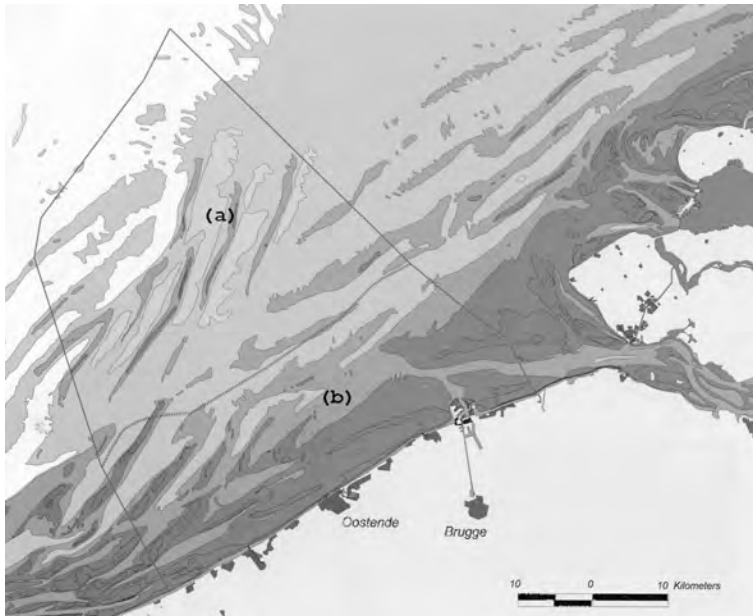


# Biodiversity of the Belgian marine areas

Francis KERCKHOF & Jean-Sébastien HOUZIAUX

## 1. INTRODUCTION

The marine areas under Belgian federal jurisdiction (further referred to as ‘Belgian marine areas’) are situated in the southernmost part of the North Sea, which is a shallow, semi-enclosed shelf sea that constitutes a ‘Large Marine Ecosystem’ of the north-eastern Atlantic Ocean. The Belgian marine areas (figure 1) can be subdivided into the territorial sea (12 nautical miles) and the Exclusive Economic Zone (EEZ). They total an area of nearly 3,500 km<sup>2</sup> (MAES *et al.* 2000), which is about 0.5% of the North Sea surface. The maximum seaward breadth of the area under Belgium’s jurisdiction amounts to some 87 km. Its



### 1

The Belgian marine areas encompass the Exclusive Economic Zone (EEZ, a) and the Belgian territorial waters (b). The boundaries, and thus also the surface, of EEZ and Belgian Continental Shelf (BCS) are identical (adapted from MAES *et al.* 2000, courtesy of the Belgian Federal Science Policy Office).

There is an influx of Atlantic water through the English Channel. This ‘Channel water’ is clear, has a high salinity and a relatively low nutrient content. In the coastal region, there is an input of fresh water through discharges from the rivers IJzer and Scheldt, and from canals. This ‘continental coastal water’ is characterised by a lower salinity, a high nutrient content and a high turbidity. Both water types remain separated. The strong semi-diurnal tidal currents and the alongshore residual current, flowing towards the north-east, tend to keep the nearshore waters well mixed. The water masses thus display a gradient

average depth is about 20 m, the maximum depth being 45 m. The Belgian coastline is very short, only 65.5 km. The boundaries of the Belgian EEZ coincide with the Belgian Continental Shelf (BCS), the latter term being frequently misunderstood when used to designate the whole Belgian maritime zone, i.e. BCS + territorial sea. The intertidal areas do not fall under federal jurisdiction, but, as they form an integral part of the marine environment, they are taken into account in this text.

Belgium’s marine areas are characterised by several geomorphological, chemical and physical gradients, determining the ecology of a region that has been affected by human activities throughout history.

The Belgian marine waters are influenced by water masses of dif-

from well-mixed coastal waters towards more oceanic transparent and less productive offshore waters. The coastal waters are very productive.

A typical feature consists in the existence of a turbidity maximum and high mud contents in the surficial sediments in front of the coast, mainly between Ostend and Zeebrugge. Muddy environments occur in some places and their distribution, driven by local hydrodynamics, is influenced by human intervention at sea such as the construction of the outer wall of Zeebrugge harbour or the navigation channels (FETTWEIS & VAN DEN EYNDE 2003). However, holocene peat and mud layers are also present (BAETEMAN 1999). In the past, the occurrence of this high turbidity zone was ascribed to a closed hydrodynamic system (gyre) in front of the coast with resuspension of local fine sediments (e.g. NIHOUL 1975, GULLENTOPS *et al.* 1976). However, FETTWEIS & VAN DEN EYNDE (2003) could not observe this feature in their sediment transport model. They consider that the local enrichment in Suspended Particulate Matter (SPM) is due to a 'congestion' of the general NE-directed transport in front of the Belgian coast, most of the SPM probably originating from the Dover strait.

The Belgian marine waters are important feeding and nursery areas for higher trophic levels such as fish and birds. Especially the well-studied western area of the Belgian coast, with its very shallow subtidal sandbanks, has an important ecological value owing to the occurrence of diverse and abundant benthic communities, which are a food source for many wintering birds.

## 2. MARINE HABITATS

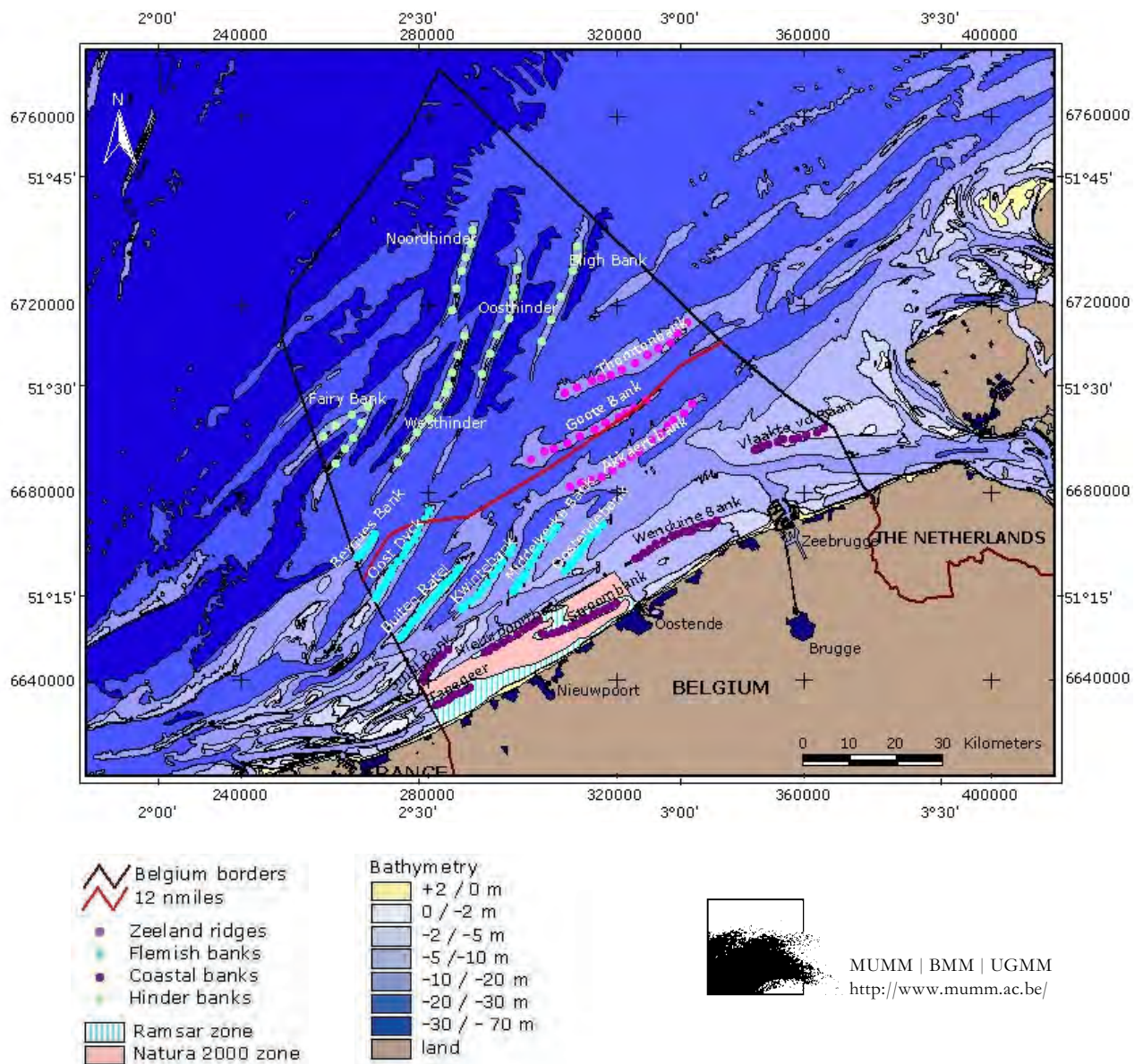
The main natural habitats of the Belgian coast include dunes, sandy beaches and subtidal sandbank systems. The subtidal marine areas and the beaches consist predominantly of deposits of soft sediments, mainly fine to medium sands. Mud fields occur on some places. Natural hard substrata are scarce and poorly documented.

### 2.1. *Soft sediments*

The subtidal sandbanks are characteristic for Belgian waters. They form a unique and very dynamic system of elongated megaridges and gullies, subject to relatively strong tidal currents, sometimes surpassing 1.5 m/s.

