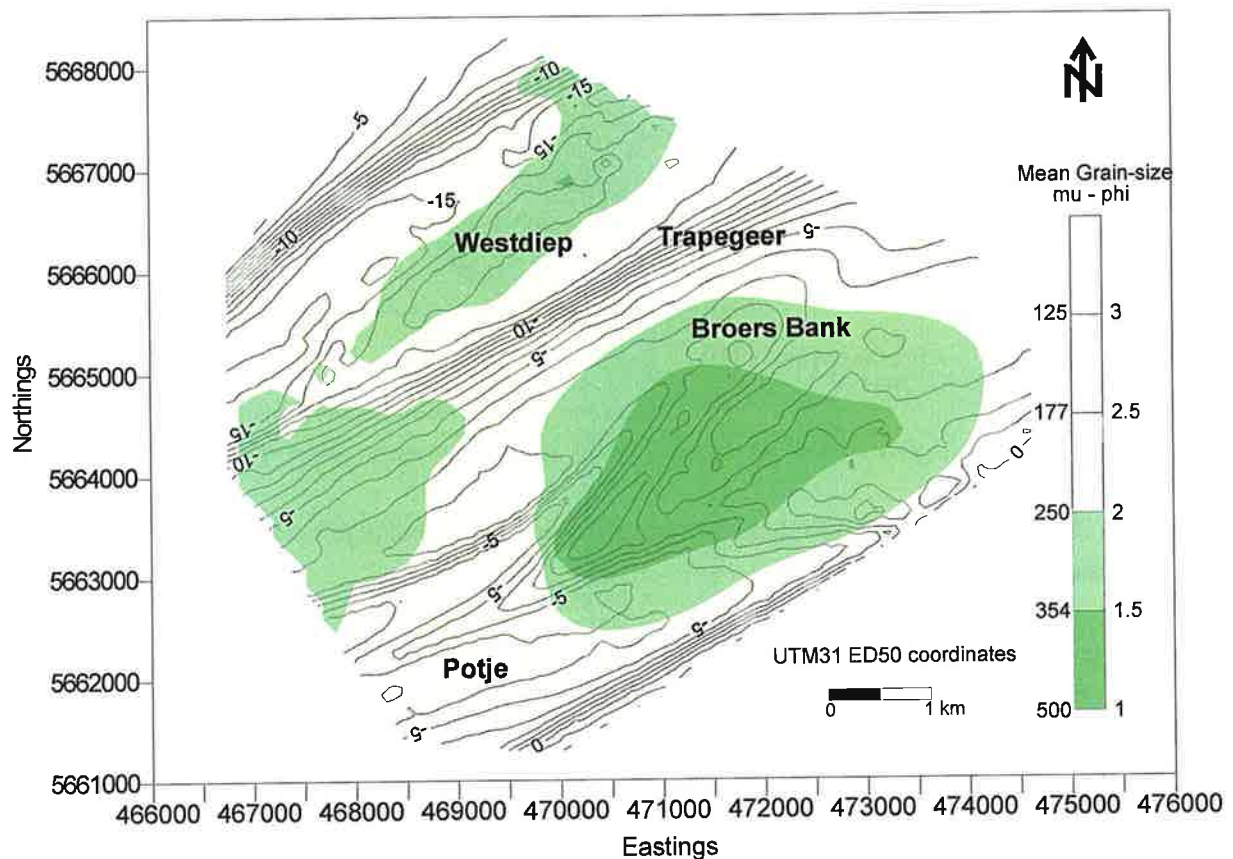


Figure 4. Contour map of the mean grain-size of the surficial sediments (median grain-size) based on a compilation of existing data.

HYDRODYNAMICAL AND SEDIMENT TRANSPORT CHARACTERISATION

The area under investigation is subdued to semi-diurnal tides of macrotidal range. In the Westdiep swale, the tidal amplitudes at Spring and Neap tides can be 5.42 m and 2.89 m respectively. The tidal currents are characterised by elongate and asymmetrical tidal current ellipses with a dominance of the NE-directed flood current. From *in*

situ measurements of the current velocity (Coastal Waterways, Ministry of the Flemish Community), Spring near-surface flood currents attain 1.32 m/s in the Westdiep swale, whilst the ebb currents have a maximum of 0.86 m/s. From the mu-BCZ numerical model results on a 750 m grid and based on a generalised bathymetry, the maximum current velocities were extracted and plotted in Figure 5. The results reveal high NE or flood directed mean depth current velocities within the Westdiep area reaching a maximum value around 0.7 m/s extending towards the foot of the slope of the Trapegeer sandbank. Based on this model, the tidal current velocities gradually diminish in a coastwards direction; only minor current velocities were calculated in the Potje swale.

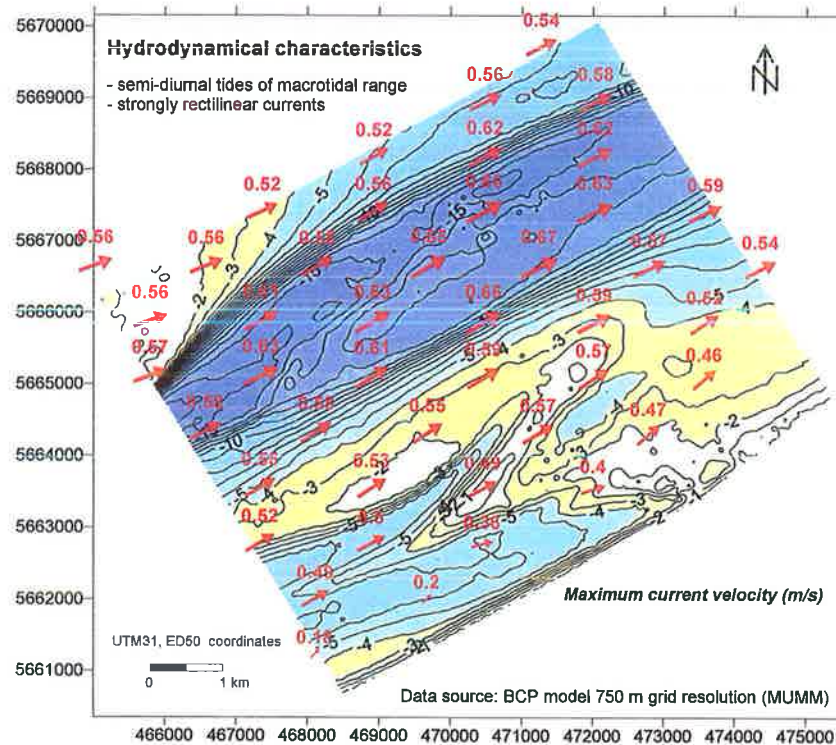


Figure 5. The maximum mean depth current velocity and direction compiled from a numerical model (mu-BCZ) (grid resolution of 750 m).

To gain insight into the tidal current propagation throughout the study area, it was felt necessary to obtain more detailed information that takes into account the complex bathymetry. Numerical model results were provided on a 250 m grid, still caution is needed as the results are still under validation. Generally, the model provides much higher current velocities as those calculated with the rougher model on a 750 m grid resolution. Moreover, areas shallower than - 6 m water depth (sandbank areas and the near coastal shoal) are treated as having a constant bottom topography of - 6 m, which may prove to be too simplified (in the perspective of the very complex side-scan sonar imagery). Still, the results do show the current variability in function of the large-scale morphology and give evidence of a reinforcement of the current velocity in the swales. Along the sandbank complex the tidal current propagation seems somewhat retarded. This is especially clear 1 hour before up to High Water when the tidal current velocity is highest, hence most significant towards sediment transport.

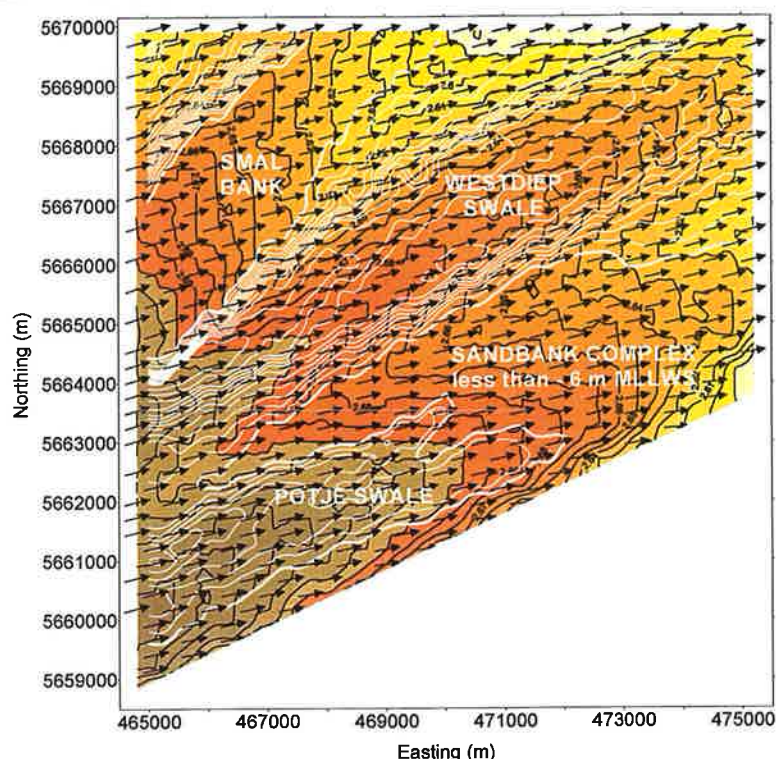


Figure 6. Relative current velocity distribution around High Water based on a numerical model on a 250 m grid resolution. The brownish colours are the highest velocities. Note the progressive decrease in velocity from west to east. The colour gradient corresponds to 0.01 m/s.

Sediment transport calculations have been performed on the basis of *in situ* current meter data from Coastal Waterways (Ministry of the Flemish Community) and using the approach described in Soulsby (1997) (Van Lancker *et al.* 2000). The results showed that the *in situ* surficial sediments are mainly mobile during Spring and Mid tide, from generally 1 hour before up to 1 hour after High Water. Interestingly, are the Westdiep swale and the Noordpas swale where also the ebb tidal current is able to resuspend sediments. Calculations of the transport capacity of the flow, taken into account a range of grain-sizes (independent of the *in situ* sediments), show that under currents alone, mean grain-sizes of up to 420 μm can be transported in the Westdiep swale. The ebb tidal current is at least able to transport sediments with a mean size of 177 μm . It needs emphasis that these results represent a minimum competence, since the combined action of currents and waves non-linearly enhances sediment transport (Van Lancker *et al.* 2000).

MACROBENTHOS DATA

In total 32 stations were sampled for their macrobenthos within the area (Figure 8). All stations are restricted to the sandbanks Trapegeer, Broersbank and the swale Potje. No samples were collected in the swale Westdiep, nor along the southern flank of the Smalbank (Flemish Banks).

The total macrobenthic density ranges from about 100 to over 26000 ind./m² (Figure 8). Higher densities (> 1000 ind./m²) are mainly found in the deeper parts of area (e.g. Potje and northern flank of Trapegeer and Den Oever), while lower densities (< 1000 ind./m²) generally occur in the shallower parts (e.g. Trapegeer, Broersbank and shallow eastern part of the area). The number of species per sampling surface area of 0.1 m² (N_0) ranges from 4 to 28 species (Figure 10). A lower N_0 (< 13 species) is found at the tops of the sandbanks Trapegeer and Broersbank and in the intertidal zone, while a higher N_0 (> 13 species) is found in the deeper parts of the area.

Three macrobenthic communities, spread over the area were distinguished (Degraer, 1999) (Figure 11). The macrobenthos-rich *Lanice conchilega* community is mainly found in the deeper parts of the swale Potje and along the northern slope of the sandbank Trapegeer, while the *Mytilus edulis* community prefers the shallowest sites (e.g. top of the Broersbank). On top of the sandbank Trapegeer and in the area of the Broersbank, the *Nephtys cirrosa* community can be found. The spatial distribution of seven macrobenthic species is presented in Figures 11 to 16. These species were selected on their abundance in the dataset, combined with their indicator value for the different macrobenthic communities. Considering the bivalve *Mytilus edulis* (Bivalvia: Mytilidae), only spat is found within the area. No (adult) musselbeds were detected so far. Spatfall of *M. edulis* is restricted to the shallow parts of the Broersbank area, where it occurs with densities up to 350 ind./m². *Magelona mirabilis* (Polychaeta: Magelonidae) is an abundant polychaete species. The species is absent only in the shallow parts of the Broersbank area. Elsewhere, densities up to over 7000 ind./m² are found. The density of *Lanice conchilega* (Polychaeta: Terebellidae) ranges from 0 to some 350 ind./m². The polychaete is mainly found along the northern flank of the Trapegeer and Den Oever. No individuals are found in the shallow area of the Broersbank nor the eastern coastal zone. The bivalve *Spisula subtruncata* (Bivalvia: Mactridae) occurs with densities up to over 300 ind./m². The species is found scattered throughout the area, but the swale Potje and the northern flank of the Trapegeer and Den Oever reveal the highest densities (> 40 ind./m²). *Nephtys cirrosa* (Polychaeta: Nephtyidae) is found in densities from 0 to about 180 ind./m². The species is present throughout the whole area, except for the deeper parts of the Potje and along the northern flank of the Trapegeer and Den Oever. The interstitial polychaete *Microphthalmus similis* (Polychaeta: Hesionidae) is restricted to the shallow parts of the Broersbank, where it occurs with densities up to about 1000 ind./m². A detailed description of the community characteristics and habitat preferences of the three communities is given by Degraer *et al.* (1999).

It has to be stressed that each presentation (map) is the result of a compilation of the available information, structured in a database (e.g. MS Access database "Macrodat", hosted by the Marine Biology Section). Based on these data, it is decided (1) on what scale the data can be presented and (2) what spatial resolution has to be used in order to map the variables. Through the possibility to integrate and superpose newly gathered data, this first phase provides a tool to visualize the natural evolution of the area. Moreover, all information is of direct use when defining the present situation of the ecosystem of the western Coastal Banks (before the application of the management plan or *t₀*-situation).

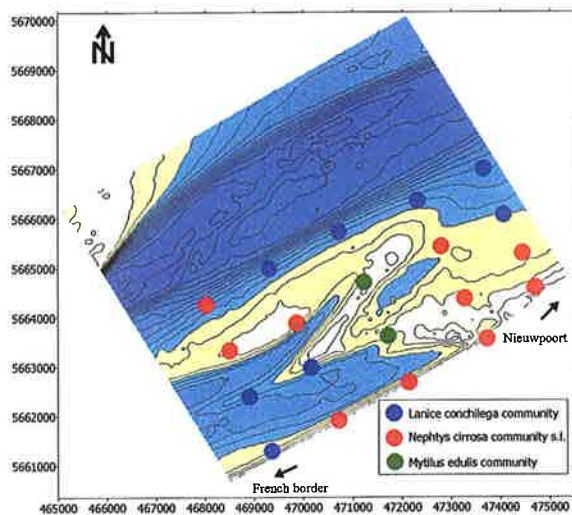


Figure 7. Schematic presentation of the occurrence of macrobenthic communities (Degraer *et al.*, 1999).

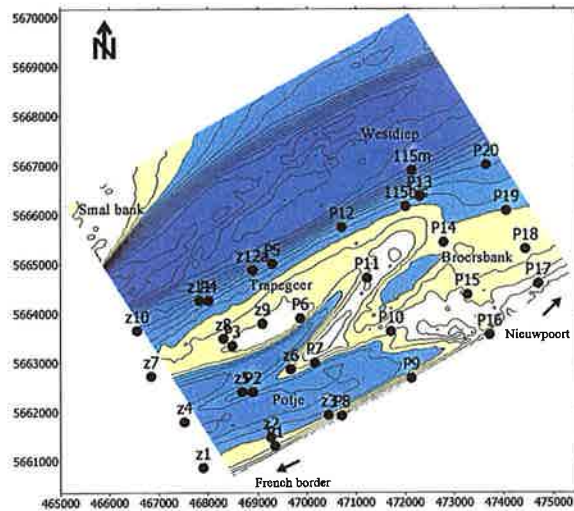


Figure 8. Distribution of 34 sampling points (Degraer *et al.*, 1999): P1 - P20; Van Steen, 1978: z1 - z12).

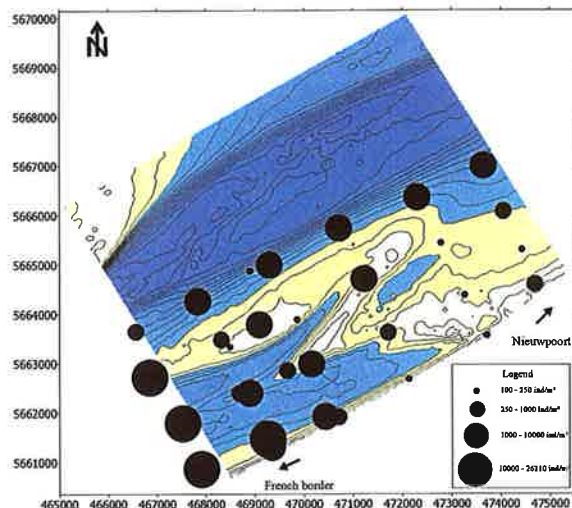


Figure 9. Distribution of the macrobenthic density (Degraer *et al.*, 1999; Van Steen, 1978).

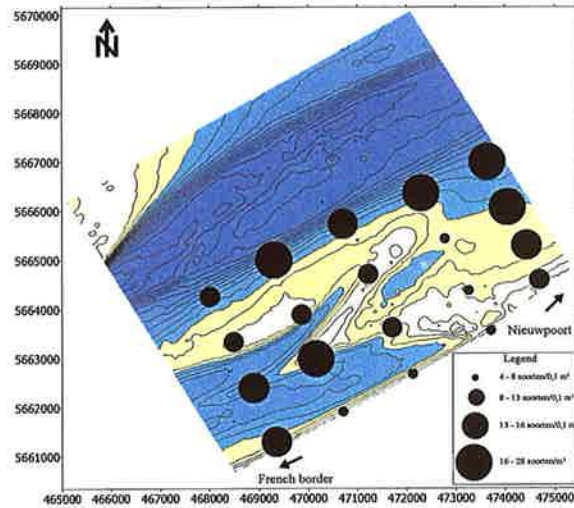


Figure 10. Distribution of the macrobenthic diversity (Degraer *et al.*, 1999).

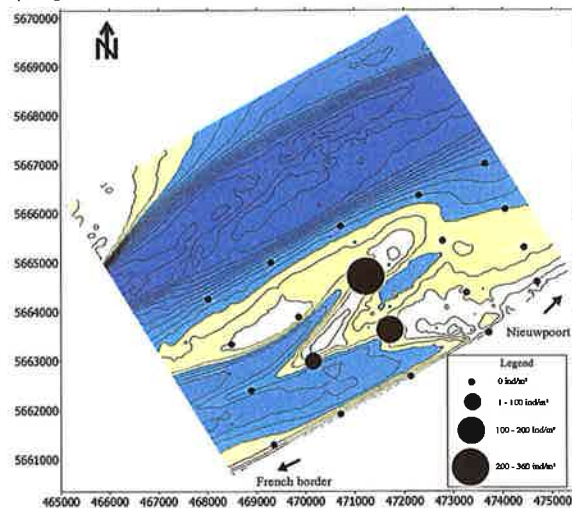


Figure 11. Distribution of the density of *Mytilus edulis* (Degraer *et al.*, 1999).

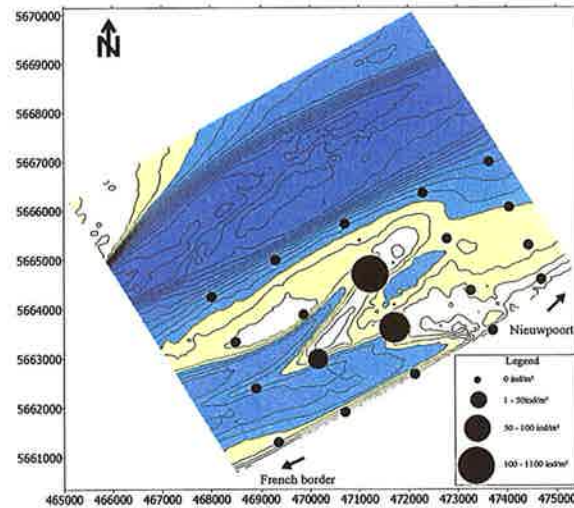


Figure 12. Distribution of the density of *Microphthalmus similis* (Degraer *et al.*, 1999).

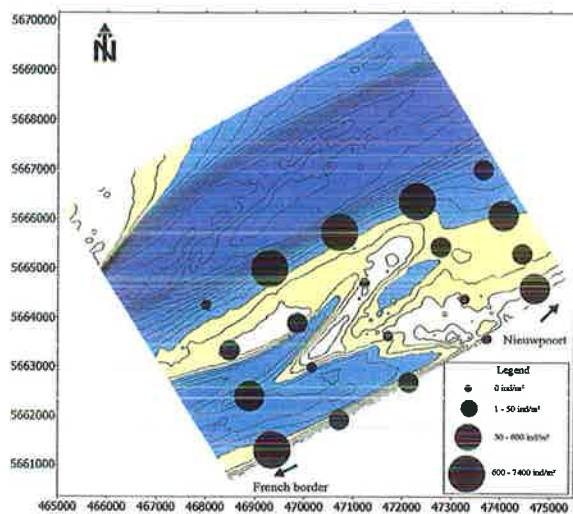


Figure 13. Distribution of the density of *Magelona mirabilis* (Degraer et al., 1999).

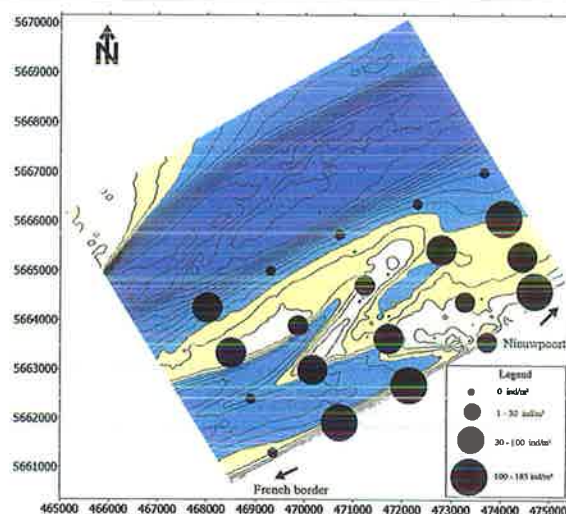


Figure 14. Distribution of the density of *Nephtys cirrosa* (Degraer et al., 1999).

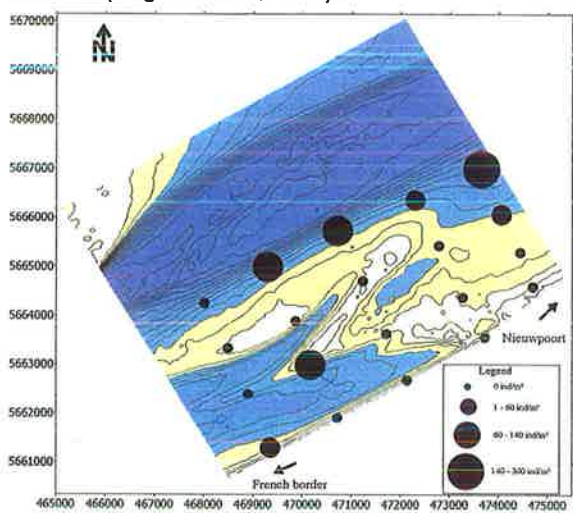


Figure 15. Distribution of the density of *Lanice conchilega* (Degraer et al., 1999).

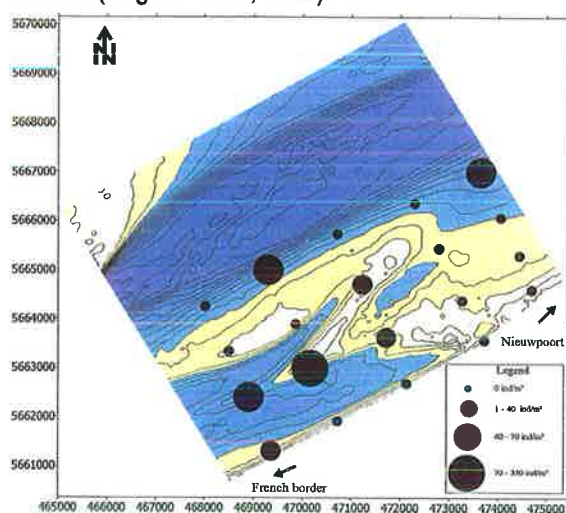


Figure 16. Distribution of the density of *Spisula subtruncata* (Degraer et al., 1999).

Discussion

An integration of the physical data was performed and was used as input of a synthesis study of sediment transport related studies on the Belgian continental shelf (Figure 17) (Lanckneus *et al.* 2001).

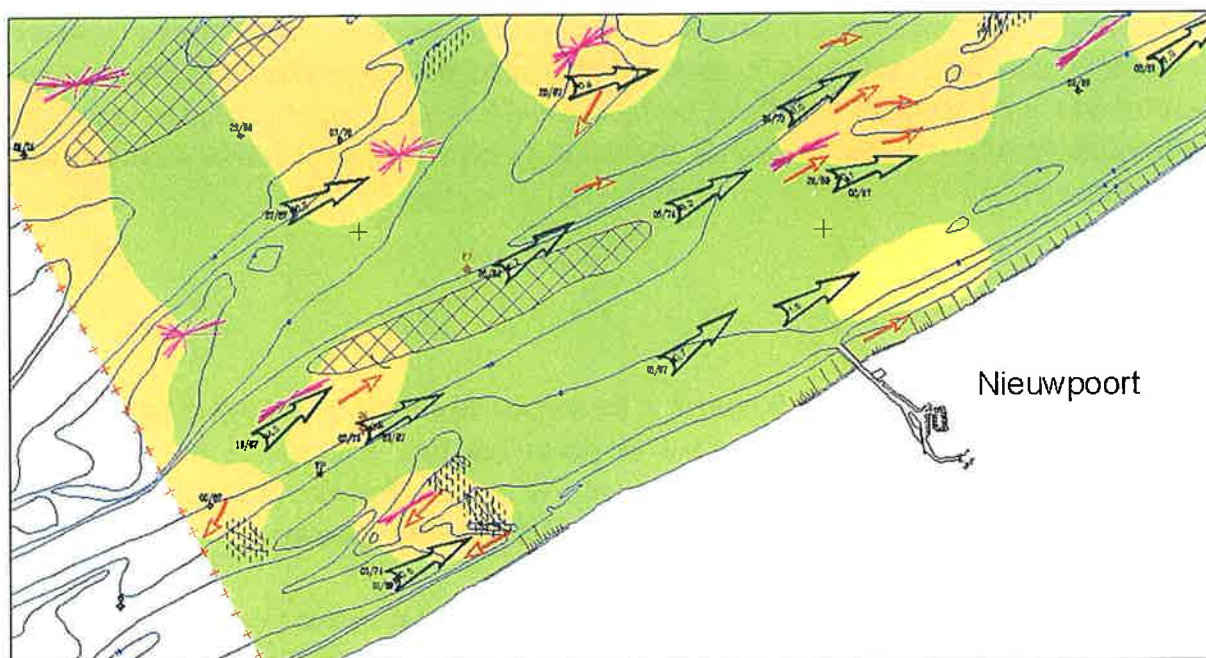


Figure 17. Sediment dynamical framework of the Western Coastal Banks (extract of the synthesis map "Natural sand transport on the Belgian continental shelf", Lanckneus *et al.* (2001)).

The background colour reflects a generalised median grain-size of the surficial sediments: orange corresponds with the presence of medium sands; green with fine sands and yellow with very fine sands. According to the classification of Folk (1957) based on the percentages of silt-clay, sand and gravel, the sediments are generally classified as slightly gravely sand (annotation of (g)S). The hatched area in the Westdiep swale corresponds with a quaternary thickness of less than 2.5 m. Tidal current ellipses are indicated based on modelling results (mu-BCZ) for a Spring tidal cycle. The black lines represent the strike of the large dunes whilst the red arrows indicate the direction of their asymmetry. The larger arrows provide a rough estimate of the suspended sediment transport and its direction based on *in situ* current meter measurements.

From the compilation and from Figure 17, it can be deduced that the area of the Western Coastal Banks is a very dynamic environment. Due to the shallowness of the area, the seabed is highly vulnerable to the hydrodynamic forces which is best illustrated on the basis of bedform occurrences. On the contrary to what is expected, the bedforms can reach heights of more than 2 m, even in shallow water. As also demonstrated somewhat northeast of the area (Van Lancker *et al.* 1997), the occurrence of bedforms is strongly correlated with the presence of medium-grained surficial sediments often with an admixture of coarse shell fragments. Likely this reflects an active input of these sand fractions in the area. In the Westdiep swale, Tertiary clay layers can potentially be eroded, as the quaternary cover is minimal; this can give rise to high amounts of fine-grained material. Apart from this, the high and rectilinear tidal currents in the Westdiep swale imply a high influx of suspended load (4.5 tonnes/m/day), whilst along the Trapegeer 0.2 tonnes/m/day and in the Potje swale 0.6 tonnes/m/day is calculated.

So far only little information about the macrobenthos of the Western Coastal Banks is available. The historical data are restricted to the Trapegeer, Broersbank, Den Oever and the Potje. Almost no information about the swale Westdiep is available.

The data provide a first view on the community structure and macrobenthic spatial distribution within the area of the Western Coastal Banks, but should be interpreted with caution. For a bathymetric-geomorphological very diversified area as the Western Coastal Banks, the data, derived from only 32 stations, should be regarded as 'point data'. No spatial extrapolation from any macrobenthic characteristic between the different sampling stations should be done.

Conclusions

To provide base maps and a physical framework of the complex depositional environment of the Westdiep - Broersbank coastal system, a compilation and integration has been performed of the bathymetrical, morphological, sedimentological, hydrodynamical and sediment transport information. Additional modelling has been performed to get acquainted with the tidal current propagation throughout the area.

From the review, the high geomorphological diversity is clearly demonstrated even on a large-scale. Moreover, a first side-scan sonar reconnaissance survey revealed very complex bedform patterns. These patterns can change on very short intervals often characterised by sharp delineations. From this, it became clear that detailed knowledge on the nature of the seabed and the structuring hydrodynamics (including the role of the ebb tidal current) is of paramount importance to get insight into the habitat structure of the Western Coastal Banks.

So far only little information about the macrobenthos of the Western Coastal Banks is available. The data provide a first view on the community structure and macrobenthic spatial distribution within the area of the Western Coastal Banks. No spatial extrapolation from any macrobenthic characteristic between the different sampling stations should be done.

THE MACROBENTHIC HABITAT OF THE WESTERN COASTAL BANKS

Characterisation, community structure, habitat preferences and spatial distribution

Introduction

The spatial distribution of the wintering Sea ducks is defined by several factors, of which food availability and the undisturbed character of the biotope are very important (Kirchoff 1981). The high geomorphological diversity of the area, including intertidal sites, is directly responsible for the restricted access of ships, hence ensuring optimal conditions for the seabirds. Because Seaducks are directly dependent from the macrobenthos, and more specifically the Bivalvia as their food resource (Cramp & Simmons 1977), the presence of high numbers of bivalves (e.g. *Abra alba*, *Tellina fabula* and especially *Spisula subtruncata* (Degraer *et al.* 1999) is extremely important. Moreover, the macrobenthos is also important as a food resource for several commercial and non-commercial fishes (e.g. Cod and Gobiids). The macrobenthos is thus an extremely important component within the ecosystem functioning of the western Coastal Banks. Therefore, knowledge of the natural spatial distribution and seasonal variation of the macrobenthos is extremely important when setting up a management plan for the proposed marine protected area (MPA).

Materials and methods

SELECTION OF THE STUDY SITES

Based on the preliminary data on the bathymetry, geomorphology, sedimentology and macrobenthos of the study area and the side-scan sonar reconnaissance survey, three zones were selected for further multidisciplinary investigation (Figure 18). Together, these zones represent the expected habitat variability within the study area. Table I gives an overview of the measuring and sampling campaigns. The methodology followed is described in the section on standard materials and methods.

Within the zones, full-coverage side-scan sonar imagery has been obtained. Along the Westdiep swale, single-beam bathymetry has been recorded, whilst in the southern area, multibeam technology was available. The samples were regularly spread over the area with an interval of 500 m. For the multidisciplinary investigation, three sampling transects were planned per zone lying perpendicular to the coastline.

The western zone includes the foreshore, the deeper part of the Potje swale, the western part of the Trapegeer and Westdiep and the southern slope of the Smalbank. The central zone includes (from shore to open sea): foreshore, southern branch of Potje, western part of Broersbank, northern branch of Potje, central part of Trapegeer and Westdiep. The eastern zone is composed of a near coastal shoal, the western part of Den Oever and the Westdiep.

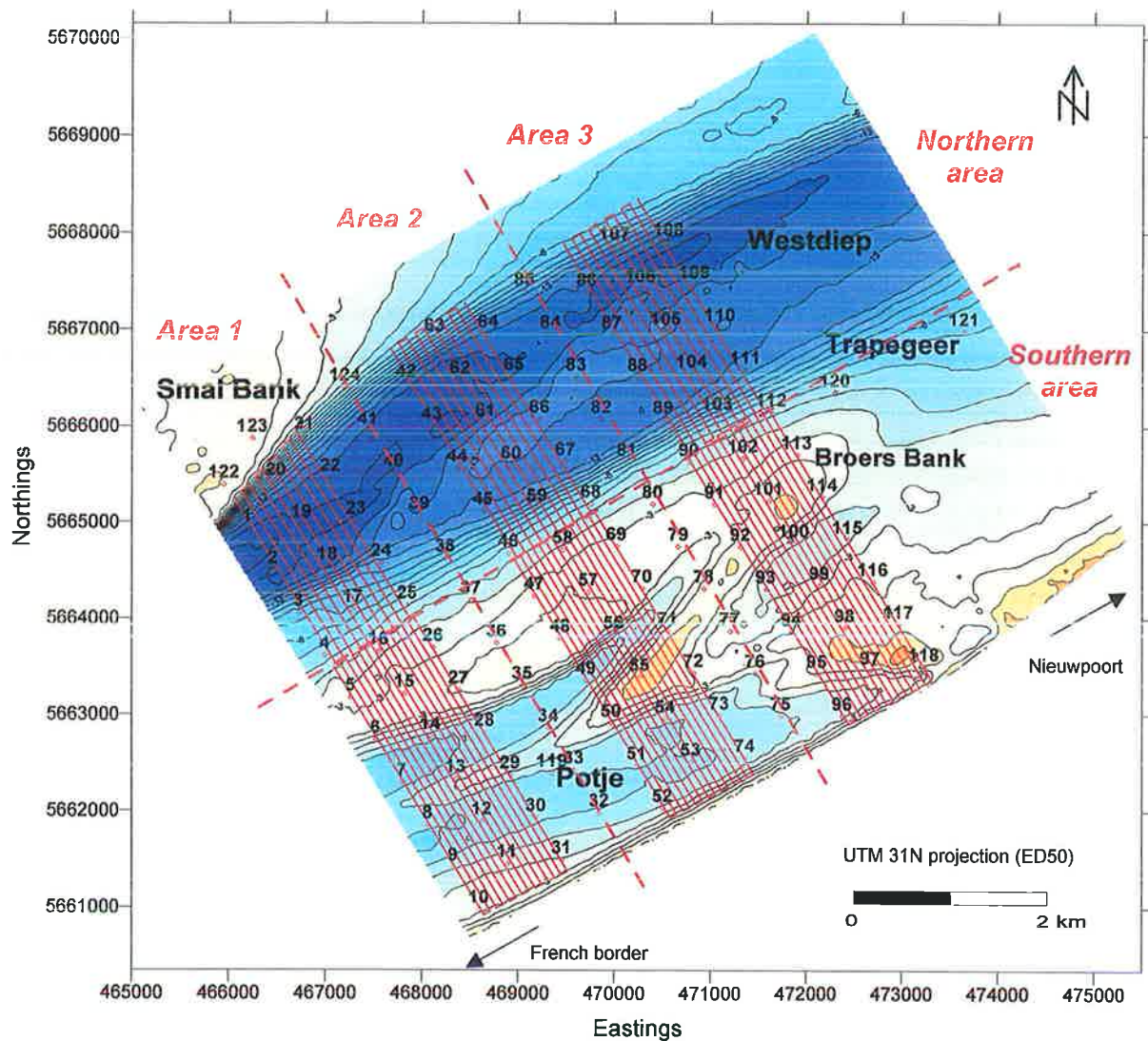


Figure 18. The sub areas selected for further investigation. The area was subdivided in 3 zones that were acoustically surveyed in full-coverage, albeit consisting of a northern and a southern part.

HYDRODYNAMICAL MEASUREMENTS

Within the framework of the project, MUMM granted the use of a bottom-mounted acoustic doppler current profiler (ADCP) to gain insight into the current variability over the vertical and near the bottom. Although, several deployments were originally planned, one dataset was obtained at the foot of the slope of the Trapegeer (for a location, see Figure 3). This location was preferred as field measurements indicated the presence of fields of the tube worm *Lanice conchilega*; moreover it was within the reach of operations with the oceanographic vessel RV Belgica. The deployment covers a Mid tidal cycle with a modelled tide range of 4.309 m.

The ADCP instrumentation was mounted in a bottom frame as to minimize the risk of loss and to avoid damage from trawling activities. Taking into account the frame height of 50 cm and a first acoustic blanking of 0.56 m, good quality data data was obtained from +/- 1 m above the bed. A cell resolution (bin size) of 0.25 m was chosen with 100 pings/ensemble. This gives a standard deviation of 0.16 m/s. The deployment characteristics are given in Table IV.

Table IV. ADCP deployment characteristics along the slope of the Trapegeer (Coordinates in ED50).

Easting (m)	Northing (m)	Start	End	Type ADCP
469130	5664757	2000-10-18 18:25	2000-10-19 15:01	RDI Workhorse sentinel 1200 kHz

MATHEMATICAL ANALYSES

Macrobenthic diversity was expressed as the number of species per sample (N_0). Community structure was analyzed by means of Two-Way Indicator Species Analysis (TWINSpan; using the quantitative and qualitative dataset), Correspondence Analysis (CA; using the quantitative dataset) and group-averaging Cluster Analysis (using the Bray-Curtis similarity index, based on the quantitative dataset). Indicator Species Analysis (IndVal) was used to determine the species indicative for the observed community structure (Dufrêne & Legendre, 1997). The correlations between different variables were analyzed by means of the nonparametric Spearman rank correlation coefficient (Siegel 1952; Conover 1971). The non-parametric Wilcoxon matched pairs signed-ranks test is used to detect general trends of dynamics (differences) or stability (similarities) between the two sampling campaigns (Conover, 1971).

Results

MORPHO-SEDIMENTOLOGICAL CHARACTERISATION

Figure 19 gives a contour map of the surficial sediments of the area based on 124 samples taken in October 1999. The same trends can be found as in Figure 4, but the map is much more detailed as the sampling interval was 500 m.

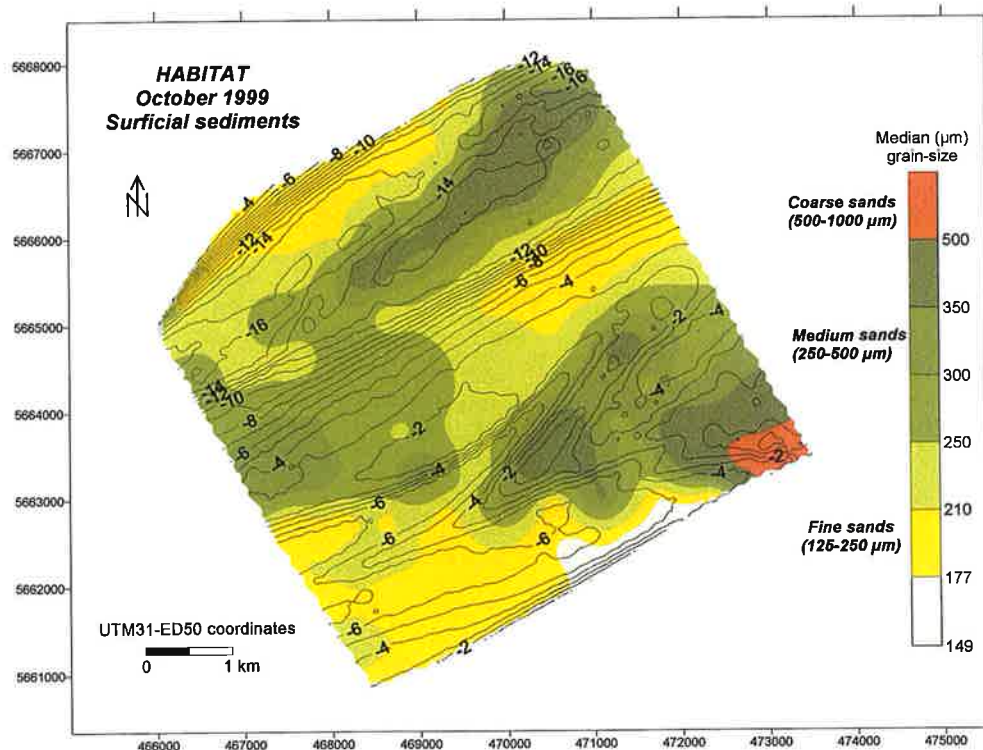


Figure 19. Contour map of the median grain-size of the surficial sediments (October 1999).

