Chapter 1

Introduction

1 Introduction

1.1 Habitat mapping

1.1.1 Context

Similar to terrestrial landscapes, the underwater world is highly diverse. Various processes are responsible for the current status of the seafloor. Knowledge on how the marine landscapes look today and in the past, how they came into existence and evolved is very important for humans, because the seabed contains an enormous richness of living and non-living resources.

For a sustainable management of the marine environment, mapping the seafloor or 'habitat mapping' is crucial. It is important in the context of marine spatial planning (e.g. delineation of aggregate extraction zones, windmill parks and marine protected areas or MPAs); the protection of specific species or communities (e.g. species listed in the Habitats Directive); and for the overall improvement of the scientific knowledge base.

This thesis aims at developing **straightforward and statistically sound methodologies** for highly reliable **sedimentological and habitat modelling and mapping, in support of a more sustainable management of our seas.**

1.1.2 From a habitat to habitat mapping

'Habitat' and 'habitat mapping' are terms that have been used since decades, although different terms still exist for similar things.

For the term '**habitat**', a whole range of definitions exist. The ICES Working Group on Marine Habitat Mapping (ICES 2006) gave an overview of definitions of a habitat starting with the classical definition of Darwin (1859) that considered only *"The locality in which a plant or animal naturally lives."*. The final ICES definition was based on definitions of Allee et al. (2000), EUNIS (2002), Kostylev et al. (2001) and Valentine et al. (2005) and is the one that will be used for this study: *"**A particular environment which can be distinguished by its abiotic characteristics and associated biological assemblage, operating at particular, but dynamic spatial and temporal scales in a recognizable geographic area.**"*. As such, it is clear, that a habitat is the combination of both the abiotic and the biotic environment (Figure 1.1).

In the framework of the MESH Project (Development of a Framework for Mapping European Seabed Habitats, 2004-2007), a MESH Guide to Marine Habitat Mapping (MESH Project 2007) has been proposed, describing the whole process of marine habitat mapping. In the first chapter of this guide (Foster-Smith et al. 2007a), '**habitat mapping**' has been defined as: "**Plotting the distribution and extent of habitats to create a complete coverage map of the seabed with distinct boundaries separating adjacent habitats**.". Furthermore, it is stressed that a habitat map is "**a statement of our best estimate of habitat distribution at a point in time, making best use of the knowledge we have available at that time.**".
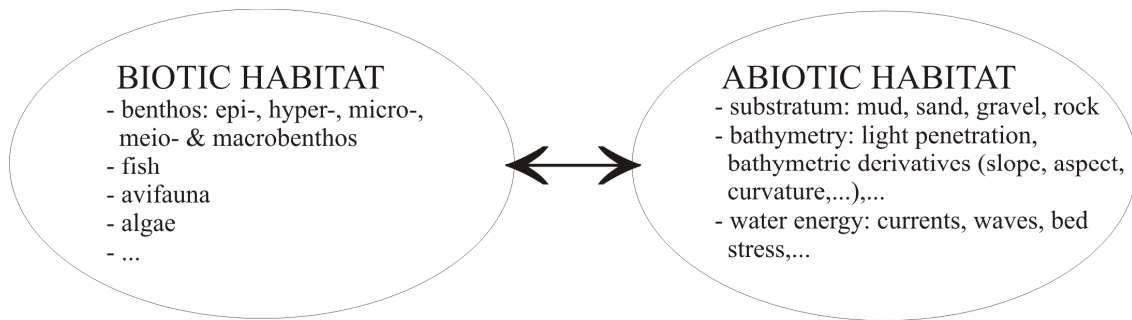
Figure 1.1: A marine habitat consists of a biotic and an abiotic part (ICES 2006). The biotic part consists of all marine fauna and flora, while the abiotic part consists of characteristics related to the substratum, bathymetry and water energy.

1.1.3   How to make a habitat map?

Van Lancker and Foster-Smith (2007) created a scheme with the main stages in the making of a habitat map by integrating sample data and full coverage abiotic data. This scheme comprises 4 steps (Figure 1.2): (1) getting the best out of the **ground-truth** data; (2) getting the best out of the **coverage** data; (3) **integration** of the ground-truth and the coverage data; and (4) habitat map **design** and **lay-out**.

Coverage data are all kinds of full coverage abiotic datasets, ranging from remote sensing data (e.g. acoustical or satellite imagery), sedimentological maps, hydrodynamical models etc. (see Coggan et al. 2007; and Van Lancker and Foster-Smith 2007 for an overview). Ground-truth data are needed for interpolating and validating the coverage data and for assigning ground types to the mapped regions. The methods for ground-truthing range from grab or core samples to video or diving datasets (see Coggan et al. 2007; and Van Lancker and Foster-Smith 2007 for an overview).

The scheme summarizes well that habitat mapping is very complex. Still, the process can even be more complex than the scheme suggests.
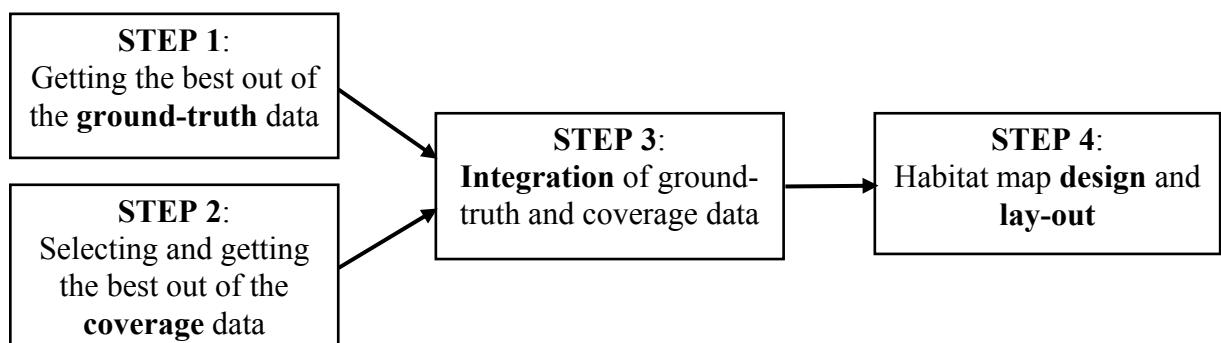

Figure 1.2: Scheme of the habitat mapping process, containing 4 steps (Van Lancker and Foster-Smith 2007).

This research focuses mainly on step 2 and step 3. Chapter 2 and 3 in this thesis can be categorized under step 2. Still, the result of these chapters is not a habitat map, but a high quality model of the abiotic environment, being a crucial intermediate stage in the habitat mapping process. In **Chapter 2** and **3**, a complex multivariate

geostatistical interpolation method is applied to produce high quality sedimentological maps. Still, both chapters integrate also in a way ground-truth data with coverage data (step 3), because sedimentological samples are interpolated using bathymetric data (and derivatives) as secondary information. However, in most cases the integration of coverage data and ground-truth data means that relations are sought between biotic ground-truth data and abiotic coverage data.

Chapter 4, 5 and 6 of this thesis can be categorized under step 3. In **Chapter 4**, a methodology is worked out to combine different abiotic datasets in an objective and statistically sound way. This results in a 'Marine Landscapes' map. Chapter 4 and 5 deal with habitat suitability models of macrobenthic communities and the species *Owenia fusiformis* respectively. The model in **Chapter 5** is based on Discriminant Function Analysis to predict the habitat suitability of four macrobenthic communities. In addition, a habitat suitability map, has also been translated into one classified habitat map, showing EUNIS classes (a pan-European habitat classification system, see further) (Schelfaut et al. 2007). **Chapter 6** uses Ecological Niche Factor Analysis to predict the habitat suitability of *Owenia fusiformis*.

1.1.4   Habitat classification versus habitat suitability modelling

The classical way of habitat mapping, as defined by Foster-Smith et al. (2007a) is based on a **habitat classification**. This means that an area is subdivided into several groups or classes, 'separated by distinct boundaries'. Numerous classification systems exist, ranging from internationally accepted to very locally used classifications.

There are two kinds of habitat classification: **top-down** and **bottom-up** (Van Lancker and Foster-Smith 2007). A top-down approach is used, when an existing classification system is applied on a dataset, matching ground-truth samples to pre-defined classes. When the ground-truth data are used to determine habitat classes (finding new associations between biological and abiotic data), this is called a bottom-up approach.

An important example of a top-down habitat classification is the mapping of '**marine landscapes**'. This approach was developed for areas where biological samples are absent or very scarce (e.g. offshore or deep-sea areas). Therefore, a concept was firstly proposed for Canadian waters by Roff and Taylor (2000) and Roff et al. (2003), classifying abiotic datasets into marine landscapes. Biological data are only used passively, to validate the ecological relevance of the marine landscapes afterwards. The combination of the abiotic datasets into different classes was performed originally in a Geographic Information System (GIS). Examples of this approach can be found also for the UK (Connor et al. 2006) and for the Baltic Sea (Al-Hamdani and Reker 2007). This concept and the related issues are discussed in detail in Chapter 4, in which a more objective and statistically sound approach is suggested.

Some classification systems strive for a standardisation and a more objective, systematic approach for habitat classification. A well known example of such a habitat classification system is the **EUNIS classification** (European Nature Information System), a pan-European system, which was developed between 1996 and 2001 by the European Environment Agency, in collaboration with European-wide experts. It incorporates the classification of marine, coastal and terrestrial habitats with the marine part being based on the National Marine Habitat Classification for Britain and Ireland (Connor et al. 2004) and the North-East Atlantic classification, developed for the OSPAR Convention in 2004. The EUNIS classification consists of **six hierarchical levels**. The first level is the separation between marine, coastal and

terrestrial habitats. Level 2 and 3 are based purely on abiotic characteristics. From level 4 to 6, references to specific biological taxa are introduced (for an overview, see Foster-Smith et al. 2007a).

Other internationally accepted classification systems have been developed by Greene et al. (1999) and Valentine et al. (2005) for North America.