Four sandbank systems can be distinguished (CATTRIJSSE & VINCX 2001) (figure 2). The 'Kustbanken' (Coastal Banks) are located in the nearshore area. They consist of sandbanks virtually parallel to the coast. They can be subdivided in an eastern and a western group. The tops of a few banks, such as the Broersbank, part of the western group, are uncovered at the lowest spring tides. Further offshore, two more sandbank systems can be recognised: the 'Vlaamse Banken' (Flemish Banks) in the west and the 'Zeelandbanken' (Zeeland Ridges) in the northeast. Finally the 'Hinderbanken' (Hinder Banks) are located further offshore, in the northern part of the Belgian Continental Shelf.

The largest part of the intertidal area consists of sandy beaches (plate 1, b). All beaches have a semi-diurnal macrotidal regime with a spring tidal range of 4.5 to 5 m and a neap tidal



## 2

Bathymetry and sandbanks of the Belgian marine waters (map by S. JANS and L. VIGIN, MUMM / RBINS).

range of 3.7 to 3.9 m (DEGRAER *et al.* 2003). Most beaches are of the ultra-dissipative type, although beaches of the low tide bar/rip type also occur (DEGRAER loc. cit.). They consist mainly of fine sandy sediments. However, for the past decades, repeated beach nourishment for coastal defence works have taken place using coarser sands. This may have resulted in a coarsening of the sands on almost all Belgian beaches.

At some locations along the Belgian coast, small areas with intertidal mudflats, salt marshes and estuaries can still be found. They can be regarded as part of the ecological continuum formerly existing between the land and the sea. These are relics from historical times, when

the Belgian coast used to be part of a large ‘wadden’ area extending from northern France to Denmark and consisting of a remarkable system of tidal mud flats, sand flats, sea gullies and salt marshes, bordered by a series of dune barrier islands. These features can still be found for example in the northern part of the Netherlands (the Wadden Sea).

In the coastal area between Ostend and the Dutch border, zones with more or less unconsolidated mud occur. These unstable habitats, somewhat on the edge between hard and soft substrata, are yet poorly studied.

## 2.2. *Hard substrata*

Natural hard substrata consist of peat banks (plate 1, d) and solid Tertiary clay banks as well as zones with gravel, pebbles and boulders. All other hard substrata along the Belgian coast are artificial. These include groynes, breakwaters, dikes, harbour walls and jetties, and wrecks (plate 1, a, e & f). They form a habitat for a community typical for rocky shores, with a high species diversity and biomass.

On some beaches (e.g. in Raversijde) it was possible, until recently, to find outcropping peat and clay banks (JOCQUÉ & VAN DAMME 1971). Because of the construction of a lot of groynes for coastal defence and beach nourishment, they have now disappeared under the sand. Such outcropping littoral clay banks were also documented by GILSON (1914), for instance on the beach of Zeebrugge. However, peat and clay banks are still observed offshore. The peat banks are relics of the former ‘wadden’ area mentioned above.

The existence of zones with pebbles and boulders is poorly documented. They were already mentioned by former authors such as VAN BENEDEN (1883), who describes “boulder fields off Oostende” with a high species richness, and GILSON (1900), who mentioned the occurrence of gravel in the area of the Westhinder Bank. More recently, GULLENTOPS *et al.* (1976), MAERTENS (1989) and DELEU (2002) confirmed the existence of such regions with pebbles and boulders. So far, studies on the fauna of these areas have never been performed in the Belgian waters. A typical and rich epibenthic community has been described in similar habitats in the French part of the North Sea (e.g. PRYGIEL *et al.* 1988, DAVOULT *et al.* 1988), suggesting that a similar fauna could be found in Belgian marine waters. However, the original status of these poorly documented deposits has possibly changed during the last century due to fishery, responsible for the removal and displacement of boulders by fishing gear.

Until the beginning of the 1900s, native oyster beds (*Ostrea edulis*) occurred off the Belgian coast (LANSZWEERT 1868, VAN BENEDEN 1883). Oysters are known to form reef-like structures with rich epifauna. Like almost everywhere else along the coasts of north-western Europe, they have now disappeared, most likely as a result of fishery activities. Another important reef-forming species is the sand mason (*Lanice conchilega*), a tube-building polychaete worm. The sand mason is considered to play an important role in sediment transport by consolidating sand bottoms. The tubes also increase the structural complexity of the bottom, allowing the occurrence of a relatively high species diversity (plate 1, c).



## Plate 1

(a) Pier and groyne marking the entrance to the harbour of Nieuwpoort (photograph by M. DECLEER). (b) Example of an ultra-dissipative sandy beach (Zeebrugge) (photograph by M. DECLEER). (c) Patch of tubes of the sand mason, *Lanice conchilega*, in the intertidal zone. Details of the end of the tubes are shown (photograph by M. DECLEER). (d) Holocene peat and clay banks on the beach of Middelkerke (around 1980) with marks of medieval peat cutting/exploitation (photograph by E. COOLS). (e) Pout (= bib, *Trichopterus luscus*) swimming above the Birkenfels wreck (photograph by A. NORRO, MUMM / RBINS). The Birkenfels sunk in 1966 and is already covered with a rich fauna (f): among others the common starfish (*Asterias rubens*, bottom left corner), dahlia anemone (*Urticina felina*, picture centre), common brittle-star (*Ophiothrix fragilis*, orange arms just under picture centre), orange-striped anemone (*Diadumene cincta*, orange-red tentacle ring, bottom right corner), and smaller species of the classes Hydrozoa (probably genus *Tubularia*, top left) and Anthozoa (bottom right) (photograph by A. NORRO, MUMM / RBINS). Some 203 ship wrecks occur on the Belgian seabed, illustrating the importance of these artificial hard substrata for biodiversity.

### 3. OVERVIEW OF THE BELGIAN MARINE BIODIVERSITY

Belgium holds a long tradition in marine sciences, in particular biology. The scientific interest for marine life started around the 1850s with pioneers such as E. LANSZWEERT, P.J. and E. VAN BENEDEN, etc. However, it is only around 1900 that ecological and oceanographic considerations motivated marine biological research, with the work of G. GILSON, sampling not only biota from all compartments of the ecosystem, but also sediments and water (see GILSON 1900). This resulted in a large collection of marine samples not fully exploited yet (VAN LOEN *et al.* 2002). In the following decades, several taxonomists worked on the collections of the aforementioned pioneers, but apart from some fishery and a few planktonic studies, actual contributions to the ecology of the area were virtually absent. It is only in the 1970s that the Belgian authorities developed an integrated marine science project, the first nationally co-ordinated 'Sea programme'. Since then, several research and monitoring projects have been conducted, strongly improving our knowledge of the region's ecology. An exhaustive overview of the Belgian marine biodiversity has however never been performed.

Many marine biota have been studied in Belgian marine areas, the best-studied components being plankton, nekton and, particularly since the mid-1990s, subtidal infauna. Recently, within the framework of the Belgian Federal Science Policy Office programme 'Sustainable management of the North Sea', research in the Belgian marine waters has received a new impulse that will lead to more holistic knowledge of the marine ecosystem. Besides the ongoing studies, less well-known areas, habitats and components are now being addressed. Since many of these studies are in progress, it was not possible to take them fully into account in the following tentative overview. Detailed taxonomic overviews of the flora and fauna recorded so far in the Belgian marine areas are provided in chapters 3 (flora) and 4 (fauna).

#### 3.1. *Plankton*

Planktonic species are generally defined as organisms living in the water column and depending on marine currents for their horizontal movements. Categories of planktonic organisms are discriminated by size (femto-, pico-, nano-, micro-, meso-, macro- and megaplankton) and by the character of organisms (bacterioplankton, phytoplankton and zooplankton). Phytoplankton ensures the primary production in the water column. Its development is mainly controlled by light penetration, water turbulence, nutrient concentrations and grazing by zooplankton. Zooplankton feeds on phytoplankton and on protistan zooplankton, transferring carbon to higher trophic levels. It can be divided in two main categories: the holoplanktonic species, which spend their whole life in the plankton, and the meroplankton, which consists of larvae of other ecosystem compartments (benthos and nekton). Both bacterioplankton (decomposition) and zooplankton (excretion) ensure the regeneration of nutrients in the water column. Planktonic species of the North Sea are part of the North Atlantic fauna. An overview of plankton ecology in the North Sea is given by JOHNS & REID (2001).

The distribution of planktonic species in Belgian marine waters is mainly driven by water masses. In both phyto- and zooplankton, gradients are observed in species composition

from coastal waters to offshore Channel waters. The bacterioplankton is still poorly documented and is not considered in this overview.

### 3.1.1. Phytoplankton

MEUNIER (1913, 1915) performed a first taxonomic characterisation of the phytoplankton of the southern North Sea, largely based on the samples collected by G. GILSON. VAN MEEL (1975, 1976) summarised the phytoplankton spectrum of the years 1951-1953 in the area of the Hinder Banks as largely dominated by diatoms, in particular Bacillariophyceae (average of 80.6% of the total species number) and Dinophyceae (average of 18.2%). The genus *Bidulphia* and *Chaetoceros* are quoted to account for 12 and 25.3% of the Bacillariophyceae biomass respectively. VAN MEEL further mentions the dominance of neritic species in early spring and the dominance of oceanic species during summer in the same area. In winter, the waters are poor in phytoplanktonic species. Two main blooms of diatom species are observed, in early spring and late summer, and are more pronounced in coastal waters. In summer, the densities tend to be lower near the coast and to increase offshore. POLK (1977) gives similar conclusions for the early 1970s. A very detailed analysis of plankton communities formerly occurring in the southern North Sea, including the successions of species in algal blooms, can also be found in LOUIS *et al.* (1974) and LOUIS & SMEETS (1981). M'HARZI *et al.* (1998) observed in winter a predominance of Chrysophyta and Euglenophyta in the area of the western coastal banks, the latter being replaced by Chlorophyta on the more offshore Westhinder bank. They identified 123 phytoplankton taxa.