In the Westdiep swale, coarse sands and shell hash is found along a zone of positive relief that extends towards the Trapegeer sandbank. To the east, a fining sediment gradient is observed. The top zone of the Broersbank is generally characterized by shell hash. Interestingly, are the coarse sands and shell hash sampled along the near coastal shoal in the SE corner of the Habitat area. The surficial sediments of the Potje swale are very fine to fine sands with a high silt-clay ratio.

The detailed bathymetric registrations that were acquired along the three subareas of detailed investigation generally fit with the already known bathymetry, still much more detailed and accurate terrain modelling could be performed. Figure 20 represents a 2D and 3D digital terrain model of the central zone (southern part) based on multibeam data. These data give a good overview of the large-scale morphology and show the merely flattened topography of the Trapegeer sandbank. Although, not so clear, the strike of a large dune is perceived along the stoss slope of the bank. The Broersbank (SW part) is much shallower and also has a flattened appearance. No large depth variations are seen along the southern branch of the Potje swale, still minor differentiations occur, that are likely associated with an undulating seafloor.

As mentioned in the standard materials and methods, the different side-scan sonar tracklines were processed at a 10 cm resolution and merged into georeferenced mosaics per zone. Figure 21 is a mosaic of the same area as presented in Figure 20 that was derived from multibeam bathymetry. The advantage of the use of side-scan sonar technology is that it already produces photo-quality imagery during the acquisition phase. The different grey-scales are a reflection of the varying signal amplitude caused by differences in seabed nature. Hence, the image directly provides insight into the seabed variability a.o. in terms of its relief and its sediments.

Multibeam bathymetry data can however be merged with side-scan sonar imagery and as such highly accurate and very-high resolution 3D multiparameter images can be produced. This procedure allows to study the intrinsic nature of the seafloor in relation to the large and small-scale morphology. Figure 22 is again the central zone. The combined imagery shows the presence of white reflectivity patches and bands in the deepest parts of the Potje swale (see also temporal variability).

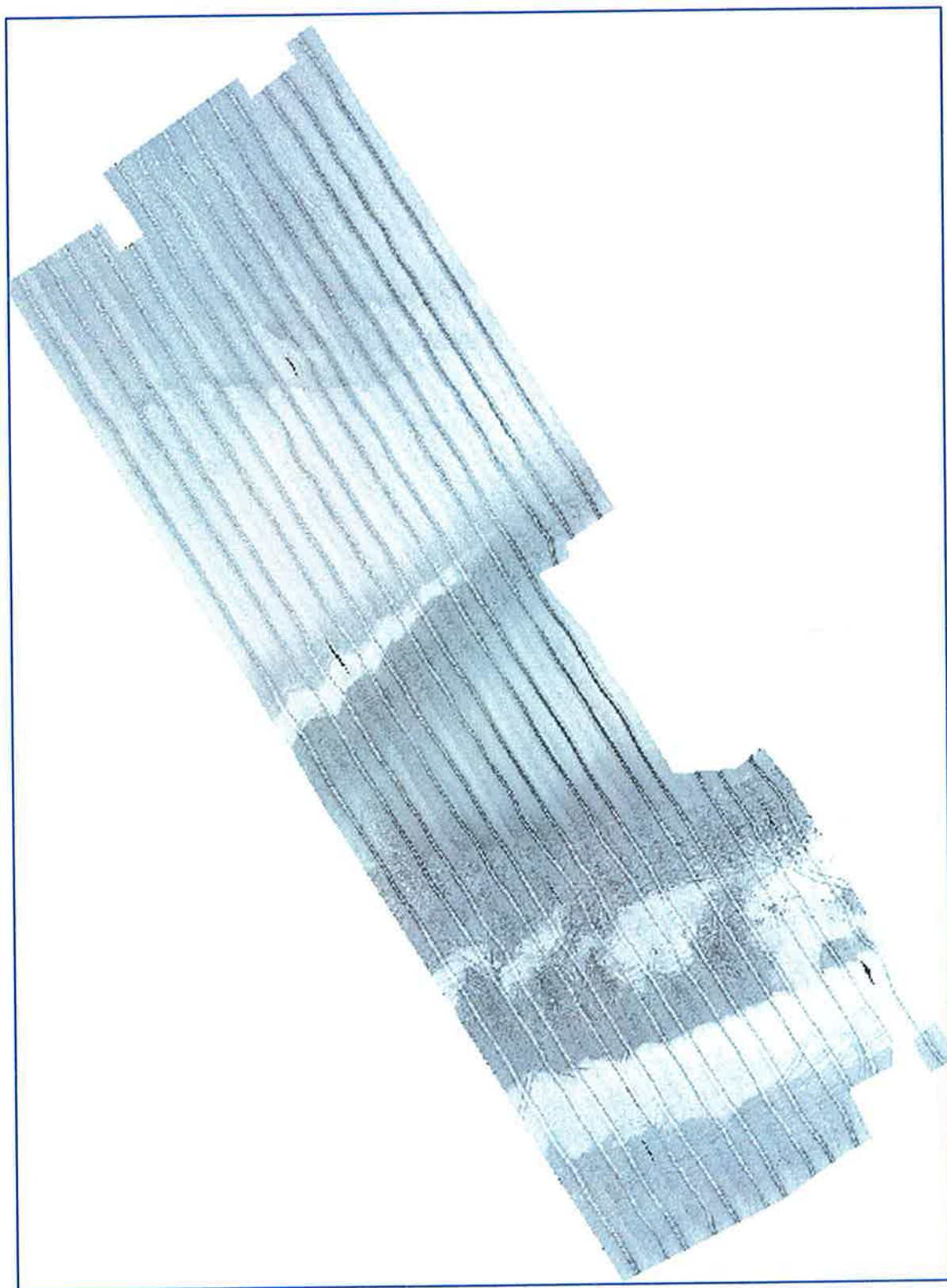


Figure 21. Side-scan sonar mosaic of the southern central zone of the study area.

Figure 20. Digital terrain model (2D and 3D) of the central part of the southern zone based on multibeam data (March 2000).

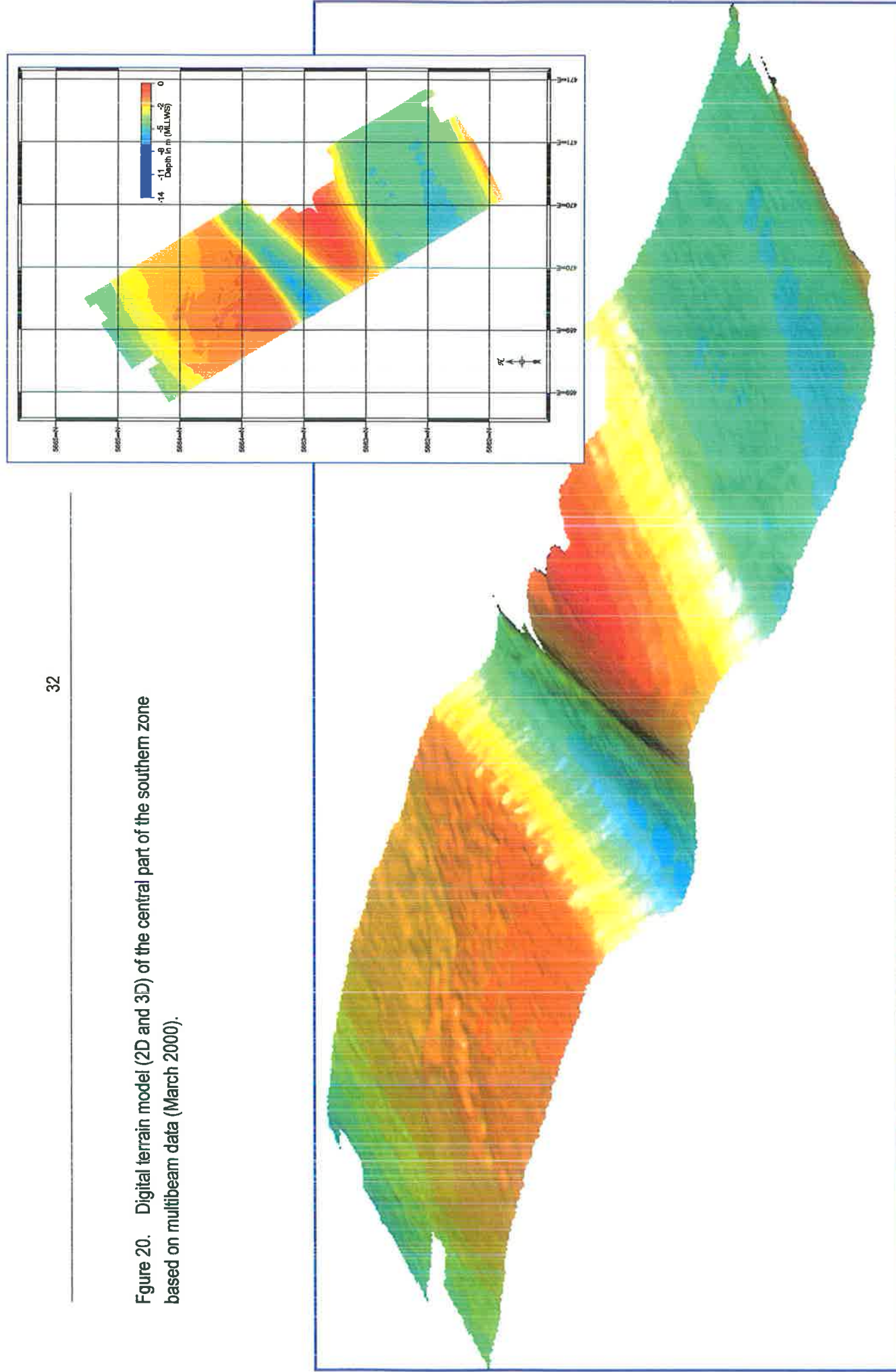




Figure 22. Very-high resolution image of the central part of the southern zone based on the combination of side-scan sonar and multibeam data (March 2000).

Zooming into the image, the diverse nature of the seabed becomes more clear (Figure 23) and can be studied in relation to the sedimentology, geomorphology, and the hydrodynamics of the area as well as to the presence of living organisms. The interrelationships are best demonstrated throughout the Figures 40 to 53.

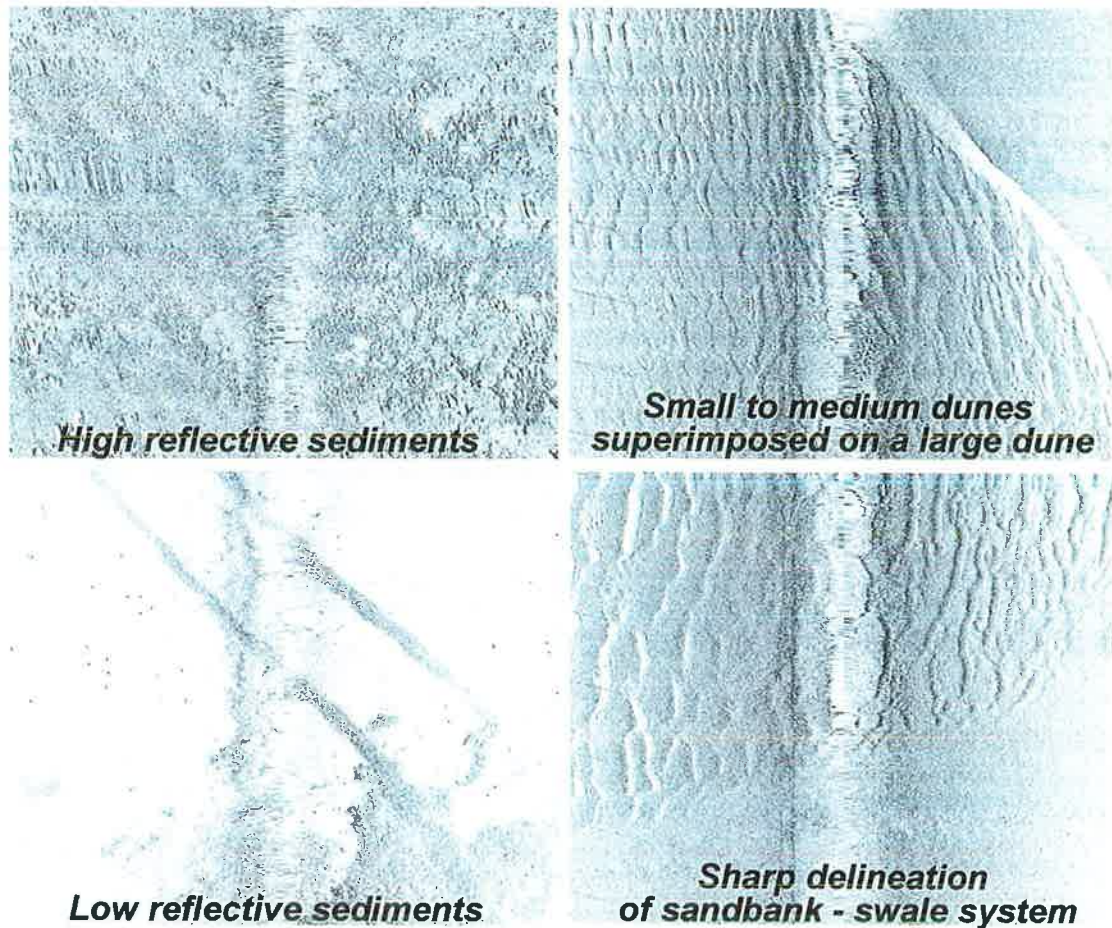


Figure 23. Demonstration of the diverse nature of the side-scan sonar imagery.

The interpretation of the acoustic imagery in terms of sedimentology is explained in the section on the macrobenthic side-scan sonar interpretation. From a geomorphological point of view, the mosaics revealed a variety of bedform patterns ranging from small-scale ripple-like features up to large dunes. One large dune of more than 2 m was observed in the Westdiep swale that was clearly NE directed. Remarkably, large dunes also occurred in the shallowest areas such as near the topzone of the Trapegeer to the west (Figure 40), southwards of the Broersbank and along the shallow near coastal shoal. All these dunes seem to be merely ebb-dominated as well in shape as in asymmetry. Generally, medium dunes occur along the slope of the Trapegeer. In the Westdiep swale a transition is observed of sandy medium dunes into small dunes composed of shell hash. Figure 24 is a typical image that is associated with these shell hash dunes. The highly variable nature of the seafloor along the Westdiep swale is best illustrated through Figure 43. This Figure also shows the current lineations in the deepest part of this swale. In order to gain insight into the spatial variability of the imagery, a standardised procedure was set-up aiming at an interpretation of the imagery in terms of an acoustic facies. Throughout this process, areas are primarily grouped according to differences in reflectivity, textures and patterns. This concept is described in the section on the macrobenthic side-scan sonar interpretation.

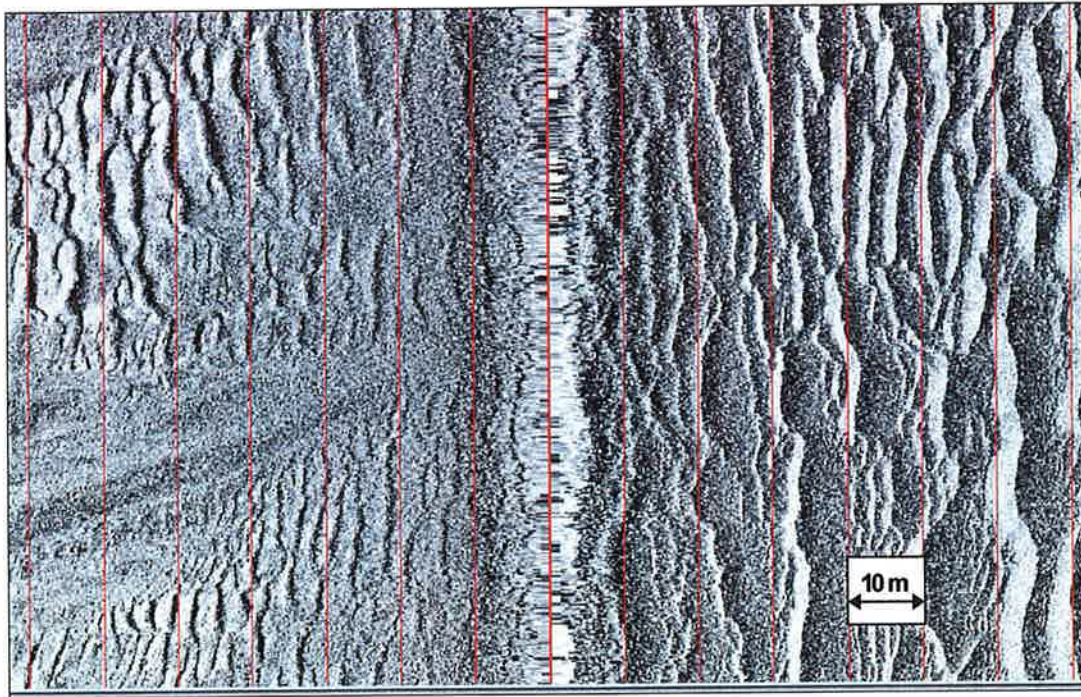


Figure 24. Corrected side-scan sonar image along the plateau-like morphology in the Westdiep swale (Localisation Figure 3) (October 1999). From ground-truthing the rippled bedforms constitute of shell hash. On the left channel lineations are seen due to scouring.

HYDRODYNAMICAL CHARACTERISATION

In order to explain the variability of the side-scan sonar imagery and to correlate the spatial distribution of the macrobenthos with the current variability in the area, numerical model results on a 250 m grid resolution were investigated. This was firstly done on the basis of the mu-BCZ model on a 750 m grid, but these results proved to be too coarse to explain the high sedimentary and biological variability in the area. However, as mentioned earlier the absolute values of the detailed model are too high and as the areas shallower than – 6 m are treated as having a constant topography, it was preferred to await a further validation of the model. It is however clear, that a detailed 3D model would be of high value for any detailed habitat study.

The vertical current velocity was studied based on acoustic doppler current profiling (ADCP) measurements that were performed along the foot of the slope of the Trapegeer. Current data was extracted from 1 m above the bed as this is most relevant for habitat studies (Figure 25). The data confirmed the highly rectilinear nature of the tidal current. The highest value that was obtained was 0.57 m/s with a direction of 51° (flood direction). Given a general threshold of 0.4 m/s for sediment movement, as well flood as ebb tidal currents are able to transport sediment. Recalculating a value of 0.57 m/s to a mean depth value, 0.67 m/s is obtained; this is within the order of magnitude of the current velocities from the mu-BCZ model (750 m grid).

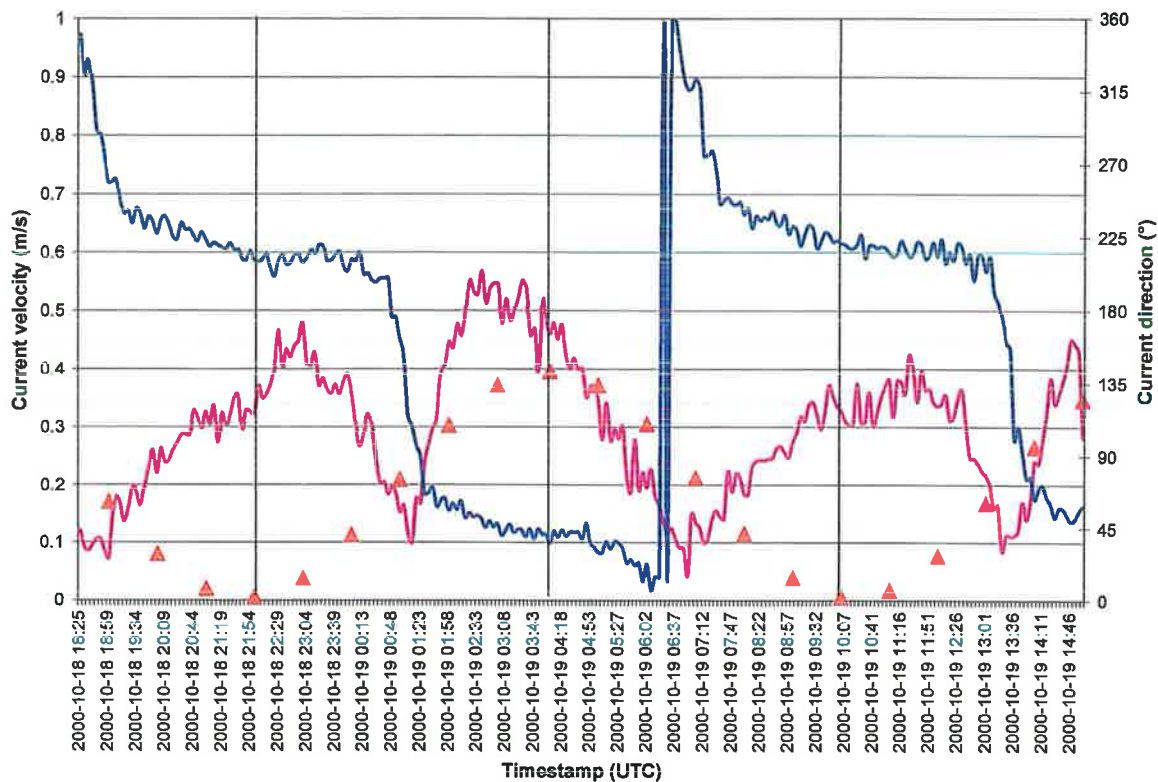


Figure 25. Variability of the current velocity magnitude (magenta) against its direction (blue) at 1 m above the bed. The ADCP data is integrated with relative values of the M2-tide from Nieuwpoort (red triangles). The vertical lines indicate the time of High Water and Low Water. Note the strong rectilinear nature of the tidal current.

PHYSICO-CHEMICAL VARIABLES

Considering the nutrients of the water column, dissolved silicium has the highest concentration ($174 \pm \text{SE } 7 \mu\text{g/l}$) (Table V). Other nutrients have a maximum average concentration of $54 \mu\text{g/l}$. Fucoxanthine and chlorophyll A (both $1 \mu\text{g/l}$ on average) have higher concentrations than chlorophyll C ($0.3 \mu\text{g/l}$ on average). Within the interstitial water of the sediments, ammonium has the highest concentrations (average: $11770 \mu\text{g/l}$). The redox potential discontinuity layer (RPD) is found at an average depth of about 7 cm. The sediments (average median grain size: $268 \mu\text{m}$) are mainly composed of fine and medium sand, with a low percentage of clay (average: 0.7 %), silt (average: 2.9 %) and gravel (average: 3.3 %). Within the study area, the median grain size is ranging from 158 to $656 \mu\text{m}$. During the sampling campaign the average water temperature, salinity and oxygen concentration were, respectively, about 15°C , 33.8 PSU and 6.9 mg/l . The sampling stations were situated at a depth ranging from 0.4 to 16.7 m below MLLWS (average: 7.5 m).

Table V. Environmental and macrobenthic data (average, standard error, maximum and minimum value).

Physico - chemical and macrobenthic data of the study area				
Environmental variables	average	sterror	max	min
Nutrients-pigments of watercolumn				
NO ₂ + NO ₃ (µg/l)	54,27	3,02	143,00	7,00
NH ₄ (µg/l)	28,01	1,81	72,00	0,00
PO ₄ (µg/l)	4,00	0,43	25,00	0,00
Si (µg/l)	174,00	6,82	398,00	47,00
Fuco (µg/l)	1,06	0,03	2,10	0,10
Chlc (µg/l)	0,31	0,01	1,10	0,02
Chla (µg/l)	1,00	0,06	3,10	0,00
Nutrients of sediment				
NO ₂ + NO ₃ (µg/l)	229,64	19,61	1084,00	3,00
NH ₄ (µg/l)	11769,76	1071,22	66463,00	1376,00
PO ₄ (µg/l)	2448,14	257,47	13489,00	36,00
Si (µg/l)	1241,19	50,33	2538,00	262,00
Sedimentology				
RPD (cm)	6,89	0,30	10,00	0,00
Median grain size (µm)	268,19	7,87	655,60	157,50
Mean grain size (µm)	251,00	8,50	616,92	108,83
Mean-median - ratio	0,92	0,01	1,04	0,64
Modal grain size (µm)	276,12	9,58	853,00	190,10
Clay (%)	0,65	0,08	3,60	0,00
Silt (%)	2,86	0,37	18,70	0,00
Very fine sand (%)	3,11	0,26	15,30	0,00
Fine sand (%)	44,40	2,03	82,44	1,60
Medium sand (%)	40,71	1,68	76,00	9,86
Coarse sand (%)	8,27	1,20	80,30	0,00
Very coarse sand (%)	2,61	0,51	43,45	0,00
Gravel (%)	3,25	0,45	26,53	0,00
General environmental variables				
Temperature (°C)	14,93	0,22	33,80	11,60
Salinity (PSU)	33,81	0,16	34,70	15,70
Oxygen concentration (mg/l)	6,87	0,03	7,60	5,90
Depth (m below MLWS)	7,46	0,44	16,65	0,39
General macrobenthic variables				
Total density	3287,66	457,65	27962,97	77,97
N ₀	21,43	1,27	55,00	4,00

MACROBENTHOS: GENERAL

The total macrobenthic density ranged from 78 to 27963 ind./m² (average: 3288 ind./m²) (Table VI). In total 128 macrobenthic species were found in the area. The number of species per sample (= 0.1 m²) ranged from 4 to 55 species (average: 21 spp.). The polychaetes were the most abundant taxon, followed by the bivalves and crustaceans (Figure 26). Other taxa present were the oligochaetes, anthozoans, echinoderms, and gastropods (in order of decreasing abundance).

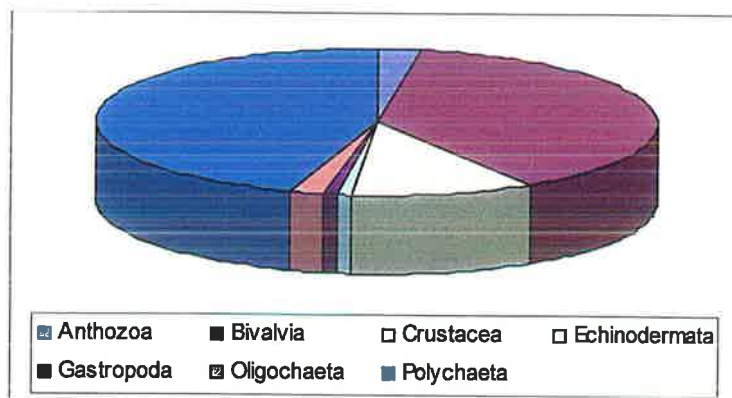


Figure 26. Relative abundances of the dominant taxa in the study area

MACROBENTHOS: COMMUNITY STRUCTURE

Multivariate techniques (TWINSPAN on the quantitative and qualitative dataset, CA and clusteranalysis) revealed the existence of station groups (Figure 27).

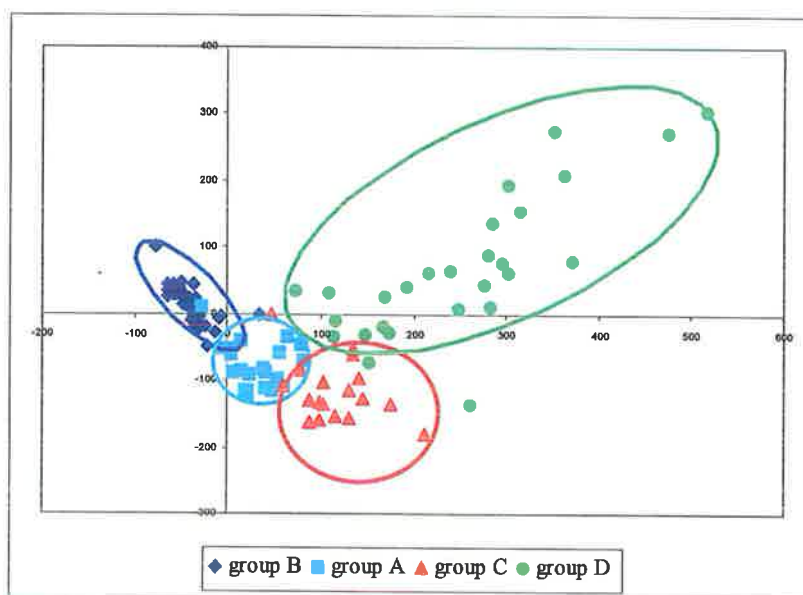


Figure 27. CA of the macrobenthic samples of October 1999, with the presentation of the four station groups (A, B, C and D)

A first station group (group A), with an average macrobenthic density of 1269 ind./m² and an average N_0 of 17 species, was dominated by the polychaete *Magelona mirabilis* (531 ind./m²). An indicator value from 30 to 50 was found for the cumacean *Diastylis bradyi*, the bivalve *Donax vittatus*, and the polychaete *M. mirabilis*. These stations were found at an average depth of 6.7 m, within fine sand-dominated sediments with a median grain size of 218 μ m (1 % clay, 4 % silt and 2 % gravel). Considering bottom nutrients, NH₄ had the highest average concentration (about 18000 μ g/l). Dissolved silicium had the highest concentration of all nutrients in the watercolumn (188 μ g/l), while fucoxanthine and chlorophyll A dominated the water column pigments (resp. 1.2 and 1.1 μ g/l).

A second station group (group B) was characterized by an average macrobenthic density of 7589 ind./m² and an average N₀ of 37 species (Table VI). The bivalves *Abra alba*, *Mysella bidentata*, the polychaete *Scoloplos armiger* and the amphipod *Pariambus typicus* had densities over 500 ind./m². The ten most abundant species within the station group all had an average density higher than 250 ind./m². The polychaetes *Pectinaria koreni*, *Notomastus latericeus*, *Owenia fusiformis*, *Sthenelais boa*, *Lanice conchilega* and *Nereis longissima*, the amphipod *P. typicus*, and the bivalves *M. bidentata*, *A. alba* and *Ensis* spp., had an indicator value of 70 or higher. The station group typically occurred in relatively deep-water sediments (10.5 m) with a median grain size of 220 µm. The fine sand-dominated sediments contained 1 % clay, 5 % silt, and 6 % gravel. NH₄ was the most dominant nutrient in the bottom (about 14000 µg/l). Dissolved silicium had the highest concentration of all nutrients in the watercolumn (158 µg/l), while fucoxanthine and chlorophyll A dominated the water column pigments (both 1.0 µg/l).

The polychaete *Nephtys cirrosa* (113 ind./m²) was the most typical species of the third station group (group C), with an average macrobenthic density of 350 ind./m² and an average N₀ of 11 species. Only the echinoderm *Echinocardium cordatum* and the polychaete *N. cirrosa* had relatively high indicator values (36 and 30, respectively). These stations occurred within medium sand-dominated sediments (median grain size: 266 µm; < 1 % clay, 1 % silt and 1 % gravel) at an average depth of 4.8 m. Again, NH₄ had the highest average concentration in the bottom (12000 µg/l). Dissolved silicium had the highest concentration of all nutrients in the watercolumn (190 µg/l), while fucoxanthine and chlorophyll A dominated the water column pigments (resp. 1.0 and 0.9 µg/l).

A fourth station group (group D) had an average density of 365 ind./m² and an average N₀ of 9 species. Species densities were 69 ind./m² at maximum. The three most abundant species were the polychaetes *N. cirrosa* and *Ophelia limacina* and the amphipod *Urothoe brevicornis*. The highest indicator values were found for the polychaete *O. limacina* (69) and the amphipod *U. brevicornis* (52). The stations' sediments mainly consisted of medium sand with an average median grain size of 345 µm. Sediment clay and silt contents were < 1 %, while 17 % consisted of gravel. An average of about 5000 µg NH₄/l was found. Dissolved silicium had the highest concentration of all nutrients in the watercolumn (195 µg/l), while fucoxanthine and chlorophyll A dominated the water column pigments (both 1.0 µg/l).

Table VI. The physico-chemical and macrobenthic variables of the four station groups.

	Group B		Group A		Group C		Group D	
	average	sterror	average	sterror	average	sterror	average	sterror
General environmental variables								
Depth (m below MLWS)	10,53	0,65	6,65	0,79	4,75	0,84	5,15	0,92
Temperature (°C)	15,72	0,46	14,30	0,41	13,81	0,40	14,70	0,33
Salinity (PSU)	33,67	0,42	33,92	0,09	33,88	0,06	33,85	0,05
Oxygen concentration (mg/l)	6,83	0,04	6,98	0,05	6,75	0,09	6,90	0,06
Sedimentology								
RPD (cm)	5,30	0,50	4,86	0,52	9,09	0,49	9,50	0,34
Median	219,73	5,39	218,10	8,69	265,51	9,75	344,61	10,60
Clay (%)	1,27	0,12	0,74	0,20	0,19	0,17	0,04	0,04
Silt (%)	5,42	0,56	3,80	1,19	0,76	0,68	0,24	0,19
Very fine sand (%)	4,95	0,36	4,28	0,76	1,65	0,25	0,62	0,15
Fine sand (%)	55,10	1,82	59,13	3,62	43,13	4,14	20,72	2,68
Medium sand (%)	30,15	1,72	30,67	3,73	50,37	3,24	61,69	1,81
Coarse sand (%)	3,11	0,76	1,38	0,54	3,91	1,09	16,69	1,98
Gravel (%)	6,13	0,74	1,95	0,36	0,87	0,21	7,57	1,02
Nutrients of sediment								
NO ₃ + NO ₂ (µg/l)	295,48	45,64	94,95	18,38	193,31	43,77	271,65	26,06
NH ₄ (µg/l)	13918,71	1806,2	17977,32	3357,0	12439,50	2839,3	4914,14	529,14
PO ₄ (µg/l)	1634,68	200,44	3448,47	668,63	4128,81	940,71	1238,65	255,26
Si (µg/l)	1504,36	66,32	1632,68	95,93	1023,69	103,29	716,48	66,51
Nutrients-pigments water column								
NO ₃ + NO ₂ (µg/l)	39,85	4,10	66,24	9,97	61,69	7,72	67,86	4,25
NH ₄ (µg/l)	26,78	2,49	24,33	4,08	30,13	5,75	32,95	4,53
PO ₄ (µg/l)	3,93	0,68	3,05	1,24	4,31	1,13	4,91	0,86
Si (µg/l)	158,29	10,85	188,14	20,03	189,63	17,92	195,18	11,13
Fuco (µg/l)	1,04	0,06	1,16	0,07	1,03	0,06	1,04	0,07
Chlc (µg/l)	0,31	0,02	0,32	0,02	0,28	0,01	0,34	0,04
Chla (µg/l)	0,98	0,11	1,11	0,12	0,85	0,14	1,04	0,14
Number of stations	44		21		18		28	
Macrobenthic variables								
N ₀ : # species/sample	37	1,06	17	1,49	11	0,79	9	0,42
Mean densities (ind/m ²)	7589	856,4	1269	245,9	350	37,0	365	35,8
10 most abundant species with average density (ind/m ²)	<i>Abra alba</i> : 992		<i>Magelona mirabilis</i> : 531		<i>Nephtys cirrosa</i> : 113		<i>Nephtys cirrosa</i> : 69	
	<i>Myrella bidentata</i> : 914		<i>Spiophanes bombyx</i> : 143		<i>Spiophanes bombyx</i> : 38		<i>Urothoe brevicornis</i> : 58	
	<i>Scoloplos armiger</i> : 691		<i>Nephtys cirrosa</i> : 73		<i>Echinocardium cordatum</i> : 19		<i>Ophelia limacina</i> : 34	
	<i>Pariambus typicus</i> : 640		<i>Urothoe poseidonis</i> : 56		<i>Montacuta ferruginosa</i> : 18		<i>Scoloplos armiger</i> : 33	
	<i>Spiophanes bombyx</i> : 395		<i>Fabulina fabula</i> : 54		<i>Bathyporeia pelagica</i> : 18		<i>Mytilus edulis</i> spat : 31	
	<i>Bumida sanguinea</i> : 320		<i>Spio martinensis</i> : 45		<i>Scoloplos armiger</i> : 14		<i>Actinaria</i> spp. : 22	
	<i>Larice conchilega</i> : 318		<i>Nephtys hombergii</i> : 41		<i>Urothoe poseidonis</i> : 14		<i>Spiophanes bombyx</i> : 18	
	<i>Cirratulidae</i> spp. : 279		<i>Scoloplos armiger</i> : 28		<i>Bathyporeia guilliamsoniana</i> : 14		<i>Gastrosaccus spinifer</i> : 9	
	<i>Magelona mirabilis</i> : 274		<i>Capitella capitata</i> : 25		<i>Magelona mirabilis</i> : 11		<i>Urothoe pulchra</i> : 8	
	<i>Fabulina fabula</i> : 273		<i>Donnax vittatus</i> : 24		<i>Fabulina fabula</i> : 10		<i>Bathyporeia elegans</i> : 8	
Indicator species with indicator value	<i>Pectinaria korei</i> : 85		<i>Diastylis bradi</i> : 48		<i>Echinocardium cordatum</i> : 36		<i>Ophelia limacina</i> : 69	
	<i>Pariambus typicus</i> : 82		<i>Donnax vittatus</i> : 39		<i>Nephtys cirrosa</i> : 30		<i>Urothoe brevicornis</i> : 52	
	<i>Notomastus latericeus</i> : 81		<i>Magelona mirabilis</i> : 32		<i>Bathyporeia guilliamsoniana</i> : 28		<i>Gastrosaccus spinifer</i> : 30	
	<i>Owenia fusiformis</i> : 81		<i>Nephtys hombergii</i> : 30		<i>Bathyporeia pelagica</i> : 28		<i>Nephtys cirrosa</i> : 29	
	<i>Sthenelais boa</i> : 79		<i>Nephtys cirrosa</i> : 24		<i>Synchelidium maculatum</i> : 22		<i>Bathyporeia elegans</i> : 21	
	<i>Myrella bidentata</i> : 75		<i>Urothoe poseidonis</i> : 24					
	<i>Abra alba</i> : 74		<i>Spio martinensis</i> : 23					
	<i>Ensis</i> spp. : 71		<i>Spiophanes bombyx</i> : 21					
	<i>Larice conchilega</i> : 70							
	<i>Nereis longissima</i> : 70							
	<i>Glycera alba</i> : 68							
	<i>Cirratulidae</i> spp. : 62							
	<i>Melita obtusata</i> : 61							
	<i>Actinaria</i> spp. : 58							
	<i>Anatides mac-muc.</i> : 57							
	<i>Capitella capitata</i> : 57							
	<i>Posidilochaelus serpens</i> : 55							
	<i>Peneropis pullastra</i> : 54							
	<i>Bumida sanguinea</i> : 53							
	<i>Heteromastus filiformis</i> : 51							
	<i>Nephtys hombergii</i> : 49							

MACROBENTHOS: COMMUNITY'S SPATIAL DISTRIBUTION

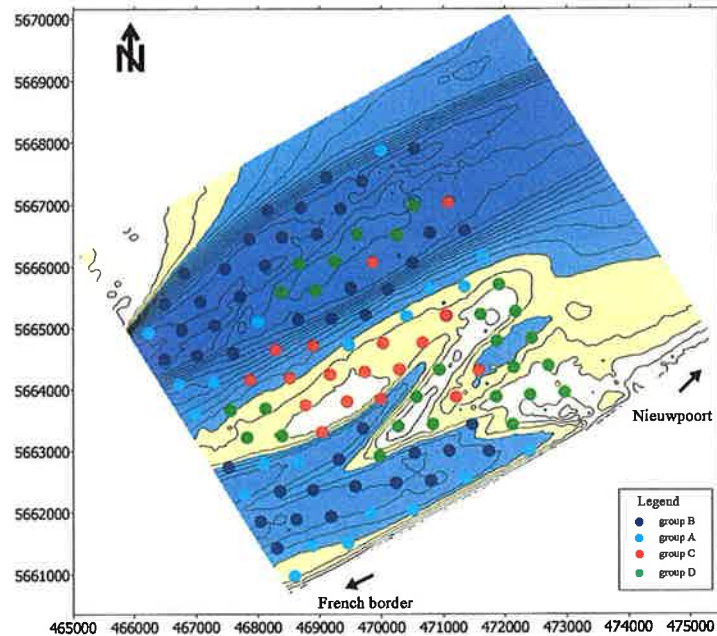


Figure 28. The spatial distribution of the four station groups in the study area

The four station groups are spread all over the western Coastal Banks. Group B is mainly found in the deeper parts of the swales Westdiep and Potje. Group C is mainly restricted to the relatively shallow tops of the Trapegeer sandbank. As expected, group A association, is mainly found in the periphery of group B. Group D is found at the shallow part of the Broersbank and the elevated central part of the Westdiep.

Lanice conchilega (Polychaeta: Terebellidae)

The polychaete *Lanice conchilega* is an important indicator species (Indicator Value: 70) for the *A. alba* – *M. bidentata* community (group B), where it is found with an average density of 318 ind./m². The polychaete was also found in the *M. mirabilis* species association (average density: 14 ind./m²). Within both species groups, a positive correlation between the macrobenthic density and N_0 , on the one hand, and the density of *L. conchilega* on the other hand was found (Spearman rank correlation: $R = 0.70$ & 0.75 , respectively; $p < 0.0001$) (Figure 29).

