SPSD II

MANAGEMENT, RESEARCH AND BUDGETTING OF AGGREGATES IN SHELF SEAS RELATED TO END-USERS (MAREBASSE)

EV-18

SCIENTIFIC SUPPORT PLAN FOR A SUSTAINABLE DEVELOPMENT POLICY

SPSD II

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V. VAN LANCKER, M. DE BATIST, M. FETTWEIS, G.PICHOT, J. MONBALIU

PART 2

GLOBAL CHANGE, ECOSYSTEMS AND BIODIVERSITY

ATMOSPHERE AND CLIMATE

MARINE ECOSYSTEMS AND BIODIVERSITY

TERRESTRIAL ECOSYSTEMS AND BIODIVERSITY

NORTH SEA

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(SPSD II)

Part 2:

Global change, Ecosystems and Biodiversity

FINAL REPORT

MANAGEMENT, RESEARCH AND BUDGETTING OF AGGREGATES IN SHELF SEAS RELATED TO END-USERS

(MAREBASSE)

EV/18

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Preface

This final report represents the results of the following multidisciplinary research group:

1. Ghent University. Renard Centre of Marine Geology (RCMG)
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The research on the Kwinte Bank was carried out in close cooperation with the EU-FP5 Research training network **EUMARSAND** and has resulted in joint publications on the impact of aggregate extraction. Related to the research activities of UG-RCMG, Marebasse was the co-funding project of the InterregIIIb project **MESH** ('Mapping European Seabed Habitats'). As such, the mapping results have been refined, validated and more standardised in a wider European framework.

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Bonne, W., Van Lancker, V., Collins, M.B. and Uriarte, A. (Eds.), (in prep.). European marine sand & gravel resources: evaluation and environmental impact of extraction. *Journal of Coastal Research*.

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Degrendele, K., Roche, M., Schotte, P., Van Lancker, V., Bellec, V. and Bonne, W. (submitted). Morphological evolution of the Kwinte Bank central depression before and after the cessation of aggregate extraction. *Journal of Coastal Research*.

Du Four, I. and Van Lancker, V. (submitted). Physical impact of dredged material disposal sites and their recovery after cessation of dumping: a case study in the Belgian coastal zone. *Marine Geology*

Fettweis, M., Francken, F., Pison, V. and Van den Eynde, D. (2006). Suspended particulate matter dynamics and aggregate sizes in a high turbidity area. *Marine Geology* 235(1-4): 63-74.

Fettweis, M., Nechad, B. and Van den Eynde, D. (2007). An estimate of the suspended particulate matter (SPM) transport in the southern North Sea using SeaWiFS images, in situ measurements and numerical model results. *Continental Shelf Research* 27(10-11): 1568-1583.

Giardino, A., Van den Eynde, D. and Monbaliu, J. (accepted). Wave effects on the morphodynamic evolution of an offshore sandbank. *Journal of Coastal Research*.

Van den Eynde, D., Giardino, A., Portilla, J., Fettweis, M., Francken, F. and Monbaliu, J. (submitted). Modelling the effects of sand extraction on the sediment transport due to tides on the Kwinte Bank. *Journal of Coastal Research*.

Van Lancker, V.R.M., Bonne, W., Velegrakis, A.F. and Collins, M.B. (submitted). Aggregate extraction from tidal sandbanks: is dredging with nature an option? An introduction. *Journal of Coastal Research*.

Van Lancker, V.R.M., Bonne, W., Bellec, V., Degrendele, K., Garel, E., Brière, C., Van den Eynde, D. and Collins, M.B. (submitted). Recommendations for a sustainable exploitation of tidal sandbanks. *Journal of Coastal Research*.

Verfaillie, E., Van Lancker, V. and Van Meirvenne, M. (2006). Multivariate geostatistics for the predictive modelling of the surficial sand distribution in shelf seas. *Continental Shelf Research* 26 (19): 2454-2468.

Verfaillie, E., Degraer, S., Schelfaut, K., Willems, W. and Van Lancker, V. (submitted). Classifying ecologically relevant marine landscapes, a statistical approach. *Continental Shelf Research*.

Books

Calewaert, J.-B., Maes, F., Lymbery, G., Engelen, G., Van Lancker, V., Douvere, F., Vanaverbeke, J., Collins, M., Mink, E. and Elliott, M. (2007). Chapter 7. Final Chapter Sumanos, pp. 260-314. In: J.-B. Calewaert and F. Maes (Editors), *Science and Sustainable Management of the North Sea: Belgian case studies*. Gent, Academia Press Wetenschappelijke Uitgeverij, 314 p.

Van Lancker, V., Deleu, S., Bellec, V., Du Four, I., Schelfaut, K., Verfaillie, E., Fettweis, M., Van den Eynde, D., Francken, F., Monbaliu, J., Giardino, A., Portilla, J., Lanckneus, J., Moerkerke, G. and Degraer, S. (2007). Chapter 4. Marebasse: bridging gaps towards other disciplines and endusers, pp. 88-141. In: J.-B. Calewaert and F. Maes (Editors), *Science and Sustainable Management of the North Sea: Belgian case studies*. Gent, Academia Press Wetenschappelijke Uitgeverij, 314 p.

Abstract

Sustainable management of the Belgian exclusive economic zone (EEZ) has become important increasingly. This is due mainly to higher exploitation demands of marine aggregates, but also the dredging industry imposes high stresses on the seafloor. To anticipate on future developments, including the implantation of windmill farms, efficient evaluation tools and strategies of seabed nature and dynamics are needed, based on the best available science.

A three-tiered approach was followed, corresponding to three spatial scales: broad-based, regional and site-specific. On the scale of the Belgian part of the North Sea (BPNS), sediment transport models were further developed to evaluate large-scale sedimentary processes and to provide a baseline for any detailed investigation. On a regional scale, evaluation tools and strategies were developed within the view of the optimisation of environmental (impact) assessments. New site investigations integrated results from state-of-the-art geo-acoustical and terrain verification tools and from a multi-sensor benthic lander, equipped with hydrodynamic and sediment transport instrumentation. To assess the environmental impact of aggregate extraction, multidisciplinary research was carried through national and international cooperation. Knowledge was integrated on the physical, geomorphological, sedimentological and biological nature of the seafloor.

Valorisation of the results comprised a series of thematic maps on the nature and dynamics of the BPNS and a suite of recommendations on sustainable management and exploitation of the EEZ. The latter include criteria to select most appropriate locations for aggregate extraction and dredging/dumping operations whilst minimising environmental effects. However, sustainability can be ensured only if good management/policy practices are in place and implemented in a structural way.

Key-words: acoustic habitat modelling; sediment transport; waves; environmental impact assessment; sustainable exploitation; aggregate extraction; dredging/dumping; threshold criteria.

Introduction

Within the framework of the second Scientific Support Plan for a Sustainable Development Policy (SPSD II) of the Belgian Science Policy (BELSPO), MAREBASSE is a strategic research network, which focuses on the *“Evaluation of sedimentary systems and the development of new evaluation technologies within the view of a sustainable management of the Belgian exclusive economic zone (EEZ)”*.

With a view to a science-based approach to management, the development of a sediment-based integrated assessment framework was aimed at, to which knowledge of the nature and dynamical behaviour of sediments is central. This framework was considered necessary in order to answer management and policy questions as to how a sustainable exploitation of the seabed should be conceived and which approaches could be envisaged. Sediments are indeed an essential, integral and dynamic part of any aquatic system and are the key for a better understanding of the marine ecosystem. They are also a valuable socio-economic resource for construction material, nourishment of eroding beaches and land reclamation. Therefore, marine aggregates are increasingly being extracted. Unfortunately, this activity cannot be carried out without causing any detrimental effects on the seabed. With the increasing importance of aggregate extraction, the need for appropriate environmental (impact) assessment tools is being felt with growing urgency. This relates back to the need for sound baseline studies, both on a large and a small-scale, and preferentially based on interdisciplinary and multidisciplinary datasets. Understanding the nature and dynamic behaviour of sediments is also crucial for the optimisation of dredging and dumping activities. The continuous siltation in ports and navigation channels requires intensive dredging, after which the dredged material is in its turn dumped at sea. Dredging could be limited if the recirculation of the dumped material to the dredging areas or the sedimentation in the dredging areas (ports) could be limited. However, the research is not only relevant for these issues, but also for supporting the management of windmill farms implantation, seabed constructions and cables and pipelines, the designation of marine nature reserves and, generally, any spatial planning initiative.

The marine aggregate extraction industry is well established in various European countries, including Great Britain, the Netherlands, Denmark, Germany, France and Belgium. It provides up to 15% of some nation’s demand for sand and gravel (ICES 1992). Over the past few years, a steadily growing interest in the use of sea sand has been observed. In 1996, about 40 million m^3 were extracted from the part of the OSPAR Convention’s maritime area known as the “Greater North Sea region” (which includes the North Sea, the Channel from 5° W on, the northern Atlantic between Scotland and Norway up to 5°W and 62°N, the Skagerrak and the Kattegat), as compared to the 34 million m³ extracted in 1989 (see Table 1). Most countries report increasing concerns about this aggregate extraction (ICES 1997). Sea sand is used in construction for beach nourishment and land reclamation. The most obvious impact of sand exploitation is on the physical properties of the seabed, the interactions between hydrodynamics and morphology, the increased turbidity and redistribution of fine particles, the increased potential for coastal erosion following enhanced wave activity and the often negative effects on the benthic flora and fauna and fishing interests (OSPAR Commission 2000). This raises questions with regard to the sustainability of the extraction of these mineral resources and the need for measures to guarantee a long-term sustainable exploitation. These concerns are dealt with in legal provisions at the international level (see Appendix V of the OSPAR Convention). The ICES Code of Practice for the Commercial Extraction of Marine Sediments (ICES 1997) provides step-by-step advice on how marine dredging should be conducted in order to minimise conflicts with other users of the sea and to optimise the use of marine resources.

The dredged material that is dumped at sea primarily comes from the removal of sediments in order to keep navigation channels and ports clear or from the removal of excess sediment generated by coastal construction engineering projects. In 1996, a total of 74 million tonnes of dry weight (tdw) was dumped in the North Sea (OSPAR Commission 2000 and national data) (see Table 1). Over the years, no increasing or decreasing trends have been observed and the need for maintenance dredging works is not expected to increase in the long term (Quality Status Report, OSPAR Commission 2000). However, if harbours continue to extend and navigation channel depths go on increasing, the need for maintenance dredging *will* increase. International provisions on how dredged material has to be managed are laid down by the (regional) OSPAR Convention (Guidelines for the Management of Dredged Material 1998) and by the (global) London Convention on the prevention of marine pollution as a result of dumping waste (Waste-Specific Guidelines for Dredged Material). Conditions for permitting the dumping of dredged material were established within the framework of the OSPAR Convention. These aspects are particularly taken into consideration by the Bio-Diversity Committee (BDC), which is supported by the "Environmental Impact of Human Activities (EIHA)" working group, at their annual meetings. The necessary legally binding aspects of these guidelines and other recommendations are translated into national legislation.

Table 1: Quantities of sand/gravel taken from marine sources and quantities of dredged material dumped in the "Greater North Sea region" in 1996 (OSPAR Commission 2000)

Country	Aggregate extraction (10^6 m^3)	Dumped material (10^6 tdw)
Belgium	1,445	14,948*
Denmark	3,700	1,536
France	0,590	13,360
Germany	1,100	19,123
Netherlands	23,200	8,016
Norway	0,086	0,042
Sweden	0	3,309
United Kingdom	9,500	14,130
TOTAL	39,621	74,464

***quantities dumped in 1997, since no earlier data in tdw are available (see http://www.mumm.ac.be)**

To develop a framework for the assessment and management of marine sediments, a significant increase in the knowledge regarding the spatial variability of the seafloor was needed, both on a broad and on a site-specific scale. This requires appropriate mapping and modelling tools and instrumentation. Additionally, impact assessments should represent ideally an integrated view of the processes involved, calling for interdisciplinary and multidisciplinary research. Finally, a good interaction with end-users was considered essential for fine-tuning and valorising the scientific results to real needs (Figure 1). In this report, the following aspects will be dealt with: (1) set-up of environmental assessment tools and strategies; (2) broad-scale characterisation of the BPNS (Figure 0); (3) environmental impact assessment of the aggregate extraction on the Kwinte Bank; and (4) research integration and valorisation and exploitation of results.

In Van Lancker *et al*. (2003, 2004) more information can be found on (1) marine aggregate usage, estimated demand and growth against resource type and availability; (2) dredging location and dumping sites in relation to bottom sediments, hydrodynamic condition and sedimentation rates; and (3) environmental (impact) assessments in a European context.

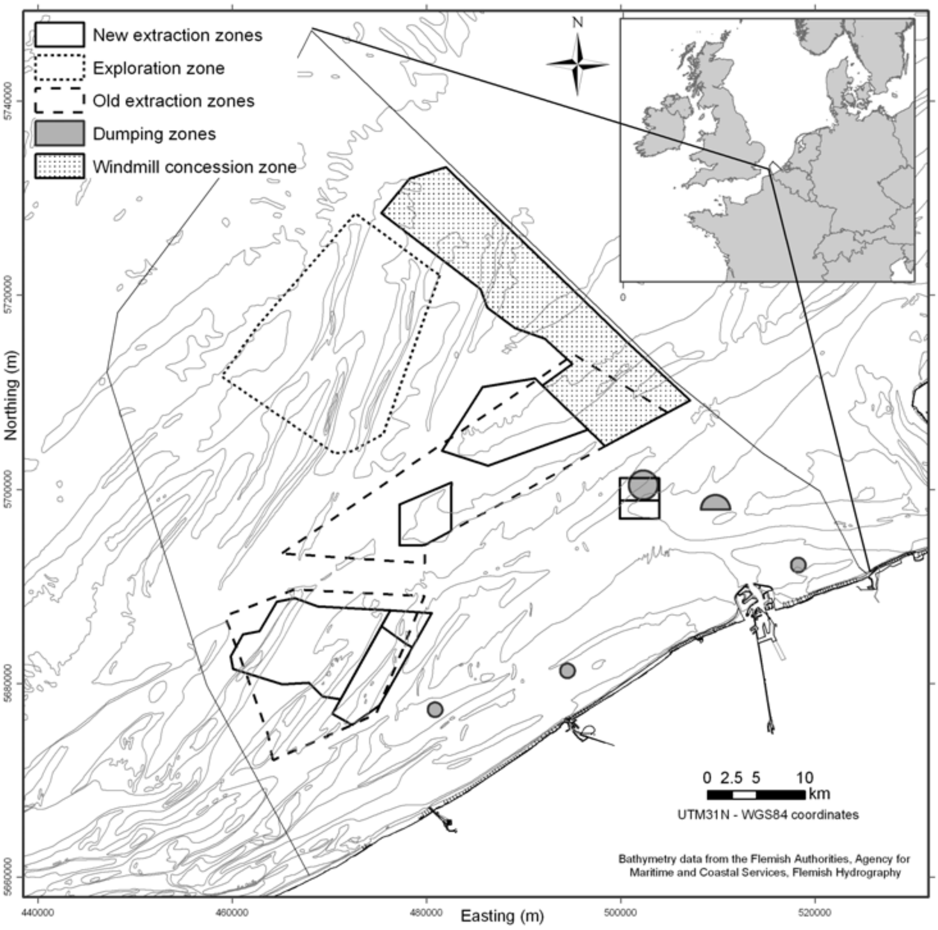

Fig. 0: The Belgian part of the North Sea with the locaiton of the main human activities, affecting the seabed.

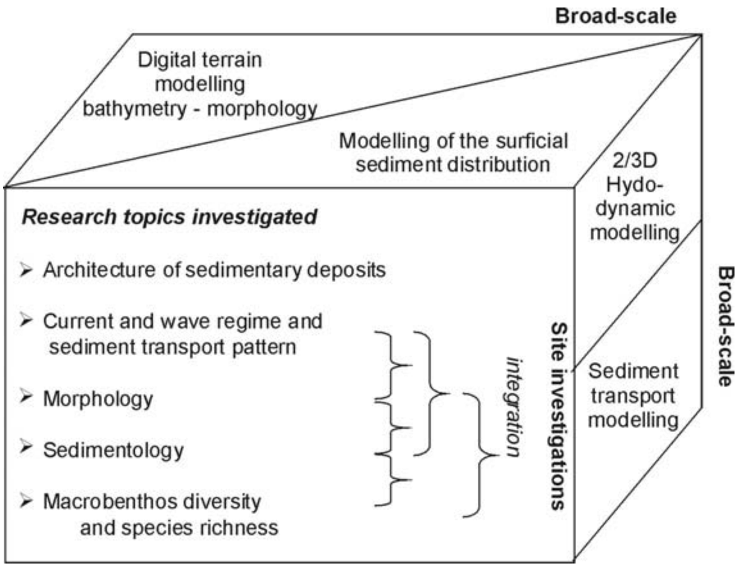

Fig. 1: The MAREBASSE research cube

Materials and Methods

Fieldwork programmes were the focal point of the regional and site-specific research. State-of-the-art instrumentation and methodologies were used for the site investigations (for locations, see Figure 2). The areas of interest were surveyed geo-acoustically using a variety of instruments. On the basis of the variability of these results, sampling locations were chosen (*'stratified random sampling approach'*). The Belgian oceanographic vessel RV/Belgica was the preferred platform for the field campaigns since it is equipped with state-of-the-art instrumentation. The RV/Zeeleeuw was used for some of the sampling operations.