Since a few decades, a major change has been observed in the composition and biomass of phytoplankton of the southern North Sea. Indeed, a general increase in phytoplanktonic biomass as well as in algal blooms frequency is noted (CADÉE 1986). Extended blooms of the colonial flagellate *Phaeocystis globosa* happen every year, producing large foam (mucilage) accumulations on the beaches. Apparently, such blooms are a natural phenomenon in the North Sea, but they have become more important during the last decades owing to the anthropogenic increase in nutrient inputs (eutrophication process or, more accurately, 'dystrophication'). In spring, a first bloom of diatoms is observed, immediately followed by an extensive bloom of *P. globosa*, which can represent up to 90% of the cell numbers (LANCELOT & MATHOT 1987).

### 3.1.2. Zooplankton

The highest concentrations of zooplankton are observed about 20 kilometres offshore. The diversity of zooplankton is clearly related to the origin of water masses. Further offshore, in Atlantic waters, the density of phytoplankton is low, whereas the diversity of zooplankton is very high. This zooplankton consists of copepods (Copepoda), larvaceans (Appendicularia) and arrow worms (Chaetognatha). In nearshore waters, the plankton communities are characterised by higher biomass and lower species diversity. Numerically, copepod crustaceans constitute 90% of the overall zooplankton in winter (M'HARZI *et al.* 1998), mainly represented by *Temora longicornis*, *Pseudocalanus elongatus* and *Centropages hamatus*. *Acartia clausi*, *Paracalanus parvus* and *Calanus helgolandicus* are found in smaller abundances. M'HARZI *et al.* (1998) observed differences in copepod species abundances between the Westhinder and the more coastal banks, probably indicating a transition from coastal, mixed waters to

Channel waters. Off the Belgian coast and part of the southern Dutch coast, three communities were recognised, each with a specific distribution related to the (hypothetical) gyre off the Belgian eastern coast and controlled by the run-off water of the Scheldt (HECQ & GOFFART 1996). These communities consist of herbivores such as *Temora longicornis* and *Oikopleura dioica*, found in the neighbourhood of the phytoplankton concentrations. A community of carnivorous species, amongst which *Sagitta setosa* is the commonest together with two cladoceran species (*Evadne nordmanni* and *Podon leuckarti*) occurs more northerly. A community of omnivores, predominantly consisting of *Acartia clausi*, *Euterpina acutifrons* and *Noctiluca miliaris*, can be found in between, off the Scheldt estuary.

### 3.2. Benthos

The benthos consists of organisms and communities found on, in or near the seabed. These include animals (zoobenthos) and plants (phytobenthos), living on the substrate (epibenthos) or in the bottom (endobenthos), as well as organisms living in the water layer close to the seabed (hyperbenthos). The benthos may be further subdivided on the basis of size into three categories. Large benthic animals caught by grabs or dredges and retained on a 1 mm sieve are collectively referred to as macrobenthos. The meiobenthos includes organisms that pass through a 1 mm sieve, but are retained by a 38 µm sieve. The microbenthos consists of organisms that pass through a 38 µm sieve.

The sampling devices used in benthic fauna assessments play a major role in the definition of invertebrate communities. For instance, most 'macrobenthos' investigations are performed with grabs, which allow quantitative sampling of large infaunal species but are not suitable for the more patchy epifauna. Consequently, most described 'macrobenthic communities' are in fact mainly constituted of infauna. On the other hand, beam trawls and dredges, commonly used to collect larger epibenthic species, are unable to collect the infauna quantitatively. Finally, only special devices such as the 'hyperbenthic sledge' are able to accurately collect animals living near the bottom. These technical limitations have led to the subdivision of the benthic communities in three main compartments, namely 'macrobenthos', 'epibenthos' and 'hyperbenthos', chiefly for practical reasons. The definition of invertebrate communities is thus strongly instrument-dependent and the decision to consider certain species for community analysis is not always obvious. This problem is currently being overcome with recent developments in high resolution acoustic technologies (such as side-scan sonar) and digital imagery, which allow accurate mapping of the seafloor. For instance, BROWN *et al.* (2001) strongly recommend the combined use of grab, beam trawl, acoustic instruments and video recording to accurately map and characterise heterogeneous gravelly areas and their benthic communities. Such techniques are also being implemented for the monitoring of important habitats in Belgian waters (see DEGRAER *et al.* 2002).

In an extensive literature review, CATTRIJSE & VINCX (2001) summarised research on benthos performed by Belgian scientists between 1970 and 1998. In the earlier days, most of the benthic studies concerned the subtidal area focusing on infauna (macro- and meiobenthos) of soft substrata. In general, research efforts in the territorial waters and the Flemish Banks were higher than in other regions. Indeed, most of the monitoring studies were related to activities such as sand and gravel extraction and the dumping of industrial

waste occurring in these areas. Owing to their ecological importance, the western Belgian coastal banks were well studied too. The intertidal and subtidal hard substrata received little attention and data concerning the epifauna are scarce. The Belgian sandy beaches have only recently been subjected to a systematic investigation (DEGRAER 1999, DEGRAER *et al.* 2003).

The structural biodiversity of the Belgian marine benthos is well documented for soft bottom meiobenthos (mainly nematodes and harpacticoid copepods) and macrobenthos (mainly polychaetes, bivalves and crustaceans). These stationary communities, easily collected with standard procedures, are directly affected by changes in the environmental conditions such as pollution or climate. Subsequently, they can be considered as bio-indicators of the local environmental quality (DEGRAER *et al.* 2002) and are the target of important research efforts.

### 3.2.1. General patterns

In their review, CATTRIJSE & VINCX (2001) were able to identify some general patterns in average species richness and densities, at least for meiobenthos, macrobenthos and hyperbenthos. A positive east-west gradient of species richness occurs in inshore waters. The lower species richness of the eastern areas is possibly related to a lower diversity of habitats (or seascapes), to a higher content of fine particles in both the water column and the sediments and to the freshwater input as well as pollution from the Scheldt. Former authors described a second gradient, perpendicular to the coastline, with larger species diversity in offshore areas. Although not in contradiction with these views, more recent data tend to indicate a more complicated situation. Some environmental parameters such as habitat diversity might indeed be more decisive to explain differences in species diversity than the parameter 'distance from the shore'. On the other hand, it is established that densities are in general highest in the more productive inshore waters.

The review of CATTRIJSE & VINCX (2001) also highlights large disparities in sampling efforts. For instance, the macrobenthos is better documented in the western coastal banks than in other regions. They also underlined that observations from the 1970s and the 1990s were performed via different procedures. This leads to discrepancies in data analysis and, subsequently, hampers attempts to quantify the long-term evolution, which is an important tool in human impact assessment.

Despite recent intensive research efforts in this field, the benthic biodiversity of the Belgian marine areas is thus still far from being understood. Some of the gaps that became apparent are now addressed in specific research projects. Moreover, certain specific habitats such as the strandlines, the fauna of floating algae and the hyperbenthos of the surfzone are now also being investigated.

### 3.2.2. Soft sediment benthos

#### 3.2.2.1. Microbenthos

The microbenthos (benthic bacteria, unicellular algae and protozoa) of the Belgian marine areas is poorly studied. Hence, almost no data on the species composition and on the spatial

and temporal dynamics of this compartment are available. This is mainly due to the fact that these organisms are difficult to sample. However, microphytobenthos, such as diatoms, is a primary source of nutrition for larger grazers in shallow waters and, suspended by wave action, is probably an important food source for filter-feeding bivalves.

#### 3.2.2.2. Epibenthos

The larger epibenthos, which includes mobile epifauna such as decapods, certain fish and echinoderms, has been monitored since the 1970s. Most data have been collected on commercial species in the framework of fishery investigations and much information remains unavailable. The sessile components of the epibenthic fauna, in particular certain erect colonial organisms such as conspicuous hydroids (e.g. *Sertularia cupressina*, *Hydrallmania falcata*) and bryozoans (e.g. *Flustra foliacea*, *Alcyonidium* spp.) and even sponges (e.g. *Haliclona oculata*) are underrepresented in the samples, and most data are unavailable. Occasionally, the standard macrobenthic samplers catch epibenthic species, but these gear are inappropriate for the sampling of this category of benthic organisms.

#### 3.2.2.3. Hyperbenthos

The hyperbenthos consists mainly of small crustaceans such as mysids, amphipods or cumaceans (permanent or holohyperbenthos), as well as larvae of epibenthic invertebrates and fish (merohyperbenthos). From the beginning of the 1990s, hyperbenthos has received more attention. DEWICKE *et al.* (2003) were able to identify six biotic communities and the earlier views of inshore-offshore and east-west gradients of species diversity were more or less confirmed. High densities of hyperbenthos have been observed in the whole coastal zone, while the highest diversities are found in the open sea, especially in the region of the Flemish Banks. Larvae of decapods and fish dominate in the coastal zone and the latter region. The holohyperbenthos is dominated by mysids (*Schistomysis kervillei*, *Schistomysis spiritus*, *Gastrosaccus spinifer* and *Mesopodopsis slabberi*) and is most abundant in the coastal zone. Off the eastern coast, mysids show a remarkable seasonal migration pattern between coastal and more offshore regions. As mysids play an important role in marine food webs, this is a possible illustration of the energy fluxes between the coastal waters and the open sea, which gives way to functional considerations on benthic biodiversity.