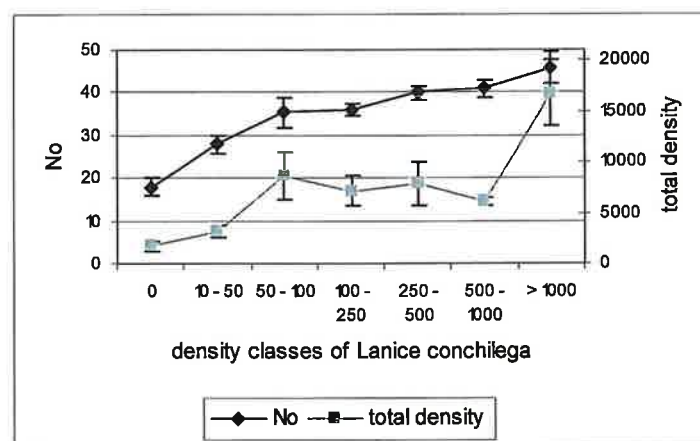


Figure 29. The relation between the density of *Lanice conchilega* and the total density and diversity.

Discussion

The intensive detailed multidisciplinary investigation led to the collection of highly valuable information regarding the physico-chemical environment and the macrobenthos.

Clear sediment grain-size trends were observed that are a reflection of active hydraulic sorting processes. It is believed that the sediment gradient as found along the Trapegeer is mainly driven from the Westdiep swale. Generally, this swale is regarded an important sediment transport pathway whereby even coarse sand can be entrained by the flood tidal current. This is also due to a funneling effect of the tidal current as it passes through the narrowest part of Westdiep with a divergence further eastward. Near the narrowest part, sand ribbons and a rather coarse substrate are found that are associated with high current velocities. Following along the transport path, current lineations are observed in the deepest part of the swale. In the divergence region, a zone of positive relief is located comprising one very large compound dune of more than 2 m that is clearly flood dominated. Moreover, very-high resolution side-scan sonar imagery revealed highly complex bedform patterns that change from sandy medium dunes to dunes composed of shell hash on very short intervals. The sandy dunes tend to be ebb-dominated. Higher up the Trapegeer, even large dunes are present that are completely ebb-shaped and dominated by the ebb tidal current. This is likely due to the higher resuspension potential of the ebb tidal current that is most effective in the shallow areas, whilst the regional sediment transport on a larger scale is flood-dominated (Van Lancker *et al.* 2000). Although, this can yet not be explained by numerical modelling, it is worthwhile investigating since this might provide another view on the processes structuring the habitats and on food availability.

Ideally, hydrodynamical information would be collected at such key locations, still operational constraints limited the number of deployments to one, along the slope of the Trapegeer sandbank, where also *Lanice conchilega* was found. Although, the measurements are highly valuable, providing current velocities along the vertical, no information is obtained in roughly the first meter above the seafloor, hence near bed dynamics and the relation with the macrobenthos cannot be studied. For future research, it would be better to carry out top-bottom measurements, still the restriction in number of deployments remains a problem. From the beginning, it was aspired to obtain continuous measurement of the vertical current along predefined profiles using a hull-mounted ADCP. Although, this approach does not guarantee a nearbed measurement, it likely does reveal current accelerations and decelerations over the large-scale morphology and provides more insight into tide-topography interactions. Although, this approach might still be too rough, it will give indications of the key locations for further investigation. Preferentially, multisensor benthic landers could additionally be used, fitted with nearbed current meter instrumentation, optical backscattering sensors and also acoustic doppler velocimeters to study turbulence. This approach would largely help to gain insight into the causal mechanisms of the spatial variability of macrobenthic occurrences.

The macrobenthos of the Western Coastal Banks is dominated by polychaetes. Densities and diversity are generally high, compared to other ecological regions on the BCS (Cattrijsse & Vincx, 2001). Within the 5x5 km area, 74 % of all macrobenthic species, recently (since 1994) found on the BCS, were detected.

At the Belgian Continental Shelf (BCS), five macrobenthic communities (three subtidal and one intertidal community) and six transitional species associations (three subtidal and three intertidal species associations) were discerned so far (Van Hoey *et al.*, in prep.). Here within, a community is defined as an entity of a specific set of species, occurring in a very specific physico-chemical habitat, which can be clearly distinguished from other

communities. Gradual changes from one habitat to another do exist. A selection of species of each of both communities, occurring in specific densities, along these gradual changes in habitat is defined as a transitional species association.

The station groups were compared with the existing descriptions of macrobenthic communities on the BCS (Van Hoey *et al.*, in prep) (Table VII). 50 % of the ten most abundant species of the first station group are identical as the *Magelona mirabilis* species association. Furthermore, the number of species per sample as well as the macrobenthic density have intermediate values: 14 and 17 species and 2017 and 1269 ind./m² for the *M. mirabilis* community and the first station group. The first station group was identified as the *M. mirabilis* transitional species association. The second station group coincided very well with the *Abra alba* – *Mysella bidentata* community of Van Hoey *et al.* (in prep.): both have a high number of species per sample and macrobenthic density and 80 % of the ten most abundant species are identical. Hence, the second station group belongs to the *A. alba* – *M. bidentata* community. The third station group has a low average number of species per sample and macrobenthic density (11 species and 350 ind./m², respectively), which is similar to the *Nephtys cirrosa* community. The station group has also 50 % of the ten most abundant species in common with the community. The third station group thus belongs to the *N. cirrosa* community. A low number of species per sample and macrobenthic density (9 species and 365 ind./m², respectively) is also typical for the fourth station group. This station group has 40 % of its most abundant species in common with the *Ophelia limacina* – *Glycera lapidum* community. It was concluded that the fourth station group is part of the *O. limacina* – *G. lapidum* community.

The macrobenthic communities and species association were compared with the communities already distinguished and described within the area (Degraer *et al.*, 1999a, b) (Table VII) Comparing the average number of species per sample, macrobenthic density and the list of the ten most abundant species, it can be concluded that the three communities from Degraer *et al.* (1999) each are a synonym for one of the former communities. The *A. alba* – *M. bidentata* community is identical to the former *Lanice conchilega* community. The *N. cirrosa* community corresponds with the former *Nephtys cirrosa* community s.l. and the *O. limacina* – *G. lapidum* community is identical to the former '*Mytilus edulis*' community. Only the *M. mirabilis* species association does not correspond with any of the former communities. According to the multivariate analyses (Figure 27), the moderately macrobenthos-rich *M. mirabilis* transitional species association appears to function as a transition between the *A. alba* – *M. bidentata* and the *N. cirrosa* community. Because of the low number of samples, collected by Degraer *et al.* (1999a, b), this species association could probably not be distinguished from the closely related *A. alba* – *M. bidentata* community. Compared to the situation of 1994 (Degraer *et al.*, 1999a) and 1997 (Degraer *et al.*, 1999b), the community structure of the three communities is still very similar. Temporal variation within the community structure is obvious, but does not overrule the "basic" structure of each community (see Seasonal variation).

As already shown by Degraer *et al.* (1999a) and Van Hoey *et al.* (in prep.), the *A. alba* – *M. bidentata* community is an ecologically highly valuable macrobenthic community on the BCS. The community is characterised by the highest macrobenthic densities and diversity. Furthermore, most bivalve species (e.g. *A. alba*, *Fabulina fabula* and *Spisula subtruncata*) do occur in high densities within the community. These bivalves are known to be an important food resource for larger epibenthic predators (e.g. cod *Gadus morus* and sole *Solea solea*) and benthos-eating diving seaducks (e.g. common scoter *Melanitta nigra*).

Although the communities can be found all over the area, zonation, mainly related to depth, was demonstrated.

The tube-building polychaete *Lanice conchilega* typically occurs within the *A. alba* – *M. bidentata* community. The tubes of the adults have a length of about 20-30 cm, which are extending up to about 3 cm above the sediment (Buhr and Winter, 1976). When found in large densities (up to 3000 ind./m²; Van Hoey and Degraer, pers. obs.), the patches of tubes create a hydrodynamically benign microclimate in which suspended material is trapped. This sediment-catching capacity of *L. conchilega* allows the polychaete to increase the amount of deposited organic matter and, thus, its food resources. Dense patches of *L. conchilega* further tend to stabilize the sediment. Local sediment elevations up to 10 cm are observed within patches of the polychaete (Seys and Musschoot, 2001). This, together with the increasing habitat complexity due to the extending upper parts of the tubes, indicate towards a strong habitat-structuring capacity of *L. conchilega*. The increase in habitat complexity in dense patches of *L. conchilega* might be responsible for the increasing macrobenthic density and diversity. Although patches of *L. conchilega* may sometimes be short-lived (Buhr and Winter, 1976), their habitat-structuring and -stabilising capacity has similar ecological consequences as f.i. *Sabellaria* reefs (e.g. increasing macrobenthic density and diversity: Mettam *et al.*, 1994; Porras *et al.*, 1996). Although juvenile *Sabellaria* species were found on the Western Coastal Banks, *Sabellaria* reefs were never found on the BCS in recent years (since 1994).

Table VII. Characterization of the general community structure of the three communities and the species association in comparison with the same communities' characterization by other authors.

Van Hoey <i>et al.</i>	<i>Abra alba</i> - <i>Myrella bidentata</i> community	<i>Magelona mirabilis</i> transitional species association	<i>Nephtys cirrosa</i> community	<i>Ophelia limacina</i> - <i>Glycera lapidum</i> community
Nº: # species/sample	28	14	7	6
Mean densities (ind/m ²)	6343	2017	402	190
10 most abundant species with average density (ind/m ²)	<i>Spisula subtruncata</i> 2536 <i>Magelona mirabilis</i> 412 <i>Scoloplos armiger</i> 363 <i>Abra alba</i> 360 <i>Parianthus typicus</i> 302 <i>Myrella bidentata</i> 296 <i>Lanice conchilega</i> 198 <i>Capitellidae</i> spp. 190 <i>Spiothanes bombyx</i> 169 <i>Burida sanguinea</i> 151	<i>Magelona mirabilis</i> 1263 <i>Microphthalmus similis</i> 116 <i>Scoloplos armiger</i> 102 <i>Spiothanes bombyx</i> 71 <i>Nephtys cirrosa</i> 60 <i>Fabulina fabula</i> 48 <i>Bathyporeia</i> spp. 27 <i>Urothoe poseidonis</i> 26 <i>Spisula subtruncata</i> 21 <i>Nephtys juvenilis</i> 20	<i>Magelona mirabilis</i> 105 <i>Nephtys cirrosa</i> 84 <i>Bathyporeia</i> spp. 76 <i>Urothoe poseidonis</i> 22 <i>Ophelia juvenilis</i> 19 <i>Scoloplos armiger</i> 15 <i>Scolelepis borealeri</i> 10 <i>Nephtys juvenilis</i> 8 <i>Hesionura elongata</i> 8 <i>Urothoe brevicornis</i> 8	<i>Hesionura elongata</i> 32 <i>Nephtys cirrosa</i> 32 <i>Ophelia limacina</i> 17 <i>Ophelia juvenilis</i> 10 <i>Glycera lapidum</i> 9 <i>Oligochaeta</i> spp. 9 <i>Behnkeofusus pusillus</i> 6 <i>Actinaria</i> spp. 6 <i>Ophelia</i> spp. 6 <i>Urothoe brevicornis</i> 5
Habitat: october 1999	group B	group A	group C	group D
Nº: # species/sample	37	17	11	9
Mean densities (ind/m ²)	7389	1269	350	365
10 most abundant species with average density (ind/m ²)	<i>Abra alba</i> 992 <i>Myrella bidentata</i> 914 <i>Scoloplos armiger</i> 691 <i>Parianthus typicus</i> 640 <i>Spiothanes bombyx</i> 395 <i>Burida sanguinea</i> 320 <i>Lanice conchilega</i> 318 <i>Cirratulidae</i> spp. 279 <i>Magelona mirabilis</i> 274 <i>Fabulina fabula</i> 273	<i>Magelona mirabilis</i> 531 <i>Spiothanes bombyx</i> 143 <i>Nephtys cirrosa</i> 73 <i>Urothoe poseidonis</i> 56 <i>Fabulina fabula</i> 54 <i>Spio martinensis</i> 45 <i>Nephtys hombergii</i> 41 <i>Scoloplos armiger</i> 28 <i>Capitella capitata</i> 25 <i>Donax vittatus</i> 24	<i>Nephtys cirrosa</i> 113 <i>Spiothanes bombyx</i> 38 <i>Rehinocardium cordatum</i> 19 <i>Montacuta ferruginosa</i> 18 <i>Bathyporeia pelagica</i> 18 <i>Scoloplos armiger</i> 14 <i>Urothoe poseidonis</i> 14 <i>Bathyporeia guillamsoniana</i> 14 <i>Magelona mirabilis</i> 11 <i>Fabulina fabula</i> 10	<i>Nephtys cirrosa</i> 69 <i>Urothoe brevicornis</i> 58 <i>Ophelia limacina</i> 34 <i>Scoloplos armiger</i> 33 <i>Mytilus edulis</i> spat 31 <i>Actinaria</i> spp. 22 <i>Spiothanes bombyx</i> 18 <i>Gastrosaccus spinifer</i> 9 <i>Urothoe pulchra</i> 8 <i>Bathyporeia elegans</i> 8
Degraer <i>et al.</i>	<i>Lanice conchilega</i> community		<i>Nephtys cirrosa</i> community s.l.	<i>Mytilus edulis</i> community
Nº: # species/sample	18		7	8
Mean densities (ind/m ²)	2500		275	450
10 most abundant species with average density (ind/m ²)	<i>Magelona mirabilis</i> 1392 <i>Burida sanguinea</i> 344 <i>Lanice conchilega</i> 228 <i>Abra alba</i> 139 <i>Fabulina fabula</i> 104 <i>Parianthus typicus</i> 69 <i>Basis</i> spp. 62 <i>Nephtys hombergii</i> 61 <i>Spisula subtruncata</i> 48 <i>Capitella capitata</i> 41		<i>Magelona mirabilis</i> 96 <i>Nephtys cirrosa</i> 81 <i>Rehinocardium cordatum</i> 21 <i>Basis</i> spp. 12 <i>Bathyporeia</i> spp. 11 <i>Donax vittatus</i> 11 <i>Scoloplos armiger</i> 7 <i>Nephtys hombergii</i> 7 <i>Portunus latipes</i> 7 <i>Pontocrates altamarinus</i> 6	<i>Microphthalmus similis</i> 237 <i>Mytilus edulis</i> spat 118 <i>Nephtys cirrosa</i> 28 <i>Hesionura elongata</i> 20 <i>Oligochaeta</i> spp. 15 <i>Basis</i> spp. 10 <i>Scoloplos armiger</i> 7 <i>Glycera lapidum</i> 7 <i>Spisula subtruncata</i> 7 <i>Ophelia limacina</i> 3

Although the *O. limacina* – *G. lapidum* and *N. cirrosa* community have the lowest macrobenthic densities and diversity, their ecological importance is illustrated by the number of species exclusively found within these communities. The first community consists of species indicative for coarse sediments, such as *O. limacina*, *Urothoe brevicornis*, *Glycera lapidum* and *Gastrosaccus spinifer*. The latter community harbours species typical

for well-sorted medium sandy sediments, such as *Echinocardium cordatum*, *N. cirrosa*, and *Bathyporeia guilliamsoniana*. Since these habitats and associated communities harbour an exclusive macrobenthic fauna, their presence substantially increases the overall diversity within the area.

Conclusion

The morpho-sedimentological characterisation of the study area largely benefited from the digital very high resolution side-scan sonar recordings and the integrated approach to drape the multiparameter imagery over accurate multibeam bathymetric data. This allowed to study the different features in a larger-scale perspective and to gain more insight into the causal processes. A variety of acoustic facies was detected, as well related to the sedimentology, geomorphology, and the hydrodynamics of the area as well as to the presence of living organisms.

Next to one transitional species association (*M. mirabilis* transitional species association), three of a total of four subtidal macrobenthic communities discerned at the BCS are found within the area of the Western Coastal Banks: *A. alba* – *M. bidentata*, *N. cirrosa* and *O. limacina* – *G. lapidum* community. Since each of these communities and species association consists of a specific set of macrobenthic species, the area is characterized by high macrobenthic diversity: 74 % of all macrobenthic species, recently found on the BCS, were detected within the study area.

The communities characterized in this study are identical to the macrobenthic communities described in previous studies (Degraer *et al.*, 1999; Van Hoey *et al.*, in prep.).

Each community or species association is restricted to a very specific physico-chemically defined habitat. Because of its densities, diversity and trophic function, the *A. alba* – *M. bidentata* community is ecologically highly valuable. *Lanice conchilega* fulfils an important habitat-structuring role within the community. Both other communities and the transitional species association contribute substantially to the overall macrobenthic diversity of the Western Coastal Banks.

TEMPORAL VARIABILITY OF THE MACROBENTHIC HABITAT OF THE WESTERN COASTAL BANKS

Introduction

The macrobenthic communities of shallow coastal waters are subject to a variety of physical and biological disturbances which vary in frequency and intensity, as well on a temporal and spatial scale (Turner *et al.*, 1995). Consequently, the communities' parameters (species composition, dominant species, abundances, etc.) are continuously changing (Arntz and Rumohr, 1986; Dörjes *et al.*, 1986). In temperate regions, these changes are primarily influenced by the seasonality (Bonsdorff and Österman, 1985; Dörjes *et al.*, 1986; Ibanez and Dauvin, 1988; Anderlini and Wear, 1992; Seys *et al.*, 1994), altering the sea water temperature, light intensity, and, consequently, the primary production within the water column (Moll, 1998). Due to this seasonality, a strong response within the time of recruitment, mortality and production of macrobenthic populations is a well-known phenomenon (Beukema, 1974; Arntz and Rumohr, 1986).

In addition, the shallow coastal water macrobenthos shows a large year-to-year variation (Arntz and Rumohr, 1986; Essink and Beukema, 1986; Beukema *et al.*, 1993; Turner *et al.*, 1995). Weather conditions are greatly influencing the success of recruitment, mortality and production of the composing macrobenthic species (Dörjes *et al.*, 1986; Meire *et al.*, 1994) and are thus constantly altering the density, biomass and, consequently, the biological interactions of the composing species of a macrobenthic community. As the biological interactions, on their turn will also influence the communities structure (Dörjes *et al.*, 1986; Meire *et al.*, 1994; Herman *et al.*, in press), by, e.g. predation, competition for food and space, and inhibition of recruitment, highly variable macrobenthic community variables are expected, even in the natural, undisturbed situation. The natural variation within the macrobenthic communities should help to explain issues fundamental to ecology, but also to the conservation and management of marine benthic habitats (Turner *et al.*, 1995).

This study therefore aims at the description and quantification of the temporal variation of the macrobenthos of the Western Coastal Banks.

Materials and methods

NUMERICAL MODELLING

Through cooperation with the Management Unit of the Mathematical Model of the North Sea and the Scheldt Estuary (MUMM), residual water transport was calculated for each period preceding a field campaign. The residual transport per 250 m spaced grid point is a measure of the residual water mass movement over the specific period. They take into account the volume of displaced water (Van den Eynde 1997):

$$u\text{-trans} = \text{SUM}(hu) / \text{SUM}(h)$$

$$v\text{-trans} = \text{SUM}(hv) / \text{SUM}(h)$$

h: the hourly value of the water depth

MATHEMATICAL ANALYSES

Wilcoxon matched pairs signed-ranks test

Dynamics and stability in the area can be described by differences or similarities between the two samples (pair) of each of the sampling stations in both different years. As the two samples within each pairs are related to each other (same station) and the measurements (diversity, density and physical parameters) are in an ordinal scale within and between pairs, the non-parametrical Wilcoxon matched pairs signed-ranks test is used to detect general trends of dynamics (differences) or stability (similarities) between the two sampling campaigns (Conover, 1971).

Results

PHYSICO-CHEMICAL ENVIRONMENT

Within a shallow near coastal area, it is known that hydro-meteorological conditions can significantly change erosional and sedimentation patterns. For a nearby coastal system, Van Lancker (1999) derived a clear relation between sedimentological/morphological variation and the ruling hydro-meteorological conditions. Moreover, a statistical significant correlation could be found between sandy sediment volumes and parameters of basically wind and waves (Van Lancker (in prep.)). From this, it was shown that SW winds clearly reinforce the flood tidal current giving rise to a higher input of finer-grained sandy sediments, whilst persistent NE conditions merely counteract the normal processes. If the latter is characterised by higher wind velocities, it can result in a coarsening of sediments as the finer-grained sediments are gradually washed away and since sediment volumes related to NE conditions are minimal, this proved that no input is expected from regions to the NE. Much is however dependent on the area of investigation and how its large-scale morphology is structured in relation to the swales.

Residual water transport was calculated for the period between the two major field campaigns of October 1999 and March 2000 (Figure 30) and based on the more detailed model with results on a 250 m grid.

Although, the model results need further validation, they reveal a zonation of the residual water transport distribution in the Westdiep and Potje swale. In the Westdiep the zonation delineates the deeper channel from the plateau-like morphology that forms the transition towards the Trapegeer. This is quite interesting since both subenvironments have a completely different sediment texture and bedform distribution. Further to the east, south of the Nieuwpoort Bank, the highest values occur. Yet, further investigation is needed for an adequate interpretation of the results

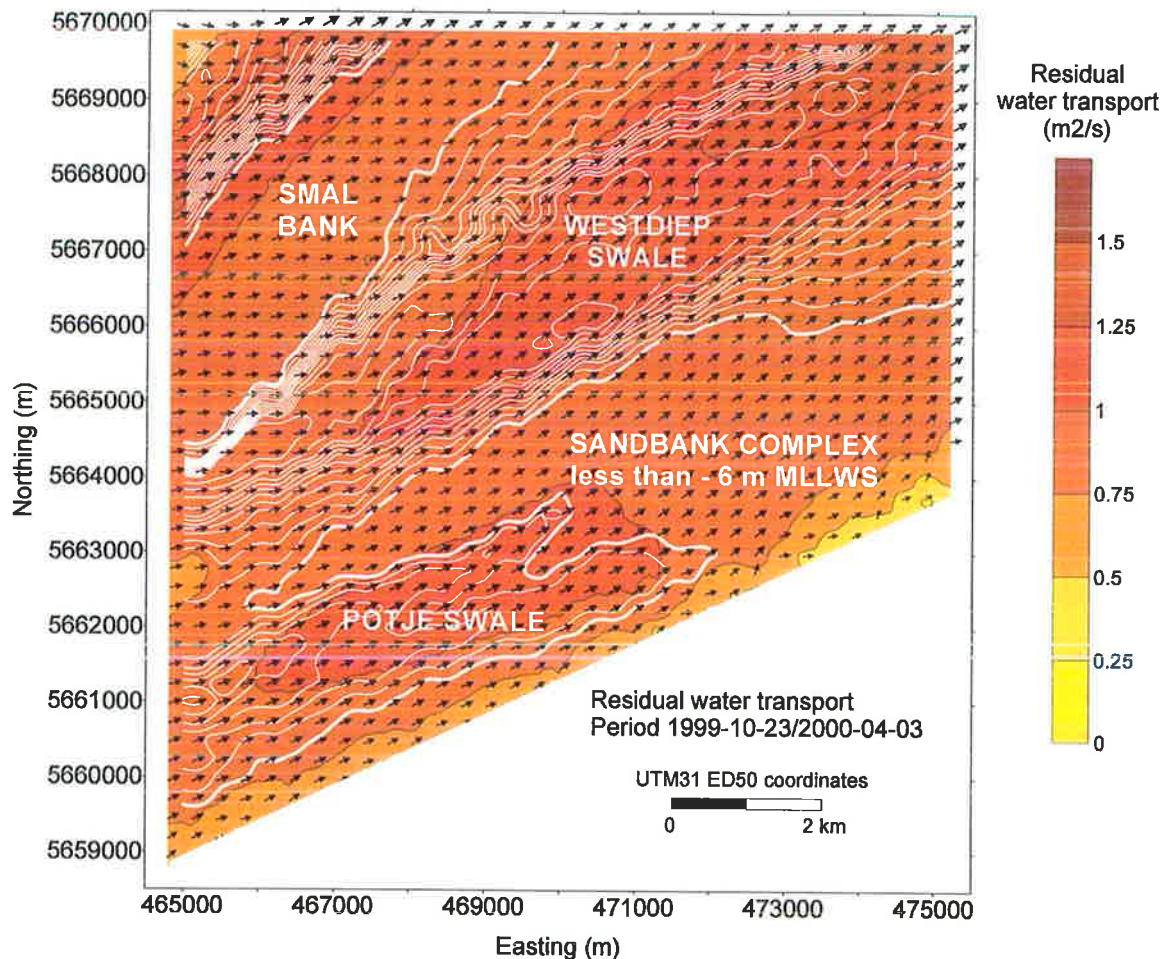


Figure 30. Residual water transport for the period between the 2 major field campaigns of October 1999 and March 2000.

If sequential bathymetrical data is available, erosion/sedimentation patterns can be studied through chart differencing (Van Lancker 1999). Within the Habitat project, bathymetrical data has been recorded in October 1999 and March 2000. An overall chart differencing of the data was not possible, as for the Westdiep swale only single-beam data was available whilst for the shallow area multibeam registrations with a complete different resolution were recorded. For the zones that could be compared the differences were generally within the detection limits (± 0.25 m).

On a sedimentological level, the temporal variability seemed to be minimal and generally, the differences lied within the error imposed by the analysis (± 0.25 phi or the resolution of sieving). This holds true for as well the mean grain-size and the median value as well calculated on the whole sediment distribution as on the sand fraction alone. More variation is seen at the foot of the Trapegeer slope (towards the east) where the median value (d_{50}) calculated on the sand fraction had clearly coarsened and a fining was observed near the foreshore in the Potje swale. It needs emphasis that the samples represent the upper 10 cm of the seafloor; hence small temporal variations are averaged. Again this is dependent on the kind of subenvironment as for the Westdiep for example, it was demonstrated that only a thin sandy sediment cover (even with dune structures) can mask underlying Tertiary clayey sediments (e.g. location 60). It is likely that temporal circumstances exist whereby the Tertiary substrate is outcropping.

The side-scan sonar imagery is likely to show more variability as it merely represents the upper seafloor characteristics. This also means that a small veneer with different sediment characteristics can give a complete other view of the seafloor. Most remarkable, were the patches and bands of lighter reflectivity that were recorded on April, 1st and 2nd 2000 in the deepest part of the Potje swale and in a well-defined band in front of the shoreface (Figure 31).

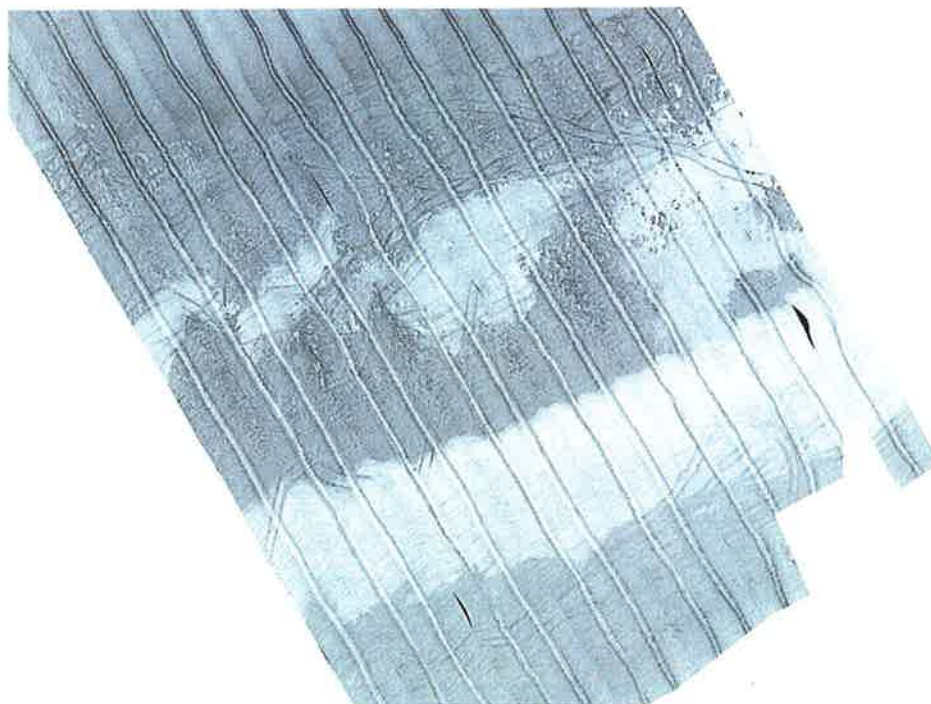


Figure 31. Detail of a side-scan sonar mosaic of the southern branch of the Potje swale. Differences in backscatter correspond with differences in sediment composition. The lightest reflectivity was correlated with the presence of fluid mud intersected with trawl marks (double lines).

Given the very light reflectivity and the smooth texture without patterns, this facies was associated with the presence of fluid mud. Since the high water content and the loose texture of these sediments, they absorb most of the acoustic energy; hence the backscatter values are very low. Interestingly, these patches were only found along the central and eastern zone, in the southern area. However, a verification of the timestamp showed that only these mosaics were recorded after a period of 4 days of consistent NE, though rather mild conditions (Coastal Waterways, Ministry of the Flemish Community). Different to the area, discussed in Van Lancker (1999), the Potje swale is largely sheltered under these circumstances and hence suspended matter is able to settle out.

Interpreting the side-scan sonar imagery in terms of an acoustic facies (see Part 2), generally similar results are obtained for both the October 1999 and March 2000 campaigns. Moreover, the results of November 2000 also fit within the distribution scheme of acoustic facies. This proves that a standardised side-scan sonar interpretation is valid on a temporal basis.

Also the sediment subsamples, meant for the detailed correlation with the macrobenthos, showed only minor differences between October 1999 and March 2000. In both months, the sediments mainly consisted of fine and medium sand (both about 40 %) and had an average median grain size of about 270 μm (Table VIII). Clay and

silt were present in low quantities (< 1 % and about 3 %, respectively), as were coarse sand and gravel (both < 3.5 %). Major differences between both months were found considering the temperature (decreasing from Autumn till early Spring: 15 to 9 °C) and bottom oxygen concentration (increasing from Autumn till early Spring: 7 to 11 mg l⁻¹. Except for silicium, major changes in bottom nutrient concentrations were observed.

Table VIII. The physico-chemical and macrobenthic variables, compared between October and March.

Physico - chemical and macrobenthic data of the study aread, compared between October and March				
variables	October		March	
	average	sterror	average	sterror
Nutrients-pigments of watercolumn				
NO ₂ + NO ₃ (µg/l)	54.27	3.02	*	*
NH ₄ (µg/l)	28.01	1.81	*	*
PO ₄ (µg/l)	4.00	0.43	*	*
Si (µg/l)	174.00	6.82	*	*
Fuco (µg/l)	1.06	0.03	*	*
Chlc (µg/l)	0.31	0.01	*	*
Chla (µg/l)	1.00	0.06	*	*
Nutrients of sediment				
NO ₂ + NO ₃ (µg/l)	229.64	19.61	854.66	59.89
NH ₄ (µg/l)	11769.76	1071.22	2125.22	144.90
PO ₄ (µg/l)	2448.14	257.47	1645.76	125.56
Si (µg/l)	1241.19	50.33	1353.05	99.93
Sedimentology				
RPD (cm)	6.89	0.30	7.69	0.24
Median grain size (µm)	268.19	7.87	271.56	7.90
Mean grain size (µm)	251.00	8.50	250.06	8.08
Mean-median ratio	0.92	0.01	0.93	0.01
Model grain size (µm)	276.12	9.58	268.56	8.99
Clay (%)	0.65	0.08	0.89	0.28
Silt (%)	2.86	0.37	3.03	0.59
Very fine sand (%)	3.11	0.26	2.39	0.21
Fine sand (%)	44.40	2.03	42.05	2.02
Medium sand (%)	40.71	1.68	43.54	1.71
Coarse sand (%)	8.27	1.20	7.26	0.98
Very coarse sand (%)	2.61	0.51	2.37	0.43
Gravel (%)	3.25	0.45	2.16	0.42
General environmental variables				
Temperature (°C)	14.93	0.22	8.71	0.03
Salinity	33.81	0.16	33.79	0.01
Oxygen concentration (mg/l)	6.87	0.03	11.28	0.05
Depth (m below MLWS)	7.46	0.44	7.44	0.44
General macrobenthic variables				
Total density	3288	457.65	1619	214.7
No	21	1.27	17	0.85

MACROBENTHOS: GENERAL

In both years, polychaetes and bivalves dominated the macrobenthos. Only slight changes in dominance were observed between October 1999 and March 2000: an increase in dominance of bivalves (from 34 to 47 %) and a decrease in dominance of polychaetes (from 50 to 42 %). Oligochaetes had a 3 % share in October 1999, while they were about absent in March 2000.

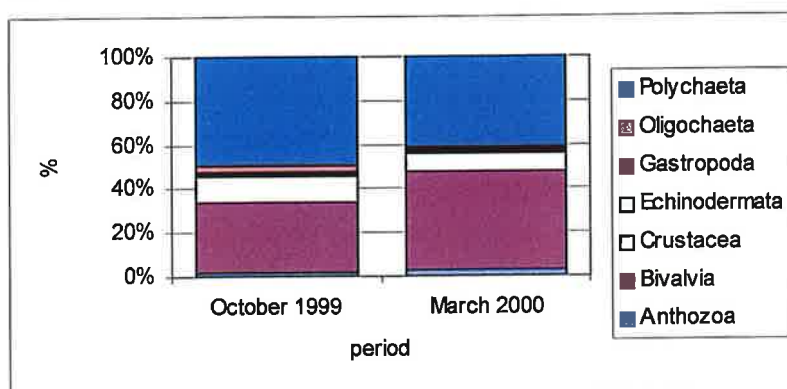


Figure 32. Relative abundances of the dominant taxa in the study area

MACROBENTHIC COMMUNITIES: MARCH 2000

Multivariate analyses of the macrobenthos data of March 2000 revealed the existence of four station groups (Figure 33).

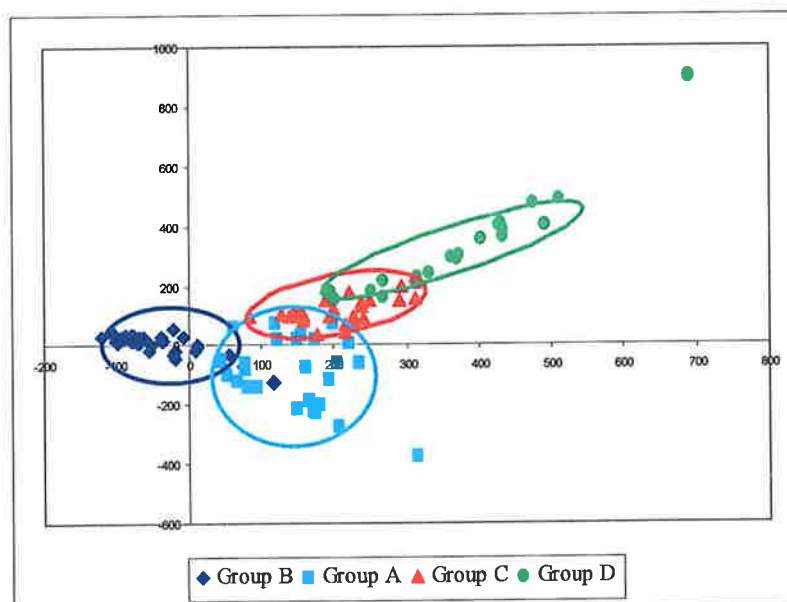


Figure 33. CA of the macrobenthic samples of March 2000, with the presentation of the four station groups (A, B, C and D)

A first station group (group A), with an average macrobenthic density of 1178 ind./m² and an average N_0 of 17 species, was dominated by the polychaete *Magelona mirabilis* (463 ind./m²). A relatively high indicator value was found for the polychaete *M. mirabilis* and the bivalves *Donax vittatus* and *Fabulina fabula*. These stations were found at an average depth of 6.95 m, within fine sand-dominated sediments with a median grain size of 225 μ m (4 % clay, 2 % silt and 1 % gravel). Considering bottom nutrients, PO₄ had the highest average concentration (about 2400 μ g/l).

A second station group (group B) was characterized by an average macrobenthic density of 3264 ind./m² and an average N_0 of 27 species (Table IX). The bivalves *Abra alba* and *Mysella bidentata* had densities over 500 ind./m². Nine from the ten most abundant species within the station group all had an average density higher than 100 ind./m². The bivalves *M. bidentata* and *A. alba*, the polychaetes *Notomastus latericeus* and Cirratulidae spp.

and Actiniaria had an indicator value of at least 70. The station group typically occurred in relatively deep-water (10.45 m) sediments with a median grain size of 204 μm . The fine sand-dominated sediments contained 7 % clay, 7 % silt, and 3 % gravel. NH_4 was the most dominant nutrient in the bottom (about 3200 $\mu\text{g/l}$).

The polychaete *Nephtys cirrosa* (69 ind./m²) was the most typical species of the third station group (group C), with an average macrobenthic density of 343 ind./m² and an average N_0 of 10 species. Only the polychaete *N. cirrosa* and the amphipod *Bathyporeia elegans* had relatively high indicator values (49 and 35, respectively). These stations occurred within medium sand-dominated sediments (median grain size: 284 μm ; < 1 % clay and silt and 6 % gravel) at an average depth of 5.40 m. PO_4 had the highest average concentration in the bottom (about 1600 $\mu\text{g/l}$).

A fourth station group (group D) had an average density of 269 ind./m² and an average N_0 of 8 species. Species densities were 60 ind./m² at maximum. The three most abundant species were the polychaetes *N. cirrosa* (60 ind./m²) and *Ophelia limacina* (28 ind./m²) and the amphipod *Urothoe brevicornis* (46 ind./m²). The highest indicator values were found for the polychaete *O. limacina* (70), the mysid *Gastrosaccus spinifer* (57) and the amphipod *U. brevicornis* (52). The stations' sediments mainly consisted of medium sand with an average median grain size of 377 μm . Sediment clay and silt contents were < 1 %, while 24 % consisted of gravel. An average of about 1000 $\mu\text{g NH}_4/\text{l}$ was found.

MACROBENTHOS: OCTOBER 1999 VERSUS MARCH 2000

To compare the station groups from this study (March 2000) with the communities identified in October (1999), a CA was run on a newly created dataset, combining all data from October 1999 and March 2000 (Figure 34). Each station group from March 2000 corresponds with a specific community present in October 1999. Hence, in March 2000 the same communities are found as in October 1999.

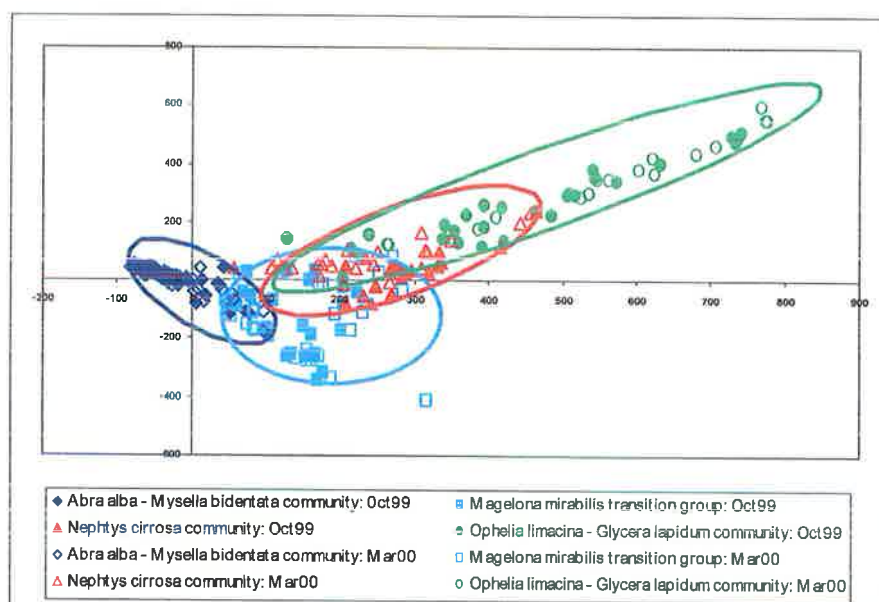


Figure 34. CA of the macrobenthic samples of October 1999, March 2000 and November 2000, with the presentation of the three macrobenthic communities and the *Magelona mirabilis* transition group.

The macrobenthic density and diversity (N_0) within the *M. mirabilis* species association (group A) remained constant over time: about 1200 ind./m² and 17 species (Wilcoxon test: $p = 0.4$). 90 % of the ten most dominant species in October 1999 correspond with those of March 2000. 75 % of the species indicative for the community in October 1999 were indicative in March 2000. For most of the indicative and dominant species (83%), their density did not change significantly (Wilcoxon test: $p > 0.1$).

Within the *A. alba* – *M. bidentata* community (group B), a significant decrease in macrobenthic density and diversity (N_0) can be observed from October 1999 to March 2000: from 7589 to 3264 ind./m² and 37 to 27 species (Wilcoxon test: $p < 0.0001$, both cases) (Table IX). 71 % of the indicator species of October 1999 were still indicative for the community in March 2000. 70 % of the ten most dominant species in October 1999 correspond with those in March 2000. A significant decrease of the density of most indicative and abundant species (85%) was observed (Wilcoxon test: $p < 0.05$).