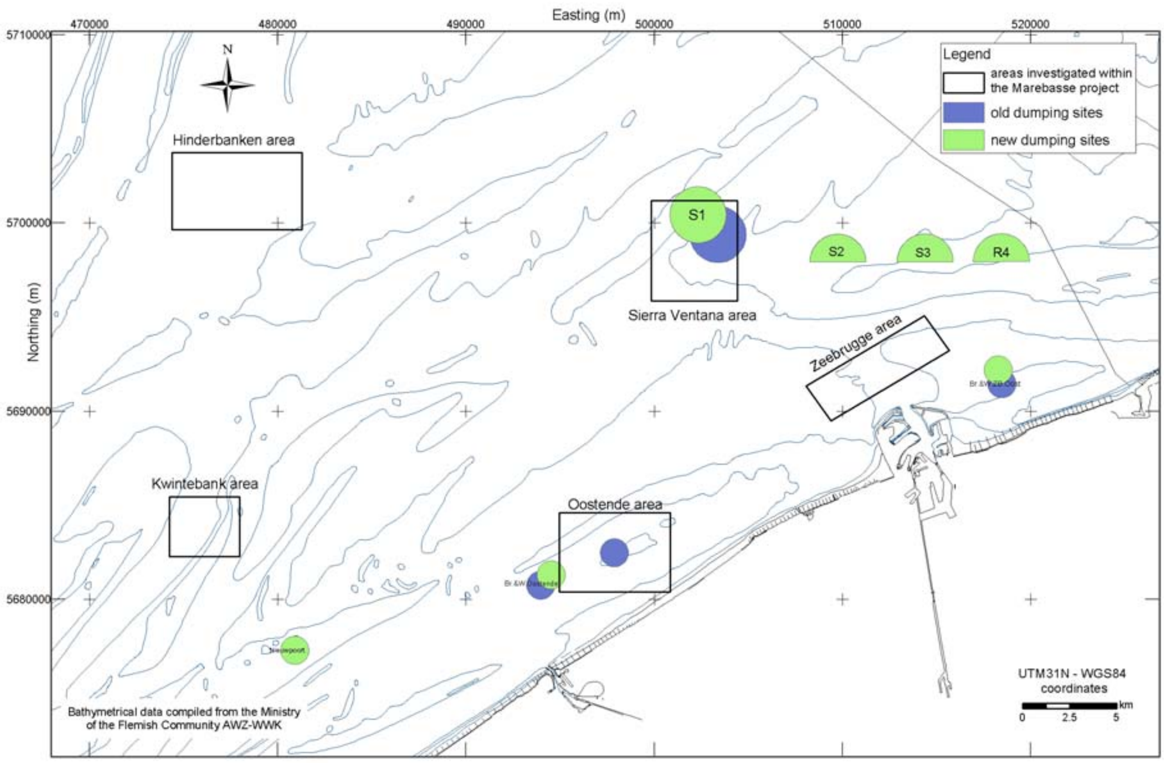

Fig. 2: Overview of the MAREBASSE site-specific research

Geo-acoustical surveying

Geoacoustic data from the following equipment was acquired mostly: (1) **very-high resolution multibeam system** (Kongsberg-Simrad EM1002S, 95-98 kHz) for detailed depth and backscatter registrations and their translation into seabed nature characteristics; (2) **very-high resolution digital side-scan sonar** (Geo-acoustics model 159D; 100/410 kHz) for optimised seabed imagery on seabed nature; (3) **very-high resolution seismics** (IKB Seistec), for examining up to which level exploitation had taken place and for evaluating resource availability in further detail.

In addition, a **towed seabed detector** (Detector type: Medusa SSU472; MEDUSA Explorations BV) was used. This instrument measured the natural radioactivity of the sediments (^{40}K, ^{232}Th and ^{238}U) and the sound from the shear of the detector with the seabed to respectively acquire information on the grain-size and roughness of the seabed (more info in Van Lancker *et al.* 2004).

For the processing of the data, **state-of-the-art software packages** were used, allowing efficient data integration. The measurement data was used for the calibration and validation of the models. Extensive research was done on the fate of seabed classification techniques in terms of their ability to discriminate fine to coarser sands and gravel on the seabed and to characterize habitats. The acoustic seabed classes of Roche (2002) were used to classify the seabed.

Ground-truthing

Good ground-truthing remains of paramount importance to obtain a representative view of the spatial and temporal variability of the seafloor. Generally, **Van Veen grabs** are ideal for a first reconnaissance of the seafloor, but remain inadequate for the sampling of mud and gravel. In muddy areas, **boxcoring** is preferred to gain insight into the upper 20-50 cm of the seafloor. Subcores are later analysed with X-rays and Gamma-densitometry. Where gravel is suspected, **a Hamon grab** is most suited since the loss of sample through 'wash out' is kept to a minimum. More information on the sampling techniques can be found in Van Lancker *et al.* (2003, 2004, 2005). **Video imagery** was obtained for the validation of acoustic backscatter and proved highly valuable in the gravel dominated areas. Details on the deployments can be found in Van Lancker *et al.* (2004, 2005).

Macrobenthos samples were collected with a Van Veen grab (sampling surface area: 0.12 m²; 1 sample per sampliong station), sieved alive over a 1 mm mesh-sized sieve, and fixed and preserved with a 8% formaldehyde-seawater solution. The post-treatment is described in Van Lancker *et al.* (2003). Based on an extensive dataset of macrobenthic samples, four subtidal communities were discerned on the BPNS (Degraer *et al.* 2003; Van Hoey *et al.* 2004): (1) *Macoma balthica* community (*M. balthica*); (2) *Abra alba – Mysella bidentata* community (or *A. alba* community; Van Hoey *et al.* 2005); (3) *Nephtys cirrosa* community; and (4) *Ophelia limacina – Glycera lapidum* community (further abbreviated as *O. limacina* community). Next to these communities, several transitional species assemblages, connecting the four communities, were defined. The described communities typically occur in a gradient of increasing grain size and decreasing silt-clay percentage.

Hydrodynamical and sediment transport measurements

Extensive hydrodynamic and sediment transport measurements were performed. The instrumentation included: **hull-** (300 kHz, RDI) and **bottom-mounted** (1200 kHz, RDI) **acoustic doppler current profilers** (AD(C)P), CTD and OBS instrumentation. ADP's are used to determine the vertical current distribution; CTD is a **conductivity-temperature-depth** meter and **optical backscattering sensors** (OBS) are used as a measure for suspended sediment concentrations. In-situ suspended particulate matter (SPM) was sampled using a **centrifuge**. Water samples were taken with **Niskin bottles** mounted on a Seabird STD/Carousel system (STCD-SBE09, OBS). Through tide measurements (13-hrs cycle) were carried out to characterise the hydrodynamics and sediment transport capacity. The water samples were filtered on board to determine SPM and POC (Particulate Organic Carbon) concentration. At every station a Reineck and/or Van Veen sample was taken. Additionally, a **laser in-situ scattering and transmissometry** (LISST100C) was used. The LISST-100 instrument allows gaining insight into the size-dependent sediment transport processes, the relation between the current stress and the mean sediment size and the settling velocity of the flocculated matter. During some spring/neap tidal cycles, a **multisensor autonomous benthic lander** (tripode) was placed on the seafloor to obtain continuous measurements using the LISST-100C, OBS and depth sensors and **ADCP**/**ADV**. This approach was new to the Belgian scientific community. A **waverider buoy** was deployed for studying wave regimes.

More detail can be found in Van Lancker *et al*. (2003, 2004, 2005). Some of the observation and modelling tools and the set-up of thematic maps are discussed further.

Results

1. IMPROVED TOOLS FOR ENVIRONMENTAL ASSESSMENTS

The set-up of evaluation tools and strategies should be viewed with respect to the optimisation and scientifically upgrading of 'environmental (impact) assessments'. These are in principle multidisciplinary and ideally integrated knowledge on the physical, geomorphological, sedimentological and biological nature of the seafloor is provided.

1.1. Observation tools

Acoustical tools have been evaluated for their use in environmental assessments. Emphasis was put on the translation of acoustic facies in terms of sediment nature ('*resource maps*') and its relation with the occurrence of macrobenthic species/communities *('habitat maps'*). Acoustic **seabed classification**, based on multibeam backscatter (Roche, 2002), allowed defining and validating seabed classes that are valuable for the mud, sand and gravel dominated areas of the BPNS. Since all of the acoustically surveyed areas were physically and biologically sampled, the results of the acoustical seabed classification could be validated for both sediment type and the likely occurrences of macrobenthic communities. Examples can be found in Du Four and Van Lancker (submitted, in Annex); Bellec *et al.* (submitted) and Van Lancker *et al.* (2005). **Acoustic habitat modelling** approaches have been tested also (Verfaillie *et al.*, in Annex). In addition, **a habitat signature catalogue** was set-up demonstrating various acoustic facies and their interpretation in terms of physically, biologically and human-induced traces on the seafloor (Annex, see also http://www.rebent.org/mesh/signatures/). However, the datasets did not allow deducing significant statistical relationships between acoustic classification and the true seabed nature. This would require very detailed observations and extensive ground truthing on the sedimentological, geotechnical and biological nature of the seafloor. In addition, very accurate video imagery would be needed. An overview of **knowledge/data and tools/innovation needs** to support a sustainable exploitation of a particular extraction site is discussed in Van Lancker *et al.* (submitted, Annex).

1.2. Modelling tools

The **hydrodynamical and sediment transport models** were improved as well. A new grid (250x250 m^2) was set-up and the models were calibrated and validated with the newly acquired data. The 3D hydrodynamic model COHERENS (Luyten *et al.* 1999) was used to calculate the currents and the water elevations as influenced by tides and atmospheric conditions. The hydrodynamic model solves the momentum equation, the continuity equation and the equations of temperature and salinity. The equations of momentum and continuity are solved using the "mode-splitting" technique. COHERENS disposes of different turbulence schemes, including the two-equation k-ε turbulence model, which was used in the present study. The model is implemented on two coupled grids. The coarse grid model BCS has a resolution of 42.86" in longitude (817-833 m) and of 25" in latitude (772 m) and has 20 σ-layers over the vertical. This model provides the open sea boundaries for the fine grid BCS-F model, which has a three times higher resolution and has 10 σ-layers over the vertical. Figure 3 indicates the extension of both models. On its open sea boundaries, the BCS model is linked to two regional models. The CSM model comprises the Northwest European Continental Shelf and calculates the boundary conditions for the North Sea model (NOS). The NOS model generates the boundary conditions for the BCS model. The CSM model runs in two dimensions and is driven by the elevation at the open boundaries, governed by four semi-diurnal and four diurnal harmonic constituents (Q_1, O_1, P_1, K_1, N_2, M_2, S_2, and K2).

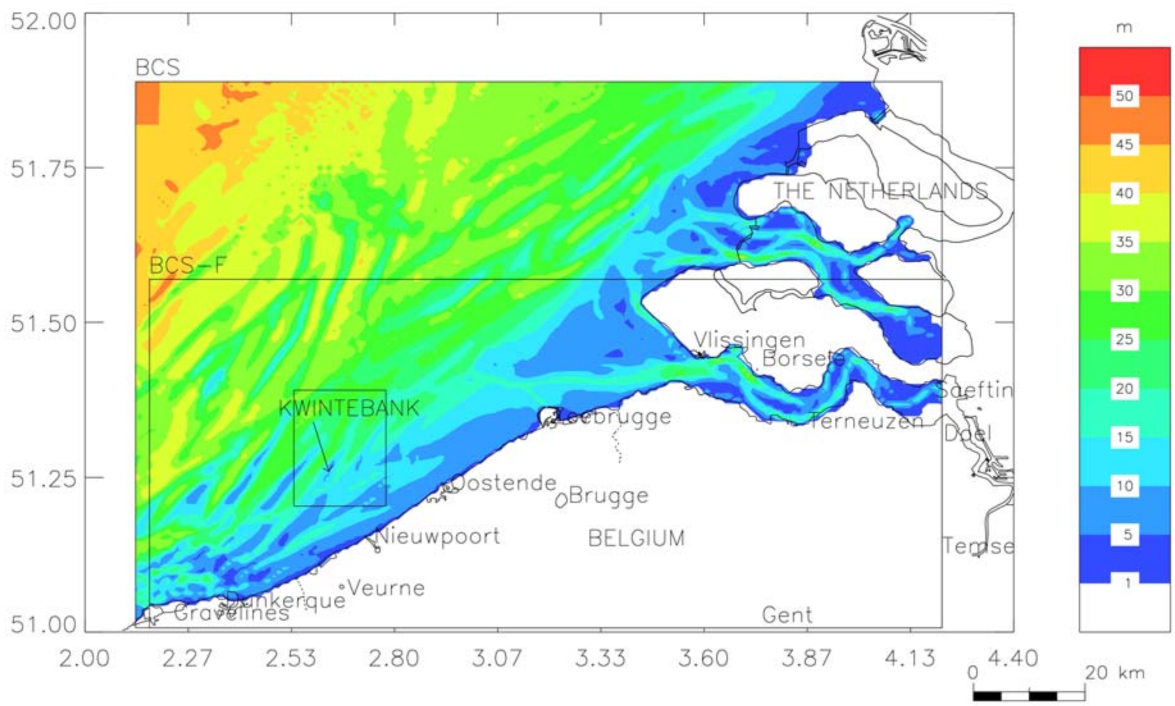

Fig. 3: Bathymetry of the Belgian coastal waters. The large rectangle indicates the extension of the coarse BCS model grid, the smaller rectangle the extension of the fine BCS-F model grid. The smallest rectangle gives an indication of the location of the Kwinte Bank and the extension of the grid where the Kwinte Bank results are shown.

The MU-SEDIM sediment transport model is implemented on the same grid as the BCS-F hydrodynamic model and calculates the total load under the influence of the local hydrodynamic conditions. The current bottom stress, one of the most important driving forces, is a function of the depth-averaged current velocity and of the Nikuradse bottom roughness. For the calculation of the Nikuradse bottom roughness, a distinction was made between the skin friction and the total friction. The skin friction is the roughness experienced by the sediments at the bottom and is calculated by using the expression of Engelund and Hansen (1967). The total friction is the friction experienced by the currents and is influenced by the bottom load and the bed forms; the calculation is based upon Grant and Madsen (1982). The bottom stress under the influence of currents and waves is based upon the formula of Bijker (1966).The formula of Ackers and White (1973) was used for the sediment transport calculations, because it yielded the best results in a comparison carried out by Sleath (1984). This equation was adapted by Swart (1976, 1977) to include the effects of waves on sediment transport. The median grain size, which is an input parameter of the sediment transport model, is taken from the map of Verfaillie *et al.* (2006). Finally, the model calculates the evolution of the bottom (erosion/sedimentation), using a continuity equation for the bottom sediments (Djenidi and Ronday 1992).

The modelling of waves was carried out using two different third-generation wave models: the WAM model (WAMDI 1988), adapted for high spatial resolution applications in shallow waters in the WAM-PRO version (Monbaliu *et al.* 2000), and the TOMAWAC model (Benoît *et al.* 1996). Both models solve the conservation of action density, but wave propagation and the source terms are computed using different numerical methods and time steps. The WAM-PRO implementation consists of four nested runs starting from a coarse grid, covering the North Sea and part of the Norwegian Sea from 47.83°N to 71.17°N and from 12.25°W to 12.25°E, with a resolution of 1/3° in latitude and 1/2° in longitude (~32 km spacing), and ending with the finest grid covering the Belgian coastal area, from 51.10°N to 51.60°N and from 2.38°E to 3.60°E, with a resolution of 1/450° in latitude and 1/240° in longitude (~300m). The TOMAWAC model was implemented on the same area as used for the WAM-PRO coarse grid. However, the use of an irregular grid mesh allows zooming in on areas of interest without successive nested model runs being required. Node distance ranged from 70 km at the boundaries of the domain to about 150 m for the Kwinte Bank area. Comparison with buoy measurements indicated a similar performance for both models, with root mean square errors of about 25 cm for the significant wave height hindcasts. Note that TOMAWAC is part of the TELEMAC software suite that also contains a hydrodynamic and sediment transport module. To allow sediment transport model intercomparisons (see Kwinte Bank case study below), the TELEMAC-2D hydrodynamic model and the SISYPHE morphodynamic model were also implemented, on the same unstructured grid, thus facilitating efficient exchange of variables between the different model components.

More information can be found in Van Lancker *et al.* (2004), Van den Eynde *et al.* (submitted) and Giardino *et al.* (submitted).

2. ENVIRONMENTAL CHARACTERISATION OF THE BELGIAN PART OF THE NORTH SEA

An appropriate evaluation of a sedimentary system can only be carried out if it can be situated in a larger scale sediment dynamical framework. The transport of sand and mud are discussed here, based on extensive hydrodynamic and sediment transport modelling.

2.1. Sand transport

The southwest-northeastward oriented sandbanks are clearly visible on the erosion/deposition pattern in Figure 4, with erosion on the western side and deposition on the eastern side (east). The Flemish Bank area is characterised by strongly varying residual sand transports (Figure 5).