#### 3.2.2.4. Macrobenthos

GOVAERE *et al.* (1980) made a first attempt towards a classification of the benthic infaunal communities in the southern bight of the North Sea. They discerned three zones (coastal area, transitional area and open sea) which host specific benthic communities. The macrobenthic biodiversity was found to increase offshore, which confirms the views of pioneers such as GILSON (1900), who considered the area of the Hinder Banks to host the highest numbers of benthic species (VAN LOEN *et al.* 2002).

However, in a recent analysis of data obtained between 1994 and 2000, covering also the macrobenthos of the beaches, VAN HOEY *et al.* (subm.) adjust this coastal-offshore gradient. They suggest a more complex situation, evidenced in areas where a more diversified seabed morphology is found, such as in the western coastal banks. The important habitat

parameters of the subtidal communities are currently considered to be depth as well as sediment median grain size and mud content (DEGRAER *et al.* 2002).

Using statistical clustering methods, VAN HOEY *et al.* (subm.) identified four major soft-bottom communities, one intertidal and three subtidal, defined as follows.

- The ***Abra alba*-*Mysella bidentata* community** occurs in fine sandy sediments with a relatively high mud content. The three dominant taxa are polychaetes, crustaceans and bivalves. It is a very rich community with a high species diversity and density, characterised by the occurrence of the bivalves *Spisula subtruncata*, *Abra alba* and *Mysella bidentata*, the polychaetes *Sthenelais boa* and the reef building sand mason *Lanice conchilega* (plate 1, c), and the crustacean *Pariambus typicus*. This community is dominant in the western coastal zone, especially in the gullies between the coastal and Flemish Banks.
- The ***Nephtys cirrosa* community** occurs in well-sorted, medium sandy sediments with low mud contents. This is a less diverse community with low densities. It is characterised by polychaetes and low densities of bivalves that in some cases are even lacking. The burrowing sea urchin *Echinocardium cordatum* is a typical member of this community. The community is typical for sandbanks further offshore.
- The ***Ophelia limacina*-*Glycera lapidum* community** occurs in sediment characterised by medium to coarse sand, with an important fraction of shell fragments. This community is found predominantly on the tops of sandbanks. It consists mainly of interstitial polychaetes and is further characterised by a low species diversity and density.
- The ***Eurydice pulchra*-*Scolelepis squamata* community** is exclusively found high in the intertidal zone of sandy beaches. It is characterised by a low diversity and high densities of the crustaceans *Eurydice pulchra* and *Bathyporeia* sp., and the polychaete *Scolelepis squamata*.

These macrobenthic communities are not isolated from each other and several transitional species associations were found.

#### 3.2.2.5. Meiobenthos

CATTRIJSE & VINCX (2001) provide a good overview of meiobenthic research performed so far. They conclude that areas with different meiobenthic species richness and community composition can be identified in the Belgian marine waters. Recent research by VAN AVERBEKE *et al.* (2000) suggests that sandbanks can be regarded as geographically isolated 'islands'. Indeed, they identified four distinct communities characterised by specific free-living nematode faunas and controlled by sedimentological differences within the studied sandbanks (Flemish, Hinder and Zeeland bank systems).

#### 3.2.3. Hard substrate benthos

Hard substrata, although generally known to host a more diverse flora and fauna than soft substrata, have been poorly studied. Only the intertidal hard substrata were adequately

investigated [e.g. DARO 1969, 1970, VAN DER BEN *et al.* 1977 (all three papers on artificial substrata) and JOCQUÉ & VAN DAMME 1971 (peat and clay banks), while DE VOS studied the algae of the (jetty) mole of Zeebrugge e.g. DE VOS (1979)].

#### 3.2.3.1. Artificial hard substrata

The intertidal artificial substrata such as groynes, dykes and other coastal defence works (plate 1, a) are the only places where large benthic brown (Phaeophyta), red (Rhodophyta) and green (Chlorophyta) macroalgae can be found. They harbour a community typical for a moderately exposed rocky coast, characterised by barnacles (*Semibalanus balanoides*, *Balanus crenatus*, *Elminius modestus*), dense mussel clusters (*Mytilus edulis*) and occasionally fucoid algae. Many other invertebrates are living in the mussel clusters. The community can be regarded as an impoverished version of the rocky shore communities existing along the coasts of the English Channel (e.g. the French 'Boulonnais' coast). For instance, large brown algae such as *Laminaria* sp. or *Himantalia elongata*, as well as a zone dominated by red macroalgae, commonly found in the English Channel, do not occur along the Belgian coast. More comprehensive studies are currently ongoing on the flora and fauna of the artificial intertidal hard substrata (ENGLEDOW *et al.* 2001, VOLCKAERT *et al.* 2003).

The subtidal fauna of ship wrecks (plate 1, e & f), never studied before, is under investigation since 2001. SCUBA-diving techniques are used to perform an inventory of the fauna associated to these artificial substrata, generally considered as 'oases' of marine life. These studies have already revealed many species new to the Belgian marine fauna (MASSIN *et al.* 2002).

Finally, the many buoys, used to demarcate shipping routes and subtidal obstacles, form another particular artificial habitat. They are distributed all over the Belgian waters but are more frequent in the vicinity of harbours. Their number is increasing. Recent investigation of the fouling community living on the buoys revealed the presence of several species new to the Belgian fauna and even to the North Sea (KERCKHOF & CATTRIJSSSE 2001; KERCKHOF, in prep.). Although these floating objects form a specific habitat, the community living on them has clear affinities with the fouling community on other (mainly man-made) hard substrata such as wrecks and intertidal constructions.

#### 3.2.3.2. Natural hard substrata

DEGRAER (1999) identified a macrobenthic community in outcropping Tertiary clay layers nearby Oostende, which he defined as the *Barnea candida* community. This community is typical for bottoms of firm clay and peat. It has a low species diversity, characterised by boring bivalves such as *Petricola pholadiformis* and *Barnea candida*. This community also occurred formerly in intertidal localities, for example at Raversijde, between Oostende and Middelkerke (JOCQUÉ & VAN DAMME 1971), or along the eastern coast (see GILSON 1914) (plate 1, d). The *Barnea candida* community is considered to be rare. However, it might be more common than believed, especially off the eastern coast (in particular off Zeebrugge) where there are indications of its presence (pers. obs. F. KERCKHOF). The sampling gear commonly used in macrobenthic research do not allow an adequate sampling of this particular community.

An additional macrobenthic community, the ‘pebble community with epifauna’, might also be present off the Belgian coast, although it was not mentioned at all during the last three decades. Indeed, a “boulder field” hosting a very high epibenthic species diversity (including several sessile erect species and *Ostrea edulis*) is mentioned to occur “off Oostende” by VAN BENEDEN (1883). French researchers, using a ‘Raillier du Baty’ dredge instead of a Van Veen grab, discerned and described this particular community along the French coasts of the southern North Sea (PRYGIEL *et al.* 1988, DAVOULT *et al.* 1988). The species composition of this community differs drastically from the surrounding sandy sediment communities and shows affinities with the macrofauna of rocky substrata and with the epifauna of ship wrecks. It is a very rich community, with a high diversity of sessile species such as sponges (Porifera), cnidarians (Cnidaria), bryozoans (Bryozoa), and a diversified mobile epifauna of decapods (Decapoda) and echinoderms (Echinodermata). This community certainly occurs in Belgian waters too, as indicated by occasional observations for instance in the region of the Hinder Banks (MAERTENS 1989; GILSON, unpublished data) and off Zeebrugge (pers. obs. F. KERCKHOF).

We can conclude that although the Belgian marine subtidal areas are dominated by fine to medium sand bottoms and, in some coastal areas, by mud fields, it also hosts naturally hard substrata species associations, largely undersampled and poorly known. These probably contribute to a large extent to the overall species richness of the ‘natural’ Belgian marine fauna, what calls for further research on this topic.

### 3.3. Nekton

The nekton represents all animals able to move horizontally in the water column independently from currents. These represent the higher trophic levels of the marine food webs and consists of molluscs (cephalopods), fish, turtles, mammals and even some birds (penguins). Apart from some cephalopod molluscs (e.g. *Loligo*, *Sepia* or *Octopus*), the nekton of the Belgian area is largely dominated by fish. The marine mammals will be presented in a separate section.

The fish fauna can be divided in two groups: pelagic species, living in the water column, and demersal fish, living near the seabed. As Belgian marine waters form only a small part of the North Sea, and because of the high mobility of fish, their fauna has to be considered on a larger scale. DAAN *et al.* (1990) recorded 224 species for the North Sea. However, a high proportion of the total fish biomass consists of a limited number of species, most of which are commercially exploited. In chapter 4, some earlier studies on the Belgian marine fish fauna are listed.

The fish fauna of the North Sea is well studied, mainly by fishery research institutes. DAAN *et al.* (1990) identified three fish communities. In the south-eastern community -relevant to Belgian waters- the dab (*Limanda limanda*), whiting (*Merlangius merlangus*), grey gurnard (*Chelidonichthys gurnardus*) and plaice (*Pleuronectes platessa*) are considered to be the most important species.

Other important demersal species are cod (*Gadus morhua*), sole (*Solea solea*), flounder (*Platychthys flesus*) and brill and turbot (*Scophthalmus* spp.). Belgian coastal waters are

important spawning grounds and nursery areas for the sole. They also form a nursery area for other commercially important fish species, such as plaice and cod.