No change within the macrobenthic density (± 350 ind./m²) and diversity (N_0 : 10-11 species) of the *N. cirrosa* community (group C) is observed (Wilcoxon test: $p > 0.8$). Only minor changes within the list of the ten most abundant species and indicator species were found between October 1999 and March 2000: 20 % and 40 %, respectively. 50 % of the list of indicative and/or abundant species showed an almost significant change in density (Wilcoxon test: $p < 0.09$).

Within the *O. limacina* – *G. lapidum* community (group D), the macrobenthic density slightly decreased from 365 to 269 ind./m² (Wilcoxon test: $p = 0.07$), but the diversity (N_0) remained constant (9 to 8 species) (Wilcoxon test: $p = 0.3$). 80 % of the indicator species of October 1999 were still indicative for the community in March 2000. 60 % of the ten most dominant species in October 1999 correspond with those in March 2000. For 60 % of the indicative and dominant species, the specific density changed significantly (Wilcoxon test: $p < 0.05$).

Table IX. General characterization of the community structure / physico-chemical environment and transitional species association in October 1999 and March 2000.

	October										March									
Environmental variables:	Group B		Group A		Group C		Group D		Group B		Group A		Group C		Group D					
	average	stdev	average	stdev	average	stdev	average	stdev	average	stdev	average	stdev	average	stdev	average	stdev				
	depth	depth	depth	depth	depth	depth	depth	depth	depth	depth	depth	depth	depth	depth	depth	depth				
Depth	219.73	5.39	218.10	8.69	265.51	9.75	344.61	203.77	10.51	284.23	10.51	376.63	18.57	1.07	1.07	1.07				
Median	1.27	0.14	0.20	0.17	0.19	0.17	0.14	0.04	3.6738	3.86	0.06	0.03	0.03	0.03	0.03	0.03				
% Clay	5.42	0.56	3.80	1.19	0.76	0.68	0.24	0.19	7.17	1.85	0.27	0.14	0.13	0.13	0.13	0.13				
% Fine sand	4.95	0.86	4.28	0.76	1.65	0.25	0.62	0.15	3.87	1.15	0.31	0.16	0.16	0.16	0.16	0.16				
% Fine sand	55.10	1.82	59.13	3.62	40.13	4.14	20.72	2.68	37.20	33.87	37.20	17.07	3.54	3.54	3.54	3.54				
% Medium sand	30.15	1.72	30.67	3.73	50.37	3.24	61.69	1.81	28.66	2.4919	54.99	27.73	3.17	3.17	3.17	3.17				
% Coarse sand	3.11	0.76	1.38	0.54	3.91	1.09	16.69	1.98	6.34	1.26	6.34	24.01	3.54	3.54	3.54	3.54				
% Gravel	6.13	0.74	1.95	0.36	0.87	0.21	7.57	1.02	3.62	1.52	2.20	8.75	1.08	1.08	1.08	1.08				
total stations	44		21		18		28		38		29		19		19					
Macroinvertebrates:	Group B		Group A		Group C		Group D		Group B		Group A		Group C		Group D					
	average	stdev	average	stdev	average	stdev	average	stdev	average	stdev	average	stdev	average	stdev	average	stdev				
	depth	depth	depth	depth	depth	depth	depth	depth	depth	depth	depth	depth	depth	depth	depth	depth				
Neg. # species/sample	37	1.06	17	1.49	11	0.79	9	0.42	27	17	10	0.75	8	8	8	8				
mean abundance (ind/m²)	7.989	8.964	1269	245.9	350	37.0	365	35.8	3264	411.1	1178	165.9	269	269	269	269				
10 most abundant species with average density (ind/m²)																				
	<i>Alba alba</i> : 592		<i>Magelona mirabilis</i> : 531		<i>Nephtys cirrosa</i> : 113		<i>Nephtys cirrosa</i> : 69		<i>Mytilus bidentatus</i> : 781		<i>Magelona mirabilis</i> : 463		<i>Nephtys cirrosa</i> : 69		<i>Nephtys cirrosa</i> : 60					
	<i>Scapharca bournoni</i> : 143		<i>Scapharca bournoni</i> : 38		<i>Scapharca bournoni</i> : 38		<i>Urechis caupo</i> : 38		<i>Urechis caupo</i> : 38		<i>Urechis caupo</i> : 38		<i>Scapharca bournoni</i> : 67		<i>Urechis caupo</i> : 38					
	<i>Scapharca bournoni</i> : 691		<i>Nephtys cirrosa</i> : 73		<i>Urechis caupo</i> : 19		<i>Urechis caupo</i> : 34		<i>Urechis caupo</i> : 142		<i>Nephtys cirrosa</i> : 66		<i>Scapharca bournoni</i> : 55		<i>Urechis caupo</i> : 38					
	<i>Scapharca bournoni</i> : 640		<i>Urechis caupo</i> : 36		<i>Urechis caupo</i> : 18		<i>Scapharca bournoni</i> : 33		<i>Scapharca bournoni</i> : 142		<i>Scapharca bournoni</i> : 66		<i>Scapharca bournoni</i> : 34		<i>Scapharca bournoni</i> : 34					
	<i>Scapharca bournoni</i> : 395		<i>Urechis caupo</i> : 54		<i>Urechis caupo</i> : 18		<i>Urechis caupo</i> : 31		<i>Urechis caupo</i> : 14		<i>Urechis caupo</i> : 34		<i>Urechis caupo</i> : 19		<i>Urechis caupo</i> : 20					
	<i>Scapharca bournoni</i> : 320		<i>Urechis caupo</i> : 45		<i>Urechis caupo</i> : 14		<i>Urechis caupo</i> : 22		<i>Urechis caupo</i> : 14		<i>Urechis caupo</i> : 34		<i>Urechis caupo</i> : 9		<i>Urechis caupo</i> : 15					
	<i>Scapharca bournoni</i> : 318		<i>Nephtys bournoni</i> : 41		<i>Urechis caupo</i> : 14		<i>Scapharca bournoni</i> : 18		<i>Urechis caupo</i> : 14		<i>Scapharca bournoni</i> : 31		<i>Scapharca bournoni</i> : 8		<i>Scapharca bournoni</i> : 9					
	<i>Scapharca bournoni</i> : 219		<i>Scapharca bournoni</i> : 28		<i>Scapharca bournoni</i> : 14		<i>Scapharca bournoni</i> : 9		<i>Scapharca bournoni</i> : 118		<i>Capitella capitata</i> : 28		<i>Scapharca bournoni</i> : 8		<i>Scapharca bournoni</i> : 6					
	<i>Scapharca bournoni</i> : 274		<i>Scapharca bournoni</i> : 25		<i>Scapharca bournoni</i> : 11		<i>Scapharca bournoni</i> : 8		<i>Scapharca bournoni</i> : 115		<i>Scapharca bournoni</i> : 26		<i>Scapharca bournoni</i> : 5		<i>Scapharca bournoni</i> : 5					
	<i>Scapharca bournoni</i> : 273		<i>Scapharca bournoni</i> : 24		<i>Scapharca bournoni</i> : 10		<i>Scapharca bournoni</i> : 8		<i>Scapharca bournoni</i> : 83		<i>Urechis caupo</i> : 25		<i>Scapharca bournoni</i> : 5		<i>Scapharca bournoni</i> : 5					
Indicator species with indicator value																				
	<i>Scapharca bournoni</i> : 85		<i>Scapharca bournoni</i> : 48		<i>Scapharca bournoni</i> : 36		<i>Scapharca bournoni</i> : 36		<i>Scapharca bournoni</i> : 36		<i>Scapharca bournoni</i> : 36		<i>Scapharca bournoni</i> : 36		<i>Scapharca bournoni</i> : 36					
	<i>Scapharca bournoni</i> : 82		<i>Scapharca bournoni</i> : 39		<i>Scapharca bournoni</i> : 30		<i>Scapharca bournoni</i> : 30		<i>Scapharca bournoni</i> : 30		<i>Scapharca bournoni</i> : 30		<i>Scapharca bournoni</i> : 30		<i>Scapharca bournoni</i> : 30					
	<i>Scapharca bournoni</i> : 81		<i>Scapharca bournoni</i> : 32		<i>Scapharca bournoni</i> : 28		<i>Scapharca bournoni</i> : 28		<i>Scapharca bournoni</i> : 28		<i>Scapharca bournoni</i> : 28		<i>Scapharca bournoni</i> : 28		<i>Scapharca bournoni</i> : 28					
	<i>Scapharca bournoni</i> : 81		<i>Scapharca bournoni</i> : 30		<i>Scapharca bournoni</i> : 28		<i>Scapharca bournoni</i> : 28		<i>Scapharca bournoni</i> : 28		<i>Scapharca bournoni</i> : 28		<i>Scapharca bournoni</i> : 28		<i>Scapharca bournoni</i> : 28					
	<i>Scapharca bournoni</i> : 79		<i>Scapharca bournoni</i> : 24		<i>Scapharca bournoni</i> : 22		<i>Scapharca bournoni</i> : 22		<i>Scapharca bournoni</i> : 22		<i>Scapharca bournoni</i> : 22		<i>Scapharca bournoni</i> : 22		<i>Scapharca bournoni</i> : 22					
	<i>Scapharca bournoni</i> : 75		<i>Scapharca bournoni</i> : 24		<i>Scapharca bournoni</i> : 22		<i>Scapharca bournoni</i> : 22		<i>Scapharca bournoni</i> : 22		<i>Scapharca bournoni</i> : 22		<i>Scapharca bournoni</i> : 22		<i>Scapharca bournoni</i> : 22					
	<i>Scapharca bournoni</i> : 74		<i>Scapharca bournoni</i> : 23		<i>Scapharca bournoni</i> : 22		<i>Scapharca bournoni</i> : 22		<i>Scapharca bournoni</i> : 22		<i>Scapharca bournoni</i> : 22		<i>Scapharca bournoni</i> : 22		<i>Scapharca bournoni</i> : 22					
	<i>Scapharca bournoni</i> : 71		<i>Scapharca bournoni</i> : 21		<i>Scapharca bournoni</i> : 21		<i>Scapharca bournoni</i> : 21		<i>Scapharca bournoni</i> : 21		<i>Scapharca bournoni</i> : 21		<i>Scapharca bournoni</i> : 21		<i>Scapharca bournoni</i> : 21					
	<i>Scapharca bournoni</i> : 70		<i>Scapharca bournoni</i> : 21		<i>Scapharca bournoni</i> : 21		<i>Scapharca bournoni</i> : 21		<i>Scapharca bournoni</i> : 21		<i>Scapharca bournoni</i> : 21		<i>Scapharca bournoni</i> : 21		<i>Scapharca bournoni</i> : 21					
	<i>Scapharca bournoni</i> : 68		<i>Scapharca bournoni</i> : 20		<i>Scapharca bournoni</i> : 20		<i>Scapharca bournoni</i> : 20		<i>Scapharca bournoni</i> : 20		<i>Scapharca bournoni</i> : 20		<i>Scapharca bournoni</i> : 20		<i>Scapharca bournoni</i> : 20					
	<i>Scapharca bournoni</i> : 62		<i>Scapharca bournoni</i> : 19		<i>Scapharca bournoni</i> : 19		<i>Scapharca bournoni</i> : 19		<i>Scapharca bournoni</i> : 19		<i>Scapharca bournoni</i> : 19		<i>Scapharca bournoni</i> : 19		<i>Scapharca bournoni</i> : 19					
	<i>Scapharca bournoni</i> : 61		<i>Scapharca bournoni</i> : 18		<i>Scapharca bournoni</i> : 18		<i>Scapharca bournoni</i> : 18		<i>Scapharca bournoni</i> : 18		<i>Scapharca bournoni</i> : 18		<i>Scapharca bournoni</i> : 18		<i>Scapharca bournoni</i> : 18					
	<i>Scapharca bournoni</i> : 58		<i>Scapharca bournoni</i> : 17		<i>Scapharca bournoni</i> : 17		<i>Scapharca bournoni</i> : 17		<i>Scapharca bournoni</i> : 17		<i>Scapharca bournoni</i> : 17		<i>Scapharca bournoni</i> : 17		<i>Scapharca bournoni</i> : 17					
	<i>Scapharca bournoni</i> : 57		<i>Scapharca bournoni</i> : 16		<i>Scapharca bournoni</i> : 16		<i>Scapharca bournoni</i> : 16		<i>Scapharca bournoni</i> : 16		<i>Scapharca bournoni</i> : 16		<i>Scapharca bournoni</i> : 16		<i>Scapharca bournoni</i> : 16					
	<i>Scapharca bournoni</i> : 56		<i>Scapharca bournoni</i> : 15		<i>Scapharca bournoni</i> : 15		<i>Scapharca bournoni</i> : 15		<i>Scapharca bournoni</i> : 15		<i>Scapharca bournoni</i> : 15		<i>Scapharca bournoni</i> : 15		<i>Scapharca bournoni</i> : 15					
	<i>Scapharca bournoni</i> : 55		<i>Scapharca bournoni</i> : 14		<i>Scapharca bournoni</i> : 14		<i>Scapharca bournoni</i> : 14		<i>Scapharca bournoni</i> : 14		<i>Scapharca bournoni</i> : 14		<i>Scapharca bournoni</i> : 14		<i>Scapharca bournoni</i> : 14					
	<i>Scapharca bournoni</i> : 54		<i>Scapharca bournoni</i> : 13		<i>Scapharca bournoni</i> : 13		<i>Scapharca bournoni</i> : 13		<i>Scapharca bournoni</i> : 13		<i>Scapharca bournoni</i> : 13		<i>Scapharca bournoni</i> : 13		<i>Scapharca bournoni</i> : 13					
	<i>Scapharca bournoni</i> : 53		<i>Scapharca bournoni</i> : 12		<i>Scapharca bournoni</i> : 12		<i>Scapharca bournoni</i> : 12		<i>Scapharca bournoni</i> : 12		<i>Scapharca bournoni</i> : 12		<i>Scapharca bournoni</i> : 12		<i>Scapharca bournoni</i> : 12					
	<i>Scapharca bournoni</i> : 52		<i>Scapharca bournoni</i> : 11		<i>Scapharca bournoni</i> : 11		<i>Scapharca bournoni</i> : 11		<i>Scapharca bournoni</i> : 11		<i>Scapharca bournoni</i> : 11		<i>Scapharca bournoni</i> : 11		<i>Scapharca bournoni</i> : 11					
	<i>Scapharca bournoni</i> : 51		<i>Scapharca bournoni</i> : 10		<i>Scapharca bournoni</i> : 10		<i>Scapharca bournoni</i> : 10		<i>Scapharca bournoni</i> : 10		<i>Scapharca bournoni</i> : 10		<i>Scapharca bournoni</i> : 10		<i>Scapharca bournoni</i> : 10					

Geographical stability

The spatial distribution of the macrobenthic communities showed only minor differences between October 1999 and March 2000: 71 % of the stations harboured the same community in both periods (Figure 35).

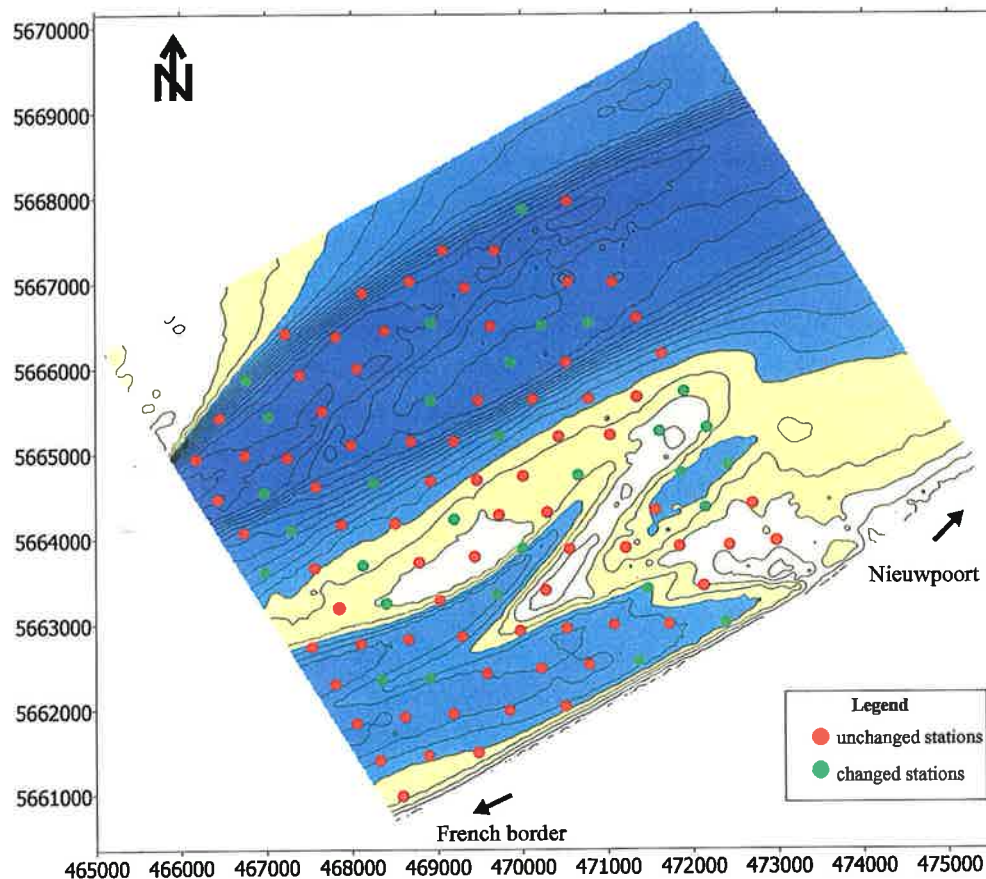


Figure 35. The changed stations of March 2000 in contrary to October 1999.

Discussion

One of the principle properties of marine benthic communities in high latitudes is their continuous change, as reflected in all population or community parameters at any time (Arntz and Rumohr, 1986). As already shown by many studies (Beukema, 1974; Bonsdorff and Östeman, 1985; Arntz and Rumohr, 1986; Dauvin and Ibanez, 1986; Dörjes *et al.*, 1986; Essink and Beukema, 1986; Ibanez and Dauvin, 1988; Dauvin, 1990, 1991; Anderlini and Wear, 1992; Feller *et al.*, 1992; Beukema *et al.*, 1993; Meire *et al.*, 1994; Seys *et al.*, 1994; Turner *et al.*, 1995; Essink *et al.*, 1998), temporal variations, both within and between years, are indeed inherent for the benthos in temperate regions. Benthic communities are thus characterized by variability (dynamics), rather than by stability. Though, the detection of community stability does not require that a community remain unchanged, but rather that a community maintains a distinctly different species composition and abundance respective to other communities (Turner *et al.*, 1995). Because of the number of similarities (species composition, abundances and diversity) between each community of

October 1999 with one of the station groups of March 2000, the same communities did occur during both sampling periods.

Stability and dynamics of the macrobenthic communities

The obvious similarity between Autumn 1999 and Spring 2000 does not mean that the macrobenthos of the western Coastal Banks remained unchanged between both periods. Quite a lot of variation is observed. Although only minor changes were observed within the *N. cirrosa* and *O. Limacina* – *G. lapidum* community and the *M. mirabilis* species association, major changes were observed in the *A. alba* – *M. bidentata* community. Obviously, different macrobenthic communities show different temporal dynamics. Because each community is composed of a specific combination of species, the temporal variation of the complex biological interactions, due to the coexistence of these species, will differ from one community to another (Bonsdorff and Österman, 1985). Species-specific winter mortality of one species, for instance, will only take place in the community where this species belongs to and not in any other community. This differential winter mortality may trigger a chain reaction of changing biological interactions (competition, predation, etc.), causing major shifts in the species composition and density of the community: formerly abundant species may become rare or even disappear and less abundant or even new species may become dominant (Meire *et al.*, 1994; Tumer *et al.*, 1995).

Geographical stability of the macrobenthic communities

The western Belgian Coastal Banks are known as a geomorphologically very diverse area. Consequently, a highly diverse hydrodynamical regime, causing a high sedimentological diversity, exists. Because macrobenthic communities are restricted to a specific physico-chemical environment, of which sedimentology is very important, the spatial distribution of the communities coincide with these of the sedimentology (Shackley and Collins, 1984; Meire *et al.*, 1994; Degraer *et al.*, 1999). As long as the sedimentology does not change, no shifts between communities are expected (Govaere *et al.*, 1980). In this study 71 % of the stations are designated to the same community in October 1999 as in March 2000. Hence, the spatial distribution of the macrobenthic communities has to be considered as being quite stable. The community shift of the remaining 29 % may be due to changes within the sedimentology of the stations. These shifts within the sedimentology and, consequently, the community of the stations can be explained by the dynamics within the sedimentology of the area of the western Coastal Banks or by positioning errors of the ship in the sedimentologically diverse area. Another reason might be the difficulties encountered when creating a biological classification of the stations. Macrobenthic communities cannot be regarded as isolated entities, but rather as entities connected with each other by means of transition zones (Mills, 1969). The ordination plot illustrates this continuum of communities, where all macrobenthic communities are clearly connected with each other. Since this biological continuity cannot match perfectly with the artificial classification of samples into communities and/or species associations, the same station might be classified differently during two subsequent sampling campaigns.

Conclusions

From a physico-chemical point of view, the study area revealed no major temporal changes. The residual water transport in the period between October 1999 and March 2000, showed a clear zonation in the Westdiep swale that matches the major sedimentological and morphological differentiation. Still, the differences in depth and

sedimentology are minor and are generally within the error range imposed by the analysis. However, the side-scan sonar imagery did show the presence of white reflectivity bands that were interpreted as fluid mud layers associated with a period of consistent NE conditions. Still, their thickness is minimal, hence no significant effect on the fauna is expected. Still, generally, the interpretation of side-scan sonar imagery towards acoustic facies seemed to be valid on a temporal basis.

Although the community structure changed within all macrobenthic communities, the communities, detected in October 1999, were still present in 2000. This variation was most obvious in the *A. alba* – *M. bidentata* community, while only minor changes were detected within the *N. cirrosa* and *O. Limacina* – *G. lapidum* community and the *M. mirabilis* species association. Because of the expected stability of the ecologically relevant physico-chemical environment (e.g. sedimentology and depth) at the sampling stations, most of the stations harboured the same community in October 1999 and 2000. A high spatial distributional stability was found within the area of the western Coastal Banks.

PART 2.
DEVELOPMENT OF METHODOLOGIES AIMING AT THE CREATION OF
TIME – AND COST- EFFICIENT MONITORING TOOLS FOR THE FUTURE MPA

HABITAT MODEL

Introduction

A first strategy within the development of time- and cost-efficient monitoring tools relies on the clear relation between the spatial distribution of the macrobenthic organisms and the physico-chemical environment. Within the future MPA, macrobenthic organisms show a distinct preference for a very specific environment or habitat (See Part 1; Degraer *et al.* 1999). A combination of the macrobenthic organisms found in the same habitat is indicated as a macrobenthic community or species association. These communities are showing a clear seasonal variability, as demonstrated by the temporal variation within the *A. alba* - *M. bidentata* community structure (See Part 1). Obvious differences within the relative abundance of the composing species occur and some species can even be absent during a certain period, causing a large seasonal variation. Hence, designating an ecological value to a macrobenthic community, based on the results from a single sampling campaign, possibly leads to an underestimation of the community's importance. Yet, even though a community impoverishment can be observed after the winter 1999-2000, this impoverishment should not necessary mean that the benthic habitat has a lower ecological value after that winter. The habitat still has its capability to host the rich community observed in October 1999. Hence, rather than valuing the benthic habitat based on its actual macrobenthic community structure, the ecological value of the habitat should be assessed on the basis of its 'macrobenthic potential'. The 'macrobenthic potential' of a habitat is defined as the dynamics of the macrobenthic community structure (e.g. species composition, diversity, and densities) within the habitat. Herewithin, knowledge of the temporal variation of the community is thus indispensable. In practice, the 'macrobenthic potential' of a habitat can be determined by assembling all macrobenthos data available (including temporal variation) within the habitat. A 'potential species list' (= list of all species ever found within a habitat/community) already provides a first view on the habitat's 'macrobenthic potential'. In the present study, both sampling campaigns (e.g. October 1999 and March 2000) already give some more information on the 'potentials' of the habitats, but in order to know all possible dynamics of a community within the habitats long-term studies are necessary (Arntz and Rumohr, 1986; Turner *et al.*, 1995).

The 'potential' of a habitat can be studied by extended sampling campaigns within different seasons over several years. When (1) the different macrobenthic communities and their seasonal variability and (2) their habitat preferences are known, information on the biologically relevant, physico-chemical parameters of a new site allows to predict the 'macrobenthic potential' of this new site. The model will thus allow evaluating the 'potentials' of non-studied places within the protected area on a time- and cost-efficient base.

A similar model for the area has been set up by Degraer *et al.* (1999). Though, within this model physical parameters (sedimentology and depth), measured at only 40 stations, of which 20 stations within the future MPA, were taken into account. Within the HABITAT model, presented in this study, a broader range of environmental variables, including bottom nutrient concentrations, measured at 120 stations within the future MPA were taken into account.

Materials and methods

DATA GATHERING

The macrobenthic potentials of each community and species association is derived from all macrobenthic data, retrieved during this research: sampling campaigns of October 1999 (120 samples), March 2000 (120 samples) and November 2000 (20 samples).

The set-up of the HABITAT model is based on the data retrieved from the sampling campaign of October 1999. A detailed description of the macrobenthic communities and their habitat preferences is provided in XXX. To test the predictive accuracy of the HABITAT model, the data retrieved from the sampling campaign of March 2000 was used.

ABBREVIATIONS

Within this section all environmental variables were abbreviated (Table X).

Table X. Abbreviations used in the text.

Abbreviation	Full name	Unit
DE	Depth below mean low low water spring	M
D50	Bulk sediment median grain size	μm
MM	Ratio mean grain size over median grain size	—
CL	Relative amount of the clay fraction within the sediment	Volume %
SI	Relative amount of the silt fraction within the sediment	Volume %
VFS	Relative amount of the very fine sand fraction within the sediment	Volume %
FS	Relative amount of the fine sand fraction within the sediment	Volume %
MS	Relative amount of the medium sand fraction within the sediment	Volume %
CS	Relative amount of the coarse sand fraction within the sediment	Volume %
VCS	Relative amount of the very coarse sand fraction within the sediment	Mass %
GR	Relative amount of the gravel fraction within the sediment	Mass %
Si	Concentration of dissolved silicium in the interstitial water	$\mu\text{g/l}$
PO ₄	Concentration of dissolved phosphate in the interstitial water	$\mu\text{g/l}$

MATHEMATICAL ANALYSES

Discriminant analysis

Discriminant function analysis is used to determine which variables discriminate between two or more naturally occurring groups (in this case: macrobenthic communities or species associations). Discriminant analysis can be used to determine which environmental variables are the best predictors of the community's physico-chemical habitat preferences. Furthermore, discriminant analysis computes classification functions, which can be used to determine to which community or species association a sample most likely belongs.

Based on a discriminant analysis, classification functions (= HABITAT model), including the discriminating environmental variables, were retrieved. To allow a broad application of the HABITAT-model, different models were set up. Each model takes into account different environmental variables. Furthermore, since the *M. mirabilis* species association represents a transition between the *A. alba* – *M. bidentata* community and the *N. cirrosa* community, one might not always want to discriminate this transitional species association and rather be interested in the distribution of the macrobenthic communities s.s.. Therefore, a first set of models was set up using all information on the three macrobenthic communities (*A. alba* – *M. bidentata*, *N. cirrosa* and *O. limacina* – *G. lapidum* community) and the *M. mirabilis* species association. A next set of models only takes into account the three macrobenthic communities. Depending on the environmental data available, a selection of the set of classification functions can be made.

The classification functions, derived by the discriminant analysis, are given by the following equation:

$$S_i = \left(\sum_1^m w_{i1,im} * Var_{i1,im} \right) + c_i$$

where S_i is the resultant classification score for community i

the subscript i denotes the respective community

the subscripts 1, ..., m denote the m variables

c_i is a constant for the i 'th group

w_{ij} is the weight for the j 'th variable for the i 'th community

Var_{ij} is the observed value for the j 'th variable for the i 'th community

The new observations are designated to the community with the highest total score.

After estimation of the discriminant functions, based on the data collected in October 1999, the *a posteriori* accuracy is measured, when using the same data to evaluate the accuracy of the designation of each sample to a certain community is. Because it is much easier to find ways to predict what is already known, confidence regarding the correct classification of future observations should not be based on the same data set from which the discriminant functions were derived. Since the HABITAT model is aiming at a predictive classification of cases, it was necessary to collect new data to validate the predictive utility of the classification functions. The *a priori* accuracy is valuing the accuracy of the designation of new samples to the correct community or species association. To test the *a priori* accuracy the samples, collected in March 2000, were used.

Results

MACROBENTHIC HABITAT POTENTIALS

A total of 128 macrobenthic species was found in the samples of October 1999 and March 2000, of which 18 species were never found in densities exceeding 10 ind./m².

Table XI gives a complete list of all macrobenthic species found in the three macrobenthic communities and species association, with their percent of occurrence in the samples of October 1999 and March 2000. Representative occurrence: a species was considered representatively present in a sample if its density exceeded 10 ind./m² in that sample (= at least two individuals found) (). Comm. 1: *A. alba* – *M. bidentata* community; Spec. ass. 1: *M. mirabilis* species association; Comm. 2: *N. cirrosa* community; Comm. 3: *O. limacina* – *G. lapidum* community.

With 96 species, the *A. alba* - *M. bidentata* community had the richest 'potential species list'. Especially annelids (40 spp.), crustaceans (31 spp.) and bivalves (19 spp.) dominated the potential species list. Furthermore, 23 species had a representative occurrence within more than 50 % of the samples. Both other communities (*N. cirrosa* and *O. limacina* - *G. lapidum* community) had a poorer potential species list (resp. 37 and 35 spp.), in which only few species had a representative occurrence within more than 50 % of the samples (resp. 2 and 4 spp.). The *M. mirabilis* species association had an intermediate potential species list richness (59 spp.), with five species with a representative occurrence within more than 50 % of its samples.

Table XI. Complete list of all macrobenthic species found in October 1999 and March 2000.

	Comm. 1	Spec. Ass. 1	Comm. 2	Comm. 3		Comm. 1	Spec. Ass. 1	Comm. 2	Comm. 3
Annelida					Cnidaria				
<i>Harmothoe spec.</i>	7	0	0	0	<i>Actinaria spec.</i>	71	12	0	11
<i>Pholoe minuta</i>	27	0	0	0	Crustacea				
<i>Sigalion mathildae</i>	18	22	0	0	<i>Aonopodactylus petiolatus</i>	0	0	0	0
<i>Sthenelais boa</i>	61	2	0	0	<i>Diastylis bradi</i>	2	14	0	0
<i>Pisone remota</i>	0	0	0	0	<i>Pseudocuma longicornis</i>	1	8	0	2
<i>Anatides groenlandica</i>	0	0	0	0	<i>Bodotria arenosa</i>	10	0	0	0
<i>Anatides maculata-mucosa</i>	55	4	7	0	<i>Bodotria scorpioides</i>	6	0	0	0
<i>Eteone flava</i>	1	0	0	0	<i>Pseudoparatanaia batei</i>	0	0	0	2
<i>Eteone longa</i>	26	0	0	0	<i>Gastrosaccus spirifer</i>	4	8	7	39
<i>Bumida sanguinea</i>	52	4	2	0	<i>Schistomys kervillei</i>	0	4	0	0
<i>Hesione elongata</i>	0	0	0	4	<i>Schistomys spirius</i>	1	0	0	2
<i>Podarkeopsis helgolandica</i>	11	0	0	2	<i>Mesopodopsis slabbari</i>	0	2	0	2
<i>Microphthalmus similis</i>	0	0	0	0	<i>Leptomys gracilis</i>	0	0	0	0
<i>Audolytus spec.</i>	32	14	4	2	<i>Ampelisca brevicornis</i>	17	2	0	0
<i>Typosyllis armillaris</i>	1	0	0	0	<i>Orchomene nana</i>	0	0	0	0
<i>Nereis longissima</i>	57	0	0	0	<i>Corophium acherusicum</i>	1	0	0	0
<i>Nephtys assimilis</i>	2	10	0	0	<i>Corophium sextonae</i>	1	0	0	0
<i>Nephtys caeca</i>	0	0	0	0	<i>Amphiloclus neapolitanus</i>	6	0	0	0
<i>Nephtys cirrosa</i>	28	82	98	93	<i>Stenothoe marina</i>	1	2	0	0
<i>Nephtys longiseta</i>	11	4	2	4	<i>Gammarus spec.</i>	1	0	0	0
<i>Nephtys hombergii</i>	88	58	9	0	<i>Urothoe brevicornis</i>	1	4	13	65
<i>Glycera alba</i>	65	6	0	11	<i>Urothoe posidonis</i>	17	40	18	0
<i>Glycera lapidum</i>	2	0	0	7	<i>Urothoe pulchra</i>	0	0	4	4
<i>Scoloplos armiger</i>	94	46	73	57	<i>Bathyporeia elegans</i>	1	8	29	20
<i>Paraonis fulgens</i>	4	0	4	15	<i>Bathyporeia guilliamsoniana</i>	0	12	27	2
<i>Spiohaneis bombyx</i>	84	54	40	24	<i>Bathyporeia pelagica</i>	0	4	20	9
<i>Spio filicornis</i>	18	18	4	9	<i>Atylus falcatus</i>	1	0	7	0
<i>Spio goniocephala</i>	0	0	0	2	<i>Atylus swammerdami</i>	0	2	0	0
<i>Spio martinensis</i>	2	12	0	0	<i>Atylus vedlomensis</i>	1	0	0	0
<i>Aonides oxycephala</i>	4	0	0	0	<i>Melita obusata</i>	41	4	2	0
<i>Pygospio elegans</i>	5	2	0	0	<i>Pontocrates altamarinus</i>	0	12	2	0
<i>Polydora paucibranchiata</i>	1	0	0	0	<i>Pericorculodes longimanus</i>	1	0	0	0
<i>Polydora pulchra</i>	6	0	0	0	<i>Synchelidium maculatum</i>	0	0	4	0
<i>Poecilochaetus serpens</i>	35	4	0	0	<i>Microtopotus maculatus</i>	15	2	0	0
<i>Mangelona mirabilis</i>	67	76	20	4	<i>Leucothoe incisa</i>	15	14	0	0
<i>Cirratulidae spec.</i>	80	24	9	2	<i>Calliopius laevisculus</i>	2	0	0	0
<i>Ophelia limacina</i>	1	0	2	63	<i>Parianthus typicus</i>	73	16	0	0
<i>Travesia forbesi</i>	0	0	0	0	<i>Phisica marina</i>	6	0	0	0
<i>Scalibregma inflatum</i>	1	0	0	0	<i>Phlocheras trispinosus</i>	2	0	0	0
<i>Capitella capitata</i>	68	20	0	0	<i>Crangon crangon</i>	0	0	2	0
<i>Capitella spec.</i>	0	0	0	0	<i>Hippolyte varians</i>	1	2	0	0
<i>Notomastus latericeus</i>	74	2	2	0	<i>Thorulus cranchii</i>	1	0	0	0
<i>Heteromastus filiformis</i>	32	0	0	0	<i>Processa modica</i>	4	0	0	0
<i>Owenia fusiformis</i>	55	0	0	0	<i>Pagurus bernhardus</i>	0	0	0	0
<i>Pectinaria koreni</i>	61	2	0	0	<i>Diogenes pugillator</i>	0	8	2	2
<i>Lanice conchilega</i>	57	12	0	0	<i>Pinnotheres pisum</i>	0	0	0	0
<i>Ampharete acutifrons</i>	0	0	0	0	<i>Macropodia rostrata</i>	1	0	0	0
<i>Sabellaria spinulosa</i>	0	0	0	0	<i>Liocarcinus arcuatus</i>	4	0	0	0
<i>Pomatoceros triqueter</i>	20	0	0	4	<i>Liocarcinus holzatus</i>	1	0	0	0
<i>Oligochaeta spec.</i>	70	12	0	9	<i>Portunus latipes</i>	0	0	0	0
Mollusca					<i>Corystes cassivelaenus</i>	0	0	0	0
<i>Mytilus edulis spat</i>	21	10	9	20	<i>Pilumnus hirtellus</i>	0	0	0	0
<i>Modiolus modiolus</i>	1	0	0	0	Echinodermata				
<i>Aequipecten opercularis</i>	2	0	0	0	<i>Ophiura albida</i>	32	6	0	0
<i>Spisula subtruncata</i>	26	28	7	15	<i>Ophiura ophiura</i>	9	2	0	0
<i>Mysella bidentata</i>	93	12	4	7	<i>Amphipura filiformis</i>	1	0	0	0
<i>Donax vittatus</i>	4	46	4	0	<i>Echinocardium cordatum</i>	30	20	31	2
<i>Macoma balthica</i>	15	14	0	0	<i>Echinocyamus pusillus</i>	1	0	0	0
<i>Montacuta ferruginosa</i>	39	40	20	0					
<i>Fabulina fabula</i>	89	74	13	2					
<i>Angulus tenuis</i>	5	4	2	2					
<i>Tellina pygmaea</i>	0	0	0	0					
<i>Abra alba</i>	98	44	4	0					
<i>Abra prismatica</i>	0	0	4	0					
<i>Venerupis pullastra</i>	54	0	0	0					
<i>Basis spec.</i>	54	2	0	0					
<i>Mya truncata</i>	7	0	0	0					
<i>Sphaeria binghami</i>	9	0	0	0					
<i>Petricola pholadiformis</i>	2	0	0	0					
<i>Crepidula fornicata</i>	27	6	0	0					
<i>Clatrus clatrus</i>	2	0	0	0					
<i>Hinia reticulata</i>	26	4	0	0					
<i>Lunatia alderi</i>	0	0	0	0					

CLASSIFICATION FUNCTIONS: THREE COMMUNITIES AND ONE SPECIES ASSOCIATION

Classification function set 1a

Within a first classification function set all physico-chemical variables (excluding mean and modal grain size and water column variables) were taken into account. The analysis selected ten discriminant variables to set up four classification functions (Table XII). The overall *a posteriori* accuracy of the classification functions is 76 % (*A. alba* – *M. bidentata* community: 65 %; *N. cirrosa* community: 87 %; *O. limacina* – *G. lapidum* community: 75 %; *M. mirabilis* species association: 85 %). The overall *a priori* accuracy is 60 % (*A. alba* – *M. bidentata* community: 61 %; *N. cirrosa* community: 62 %; *O. limacina* – *G. lapidum* community: 87 %; *M. mirabilis* species association: 33 %).

Table XII. List of the selected environmental variables, with indication of their community specific weight in the classification functions. Spec. ass. 1: *M. mirabilis* species association; Comm. 1: *A. alba* – *M. bidentata* community; Comm. 2: *N. cirrosa* community; Comm. 3: *O. limacina* – *G. lapidum* community.

	Spec. ass. 1	Comm. 1	Comm. 2	Comm. 3
D50	11.37	11.26	11.38	11.46
DE	-0.20	0.12	-0.46	-0.68
MS	36.62	36.25	36.83	37.00
GR	-7.05	-6.46	-6.76	-6.80
RPD	5.01	5.83	5.78	5.83
CL	-81.69	-74.64	-77.59	-78.90
VCS	27.74	27.21	27.68	27.41
SI	136.41	134.22	136.01	136.83
FS	58.51	57.92	58.53	58.79
Si	-0.03	-0.03	-0.03	-0.04
Constant	-3753.65	-3689.30	-3766.09	-3808.82

Classification function set 2a

A second classification function set takes into account only physical variables (excluding mean and modal grain size), depth and the depth of the RPD layer. The analysis selected seven discriminant variables to set up four classification functions (Table XIII). The overall *a posteriori* accuracy of the classification functions is 80 % (*A. alba* – *M. bidentata* community: 69 %; *N. cirrosa* community: 88 %; *O. limacina* – *G. lapidum* community: 79 %; *M. mirabilis* species association: 100 %). The overall *a priori* accuracy is 64 % (*A. alba* – *M. bidentata* community: 62 %; *N. cirrosa* community: 77 %; *O. limacina* – *G. lapidum* community: 87 %; *M. mirabilis* species association: 33 %).

Table XIII. List of the selected environmental variables, with indication of their community specific weight in the classification functions. Spec. ass. 1: *M. mirabilis* species association; Comm. 1: *A. alba* – *M. bidentata* community; Comm. 2: *N. cirrosa* community; Comm. 3: *O. limacina* – *G. lapidum* community.