Although there is a strong need for a standardization of national, regional and local habitat mapping programmes (ICES 2007), most examples of marine habitat mapping in literature are based on **national, regional and local classification systems**:
- **Europe**: Sotheran et al. (1997); Service (1998); Brown et al. (2002); Freitas et al. (2003a); Freitas et al. (2003b); Bates and Oakley (2004); Kobler et al. (2006); and Brown and Collier (2008);
- **Central America**: Mumby and Harborne (1999); and Mishra et al. (2006);
- **North America**: Zacharias et al. (1999); Roff and Taylor (2000); Zajac et al. (2000), Kostylev et al. (2001); Anderson et al. (2002); Cochrane and Lafferty (2002); Edwards et al. (2003); Franklin et al. (2003); Roff et al. (2003); Zajac et al. (2003); Dartnell and Gardner (2004); Ojeda et al. (2004); Lathrop et al. (2006); and Rooper and Zimmermann (2007);
- **Oceania**: Banks and Skilleter (2002); and Porter-Smith et al. (2004);
- **Pacific Ocean**: Lundblad et al. (2006); and Gregr and Bodtker (2007).

Unlike the definition of habitat mapping, there is a trend in habitat mapping to omit distinct boundaries or habitat classes, but rather uses a continuously grading scale. In these cases, the suitability is shown (e.g. on a scale $0 - 1$ or $0 - 100$) for a single species or community and is often called a '**habitat suitability model**' (HSM) (for an overview, see Willems et al. in prep.). In general, HSMs are based on a range of statistical techniques, such as regression, environmental envelopes or neural networks (for an overview, see Guisan and Zimmerman 2000), integrating the biological data with the abiotic or ecogeographical variables (EGVs) from the beginning (i.e. bottom-up approach).

Although HSMs are, in general, based on statistical and thus objective methods, no or only few international standards exist. As such, most case studies are also of a national, regional or local nature. Some examples of marine HSMs are:
- **Arctic Ocean**: Jerosch et al. (2006); and Jerosch et al. (2007);
- **Europe**: Eastwood et al. (2001); Brinkman et al. (2002); Le Pape et al. (2003); Nicolas et al. (2007); Wilson et al. (2007); Degraer et al. (2008); Skov et al. (2008); and Willems et al. (2008);
- **North America**: Iampetro and Kvitek (2005); Bryan and Metaxas (2007);
- **Oceania**: Bradshaw et al. (2002).

The most important advantages and disadvantages, of both habitat classification and HSMs, are given in Table 1.1.

Chapter 2 and 3 of this thesis resulted in sedimentological coverages as input for both a habitat classification of marine landscapes (Chapter 4) and HSMs (Chapter 5 and 6). All results are mapped on a national and a local level, although the HSMs of the macrobenthic communities of Chapter 5 have been translated to a EUNIS level 5 map (Schelfaut et al. 2007), the pan-European classification system.

Table 1.1: Advantages and disadvantages of habitat classification versus habitat suitability modelling.

	Advantages	Disadvantages
Habitat classification	- simple methodologies	- in general no statistical methods: subjective
	- international classification systems exist	- existing international classification systems not suitable for all datasets
	- not limited to a single species or community	- sometimes artificial boundaries between habitat classes
Habitat suitability models	- statistical methods: more objective	- complex methodologies
	- continuous scale: no artificial boundaries	- limited to a single species or community

1.1.5 Difficulties in habitat mapping

With an increasing number of habitat mapping initiatives, a growing need exists for harmonized approaches. The main difficulties that need to be dealt with relate to:

i. Numerous habitat mapping methodologies and approaches exist, but there is a strong need for **standardisation** and for a **common approach** to a more coherent mapping of wider areas and to improve consistency towards management and decision making.

ii. Methodologies are often based on 'expert judgement' and subjective decisions (e.g. traditional method of marine landscape mapping in which abiotic datasets and their class breaks have to be chosen and in which the number of landscapes is dependent on the combination of all the classes of the different datasets; e.g. 3 sediment classes and 2 bathymetry classes result already into 6 marine landscapes). As such, there is a strong need for more **objective methodologies**.

iii. The **choice of abiotic or ecogeographical variables** (EGVs), defining the abiotic habitat (substrate, bathymetry, energy and related variables), as input for habitat mapping studies, is often difficult. The variables have to be ecologically relevant, but in some cases, the relationship between the biological data and the EGVs is not known.

iv. Moreover, the reliability of EGVs and habitat maps is highly variable. EGVs based on 100 or 20 sedimentological samples logically do not have the same reliability. As such, there is a need for **tools to estimate the EGV reliability**.

v. Different spatial scales of EGVs can be related to the occurrence of species or communities (e.g. a sandbank may be superimposed by dunes, ranging from small to very-large (Ashley 1990); a species can have a preference for certain topographic locations on the sandbank or on the dunes). There is a need for a **multi-scale approach** regarding EGVs that predict the occurrence of species or communities.

Above, only those issues have been enumerated that were dealt with throughout this study. However, many other aspects remain important; these relate mainly to:

i. Habitat mapping studies performed on **different spatial scales**, going from fine- to intermediate- to broad-scale (cfr. Van Lancker and Foster-Smith 2007), are based on datasets of different spatial resolution and result into habitat maps that partly do **not overlap**.

ii. As mentioned before, most studies are of a local, regional or national nature. As such, datasets of different resolutions and qualities are used, resulting into **transborder problems**, problems of non-overlapping habitat classes and different classification systems.

iii. Moreover, different areas have **different priorities** of species and communities that are in need of protection.

iv. A last problem is related to the **temporal scale**. A habitat map is mostly represented as a final, unchanging result. Logically, habitats of species and communities change in time due to natural (e.g. seasonal) and anthropogenic (e.g. destruction of habitats by fishery impact) variation.

1.1.6 <u>Research strategy</u>

The general objective of this thesis is to develop **spatial distribution models** as input for marine habitat mapping. The spatial distribution models concern both the production of high quality **physical coverages** as well as the **integration of ground-truth data and coverages**, based on (geo)statistical methods. All models were **validated and intercompared**.

Particularly, the objectives anticipate to the following needs in habitat mapping:

A **new approach for marine landscape mapping** is proposed, which is simple, statistically sound and easy applicable to other regions. The proposed methodology is a step forward in standardising marine landscape mapping throughout Europe.

Methodologies are developed that are straightforward, **objective** and **statistically sound**. For the mapping of sediment distribution, multivariate geostatistics are applied (Chapter 2 and 3); and for the mapping of marine landscapes, the combined use of principal components and cluster analysis (Chapter 4) is proposed. Moreover, the physical coverages (sedimentological maps, multi-scale derivatives of the bathymetry and other coverages) are used as input for two kinds of HSMs, predicting the occurrence of macrobenthic communities and species (Chapter 5 and 6).

A **maximal input of EGVs**, is used for the modelling of the marine landscapes and for the HSMs (Chapter 4, 5 and 6). This is possible with factor analysis (both Principal Components Analysis and Ecological Niche Factor Analysis), transforming the correlated datasets into linear combinations of the original EGVs.

The reliability of EGVs is optimised by applying **multivariate geostatistics** for the sedimentological maps (Chapter 2 and 3). **Validation** of the sedimentological maps, marine landscapes map and the HSMs is performed (Chapter 2, 3, 4, 5 and 6).

Multi-scale topographical EGVs, derived from the bathymetry, can be used for both the modelling of sedimentological maps (Chapter 3) and for the modelling of the HSMs of the species *Owenia fusiformis* (Chapter 6).

The Belgian part of the North Sea (BPNS) served as an ideal 'test case' for all of these methodologies, because of its high amount of datasets available. The datasets concern both the abiotic and the biotic environment. The main sources of 'raw' information that were important for this research were:

- Abiotic datasets:
    - Surficial sediment data, extracted from the sedimentological database 'sedisurf@' (hosted at Ghent University, Renard Centre of Marine Geology), with samples covering the entire BPNS (of importance in Chapter 2, 3, 4, 5 and 6);
    - Bathymetric data of the BPNS (based on single beam acoustics, obtained from the Flemish Authorities, Agency for Maritime and Coastal Services, Flemish Hydrography) (of importance in Chapter 2, 3, 4, 5 and 6);
    - Bathymetric data of the study area of Chapter 3 and 6 (based on multibeam acoustics), acquired by Ghent University, Renard Centre of Marine Geology;
    - Hydrodynamical data of the BPNS, modelled by the Management Unit of the North Sea, Mathematical Models and the Scheldt Estuary (of importance in Chapter 4 and 6).
- Biological dataset:
    - Macrobenthic database 'Macrodat' (Marine Biology Section, Ugent – Belgium, 2008), with samples covering the entire BPNS (of importance in Chapter 4, 5 and 6).

1.2 Study area

This section provides an introduction to the environmental datasets that have been used in the context of habitat mapping along the Belgian part of the North Sea (BPNS). In addition, it describes the relevant legal framework.

1.2.1 General seabed characterization

The BPNS is part of the Greater North Sea and is situated on the north-west European Continental Shelf (Figure 1.3). Its surface area is 3600 km², which represents hardly 0.6 % of the north-west European shelf. The BPNS is characterized by its relative shallowness. The depth of the seabed ranges from 0 m to -46 m (Mean Lowest Low Water at Spring, MLLWS) (Figure 1.4). In the coastal zone (10-20 km), depths range between 0 m and -15 m MLLWS, followed by a central zone of -15 m to -35 m. Towards the northern part of the shelf, water depths range between -35 and -50 m MLLWS.

The seabed surface is characterized by a highly variable topography, with a series of sandbanks and swales. Sandbanks are characteristic for continental shelves with a high amount of sand and sufficiently strong currents (Stride 1982). Along the BPNS, numerous large sandbanks occur in parallel groups (Figure 1.3): the Coastal Banks and the Zeeland Banks are quasi parallel to the coastline, whereas the Flemish Banks and the Hinder Banks have a clear offset in relation to the coast. The direction of their asymmetry is mostly to the northeast for the Flemish Banks and to the southwest for the Hinder Banks, although the direction can change along the sandbanks (e.g. Buiten Ratel); the Coastal Banks and the Zeeland Banks have their steep side oriented towards the coast. Some sandbanks have a central kink (Deleu et al. 2004; and Bellec et al. in press). On the BPNS, sandbanks play an important role in natural coastal defense and as a source for marine aggregates (for an overview, see Van Lancker et al. in press).