In Belgian waters, lacking rocky shores or bottoms, some fish species are almost exclusively found in the vicinity of wrecks. These fish, such as the ling (*Molva molva*), conger eel (*Conger conger*) and tompot blenny (*Parablennius gattorugine*), are considered to be rare. Given the large number of wrecks off the Belgian coast, it is possible that some of them are not as rare as thought. Some species, such as the common goby (*Pomatoschistus microps*) and black goby (*Gobius niger*), are uncommon at sea, but may be locally common in and near ports. Other species, such as the shanny (*Lipophrys pholis*) and butterfish (*Pholis gunnellus*), may occur rather frequently on breakwaters and harbour walls.

It is clear that most elasmobranchs (skates, rays and sharks), which are long living, slowly reproducing predators formerly common in our waters, have severely declined. These fish are generally not targeted by fisheries but are collected as by-catch. WALKER (1998) has evidenced major changes in the population dynamics of North Sea rays. Increased fish mortality is considered to be the cause of observed shifts in species composition, leading to an expansion of species with the lowest age and size at sexual maturity (e.g. starry ray, *Amblyraja radiata*) and severe declines in more sensitive species such as the thornback ray (*Raja clavata*). The common skate (*Dipturus batis*), the largest species of the area, is considered as extirpated from the North Sea since the 1950s (NILSEN *et al.* 2002). For shark species, data are scarce since most fishery statistics do not identify the catch at the species level. But the landings of several species that used to be common in the area have dramatically decreased in the southern North Sea, as is observed elsewhere (HEESSEN 2003).

Most commercial species are far less abundant in the North Sea than they used to be. This is the case for the herring (*Clupea harengus*), mackerel (*Scomber scombrus*), cod (*Gadus morhua*) and plaice (*Pleuronectes platessa*). Herring used to be a very important resource for Belgian fishermen (POLL 1947). The main reason for the decline is overfishing. Although there is no evidence of a major change in species composition in the North Sea over the last century, there is more convincing evidence of changes in size composition. The increasing exploitation of the North Sea fish stocks resulted in a shift towards smaller-sized fish. Overfishing, together with river construction works, habitat destruction and pollution, also led to severe decline or disappearance of all diadromic fish, including the salmon (*Salmo salar*), sturgeon (*Acipenser sturio*), smelt (*Osmerus eperlanus*) and allis shad (*Alosa alosa*).

#### 3.4. Marine Birds

High numbers of sea birds occur in the southern North Sea owing to food availability (e.g. fish and benthic invertebrates). In a study by BirdLife International, the whole region from the north of France up to the Dutch Wadden Sea, including half of the Belgian waters, has been designated as an Important Bird Area (SKOV *et al.* 1995). The importance of the Belgian marine waters as a wintering area became evident once more after the oil spill of the TRICOLOR in winter 2003, when thousands of oiled birds, mainly auks (*Alca torda*) and guillemots (*Uria aalge*), stranded on the Belgian beaches. The Belgian waters, in particular the coastal sandbanks of the western coast, are important for the common scoter (*Melanitta nigra*).

The Channel area, including the Belgian marine waters, is a very important corridor for many migratory species. During the 20<sup>th</sup> century, the abundance of most species of sea birds have increased in the North Sea, predominantly due to the availability of discards from fishing activities (MC GLADE 2002).

Sea birds are one of the most conspicuous faunal groups and can traditionally boast of a great deal of interest. Because they occupy high trophic levels, sea birds can be used as indicators of changes in the marine environment. Especially after World War II, increasing interest for activities such as sea watching and beached bird surveys arose among various individuals and groups. The results were -if at all- published in a scattered way. In 1992, a sea bird monitoring programme was set up at the Flemish Institute of Nature Conservation, aimed to fill the lack of information on the distribution of sea birds in the Belgian marine waters. This has resulted in various publications (e.g. OFFRINGA *et al.* 1996, SEYS *et al.* 1999, etc.) which emphasised the importance of the Belgian marine waters for birds. At present, the knowledge of the species and numbers occurring seasonally in these waters is good.

In a recent study, SEYS (2001) gives a comprehensive overview of the Belgian marine and coastal birds. During the period 1992-1998, 124 bird species were encountered at sea. Of these, 23 true marine species occur in relatively high densities within the Belgian marine areas. Six out of these 23 were retained as 'focal species', i.e. species that require increased attention due to both insufficient conservation efforts at the international level and a remarkable high abundance in Belgian areas. They include species that attain 1% of the flyway population and are listed in international conventions such as the EU Birds Directive or the Bern and Bonn Conventions. These species are the little gull (*Larus minutus*), red-throated diver (*Gavia stellata*), common scoter (*Melanitta nigra*), Sandwich tern (*Sterna sandvicensis*), common tern (*Sterna hirundo*) and little tern (*Sterna albifrons*). Five species, the great crested grebe (*Podiceps cristatus*), great skua (*Stercorarius skua*), lesser black-backed gull (*Larus fuscus*), herring gull (*Larus argentatus*) and great black-backed gull (*Larus marinus*) were classified as 'locally important species'. These are species that surpass the 1% criterion but are not included in the highest priority lists of the international conventions.

The harbour of Zeebrugge must be mentioned as a particularly important area for terns. Indeed, three species, the Sandwich tern, common tern and little tern, have established breeding colonies there. Apparently, they found in these vast areas new nesting opportunities after their natural nest sites on beaches and in dunes became gradually unavailable as a consequence of, among others, evolving mass tourism (SEYS 2001). Moreover, the importance of the outer harbour of Zeebrugge is also illustrated by the occurrence of a huge breeding colony of the lesser black-backed gull.

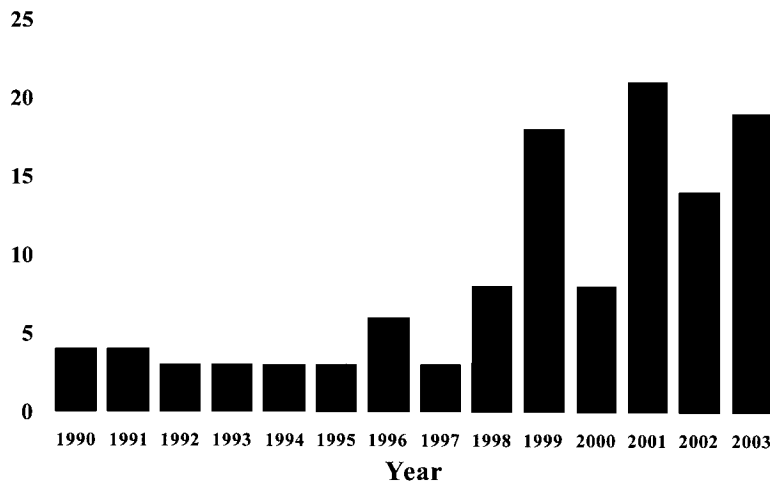
During the study cited above, marked differences in counting efforts were reported between regions and seasons. Most data were collected during winter and autumn, and there were important data gaps for areas further offshore. Attempts are going on to fill these gaps gradually.

### 3.5. Marine mammals

Marine mammals, as birds, are important top predators controlling the marine food chain with widely distributed populations that can only be protected within international agreements. In Belgium, a large number of historical data on cetacean strandings have been collected by the Royal Belgian Institute for Natural Sciences (RBINS) and published by DE SMET (1974, 1981). From these publications, it is obvious that strandings of small, inconspicuous but perhaps common cetaceans were usually not documented, whereas the stranding of larger toothed whales or baleen whales, most of which do normally not occur in the southern North Sea, received a more widespread media and public attention. Stranding records have been systematically gathered from the late 1970s by VAN GOMPEL (1991, 1996), while the RBINS has coordinated technical interventions and collected specimens.

In 1992, an intervention network was established with the aim of meeting specific obligations of the Belgian government in the framework of the North Sea Conferences and ASCOBANS (Agreement on the Conservation of Small Cetaceans of the Baltic and North Seas, Bonn, 1997). This interdisciplinary network is responsible for the scientific investigations on both marine mammals and sea birds washed ashore or by-caught in Belgium.

Only five species of marine mammals can be considered indigenous in the Belgian part of the southern North Sea: the harbour porpoise (*Phocoena phocoena*), white-beaked dolphin (*Lagenorhynchus albirostris*), bottlenose dolphin (*Tursiops truncatus*), harbour seal (*Phoca vitulina*) and grey seal (*Hali-choerus grypus*). Other species are regarded as irregular visitors or stragglers.



3

Number of harbour porpoises, *Phocoena phocoena*, washed ashore per year in Belgium from 1990 to June 2003.

observations (inshore and offshore) as well as the number of strandings has been rising again since 1995 (figure 3).

During the early 20<sup>th</sup> century, harbour seals were commonly encountered on beaches. Since then, the species virtually disappeared from Belgian waters. Nowadays, adults are occa-

sionally observed at sea and in harbours, and each year, in summer, five to twenty pups, originating from colonies present in France, the United Kingdom or the Netherlands, wash up on the shores in Belgium. Adult grey seals are less common in Belgium than harbour seals, although a small number of grey seal pups wash ashore each year in winter.

In the years 1988-1989, an estimated 72% of the North Sea population of harbour seal was affected by a morbillivirus, the 'Phocine Distemper Virus' (PDV), leading to mass stranding events (see JAUNIAUX & COIGNOUL 2001). In 1998, and even more remarkably in 2002, a new morbillivirus infection led again to a dramatic increase in the numbers of stranded common seals. The causes for such epidemiological disasters are still unknown. So far, there is no evidence that the body burden of micropollutants, known to weaken the resistance of the populations to such infections, is involved. Similarly, fishing practices, by affecting the number of individuals in the population, may be involved but their role as facilitator can hardly be evidenced.