	Spec. ass. 1	Comm. 1	Comm. 2	Comm. 3
D50	0.1893	0.1824	0.1945	0.2701
DE	-0.0097	0.1351	-0.2621	-0.3852
MS	-0.1884	-0.1715	-0.0256	-0.0782
RPD	1.1213	1.7518	1.9635	2.0997
CL	-1.4801	5.1623	1.6199	0.1915
GR	0.0453	0.3140	0.2749	0.3689
SI	1.3109	0.3584	0.9263	1.3227
Constant	-22.7481	-28.9473	-35.0956	-56.2045

Classification function set 3a

A third classification function set takes into account only sedimentological variables (excluding mean and modal grain size) and the depth. The analysis selected seven discriminant variables to set up four classification functions (Table XIV). The overall *a posteriori* accuracy of the classification functions is 73 % (*A. alba* – *M. bidentata* community: 75 %; *N. cirrosa* community: 69 %; *O. limacina* – *G. lapidum* community: 79 %; *M. mirabilis* species association: 64 %). The overall *a priori* accuracy is 67 % (*A. alba* – *M. bidentata* community: 72 %; *N. cirrosa* community: 67 %; *O. limacina* – *G. lapidum* community: 79 %; *M. mirabilis* species association: 54 %).

Table XIV. List of the selected environmental variables, with indication of their community specific weight in the classification functions. Spec. ass. 1: *M. mirabilis* species association; Comm. 1: *A. alba* – *M. bidentata* community; Comm. 2: *N. cirrosa* community; Comm. 3: *O. limacina* – *G. lapidum* community.

	Spec. ass. 1	Comm. 1	Comm. 2	Comm. 3
D50	0.40	0.39	0.49	0.41
DE	-0.77	-0.63	-1.17	-1.04
MS	0.18	0.20	0.30	0.35
CL	382.33	391.62	388.85	386.61
SI	33.49	32.76	33.90	33.19
MM	4715.21	4755.78	4787.08	4739.99
GR	2.27	2.40	2.39	2.30
Constant	-2383.87	-2426.98	-2483.44	-2415.61

Classification function set 4a

Within the fourth classification function set sedimentological fractions and depth were taken into account. The analysis selected five discriminant variables to set up four classification functions (Table XV). The overall *a posteriori* accuracy of the classification functions is 75 % (*A. alba* – *M. bidentata* community: 80 %; *N. cirrosa* community: 63 %; *O. limacina* – *G. lapidum* community: 79 %; *M. mirabilis* species association: 64 %). The overall *a priori* accuracy is 68 % (*A. alba* – *M. bidentata* community: 81 %; *N. cirrosa* community: 70 %; *O. limacina* – *G. lapidum* community: 84 %; *M. mirabilis* species association: 39 %)

Table XV. List of the selected environmental variables, with indication of their community specific weight in the classification functions. Spec. ass. 1: *M. mirabilis* species association; Comm. 1: *A. alba* – *M. bidentata* community; Comm. 2: *N. cirrosa* community; Comm. 3: *O. limacina* – *G. lapidum* community.

	Spec. ass. 1	Comm. 1	Comm. 2	Comm. 3
MS	0.25119	0.25802	0.4310	0.5074
DE	0.12888	0.28131	-0.1461	-0.2945
CS	-0.13779	-0.12152	-0.0766	0.2932
CL	-2.76508	3.21971	-0.4398	-1.6130
SI	1.19076	0.20301	0.7016	0.9172
Constant	-6.25791	-9.17659	-11.6870	-19.1027

CLASSIFICATION FUNCTIONS: THREE COMMUNITIES

Classification function set 1b

Within a first classification function set all physico-chemical variables (excluding mean and modal grain size and water column variables) were taken into account. The analysis selected six discriminant variables to set up three classification functions (Table XVI). The overall *a posteriori* accuracy of the classification functions is 84 % (*A. alba* – *M. bidentata* community: 92 %; *N. cirrosa* community: 80 %; *O. limacina* – *G. lapidum* community: 75 %). The overall *a priori* accuracy is 80 % (*A. alba* – *M. bidentata* community: 94 %; *N. cirrosa* community: 54 %; *O. limacina* – *G. lapidum* community: 90 %).

Table XVI. List of the selected environmental variables, with indication of their community specific weight in the classification functions. Community 1: *A. alba* – *M. bidentata* community; Community 2: *N. cirrosa* community; Community 3: *O. limacina* – *G. lapidum* community.

	Community 1	Community 2	Community 3
D50	0.2384	0.2428	0.2696
DE	0.2975	-0.2892	-0.4771
PO ₄	0.0017	0.0024	0.0021
MS	-0.2506	-0.0279	-0.0056
VCS	-1.1588	-1.1473	-0.6582
Si	0.0164	0.0155	0.0138
Constant	-37.5992	-44.2510	-51.3515

Based on an *a priori* classification of the stations of the *M. mirabilis* species association (sampling campaign: October 1999), 85 % of the stations were designated to the *A. alba* – *M. bidentata* community, while 15 % were designated to the *N. cirrosa* community.

Classification function set 2b

A second classification function set takes into account only physical variables (excluding mean and modal grain size), depth and the depth of the RPD layer. The analysis selected six discriminant variables to set up three classification functions (Table XVII). The overall *a posteriori* accuracy of the classification functions is 87 % (*A. alba* – *M. bidentata* community: 92 %; *N. cirrosa* community: 88 %; *O. limacina* – *G. lapidum* community: 79 %). The overall *a priori* accuracy is 88 % (*A. alba* – *M. bidentata* community: 94 %; *N. cirrosa* community: 92 %; *O. limacina* – *G. lapidum* community: 80 %).

Table XVII. List of the selected environmental variables, with indication of their community specific weight in the classification functions. Community 1: *A. alba* – *M. bidentata* community; Community 2: *N. cirrosa* community; Community 3: *O. limacina* – *G. lapidum* community.

	Community 1	Community 2	Community 3
D50	0.1852	0.1901	0.2476
DE	0.3309	-0.0914	-0.2558
VFS	4.8519	4.3071	4.4678
MS	0.1698	0.2878	0.2837
VCS	-0.4834	-0.3932	-0.1892
RPD	1.1232	1.3749	1.4137
Constant	-40.1236	-42.7583	-60.4067

Based on an *a priori* classification of the stations of the *M. mirabilis* species association (sampling campaign: October 1999), 39 % of the stations were designated to the *A. alba* – *M. bidentata* community, while 61 % were designated to the *N. cirrosa* community.

Classification function set 3b

A third classification function set takes into account only sedimentological variables (excluding mean and modal grain size) and the depth. The analysis selected six discriminant variables to set up three classification functions (Table XVIII). The overall *a posteriori* accuracy of the classification functions is 86 % (*A. alba* – *M. bidentata* community: 90 %; *N. cirrosa* community: 88 %; *O. limacina* – *G. lapidum* community: 80 %). The overall *a priori* accuracy is 85 % (*A. alba* – *M. bidentata* community: 86 %; *N. cirrosa* community: 85 %; *O. limacina* – *G. lapidum* community: 84 %).

Table XVIII. List of the selected environmental variables, with indication of their community specific weight in the classification functions. Community 1: *A. alba* – *M. bidentata* community; Community 2: *N. cirrosa* community; Community 3: *O. limacina* – *G. lapidum* community.

	Community 1	Community 2	Community 3
D50	0.1881	0.1923	0.2505
DE	0.2561	-0.1875	-0.3564
VFS	4.5212	3.8373	3.9894
MS	0.2055	0.3235	0.3208
VCS	-0.8322	-0.6568	-0.4600
GR	0.3244	0.1815	0.1892
Constant	-37.3224	-37.0863	-54.6437

Based on an *a priori* classification of the stations of the *M. mirabilis* species association (sampling campaign: October 1999), 39 % of the stations were designated to the *A. alba* – *M. bidentata* community, while 61 % were designated to the *N. cirrosa* community.

Classification function set 4b

Within the fourth classification function set sedimentological fractions and depth were taken into account. The analysis selected five discriminant variables to set up three classification functions (Table XIX). The overall *a posteriori* accuracy of the classification functions is 88 % (*A. alba* – *M. bidentata* community: 93 %; *N. cirrosa* community: 88 %; *O. limacina* – *G. lapidum* community: 79). The overall *a priori* accuracy is 90 % (*A. alba* – *M. bidentata* community: 89 %; *N. cirrosa* community: 85 %; *O. limacina* – *G. lapidum* community: 100 %).

Table XIX. List of the selected environmental variables, with indication of their community specific weight in the classification functions. Community 1: *A. alba* – *M. bidentata* community; Community 2: *N. cirrosa* community; Community 3: *O. limacina* – *G. lapidum* community.

	Community 1	Community 2	Community 3
MS	4.268	4.647	4.739
DE	1.563	1.138	0.951
CS	5.545	5.793	6.075
FS	5.137	5.363	5.369
VCS	-0.690	-0.611	-0.442
Constant	-223.555	-247.484	-255.264

Based on an *a priori* classification of the stations of the *M. mirabilis* species association (sampling campaign: October 1999), 77 % of the stations were designated to the *A. alba* – *M. bidentata* community, while 23 % were designated to the *N. cirrosa* community.

COMPARISON OF THE DIFFERENT CLASSIFICATION FUNCTIONS

The majority of the classification function (78 %) revealed a community specific and overall *a posteriori* and *a priori* accuracy higher than 70 % (Table XX). Only in three cases (*a priori* accuracy of classification function sets 1a, 2a and 4a for the *M. mirabilis* species association) an accuracy lower than 50 % was found.

Considering the community specific and overall *a posteriori* accuracy, from four to three groups an increasing accuracy was found for the *A. alba* – *M. bidentata* community (all classification function sets) and the *N. cirrosa* community (classification function sets 3a,b and 4a,b). Only minor changes within the *a posteriori* accuracy for the *O. limacina* – *G. lapidum* community occurred. The same trend was found considering the *a priori* accuracy.

Table XX. Overview of the predicted *a posteriori* and *a priori* accuracy of the eight classification function sets. M1a to M4b: Classification function set 1a to Classification function set 4b.

PREDICTED ACCURACY		Four groups				Three groups			
		M1a	M2a	M3a	M4a	M1b	M2b	M3b	M4b
<i>a posteriori</i>	<i>A. alba</i> – <i>M. bidentata</i> community	65	69	75	80	92	92	90	93
	<i>N. cirrosa</i> community	87	88	69	63	80	88	88	88
	<i>O. limacina</i> – <i>G. lapidum</i> community	75	79	79	79	75	79	80	79
	<i>M. mirabilis</i> species association	85	100	64	64	—	—	—	—
	Overall	76	80	73	75	84	87	86	88
<i>a priori</i>	<i>A. alba</i> – <i>M. bidentata</i> community	61	62	72	81	94	94	86	89
	<i>N. cirrosa</i> community	62	77	67	70	54	92	85	85
	<i>O. limacina</i> – <i>G. lapidum</i> community	87	87	79	84	90	80	84	100
	<i>M. mirabilis</i> species association	33	33	54	39	—	—	—	—
	Overall	60	64	67	68	80	88	85	90

TEST OF THE CLASSIFICATION FUNCTIONS

Because of the failure to measure several environmental variables in November 2000, only four models (M3a, M3b, M4a and M4b) could be evaluated. The predictive power of all other models could only be evaluated on the basis of data from at maximum five observations, which is too low to attain a reliable evaluation.

Table XXI. The *a priori* accuracies (%) of the models, tested using the data retrieved in November 2000. Acc.: Accuracy (%); Sampl.: number of samples to be designated by the model; Spec. ass. 1: *M. mirabilis* species association; Comm. 1: *A. alba* – *M. bidentata* community; Comm. 2: *N. cirrosa* community; Comm. 3: *O. limacina* – *G. lapidum* community.

	Spec. Ass. 1		Comm. 1		Comm. 2		Comm. 3	
	Acc.	Sampl.	Acc.	Sampl.	Acc.	Sampl.	Acc.	Sampl.
M3a	50	4	20	5	60	5	83	6
M4a	0	4	0	5	0	5	100	6
M3b	—	—	0	2	100	5	67	6
M4b	—	—	0	2	0	5	100	6

Except for the *A. alba* - *M. bidentata* community (accuracy: 20 %), the M3a model showed a minimum accuracy of 50%. The model M3b, had high accuracies for the *N. cirrosa* and the *O. limacina* - *G. lapidum* communities (up to 100 %). Though, both stations, biologically classified within the *A. alba* - *M. bidentata* community, were classified as being part of the *N. cirrosa* community by the M3b model. Both M4 models had no accuracy for all communities, except for the *O. limacina* - *G. lapidum* community: all samples were classified as being part of the *O. limacina* - *G. lapidum* community.

Discussion

The 'macrobenthic potential' of a habitat/community, as illustrated by their respective 'potential species list' in this study, revealed the extraordinary ecological value of the *A. alba* - *M. bidentata* community relative to both other communities. Being a transition between the *A. alba* - *M. bidentata* and the *N. cirrosa* community, the *M. mirabilis* species association logically had an intermediate ecological value. Hence, when valuing the different habitats of the Western Coastal Banks, the habitat of the *A. alba* - *M. bidentata* community is clearly ecologically superior to all other habitats. Yet, this should not be interpreted as the other habitats being ecologically unimportant. Despite their relative low macrobenthic richness, several species are restricted to these specific habitats. As generally agreed upon, biodiversity should be conserved at different levels. Both within and in between habitat biodiversity, resp. ©-biodiversity and ®-diversity, are important. Hence, the protection of all habitats is important for the well-functioning of the whole ecosystem of the Western Coastal Banks.

As already demonstrated by Degraer *et al.* (1999b), knowledge on the physico-chemical environment can be used to predict the occurrence of the macrobenthos. Since 78 % of the classification functions revealed a community specific and overall *a posteriori* and *a priori* accuracy higher than 70 %, the results, presented in this study, confirm this statement.

Taking into account the *M. mirabilis* species association, compared to only using the three macrobenthic communities, lower *a posteriori* and *a priori* accuracies were generally found. This can be explained by the fact that the *M. mirabilis* species association is described as a transition between the *A. alba* – *M. bidentata* and the *N. cirrosa* community. The transitional state of the community is also illustrated by means of the classification of the samples, belonging the *M. mirabilis* community, using the classification function sets 1b to 4b: all samples from the *M. mirabilis* community were classified as belonging to the *A. alba* – *M. bidentata* or the *N. cirrosa* community. No samples were classified as the *O. limacina* – *G. lapidum* community. Depending on the classification function set under consideration, the majority of the samples was classified as the *A. alba* – *M. bidentata* or the *N. cirrosa* community. No clear preference for one or the other community was found. Furthermore, comparing the *a posteriori* and *a priori* accuracy of the classification function sets for four groups with those for three communities, a general higher accuracy is found for the *A. alba* – *M. bidentata* and the *N. cirrosa* community, while the accuracy for the *O. limacina* – *G. lapidum* community remained unaffected.

The classification function set of Degraer *et al.* (1999b) is based on sedimentological and bathymetrical variables and discriminates between the three macrobenthic communities. The same classification function set is set up in this study (Classification function set 3b). The *a priori* accuracy for the classification function set 3b (80 %), is well above the *a priori* classification accuracy of 74 % of Degraer *et al.* (1999b). The major difference between the dataset of Degraer *et al.* (1999b) and the dataset of this study is the number of samples taken into account: 40 versus 120 samples, respectively. The increase in *a priori* accuracy may thus be due to the increase in the number of samples used. Furthermore, the *a priori* accuracy of Degraer *et al.* (1999b) was tested using data collected during the same season as the samples for the estimation of the classification functions: October 1994 versus October 1997. In this study the *a priori* accuracy was tested using data from a different season: October 1999 versus March 2000. Within one year major seasonal changes within the community structure can be expected, while interannual changes might be significant as well. These biological changes will certainly impact the community analyses and, thus, the accuracy of the classification functions. The effect of interannual variation on the models' accuracy was tested using the data retrieved in November 2000. Unfortunately, because of a failure to measure several ecologically relevant variables in many samples of November 2000, only 50 % of the models could be tested. Two models proved to be relatively useful, while both other models had a zero accuracy. Eventhough the models could be tested, the reliability of the tests is doubtful. Since at maximum 20 samples were available per test, a low number of replicate samples per community was found (maximum six samples). This low number might be unrepresentative for the community's variation. Hence, an incorrect classification of only one sample results in a decrease in accuracy of at least 17%. Probably, this fact can explain the erratic accuracies of both M3 models. Whether this fact also explains the failure of the M4 model is unknown. Further evaluation of the models, using new data, as well as refinement of the models using new data is advised.

Comparing the community specific accuracy of each classification function set, no set can be put forward as superior to the other sets. When using the HABITAT model, the selection of the classification function sets will therefore primarily depend on the environmental data available. If possible, the accuracy of the HABITAT model might be improved by the application of different classification function sets, providing a replication of the classification of the new samples.

Conclusions

The HABITAT model allows to predict the presence or distribution of macrobenthic communities, based on knowledge of the physico-chemical environment. The model thus allows to evaluate the 'potentials' of non-studied places within the protected area on an time- and cost-efficient base. By increasing the number of samples, used to set up the classification function sets, a higher accuracy, compared to Degraer *et al.* (1999b), is obtained. Furthermore, the accuracy can be drastically increased if only the three macrobenthic communities are taken into account, rather than using the *M. mirabilis* species association as well. Comparing the community specific accuracy of each classification function set, no set can be put forward as superior to the other sets. The disappointing accuracy of the models, when using the data of November 2000, should not be interpreted as the models to be useless, but rather as the need for further testing and refinement.

MACROBENTHIC INTERPRETATION OF SIDE-SCAN SONAR IMAGES (MSSSI)

Introduction

Generally, when using side-scan sonar technology, the intensity of the reflected acoustic signals is an important tool for the mapping of seafloor substrates. Not taking into account the physical aspect, differences in intensity can also be a translation of the presence of living and even organic materials (Curran 1995). The concept of the Macrobenthic Side-Scan Sonar Interpretation (MSSSI) thus relies on the already known relationships between the physical environment (of which the sedimentological nature is the most discriminating), on the one hand and the macrobenthos and side-scan sonar recordings on the other hand (Figure 36).

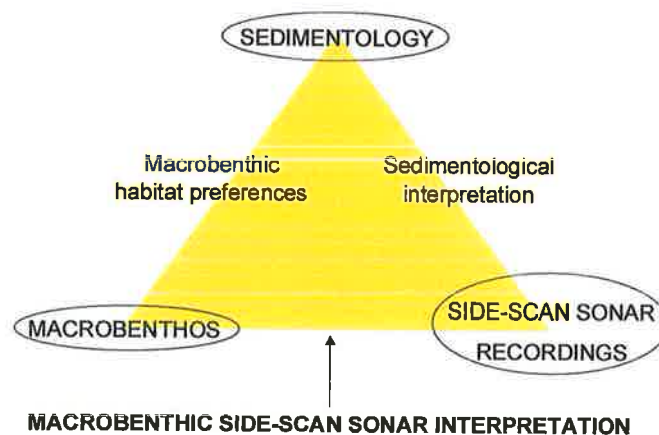


Figure 36. The concept of the macrobenthic side-scan sonar interpretation

Materials and methods

DATA GATHERING

The information needed for the set-up of a standardised macrobenthic side-scan sonar interpretation has been collected during the multidisciplinary field campaigns of October 1999 and March 2000 and have been described in part 1. Hence, detailed information on the spatial distribution of the different sediment types and the macrobenthic community structure is available.

Results

MACROBENTHOS VERSUS SEDIMENTOLOGY

Throughout Part 1, the link of the occurrences of macrobenthos was described in function of the sedimentological characteristics of the area. Figure 37 is a superposition of the different communities, the distribution map of the surficial sediments and the bathymetry.

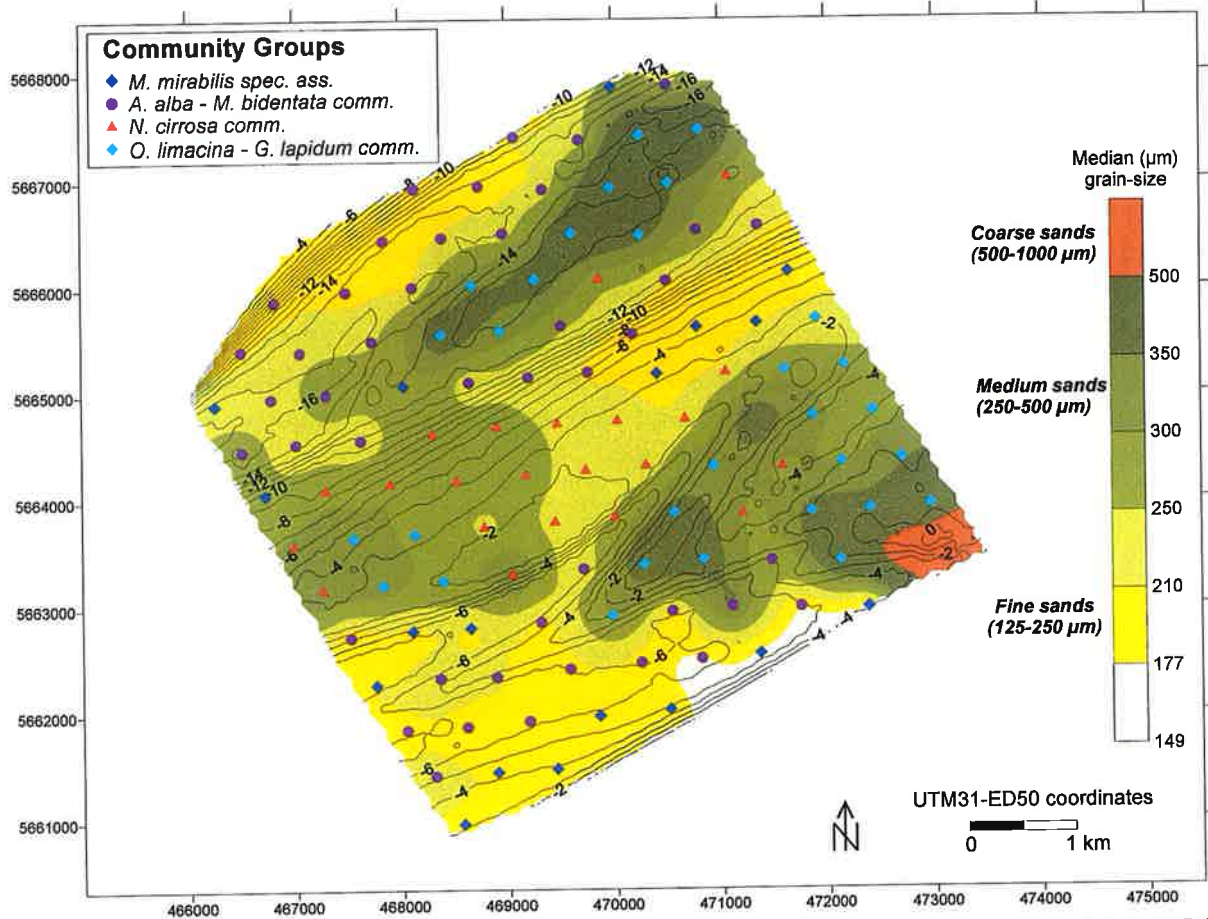


Figure 37. Relation of the occurrence of macrobenthic communities with the areal distribution of the surficial sediments and the bathymetry.

From Figure 37, the *Magelona mirabilis* species association is generally present along the shoreface and the swales. Especially, in the latter, the surficial sediments are characterised by a higher silt-clay ratio. This species association also occurs along the slope of the Trapegeer albeit restricted to the east where the sediments are finer. The *Abra alba* – *Mysella bidentata* community preferentially occurs near and along the slopes of the topographic highs characterised by sediments with a broader range of sediment fractions, though it also occurs in the swales even in areas with strong bottom tidal currents. The *Nephtys cirrosa* community is found along the topographic highs where fine to medium sands predominate without significant silt-clay enrichment. The *Ophelia limacina* – *Glycera lapidum* community is mostly associated with the top zone of sandbanks, shoals or higher areas in the swales. The surficial sediments are composed of medium to coarse sands often with an abundance of shell fragments or localised gravel in the swales.

SIDE-SCAN SONAR VERSUS SEDIMENTOLOGY

Interpreting the sediment texture of side-scan sonar recordings is not always an easy task and much is dependent on the dynamics of the area. Normally high reflective sediments tend to be associated with coarse sediments whilst finer

sediments normally induce a low backscattering of the acoustic signal. However, as mentioned in the section on standard materials and methods, the compaction of sediments is of higher priority to determine the backscatter. Areas with sediments with higher silt-clay percentages such as in the swales have a higher degree of compaction, which is translated into a higher reflectivity. This is most clearly shown on Figure 41 where well-distinguished acoustic facies are shown, whilst the corresponding median diameter of the surficial sediments is similar, but with a difference in the silt-clay ratio. On the contrary, an area can have coarser sediments, but if these are recently deposited, they are loosely packed, absorb more energy and hence have a lighter reflectivity. An example is the Trapegeer sandbank that is characterised by a lighter reflectivity as it is within an active depositional environment with a regular input and hydraulic sorting of sediments (Figures 22, 40). The Broersbank is a zone of high reflectivity with a clear coarse texture. From sampling, this was correlated with the presence of compacted coarse sands and shell hash, often in combination with coarse-grained wave ripples. Figure 38 is another demonstration of a sedimentological interpretation of side-scan sonar imagery.

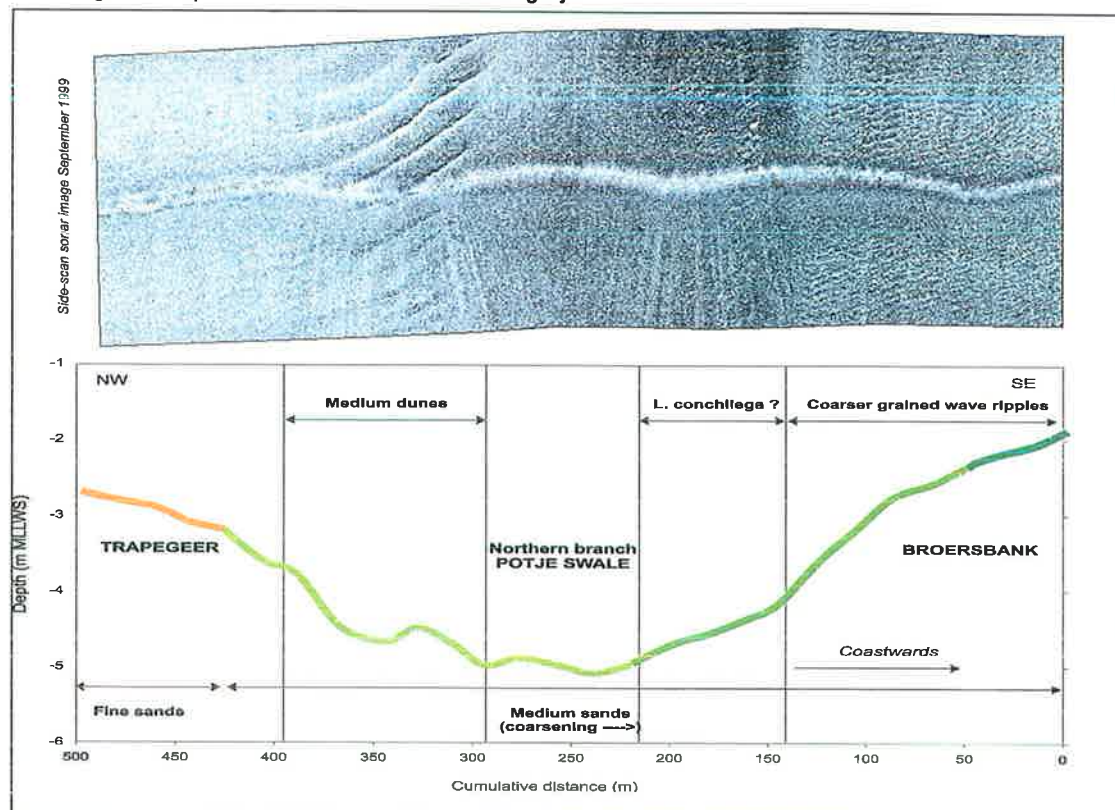


Figure 38. Demonstration of the relation of sediment texture with the observed reflectivity on side-scan sonar imagery. Additionally, the corresponding bathymetric profile is given.

SIDE-SCAN SONAR VERSUS MACROBENTHOS

Two approaches were followed in the interpretation of side-scan sonar imagery in terms of the occurrence of macrobenthic communities.

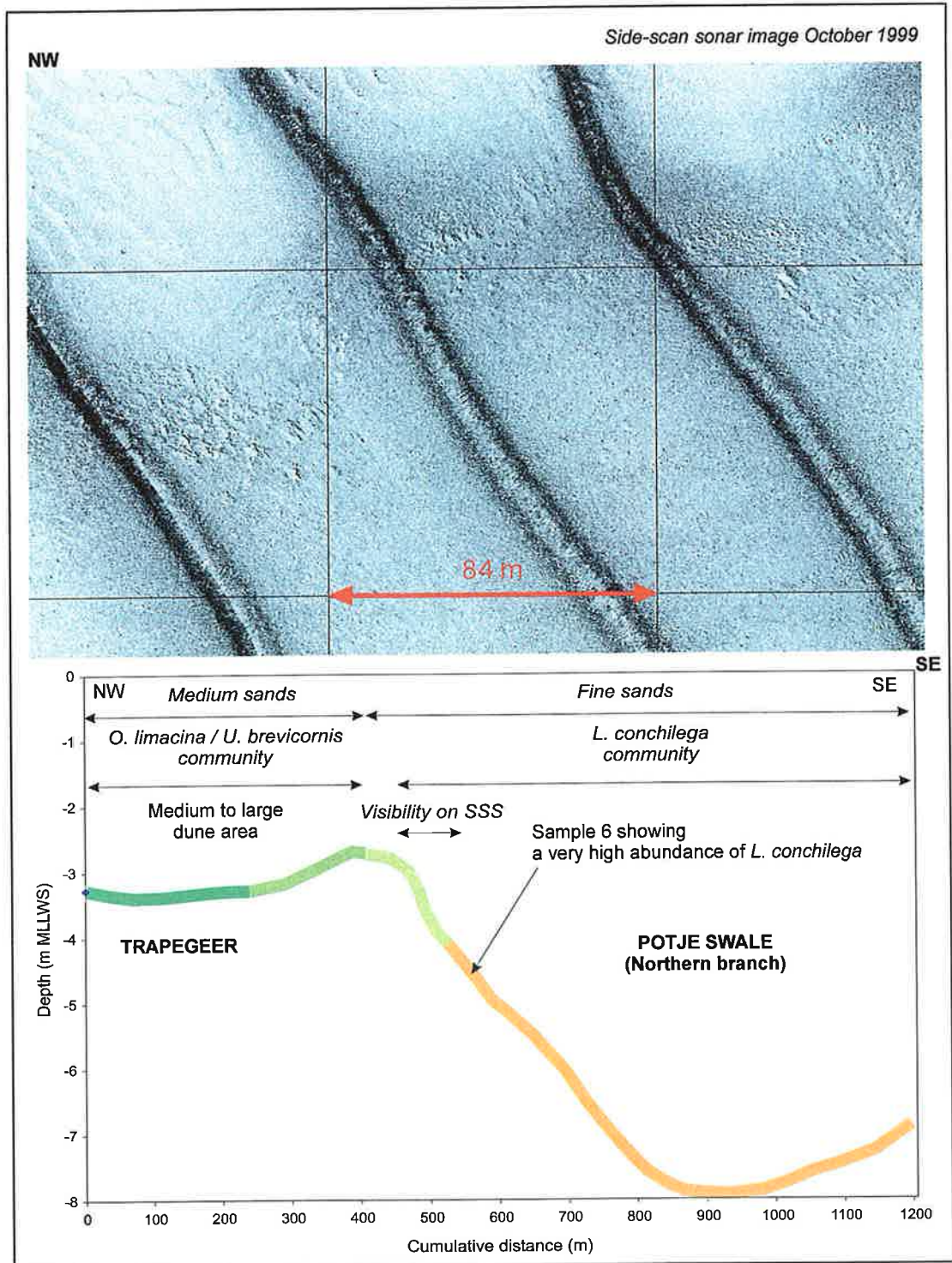


Figure 39. Side-scan sonar image showing a circular patchy texture that is correlated with a high abundance of *Lanice conchilega*.

The first approach was based on a direct correlation of high abundances of macrobenthos with a specific acoustic facies that could not be described or interpreted in terms of the ruling physical factors. As such, a medium to high reflectivity patchy to mottled texture was correlated with the presence of dense fields of the tube-building polychaete *Lanice conchilega*, the key species of the *Abra alba* – *Mysella bidentata* community and richest in its macrobenthos. This polychaete worm is known to be able to influence the sedimentological structure of the seafloor by building (semi)-permanent tubes. The tubes can extend above the sediment for some centimetres and can thus significantly alter and even raise the sediment surface by up to 20 cm (Berné *et al.* 1988). If the density of this polychaete worm is high enough, they can indeed give rise to local sediment accumulations that can be detected by side-scan sonar technology (see also Part 1). Figure 39 demonstrates the association of a patchy texture on side-scan sonar imagery with a high abundance of *Lanice conchilega*. A quantitative relation was sought between the side-scan sonar backscatter values and density distributions of macrobenthos, but hitherto proved to be unsuccessful (Rennie 2000).

Secondly, an indirect link was sought based on a compilation of previous correlations. To facilitate this process and to evolve into a standardised interpretation of side-scan sonar recordings, a table was set-up with different criteria and interpretation keys (Table XXII). This table provides a discrimination of acoustic facies into a maximum of classes that are finally linked to a macrobenthos community preference.

The criteria are reflectivity, texture and a primary descriptor. The reflectivity is divided into low, medium and high and is related to the darkness of the imagery (signal amplitude). It should be evaluated relatively along the imagery as the backscattering is not standardized and is acquisition dependent. The texture can primarily be described as smooth, grainy, coarse to rough. A smooth texture means that almost all of the acoustic energy is lost, absorbed by loose to loosely packed sediments. These can easily be distinguished and are generally associated with fluid mud layers or strongly homogenised silt to fine sandy seafloors (Figure 31). A rough texture means that most of the energy is reflected, hence associated with hard substrates that can be localised shell accumulations or gravel. Patterns relate to the organisation of features on an image. An image can be featureless, or with irregularities or organised. The primary descriptors include the occurrence of lineation whereby bedform features are most common.

The interpretation keys are introduced to be able to maximally describe the variability of the area and to facilitate a further set-up of correlations. Finally, a maximum of 21 classes or acoustic facies was defined. For each class, a community preference was indicated. Through the set-up of Table XXII, the occurrence of macrobenthic communities can be primarily evaluated through the described correlations with the physical environment. Table XXII also contains the acoustic facies that could be directly correlated with the presence of the *Abra alba* – *Mysella bidentata* community (classes 12 and 15). It needs emphasis that Table XXII integrates all the data that is acquired throughout the project.

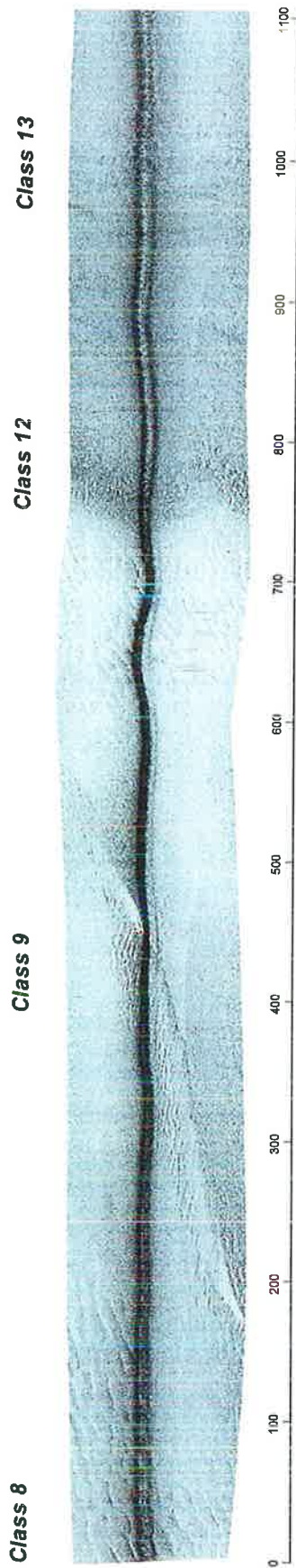
In Figures 40 to 53, the different seabed classes are demonstrated on the side-scan sonar imagery together with a bathymetric profile and the predicted community preference.

To gain insight into the spatial distribution of the different acoustic facies, their occurrence has been digitised and annotated with a class number. Figure 54 shows the distribution of the different acoustic facies along the Western Coastal Banks based on the side-scan sonar data of March 2000.

Table XXII. Set-up of a standardised side-scan sonar interpretation with prediction towards a community preference.

SIDE-SCAN SONAR											
DESCRIPTION				INTERPRETATION							
REFLECTIVITY	TEXTURE	PATTERN	PRIMARY DESCRIPTOR	PACKING	BEDFORMS	SEDIMENT	PROCESSES	ENVIRONMENT	CLASS	COMMUNITY PREFERENCE	
LOW	SMOOTH	Featureless		Loose		Fluid mud		Swale, flat environments, low seafloor gradient	1	NA	
				Loosely packed		Mud			2	NA	
	SMOOTH TO SLIGHTLY GRAINY	Spots incl.		Loosely packed		Silt to fine sand			3	(B)	
	SLIGHTLY GRAINY	Patchy		Loosely packed		Silt to fine sand			4	(B)	
MEDIUM	SLIGHTLY GRAINY	Featureless		Packed		Fine to medium sand		Shoreface	5	A-C	
		Featureless		Packed		Fine sand		Swale	6	B	
	SLIGHTLY GRAINY TO GRAINY	Lineations / streaks	Fields of aligned straight to sinuous lineations of higher reflectivity with associated acoustic shadow	Loosely packed	Small to medium dunes	Fine to medium sand	Important bedload	Flanks, lagoon channelised swale areas	7	A-C	
				Packed					8	A-C	
				Loosely packed / packed	Large to very large dunes / compound dunes	Medium sand			9	C	
				Loosely packed / packed					10	B	
		Ribbons	Alternance of higher and lower reflectivity bands	Loosely packed / packed	Current lineations	Sand veneers on packed sediments	Sheet flow conditions	Channelised swale areas	11	B	
		GRAINY	Patchy	Circular to elongated patches with slightly different reflectivity	Packed	Scoured relief	Fine sand	Biologically altered	Flanks of the topographic highs	12	B
	SMOOTH	Featureless		Compact			Sand with silt/clay enrichment	Strong bottom tidal currents	Swales	13	B
		Undulated	14							B	
	GRAINY	Mottled			Sand with silt/clay enrichment	Biologically altered / Strong bottom tidal currents	Sandbank slope / swales	15	B		
	HIGH		Featureless				Coarse sand / shells		Top zone sandbanks	16	D
		COARSE	Ribbons / scars	Straightened areas with alternance of higher and lower reflectivity		Elongated bands		Current induced lag erosion / Strong bottom tidal currents	Swales	17	?
Lineations / streaks			Irregular, small to medium dunes, straight sometimes double crested	Packed		Medium to coarse sand	Current and/or wave induced Strong bottom tidal currents	Top zone sandbanks, higher areas in the swales, shoals	18	D	
ROUGH		Spotted / dotted	Point source reflector i.e. high reflectivity spots or species	Hard		Localised shell accumulations, shell hash	Strong bottom tidal currents	Small depressions	20	?	
						Gravel, gravelly coarse sands	Swales	21	?		

Side-scan sonar interpretation (zone 1B, October 1999)



Area representative of
Community C to D

Area representative of
Community B

Trapegeer sandbank

Landward steep slope of the
Trapegeer sandbank

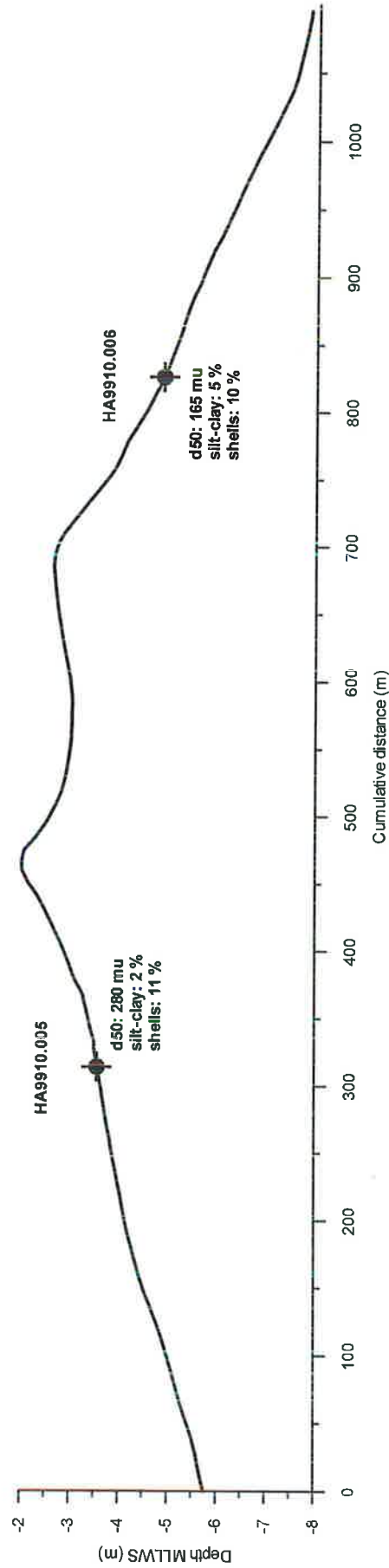


Figure 40. Macrobenthic side-scan sonar interpretation of a profile covering the Trapegeer sandbank.