1.2.2 Geological background

The substratum of the BPNS is composed of solid layers of various ages. The Palaeozoic basement (London-Brabant Massif), flooded since Late Cretaceous times, is covered with a series of Cretaceous, Palaeogene (Tertiary) and Pleistocene and Holocene (Quaternary) sediments (for an overview, see Le Bot et al. 2003).

The Palaeogene deposits Y1 to P1 dip gently (0.5 − 1°) towards the NNE, and the units are superposed from WSW towards ENE; the direction in which they subcrop successively (Figure 1.5) (Le Bot et al. 2003).

The Quaternary sediments are non-cemented, partly relict and partly subject to movement, caused by tidal currents and wave action. Most of the sediments are of Holocene age. Because of an important sediment reworking during the Holocene, only few sediments are considered of Pleistocene age, a period characterized by a succession of glacial and interglacial stages (Le Bot et al. 2003). However, it is possible that within deep incised scour hollows Pleistocene infillings are present (Liu et al. 1993, Stolk 1996, Trentesaux et al. 1999), although some authors assume a Holocene age (Trentesaux 1993, Berné et al. 1994).

The Holocene started 10.000 years ago and can be considered as the present interglacial. During the first part of this period, a sharp sea level rise in the Southern North Sea took place, known as the Flandrian transgression. The Holocene sediments form mainly the present tidal sandbanks (Le Bot et al. 2003).

1.2.3 <u>Morpho-sedimentological characterization</u>

The seabed surface is mainly sandy in nature. Sediments are sorted as a consequence of the interaction between the currents and the specific morphology of the seabed. Generally, sediments coarsen in an offshore direction (Lanckneus et al. 2001). The sand fraction (63 μm - 2 mm; Verfaillie et al. 2006) is found merely on the sandbanks, whereas in the swales, also coarser sands, gravel (> 2 mm) and higher silt-clay fractions (< 63 μm) can occur (Figure 1.6). The depth and the characteristics of the seabed sediments in the swales can differ along the two sides of a sandbank (e.g. Buiten Ratel). The sandbanks, as well as some of the swales, are covered with dune structures. The heights of the dunes differ from one region to another. Tidal action and movement of water masses under changing meteorological conditions are responsible for the displacement of these bedforms.

The coastal area around the harbour of Zeebrugge and Oostende is characterized by very high silt-clay percentages of more than 25 % (Figure 1.7). Furthermore, a gradient from high to low silt-clay percentages occurs in the whole coastal area, increasing from west to east. This zone of higher silt-clay percentage is situated mainly in an area of 20 km from the coastline. Some exceptions are the zones between the northern part of the Buiten Ratel and Oostdyck and between the Goote- and the Thorntonbank.

The Coastal and Flemish Banks are characterized by fine to medium sands with grain-sizes ranging from 63 until 350 μm (Figure 1.6). Higher grain-sizes in this area are found locally (e.g. on the Ravelingen and the Middelkerkebank). 20 km offshore from the Belgian coastline (i.e. at the northwestern side of the Akkaertbank), all sands have grain-sizes coarser than 300 μm, except for some local anomalies (note that the low grain-sizes on the Fairy Bank are due to a lack of samples). Generally, coarser sands characterize the Hinder Banks with grain-sizes of more than 350 μm. In the swales, between the Noordhinder-, Oosthinder- and Bligh Bank, sand coarser than 400 and even 500 μm is found. This is also the case for the most offshore part of the BPNS, north of the Noordhinderbank, where grain-sizes range between 350 and 600 μm (note that the highest grain-sizes are due mainly to shell fragments). Figure 1.8 shows the distribution of coarse sand, together with potential areas of gravel. The potential gravel areas are situated mainly further offshore than 20 km from the coastline; they are concentrated in the swales of the sandbanks. The most important areas of gravel occur between the Oostdyck and Buitenratel (and the continuation of this swale further to the east, between the Goote- and Akkaertbank), between the Goote- and the Thorntonbank and, locally, in the swales of all of the Hinder Banks (with a large concentration between the Westhinder- and Oosthinderbank and near the western parts of the Goote- and Thorntonbank). New insights in their occurrence and origin are described in Deleu and Van Lancker (2007).

The bedforms of the BPNS (Figure 1.9) have heights ranging from 1 to more than 6 m (although the latter are exceptional). Most of the dunes have heights between 1 and 4 m. Ashley (1990) classifies dunes as follows: small dunes, medium dunes, large dunes and very large dunes with spacings of respectively 0.6-5 m, 5-10 m, 10-100 m and

more than 100 m, with heights of respectively 0.075-0.4 m, 0.4-0.75 m, 0.75-5 m and more than 5 m.

To summarize, the trends from the coastline to further offshore (SE to NW) and parallel to the coastline (SW to NE) are given for all of the described parameters (Table 1.2).

Table 1.2: Sedimentological trends along the Belgian part of the North Sea, in an offshore direction and in a direction parallel to the coastline.

	further offshore; SE to NW	parallel to coastline; SW to NE
Median grain-size	coarser	finer
Silt-clay %	lower	higher
Gravel	more	less
Bedforms	more/higher	no trend