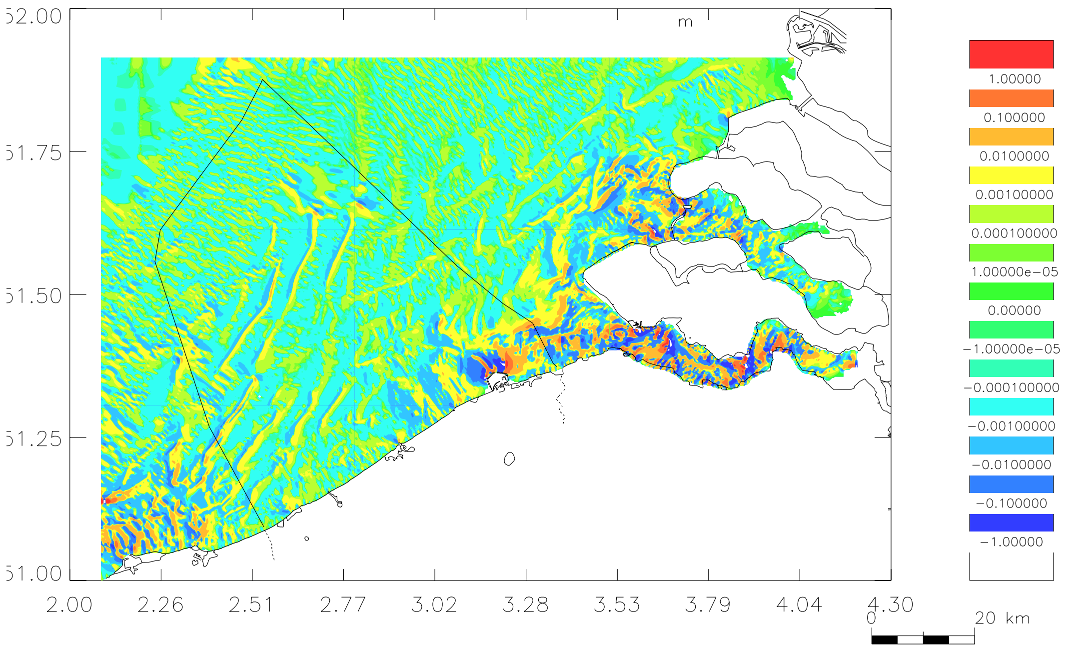

Fig. 4: Erosion and deposition pattern of sand (in m/14days) as calculated by a 2D sand transport model (see annex for results of 3D model). The very high values between Oostende and the Westerschelde are likely erroneous because of the muddy sediments of which the transport is not correctly calculated by sand transport formulae.

The Easter- and Westerschelde are dynamic places, with high erosion and deposition; this is caused by the big variations in bathymetry and current velocities over short distances.

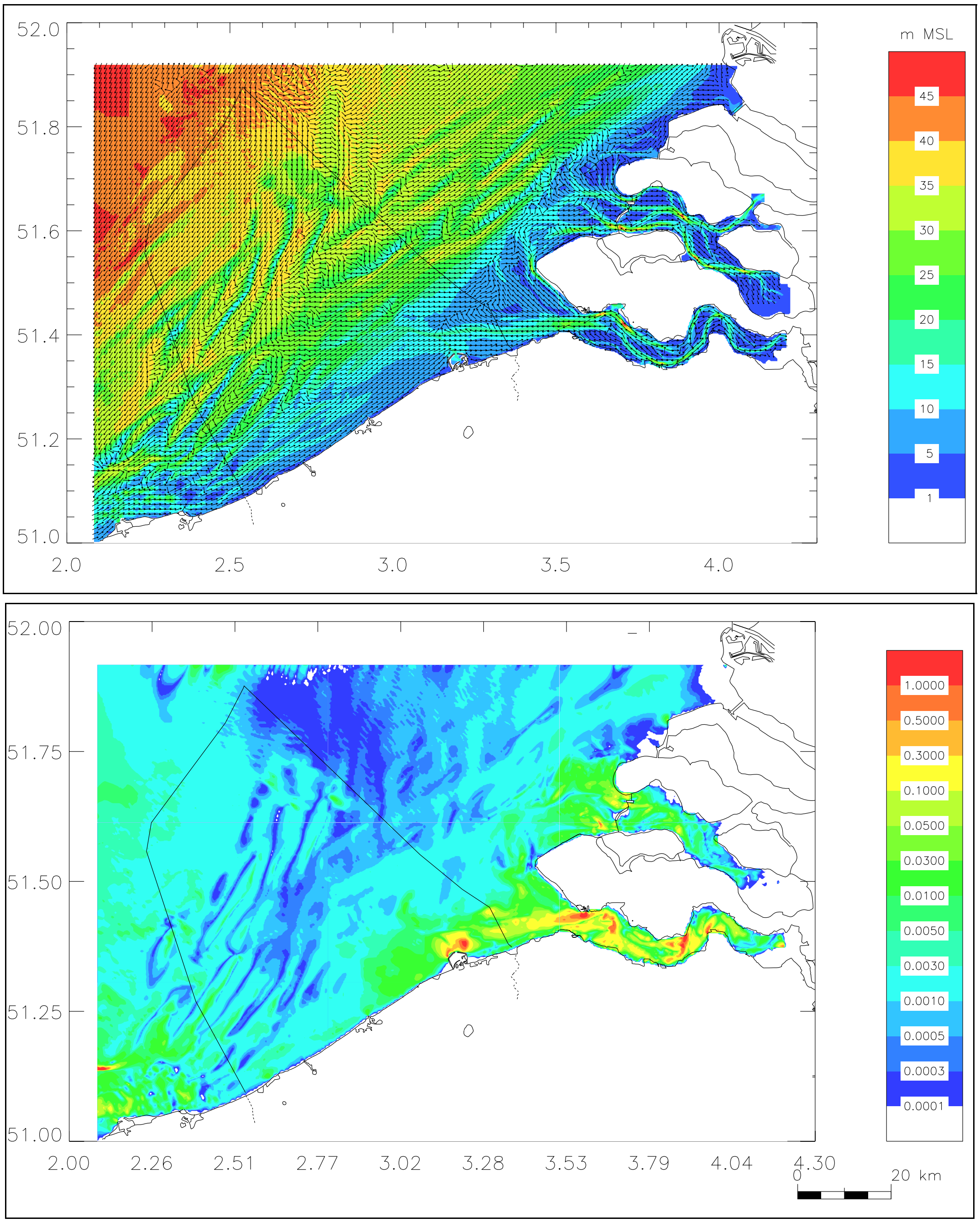

Fig. 5: Residual sand transport direction (above) and magnitude (kg/m²s) of residual sand transport (below) on the BPNS. The sand transport has been simulated over 14 days using the fine grid 2D sand transport model, including tidal forcing.

2.2. Mud transport in the southern North Sea

Residual flow in the southern North Sea

The residual flow has been simulated using the 2D OPTOS-CSM hydrodynamic model for the period 1997-2002 taking into account meteorological influences. This model covers the North Sea and the English Channel and has as west boundary the 200 m isobath line along the continental shelf in the Atlantic. The grid size is about 5×5km². The results show that the net inflow of water towards the North Sea through the Strait of Dover is higher during spring and winter than during autumn and summer and that the inflow is for about 50% determined by wind effects. The wind effects are limited during summer and autumn to about 10%. The residual discharge through the Strait of Dover varies following our calculations between 0.049 Sv and 0.089 Sv (yearly average is 0.070 Sv). These are values similar as in literature: Salomon *et al.* (1993) have calculated using a 2D model a residual flow of 0.114±0.016 Sv for the period 1983-1991. The highest values occur between October and January and the lowest between May and August. Bailly du Bois *et al.* (1995) estimate a water flux through the Strait between 0.097 Sv and 0.195 Sv for 1988. Prandle *et al.* (1993) mention a long term net inflow of 0.11 Sv. By combining HF-radar measurements and ADCP current profiles Prandle *et al.* (1996) have calculated a net flow of 0.094 Sv. Garreau (1997) estimates a residual flow of 0.105 Sv for a yearly average wind forcing and direction.

Residual mud transport in the southern North Sea

The SPM transport in the southern North Sea has been calculated by multiplying the residual discharge with the seasonal averaged SPM concentration, derived from corrected SeaWiFS images of 1997-2002 (Fettweis *et al.*, 2006 and 2007). SPM enters the southern North Sea through the Strait of Dover where it is partly deviated towards the English and partly towards the Belgian coast. The highest residual mud transports occur during winter and the lowest during summer. Winter and also autumn are seasons with a high SPM concentration while during winter and spring the highest residual discharges occur. Therefore the net mud transported are almost equal during spring and autumn and the highest mud transports are observed during winter, see Figure 6. For this figure, the SPM transport has been calculated by multiplying the residual H2O transport simulated by the OPTOS-CSM model (with meteorological forcing) with the seasonal averaged SPM concentration, derived from SeaWifs SPM maps (1997-2002) and through tide measurements. (from up to down: spring, summer, autumn, winter).

The residual mud transport has been calculated through the Strait of Dover (51°N, 1°E-2.0°E) and through a boundary between the UK and the Netherlands at 51.9°N. The residual transport through the Strait of Dover is situated – following our calculations - between 1.45×10^6 t during summer and 11.59×10^6 t during winter. This results in a yearly SPM transport of 21.96×10^6 ton entering the southern North Sea, divided about equally between the English and French side of the Strait. Lafite *et al.* (1993) estimated the SPM transport through the Strait during the EC FLUXMANCHE project as 19.22×10^6 t/yr (they used an average SPM concentration of 6.1 mg/l), from which 0.92×10^6–4.19×10^6 t/yr (i.e. 5-22%) along the French coastal zone. On the basis of SPM concentration data and averaged water discharge they obtained $21.6\times10^6 \pm 2.1\times10^6$ t/yr. McManus and Prandle (1997) used model results and measuring data of SPM concentration to obtain a residual transport through the Strait of Dover of 44.4×10^6 t/yr. In the review of Velegrakis *et al.* (1997) the residual SPM transport varies between 2.5×10^6 and 30.5×10^6 t/yr.

On average the calculation results in an outflow of SPM of about 23.02×10^6 t/yr through the northern boundary (51.9°N 1°-4°E). Compared with the inflow there is a difference of 1.06×10^6 t/yr, which corresponds to an error of 5% on the mud balance of the southern North Sea.

The residual transport of SPM entering the Belgian coastal zone is situated between 1.18×10^6 t during summer and 7.45×10^6 t during winter, corresponding thus to 14.38×10^6 t/yr. This corresponds well with the 15.4×10^6 t/yr of mud input calculated by the MU_BCZ model (Fettweis and Van den Eynde, 2003).

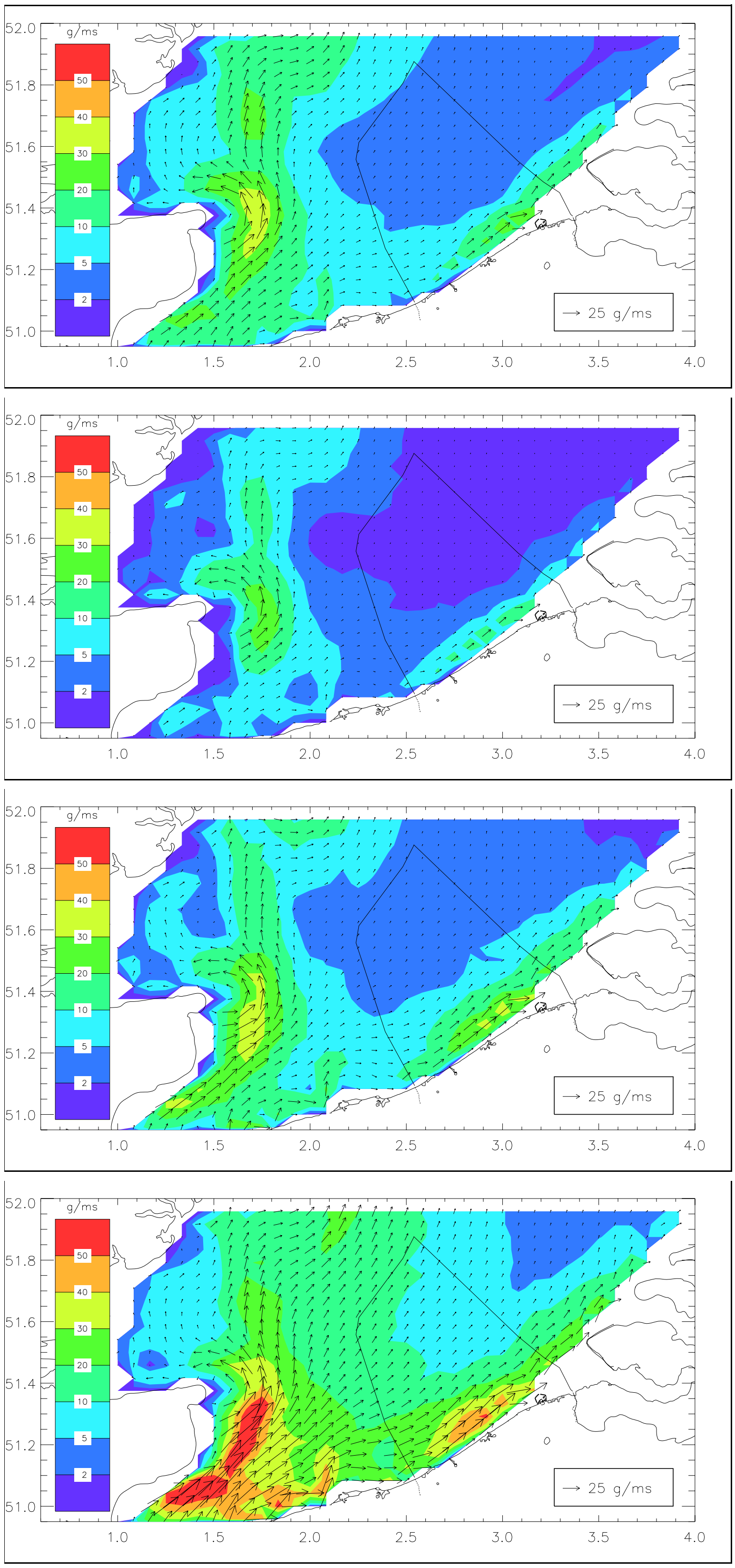

Fig. 6: SPM/season (g/ms); from up to down: spring, summer, autumn and winter *(see text).*

3. ENVIRONMENTAL ASSESSMENTS ALONG THE MUD-SAND-GRAVEL GRADIENT

3.1. Introduction

Sites were selected that are resource, but also issue-driven. On a resource level, the variety of marine sediment types, found on the BPNS, were covered to test and tune the best available techniques to the evaluation and prospecting of sediments along the mud-sand-gravel gradient. The choice of the sites was biased towards areas that are important within the context of the sustainable exploitation of the EEZ such as areas of interest related to marine aggregate extraction, dumping/dredging and to the implantation of windmill farms. The sand/mud dominated environments were located around dumping locations. For both the Sierra Ventana (S1) as the Oostende region (Br&W Oostende), the old dumping sites had to be abandoned as they reached their maximum capacity. As such, the old areas became interesting from a marine aggregate extraction perspective. Presently, two extraction zones (3A, 3B) have been defined in the vicinity of the old S1 dumping site. The site for an environmental impact study was fixed to the central part of the Kwinte Bank as marine aggregate extraction is there prohibited since 2003; as such the potential recovery of the area could be studied. An area representative of gravel deposits was selected on the basis of former geological, morphololological and sedimentological data. From these, the southern part of the Hinder Banks was most promising.

3.2. Oostende dumping site of dredged material *(only summary)*

The Oostende dumping site region is characterized by three main sedimentological areas. The western part consists of mud with sometimes a thin top layer of sand, the central part consists of shell fragments, mixed with sand or mud and the eastern part consists of sandy sediments. The relation of the sedimentology with the morphology is obvious as the sand is present on the shallowest part of the region and small bedforms can be observed here. This is confirmed by the residual water transport which flows strongest over the shallowest part towards the NE. Side-scan sonar and multibeam recordings reveal a fair amount of residual dredge spoils near the old dumping site, representing hard material. The central area of the region is characterised by small positive structures, which might be due to dumping. In general, the bottom stress is favourable for mud deposition, especially in the deeper parts. An acoustic seabed classification based on multibeam backscatter values reveals a certain correlation, especially for the very fine (mud) and very coarse (shells) sediments, but holds also many uncertainties. Seabed classification based on the radiometric MEDUSA technique however reveals a good correlation between the mud fraction, the median grain-size (d50) and the bottom roughness determined by this technique and respectively the weigth percentage of silt-clay, the mean grain-size (mean) and the weigth percentage of shells determined by the in-situ samples. Biological analysis showed the presence of mainly the *Abra alba – Mysella bidentata* community (SA1), the *Nephtys cirrosa* community (SA4) as well as their transitional species associations. The area is regarded density- and diversity poor. A full description of the site can be found in Van Lancker *et al.* (2004).

3.3. S1 dumping site of dredged material

The dumping ground S1 is the main dumping site on the BPNS. Annually, on average $5x10^6$ ton dry matter (TDM) is dumped, originating mainly form the shipping channels Scheur, Pas van het Zand and the outer part of the harbour of Zeebrugge (Figure 7). The average current velocity is 0.3 m/s, increasing to 1 m/s during flood (Lanckneus *et al.*, 2001; TVNK, 1998). The hydrodynamics are mainly tidally driven; nevertheless wind and density currents can be important.