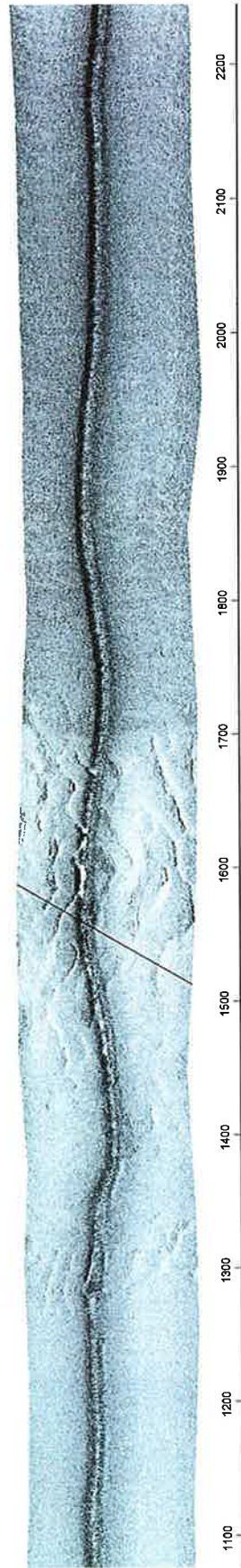
(Community A: *M. mirabilis* spec. ass.; Community B: *A. alba* – *M. bidentata* comm.; Community C: *N. cirrosa* comm.; Community D: *O. limacina* – *Glycera lapidum* comm.)

Side-scan sonar interpretation (zone 1b, October 1999)

Class 12

Class 9

Class 13



Area
representative of
Community A

Area
representative of
Community B

Area
representative of
Community B

Potje swale
(northern branch)

Westward extension
of the Broers Bank

Potje swale
(southern branch)

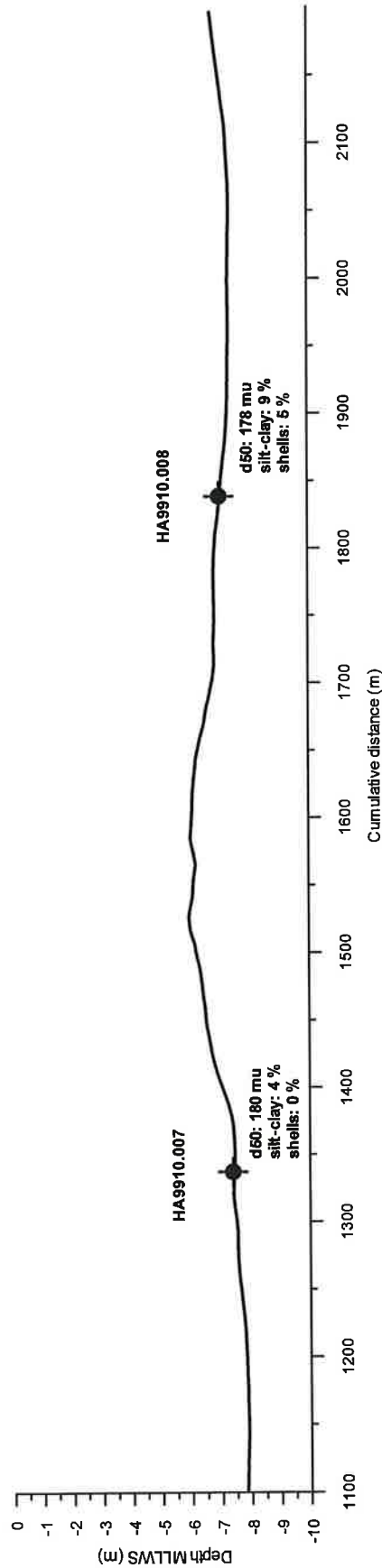


Figure 41. Macrobenthic side-scan sonar interpretation of a profile covering the Potje swale and the westward extension of the Broersbank. (Community A: *M. mirabilis* spec. ass.; Community B: *A. alba* – *M. bidentata* comm.; Community C: *N. cirrosa* comm.; Community D: *O. limacina* – *Glycera lapidum* comm.)

Side-scan sonar interpretation (zone 1b, October 1999)

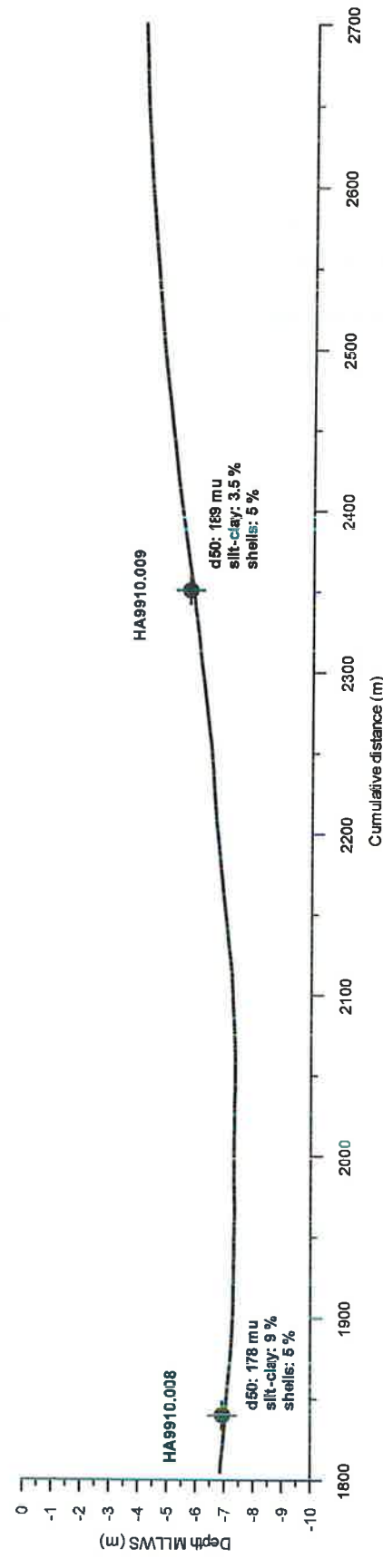
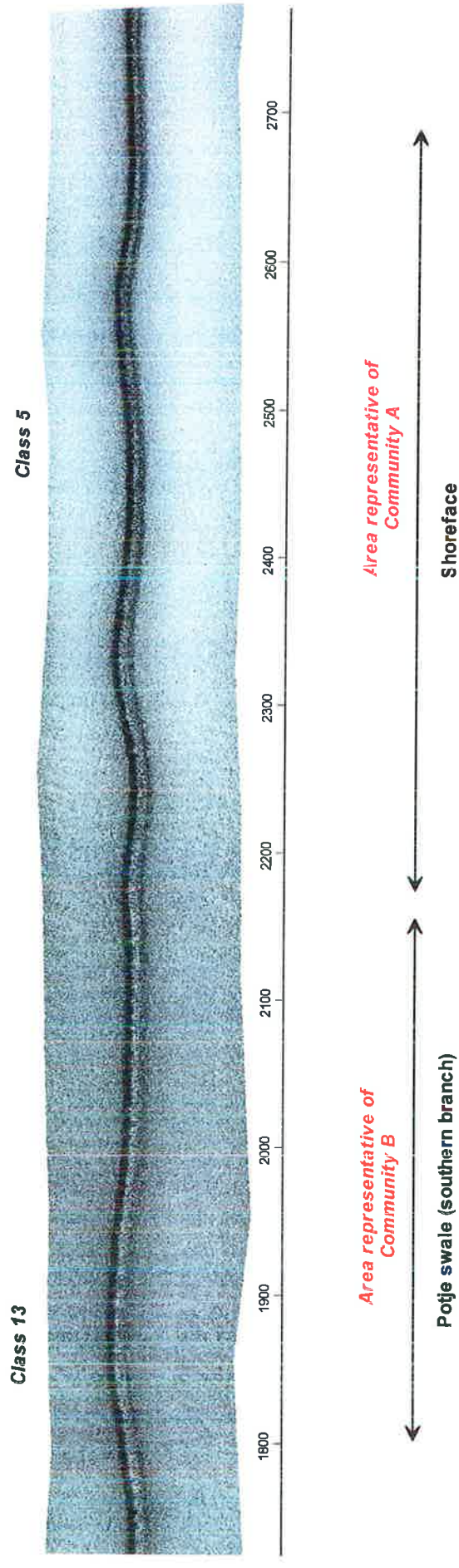


Figure 42. Macro-benthic side-scan sonar interpretation of a profile covering the Potje swale and the shoreface. (Community A: *M. mirabilis* spec. ass.; Community B: *A. alba* – *M. bidentata* comm.; Community C: *N. cirrosa* comm.; Community D: *O. limacina* – *Glycera lapidum* comm.)

Side-scan sonar interpretation (zone 3A, October 1999)

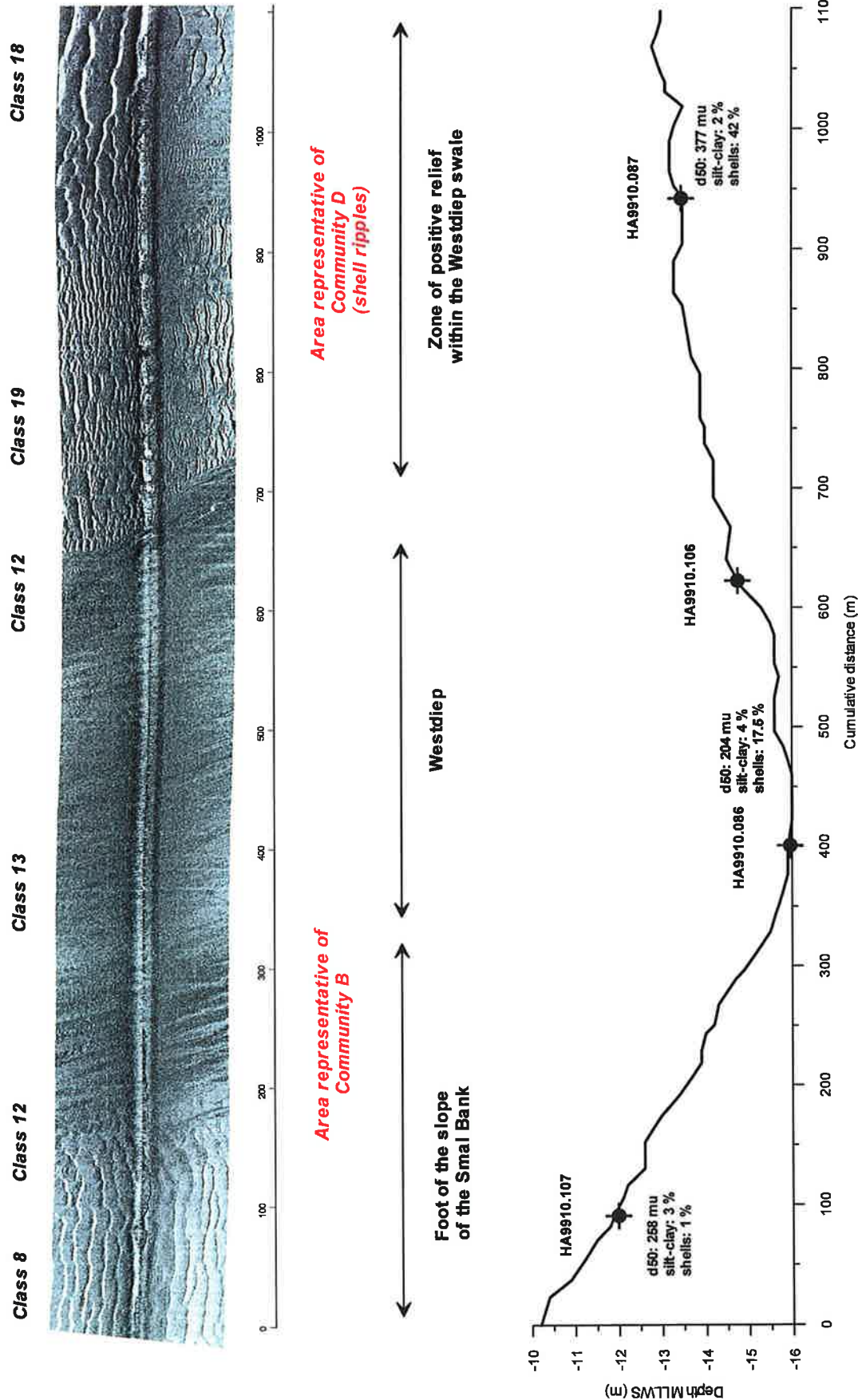


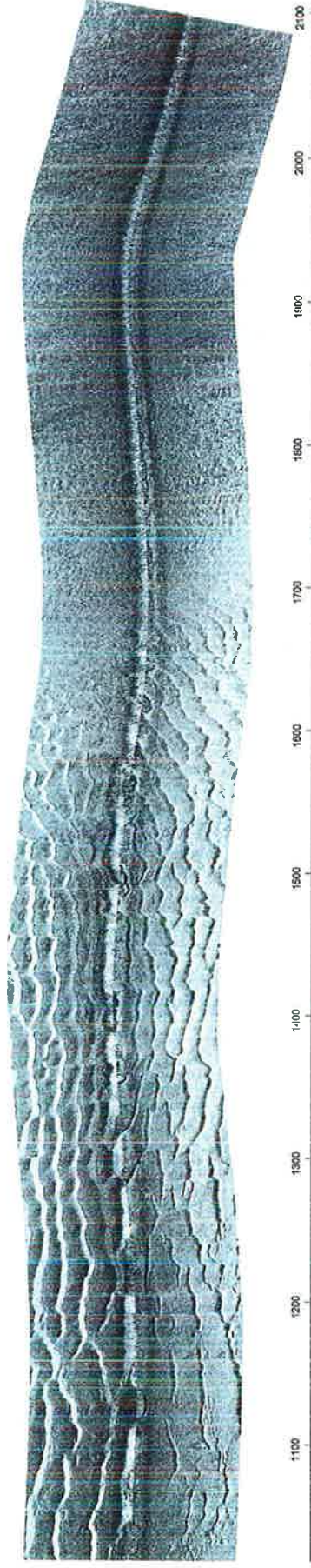
Figure 43. Macrobenthic side-scan sonar interpretation of a profile covering the Westdiep swale. (Community A: *M. mirabilis* spec. ass.; Community B: *A. alba* – *M. bidentata* comm.; Community C: *N. cirrosa* comm.; Community D: *O. limacina* – *Glycera lapidum* comm.)

Side-scan sonar interpretation (zone 3A, October 1999)

Class 19

Class 18

Class 12



Area representative of
Community C to D

Area representative of
Community B

Zone of positive relief within the Westdiep swale

Foot of the seaward slope
of the Trapegeer sandbank

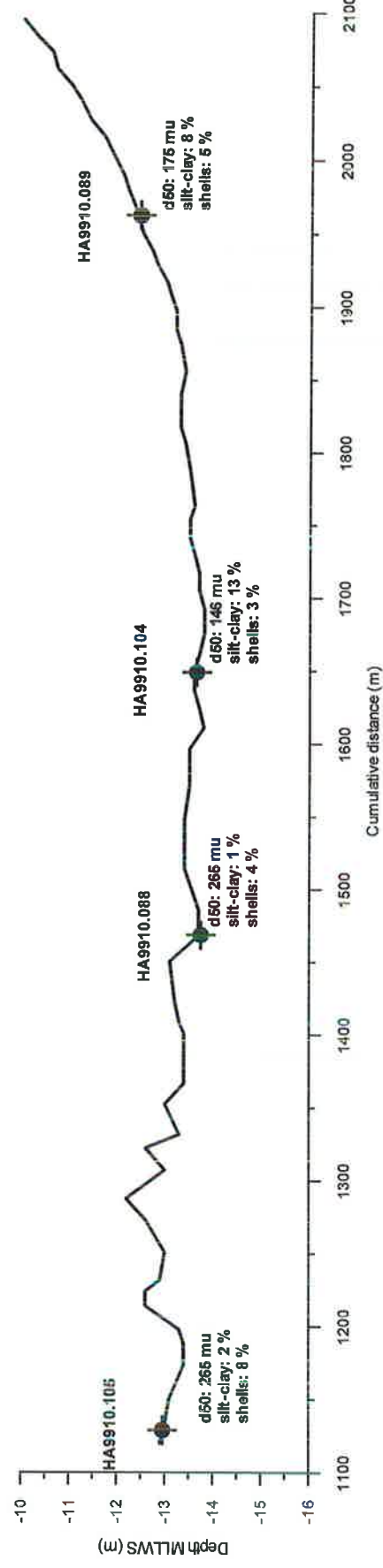
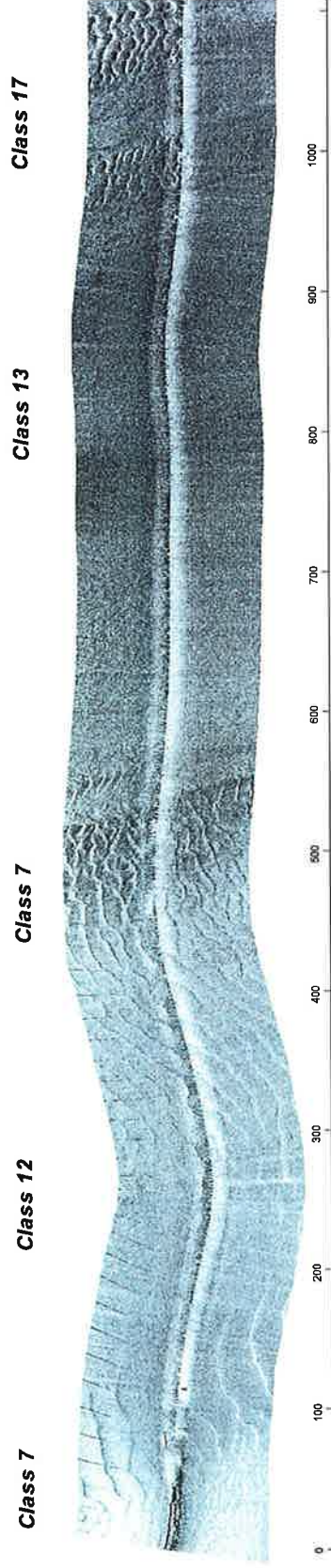


Figure 44. Macrobenthic side-scan sonar interpretation of a profile covering the Westdiep swale and the foot of the seaward slope of the Trapegeer sandbank. (Community A: *M. mirabilis* spec. ass.; Community B: *A. alba* – *M. bidentata* comm.; Community C: *N. cirrosa* comm.; Community D: *O. limacina* – *Glycera lapidum* comm.)

Side-scan sonar interpretation (zone 1A, March 2000)



Area representative of Community B

Landward slope of the Smal Bank

Westdiep swale

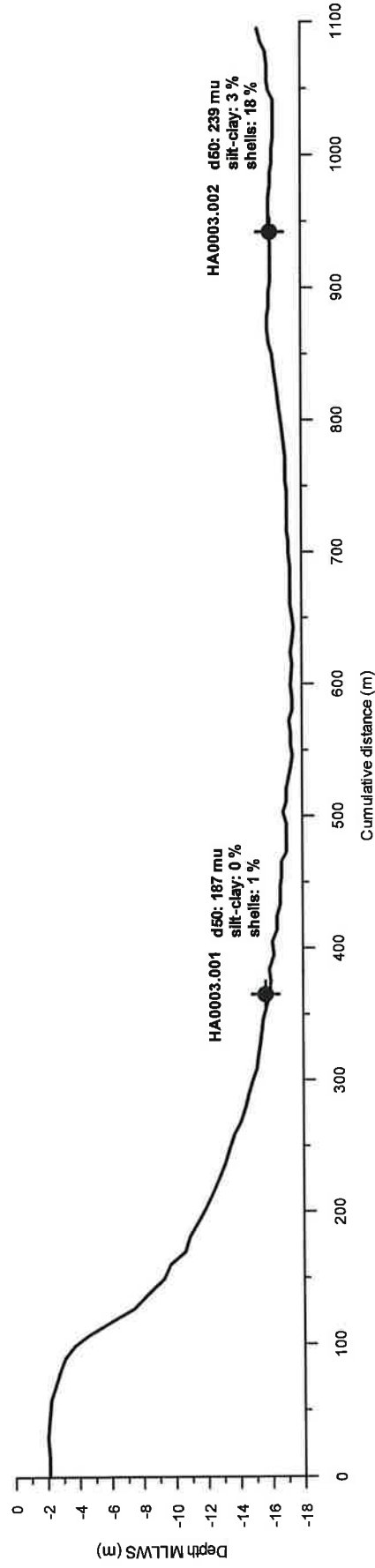
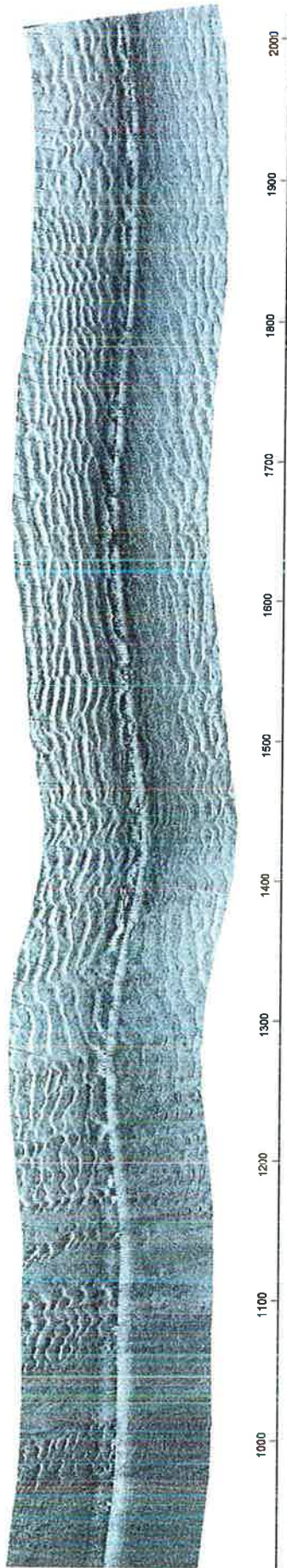


Figure 45. Macrobenthic side-scan sonar interpretation of a profile covering the landward slope of the Smal Bank and the Westdiep swale. (Community A: *M. mirabilis* spec. ass.; Community B: *A. alba* – *M. bidentata* comm.; Community C: *N. cirrosa* comm.; Community D: *O. limacina* – *Glycera lapidum* comm.)

Side-scan sonar interpretation (zone 1A, March 2000)

Class 17

Class 8



Area representative of Community B

Area representative of Community A

Westdiep swale

Transition zone Westdiep swale - slope Trapegeer sandbank

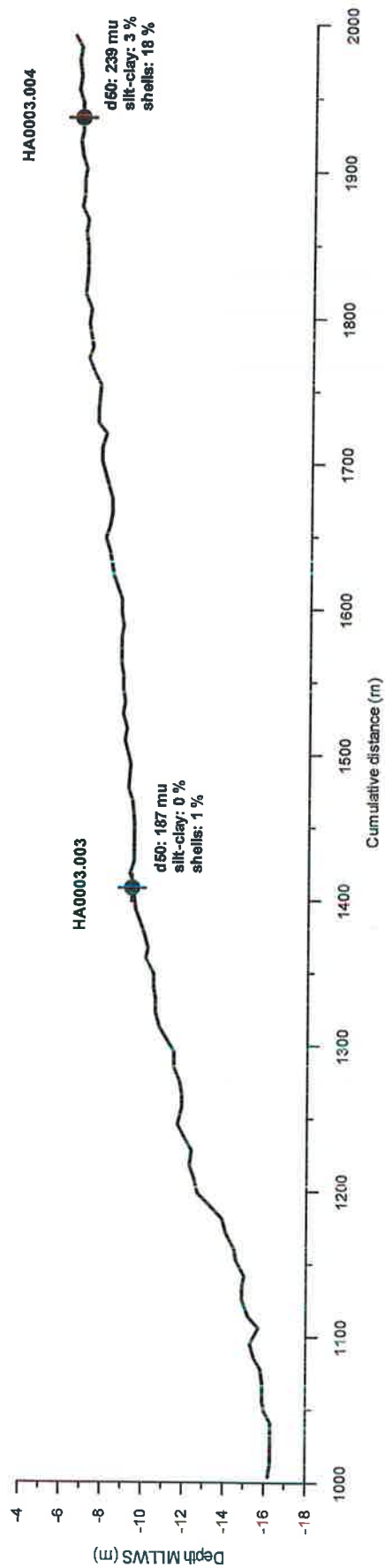


Figure 46. Macrobenthic side-scan sonar interpretation of a profile covering the Westdiep swale and the transition zone towards the slope of the Trapegeer sandbank. (Community A: *M. mirabilis* spec. ass.; Community B: *A. alba* - *M. bidentata* comm.; Community C: *N. cirrosa* comm.; Community D: *O. limacina* - *Glycera lapidum* comm.)

Side-scan sonar interpretation (zone 1A, March 2000)

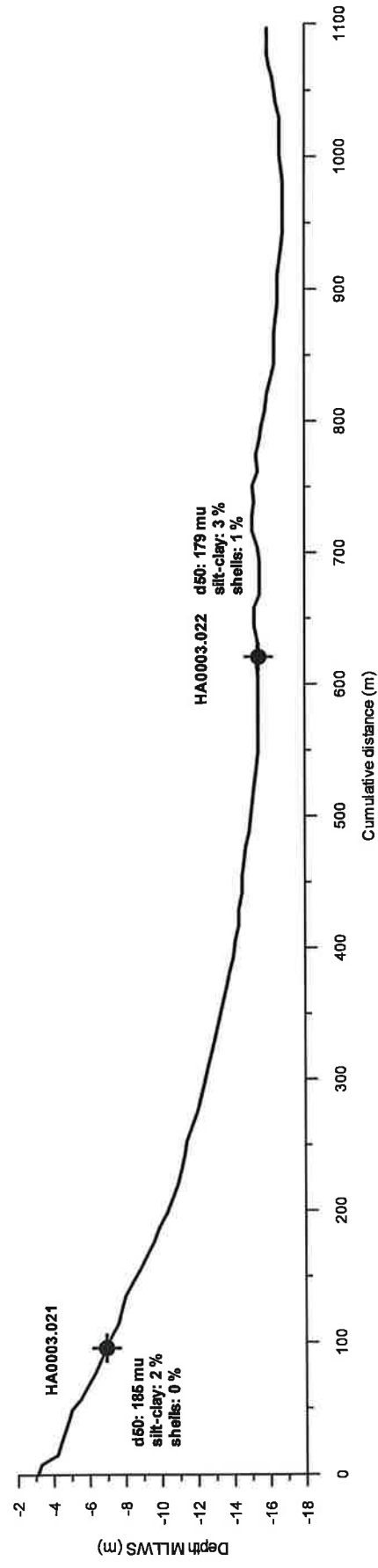
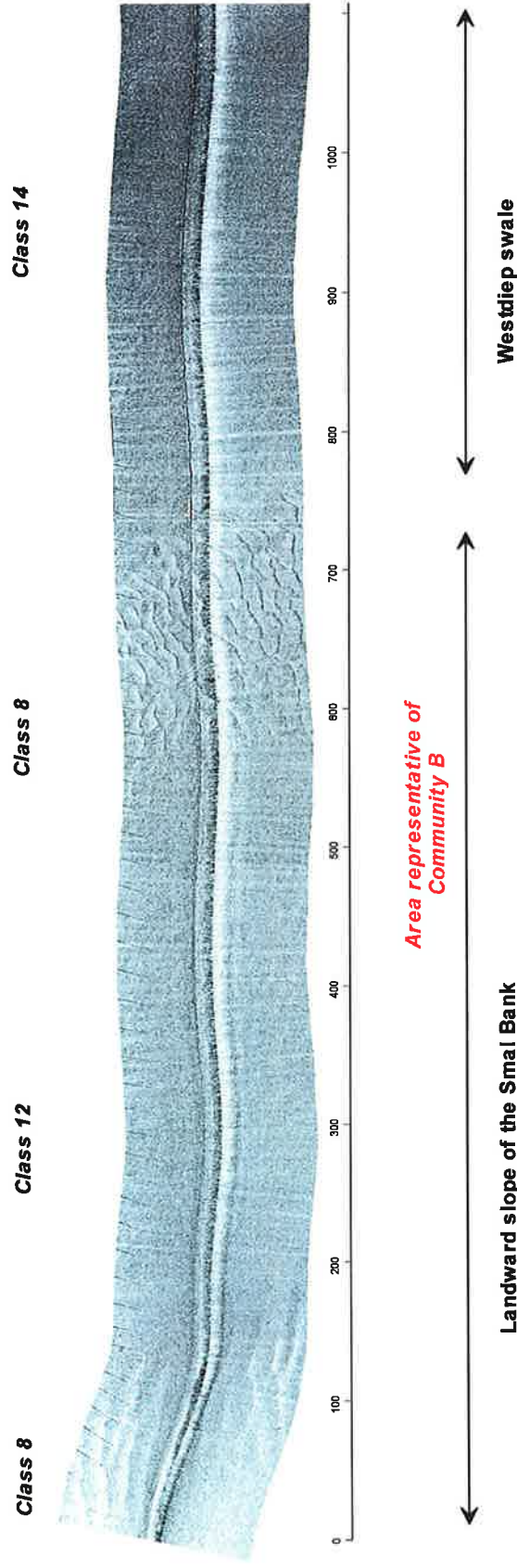


Figure 47. Macrobenthic side-scan sonar interpretation of a profile covering the landward slope of the Smal Bank and the Westdiep swale.

(Community A: *M. mirabilis* spec. ass.; Community B: *A. alba* – *M. bidentata* comm.; Community C: *N. cirrosa* comm.; Community D: *O. limacina* – *Glycera lapidum* comm.)

Side-scan sonar interpretation (zone 1A, March 2000)

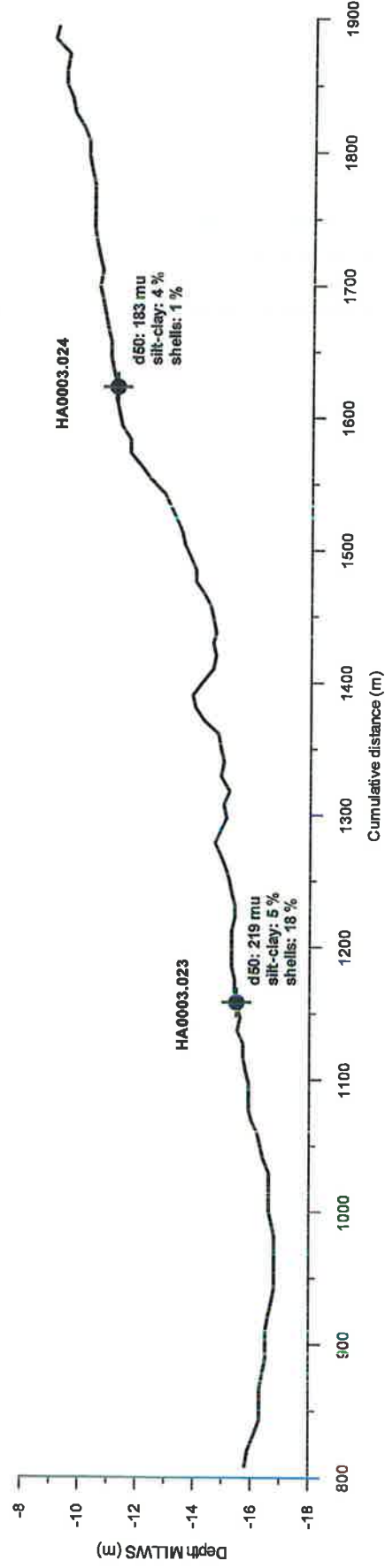
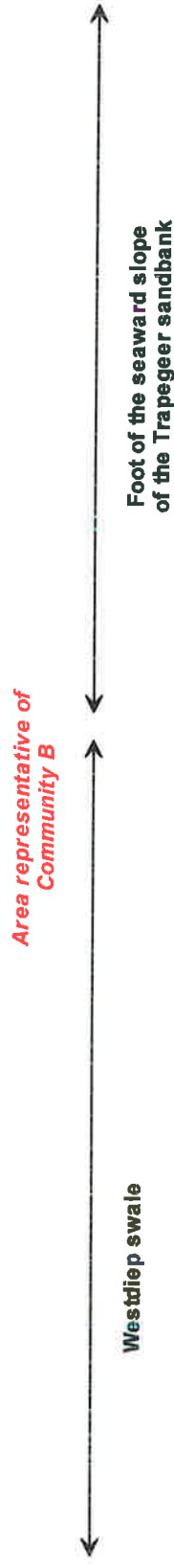


Figure 48. Macrobenthic side-scan sonar interpretation of a profile covering the Westdiep swale and the foot of the seaward slope of the Trapegeer sandbank. (Community A: *M. mirabilis* spec. ass.; Community B: *A. alba* – *M. bidentata* comm.; Community C: *N. cirrosa* comm.; Community D: *O. limacina* – *Glycera lapidum* comm.)

Side-scan sonar interpretation (zone 2B, March 2000)

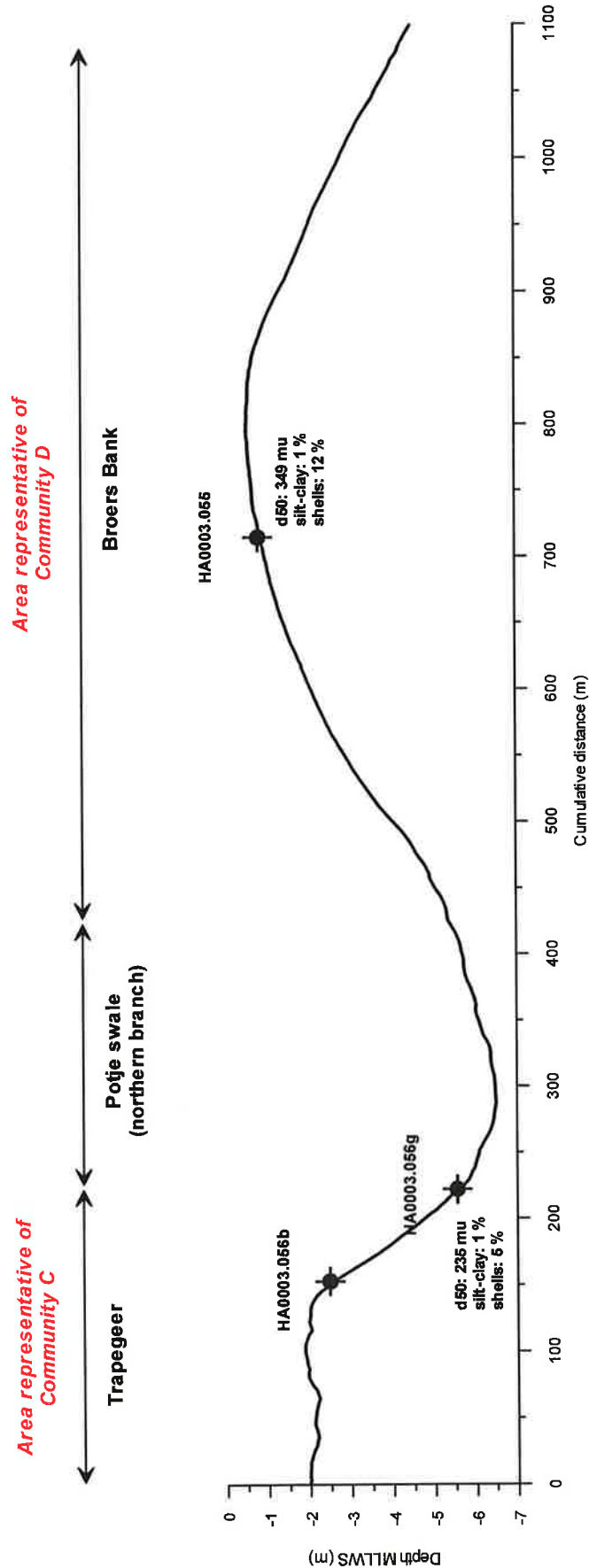
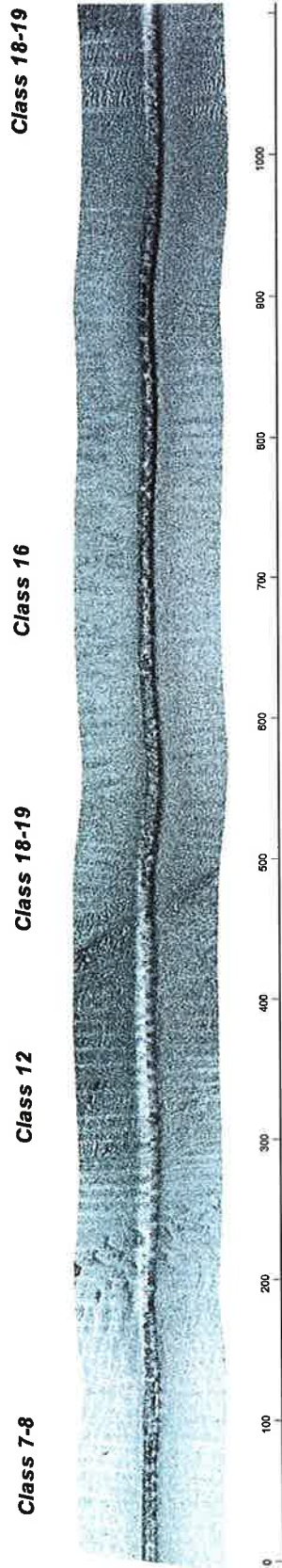


Figure 49. Macro-benthic side-scan sonar interpretation of a profile covering the Trapegeer sandbank, the Potje swale and the Broersbank. (Community A: *M. mirabilis* spec. ass.; Community B: *A. alba* – *M. bidentata* comm.; Community C: *N. cirrosa* comm.; Community D: *O. limacina* – *Glycera lapidum* comm.)

Side-scan sonar interpretation (zone 2b, March 2000)

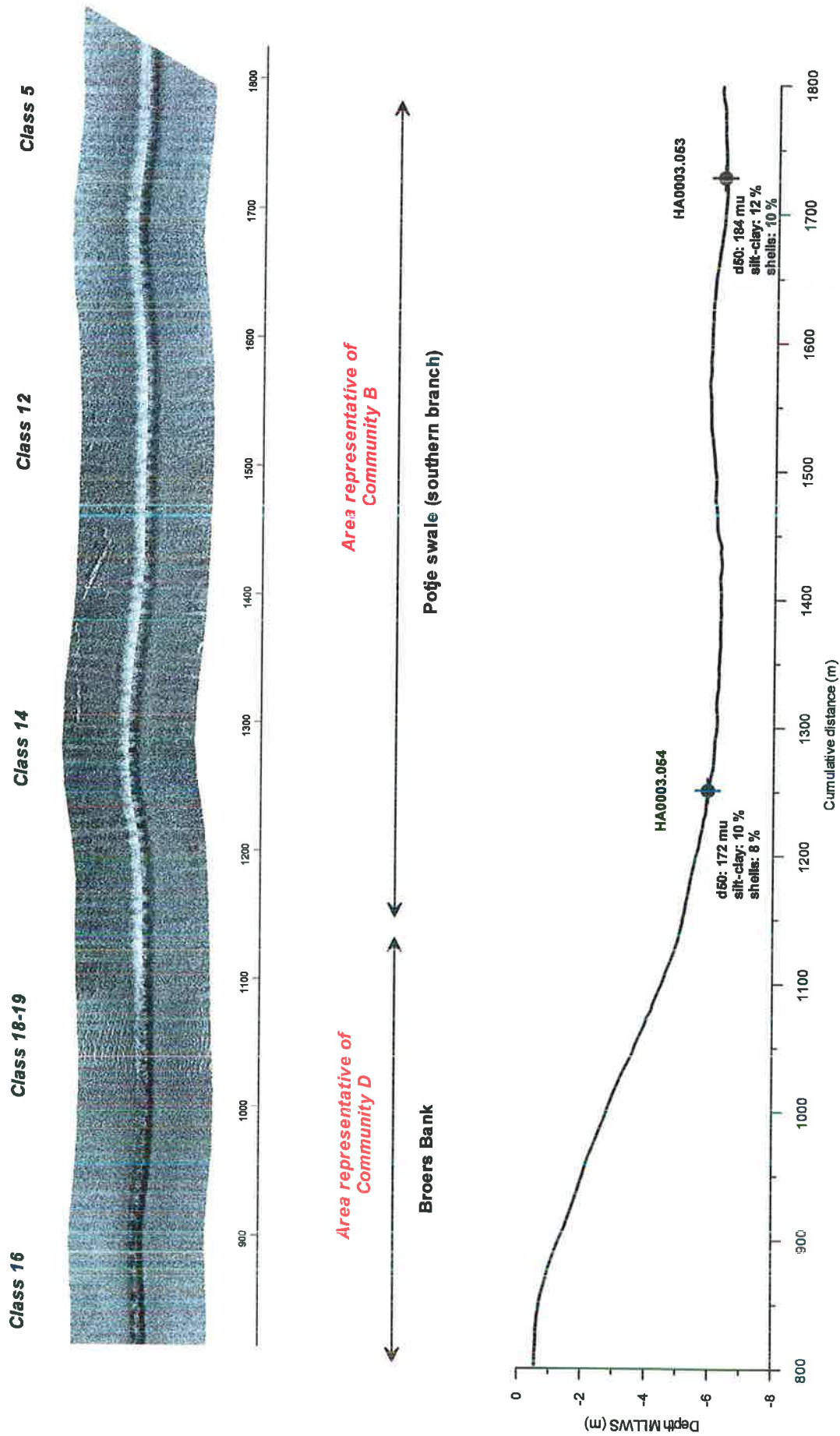
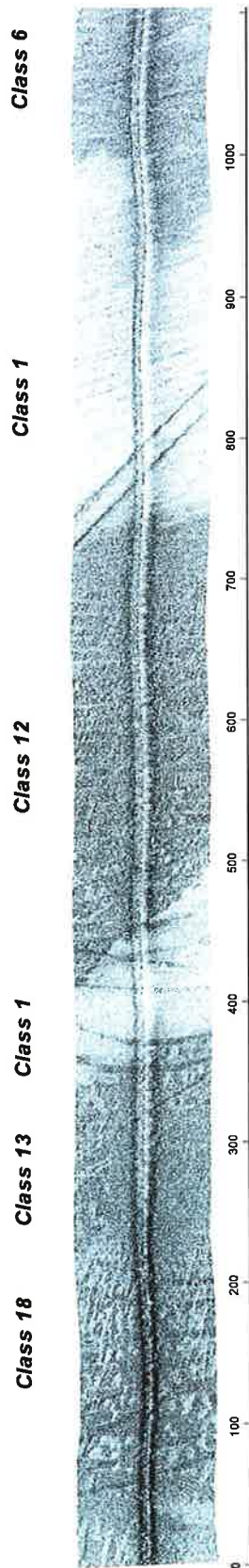


Figure 50. Macro-benthic side-scan sonar interpretation of a profile covering the Broersbank and the Potje swale.