Further details on the origin and composition of the sediments and on the morphology can be found in Lanckneus et al. (2001) and Van Lancker et al. (2007).
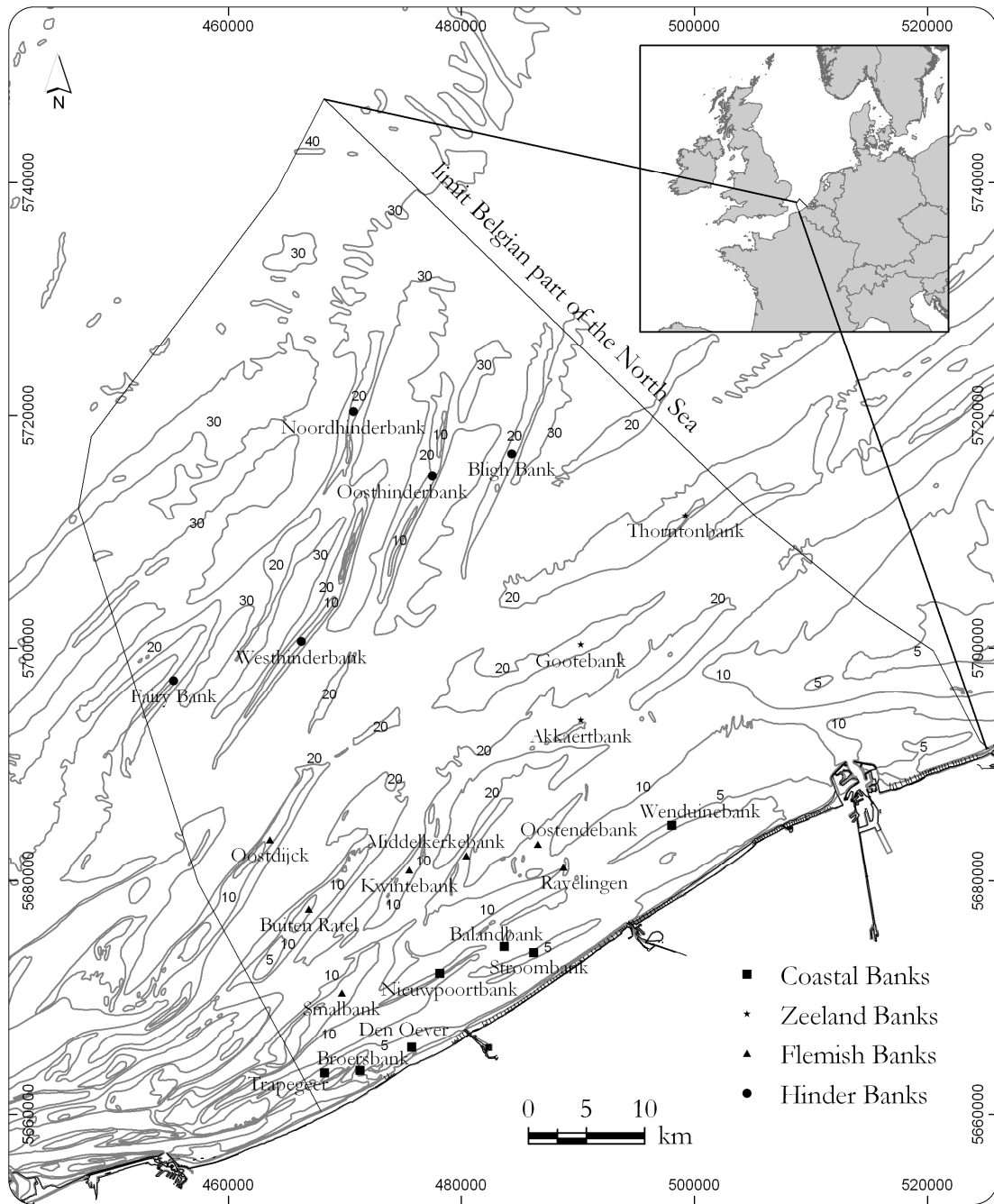
Figure 1.3: General seabed characterization of the Belgian part of the North Sea with the 4 groups of sandbanks. The contour lines of the bathymetry are marked with depth values (MLLWS).
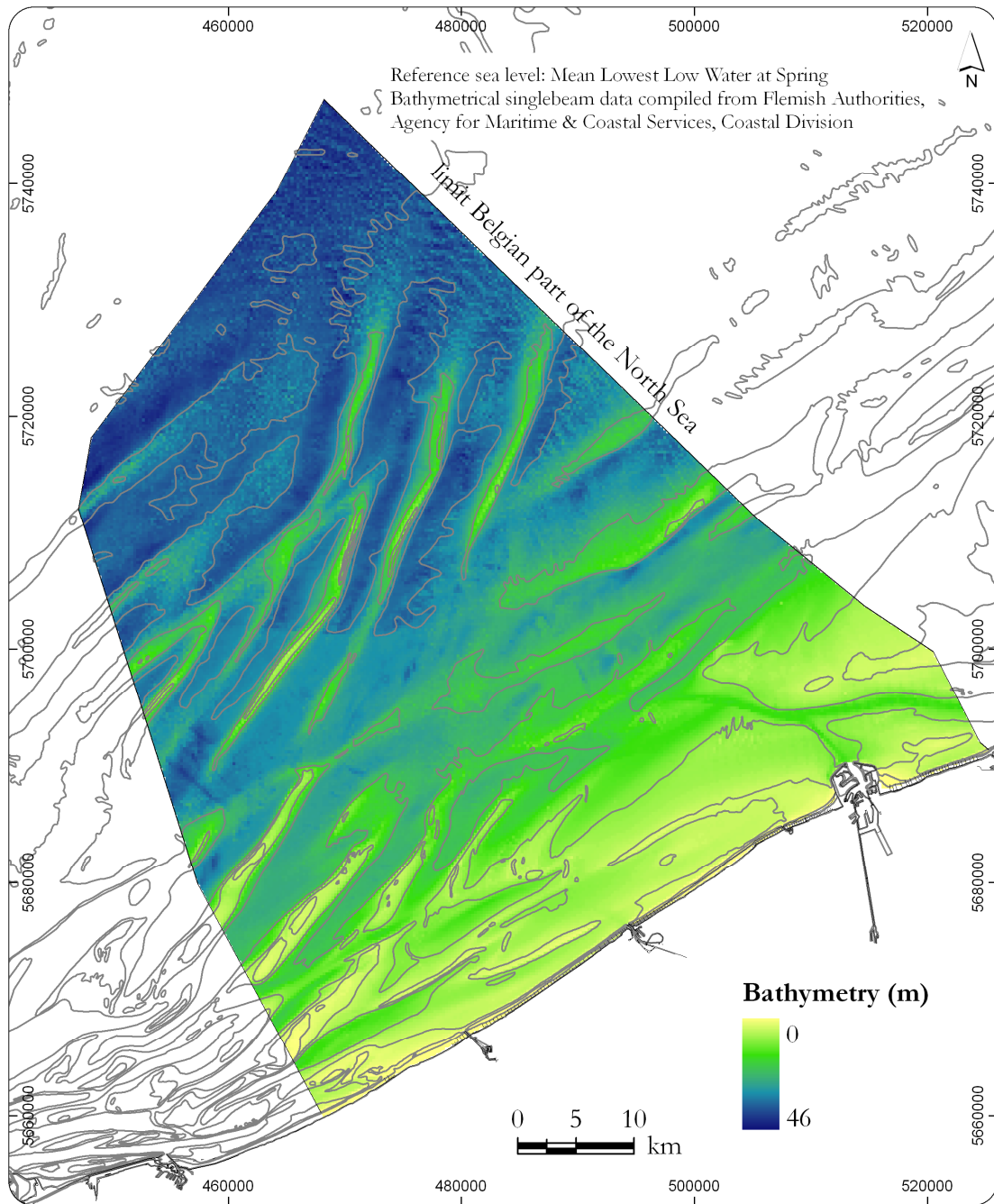
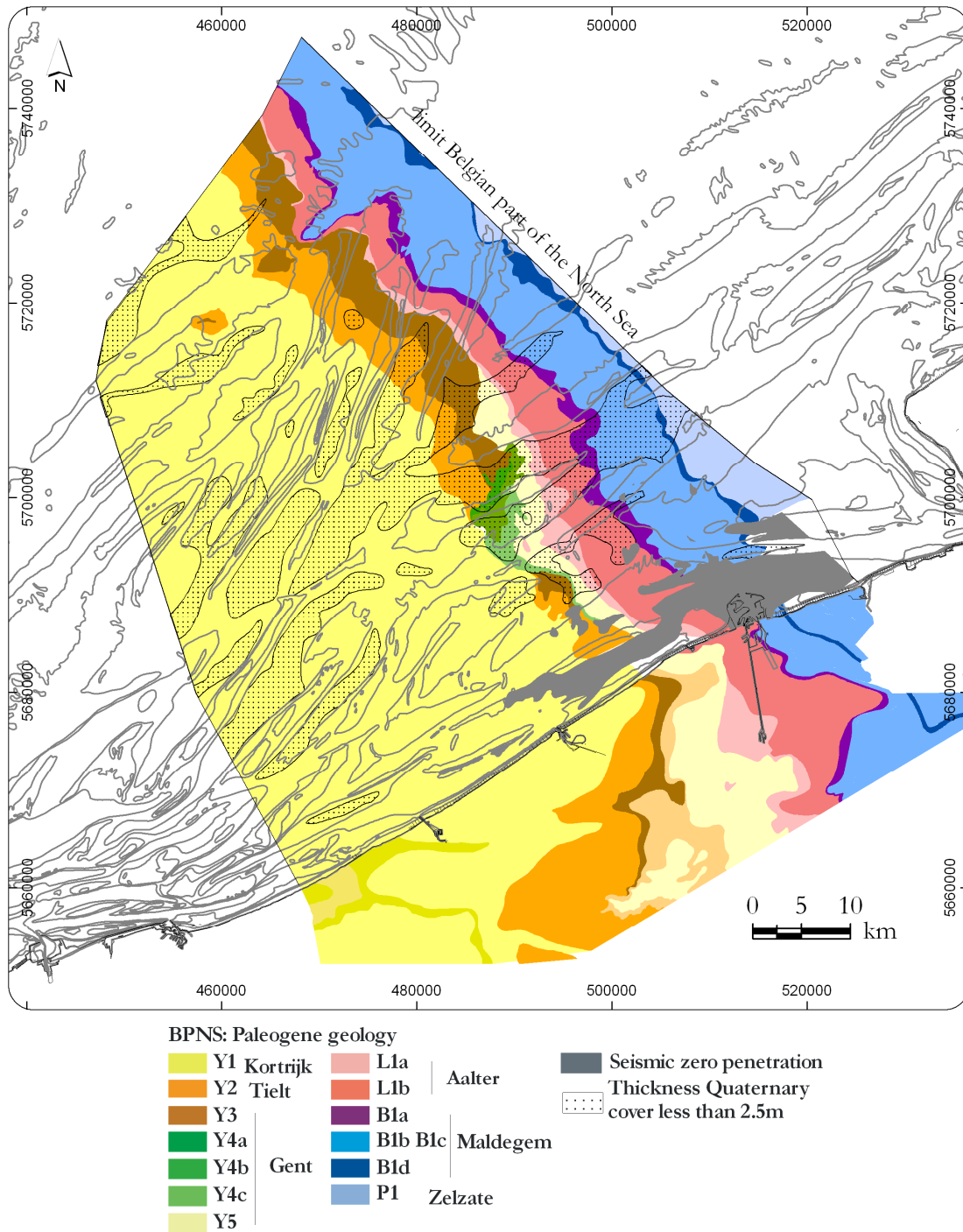**Figure 1.4: Bathymetric map of the Belgian part of the North Sea.**