The dredged material consists mainly of fine-grained material. The proportion between the sand and the mud fraction is variable, partly depending on the place of dredging. Measurements indicate that 80-90% of the dumped sand stays on the dumping place, the remaining is transported back to the navigation channel Scheur West (HAECON, 1994). Tracer experiments, which were later confirmed by model results, have shown that the mud fraction is spread out over a wide area under the influence of the prevailing meteorological conditions. In calmer weather conditions, the mud is recirculated towards the coast, where a turbidity maximum occurs (Van den Eynde, 2004). S1 came into use in 1966 and since then it has been relocated 4 times when its maximum dumping capacity was reached. Research was focussed on the two most recent dumping sites. They will be referred to as the 'old' dumping site (1984-1999) and the 'new' dumping site (1999-present). Both sites are circular, with a surface area of 7.1 km^2.

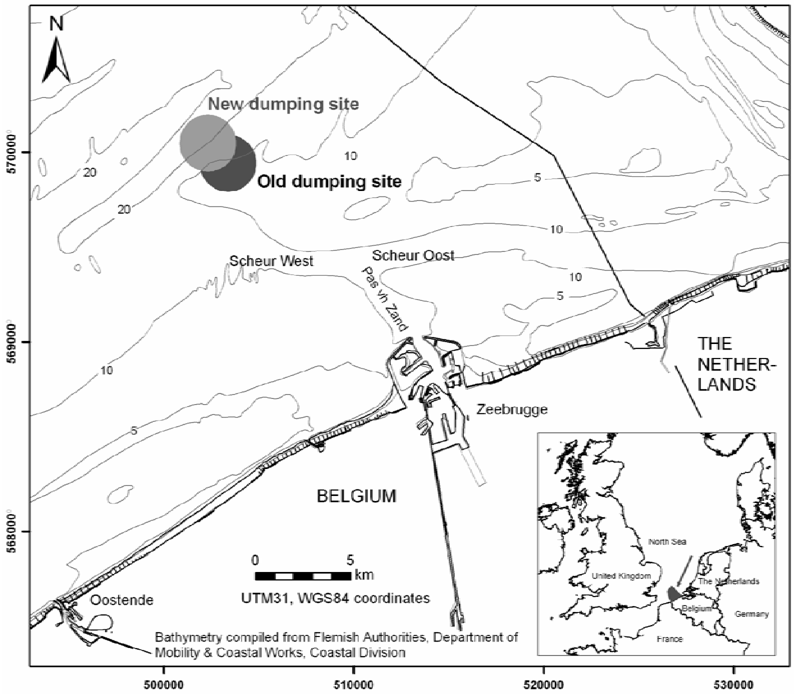

Fig. 7: Location of the old and new dumping site Br&W S1 on the BPNS.

The interaction of dumped sediments with the existing morphological and sedimentological conditions and the recovery after cessation of dumping activities is still poorly known, especially on the long-term. From the research results obtained in this area, a quantitative impact study has been performed of the dumping of dredged material on two overlapping dumping sites (Du Four and Van Lancker, submitted (in Annex)). The sites are situated on different morphological entities; an old dumping site closed in 1999 and located on a sandy shoal, and a new one located in a tidal swale. Chrono-sequential single-beam echosoundings, high-resolution multibeam bathymetrical and backscatter data, ground-truthed with boxcores and vibrocores, were analysed. The results clearly show that the dumping has caused a clear depth reduction between 1995 and 2004. Different yearly growth values and sedimentation patterns were found for the old and new dumping sites, due to the difference in morphological setting. The present morphology of the old dumping site -an irregular-shaped dump mound, with sand piles on the edges and a depression in the centre- reflects the way of disposal of the dredged material. On the new dumping site, a dump mound is found, which is characterised by impact features such as depressions and topographic highs. After cessation of the disposal of dredged sediments on the old dumping site, the site has restored quickly its morphodynamic equilibrium. Bedforms were formed within less than one year and their distribution and corresponding sedimentology is again representative for the Belgian coastal zone. Between the large dunes, small depressions occur, which are thought to be remnants of single dumping events. The results of the physical impact can be found in Annex (Du Four and Van Lancker, submitted).

It is clear that dumping has had a negative ecological impact. On the old dumping site, the macrobenthos is characterized by the presence of (1) the *Nephtys cirrosa* community, which is typically found in clean fine to medium sands; and (2) a transitional species association, biologically situated between the *N. cirrosa* community and the *Ophelia limacina – Glycera lapidum* community, which is typically encountered in medium to coarse sands. Both species associations are known to be poor in species variety and density (Van Hoey *et al.* 2004). Furthermore, nine of the stations at the old dumping site or in its close vicinity are devoid of macrobenthos, a condition that is rarely found in the Belgian sector of the North Sea. Poor to extremely poor macrobenthic life is generally characteristic of the old dumping site. Due to the lack of a representative amount of samples from the new dumping site, its current biological state cannot be elaborated on. Contrary to the old dumping site, the wide area of the Sierra Ventana is dominated by the biologically rich *Abra alba* community, which inhabits fine to medium sands enriched with a low percentage of mud (average about 5%). It remains unclear whether this community should be considered as the natural macrobenthic state of the area or if it was positively impacted by the outwash of fines during the dumping activities.

Although the study was only meant to provide baseline information for guiding the further exploitation of this region, it has also lead to numerous research questions still to be investigated:

The long-term topographical evolution of the Sierra Ventana region has been strongly influenced by the dumping activities from 1966 onwards. Between 1962 and 1986 an accretion of sediments of up to 7.5 m took place. This demonstrates that the recent evolution needs to be investigated over a large area, as the accretion occurs also outside the dumping site, mostly towards the navigation channels.

This study was the first to explore the seafloor morphology in detail. In doing so, it has revealed a persistent occurrence of an ebb-dominated bed-load transport. Further investigation is required to establish the implications of this observation regarding the recirculation of dumped material towards the dredged areas and the harbour.

Further research is also needed on the impact of the altered morphology on the hydrodynamic regime and on sediment transport. The most prominent impact has been observed at the old Oostende dumping location. There, dumping caused a topographical high that divided the near-coastal swale in two, with increasing current velocities towards the coast.

The internal structure of the dumping site still needs to be investigated from a sedimentological point of view. This is needed in order to establish the sedimentation pattern of dumping sites situated in a tidal gully and of those situated on a sandy shoal.

The resulting knowledge is crucial for the planning of marine aggregate extraction at former dumping sites.

Finally, further investigation is needed to find out whether the presence of the *A. alba* community in the wider area is to be attributed to the unique location, just outside the high turbidity zone of the Belgian coastal zone, or whether it is related to the increase in fines due to the dumping activities.

From the results, it is recommended that the geographic extension of dumping sites as well as their displacement be restricted. If this recommendation is taken to heart, possible medium- to long-term negative impact will be concentrated in a small area. If displacement of dumping sites is needed, it has to happen on the basis of an integrated study incorporating both short-term and long-term effects. Sites that are characterized by (1) limited recirculation towards the dredged areas, (2) sediments similar to the sediment that will be dumped, and (3) poor macrobenthic life are to be preferred. Moreover, the quantity as well as the quality of the dumped material is to be taken into account. If a large increase in turbidity is to be expected, this may significantly influence the wider area of the dumping site.

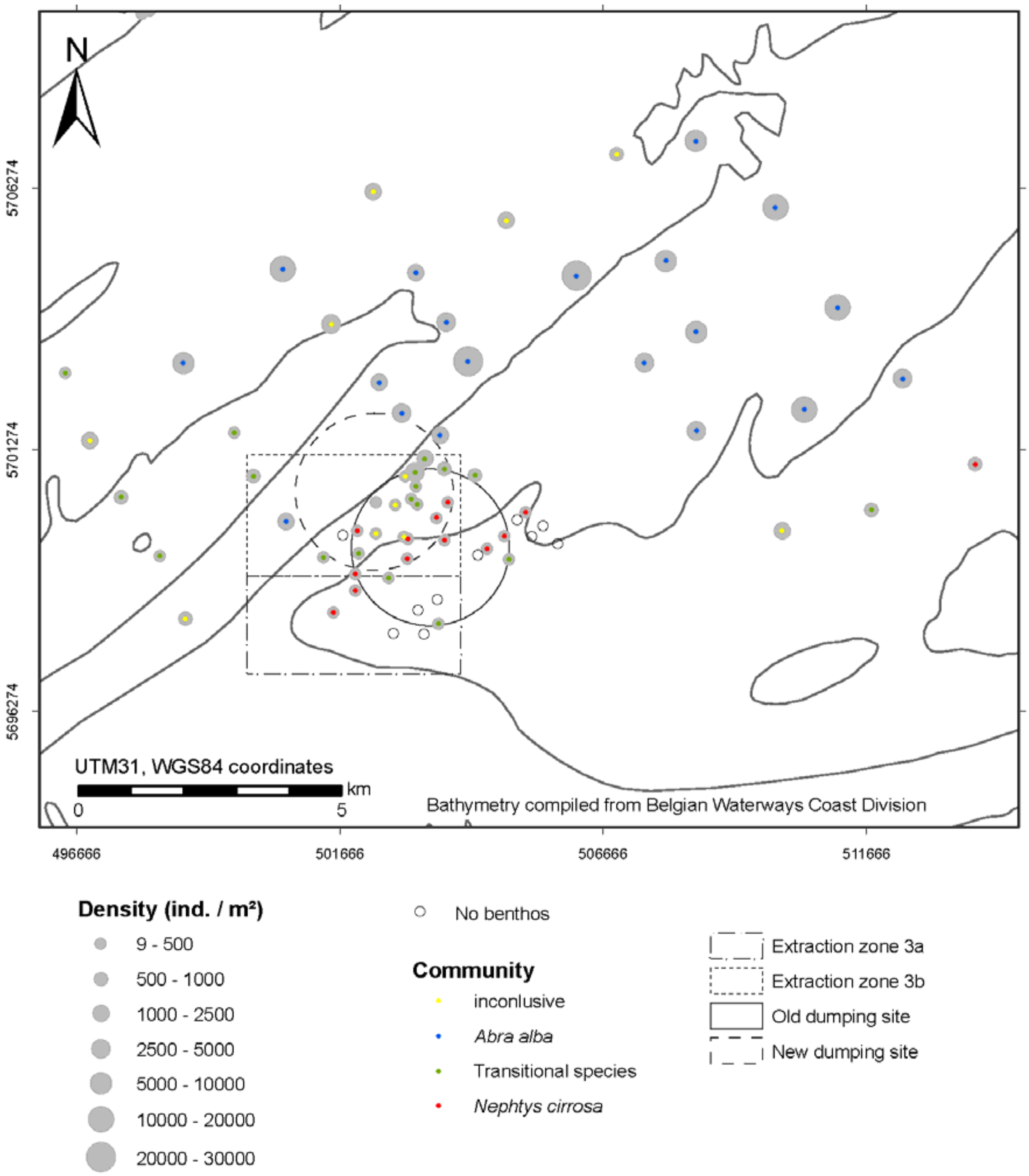

Fig. 8: Macrobenthos densities and communities along the Sierra Ventana region. The dumping sites are generally characterized by low species densities. Sometimes no fauna is found at all. To the NE, on the other hand, the richest and most diverse macrobenthic community (*Abra alba*) is found in its highest densities. *All inconclusive samples should be considered as problematic with regard to classification, not because of biological anomalies, but because of the difficulties involved in drawing a line into a continuous biological gradient.*

3.4. Gravel dominated area along the southern part of the Hinder Banks

Based on acoustic seabed classification results, obtained in 2000 (Deleu, 2001), the probability for gravel occurrences seemed highest in the swales in the southern parts of the Westhinder and Oosthinder area (Figure 9).

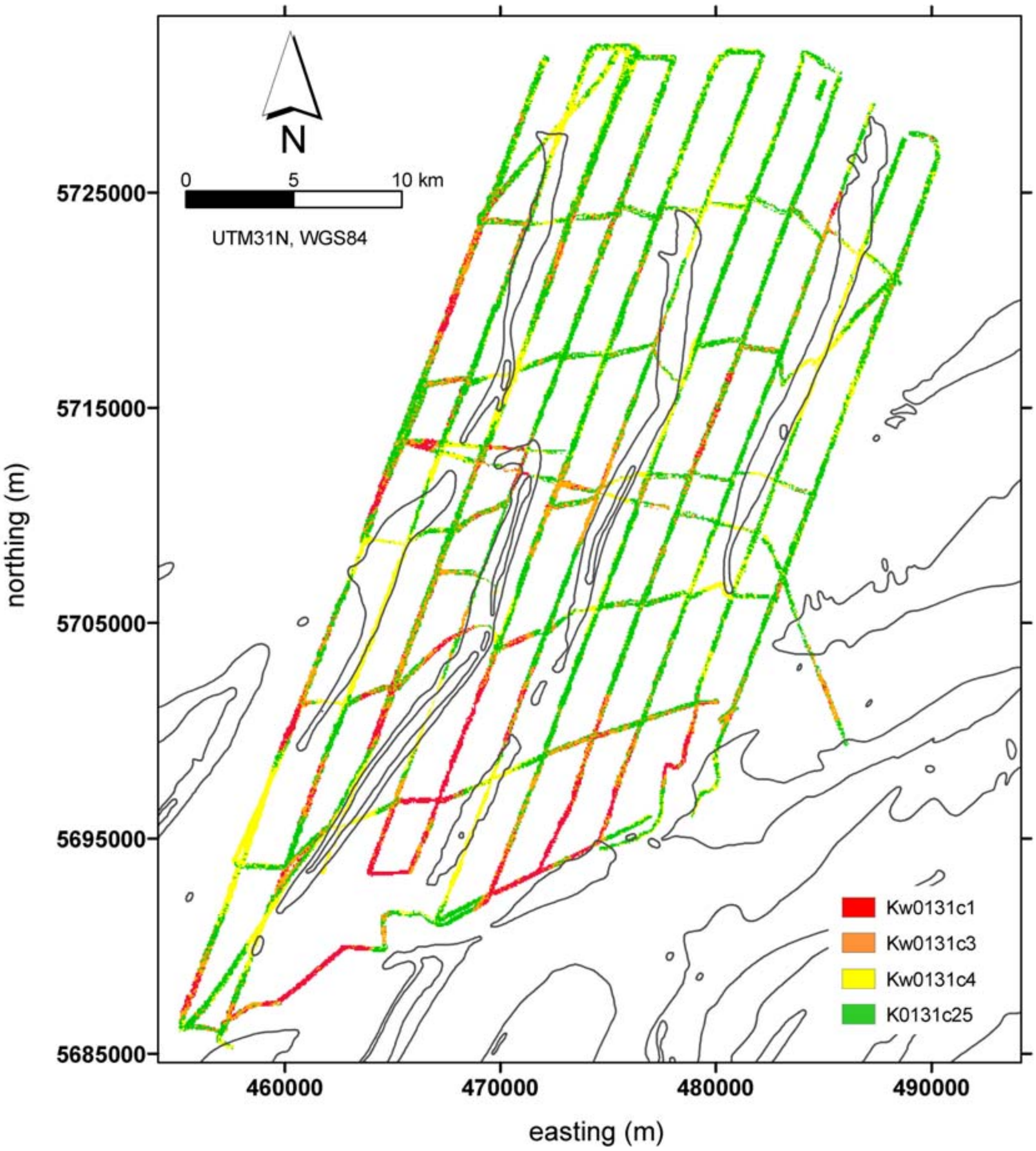

Fig. 9: Acoustic seabed classification results along parallel lines covering the Hinder Banks region. Gravel occurrences are associated with the acoustic class Kw013c1 (class 1).

Based on these results the area, east of the Oosthinder, was surveyed first. With subsequent sea-going campaigns, the area was further surveyed to the west (Figure 10). Most remarkable was the abrupt depth difference of 2-3 m which is clearly visible in the swales. Its location corresponds with a known offshore scarp in the Top Tertiary erosion surface (Liu *et al.*, 1992) and might be a remnant of an old river terrace (Deleu and Van Lancker, Annex).