#### 4. MAIN THREATS TO THE BELGIAN MARINE BIODIVERSITY

Marine biodiversity worldwide is threatened in many ways. During the past 50 years, the composition and organisation of the ocean's biota and of their habitats underwent dramatic changes owing to increased human activities at sea and significant climate change. This is especially the case in coastal zones and shelf seas where the direct and indirect disturbances, resulting in a general deterioration of the environment quality, are concentrated (GRAY 1997). These areas are highly productive as compared with the open sea. Losses of species and habitats in coastal areas have therefore a high impact on the marine biodiversity as a whole.

The coasts of the shallow southern North Sea, surrounded by densely populated developed countries, are a good example of such a very productive but intensively exploited coastal zone. This region produces several consumption goods and plays an important role in the socio-economics of its surrounding countries, in particular Belgium.

The Belgian marine areas have been intensely used for several purposes since long. As a consequence, no region of the Belgian marine waters can actually be considered as pristine. Furthermore, local impacts on marine biodiversity are superimposed on larger-scale impacts and natural variability, making it difficult to identify cause-consequence relationships. Observed changes cannot be attributed to one single cause and should be regarded as the result of a cascade of adverse effects.

##### 4.1. *Human activities at sea and their impacts*

The main activities occurring in the Belgian marine area and their main effects can be summarised as follows (see also MAES *et al.* 2000).

###### 4.1.1. Fisheries

Fishing has been an important activity along the Belgian coast for centuries (figure 4). But since the beginning of the 20<sup>th</sup> century, a sharp increase of its impact on all levels of marine life has resulted from several technological innovations. The main fishing method currently



#### 4

On the left, a decked 'cutter', typical for Belgian offshore fishing around 1900, landing its fish. Note the large beam trawl equipped with a wooden beam (archives of G. GILSON, RBINS). On the right a modern powerful fishing vessel operating two beam trawls in parallel (photograph by the Aerial Surveillance Unit of the MUMM / RBINS).

used in Belgian waters is beam trawling, targeting demersal fish and brown shrimp (*Crangon crangon*). The trawling intensity is very high, especially inshore. Apart from the general, well-known environmental problems generated by fisheries such as overexploitation of target species, threats to sensitive by-catch species, or increase in populations of resistant, short-living and opportunistic species, the beam trawl specifically has strong adverse effects on the sea bottom (LINDEBOOM & DE GROOT 1998, LAVALEYE *et al.* 2000). Beam trawl tracks can be observed on sandy bottoms several days after fishing. It is therefore also considered as a very important threat to sensitive benthic habitats and biological associations, especially those related to reef or bank-forming species ('structuring' species). In coastal areas, JACKSON *et al.* (2001) showed that ecological extinction caused by overfishing always precedes all other pervasive disturbances. They stated that overfishing was the initial factor in the deterioration of coastal ecosystems worldwide. Thus, adverse effects due to other causes such as pollution, degradation of water quality or (anthropogenic) climate changes are favoured, if not amplified, in overfished areas.

#### 4.1.2. Chronic pollution

The sea is the ultimate recipient of pollutants from activities carried out by man. They reach the sea from land-based activities (80%) through river runoff (mainly the Scheldt in Belgium), atmospheric deposition, direct discharges and maritime traffic (oil spills and operational ship-borne pollution). Several organic and inorganic micropollutants are produced intentionally or as by-product and accumulate in living organisms (bioaccumulation) and food chains (biomagnification). When high tissue concentrations are reached, several adverse effects occur (reproduction impairment, endocrine disorders, genetic mutations, increased sensitivity to natural diseases, etc.). They lead to a general weakening of populations of sensitive species, in particular the highest trophic levels (larger fish, birds, mammals) making them more vulnerable to other human pressures but also to natural events such as diseases or unusual climatic conditions. However, their effects may vary considerably from one species to another and are generally difficult to identify because of the interaction of several other factors affecting biodiversity.

#### 4.1.3. Eutrophication

An increased load of land-based nutrients (N, Si, P), originating from transboundary sources (SW Atlantic, Rhine) and, to a lesser extent, from local riverine inputs (in Belgium, Scheldt and IJzer), is responsible for strong eutrophication problems in coastal areas of the southern North Sea. Since the 1970s, increasing algal biomasses have been reported to result from the increased nutrient content of the coastal waters. Furthermore, anthropogenic nutrient sources lead to changes in the nutrient balance (in particular N/P ratio) in the water column and, consequently, in the species successions normally occurring during blooms. Blooms of phytoplankton species harmful to marine animals and humans (such as *Gyrodinium*, *Dinophysis* or *Alexandrium*) have caused much concern. Since the 1970s, an increase in the bloom frequency of the colonial flagellate *Phaeocystis globosa* also seems to occur. This species is not grazed by the zooplankton. The large quantity of ungrazed algae, resulting from the larger biomasses and higher bloom frequency, increase the quantity of organic material decomposed in the water column or on the bottom. This leads to severe oxygen depletion in some areas of the North Sea (such as the German bight) responsible for mass mortalities in invertebrate and fish species. Several studies reported also an increase in biomass of benthic organisms especially in coastal waters although these effects have not been reported for the Dutch coastal waters (LAVALEYE *et al.* 2000).

#### 4.1.4. Sand and aggregate extraction

Besides fisheries, the only other natural resources exploited in Belgian marine waters are minerals. Although several areas were designated for sand extraction, most of the sand has been extracted from the Kwinte Bank. Considerable amounts of sand and gravel are landed each year and used for building and beach nourishment. This activity locally affects the benthic communities. Generally, organisms living in the highly dynamic environment of sandbanks are able to withstand high level of environmental disturbance by waves and currents. However, the sand and gravel extraction activities form an additional stress factor. Currently, the demand for aggregate extraction is increasing.

#### 4.1.5. Dredging and dredge spoil dumping

The eastern Belgian coast is subject to extensive maintenance dredging operations to remove large sediment accumulations occurring in ports and navigation channels. The large quantities of dredged material resulting from these activities are dumped back in the sea in specifically designated areas. This practice locally increases the mud content of the surface sediment, which directly affects the local benthic communities. On a larger scale, dredging and dumping increase the turbidity in the water column and allow the resuspension of contaminants such as trace metals initially trapped in the sediment, making them available to the trophic chains.

#### 4.1.6. Alien species introductions

Introduction of non-indigenous species (plate 2) takes place in different ways. The southern North Sea is one of the most frequented maritime routes in the world, and Belgium hosts two major ports: Zeebrugge and Antwerp. This leads to the import of several non-

indigenous species by ships in ballast waters or as fouling. Leisure navigation and marinas also contribute to this phenomenon. Another source of introductions is the mariculture, since undesirable non-indigenous species are also imported together with the target species. Climate change may also lead to the extension of the geographic distribution of species not found in the area before. Most alien species cannot find an appropriate ecological niche to survive. However, a few species that are able to settle down can colonise the area and enter into competition with local species.

#### 4.1.7. Coastal defence, harbour works and coastal constructions

Man-made constructions have a strong impact on the coastal hydrodynamics and sediment balance. They have negative consequences in subtidal and intertidal habitats, but also on land (dunes). Furthermore, they represent artificial habitats allowing many non-indigenous species to settle down. As a result of continuous and ongoing beach nourishment on nearly all the Belgian beaches, the natural sediments have been replaced by coarser sand, more appropriate for coastal defence. The effects on the beach fauna are unknown since the study of the Belgian beach fauna started only after the sand suppletions. On the other hand, those artificial substrata are colonised by typical flora and fauna. In harbours, harsh conditions prevail and favour the development of resistant, often non-indigenous species.

#### 4.1.8. Recreation

The Belgian coast is also an important recreative area in summer. Activities take place at sea, on beaches and in dune areas. High disturbance levels are known to have negative impacts on the local populations of marine mammals. A very large portion of the Belgian coast is covered with constructions developed to the detriment of dunes and other important natural features, fragmenting coastal habitats and affecting the land-sea sediment balance. The extreme population increase in summer also affects the microbiological quality of the coastal waters. A particular problem is the ecological impact of mechanical beach cleaning, which is carried out by many local authorities to keep popular beaches clean. The frequent removal of natural strandline detritus, even in winter, and the disturbance of the sand by raking has led to the almost complete disappearance of the specific flora and invertebrate fauna of the strandline. This practice also prevents the natural formation of embryonic dunes.

#### 4.1.9. Storage of WWI chemical weapons

About 100 to 500 tons of toxic material is estimated to be present in the 'Paardenmarkt', a shallow area situated east of Zeebrugge where 35,000 tons dumped German ammunition dating from World War I lay since 1919. An important layer (2-4 m) of anoxic sediment has covered the weapons following natural sand transport and preserves them from corrosion by sea water. Two types of chemical weapons constitute the main environmental threat: the 'mustard gas' (Yperite), a blistering agent, and the vomiting agents 'Clark I' and 'Clark II'. Although responsible for severe acute intoxication, it is unlikely that the mustard gas could cause important environmental damage. On the contrary, the hydrolysis of 'Clark' reagents will lead to the release of organic and inorganic arsenic, a severe poison threatening marine wildlife (FRANCKEN & RUDDICK 2003). Fishing activities and ship

anchoring are prohibited in this area and a chemical monitoring of the sediment is performed regularly. So far, considering the good storage conditions of the ammunition, the Belgian authorities have conducted a 'do not disturb' policy. For the future, management projects are not yet established. A proposal has been made to build an artificial island upon the site and to transform it into a sanctuary area for marine birds and mammals (MISSIAEN *et al.* 2002).