Figure 1.5: Subcrops of solid Paleogene deposits under the non-consolidated Quaternary deposits on the Belgian part of the North Sea (BPNS) (from Le Bot et al. 2003; offshore data: after Maréchal et al. 1986; De Batist 1989; and De Batist and Henriet 1995 / onland data: Jacobs et al. 2002)
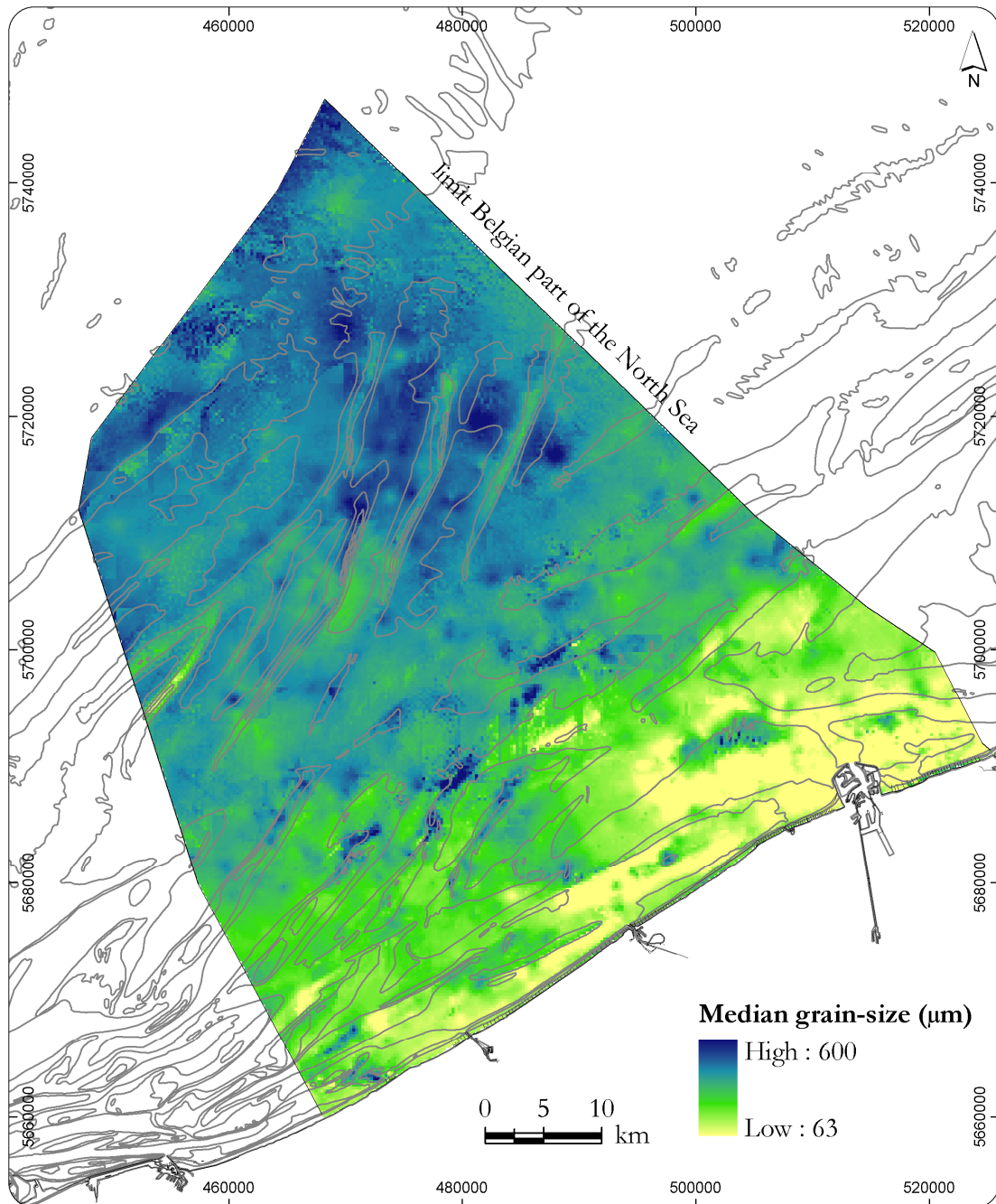
Figure 1.6: Median grain-size of the sand fraction (63 – 2000 µm) in the Belgian part of the North Sea.
The methodology to come to this map is described in detail in Chapter 2 of this thesis. This figure corresponds with Figure 2.10b. The density of point data to come to this map is presented in Figure 2.12.
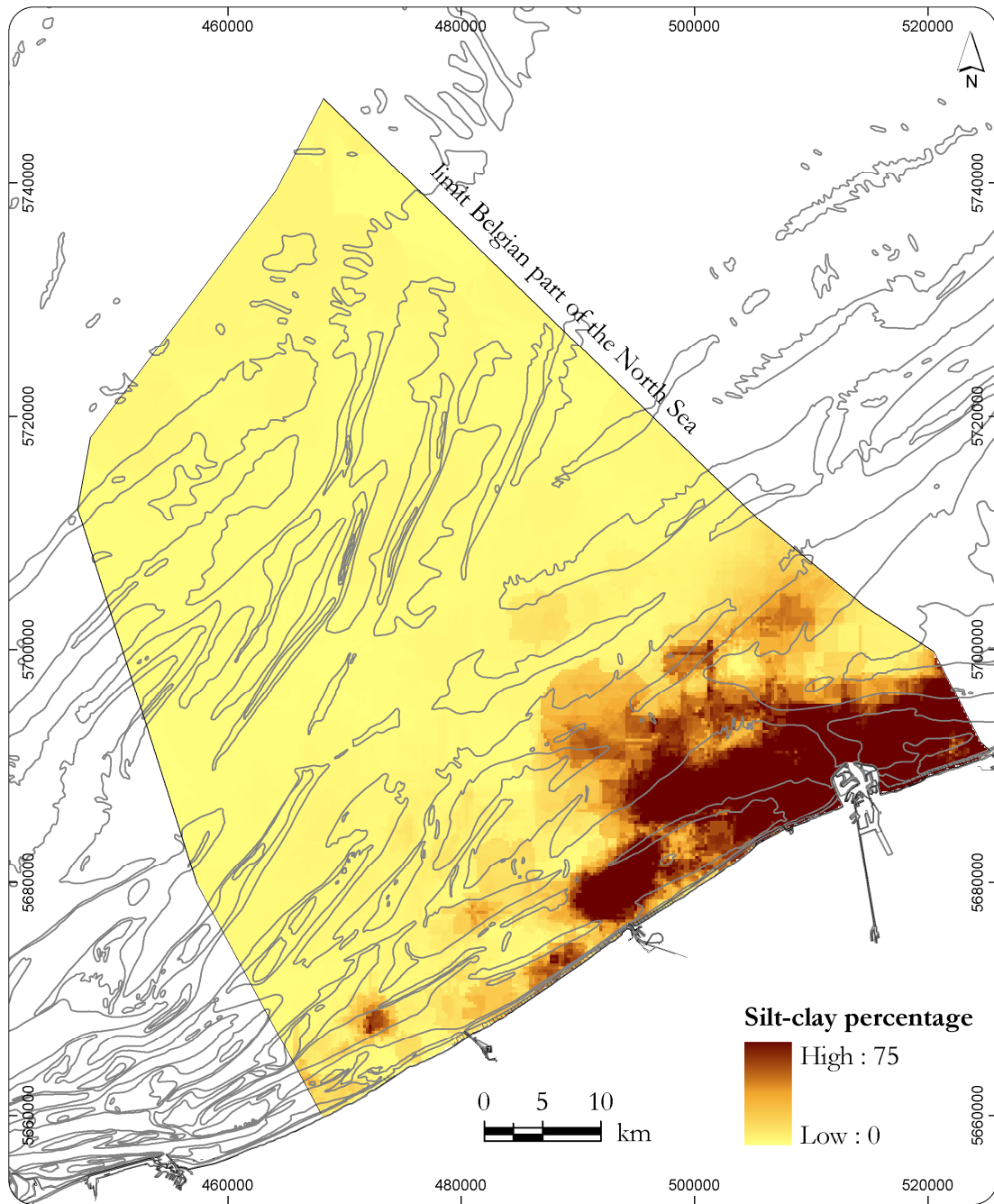
Figure 1.7: Silt-clay percentage in the Belgian part of the North Sea (Van Lancker et al. 2007). The density of point data to come to this map is presented in Figure 2.12.
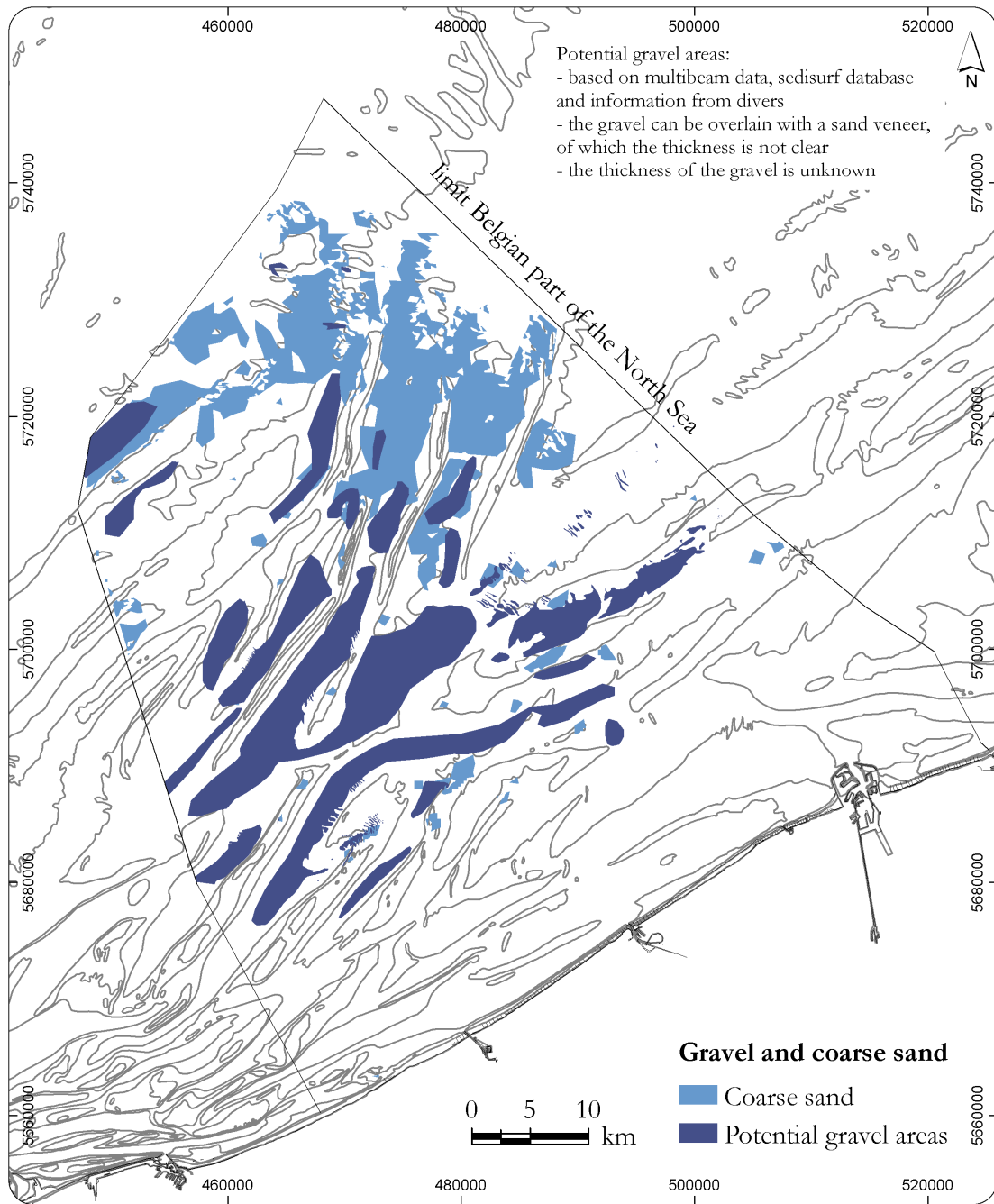
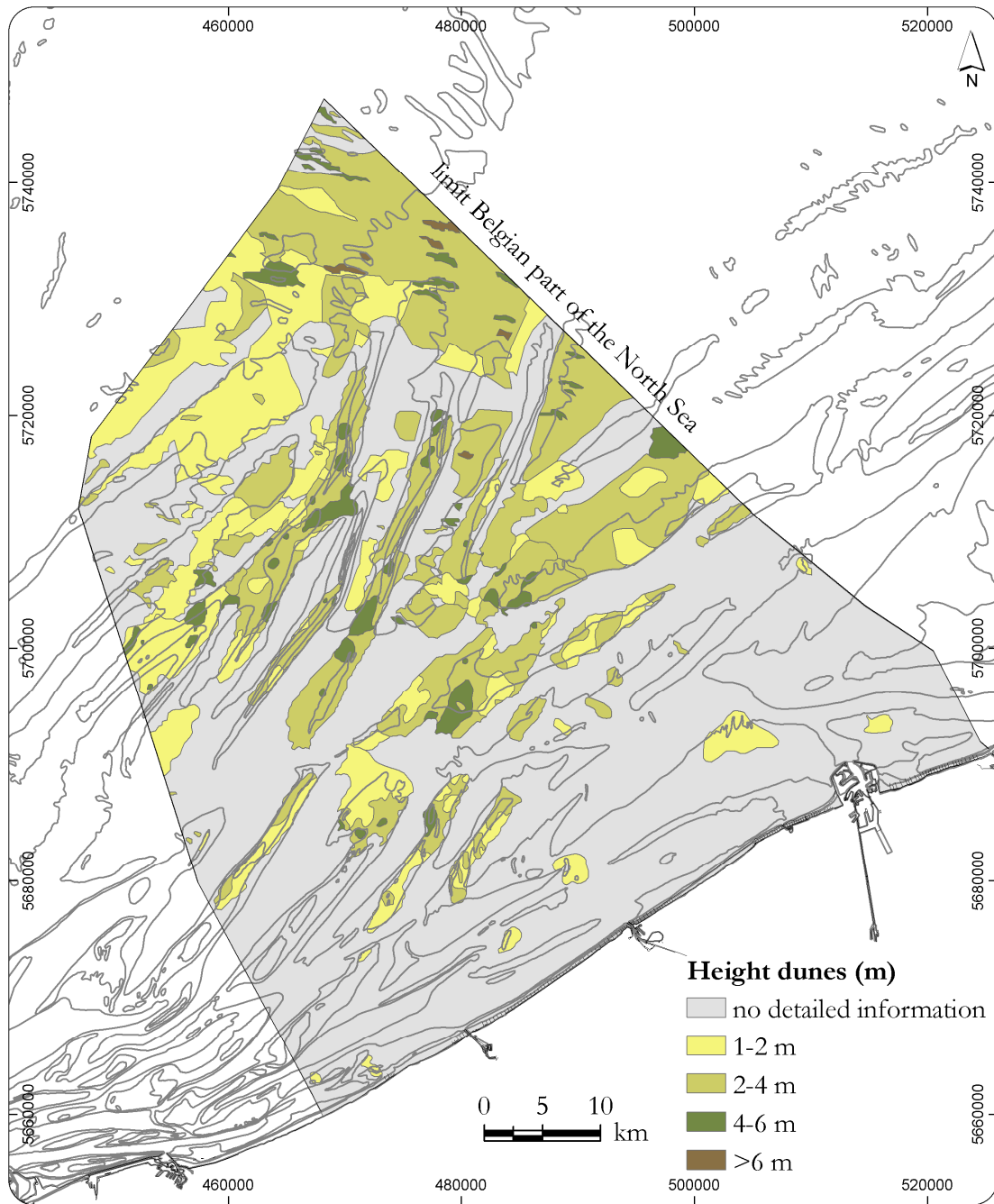**Figure 1.8: Gravel and coarse sand in the Belgian part of the North Sea (Van Lancker et al. 2007).**