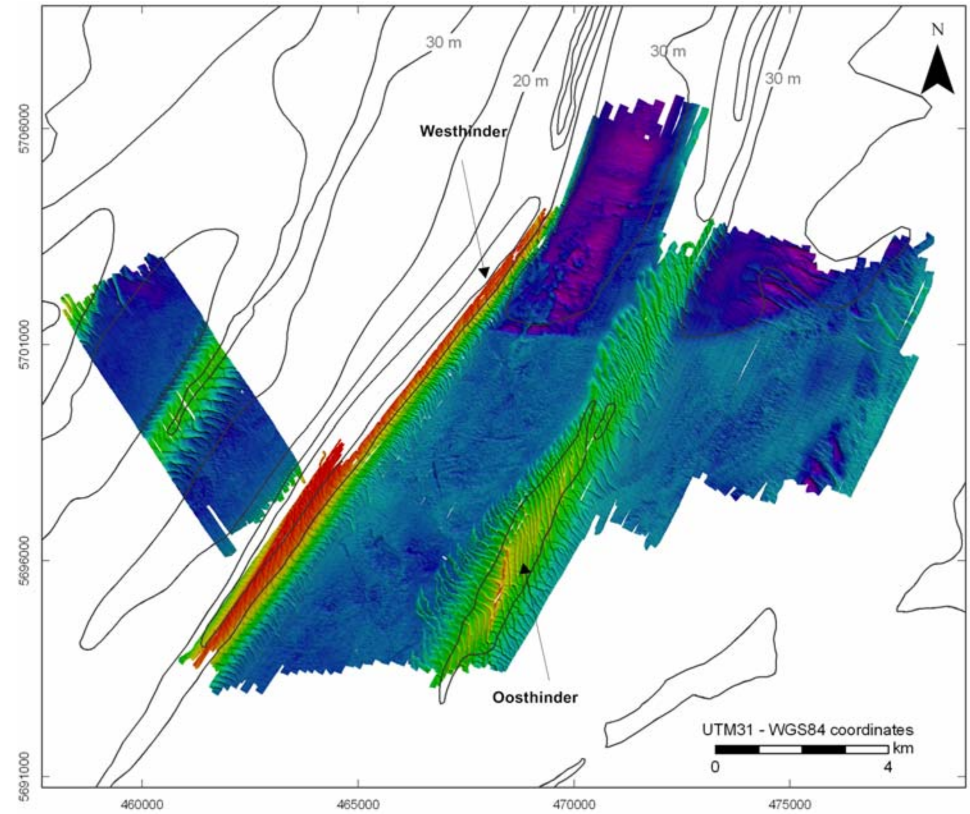

Fig. 10: Newly acquired multibeam bathymetry sailed in the southern region of the Hinder Banks. Note the abrupt depth difference corresponding with the location of an offshore scarp in the Top Tertiary erosion surface.

Water depths are around 35m below MLLWS. The dominant sedimentology is a mixture of coarse sand with gravel and sometimes a slight amount of mud. Here only the newly processed multibeam imagery is discussed together with the results of the ground truthing. The latter was for the first time performed with a Hamon grab allowing a more quantitative sampling of the seafloor. New insights into the geological setting of the gravel deposits are discussed in Annex (Deleu and Van Lancker).

Morphology

In the swales, a variable morphology is observed with localised pits of 2-5m deep with a spatial extension of more than 1 km (Figure 11 and 15). Side-scan sonar imagery in these areas shows a high reflectivity and a coarse to rough texture. In the swale east of the Oosthinder, numerous objects were revealed (Figure 12). Their distribution is random, but there is a higher concentration in the middle and southern parts, where detailed morphological characteristics point to a gravel region. In the past, Army divers have identified large blocks of 2-3 m.

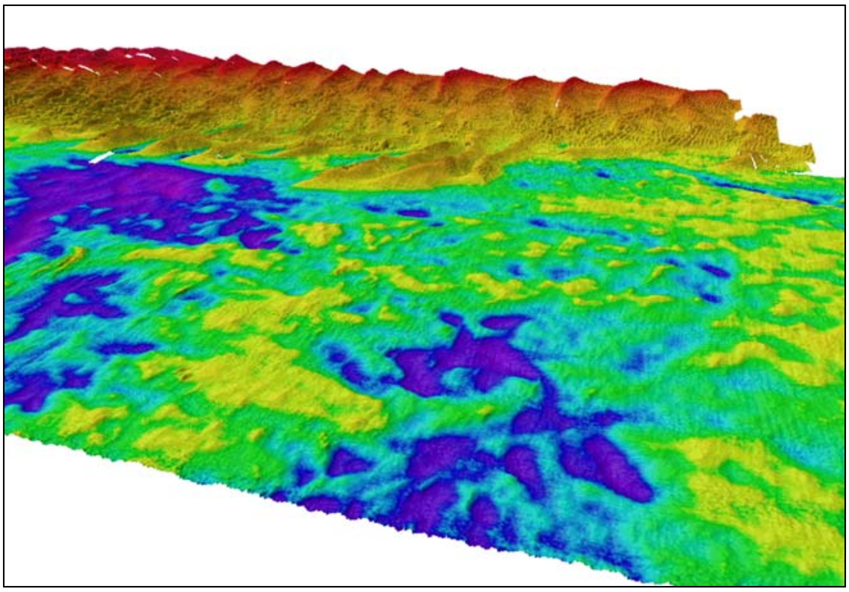

Fig. 11: 3D view from the swale in between the Westhinder and Oosthinder. View towards the Oosthinder. Note the variable morphology in the swale typically for gravel dominated areas. At the foot of the Oosthinder, barchan dunes occur; these are typical for coarse substrates.

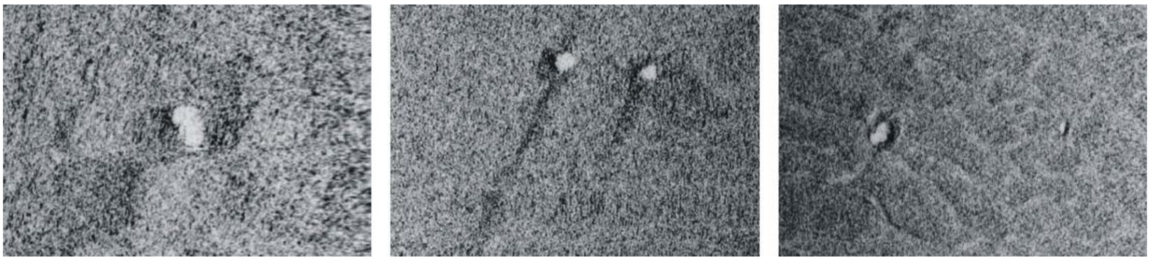

Fig. 12: Side-scan sonar images of obstacles. The block are 2-3 m in diameter.

Surficial sedimentology

The acoustic seabed classes of Roche (2002) were used to classify the seabed into the following sediment types: (1) class 1: highest BS: sandy gravel occurring in the swales of the sandbanks; (2) class 2 and class 5: moderate BS: medium sand with shells or shell debris occurring on sand dune fields in swales and on sandbanks; (3) class 3: high BS: fine muddy sand, occurring on flat areas in the swales and generally associated with bioturbation of tube worms; and (4) class 4: lowest BS: fine homogeneous sand occurring in the shallowest areas.

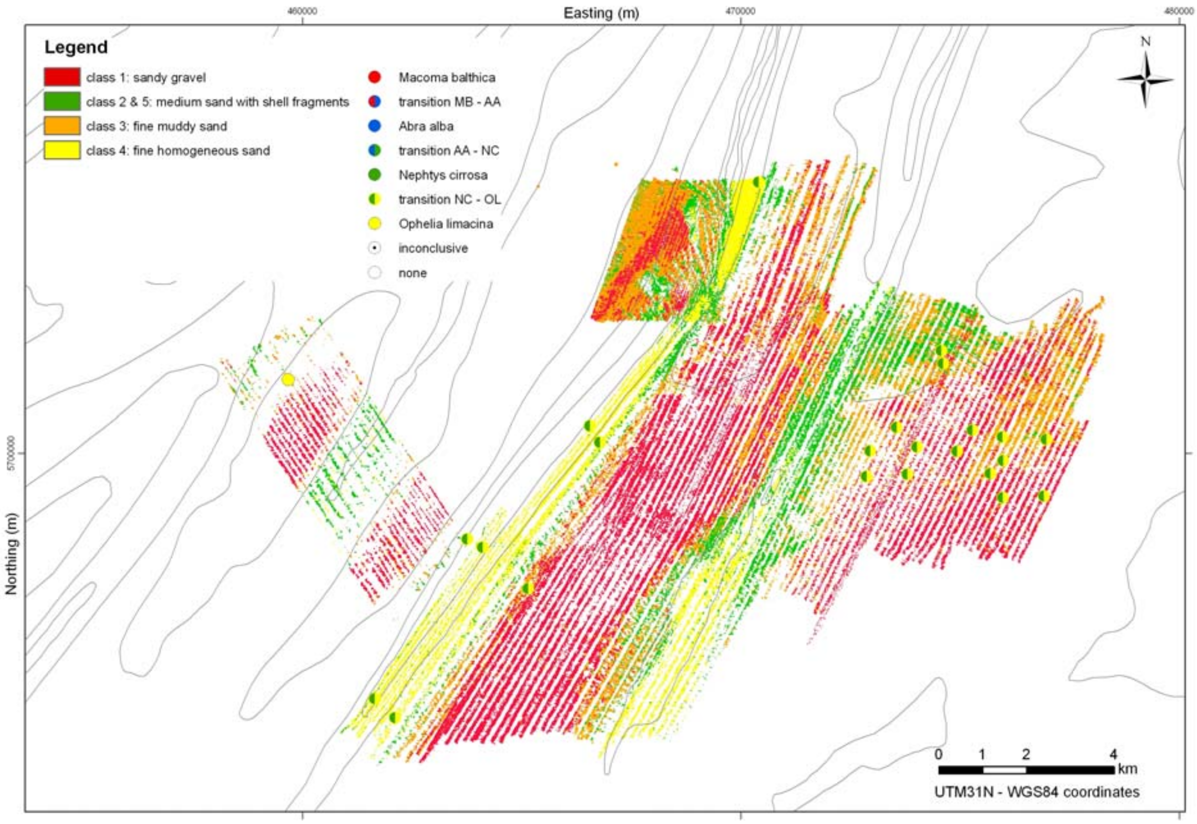

Fig. 13: Acoustic seabed classification in the southern region of the Hinder Banks.

The classifcation results (Figure 13) clearly show that sandy gravel dominates the swales whilst medium sand with shells and finer sand characterise the sandbanks.

Video recordings in the swales bordering the southern parts of the Oosthinder revealed coarser and higher amounts of gravel in the swale between the Westhinder and Oosthinder than anywhere else. Fragments up to two meters have been observed here. The swale, east of the Oosthinder, holds somewhat higher gravel amounts in its southern part and higher sand amounts to the north. The swales bordering the southern part of the Noordhinder also contain considerable amounts of gravel. Considering the location of the offshore scarp, gravel seems to occur regularly south of it; whilst north of the scarp less gravel is observed (Figure 14). It is clear from all of the measurements that there is no continuous gravel seabed surface, but that the gravel spots are more or less isolated and most of the gravel is covered with sand. The thickness of this layer might be very thin, being only a few centimetres.

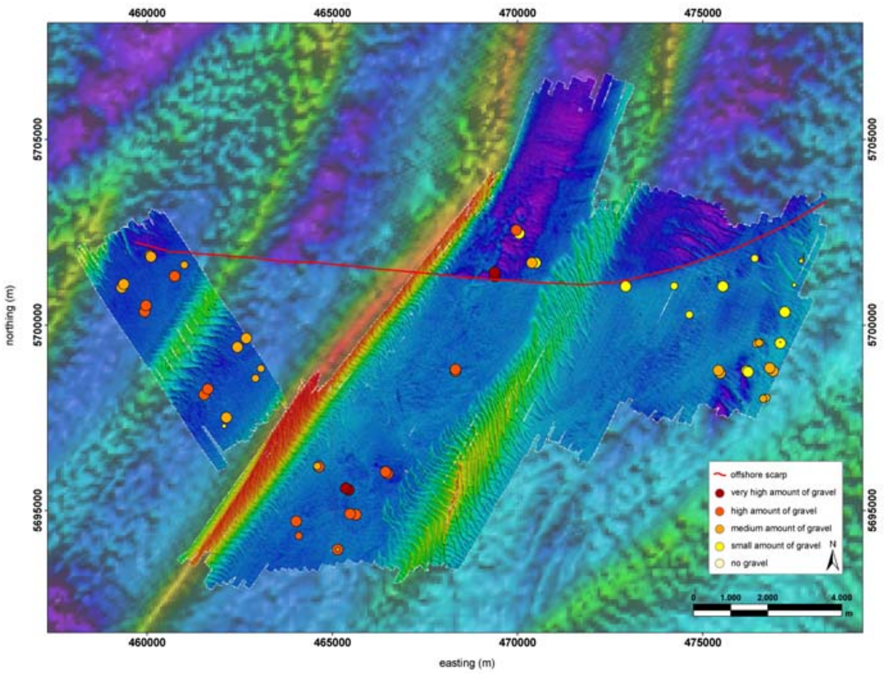

Fig. 14: The amount (colours) and size (size of the symbols) of gravel near the offshore scarp. The background shows a detailed multibeam image of the area superposed on less detailed single-beam imagery.

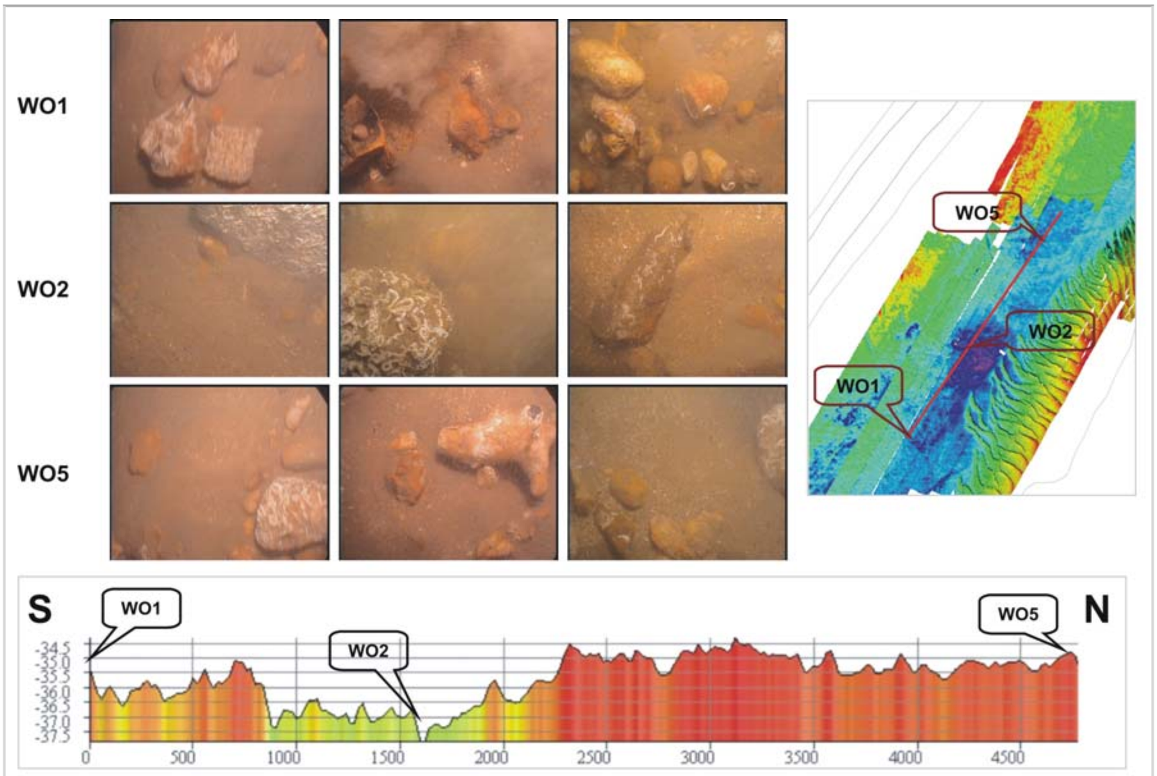

Fig. 15: Video recordings in the swales bordering the southern part of the Oosthinder. Note the variable morphology in the swale with localised pits of 2-3 m in depth with an extension of more than 1 km. More examples can be found in Van Lancker *et al.* (2005).

The sampled gravel is very heterogeneous in composition and in size (Figure 16) (see Deleu and Van Lancker, Annex for more details).

Biological characterisation

Biological samples were only taken in the swale east of the Oosthinder sandbank. All of the samples belonged to the *Ophelia limacina* community (Van Hoey *et al.,* 2004). Their location is indicated on Figure 13. They are representative of the sand occurring on top of the gravel, not of the fauna associated with the gravel itself.

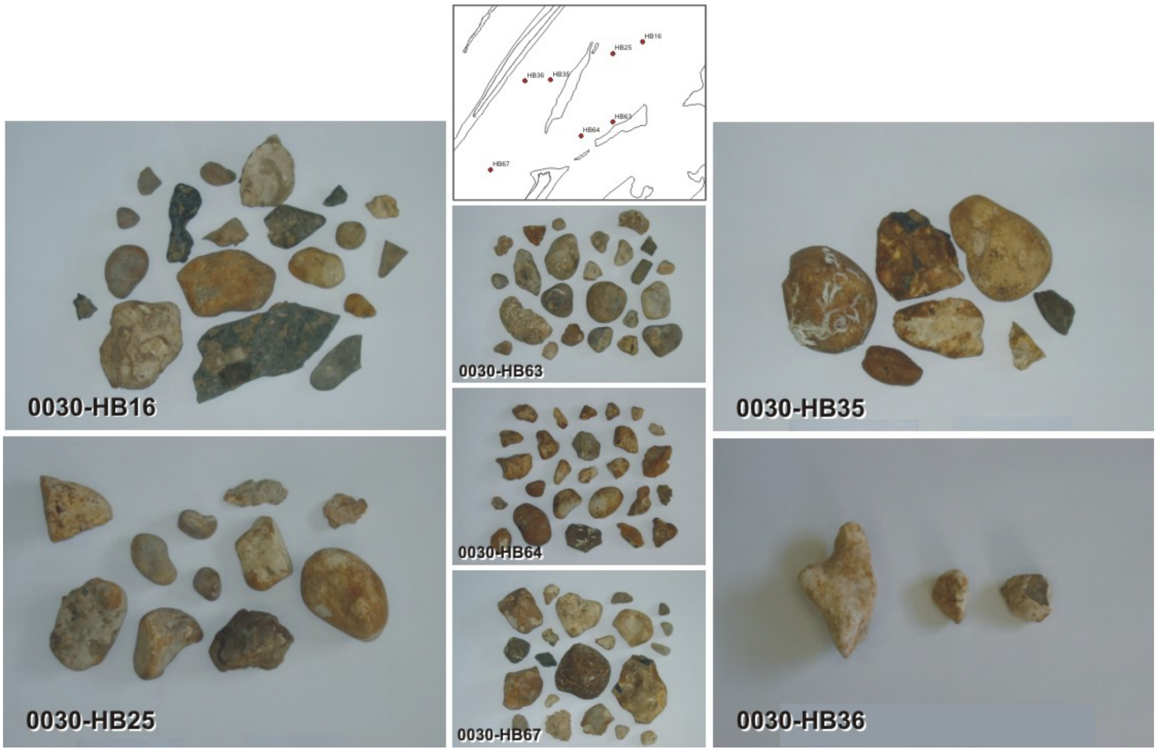

Fig. 16: Gravel occurrences on the BPNS: rounded as well as angular gravel fragments are observed.