#### 4.1.10. Wind power plants

These important 'green energy' sources will be installed in the forthcoming years in some areas of the Belgian marine waters. The wind power plants will constitute new artificial hard substrata and are expected to threaten migrating sea bird populations. Monitoring programmes are planned in order to ensure adequate management in these areas.

#### 4.1.11. Wrap up on activities

All the activities listed above are still expanding and pose direct threats to biodiversity (for instance, fragmentation and loss of natural habitats, or extirpation of target and sensitive species) at both local and global scales. Indirect threats that may lead to biodiversity loss are, amongst others, the overall increase in human population, weakness of legal systems and institutions, and absence of adequate scientific knowledge (including ineffective transmission of information).

### 4.2. *Some observed structural changes in the marine biodiversity*

Overall, fisheries, eutrophication and pollution, respectively, are considered to have the strongest impact on marine life in the North Sea (OSPAR Commission 2000, MC GLADE 2002). They lead to a global weakening of environmental health and favour impacts by more local activities. In this section, we will address remarkable changes observed or suspected to occur in Belgian marine areas as a consequence of human activities.

#### 4.2.1. Fisheries

The geomorphological situation makes the Belgian coastal area ideal for beam trawling. Centuries of fishing pressure, and especially the almost 100 years of trawling impact, together with recent technical improvements, have certainly restructured the benthic system along the Belgian coast. It is however difficult to assess the impacts properly, as systematic scientific studies only started mid-19<sup>th</sup> century, already in a disturbed situation. This makes it difficult to describe a pristine condition. The lack of data and long-term monitoring of benthic invertebrates and fish also hampers the evaluation of the impact of fishing activities. Indeed, a very long monitoring period is often needed to distinguish them from e.g. natural fluctuations.

The most obvious impact of fishery concerns the fish community. In general, the fish community in the North Sea shows a decrease in abundance of larger fish. This has resulted in a shift towards smaller-sized fish, a progressive decline in species diversity amongst the larger size groups, alterations of the trophic chain and an overall decrease in biomass. All

these impacts apply to the Belgian waters as well as to the entire North Sea, illustrated by a noticeable decline in some commercially important fish species such as the herring and cod. Several species of rays and sharks, which are poorly known but important predators, have dramatically declined (WALKER 1998, HEESSEN 2003). The resulting fish community now occurring off the Belgian coast is thus the result of decades of fishing and overfishing. Already MANN (1780) noted marked changes in the fish fauna. More than two centuries ago he mentioned, for example, a severe decline in stocks of herring and cod. He therefore blamed certain unsustainable fishery methods and practices such as the use of herring and young fish as pig food. It is generally difficult to find indications of the composition and size distribution of North Sea fish communities in the past. Archaeozoological investigations such as the analyses of growth increments of fish otoliths from medieval and post-medieval populations of commercially important fish species (e.g. VAN NEER *et al.* 2002), and their comparison with modern samples, look promising to provide such evidence.

In general, an increase in biomass accompanied by a decrease in diversity is observed along the Belgian coast, especially during the last decades. In benthic communities, this is caused by an increase in opportunistic (small size, rapidly reproducing) short-living species, and a decrease in sensitive (large size, fragile) long-living organisms such as some bivalves. For instance, the *Abra alba* macrobenthic community described above, with its high productivity and its many short-living species, might well be a result of ages of intensive fishing activities. This community has also undergone important changes during the last decades, after the arrival of several opportunistic alien species.

The populations of many reef-building organisms such as the European flat oyster (*Ostrea edulis*) and the sand mason (*Lanice conchilega*) have been destroyed or have dramatically declined due to beam trawling and harvesting. The reefs formed by *O. edulis* have apparently disappeared from our waters. The reefs formed by the *Lanice conchilega* are threatened. Their distribution seems to be restricted by fishing activities, as they now occur predominantly in patches on the slopes of sandbanks where they are less frequently disturbed by fishing activities (DEGRAER *et al.* 2002). As outlined earlier, a fauna typical for pebbles and boulder fields should be present in our waters but has not recently been mentioned. However, it may be feared that, if such features are still found in some places, they do not longer exist under the form of 'fields' as initially described by VAN BENEDEN (1883). Indeed, they are expected to be incidentally displaced and even removed by powerful fishing vessels. Ongoing seabed mapping experiments will probably allow to answer this question in the near future.

In the coastal areas, a general decline of several large ramous epibenthic organisms, such as sponges, bryozoans and conspicuous hydroids seems to have taken place. These species increase the structural complexity of the colonised area and provide an important microhabitat for smaller animals such as amphipods and shrimps. More mobile and larger epibenthic species such as the polychaete *Aphrodite aculeata* and the whelk, *Buccinum undatum*, declined as well. In most cases, a decline of these species is difficult to prove because of a lack of scientific evidence and historical records (see also LAVALEYE *et al.* 2002). Sometimes, an indication of a decline is based only on anecdotal evidence or on observations and studies in other comparable regions.

On the other hand, some scavengers and predators have increased. This is the case for some crustaceans, such as the hermit crab *Eupagurus bernhardus*, and gastropods, such as the netted dog whelk (*Nassarius reticulatus*), as well as the common starfish (*Asterias rubens*). During the past decades, another hermit crab, *Diogenes pugilator*, became extremely common. This species has taken advantage of the warming up and has spread more to the north. It uses empty shells of small gastropods for protection, in most cases the shells of *Nassarius*. To what extent the appearance of *Nassarius* might have benefited the occurrence and spreading of *Diogenes pugilator* by providing shelter remains an intriguing question.

#### 4.2.2. Eutrophication

The most striking effects of eutrophication in our waters are the phytoplankton blooms in spring and, to a lesser extent, also in autumn, in particular the yearly occurrence of *Phaeocystis globosa* (see section 4.1.3.). TUNGARAZA *et al.* (2003) conclude that the succession of the diatoms and *Phaeocystis* blooms in the southern bight of the North Sea is controlled by the concentrations of silica and ammonium in the water. The silica concentration is the limiting factor for the diatoms, which use it for the constitution of their exoskeleton, while the level of ammonium controls the prevalence of diatoms or *Phaeocystis* for nitrogen uptake. It seems that *Phaeocystis* blooms, to a large extent not grazed by the local zooplankton species (GASPARINI *et al.* 2000), have become more important during the last decades, although evidences of earlier explosive blooms in the North Sea exist (VAN MEEL 1975, CADÉE & HEGEMAN 2002).

An example of a species of a higher trophic level thriving in eutrophic habitats is the clam *Corbula gibba*, which is currently spreading worldwide, mainly in eutrophic harbour environments. Although indigenous to Europe, it has been recently introduced in several harbours and estuarine environments of the southern North Sea (Zeebrugge, Dunkerque and the Scheldt estuary) (KERCKHOF 1998).

#### 4.2.3. Hazardous substances

Biodiversity effects induced by organic and inorganic pollutants have not been reported as such from the Belgian marine areas. Indeed, the typical effects of contaminant families vary greatly from species to species and synergistic or antagonist effects may occur between different compounds. The real dose-effect relationship is therefore often very difficult to establish. Environmental risk assessment largely relies on the definition of 'acceptable' levels of the various compounds based on their toxicological effect in laboratory experiments. Due to their high trophic position, marine mammals and birds tend to accumulate high quantities of pollutants and are therefore subject to several ecotoxicological investigations and monitoring procedures. Lower trophic levels such as invertebrates or fish are mainly monitored within the framework of seafood safety programmes.

One of the most striking examples of the potential effect of high body burdens of pollutants is the case of the antifouling agent tributyltin (TBT), an additive in ship paints. TBT is responsible for the appearance of a phenomenon known as 'imposex', being for example the development of male sexual organs in females in some invertebrate species, and leading to dramatic changes in their sex ratios and a subsequent population decline (OSPAR Commis-

sion 2000). The most obvious consequence of the occurrence of this antifouling agent in sea water was the complete eradication of the dog whelk (*Nucella lapillus*) in Belgian waters. This mollusc was once a common predator on the groynes along the Belgian coast but disappeared during the first half of the 1980s (KERCKHOF 1988). There are no signs of recovery yet. So far, the consequences of the loss of this important predator have not been studied. But many other species, invertebrates as well as vertebrates, show effects of TBT and the decline of some of them, e.g. the whelk (*Buccinum undatum*), could at least partly be attributed to the use of this antifouling agent. At present, TBT is still being used as ship paints additive, but should soon be banned within agreements at the level of the International Maritime Organisation (IMO) (NILSEN *et al.* 2002).

Well-studied substances like trace metals and organic micropollutants, such as polychlorinated biphenyls (PCBs) or poly-aromatic hydrocarbons (PAHs), have been listed in international agreements as priority substances, the emissions of which must be lowered. For these and other more recently recognised substances (for instance dioxin-like compounds), measures have resulted in a general decrease in the emissions (NILSEN *et al.* 2002) as well as in the levels measured in marine fauna (e.g. VINCKE *et al.* 1999, GUNS *et al.* 1999, ROOSE *et al.* 1998). However, other substances for which long-term effects on living organisms are poorly documented, such as volatile organic compounds (ROOSE & BRINKMAN 2000), endocrine disruptors or brominated flame retardants (NILSEN *et al.* 2002), still threaten marine life.

The monitoring of such 'cocktails' of anthropogenic contaminants in the marine environment and food chains calls for a battery of expensive laboratory analyses, although their overall effects are largely unknown. Therefore, cost-effective analysis techniques aimed at measuring the biological effects of contaminants rather than the levels of individual compounds are increasingly popular and currently attract a great deal of innovative analytic research in Belgium and elsewhere.