Figure 1.9: Bedforms and the height of the large to very large dunes in the Belgian part of the North Sea.
This map is based on singlebeam, side-scan sonar and multibeam data (Van Lancker et al. 2007).

1.2.4 <u>Hydrodynamical characterization</u>

Tides, wind and wave activity are the main hydrodynamic agents of the BPNS. Tides are semi-diurnal and slightly asymmetrical with a mean spring tidal range of 4.3 m at Zeebrugge and 2.8 m at neap tide. At spring tide, current velocities can be more than 1 m/s. Winds and waves originate mainly from the SW or from the NE. Winds are for almost 90% of the time below 5 Bft, while the significant wave height at the Westhinder is for 87% of the time below 2.0 m. The residual transport of the water masses is mainly to the NE (Van den Eynde 2004).

The Management Unit of the North Sea Mathematical Models and the Scheldt Estuary (MUMM) modelled a whole set of hydrodynamical variables such as the maximal current velocity (m/s) and the maximum bottom shear stress (N/m²). The maximum bottom shear stress is the maximal frictional force exerted by the flow per unit area of the seabed. Further details can be found in Van Lancker et al. (2007).

For both the maximum bottom stress (Figure 1.10) as well as the maximum current velocity (Figure 1.11), the same trend is visible on the BPNS: very high values occur around the harbour of Zeebrugge and along the northwestern part of the BPNS (mainly along the Oostdyck and in particular along its northern side). The lowest values occur along the western Coastal Banks. Intermediate values are found mainly along the central part of the BPNS (near the western part of the Gootebank) and to the east of the BPNS.

1.2.5 <u>Biological characterization of the BPNS</u>

Marine bottom fauna (or benthos) can be subdivided into five ecosystem components: species living just above and on the seafloor (hyperbenthos and epibenthos, respectively) and the fauna that lives inside of the sea bottom (infauna: micro-, meio- and macrobenthos).

Hyperbenthos are smaller species, like amphipods or larvae of epibenthos. Epibenthos are large, active benthos species, including sea stars, brittle stars, crabs, lobsters, bottom fish and cephalopods.

The microbenthos species are unicellular and bacterial organisms that live between and on the sand and silt grains. Meiobenthos species are multicellular organisms, smaller than 1 mm, e.g. copepod crustaceans and round worms inhabiting the interstitial spaces of the sediment. The macrobenthic species are all multicellular organisms and organisms larger than 1 mm. Examples of macrobenthos are bivalves, bristle worms, small crustaceans, such as amphipods and isopods and echinoderms.

Cattrijsse and Vincx (2001) give a summary of data on the BPNS for the five ecosystem components; for this research, only relationships between the physical environment and the macrobenthos has been dealt with.

A large amount of biological data were collected from the BPNS (Marine Biology Section, Ugent – Belgium, 2008). Between 1976 and 2001, over 1500 biological samples have been collected on the BPNS. The data were gathered in the framework of different research projects, resulting in an uneven distribution throughout the area. The sandbanks are mostly well-sampled, whereas almost no samples are available from the open sea and the eastern part of the Flemish Banks (Van Hoey et al. 2004). In general, the highest sample density (number of samples per km²) is found in inshore areas, decreasing steadily in an offshore direction.

As the BPNS is characterized by a highly variable topography, several macrobenthic communities and assemblages are distinguished. A community is defined as a group of organisms, occurring at a particular place (a physico-chemical environment) and time, interacting with each other and the environment. Distribution and diversity patterns of communities are therefore linked to a specific habitat type.