4. INTEGRATED PHYSICAL IMPACT ASSESSMENT OF THE KWINTE BANK

4.1. Introduction

Sand extraction activities on the BPNS are regulated in the sense that no major changes to the seabed should occur and natural regeneration of the banks was considered to balance the extraction rates. However, the centre of a tidal sandbank (Kwinte Bank), exploited intensively since the 1970's, is now transformed into a depression; as such, sand extraction is halted since February 2003. The impacted site lies more than 12 km away from the shore and is located in water depths of 8 to 15 m. Since the full extension of the central depression was revealed in 2000, new insights have arisen on the impact of aggregate extraction on the marine environment.

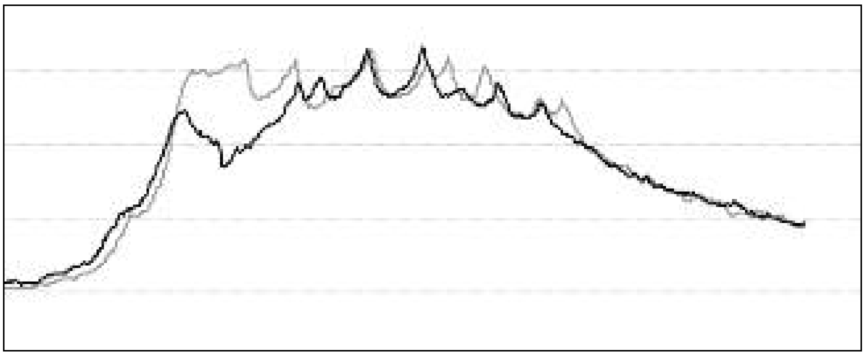

Fig. 17: The central depression in the Kwinte Bank. Comparison of a single-beam bathymetry profile of 1992 (grey) and a multibeam profile of 1999 (black). The depression is 5 m deep, 700 m wide and 1 km long (Degrendele *et al.,* submitted).

Extensive research was carried out in cooperation with researchers from the EU Research Training Network EUMARSAND and with the Fund for Sand Extraction (FPS Economy, SME's, Self-Employed and Energy). As such, the present seabed characteristics, dynamics and the recovery potential of this central part of the Kwinte Bank have been studied, in a multidisciplinary context.

4.2. Results

The joint research results are submitted for publication in a Special Volume on European Marine Sand & Gravel Resources: Evaluation and Environmental Impact of Extraction (*Journal of Coastal Research*). The main paper contributions of the Marebasse partners were: (1) An introduction to the impact of marine aggregate extraction on tidal sandbanks and on the Kwinte Bank, in particular (Van Lancker *et al.*); (2) Geo-environmental characterisation of the Kwinte Bank (Bellec *et al.*); (3) The effects of sand extraction on the sediment transport along the Kwinte Bank due to tides (Van den Eynde *et al.*); (4) Wave effects on the morphodynamic evolution of an offshore sandbank (Giardino *et al.*); and (5) Recommendations for a sustainable exploitation of tidal sandbanks (Van Lancker *et al.*) including an integration of all research results. The recommendations paper can be found in Annex.

4.3. Main conclusions

The investigations showed that dredging along topzones of subtidal sandbanks can cause depressions in the seafloor that may evolve in distinguished sedimentary environments. The sediment characteristics resemble more those of swale sediments, i.e. differing from the crestline of a sandbank. Large to very-large dunes (4-6 m in height) still occur, but their height is lower than surrounding bedforms enabling a faster progression of the flood current. After the cessation of dredging, the morphology remained remarkably stable and no cumulative effects were observed. The intensive dredging led to a change, albeit locally, of the hydrodynamic regime and the depression acts as a transport pathway for sediments. Modelling results, in the short-term, confirm the somewhat erosive nature of the depression, though regeneration is modelled in the medium to long-term. No impact on the adjacent coast could be identified.

Considering the above findings on a larger scale, the depression appears to have a local impact only. However, the sustainability of the exploitation can be questioned, at least, from a physical perspective. No significant refill of dredged areas is seen, partly because of coarser, relict sediments that have been extracted; the transport of these being limited by sporadic and enhanced wave conditions. In addition, there is only a very thin cover of sediments in the swales limiting a fast regeneration after extensive extraction. Trend analysis of observations over the whole of the Flemish Banks region have shown overall erosion of the sandbanks. As such, it is very unlikely that aggregate extraction activities would be counterbalanced by natural regeneration. A potential sand deficiency over the larger sedimentary system remains to be investigated.

Criteria have been proposed that can guide sustainable exploitation, assist in selecting the most appropriate locations for extraction, from a resource perspective as to minimise environmental effects. More general recommendations on monitoring have been iterated because of their importance of being implemented in existing monitoring programmes. However, sustainability can be ensured only if good management/policy practices are in place and implemented in a structural way.

5. EXPLOITATION OF THE RESULTS

5.1. Mapping products

An appropriate evaluation of a sedimentary system can only be carried out if it can be situated in a larger scale sediment dynamical framework. Therefore, **a series of thematic datasets** have been compiled and/or derived to prospect and evaluate the state, dynamics and stress of the seabed. Data grids with a resolution of 250 m have ben produced; they relate to the: (1) large-scale bathymetry, showing the overall morphology; (2) mud percentage; (3) median grain size of the sand fraction; (4) the occurrence of gravel deposits; (4) bedform distribution and height. Hydrodynamic and sediment transport modelling results are produced on the same grid. The maps were produced using GIS tools, sometimes in combination with more powerful geostatistical software packages for a sound interpolation of the data (Verfaillie *et al.* 2006).

The **bathymetry digital terrain model** was compiled on the basis of bathymetrical data from the Ministry of the Flemish Community (Department of Environment and Infrastructure, Waterways and Marine Affairs Administration, Division Coast, Hydrographic Office) and was completed with data from the Dutch and English Hydrographic Offices. The **mapping of the seabed sediments** has resulted in highly-detailed distribution maps of the median grain-size and the silt/clay percentage. The data is derived from the sedisurf@database (1976 onwards) hosted by Ghent University. Interpolation is done using advanced geostatistical techniques (Verfaillie *et al.*, 2006). The map of gravel occurrences is merely qualitatively and is based on a combination of data sources: (1) geological information; (2) acoustic data; (3) sample data; and (4) observations with video and from divers. The **map of bedform occurrence and heights** was derived from monitoring studies, albeit restricted mainly to the sandbank areas. The data was derived from individual single-beam measurements and was added with available side-scan sonar and multbeam data. Where no such data existed, the newly derived digital terrain model was used.

The thematic maps and data grids have already been used in various contexts, in support of both management and research.

5.2. Data management

Geographic Information Systems were extensively used throughout the research. It was demonstrated that GIS integration is beneficial for data management, coherent scientific output and as a stimulus for new research. Data visualisation and mapping output in paper and in digital format (GIS layers) are coupled with appropriate metadata. These are compiled according to international standards and protocols for seabed mapping studies (see webGIS at www.searchmesh.net and GNOSIS).

As such, visualisation can be steered in accordance with various environmental applications (e.g. habitat and resource mapping; marine spatial planning). The main mapping results are distributed on the **GIS@SEA** DVD (*GIS of the Physical Seabed in Support of Studies and Environmental Assessments*).

The GIS data management has been substantially improved by linking MAREBASSE to the MESH project: (1) experiences with regard to representing data in an on-line webGIS mapping system were shared; (2) all of the datasets were converted in accordance with European data exchange formats; (3) the visibility of the results to the European mapping community; (4) a strategy is being developed to guarantee the longevity of the mapping products.

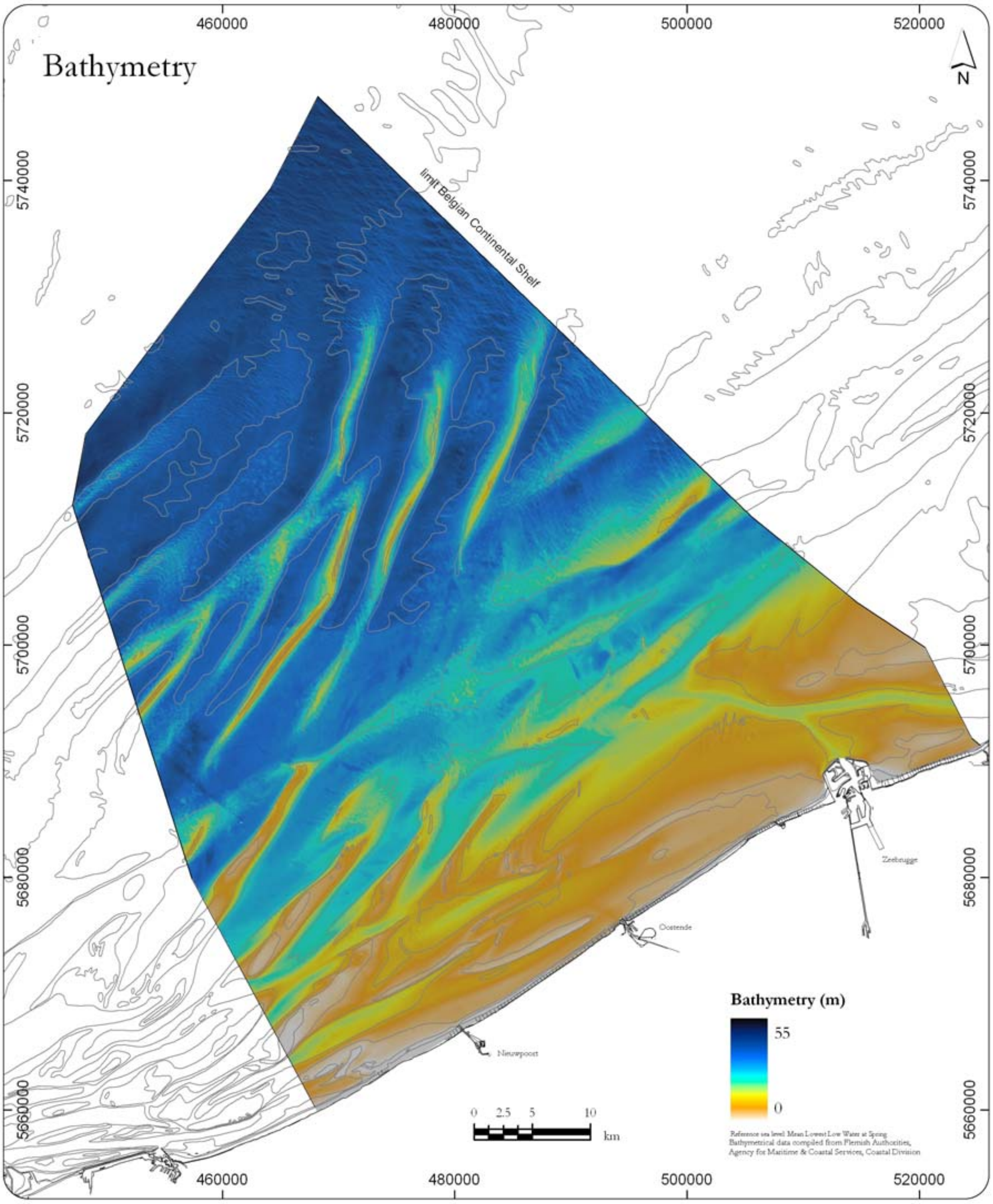

Fig. 18: Bathymetry digital terrain model.

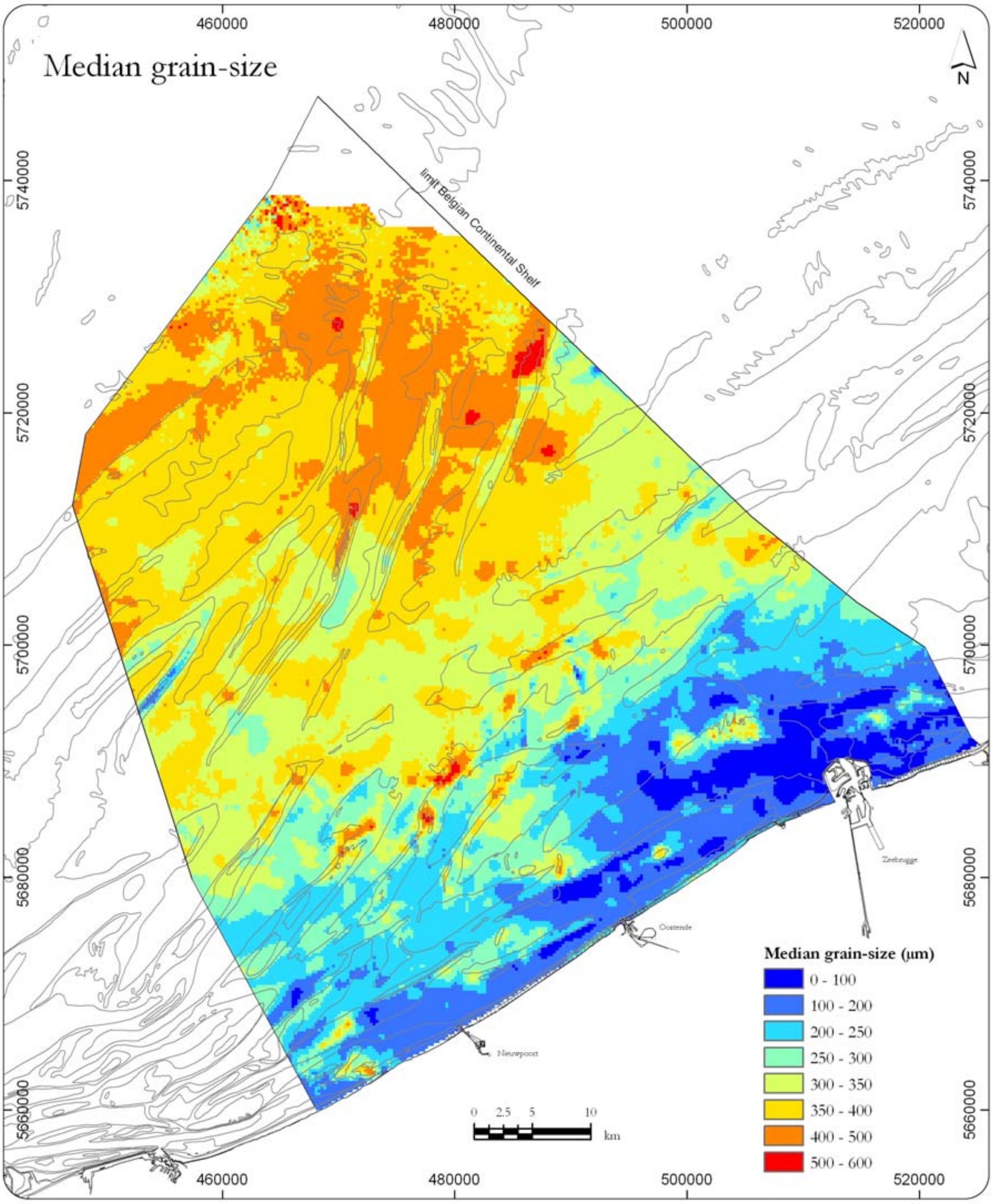

Fig. 19: Spatial distribution map of the median grain-size. Caution is needed for the sediment distribution at the northern extremity of the Bligh Bank and the Fairy Bank due to a lack of samples. See Verfaillie *et al.* (2006) for details on the technique used.