(Community A: *M. mirabilis* spec. ass.; Community B: *A. alba* - *M. bidentata* comm.; Community C: *N. cirrosa* comm.; Community D: *O. limacina* - *Glycera lapidum* comm.)

Side-scan sonar interpretation (zone 2B, March 2000)



Area representative of
Community D

Broers Bank

Area representative of
Community B

Potje swale
(southern branch)

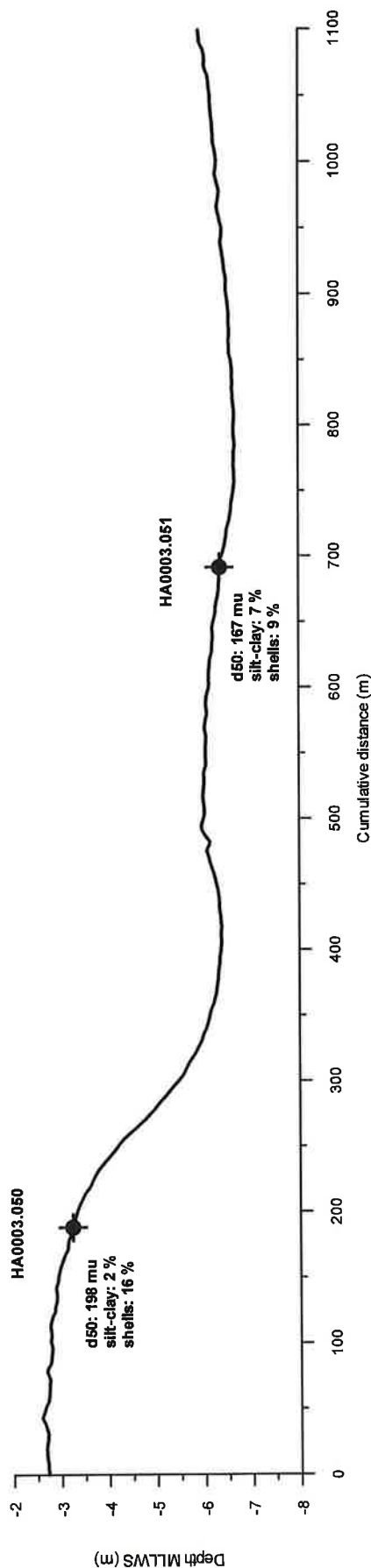
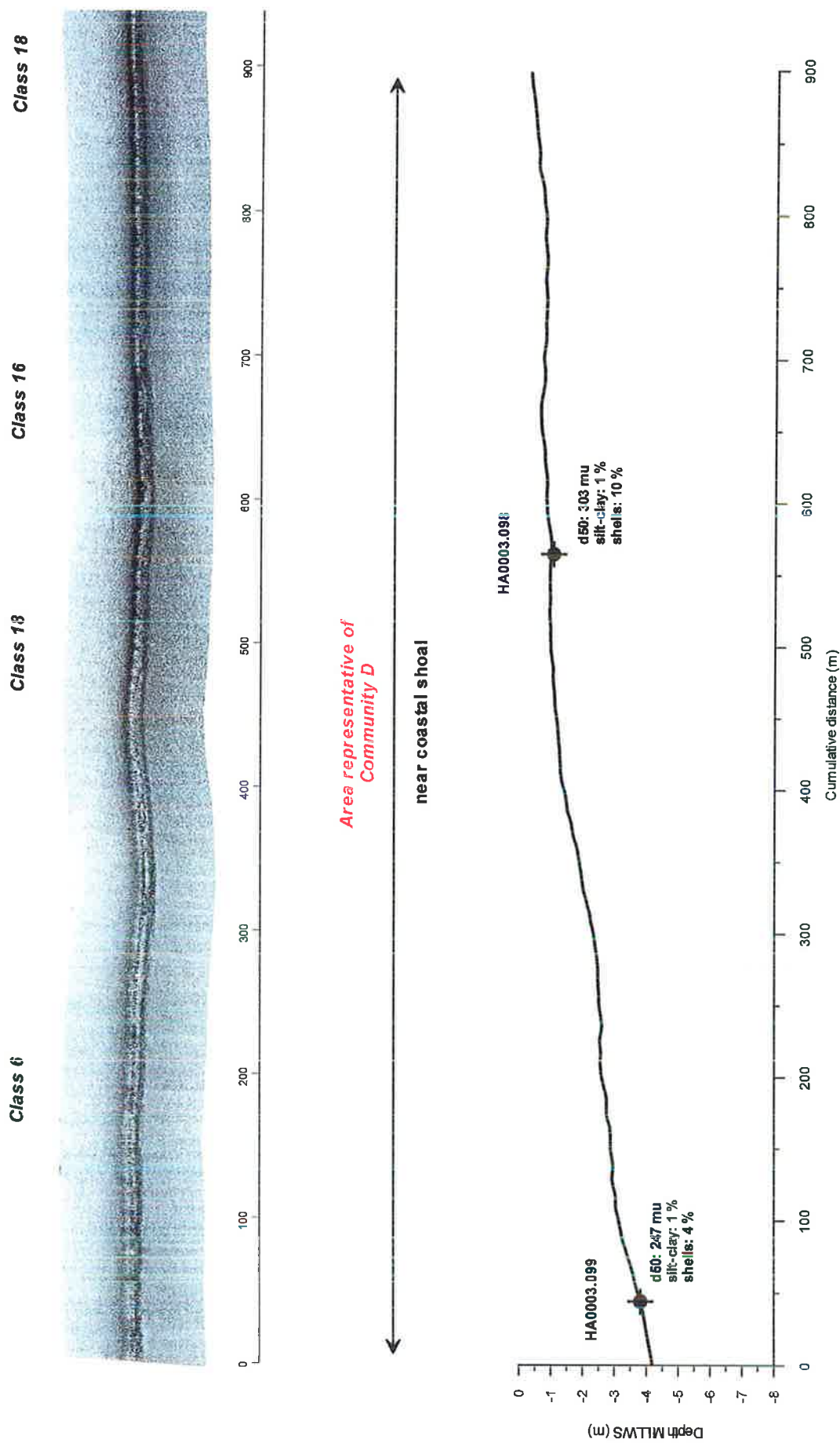


Figure 51. Macrobenthic side-scan sonar interpretation of a profile covering the Broersbank and the Potje swale.
(Community A: *M. mirabilis* spec. ass.; Community B: *A. alba* – *M. bidentata* comm.; Community C: *N. cirrosa* comm.; Community D: *O. limacina* – *Glycera lapidum* comm.)



Side-scan sonar interpretation (zone 3B, March 2000)

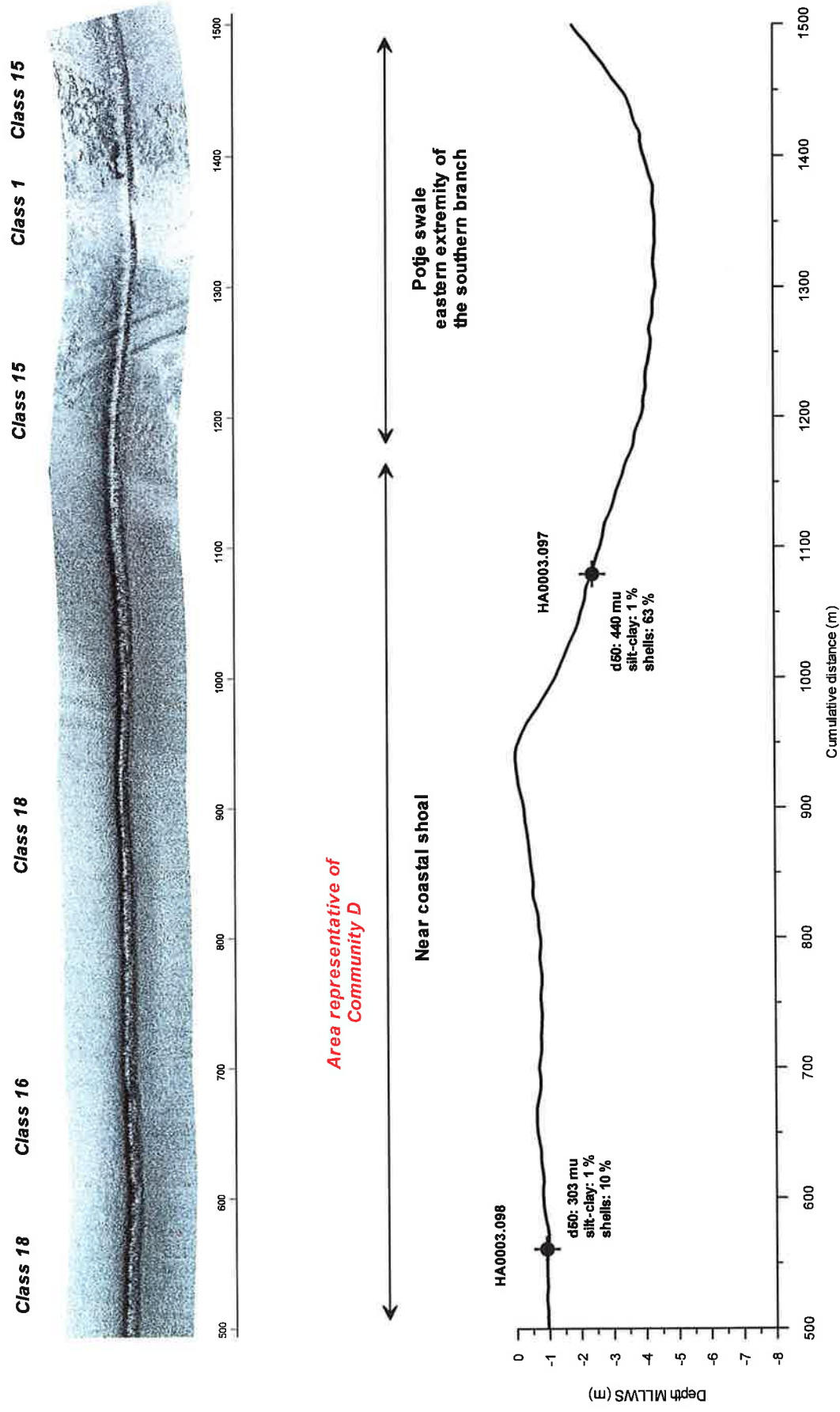


Figure 53. Macrobenthic side-scan sonar interpretation of a profile covering the near coastal shoal and the Potje swale.

(Community A: *M. mirabilis* spec. ass.; Community B: *A. alba* – *M. bidentata* comm.; Community C: *N. cirrosa* comm.; Community D: *O. limacina* – *Glycera lapidum* comm.)

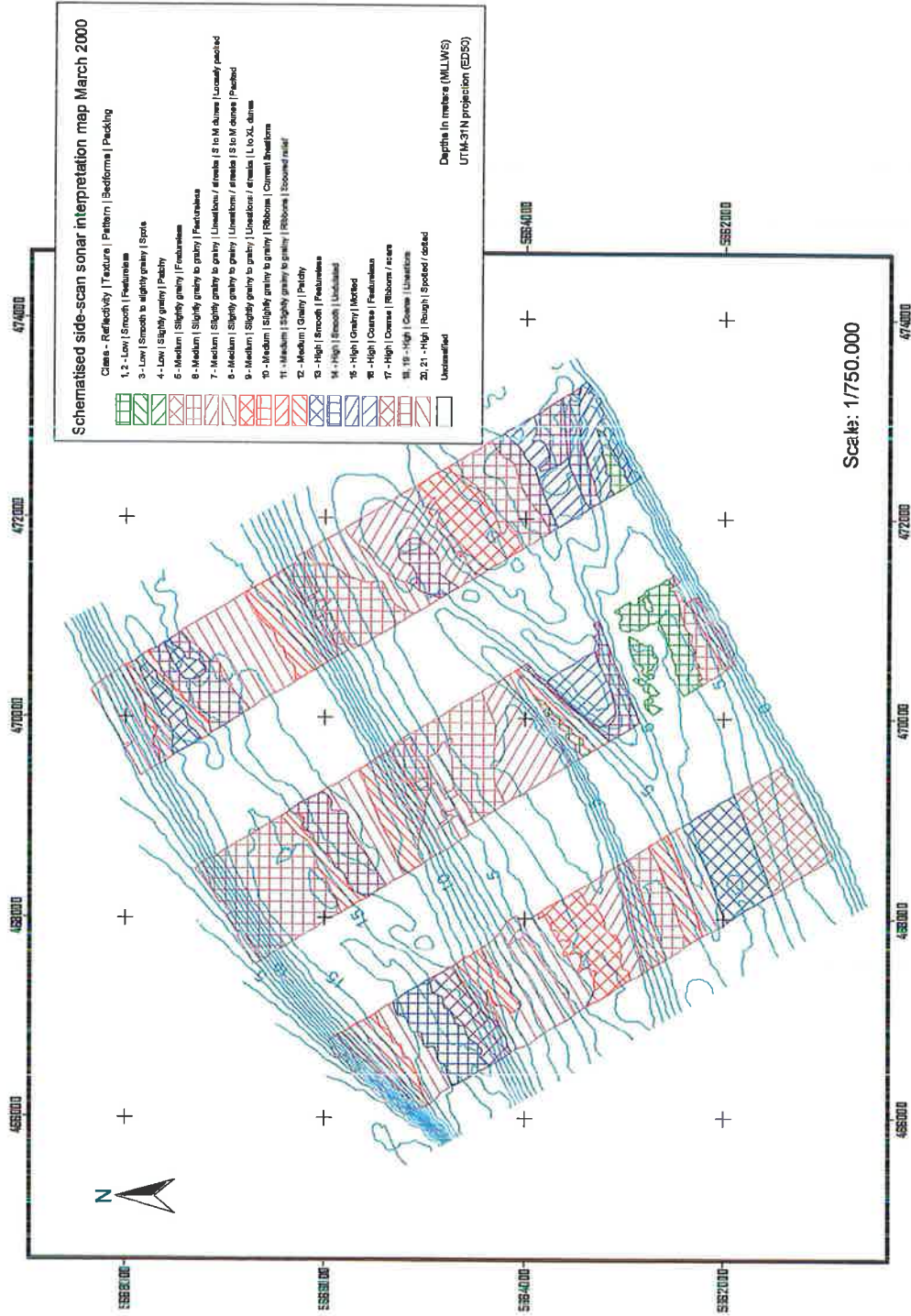


Figure 54. Distribution of the different acoustic facies along the Western Coastal Banks (March 2000).

The low reflectivity acoustic facies are most peculiar. They were only recognised from the data recorded in March 2000. Most often, they are associated with the presence of fluid mud deposited on fine sandy sediments in swale or low seafloor gradient environments. However, their occurrence is temporally dependent and as such this facies will not imply a different community preference. For the latter an annotation of NA or 'not applicable' was set.

A medium reflectivity acoustic facies is most common and occurs as well in the swales as along the slopes to the top zone of the topographic highs. These classes also comprise the areas where bedforms occur. The acoustic facies corresponding with the presence of small to medium dunes mainly occurs along the slopes whilst large to very large dunes are merely perceived near the top zones. Ribbons, characterised by an alternance of high and lighter reflectivity bands, were only detected near the narrow passage of the Westdiep swale. They are representative of higher current velocities. The pattern characterised by circular to elongated patches with slightly different reflectivity is associated with the presence of dense faunal assemblages that are able to alter the upper seafloor sedimentary layers (see also the paragraph on direct evidence). As already outlined this facies is associated with the presence of the *Abra alba* – *Mysella bidentata* community. Most interesting, this acoustic facies is well spread throughout the area, and is most easily perceived near and along the slopes of the topographic highs (Figure 54).

Two major distinctions should be made interpreting high reflectivity acoustic facies. It can be related to medium to coarse-grained sediments or to the presence of compacted sediments. The latter mainly occurs in the swales characterised by sediments with silt-clay enrichment. Towards the slopes, again a mottled pattern can occur that again corresponds with the presence of the *Abra alba* – *Mysella bidentata* community (also Figure 38). Along the shallowest areas, a smooth, featureless acoustic facies can occur (as along the central part of the Broersbank), but often small symmetrical bedforms occur corresponding with coarse-grained wave ripples. This facies is easily recognisable and has been described along other zones of the near coastal area (Van Lancker 1999). Localised shell accumulations or gravel are detected as a rough texture with spotted/dotted appearance. These can occur in the swales or in small depressions such as in the troughs of larger-scale bedforms. It is not clear whether this is associated with living organisms (Van Lancker 1999). The same holds true for the coarse-grained ribbon area that is representative of high current velocities.

Discussion

The use of side-scan sonar imagery was evaluated as a tool for the prediction of the occurrence of macrobenthos. Although its very-high resolution, it was clear from the beginning that a detection of individual species was beyond the scope of the objectives. Still, as different species can be statistically grouped into communities with their specific structure, it was believed that dense faunal assemblages should be detected with very-high resolution acoustic techniques. In literature, examples were a.o. found on the detection of fields of *Crepidula fornicata* L. in the baie de Marennes-Oléron (Sauriau *et al.* 1998) and Berne *et al.* (1988) also detected *Lanice conchilega* fields. Moreover, side-scan sonar is regarded as 'the' habitat mapping tool and its use is recommended through guidelines and protocols (Kenny *et al.* 2000).

Within the project, direct evidence has been provided of the ability to detect dense fields of the polychaete *Lanice conchilega*, the key species of the richest macrobenthic community (*Abra alba* – *Mysella bidentata*). The associated acoustic facies has a patchy or mottled texture and consistently occurs near the foot and/or along the slope of topographic highs. However, from the macrobenthic sampling, it is clear that this community is not

restricted to these environments. Hence, if side-scan sonar imagery does not detect the mottled acoustic facies, it does not necessarily mean that this community is not present. It is believed and it should be further investigated that this mottled facies only occurs in areas with a higher influx of suspended matter. Likely these environments are preferred by suspension feeders and consequently they are able to actively trap finer grained material forming those sediment bumps, detectable through side-scan imagery. The highest densities of the *Abra alba* – *Mysella bidentata* community occur along the deepest part of the Westdiep swale. Given, the high current velocities through this channel, it is the main conduit of suspended matter. Still, the higher bed shear stress will likely prevent the build-up of sediment bumps.

Similar patches than those that were found and characterised in this study, were also observed around the estuary mouth of Teignmouth (UK). Van Lancker *et al.* (in press) argued on the correlation with the presence of tubeworms as there was a consistent match of the occurrence of patches on the side-scan sonar imagery and the sampling of *Lanice conchilega*. Since the high dynamics of the estuary mouth, it was here more obvious that the tubeworms were settled in an environment with a high influx of suspended matter, hence able to actively trap finer grained material.

It needs emphasis that through Table XXII, the prediction of a variety of information is aimed at including macrobenthic community preferences. Given the high geomorphological and biological diversity of the Western Coastal Banks, the set-up of the Table was largely facilitated through the wide range of variables recorded in the area. Moreover, the area is directly hydrodynamically determined meaning that mostly native acoustic facies are described. The use of the Table will be further validated along different depositional environments (a.o. Vanstaen in prep.). It is believed that variants of the acoustic facies will be detected and as such the Table can be refined or if necessary new classes can be added if these significantly differ from the rest.

Conclusions

Two approaches were followed in the interpretation of side-scan sonar imagery in terms of the occurrence of macrobenthic communities.

The first approach was based on a direct correlation of high abundances of macrobenthos with a specific acoustic facies. A medium to high reflectivity patchy to mottled texture was correlated with the presence of dense fields of the tube-building polychaete *Lanice conchilega*. If the density of this polychaete worm is indeed high enough, local sediment accumulations, detectable by side-scan sonar technology, can be formed. Interestingly, the occurrence of this acoustic facies is highly correlated with slope environments leading to the assumption that these environments have a high input of suspended matter.

Secondly, an indirect link was sought based on the known correlations of the macrobenthos versus sedimentology on the one hand and sedimentology versus side-scan sonar imagery on the other hand. This means that if side-scan sonar imagery can be interpreted in terms of sediment nature, the occurrence of macrobenthic communities can be predicted. To facilitate this process, a standardised interpretation is put forward through the set-up of a table with different criteria and interpretation keys. This table provides a discrimination of acoustic facies into a maximum of classes that are finally linked to a macrobenthos community preference. It needs emphasis that the standardised interpretation of side-scan sonar imagery is meant to be applicable for a wide range of depositional environments making it a powerful evaluation tool.

HABITAT STRUCTURE MAP

Introduction

To be able to set up a scientifically approved management plan for the Western Coastal Banks and to allow a good future decision making, it is necessary to have as much data as possible on the ecosystem. As presented above, lots of information about the benthic habitat already exists. Yet, at this moment it might be difficult to have a good view on what exactly this information consists of and how to interpret the data from a management point of view. An overview of the data, summarizing their basic significance, will thus add to the usefulness of the projects outcome.

This part specifically aims at the development of a 'habitat structure map' from the database, which combines the available and, especially, the newly gathered data. This map of the complete future protected area presents the current knowledge of the macrobenthos and its physico-chemical environment and aims at the presentation of the macrobenthic and physico-chemical situation before the application of the management plan (t_0 -situation).

Materials and methods

All gathered data and interpretations have been compiled into a 'habitat structure map'. The background of this map is the sedimentology simplified to the level of the occurrence of fine, medium and coarse sands. This map is superimposed with the bathymetrical information and the different acoustic facies. Finally, the different macrobenthic communities are indicated with their relative densities. This approach visualises the interactions between the physical environment and the macrobenthos. It has to be stressed that this map is just an example of how geological and biological data can be integrated. Given the multitude of available parameters, other maps can be produced according to the differential end-users' needs.

Results

The 'habitat structure map', providing an interpretation of the major data, obtained within the project, is presented in Appendix.

Discussion and conclusions

At this point, the 'habitat structure map' allows having a quick overview of the major data, obtained within the project. Though not being exhaustive, it might help the decision making within the future management plan. It has to be stressed, that in this project only the (macro)benthic habitat was taken into account. Although the macrobenthos plays an important role within the ecosystem of the Western Coastal Banks, other ecosystem compartments (e.g. avifauna, pelagic fish, and other benthic fauna) are important as well.

Because of the standardized methods, and the uniform production of maps, a future integration of all information into a Geographical Information System (GIS) is possible. If a GIS could be implemented, the means are created to ideally anticipate on the nature and variability of an ecosystem. Since this it would give more insight into the possible risks and it would be the base of future policy decisions (Malafant & Fordham 1998), it would provide a powerful tool for the policy makers. Moreover, it is fully conform to the cost-benefit aspect of a future management plan.

In a further stage, the obtained data may also be used to create a thematical atlas, describing and visualizing the interactions between the macrobenthos on the one hand and the sedimentology and the hydrodynamics on the other hand. This approach will allow deciding quickly about alternative measures in the area of the Western Coastal Banks (Malafant & Fordham 1998). It has to be stressed that only a standardized, interdisciplinary approach of the problem provide a scientifically sustained evaluation of this unique ecosystem.

PART 3.
GENERAL DISCUSSION AND RECOMMENDATIONS
AND
SYNTHESIS

**GENERAL DISCUSSION AND RECOMMENDATIONS:
IMPLICATIONS OF THE RESULTS OF THE PROJECT
FOR THE MANAGEMENT AND MONITORING OF THE WESTERN COASTAL BANKS**

Spatial extrapolation of point-data

So far, knowledge on the spatial distribution of the macrobenthos was restricted to the description of the macrobenthos present at the sample stations. In most studies, full-coverage spatial extrapolation between the sample points (point data) proved to be unreliable. A positive relationship between the geomorphological diversity and the number of samples needed to attain a reliable full-coverage view on the macrobenthic spatial distribution through spatial extrapolation of the point data exists. Hence, in a geomorphological highly diverse area, as the western Coastal Banks, a very high number of samples would be needed. In the present study, it was illustrated that 120 samples spread over a 25 km² area (= inter-sample distance: \pm 500 m) was insufficient to allow a reliable spatial extrapolation of the point data. A drastic increase of the number of sampling stations for the macrobenthos would be very time consuming and thus not time- and cost-efficient. Yet, full-coverage knowledge on the spatial distribution of the macrobenthos would allow to better manage the benthic habitat within the MPA. To retrieve time- and cost-efficient, full-coverage knowledge on the spatial distribution of the macrobenthos, based on the results of the HABITAT projects, two methods are put forward: a first based on the HABITAT model and a second based on the macrobenthic side-scan sonar interpretation.

HABITAT model

Throughout the HABITAT project, it was demonstrated that knowledge of the physico-chemical environment can be used to predict the occurrence of macrobenthic communities. The HABITAT model allows to predict the presence and distribution of macrobenthic communities, based on knowledge of the physico-chemical environment. Information on the sediment grain size distribution and the bathymetry of an area, already provides enough information to predict the spatial distribution of the 'macrobenthic potentials' with an accuracy of up to 90 %. Once the spatial distribution of the 'macrobenthic potentials' is predicted using the HABITAT model, a first evaluation of the spatial distribution of the ecological value can be performed.

Since the collection of data to retrieve a detailed bathymetric-sedimentological map of an area is less time-consuming than the collection of those for a detailed macrobenthic map, the HABITAT model provides a powerful time- and cost-efficient tool to retrieve a full-coverage view on the spatial distribution of the 'macrobenthic potentials'.

Macrobenthic side-scan sonar interpretation

Within this study it was further demonstrated that the macrobenthic spatial distribution could be predicted from textural differentiations on side-scan sonar imagery. Moreover, bioherm structures, such as *Lanice conchilega* 'bumps' could be detected. This technique thus provides insight into the delineations of communities and bioherms. Moreover, the model allows evaluating the 'macrobenthic potentials' of non-studied places within the protected area on a time- and cost-efficient base.

Stratified random sampling strategy based on remote sensing

The macrobenthos of a site is determined by a series of environmental, both physico-chemically and biologically, parameters, including the habitat's history. If all this information would be available, it should be possible to explain the macrobenthic community structure of the site for 100 %. Unfortunately, at this moment it is not known what exactly this information consists of and how these parameters interact with the macrobenthic community structure. Furthermore, even though it would be known, the information would not always, if not never, be present. Hence, a lot of questions will always remain when trying to explain the macrobenthic community structure. Because of this fact several sampling strategies to monitor the macrobenthic community structure were put forward.

If no information on the macrobenthic habitat of an area is available, a random sampling design provides a good strategy to study the benthos. A major disadvantage of a random sampling strategy is the fact that a high number of samples is needed to retrieve a representative view on the macrobenthic spatial distribution. Since the macrobenthic spatial distribution is known to be related to several environmental variables (e.g. depth and sedimentology), knowledge of these environmental variables allows the delineation of different - ecological relevant - strata. A stratified random sampling design is defined as a random sampling within each stratum of the area under consideration. If a stratified random sampling strategy is applied, each set of macrobenthos samples within a stratum is considered to consist of replicate samples of that stratum and should provide a representative view on the macrobenthos of the stratum. Hence, the application of a stratified random sampling design already leads to a decrease in the number of samples needed to achieve a representative view of the macrobenthic community structure.

Since remote sensing imagery (e.g. derived from side-scan sonar) (1) provide a full-coverage view of the benthic habitat and (2) is known to be related to the macrobenthic community structure (as illustrated above), remote sensing provides an extremely useful tool for the delineations of the strata. Thus, a stratified random sampling design for the study of the macrobenthos, based on the delineation of strata through side-scan sonar images, will not only decrease the numbers of samples needed (= time- and cost-efficient), but will further provide a reliable, full-coverage view on the temporal variation of the macrobenthos within the area.

Strategies for future monitoring of the benthic habitat

In biology, the term monitoring is defined as the follow-up of (part of) the ecosystem. Since monitoring aims at the detection of changes, monitoring always includes a temporal factor: time-series are indispensable. Because of practical problems to monitor the whole ecosystem (e.g. extremely time consuming), monitoring always concentrates on a specific part of the ecosystem. The monitoring of this specific part of the ecosystem should provide information allowing an extrapolation of the results to the whole ecosystem. A careful selection of the subject of monitoring is thus of primary importance. Being (1) clearly linked to the physico-chemical environment, (2) sedentary, (3) fulfilling an important role within the marine ecosystem, and (4) relative easily identifiable, the macrobenthos is known to be an useful tool to monitor the marine ecosystem.

Yet, even though only a part of the ecosystem (e.g. macrobenthos) is monitored, monitoring is still very time consuming and thus expensive. Hence, it is important to select the optimal monitoring strategy and techniques for a given situation. Using the implications of the results of the project, as mentioned above, a sampling strategy was set up.

In practice, three steps are proposed for the monitoring of the Western Coastal Banks: (1) selection of the strata to monitor, (2) monitoring of the macrobenthic habitat of monitoring stations, and (3) full-coverage monitoring of the macrobenthic habitat.

1. Selection of the strata

At first, a selection of strata to be monitored should be made. At present, 21 strata were identified, based on the results of the standardised side-scan sonar interpretation. Towards the prediction of communities, the classes can be simplified or the level of division can be discussed according to end-users' needs and the available budget.

2. Monitoring of the macrobenthic habitat at a selected set of monitoring stations

After the selection of the strata, a stratified random sampling design is advised. Within each stratum, at least five monitoring stations should be selected randomly. Each station is considered as a replicate station for its stratum. At least once a year, all monitoring stations should be sampled for their macrobenthos and their ecological relevant environmental variables (one sample per station). Monitoring of the physico-chemical environment provides important information for the detection and evaluation of possible changes of the macrobenthic community structure. As indicated by the HABITAT model, this monitoring should concentrate on the bathymetry, the grain size distribution and the depth of the anoxic layer, being the ecologically most important environmental variables for the macrobenthos. However, this should be combined with a side-scan sonar survey to reassure the nature of the substratum that is sampled and to prevent difficulties in interpretation imposed by temporal changes on an event scale. Moreover, given the patchy nature of some communities, it will be very important to know whether a sample is taken within or outside such a patch as this will have a large impact on the densities of the macrobenthos.

3. Full-coverage monitoring of the macrobenthic habitat

Every second year, a full-coverage remote sensing survey is recommended (1) to evaluate major changes within the macrobenthic habitat, (2) to evaluate the correctness of the monitoring stations' position relative to the selected strata, (3) to be able to extrapolate the monitoring data to the whole area. Because of the direct link between side-scan sonar recordings and the macrobenthic habitat, ecological relevant changes within the macrobenthic habitat can be traced by means of remote sensing. These changes can result from natural dynamics or measures taken within the framework of the management plan, but also from unwanted anthropogenic influences, such as beam trawling, which can easily be visualised and followed in time. If drastic changes in the spatial distribution of the strata are observed, the geographic position the monitoring stations should be adjusted to this new position. Furthermore, since each monitoring station represents a replicate sample for its stratum, the data retrieved from the stations can be extrapolated to the whole stratum. Due to the very-high resolution and high quality imagery, side-scan sonar technology remains the preferred tool for monitoring purposes.

Following this strategy, a fast evaluation of measures, taken in the frame of the management plan for an area, is possible.

SYNTHESIS

Introduction

The area of the Belgian Western Coastal Banks (3400 ha) consists of some Coastal Banks (Trapegeer, Broersbank, and Den Oever), as well as two swales (Potje and Westdiep) and is characterised by water depths of -15 m to 0 m MLLWS. The geomorphological structure, being the most diverse along the Belgian coast, is directly responsible for the high biological diversity and richness of the area. At first, its ecological importance was demonstrated by the high numbers of bird species wintering in the area (e.g. common scoter *Melanitta nigra*). Because of the abundant occurrence of seabirds, the area is regarded as an area with international importance for waterfowl (Ramsar convention). Furthermore the area fulfils the criteria of the EC-Bird Directive and is proposed as an EC-Habitat Directive area. Hence, the Belgian government is investigating the necessity and possibility to give the Western Coastal Banks the status of a marine protected area (MPA).

Being a food resource for several seabirds and demersal fish species, the macrobenthos is an important component within the ecosystem functioning of the Western Coastal Banks. Therefore, knowledge of the natural spatial distribution and seasonal variation of the macrobenthos is extremely important when setting up a management plan for the proposed MPA.

The general objective of the project includes the provision of data, necessary for the definition and scientific evaluation of a management plan of the future MPA. Due to the crucial role of the macrobenthos within the coastal ecosystem, especially, the distribution of macrobenthic communities in relation to sedimentological, bathymetrical and hydrodynamical characteristics has been determined. Furthermore, time- and cost-efficient evaluation tools of the management plan of the future MPA are developed.

Materials and methods: general

Shiptime was granted by Coastal Waterways, Ministry of the Flemish Community (Oostende XI and Ter Streep). Additional shiptime was provided by the Management Unit of the Mathematical Modelling of the North Sea (MUMM) aboard the R/V Belgica (acoustical doppler current profiler (ADCP) measurements). The research vessels were all equipped with differential global positioning systems (DGPS).

Single-beam as well as multibeam bathymetry was recorded. Both the analogue and digital recordings were corrected for the vertical movement of the ship. A tidal correction was performed.

Side-scan sonar imagery (*in casu* GeoAcoustics dual frequency side-scan sonar at a frequency of 410 kHz) was collected to obtain very-high resolution imagery of the seafloor. During the surveying, an optimal ship speed of 4 knots was maintained.

To obtain full coverage data on the macrobenthos and its physico-chemical environment, a total of 120 sampling stations were uniformly distributed over the study area with a sampling interval of 500 m. At each station, samples for macrobenthos (Van Veen grab sample), sedimentology (Van Veen grab sample), suspended particulate matter, SPM (Niskin bottle sample), nutrient concentrations within the bottom (Van Veen grab sample) and water column (Niskin bottle), as well as pigment concentrations in the water column (Niskin bottle) were collected.

Water depth at the time of sampling was measured. Sampling was performed in October 1999, March and November 2000. The samples for the macrobenthos were sieved using a 1 mm mesh-sized sieve and all organisms were identified to species level. Samples for sedimentology were used to determine the sediment's grain size distribution, using a LS Coulter counter and standard sieve grain size analysis. Bottom and water column nutrients (nitrite, nitrate, ammonia, phosphate, and silicium) were measured through an automatic chain (SAN^{plus} segmented flow analyser, SKALAR). Pigments within the water column (chlorophyll-a, -c and fucoxanthine) were measured: an immediate extraction with acetone was performed prior to chromatography, with a Gilson high-performance liquid chromatography chain using the method of Mantoura & Llewellyn (1983). SPM was measured by filtering water through a GF/C filter and determining the net dry weight of the filter after filtering.

Regional presentation of the macrobenthos and its physico-chemical environment

REVIEW OF THE BENTHIC HABITAT

Because of the supposed high ecological value of the area, indicated by the large numbers of seabirds wintering in the area, the benthic habitat of the Western Coastal Banks already received some scientific attention. A review on the benthic habitat is presented. Here within, special attention is paid to the development of a database and the production of maps, as an orderly tool to present the spatial distribution of different variables.

In a first phase, maps were drawn on the basis of existing data, both from literature and reports. This included a compilation and integration of bathymetrical, morphological, sedimentological, hydrodynamical and macrobenthos data and provided a better characterisation of the benthic habitat of the study area. Each map is the result of a compilation of the available information, structured in a database. The database allows integrating and superposing newly gathered data and thus provides a tool to visualize the natural evolution of the area. This tool is of direct use when defining the present situation (*t*-situation) of the ecosystem of the Western Coastal Banks.

A bathymetrical-morphological map, comprising the occurrences of bedforms and their relative asymmetry, was set up. The area is characterized by an alternation of sandbanks and swales of varying depths. Sand dunes of different sizes are superimposed on the large-scale bathymetry. Due to the shallowness of the area, the seabed is highly vulnerable to the hydrodynamic forces, which is best illustrated on the basis of bedform occurrences. A digital very-high resolution side-scan sonar reconnaissance survey (September 1999) confirmed the presence of those bedforms and gave evidence of the highly diverse and complex nature of the seafloor.

The surficial sediments are dominated by fine to medium sands with a coarsening of sediments towards the top of the bathymetric highs. The sand bank areas are generally coarsest, often characterised by coarse shell hash whilst the surficial sediments of the swales can have high percentages of the silt-clay fraction.

Semi-diurnal tides of macrotidal range (5.4 m) dominate the area. The tidal currents, characterised by asymmetrical tidal current ellipses, are highly rectilinear with a dominance of the flood current (NE-ENE) that can amount up to 1.32 m/s in the Westdiep swale. Numerical modelling (μ -BCZ) on a 750 m grid showed the highest current velocities in the Westdiep swale and near the foot of the slope of the Trapegeer. From sediment transport calculations, it was shown that the surficial sediments are mainly mobile during Spring and Mid tide, from generally 1 hour before up to 1 hour after High Water. In the Westdiep swale and the Noordpas swale the ebb tidal current is also able to resuspend sediments. To gain insight into the tidal current propagation throughout

the study area, numerical modelling was performed on a 250 m grid taking into account the complex bathymetry. Although the results still need further validation, they do show the current variability in function of the large-scale morphology and give evidence of a reinforcement of the current velocity in the swales.

Only little information about the macrobenthos of the Western Coastal Banks from the period before 1999 is available (32 stations). The historical data are restricted to the Trapegeer, Broersbank, Den Oever and Potje. Almost no information about the Westdiep swale was available. Total macrobenthic density ranged from about 100 to over 26000 ind./m², while the number of species per sampling surface area of 0.1 m² (N₀) ranged from 4 to 28 species. Generally, lower densities and species richness were found at the tops of the sandbanks Trapegeer and Broersbank compared to the deeper parts of the area. Three macrobenthic communities, spread over the area were distinguished. The macrobenthos-rich *Abra alba* – *Mysella bidentata* community (syn. *Lanice conchilega* community) is mainly found in the deeper parts of the Potje swale and along the northern slope of the sandbank Trapegeer, while the *Ophelia limacina* – *Glycera lapidum* community (syn. *Mytilus edulis* community) prefers the shallowest sites (e.g. top of the Broersbank). On top of the sandbank Trapegeer and in the area of the Broersbank, the *Nephtys cirrosa* community was found. The spatial distribution of seven macrobenthic species is presented. Although these data provide a first view on the community structure and macrobenthic spatial distribution within the area of the Western Coastal Banks, they should be interpreted with caution. For a geomorphological very diversified area as the Western Coastal Banks, the data, derived from only 32 stations, should be regarded as 'point data': spatial extrapolation of any macrobenthic characteristic was impossible.

MACROBENTHIC HABITAT: SPATIAL DISTRIBUTION

Because of its important trophic function, as a food resource for seabirds and demersal fish, the macrobenthos comprises an extremely important component within the ecosystem functioning of the Western Coastal Banks. Therefore, at first, knowledge of the spatial distribution of the macrobenthos is indispensable when setting up a management plan for the proposed MPA. To update and extend the knowledge on the spatial variation within the macrobenthic habitat, three sub areas, with a maximum geomorphological diversity, were intensively investigated for their physico-chemical environment and macrobenthos in October 1999.

Within the subareas, full-coverage very-high resolution side-scan sonar imagery was obtained that allowed to study the intrinsic nature of the seafloor in relation to the large-scale morphology. The combination of reflectivity, texture and patterns was translated into specific acoustic facies that could be primarily interpreted in terms of the small-scale morphology and bedform occurrences, distribution of sediments and their relative compaction superimposed with hydrodynamical effects.

Sediment samples confirmed the highly variable nature of the sediments and this often on very short spatial intervals. On the sandbanks, the distribution of the surficial sediments is hydrodynamically determined: the currents are strong enough to distribute the sediments. In the swales, a variety of sediments is deposited. This is mainly due to the high availability of fine-grained sediments that can settle out during slack water. On the contrary, the Westdiep swale is generally characterised by coarser sediments. As confirmed by side-scan sonar imagery, this swale should be regarded a high-energy depositional environment.