Up till now, five subtidal soft-bottom macrobenthic communities and six transitional communities (three subtidal and three intertidal species associations) are discerned (Degraer et al., 1999b; Degraer et al. 2002; Van Hoey et al. 2004). The occurring species associations differ drastically in habitat and species composition. The *Macoma baltica* community is bound to fine sandy, shallow locations characterized by high mud contents. These locations are only found close to estuarine environments (De Waen 2004). In nearshore muddy sands, species of the *Abra alba* community occur. The assemblage is characterized by a high species abundance, as well as a high diversity. Within the community, bivalve species occur in high densities (Van Hoey et al. 2004). These serve as an important food resource for epibenthic predators and benthic eating diving sea ducks (Degraer et al. 2002). Van Hoey et al. (2005) demonstrated that the ecological variation within the *A. alba* community is significant, as the BPNS can be considered as a major transition from the rich southern to the relatively poorer northern distribution area of this community. Furthermore, the community is due to temporal variations as well (Van Hoey et al. 2007). The *Nephtys cirrosa* community is characterized by a low species abundance and diversity and is typical for sandy areas. The *Ophelia limacina* community is found in medium to coarse sediments, often associated with gravel and shell fragments. However, this community is also represented in fine to medium sands with very low mud content. The distribution and description of the different communities and a selection of their macrobenthic species, is given in Degraer et al. (2006). The last community is the *Barnea candida* community (Degraer et al. 1999b). This community has a low diversity and density and is typically found in places where compact, tertiary clay layers outcrop. The rarity of this community is directly linked to the rarity of its habitat.
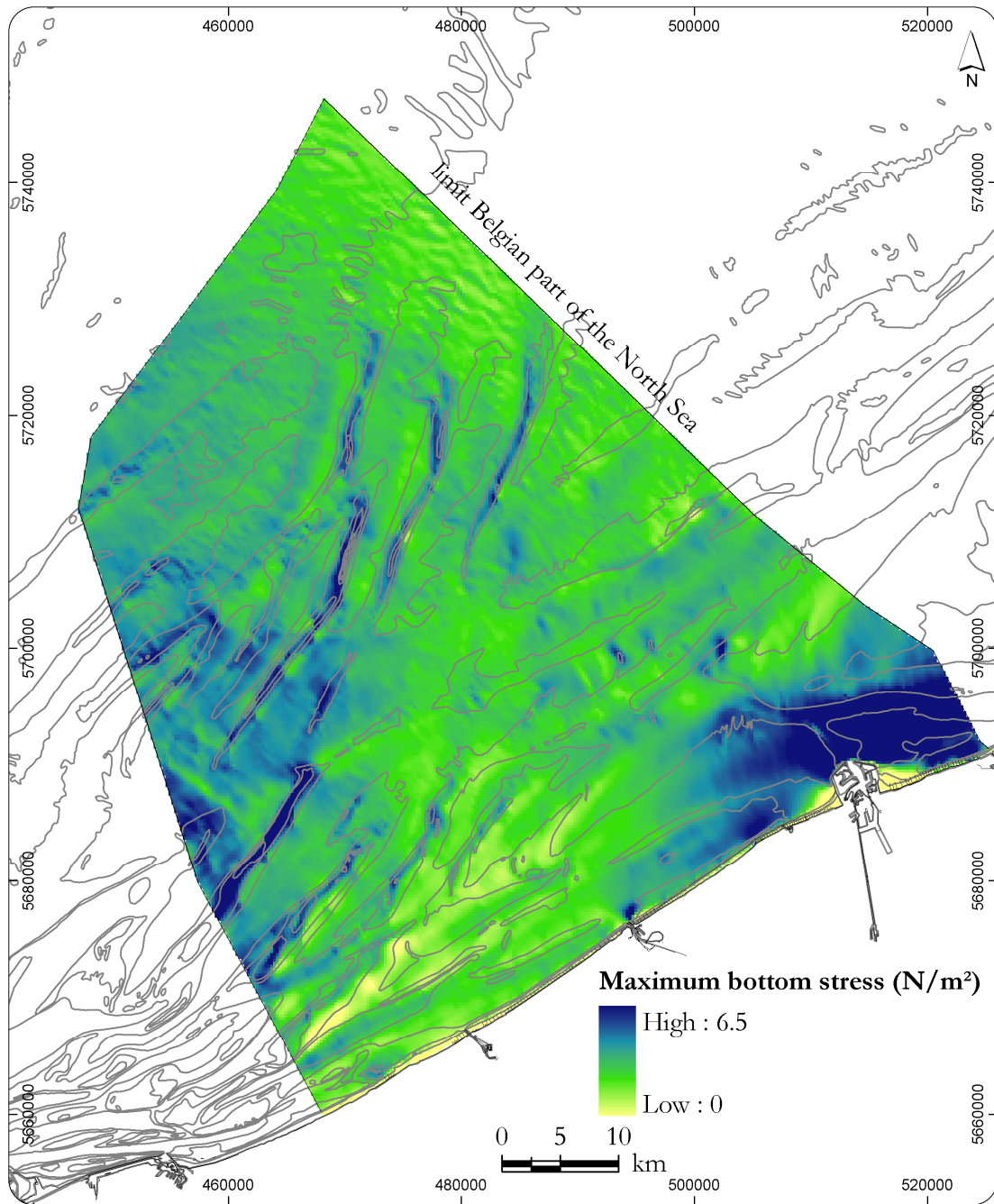
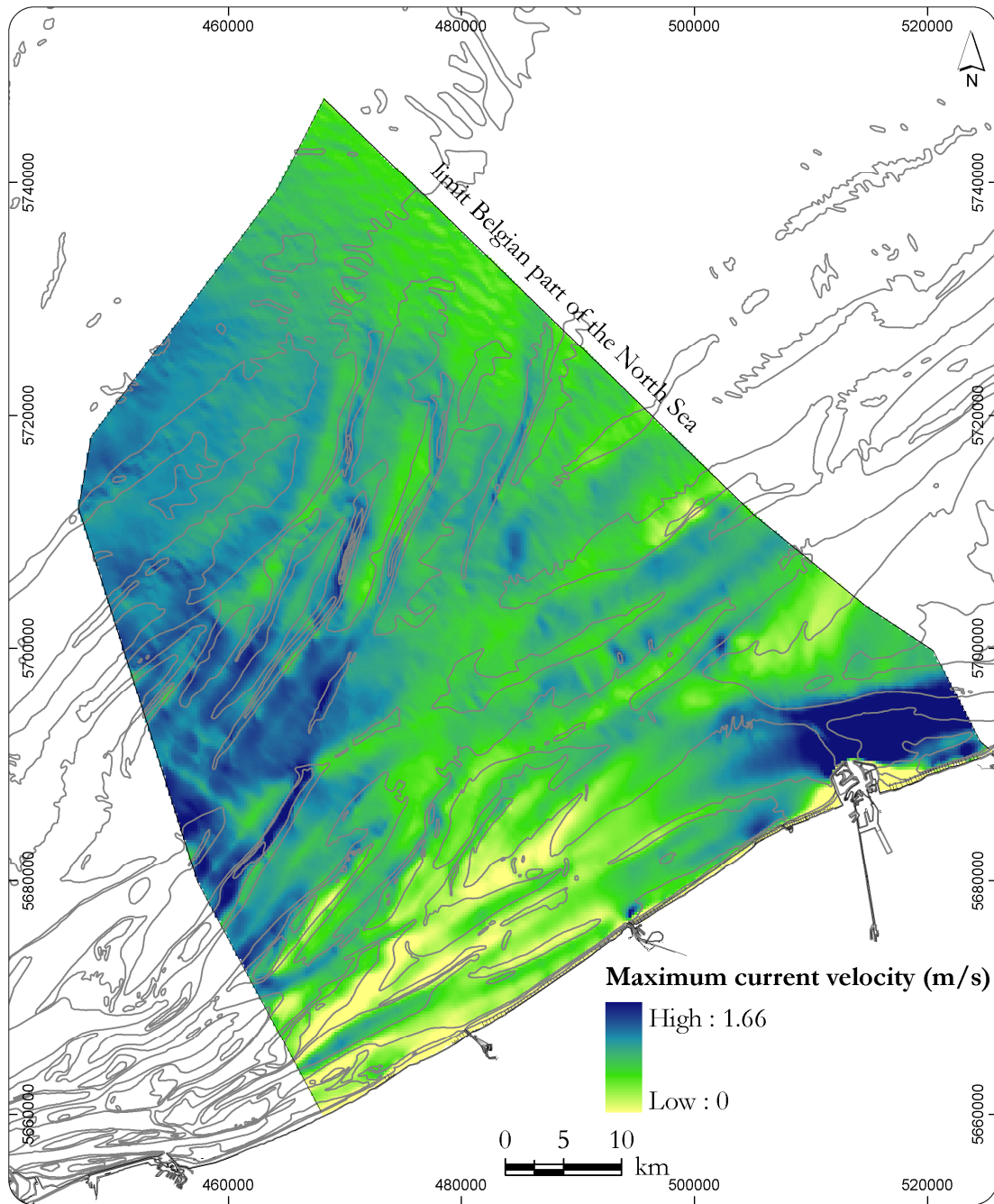**Figure 1.10: Maximum bottom stress in the Belgian part of the North Sea (Van Lancker et al. 2007).**

Figure 1.11: Maximum current velocity in the Belgian part of the North Sea (Van Lancker et al. 2007).

1.2.6   Legal characterization of the BPNS

Habitat maps are relevant in the context of **policy making**, although the link between science and policy is often difficult and not at all evident.
Table 1.3 gives an overview of international, European and Belgian obligations, commitments and laws related to habitat mapping on the BPNS.

Table 1.3: Overview of the most important regulations concerning the designation of marine protected areas on the BPNS in an international, European and Belgian context (modified from Cliquet et al. 2007).

INTERNATIONAL	
- Obligations	- Convention on Wetlands of International Importance, especially as Waterfowl Habitat (Ramsar 1971)[1] - Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR 1992)[2] - Convention on Biological Diversity of Rio the Janeiro (1992)[3]
- Commitments	- designation and management of marine protected areas, such as those agreed at the World Summit on Sustainable Development, to establish a representative system of marine protected areas by 2012[4] - decision from the 7th conference of state parties to the Biodiversity Convention to establish and maintain (by 2012) marine and coastal protected areas that are effectively managed, ecologically based and contribute to a global network of marine and coastal protected areas[5]
EUROPEAN	
- Obligations	- Birds Directive 79/409/CEE (1979)[6] - Habitats Directive 92/43/CEE (1992)[7]
- Commitments	- EU Biodiversity Action Plan has as objective to complete a network of Special Protection Areas by 2008 for marine areas, adopt lists of Sites of Community Importance by 2008 for marine areas, designate Special Areas of Conservation and establish management priorities and necessary conservation measures for Special Areas of Conservation by 2012, and establish similar management and conservation measures for Special Protection Areas by 2012 for marine areas[8]
BELGIAN	
- Legislation	- Law on the protection of the marine environment in marine areas under Belgian jurisdiction on the marine environment[9] - Royal Decree of 14 October 2005[10]

The Marine Protection Law of 1999[11] was the first Belgian law, enabling the federal government to designate marine protected areas (MPAs). This law permits the designation of 5 types of marine protected areas: 1) integral marine reserves; 2) specific marine reserves; 3) Special Protection Areas (SPAs) or Special Areas of Conservation (SACs) for specific habitats or species; 4) closed zones for certain activities during certain periods; and 5) buffer zones (Cliquet et al. 2007). However, because of an initial lack of public participation or consultation of stakeholders, it

took the Belgian government until **2005** to legally designate the first **5 MPAs on the BPNS**[12] (Cliquet et al. 2007):

- **3 SPAs** in the framework of the **Birds Directive**[13]:
    - SBZ-V1 Nieuwpoort;
    - SBZ-V2 Oostende;
    - SBZ-V3 Zeebrugge.
- **2 SACs** in the framework of the **Habitats Directive**[14]:
    - SBZ-H1 Trapegeer Stroombank;
    - SBZ-H2 Vlakte van de Raan.

The designation of the SPAs is based on Haelters et al. (2004). Together, the SACs and the SPAs will create a network of protected areas across the EU, known as **Natura 2000** (Douvere et al. 2007).

However, in February 2008, the Belgian Council of State annulled the designation of the Vlakte van de Raan as SAC[15] (after a complaint by the energy company Electrabel).

In 2006, a 6th area was designated: the **specific marine reserve** Bay of Heist[16].
All Belgian MPAs are presented in Figure 1.12.