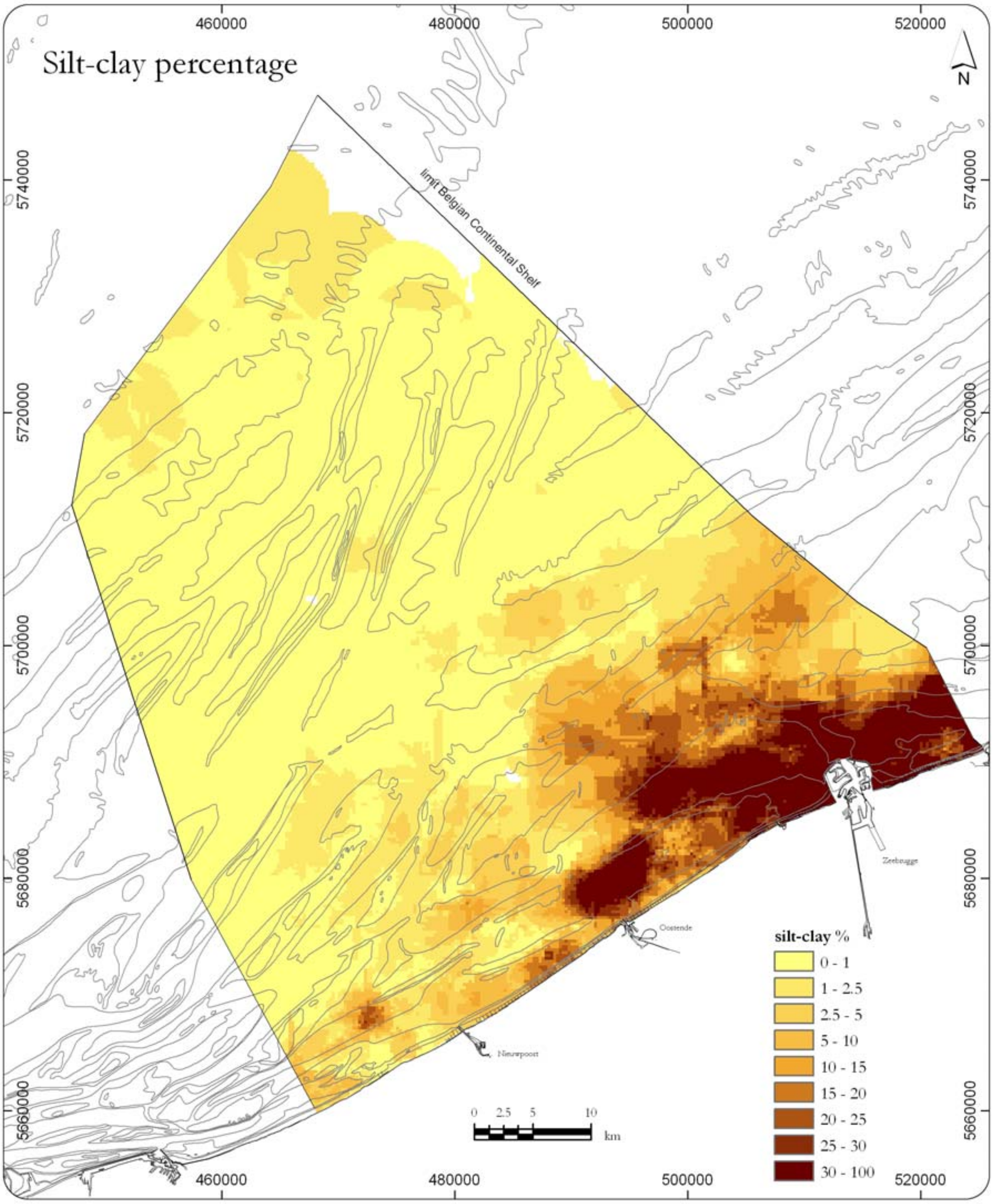

Fig. 20: Spatial distribution map of the silt/clay percentage.

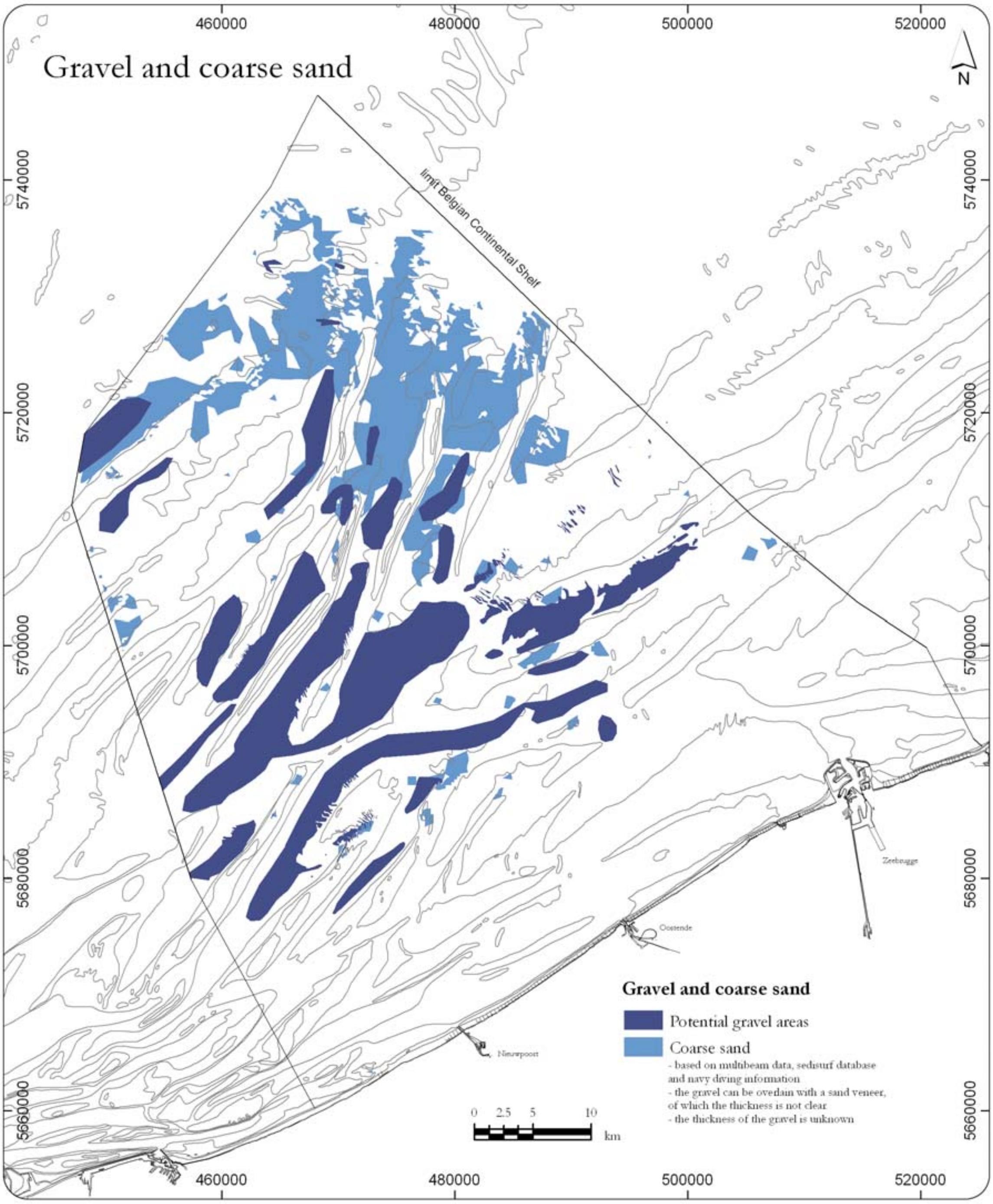

Fig. 21: Spatial distribution map of gravel occurrences

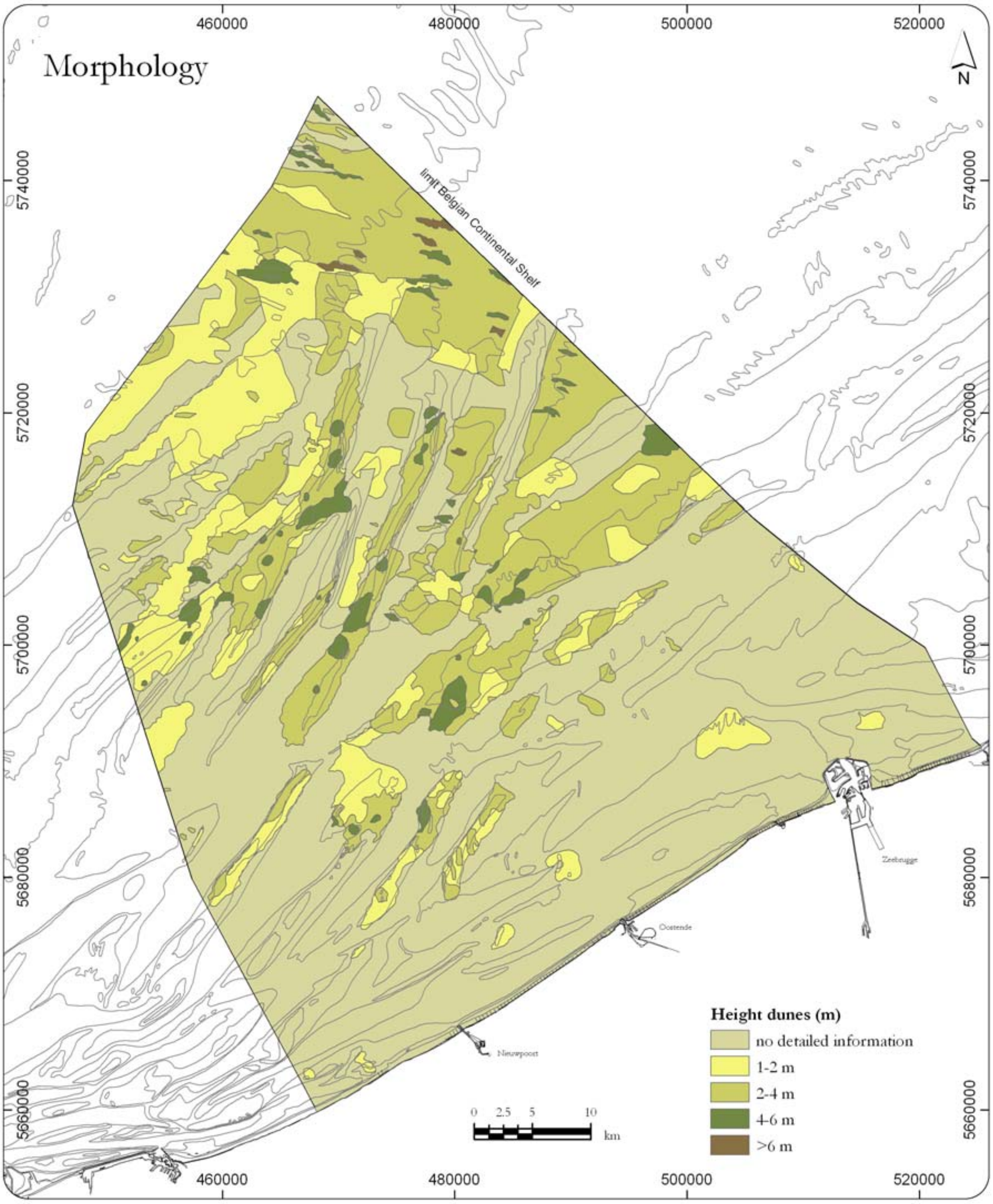

Fig. 22: Spatial distribution map of bedform occurrences and the height of the large to very-large dunes.

Outreach

Scientific output

A number of scientific papers have been submitted to peer-reviewed journals; some are still in preparation. A Special Volume on Marine Sand and Gravel Resources is being prepared. The research was presented at conferences. Some contributions to newsletters have been made, both nationally as well as internationally.

Workshops

The final workshop was very successful and allowed a more intensive interaction with a diverse group of stakeholders. Out of 77 registrations, 13% represented the industry sector *sensu stricto*, 44% various governmental bodies, 18% private/consultancy firms and 25% were university-related. Round-table discussions were held with the Marebasse maps as a central point of discussion. A questionnaire on stakeholder needs revealed that most people are interested in the micro- to mesoscale cartographic products with annotations of their quality. Knowledge on the small-scale spatial and temporal variability is regarded important, as also adequate sediment transport estimations. However, the industry, government and research stakeholders have also shown a significant interest in the long-term evolution of the seabed, with a view to a sustainable exploitation and marine spatial planning. It is generally acknowledged that this requires continuity in measurements. The integration of various disciplines, techniques and methodologies was viewed positively.

Interaction with end-users

On average 20 stakeholders attended each of the 6 end-user meetings. The interaction was generally good including data exchange to the benefit of both researchers and end-users. The expectations of the end-users were generally met.

Policy relevance

A synthesis of findings and projections for the future management of sand and gravel extraction was formulated on behalf of the advisory committee regulating marine aggregate extraction activities. In brief, the contacts were experienced as being very positive and it is hoped that the scientific results can assist in decision-making.

The use of MAREBASSE results within other contexts

An active data exchange occurred both on a national and international level and strengthened the output in terms of relevance and value towards management. The interaction was facilitated by the consistent build-up of the project datasets. More detail on the various project interactions is given in Van Lancker *et al.* (2007).

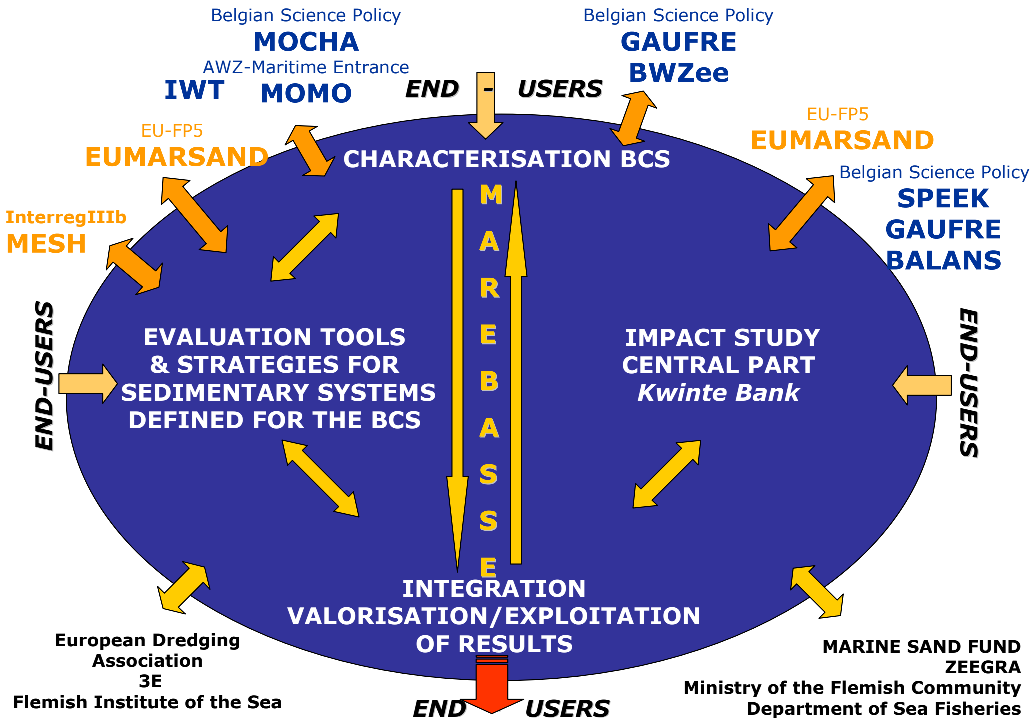

Fig. 23: MAREBASSE interaction scheme. Only recent projects (*orange: EU projects; blue: nationally funded project*) with a direct exchange of information are mentioned. The end-users are indicated in black.

Discussion and conclusions

A suite of physical and some biological variables were acquired through in-situ measurements and were integrated through mapping and modelling. The end-products were set-up taking into account various scientific and environmental themes and respecting the ecological relevance of the results. The sites were chosen based on their broader societal, governmental and industrial interest, as was reflected in the set-up of the end-user committee.

Sustainable management

Generally, extensive background information is provided for environmental assessments related to the BPNS. Hence, the results are relevant for any human activity affecting the seabed. The large-scale mapping and modelling results provide a sedimentary framework for more detailed studies. The integrated results on a site-specific scale can serve as **baseline studies** for the implementation of future human activities. Moreover, various tools have been refined for an effective seabed evaluation and follow-up. All of these aspects are highly important for the sustainable management of the EEZ. Moreover, existing **monitoring** results can now be framed within a wider context. However, it needs emphasis that the project focussed on the spatial scale of seabed nature and processes only. Knowledge of the natural evolution of the seabed and its temporal variability remains poor. This hampers the formulation of sound conclusions on the impact of human activities on the seabed and, especially, the evaluation of the impact of sand extraction on the seabed.

Site investigations on the former dumping grounds for dredged material have shown that dumping activities have a significant impact on the nature, morphology and dynamics of the seafloor. It was hypothesised that the impact of these activities may be cumulative, both regionally and towards the coast. When dumping sites have reached their maximum capacity, they form an important sediment accumulation with the dimensions of a small sandbank. When a dumping site of this kind is located in the near proximity of the coast, this may lead to a change in the hydrodynamic regime, with accelerating currents closer to the coast. This may have a steepening effect on the foreshore, with significant implications for coastal erosion. This relation should be further investigated, especially with a view to the future management of dumping grounds.

Sustainable exploitation

Most emphasis was put on developing a scientific supportive framework related to sand and gravel extraction to cater for both **governmental and industrial needs**. Measurements, mapping and modelling were used for studying the impact of extraction and for making predictions under different extraction scenarios. The data is useful to the government, which is responsible for the management and monitoring of the extraction sites, but also to the industry itself. Finally, recommendations were formulated for a more sustainable exploitation of marine aggregates. These include the need for better maps that serve both management as seabed exploration practices (see Table 2). Combinations of these data layers can be used for making multicriteria resource maps. An example of this can be found in Van Lancker *et al.* (submitted).