Along the foot of the slope of the Trapegeer sandbank, acoustic doppler current meter results confirmed the highly rectilinear nature of the tidal currents with a predominance of the flood current. Yet, the correlation between the high spatial variability and the hydrodynamical numerical model results still needs further investigation.

The knowledge on the macrobenthic community structure, based on historical data (see above), was confirmed by the detailed investigation. Next to one transitional species association (*Magelona mirabilis* transitional species association), three of a total of four subtidal macrobenthic communities discerned at the BCS were found within the area of the Western Coastal Banks: *A. alba* – *M. bidentata*, *N. cirrosa* and *O. limacina* – *G. lapidum* community. Each community or species association is restricted to a very specific physico-chemically defined habitat. Although the communities were spread all over the area, zonation, related to depth amongst others, was demonstrated. The *A. alba* – *M. bidentata* community proved to be an ecologically highly valuable macrobenthic community on the BCS. The community is characterised by the highest macrobenthic densities (average: 7589 ind./m²) and diversity (average N₀: 37 spp.). Furthermore, many bivalve species are found in high densities within the community (e.g. on average *A. alba*: 992 ind./m² and *Fabulina fabula*: 273 ind./m²). These bivalves are known to be an important food resource for larger epibenthic predators (e.g. cod *Gadus morus* and sole *Solea solea*) and benthos-eating diving seaducks (e.g. common scoter *Melanitta nigra*). Because of (1) the local sediment stabilization by dense patches of *Lanice conchilega* and (2) the increasing habitat complexity due to the extending upper parts of the tubes, the tube-building polychaete *L. conchilega*, primarily occurring within the *A. alba* - *M. bidentata* community, probably fulfills an important habitat-structuring role within the ecosystem. Indeed, a positive correlation between the macrobenthic density and N₀, on the one hand, and the density of *L. conchilega* on the other hand was found. Both other communities and the transitional species association contribute substantially to the overall macrobenthic diversity of the Western Coastal Banks: 74 % of all macrobenthic species, recently (since 1994) found on the BCS, were detected within the study area. Furthermore, macrobenthic densities and diversity were generally high, compared to other ecological regions on the BCS. The Western Coastal Banks should thus be considered as a hotspot for macrobenthic life on the BCS.

MACROBENTHIC HABITAT: TEMPORAL VARIATION

The macrobenthic communities of shallow coastal waters are subjected to a variety of physical and biological disturbances that vary in frequency and intensity, as well on a temporal as on a spatial scale. The natural variation within the macrobenthic communities should help to explain issues fundamental to ecology, but also to the conservation and management of the marine benthic habitat. To study the temporal variability within the macrobenthic habitat of the Western Coastal Banks, the multi-disciplinary study of October 1999 was repeated in March 2000.

On a sedimentological level, the temporal variability was minimal and generally, the differences were within the error imposed by the analysis. In both months, the sediments mainly consisted of fine and medium sand (both about 40 %) and had an average median grain size of about 270 µm. The side-scan sonar imagery shows more variability as it reflects the upper seafloor characteristics. Most striking was the presence of white reflectivity bands in the deepest parts of the swales that could be interpreted as fluid mud layers superimposed on fine sandy sediments. Still, in terms of an interpretation towards an acoustic facies, hardly any differences were observed indicating that a standardised side-scan sonar interpretation is valid on a temporal basis.

In both months, polychaetes and bivalves dominated the macrobenthos. Although the community structure changed within all macrobenthic communities, the communities, detected in October 1999, were still present in 2000: 50 to 90 % of the most abundant species of each community was identical in both months. Because of the relative low temporal variation of the structure of the three communities, the temporal variation does not overrule the "basic" structure of each community. It was demonstrated that different macrobenthic communities show different temporal dynamics. The temporal variation was most obvious in the *A. alba* – *M. bidentata* community. A significant decrease in macrobenthic density and diversity (N_0) was observed from October 1999 to March 2000: from 7589 to 3264 ind./m² and from 37 to 27 species, on average. Furthermore, 85 % of the indicative and abundant species within the community showed a significant decrease in density. Only minor, non-significant changes within the density and diversity were detected within the *N. cirrosa* and *O. Limacina* – *G. lapidum* community and the *M. mirabilis* species association. Because of the spatial stability of the ecologically most relevant physico-chemical environment (e.g. sedimentology and depth) at the sampling stations, 71 % of the stations harboured the same community in October 1999 and March 2000. A high spatial distributional stability of the macrobenthos was found within the area of the Western Coastal Banks.

Development of methodologies for the creation of time- and cost-efficient monitoring tools for the future MPA

HABITAT MODEL

The 'macrobenthic potential' of a habitat is defined as the dynamics of the macrobenthic community structure (e.g. species composition, diversity, and densities) within the habitat. When, within a certain area, information is available about (1) the different macrobenthic communities present, (2) their seasonal variability and (3) their habitat preferences, information on the biologically relevant, physico-chemical parameters of a site within the area allows to predict the 'macrobenthic potential' of that site. Within this part of the study, at first, the 'macrobenthic potentials' of the different habitats were assessed. Secondly, the HABITAT model, aiming at modelling the correlations between the macrobenthos and its physico-chemical habitat, was set up. The HABITAT model will allow evaluating the 'potentials' of non-studied places within the protected area on a time- and cost-efficient base.

The 'macrobenthic potential' of a habitat/community, as illustrated by their respective 'potential species list' in this study, revealed the extraordinary ecological value of the *A. alba* – *M. bidentata* community relative to both other communities. Being a transition between the *A. alba* – *M. bidentata* and the *N. cirrosa* community, the *M. mirabilis* species association had an intermediate ecological value. Hence, when valuing the different habitats of the Western Coastal Banks, the habitat of the *A. alba* – *M. bidentata* community is clearly ecologically superior to all other habitats. Yet, this should not be interpreted as the other habitats being ecologically unimportant. Both within and in between habitat biodiversity, resp. ©-biodiversity and ®-diversity, are important within the ecosystem functioning.

The HABITAT model consists of eight classification function sets derived from multiple discriminant analysis. Each set of classification functions takes into account a different series of environmental variables. Based on the macrobenthos data of October 1999 and March 2000 (three communities and one transitional species association), 78 % of the classification functions revealed a community specific and overall *a posteriori* and *a priori* accuracy of at least 70 %. These accuracies can be drastically improved if only the three macrobenthic communities are taken into account. Comparing the community specific accuracy of each classification function

set, no set can be put forward as superior to the other sets. As a result of a test of the HABITAT model, using data collected in November 2000, further testing and refinement of the models is advised.

STANDARDIZED MACROBENTHIC INTERPRETATION OF SIDE-SCAN SONAR IMAGES (MSSSI)

Two approaches were followed in the interpretation of side-scan sonar imagery in terms of the occurrence of macrobenthic communities.

The first approach was based on a direct correlation of high abundances of macrobenthos with a specific acoustic facies. A medium to high reflectivity patchy to mottled texture was correlated with the presence of dense fields of the tube-building polychaete *Lanice conchilega*. If the density of this polychaete worm is indeed high enough, local sediment accumulations, detectable by side-scan sonar technology, can be formed. Interestingly, the occurrence of this acoustic facies is highly correlated with slope environments leading to the assumption that these environments have a high input of suspended matter.

Secondly, an indirect link was sought based on the known correlations of the macrobenthos versus sedimentology on the one hand and sedimentology versus side-scan sonar imagery on the other hand. This means that if side-scan sonar imagery can be interpreted in terms of sediment nature, the occurrence of macrobenthic communities can be predicted. To facilitate this process, a standardised interpretation is put forward through the set-up of a table with different criteria and interpretation keys. This table provides a discrimination of acoustic facies into a maximum of classes, which are finally linked to a macrobenthos community preference.

HABITAT STRUCTURE MAP

To be able to set up a scientifically approved management plan for the Western Coastal Banks and to allow a good future decision making, it is necessary to have as much data as possible on the ecosystem. An overview of the data, summarizing their basic significance, will thus add to the usefulness of the projects outcome. This part of the study specifically aims at the development of a 'habitat structure map' from the database, which combines all available information on the benthic habitat of the Western Coastal Banks.

As such, the 'habitat structure map' reflects the present knowledge on the bathymetry, sediment nature, the acoustic facies and the occurrence of the macrobenthic communities. This approach visualises the interactions between the physical environment and the macrobenthos and is a tool for a scientifically sustained evaluation of this unique ecosystem. Together with the other maps, the habitat structure map reflects the situation of the ecosystem before the effectiveness of a support plan. Knowledge on the t_0 -situation is of primary importance for the evaluation of the effects of the policy decisions. Because of the standardized methods and the uniform production of maps, a future integration of all information into a Geographical Information System (GIS) or a thematical atlas is possible.

Implications for future management and monitoring

SPATIAL EXTRAPOLATION OF POINT-DATA

So far, knowledge on the spatial distribution of the macrobenthos was restricted to the description of the macrobenthos present at the sample stations. In most studies, full-coverage spatial extrapolation between the sample points proved to be unreliable. Yet, full-coverage knowledge on the spatial distribution of the macrobenthos would allow to better manage the benthic habitat within the future MPA. To retrieve time- and cost-efficient, full-coverage knowledge on the spatial distribution of the macrobenthos, based on the results of the HABITAT projects, two methods are put forward.

Since the collection of data to retrieve a detailed bathymetric-sedimentological map of an area is less time-consuming than the collection of those for a detailed macrobenthic map, the HABITAT model provides a powerful time- and cost-efficient tool to retrieve a full-coverage view on the spatial distribution of the 'macrobenthic potentials'. Through the macrobenthic side-scan sonar interpretation, (MSSSI) very-high resolution side-scan sonar imagery can be used to predict the occurrence of the macrobenthic communities and bioherm structures, such as *Lanice conchilega* 'bumps'. This technique thus provides insight into the full-coverage delineations of communities and bioherms and thus allows evaluating the 'macrobenthic potentials' of non-studied places within the protected area on a time- and cost-efficient base.

STRATIFIED RANDOM SAMPLING STRATEGY BASED ON REMOTE SENSING

If no information on the macrobenthic habitat of an area is available, a random sampling design provides a good strategy to study the benthos. Yet, a major disadvantage of a random sampling strategy is the fact that a high number of samples is needed to retrieve a representative view on the macrobenthic spatial distribution. If a stratified random sampling strategy can be applied, each set of macrobenthos samples, collected within a stratum, is considered to consist of replicate samples of that stratum and should provide a representative view on the macrobenthos of the stratum. The application of a stratified random sampling design already leads to a decrease in the number of samples needed to achieve a representative view of the macrobenthic community structure. Since remote sensing techniques (e.g. side-scan sonar) (1) provide a full-coverage view of the benthic habitat and (2) are known to be related to the macrobenthic community structure, remote sensing provides an extremely useful tool for the delineations of ecological relevant strata. Thus, a stratified random sampling design for the study of the macrobenthos, based on the delineation of strata through side-scan sonar images, will not only decrease the numbers of samples needed (= time- and cost-efficient), but will further provide a reliable, full-coverage view on the temporal variation of the macrobenthos within the area.

STRATEGIES FOR FUTURE MONITORING

To allow a time- and cost-efficient monitoring of the ecosystem after the implementation of a management plan, it is important to select the optimal monitoring strategy and techniques for a given situation. Three steps are proposed for the monitoring of the macrobenthos of the Western Coastal Banks: (1) selection of ecologically relevant strata, based on the available side-scan sonar recordings, (2) monitoring of the macrobenthic habitat, through the investigation of the macrobenthos (bottom samples) and its physico-chemically environment (remote sensing and bottom samples) based on a stratified random sampling design, and (3) full-coverage monitoring of the macrobenthic habitat, using remote sensing. Following this strategy, a fast evaluation of measures, taken within the framework of the management plan for the area of the Western Coastal Banks, is possible.

SYNTHESE

Inleiding

Het gebied van de westelijke kustbanken (3400 ha) is een zandbank- (Trapegeer, Broersbank en Den Oever), geulensysteem (Potje en Westdiep) gekenmerkt door waterdieptes van -15 m tot 0 m GLLWS. De geomorfologie is de meest diverse langsheen de Belgische kust en is verantwoordelijk voor de hoge biologische diversiteit en rijkdom van het gebied. Het ecologisch belang werd reeds aangetoond door het hoge aantal aan vogelsoorten die in dit gebied overwinteren (m.n. de zwarte zee-eend *Melanitta nigra*). Omwille van het talrijk voorkomen van zeevogels, wordt het gebied dan ook erkend als internationaal belangrijk voor zeevogels (Ramsar conventie). Bovendien vervult het gebied de criteria van de EU-Vogelrichtlijn en werd het voorgesteld als een EU-Habitatrichtlijngebied. Bijgevolg onderzoekt de Belgische overheid de noodzaak en de mogelijkheid om de zone van de Westelijke Kustbanken het statuut van marien beschermd gebied toe te kennen.

Als voedselbron voor verschillende zeevogels en demersale vissoorten, vervult het macrobenthos een belangrijke rol binnen het ecosysteem van de Westelijke Kustbanken. Ter ondersteuning van een beheersplan van het voorgestelde natuurgebied, is het dan ook noodzakelijk een goed onderbouwde kennis omtrent de natuurlijke ruimtelijke verspreiding en de temporele variabiliteit van het macrobenthos te bezitten.

De algemene doelstelling van het project omvat in de eerste plaats het aanrijken van data, noodzakelijk voor de opmaak en wetenschappelijke evaluatie van een beheersplan van een toekomstig marien natuurgebied. Omwille van de cruciale rol van het macrobenthos in het mariene ecosysteem, wordt in het bijzonder de verspreiding en temporele variatie van de macrobenthische gemeenschappen bestudeerd en dit in relatie tot de sedimentologische, bathymetrische en hydrodynamische gesteldheid. Bovendien, werden tijd- en kostenbesparende evaluatiemiddelen ontwikkeld ten behoeve van een beheersplan.

Materiaal en methode: algemeen

Scheepstijd werd toegekend door de Afdeling Waterwegen Kust van het Ministerie van de Vlaamse Gemeenschap (Oostende XI en Ter Streep). Bijkomende scheepstijd (R/V Belgica), voor het uitzetten van een akoestische doppler stromingsprofileerder (ADCP), werd bekomen via het Mathematisch Model van de Noordzee en Schelde-estuarium (BMM). De onderzoeksschepen zijn alle uitgerust met differentiële positioneringssystemen (DGPS).

Zowel single-beam als multibeam bathymetrische gegevens werden opgenomen en gecorrigeerd voor de verticale beweging van het schip en voor het getij.

Side-scan sonar beelden (*in casu* GeoAcoustics dual frequency side-scan sonar met een frekwentie van 410 kHz) werden opgenomen teneinde heel hoge resolutie beelden van de zeebodem te bekomen. Voor de snelheid van het schip werden 4 knopen nagestreefd.

Teneinde gebiedsbedekkende data van het macrobenthos en de fysico-chemische omgeving te verwerven, werden in totaal 260 bodemstalen verzameld, uniform verdeeld over het studiegebied en met een onderlinge spatiëring van 500 m. In elk station werden stalen genomen voor het macrobenthos (Van Veen grijper),

sedimentologie (Van Veen grijper), gesuspendeerd materiaal (SPM) (Niskin fles), nutriëntenconcentraties in de bodem (Van Veen grijper) en de waterkolom (Niskin fles), evenals pigmentconcentraties in de waterkolom (Niskin fles). De waterdiepte op het moment van staalname werd geregistreerd. Bemonsteringen werden uitgevoerd in oktober 1999, maart en november 2000. De macrobenthos stalen werden gezeefd op een 1 mm zeef en alle organismen werden gedetermineerd tot op soortniveau. De sedimentologische monsters werden geanalyseerd met zowel een LS Coulter counter als gezeefd op $\frac{1}{4}$ phi ter bepaling van korrelgrootteparameters. De bodem- en waterkolomnutriënten (nitriet, nitraat, ammonium, fosfaat en silicium) werden gemeten m.b.v. een automatische keten (SAN^{plus} segmented flow analyser, SKALAR). Pigmenten in de waterkolom (chlorofyl-a, -c en fucoxanthine) werden gemeten door een onmiddellijke extractie met aceton vooraleer een 'Gilson high-performance liquid chromatography chain' werd uitgevoerd volgens de methode van Mantoura & Llewellyn (1983). Het gehalte aan gesuspendeerd materiaal werd bekomen door filtratie van zeewater doorheen een GF/C filter en de bepaling van het nettodrooggewicht van de filter na filtratie.

Regionale presentatie van het macrobenthos en zijn fysico-chemische omgeving

OVERZICHT VAN HET BENTHISCHE HABITAT

Omwille van de veronderstelde hoge ecologische waarde van het gebied, zoals aangegeven door de hoge aantallen aan zeevogels die in het gebied overwinteren, ging vanuit wetenschappelijk oogpunt reeds aandacht uit naar het benthische habitat van de Westelijke Kustbanken. Een overzicht hieromtrent werd opgesteld met speciale aandacht aan de ontwikkeling van een databank en de opmaak van kaartmateriaal als een middel om de ruimtelijke verdeling van de verschillende variabelen voor te stellen.

In een eerste fase, werden kaarten gemaakt op basis van bestaande data, zowel vanuit de literatuur als van rapporten. Dit omvatte een compilatie en integratie van bathymetrische, morfologische, sedimentologische, hydrodynamische en macrobenthos data teneinde een betere karakterisatie van het benthische habitat van het studiegebied te bekomen. Elke kaart is het resultaat van een compilatie van de beschikbare informatie, gestructureerd in een databank. Aangezien de databank toelaat gegevens te integreren en nieuw verworven data te superponeren, vormt deze een middel om de natuurlijke evolutie van het gebied te visualiseren en is deze onmiddellijk bruikbaar bij het definiëren van de huidige situatie (t_0 -situatie) van het ecosysteem van de Westelijke Kustbanken.

Een bathymetrisch-morfologische kaart werd opgesteld, met een schematische aanduiding van de voorkomende bodemstructuren en hun relatieve asymmetrie. Het gebied is gekarakteriseerd door een zandbank-geulensysteem met variërende dieptes. Zandige duinstructuren van verschillende dimensies zijn gesuperponeerd op de grootschalige morfologie. Omwille van de ondiepte van het gebied, is de zeebodem sterk onderhevig aan de hydrodynamische krachten; dit wordt het best geïllustreerd aan de hand van de bodemstructuren. Een digitaal heel-hoge resolutie side-scan sonar verkennende meetcampagne (September 1999) bevestigde het voorkomen van deze bodemstructuren en getuigde van de hoge diversiteit en complexe aard van de zeebodem.

De oppervlakkige sedimenten zijn gedomineerd door het voorkomen van fijne tot gemiddelde zanden met een duidelijke vergroving naar ondieper wordende gebieden. De zandbanken zijn algemeen het grofst, veelal gekarakteriseerd door opgebroken schelpenmateriaal; de oppervlakkige sedimenten in de geulen daarentegen vertonen een hoger percentage aan silt-klei.

Het gebied wordt gekenmerkt door een macrotidaal semi-diurnaal getij (5.4 m). De getijdestroming wordt gekarakteriseerd door langgerekte, asymmetrische getijdestroomellipsen met een dominantie van de vloedstroming (NE-ENE) die tot 1.32 m/s kan oplopen in de Westdiepgeul. Numerische modellering (mu-BCZ) met een 750 m gridresolutie toonde de hoogste stroming in de Westdiepgeul en naar de voet van de helling van de Trapegeer toe. Uitgaande van sedimenttransportberekeningen, werd aangetoond dat de oppervlakkige sedimenten vooral mobiel zijn tijdens spring- en middeltij en dit van nagenoeg 1 uur voor tot 1 uur na hoogwater. Vooral in de Westdiepgeul en in de Noordpas is de ebstroming tevens competent genoeg om sediment in suspensie te brengen. Om inzicht te verwerven in de voortplanting van het getij doorheen het gebied werd tevens numerische modellering uitgevoerd op een 250 m gridresolutie en dit gebaseerd op de gedetailleerde bathymetrische informatie. Alhoewel de resultaten nog onder validatie zijn, wordt duidelijk de stromingsvariatie in functie van de grootschalige morfologie aangetoond inclusief een stromingsverhoging in de geulen.

Voor de periode 1999, is slechts weinig informatie beschikbaar omtrent het macrobenthos van de Westelijke Kustbanken (32 stations). De data is gelimiteerd tot de Trapegeer, Broersbank, Den Oever en het Potje en bijna geen informatie omtrent de Westdiepgeul was beschikbaar. De totale macrobenthische dichtheid varieerde van nagenoeg 100 tot meer dan 26000 ind./m², welsiwaar met een soortenaantal per bemonsterd oppervlakte van 0.1 m² (N₀) dat varieerde van 4 tot 28 soorten. Algemeen, werden de laagste dichtheden en soortenrijkdom gevonden op de zandbanken Trapegeer en Broersbank en dit in tegenstelling tot de diepere gedeelten van het gebied. Drie macrobenthische gemeenschappen, verspreid over het gebied, werden onderscheiden. De macrobenthisch rijke *Abra alba* – *Mysella bidentata* gemeenschap (syn. *Lanice conchilega* gemeenschap) wordt vooral gevonden in de diepere gedeelten van het Potje en langsheen de noordelijke helling van de Trapegeer zandbank, terwijl de *Ophelia limacina* – *Glycera lapidum* gemeenschap (syn. *Mytilus edulis* gemeenschap) bij voorkeur voorkomt in de ondiepste gebieden (bv. top van de Broersbank). In de topzone van de Trapegeer zandbank en op de Broersbank, werd de *Nephtys cirrosa* gemeenschap bemonsterd. De ruimtelijke verspreiding van 7 macrobenthische soorten wordt voorgesteld. Alhoewel deze data een eerste overzicht bieden van de gemeenschapsstructuur en de macrobenthische ruimtelijke verspreiding in het gebied van de Westelijke Kustbanken, moeten deze echter met enige voorzichtigheid geïnterpreteerd worden. Dit is vooral te wijten aan het feit dat het gebied geomorfologisch sterk gevarieerd is en aldusdanig moet data van slechts 32 stations, als puntdata worden beschouwd en is ruimtelijke extrapolatie van de macrobenthische karakteristieken niet opportuun.

MACROBENTHISCH HABITAT: RUIMTELIJKE VERDELING

Omwille van de belangrijke trofische functies, als voedselbron van zeevogels en demersale vissoorten, is macrobenthos een heel belangrijke component binnen het ecosysteem van de Westelijke Kustbanken. Hiertoe is dan ook eerst kennis noodzakelijk omtrent de ruimtelijke verspreiding van het macrobenthos ook in functie van het opzetten van een beheersplan van het voorgestelde marien beschermd gebied. Voor de opwaardering en de uitbreiding van de kennis van de ruimtelijke verspreiding binnen het macrobenthisch habitat, werden drie subgebieden onderscheiden met een maximale geomorfologische diversiteit. In Oktober 1999, werden deze intensief onderzocht ter bepaling van het fysico-chemische milieu en het macrobenthos.

Aan de hand gebiedsbedekkende heel hoge resolutie side-scan sonar beeldvorming in combinatie met single- en multibeam bathymetrische opnamen, werden de drie subgebieden volledig akoestisch opgenomen Dit liet toe de

intrinsieke aard van de zeebodem te bestuderen en dit in relatie tot de grootschalige morfologie. De combinatie van reflectiviteit, textuur en patronen zoals afgeleid van de side-scan sonar beelden werden vertaald naar een akoestisch facies dat in hoofdzaak werd geïnterpreteerd in functie van de kleinschalige morfologie en bodemstructuren, verdeling van sedimenten en hun relatieve compactiegraad en dit gesuperponeerd door hydrodynamische effecten.

De sedimentstalen bevestigden de brede waaier aan sedimenten en de grote variatie op soms heel korte afstand. Op de zandbanken, is de verdeling van de oppervlakkige sedimenten hydrodynamisch bepaald t.t.z. de stromingen zijn sterk genoeg om het sediment hydraulisch te sorteren. De geulen zijn gekenmerkt door een diverse sedimentsamenstelling. Dit is vooral te wijten aan de hoge beschikbaarheid aan fijnkorrelig sediment dat zich kan afzetten tijdens tijkentering. In tegenstelling is de Westdiepgeul gekarakteriseerd door grover sediment. Dit werd tevens aangetoond door side-scan sonar opnamen wat bevestigt dat deze geul kan aanzien worden als een hoog energetisch milieu.

Akoestische dopper stromingsprofileringen (ADCP) werden uitgevoerd aan de voet van de zeewaartse helling van de Trapegeer zandbank; deze bevestigden de rectilineaire, sterke vloedgedomineerde getijdestroming en dit tevens op nagenoeg 1 m boven de bodem. De correlatie van de hoge ruimtelijke verscheidenheid van het gebied met hydrodynamische numerische modelresultaten dient echter nog verder onderzocht.

De ruimtelijke verspreiding van het macrobenthos, zoals bepaald aan de hand van historische data, werd bevestigd door het gedetailleerd onderzoek in het gebied. Naast de *Magelona mirabilis* soorten associatie, werden drie van de vier subtidale macrobenthische gemeenschappen van het BCP in het gebied van de Westelijke Kustbanken aangetroffen: de *A. alba* - *M. bidentata*, de *N. cirrosa* en de *O. limacina* - *G. lapidum* gemeenschap. Iedere gemeenschap komt enkel voor in een heel specifieke fysico-chemische omgeving. Alhoewel iedere gemeenschap verspreid over het ganse gebied werd gevonden, kon toch een zekere zonatie, bepaald door onder andere de diepte, worden aangetoond. De *A. alba* - *M. bidentata* gemeenschap werd aangeduid als een ecologisch zeer waardevolle gemeenschap op het BCP. De gemeenschap wordt namelijk gekenmerkt door zeer hoge macrobenthische dichtheden (gemiddeld 7589 ind./m²) en diversiteit (gemiddeld 37 spp./0.1 m²). Verder werden er ook vele soorten tweekleppigen in hoge dichtheden aangetroffen (o.a. *A. alba*: 995 ind./m² en *Fabulina fabula*: 273 ind./m²). Deze tweekleppigen zijn gekend als belangrijke voedselbron voor grote epibenthische predatoren (o.a. kabeljauw *Gadus morus* en zeetong *Solea solea*) en benthos-etende zee-eenden (o.a. zwarte zee-eend *Melanitta nigra*). Ook de kokerbouwende borstelworm *Lanice conchilega* wordt voornamelijk in de *A. alba* - *M. bidentata* gemeenschap aangetroffen. Omwille van (1) de lokale stabilisatie van het sediment door hoge dichtheden aan *L. conchilega* en (2) een verhoogde habitatcomplexiteit als gevolg van de aanwezigheid van kokers, vervult deze borstelworm hoogstwaarschijnlijk een belangrijke habitatstructurende rol in het ecosysteem. Een positieve correlatie tussen de macrobenthische dichtheid en diversiteit enerzijds en de dichtheid van *L. conchilega* anderzijds werd dan ook aangetoond. Beide andere gemeenschappen en de soortenassociatie dragen in grote mate bij tot de macrobenthische diversiteit van de Westelijke Kustbanken: 74 % van alle macrobenthische soorten, recent (sinds 1994) op het BCP aangetroffen, werden in het studiegebied waargenomen. Verder werd, in vergelijking met andere ecologische regio's op het BCP, een algemeen hogere dichtheid en diversiteit in het gebied gevonden. De Westelijke Kustbanken kunnen dus worden beschouwd als een 'hotspot' voor macrobenthisch leven op het BCP.

MACROBENTHISCH HABITAT: TEMPORELE VARIATIE

Macrobenthische gemeenschappen van ondiepe kustgebieden zijn onderhevig aan een waaier van fysische en biologische verstoringen die variëren in frequentie en in intensiteit en dit zowel op een temporele als ruimtelijke schaal. De natuurlijke variatie binnen de macrobenthische gemeenschappen zouden moeten helpen om fundamentele ecologische aangelegenheden te verklaren, maar tevens voor de conservatie en het beheer van het mariene benthische habitat. Om de temporele variabiliteit binnen het macrobenthische habitat van de Westelijke Kustbanken te bestuderen, werd de multidisciplinaire studie van Oktober 1999 herhaald in Maart 2000.

Naar de aard van de oppervlakkige sedimenten toe, bleek de temporele variabiliteit tussen beide campagnes minimaal en algemeen waren de verschillen binnen de foutmarge van de analyses. In beide maanden waren de sedimenten gekarakteriseerd door fijne tot gemiddelde zanden (+/- 40 %) met een gemiddelde mediane korrelgrootte van nagenoeg 270 µm. De side-scan sonar beelden tonen meer variatie aangezien de oppervlakkige kenmerken primeren. Vermoemenswaardig was echter het voorkomen van banden van heel lage reflectiviteit en dit in de diepste gedeelten van de geulen. Correlatie was mogelijk met het voorkomen van vloeibaar slib en dit afgezet op een fijn zandig substraat. De interpretatie van de side-scan sonar beelden naar akoestische faciessen toe, vertoonde echter geen fundamentele verschillen wat aantoont dat een gestandaardiseerde side-scan sonar interpretatie geldig is op temporele basis.

Het macrobenthos wordt tijdens beide maanden gedomineerd door borstelwormen en tweekleppigen. Alhoewel de gemeenschapsstructuur van alle gemeenschappen wijzigde tussen de beide staalname campagnes, konden toch nog steeds dezelfde gemeenschappen in maart 2000 als in oktober 1999 worden onderscheiden: 50 tot 90 % van de meest dominante soorten waren identiek in beide maanden. Omwille van de relatief lage temporele variatie wordt de gemeenschapsstructuur voornamelijk bepaald door de ruimtelijke verspreiding. Verder werd aangetoond dat iedere gemeenschap een heel specifieke temporele variatie vertoont. Temporele variatie was het meest opvallend in de *A. alba* – *M. bidentata* gemeenschap. Binnen deze gemeenschap werd een significante daling van de macrobenthische dichtheid en diversiteit waargenomen tussen oktober 1999 en maart 2000: van 7589 naar 3264 ind./m² en van 37 naar 27 soorten. Gemiddeld 85 % van de indicator en dominante soorten van de gemeenschap vertoonden een significante daling in dichtheid. Binnen de *N. cirrosa* en de *O. limacina* – *G. lapidum* gemeenschap en de *M. mirabilis* soortenassociatie werden slechts kleine, niet-significante veranderingen in dichtheid en diversiteit waargenomen. Omwille van de ruimtelijke stabiliteit van de ecologisch meest relevante fysico-chemische omgevingsvariabelen (o.a. sedimentologie en diepte) in het gebied, werd tijdens beide maanden in 71 % van de bemonsterde stations dezelfde gemeenschap aangetroffen. Het gebied van de Westelijke Kustbanken vertoont aldus een hoge ruimtelijke stabiliteit binnen het macrobenthos.

Ontwikkeling van methodologieën voor de creatie van tijd- en kostenbesparende opvolgingsmiddelen voor een toekomst marien beschermd gebied

HABITAT MODEL

Het 'macrobenthisch potentieel' van een habitat wordt gedefinieerd als het geheel van de dynamiek van de macrobenthische gemeenschapsstructuur (o.a. soortensamenstelling, diversiteit en dichtheden) binnen het habitat. Wanneer binnen een gebied informatie betreffende (1) de aanwezige macrobenthische gemeenschappen, (2) hun temporele variabiliteit en (3) hun habitatpreferenties voorhanden is, laat de kennis van

de biologisch relevante fysico-chemische omgevingsvariabelen van een station toe het 'macrobenthische potentieel' van het station te voorspellen. Vooreerst werden binnen dit deel van de studie de 'macrobenthische potentiëlen' van de verschillende habitats binnen het studiegebied bepaald. Hierop gebaseerd, werd het HABITAT model opgesteld. Dit model heeft als doel de correlaties tussen het macrobenthos en hun fysico-chemische omgeving mathematisch vast te leggen. Het HABITAT model laat toe de potentiëlen van ongekende sites binnen het toekomstige beschermde gebied op een tijd- en kostenbesparende manier te evalueren.

Het 'macrobenthisch potentieel' van een habitat/gemeenschap, zoals aangetoond door onder andere de 'potentiële soortenlijst', duidde op een zeer hoge ecologische waarde van de *A. alba* – *M. bidentata* gemeenschap. Als overgangssituatie tussen de *A. alba* – *M. bidentata* en de *N. cirrosa* gemeenschap, vertoonde de *M. mirabilis* soortenassociatie een intermediaire ecologische waarde. Het habitat van de *A. alba* – *M. bidentata* gemeenschap is dus duidelijk ecologisch superieur t.o.v. alle overige habitats binnen het gebied. Dit mag echter niet worden geïnterpreteerd als zouden de overige gemeenschappen ecologisch onbelangrijk zijn. Zowel de diversiteit binnen een habitat als tussen habitats, respectievelijk alfa- en beta-diversiteit, zijn belangrijk binnen het functioneren van een ecosysteem.

Het HABITAT model is opgebouwd uit acht sets van klassificatiefuncties, bekomen via een 'multiple discriminant analysis'. Elke set neemt een welbepaalde set omgevingsvariabelen in rekening. Gebaseerd op de macrobenthos data van oktober 1999 en maart 2000 (drie gemeenschappen en één soortenassociatie), werd een gemeenschapsspecifieke en overkoepelende *a posteriori* en *a priori* accuraatheid van minimum 70 % gevonden in 78 % van de klassificatiefuncties. De accuraatheid kan drastisch verhoogd worden indien enkel de drie gemeenschappen in rekening worden gebracht. Wanneer de gemeenschapsspecifieke accuraatheid van de verschillende sets klassificatiefuncties wordt vergeleken, kan geen enkele set als superieur ten opzichte van de overige naar voor worden geschoven. Als gevolg van de resultaten van de testen van het model aan de hand van data verzameld in november 2000, wordt echter een verder testen en verfijning van het model aangeraden.

GESTANDARDISEERDE MACROBENTHISCHE INTERPRETATIE VAN SIDE-SCAN SONAR BEELDEN (MSSSI)

Twee benaderingen werden uitgewerkt voor de interpretatie van side-scan sonar beelden in functie van het voorkomen van macrobenthische gemeenschappen.

Een eerste benadering is gebaseerd op een directe correlatie van hoge dichtheden van macrobenthos en een specifiek akoestisch facies. Een gemiddelde tot hoge reflectieve vlekkerige textuur werd gecorreleerd met de aanwezigheid van dense velden van de kokerbouwende borstelworm *Lanice conchilega*. Als de dichtheid van deze borstelworm hoog genoeg is, kunnen deze aanleiding geven tot lokale sedimentaccumulaties die detecteerbaar zijn door side-scan sonar. Bovendien vertoont het voorkomen van dit typisch akoestisch facies een sterke correlatie met hellingsgebieden wat doet vermoeden dat deze milieus mogelijk gekenmerkt zijn door een verhoogde aanvoer van suspensiemateriaal.

In tweede instantie werd een indirecte relatie gezocht, gebaseerd op de huidige kennis van enerzijds de correlatie macrobenthos versus sedimentologie en anderzijds sedimentologie versus side-scan sonar beeldvorming. Dit betekent dat indien side-scan sonar beelden sedimentologisch kunnen geïnterpreteerd worden, het voorkomen van macrobenthische gemeenschappen kan voorspeld worden. Om dit proces te begeleiden, werd een gestandaardiseerde interpretatie uitgewerkt door middel van een tabel met verschillende criteria en

interpretatiesleutels. Deze tabel laat toe een maximaal aantal akoestische klassen te onderscheiden die finaal werden gecorreleerd met een macrobenthische gemeenschapsvoorkeur.

HABITATSTRUCTUURKAART

Teneinde een wetenschappelijk onderbouwd beheersplan van de Westelijke Kustbanken toe te laten en voor toekomstige beheersopties, is het noodzakelijk zoveel mogelijk data te verwerven omtrent het ecosysteem. Een overzicht van de data, die op een synthetiserende manier de onderlinge relaties weergeeft, zal dan ook het gebruik van de projectresultaten maximaliseren. Dit gedeelte van de studie spitst zich toe op de ontwikkeling van een 'habitatstructuurkaart' die alle beschikbare informatie van het benthische habitat van de Westelijke Kustbanken combineert.

De 'habitatstructuurkaart' stelt dan ook de huidige kennis van de bathymetrie, aard van de sedimenten, het akoestisch facies en het voorkomen van macrobenthische gemeenschappen voor. Deze aanpak reflecteert dan ook de interacties van het fysische milieu en het macrobenthos als een middel voor een wetenschappelijk verantwoorde evaluatie van dit unieke ecosysteem. Tesamen met het andere kaartmateriaal, toont de 'habitatstructuurkaart' de situatie van het ecosysteem voor de effectieve uitvoering van een beheersplan. Kennis omtrent de t_0 -situatie is van groot belang voor de evaluatie van de effecten van beleidsbeslissingen. Omwille van de gestandaardiseerde methoden en de uniforme productie van kaartmateriaal, wordt een toekomstige integratie van alle informatie in een Geografisch Informatie Systeem (GIS) of in een thematische atlas mogelijk.

Betekenis voor het toekomstige beheer en monitoring

RUIMTELIJKE EXTRAPOLATIE VAN PUNTGEGEVENS

Totnogtoe was de kennis van de ruimtelijke verspreiding van het macrobenthos beperkt tot de beschrijving van het macrobenthos ter hoogte van de verschillende staalnamepunten. In de meeste studies kan geen betrouwbare gebiedsbedekkende ruimtelijke extrapolatie vanuit deze puntgegevens worden bekomen. Een gebiedsbedekkende kennis van de macrobenthische ruimtelijke verspreiding is echter noodzakelijk ten einde een degelijk onderbouwd beheersplan voor het volledige toekomstige natuurgebied op te stellen. Om een gebiedsbedekkende kennis van de ruimtelijke verspreiding van het macrobenthos op een tijd- en kostenbesparende manier te bekomen, werden twee methodes voorgesteld.

De opstelling van een gedetailleerde, gebiedsbedekkende bathymetrisch-sedimentologische kaart van het gebied vergt minder tijd dan deze van het macrobenthos. Zodoende blijkt het HABITAT model een krachtig tijd- en kostenbesparend gebruiksinstrument bij het opstellen van een gebiedsbedekkend overzicht van de 'macrobenthische potentiëlen' binnen het gebied. Gebruikmakende van de macrobenthische side-scan sonar interpretatie (MSSSI), kan hoge-resolutie side-scan sonar beeldvorming dienen ter voorspelling van het voorkomen van macrobenthische gemeenschappen en biohermstructuren, zoals *Lanice conchilega* 'heuveltjes'. Deze techniek laat dus een gebiedsbedekkende afbakening van gemeenschappen en biohermen toe. Dit laat toe het 'macrobenthisch potentieel' van niet-bestudeerde zones binnen het gebied op een tijd- en kostenbesparende manier te evalueren.

'STRATIFIED RANDOM SAMPLING' STRATEGIE GEBASEERD OP REMOTE SENSING

Indien geen informatie betreffende het macrobenthische habitat voorhanden is, is een 'random sampling' strategie een goede manier om het macrobenthos te bestuderen. Een belangrijk nadeel van deze strategie is echter het hoge aantal stalen noodzakelijk om een representatief beeld van de ruimtelijke verspreiding van het macrobenthos te bekomen. Als een 'stratified random sampling' strategie kan worden toegepast, wordt ieder staal, bemonsterd binnen eenzelfde stratum, beschouwd als een replica voor het stratum. Iedere set stalen binnen een stratum dient een representatief beeld van het macrobenthos binnen het stratum weer te geven. De toepassing van deze strategie heeft dus een drastische daling van het aantal stalen, noodzakelijk om een representatief beeld van het macrobenthos binnen het gebied, als gevolg. Aangezien remote sensing (o.a. side-scan sonar) (1) een gebiedsbedekkend beeld van het bentisch habitat toelaat en (2) aan de macrobenthische gemeenschapsstructuur kan worden gerelateerd, biedt deze een zeer bruikbaar middel ter afbakening van ecologisch relevante strata. Een 'stratified random sampling' strategie, gebaseerd op de afbakening van strata aan de hand van remote sensing, heeft niet alleen een daling van het aantal noodzakelijke stalen als gevolg, maar zal ook voorzien in een betrouwbaar en gebiedsbedekkend beeld van de temporele variatie van het macrobenthos in het gebied.

STRATEGIEËN VOOR TOEKOMSTIGE MONITORING

Teneinde, tijdens de toepassing van het beheersplan, een tijd- en kostenbesparende monitoring van het ecosysteem uit te voeren, is het noodzakelijk een degelijke strategie en techniek voor de monitoring te selecteren. Drie stappen worden voorgesteld voor de monitoring van het macrobenthisch habitat van de Westelijke Kustbanken: (1) selectie van de ecologisch relevante strata, gebaseerd op de beschikbare side-scan sonar opnames, (2) monitoring van het macrobenthisch habitat via de studie van het macrobenthos (bodemstalen) en de fysico-chemische omgeving (remote sensing en bodemstalen) volgens een 'stratified random sampling' strategie en (3) een gebiedsbedekkende monitoring van het bentisch habitat via remote sensing technieken. Deze strategie zal toelaten de maatregelen, genomen binnen de uitvoering van het beheersplan voor de Westelijke Kustbanken, op een snelle manier ecologisch te evalueren.

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