Moreover, other **European Directives** for the conservation or protection of marine environments exist (**Water Framework Directive; 2000/60/EC**) or are in development (**Marine Strategy Directive**) and have to be implemented by the European member states (Derous et al. subm. b). The Water Framework Directive establishes a framework for the protection and improvement of all European surface and ground waters, with a 'good ecological water status' by 2015 (Derous et al. subm. b). The future Marine Strategy Directive (included into the EU Marine Thematic Strategy) will establish a framework for the protection and preservation of the marine environment, the prevention of its deterioration and the restoration of that environment in areas where it has been affected adversely (Derous et al. subm. b), with a 'good environmental status' in the marine environment as ultimate objective by 2021 (DEFRA 2006). The overall aim of this strategy is to promote sustainable use of the seas and to conserve marine ecosystems against certain threats (e.g. loss of habitats, degradation of biodiversity) and pressures (e.g. physical degradation of habitat from dredging and extraction of sand and gravel) (European Commission 2006). The EU Maritime Policy calls in its **Green Paper** (Commission of the European Communities 2006) for a system of ecosystem-based marine spatial planning for a growing maritime economy aiming to manage the increasingly competing economic activities, while at the same time safeguarding biodiversity (Douvere et al. 2007).

In the context of **marine spatial planning** (MSP), there is a growing need to meet these international and national commitments regarding biodiversity conservation. Until recently, MSP on the BPNS was done on an ad hoc basis with legal driving forces (Law of the Sea and Belgian legislation) and economic driving forces (e.g. aggregate extraction and fisheries) (Douvere et al. 2007). The BPNS has a very limited surface (3600 km²) and is, regarding the anthropogenic activities, one of the most occupied shelf seas of the world (Figure 1.13) (see Maes et al. 2005, for an overview).
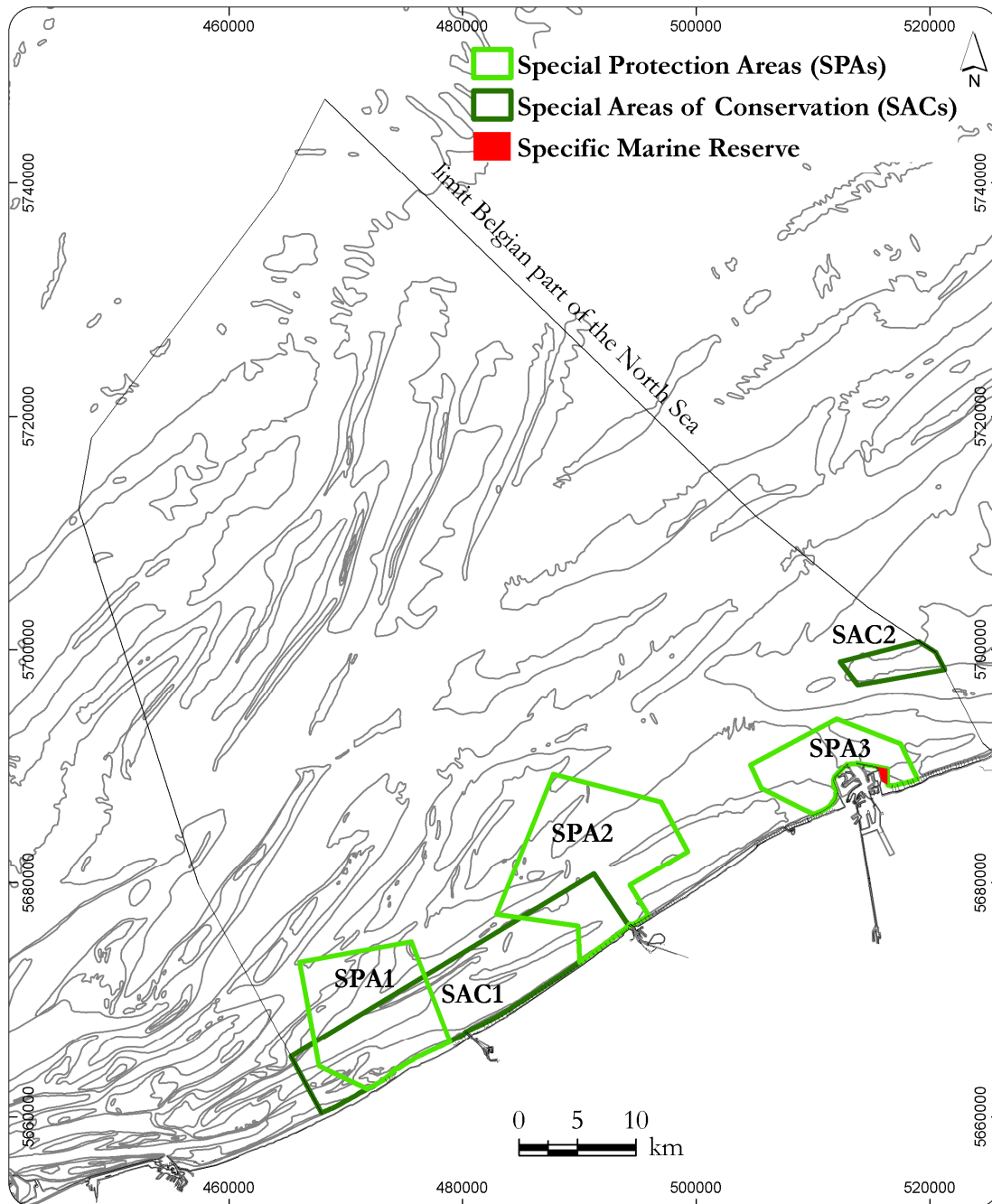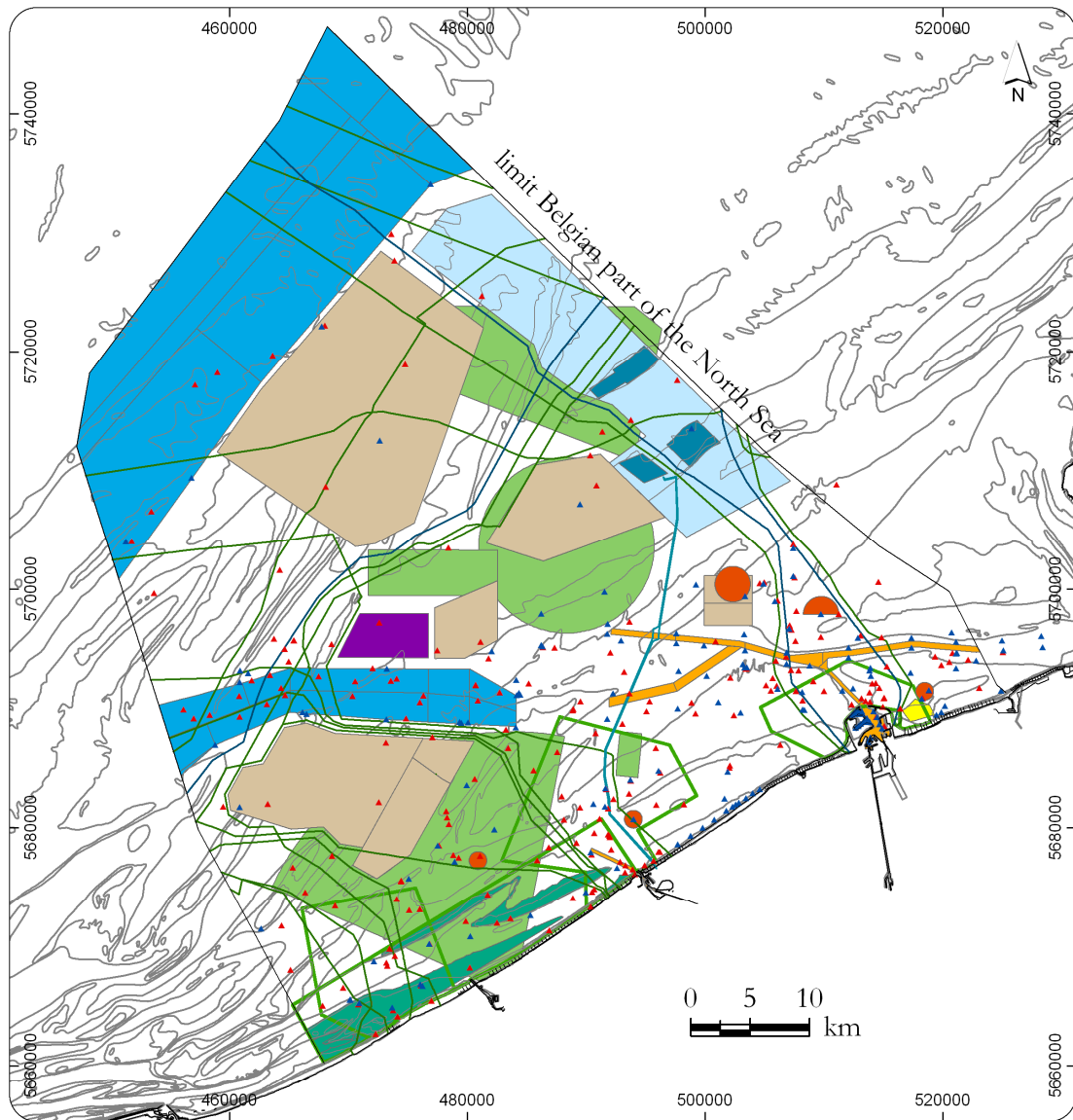
Figure 1.12: Marine Protected Areas on the Belgian Part of the North Sea: 3 Special Protection Areas (SPA1 = SBZ-V1 Nieuwpoort; SPA2 = SBZ-V2 Oostende; and SPA3 = SBZ-V3 Zeebrugge); 2 Special Areas of Conservation (SAC1 = SBZ-H1 Trapegeer Stroombank; and SAC2 = SBZ-H2 Vlakte van de Raan)[17] and 1 specific marine reserve (Bay of Heist)[18]. In February 2008, SAC2 was annulated by the Belgian Council of State, after a complaint by the energy company Electrabel.

Figure 1.13: Combination of all activities on the Belgian part of the North Sea (Maes et al. 2005).

Legend:

- Main shipping route
- Anchorage area
- Dredged zones
- Dumping zones
- Aggregate extraction
- Former war munition dumping site
- Windmill zone
- Wind turbine concessions
- Special Area of Conservation / Special Protection Area
- Military exercises
- Buoys and weather masts
- Wrecks
- Cables in use
- Electricity cables
- Pipelines