Table 2: Large-scale information/maps needed for supporting the sustainable exploitation of marine aggregates (Van Lancker *et al.* submitted)

Type of map	Use
Detailed grain-size maps	*targeting the right aggregate quality* *identifying potential source areas*
Thickness and suitability of the quaternary deposits	*ensuring long-term availability* *ensuring constant quality*
Sediment transport/erosion-deposition maps supported with morphology/bed-form maps	*choosing areas of deposition* *identifying bed-load convergence zones* *avoiding kink areas and the extremities of the bank in order to maximise chances of regeneration and minimise detrimental physical impact*
Maps on wave energy distribution	*evaluating possible impact on the coast*
Maps on ecological functioning	*avoiding sensitive areas or important habitats*

Recommendations

The measurements, mapping and modelling have demonstrated the potential of present-day research on the physical seabed and the biological relevance thereof. With respect to aggregate extraction, research reveals that non-renewable sediments are increasingly being extracted. Therefore, a **targeted and efficient use of seabed resources** is called for. This requires that knowledge of the marine environment continues to increase. **Mapping tools and approaches should be further developed and improved**, as they will allow the identification of optimal resource areas for extraction. Moreover, the measurements and mapping data enable the **sound parameterisation of the physical environment**, both at a large- and at a small-scale. The results can be linked to a suite of variables that are useful for other ecosystem component studies. This aspect should be further explored in the future. The modelling of the main hydrodynamic features (currents and waves) is becoming more realistic. The **modelling of sediment transport**, on the other hand, **remains a challenge**, and additional research will be required. Further efforts should include the quantification of sediment transport in the presence of waves, both in terms of modelling and of measurements, and non-cohesive and cohesive sediments should be modelled in a combined way. This is essential for producing more reliable estimates of the possible impact of changes caused by natural and/or anthropogenic factors.

In a short to medium term, the effects of aggregate extraction and dredging/dumping operations seem to be relatively localised. Nevertheless, there are indications that the **long-term impact** must not be underestimated and **requires further investigation**. However, this can only be addressed based on **sound research strategies that allow distinguishing natural versus anthropogenically induced sediment dynamics**. This is not possible yet, because knowledge regarding the natural evolution of the seabed remains largely insufficient. To expand this knowledge, **good datasets** and **careful analysis** are needed. Investment in this type of research is necessary, since it supplies the basis for any further research on the **long-term evolution** of the seabed.

Ideally, investments are to be made in **continuous seabed and water column measurements**, at both naturally and anthropogenically dominated sites. These measurements are the key to an **adequate monitoring** of the status of the marine environment.

Specific **recommendations on sustainable management and exploitation of marine aggregates** and on the **allocation of dredging/dumping grounds** have been formulated and can be found in Annex (Van Lancker *et al*. submitted; Du Four and Van Lancker, submitted).

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The **end-users** are acknowledged for their interest and willingness to provide data and/or instrumentation: Federal Public Service Economy, SMEs, Self-employed and Energy – Marine Sand Fund; Zeegra vzw.; Ministry of the Flemish Community, Administration Waterways, Infrastructure and Nautical Affairs, Waterways and Coastal Section (AWZ-WWK); European Dredging Association; 3E NV; Flanders Marine Institute and The Department of Sea Fisheries.

The impact analysis on the Kwinte Bank was conducted in cooperation with the EU-FP5 research training network **EUMARSAND** (*European Marine Sand and Gravel Resources: Evaluation and Environmental Impact of Extraction*) (contract HPRN-CT-2002-00222). The results were validated and refined within the Interreg IIIb (NW Europe) project **MESH** (Mapping European Seabed Habitats) (www.searchmesh.net).

The Management Unit of the Mathematical Model of the North Sea and the Scheldt Estuary (**MUMM**) and the Flemish Institute of the Sea provided shiptime on board the R.V. *Belgica* and the R.V. *Zeeleeuw* respectively. The captains and the crew of the research vessels are warmly thanked for their flexibility and help on the project's numerous campaigns. **VLIZ** is particularly acknowledged for the purchase of a Hamon grab for the sampling of coarser seabed material.

Literature Cited

ACKERS P, WHITE WR (1973) Sediment transport: new approach and analysis. In: Proceedings of the ASCE Journal of Hydraulics Division, 99 (HY11): 2041-2060

BAILLY DU BOIS P, SALOMON JC, GANDON R. AND GUÉGUÉNIAT, P (1995). A quantitative estimate of English Channel water fluxes into the North Sea from 1987 to 1992 based on radiotracer distribution. Journal of Marine Systems, 6, 457-481

BELLEC V, VAN LANCKER V, DEGRENDELE K, ROCHE M AND LE BOT S (submitted) Geo-environmental characterization of the Kwinte Bank in relation to sand extraction. Journal of Coastal Research

BENOÎT M, MARCOS F, BECQ F (1996) Development of a third generation shallow-water wave model with unstructured spatial meshing, Proceedings of the 25th International Conference on Coastal Engineering, American Society of Civil Engineers, Orlando, Florida, USA, p 465-478

BIJKER EW (1966) The increase of bed shear in a current due to wave motion. In: Proceedings of the 10th Conference on Coastal Engineering, American Society of Civil Engineers, Tokyo, Japan, p 746-765

BONNE W, COLLINS MB, VAN LANCKER V, URIARTE A (in prep.) European marine sand and gravel resources: evaluation and environmental impact of extraction. Special Volume Journal of Coastal Research

DEGRENDELE K., ROCHE M, SCHOTTE P, VAN LANCKER V, BELLEC V and BONNE W (submitted). Morphological evolution of the Kwinte Bank central depression before and after cessation of aggregate extraction. *Journal of Coastal Research*.

DELEU S (2001) Zeebodemmobiliteitsstudie van de Hinderbanken regio. Unpublished Msc Thesis, Universiteit Gent, RCMG. Gent, 135 pp

DELEU S, VAN LANCKER V, VAN DEN EYNDE D, MOERKERKE G (2004) Morphodynamic evolution of the kink of an offshore tidal sandbank: the Westhinder Bank (Southern North Sea). Cont Shelf Res 24: 1587-1610

DELEU AND VAN LANCKER. See Annex

DJENIDI S, RONDAY F (1992) Dynamique sédimentaire en mer à marée. In: Etude du plateau continental nord-ouest Européen: Structure et mouvements verticauxs. Institut de recherches marines et d'interactions air-mer. Université de Liège, p 53-61

Du Four, I. and Van Lancker, V. (submitted). Physical impact of dredged material disposal sites and their recovery after cessation of dumping: a case study in the Belgian coastal zone. Marine Geology

ENGELUND FA, HANSEN E (1967) A monograph on sediment transport in alluvial streams. Teknikal Forlag, Copenhagen

FETTWEIS M, VAN DEN EYNDE D (2003) The mud deposits and the high turbidity in the Belgian-Dutch coastal zone, southern bight of the North Sea. Cont Shelf Res 23: 669-691

FETTWEIS M, FRANCKEN F, PISON V. AND VAN DEN EYNDE D. (2006). Suspended particulate matter dynamics and aggregate sizes in a high turbidity area. Marine Geology 235(1-4): 63-74

FETTWEIS M, NECHAD B. AND VAN DEN EYNDE D. (2007). An estimate of the suspended particulate matter (SPM) transport in the southern North Sea using SeaWiFS images, in situ measurements and numerical model results. Continental Shelf Research 27(10-11): 1568-1583

GARREAU P. 1997. Task N: Numerical hydrodynamic modelling. In: Hydrodynamics Biogeochemical Processes and Fluxes in the Channel, FLUXMANCHE II Final report, MAS2CT940089. (eds.), 12-38

GRANT WD, MADSEN OS (1982) Movable bed roughness in unsteady oscillatory flow. Journal of Geophysical Research 87: 469-481

HAECON (1994) Stortplaatsonderzoek, Eindrapport sedimenttrendanalyse: interpretatie van de STA-resultaten (STA). Intern rapport, nr. ISS1165-00032, Drongen

ICES (1992) Effects of extraction of marine sediments on fisheries. ICES Cooperative Research Report 182

ICES (1997) Report of the working group on the effects of extraction of marine sediments on the marine ecosystem. ICES CM 1997/E:4

ICES ADVISORY COMMITTEE ON THE MARINE ENVIRONMENT (2003) Annex 2: ICES guidelines for the management of marine sediment extraction. ICES Cooperative Research Report 263: 210-215

LAFITE R, SHIMWELL S.J, NASH L.A, DUPONT J.P, HUAULT M.F, GROCHOWSKI N.T.L., LAMBOY J.M., COLLINS M.B. (1993). Sub-Task S1: Suspended material fluxes through the Strait of Dover, Hydrodynamics and Biogeochemical Fluxes in the Eastern Channel: Fluxes into the North Sea. FLUXMANCHE I Second annual rep., MAST 0053-C (EDB), 81-106

LANCKNEUS J, VAN LANCKER V, MOERKERKE G, VAN DEN EYNDE D, FETTWEIS M, DE BATIST M, JACOBS P (2001) Investigation of the natural sand transport on the Belgian Continental Shelf (BUDGET). Final report. Federal Office for Scientific, Technical and Cultural Affairs OSTC, Brussels

LIU A.C, MISSIAEN T. AND HENRIET J.P (1992). The morphology of the top-Tertiary erosion surface in the Belgian sector of the North Sea. Marine Geology, 105: 275-284

LUYTEN PJ, JONES JE, PROCTOR R, TABOR A, TETT P, WILD-ALLEN K (1999) COHERENS: A Coupled Hydrodynamical-Ecological Model for Regional and Shelf Seas: User Documentation. Technical Report, Management Unit of the North Sea Mathematical Models, Brussels

MCMANUS J.P, PRANDLE D. (1997). Development of a model to reproduce observed suspended sediment distributions in the southern North Sea using Principal Component Analysis and Multiple Linear Regression. Continental Shelf Research, 17, 761-778.

MONBALIU J, PADILLA-HERNANDEZ R, HARGREAVES JC, ALBIACH JCC, LUO W, SCLAVO M, GÜNTHER H (2000) The spectral wave model, WAM, adapted for applications with high spatial resolution, Journal of Coastal Engineering 41: 1-3, 41-62

OSPAR COMMISSION (2000) Quality Status Report 2000, Region II –Greater North Sea. Ospar Commission, London

PRANDLE D, JAGO C.F., JONES S.E., PURDIE D.A. AND TAPPIN A. (1993). The influence of horizontal circulation on the supply and distribution of tracers. Phil. Trans. Royal Soc. London, A 343, 405-421

PRANDLE D, BALLARD G, FLATT D, HARRISON A.J, JONES S.E, KNIGHT P.J., LOCH S.G, MCMANUS J.P, PLAYER R AND TAPPIN A. (1996). Combining modelling and monitoring to determine fluxes of water, dissolved and particulate metals through the Dover Strait. Continental Shelf Research, 16 (2), 237-257

ROCHE M (2002). Utilisation du sonar multifasceaux pour la classification acoustique des sédiments et son application à la cartographie de la zone de concession 2 de la mer territoriale et du plateau continental belge. Mémoire de Stage, Avril 2002 : 67 pp

SALOMON J.C, BRETON M. AND GUEGUENIAT P. (1993). Computed residual flow through the Dover Strait. Oceanologica Acta, 16 (5-6), 449-455

SLEATH JFA (1984) Sea Bed Mechanics, Wiley-Interscience, New York

SWART DH (1976) Coastal sediment transport. Computation of longshore transport. Report R968 (1), Delft Hydraulics Laboratory, The Netherlands

SWART DH (1977) Weighted value of depth of initiation of movement. Report NR10, Stellenbosch, South Africa

TVNK (1998). Rapport over stortplaatsen B&W S1. Tijdelijke Vereniging Noordzee en Kust, TVNK/ZB/MDR/98018/PHE

VAN DEN EYNDE D (2004) Interpretation of tracer experiments with fine-grained dredging material at the Belgian Continental Shelf by the use of numerical models. Journal of Marine Systems 48: 171-18

VAN DEN EYNDE D, GIARDINO A, PORTILLA J, FETTWEIS M, FRANCKEN F, MONBALIU J (submitted) Modelling the effects of sand extraction on the sediment transport due to tides on the Kwinte Bank. Journal of Coastal Research

VAN HOEY G, DEGRAER S, VINCX M (2004) Macrobenthic community structure of soft-bottom sediments at the Belgian Continental Shelf. Estuarine, Coastal and Shelf Science, 59(4), 599-613

VAN LANCKER V, DELEU S, LE BOT S, VAN NIEUWENHOVE B, FETTWEIS M, FRANCKEN F, PISON V, VAN DEN EYNDE D, MONBALIU J, LANCKNEUS J, MOERKERKE G, DEGRAER S (2003) Management, research and budgeting of aggregates in shelf seas related to end-users (MAREBASSE). Scientific Report Year 1. Federal Office for Scientific, Technical and Cultural Affairs (OSTC), Brussels

VAN LANCKER V, DELEU S, BELLEC V, LE BOT S, VERFAILLIE E, FETTWEIS M, VAN DEN EYNDE D, FRANCKEN F, PISON V, WARTEL S, MONBALIU J, PORTILLA J, LANCKNEUS J, MOERKERKE G, DEGRAER S (2004) Management, research and budgeting of aggregates in shelf seas related to end-users (MAREBASSE). Scientific Report Year 2. Belgian Science Policy, Brussels

VAN LANCKER V, DELEU S, BELLEC V, DU FOUR I, VERFAILLIE E, FETTWEIS M, VAN DEN EYNDE D, FRANCKEN F, MONBALIU J, GIARDINO A, PORTILLA J, LANCKNEUS J, MOERKERKE G, DEGRAER S (2005) Management, research and budgeting of aggregates in shelf seas related to end-users (MAREBASSE). Scientific Report Year 3. Belgian Science Policy, Brussels

VAN LANCKER, V.RM, BONNE, W, VELEGRAKIS, AF, COLLINS MB (submitted) Sand extraction on tidal sandbanks: is dredging with nature an option? An introduction. Journal of Coastal Research

VAN LANCKER V, BONNE W, GAREL E, DEGRENDELE K, ROCHE M, VAN DEN EYNDE D, BELLEC V, BRIERE C, COLLINS MB (submitted) Recommendations for a sustainable exploitation of tidal sandbanks. Journal of Coastal Research

VAN LANCKER V, DELEU S, BELLEC V, DU FOUR I, SCHELFAUT K, VERFAILLIE E, FETTWEIS M, VAN DEN EYNDE D, FRANCKEN F, MONBALIU J, GIARDINO A, PORTILLA J, LANCKNEUS J, MOERKERKE G AND DEGRAER S (2007). Chapter 4. Marebasse: bridging gaps towards other disciplines and endusers, pp. 88-141. In: J.-B. CALEWAERT AND F. MAES (Editors), *Science and Sustainable Management of the North Sea: Belgian case studies*. Gent, Academia Press Wetenschappelijke Uitgeverij, 314 p

VELEGRAKIS A.F, BISHOP C, LAFITE R, OIKONOMOU E.K., LECOUTURIER M, COLLINS M.B, (1997). Sub-Task S3: Investigation of meso- and macro-scale sediment transport, Hydrodynamics

Biogeochemical Processes and Fluxes in the Channel. FLUXMANCHE II Final report, MAST II, MAS2CT940089, 128-143

VERFAILLIE E, VAN LANCKER V, VAN MEIRVENNE M (2006) Multivariate geostatistics for the predictive modelling of the surficial sand distribution in shelf seas. Continental Shelf Research 26 (19): 2454-2468

Content of the DVD

The **GIS@SEA** (*GIS of the Physical Seabed in Support of Studies and Environmental Assessments*) DVD contains both ArcGIS and ArcReader GIS project files of all the mapping results. A readme file explains the file extensions and how best using the data.

The DVD contains a range of products: (a) Geographic Information System (GIS) products that allow users to view the data layers, used in the Marebasse project; (b) Technical Reports; (c) Fact sheets on the thematic maps; (d) Extended metadatasheets; and (e) Printer friendly maps with full legend (in different formats, also A0).

For each project, **metadata** is created and these are viewable in the Metadata tab of the ArcCatalog. Metadata for geographical data give information about how, where and by whom the data was collected, availability, projection, scale and other characteristics of data. The metadata can be be viewed also on a webGIS, set-up in the framework of the Interreg IIIb Project MESH ('*Mapping European Seabed Habitats*') (see http://www.searchmesh.net/.)

Multibeam data, as well as backscatter data, performed seabed classifications as well as side scan sonar data are represented as georeferenced TIF images.

The DVD contains the positions, timestamp and type of sample of both sedimentological and biological sampling points. For the data itself, the Belgian Marine Data Centre (http://www.mumm.ac.be/datacentre/) can be contacted.

The projects, grids, tif images and shapefiles are projected in WGS 1984 UTM Zone 31N, unless stated otherwise.

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SPSD II

EV-18 MANAGEMENT, RESEARCH AND BUDGETTING OF AGGREGATES IN SHELF SEAS RELATED TO END-USERS (MAREBASSE)