#### 4.2.4. Sand and gravel extraction

The effects of sand extraction on the benthic fauna, especially on the Flemish banks, and more specifically the Kwinte Bank, have been investigated in some studies. The continuous extraction activities since 1977 on the Kwinte Bank (BAETEMAN 1982) have resulted in a clear depression in the centre of the bank and also in a coarsening of the grain size (BONNE 2003). This author was able to demonstrate a clear impact of sand and gravel extraction on the meiofauna. By comparing data on the species composition of benthic harpacticoid copepods on the Kwinte Bank sampled between 1978 and 1997, BONNE found drastic changes both in sediment characteristics and in the associated copepod communities. In the centre of the sandbank, the copepod diversity decreased and a shift was recorded from a species-rich northern community to a less diverse southern community with more interstitial species instead of epi- and endobenthic species, obviously related to the changes in sediment characteristics. On the other hand, the author could not demonstrate changes in the community structure of the macrobenthic fauna of the Kwinte Bank. This was due to differences in sampling methods between the different sampling campaigns and because they were not designed for long-term investigation of the macrobenthic fauna.

#### 4.2.5. Man-made constructions

On the eastern coasts of the southern North Sea (e.g. the Netherlands and Belgium), land reclamation and consolidation of coastal defences have taken place since several centuries. For the last decades, besides the accelerated decline of most of our natural marine habitats, another characteristic feature was the creation of many new man-made habitats. Along the Belgian coast, more and more artificial constructions appeared including groynes, wrecks, buoys, measuring piles and harbour installations. Apart from affecting the local hydrodynamics and sedimentary processes, they certainly have an impact on biodiversity by hosting a whole range of species that otherwise would not be able to live in Belgian marine waters nor in the southern North Sea. Some researchers therefore argue that such species, sometimes referred to as ‘anthropogenic species’, should be regarded as non-indigenous. The limpet, *Patella vulgata*, is an example of such a species. It became more common during the past decades, at least partly taking advantage of the construction of many more groynes in the littoral zone. However, other effects like the disappearance of the dog whelk, or the recent warming up can also have played a role.

It is generally acknowledged that biodiversity is higher on hard substrata than in soft sediment areas, because a rich encrusting flora and fauna occurs on most rocky surfaces. However, although they certainly contribute to the increase in general species richness, artificial substrata cannot be regarded as a compensation for the loss of biodiversity values elsewhere.

All these structures -and their number is continuously increasing all along our coasts- may act as stepping stones for a typical rocky shore fauna and flora. Combined with climate change, they may thus favour the spreading of some species by facilitating the colonisation of other suitable habitats further to the north, e.g. in the Oosterscheldt. The ecological monitoring of the future windmill parks off the Belgian coast and elsewhere in the North Sea will probably provide interesting data regarding this issue. Indeed, these will include the implantation of several piles surrounded by an artificial reef-like structure aimed at their protection from wave action.

#### 4.2.6. Introduction of non-native species

A direct threat recently recognised as becoming more and more important is the invasion of non-indigenous species as a result of combined human activities (transplantations) and climatic changes (extension of the biogeographical range). The introduction of non-indigenous species through human activities is explicitly mentioned in the OSPAR Quality Status Report (OSPAR Commission 2000) as an important pressure threatening marine biodiversity.

A species is considered to be non-indigenous to the North Sea if its ‘natural’ (i.e. historical) range of occurrence is geographically remote from the North Sea. Such species are also referred to as exotic or alien species. There are currently around 120 known exotic plants and animals more or less established in the North Sea as a whole (ENO *et al.* 1997). This figure is probably underestimated, as it is sometimes difficult to find out whether or not certain species are historically indigenous. The larger organisms are well studied, but



(a)



(b)



(c)



(d)

## Plate 2

Some examples of alien species: (a) washed up shells of the American jack-knife clam, *Ensis directus* (photograph by M. DECLEER), (b) Pacific oyster bank, *Crassostrea gigas*, in the Sluice dock of Ostend (photograph by M. DECLEER), (c) The New Zealand barnacle *Elminius modestus* living in the upper tidal zone (photograph by M. DECLEER), (d) Individuals of the slipper limpet (*Crepidula fornicata*) occurring on the shell of *Ensis directus* (photograph by F. KERCKHOF, MUMM / RBINS).

information is lacking for micro-organisms. Our climate is unsuited to many newcomers, and after a while they die out. However, the number of species that adapt and remain permanently is increasing strongly. The process is certainly favoured by recent climate change as reflected in the increase of the mean annual temperatures (IPCC 2001).

Some of these exotic species have even developed so strongly that they now form a dominant part of our marine flora and fauna. During the past two decades, the coastal benthic communities have undergone some remarkable alterations in their species composition. In the subtidal *Abra alba* community, the American jack-knife clam *Ensis directus* became very common after its first appearance in Belgian marine waters in 1987 (KERCKHOF & DUMOULIN 1987, 1988). Nowadays, the shells of this species are washed onto our beaches in millions (plate 2, a). However, the current sampling techniques (Van Veen grab or beam trawls) do not allow the accurate collection of this important species. *Ensis directus* has all the typical characteristics of an opportunistic species, being fast growing and able to withstand disturbance. Unlike the indigenous *Ensis* species, it is able to colonise a broad range of substrata and tolerates a broad salinity range. The consequences of the sudden and massive

appearance of this species in the *Abra alba* community are not well understood nor even studied, but its appearance certainly has consequences on the abundance of other invertebrates. Indeed, bivalves like *Cerastoderma* spp., *Tellina* spp. or *Macra* spp., all species that used to be common, have now apparently declined, although the relationship with the explosive expansion of *E. directus* has not been evidenced so far. Therefore, long-term monitoring of some habitats as well as the development of more accurate sampling strategies is needed.

During the last decades, the intertidal hard substrata of the Belgian waters also underwent important changes. Two of the most commonly observed organisms on artificial substrata, the New Zealand barnacle, *Elminius modestus*, and the pacific oyster, *Crassostrea gigas*, are in fact alien species (plate 2, b & c). The introduction of *E. modestus* in European waters took place during World War II. It is now the most common barnacle on artificial substrata along the Belgian coast. But even more striking is the recent explosive population increase of the pacific oyster, *C. gigas*. This species, although already introduced earlier in the 1970s for mariculture purposes, established stable wild populations in the early 1990s, obviously favoured by an increase in temperature. Now, pacific oysters can be found in huge numbers on groynes, all the offshore buoys and in harbour environments, where they often form reefs. The population increase of this newcomer causes concern since it could result in the substitution of the original mussel community by a pacific oyster community, which would have dramatic effects on the local fauna. On the other hand, pacific oyster reefs may by no means be regarded as an alternative for the reefs of the indigenous flat oyster, *Ostrea edulis*, which disappeared from the area. *Crassostrea gigas* is indeed mainly an intertidal species, while *Ostrea edulis* used to live offshore in a very specific subtidal habitat.

Another striking example is the recent increase in numbers of the slipper limpet, *Crepidula fornicata* (plate 2, d). This species has been introduced into Europe from North America at the end of the 19<sup>th</sup> century. In Belgian waters, it was already present in 1911 (POLK 1962). The slipper limpet is now extremely common, not only on hard substrata, but also on offshore soft sediments where it lives attached to substrata such as empty shells and behaves as a filter feeding bivalve. In the latter habitat, it recently underwent an explosive expansion, a feature also noted along other western European coasts (e.g. France). It is thought that bottom trawling practices favour the development of this species (HAMON 1996).

Harbours, with their many man-made constructions and harsh conditions, constitute a special environment characterised by a low species richness and by the dominance of species well adapted to environmental stress. In such conditions, several opportunistic alien species can thrive. This is also the case in Belgian harbours where alien species dominate the species associations. During preliminary studies, about 30 alien species were identified. But more specific research of the fauna and flora of the Belgian ports would certainly reveal the presence of many more non-indigenous species.

Even tourist activities play a major role in species introductions. Indeed, some large marinas exist along the Belgian coast and increasing yachting and sailing activities certainly favour the spreading and (secondary) introduction of fouling alien species. Recent examples are the barnacle *Balanus amphitrite* (KERCKHOF 1996) and the Indo-Pacific macro-alga *Undaria pinnatifida* (DUMOULIN & DE BLAUWE 1999).

Surprisingly, there are no known cases of species disappearing in the North Sea as a result of exotic species introductions, as is the case in freshwater environments and estuaries. Even the American piddock *Petricola pholadiformis*, which was introduced a long time ago and lives in the same environment as the native piddock *Barnea candida* (namely peat and clay banks), was not able to outcompete the latter, although it was frequently argued that this would happen. Another example can be found within the barnacle fauna. From the five common species found nowadays, three are non-indigenous. The newcomers have restricted the occurrence of the indigenous species but none of the native species have disappeared (KERCKHOF 2002). However, the newcomers tend to reduce the populations of local species, which might then be more sensitive to other environmental stresses.

It may be argued that the introduced species increase biodiversity e.g. in the harbour environments. But the newcomers are usually fast-growing species that are able to withstand disturbance and pollution. The above-cited species *Crassostrea gigas*, *Ensis directus*, *Crepidula fornicata*, *Elminius modestus* and *Balanus amphitrite* are all examples of such opportunist species. They feel very much at home in environments created or heavily influenced by man, such as harbours and coastal areas. Such disturbed areas are highly suitable for relatively undemanding immigrants, affecting the distribution of indigenous species or, in the worst case, even displacing them. Consequently, there is a worldwide risk that marine flora and fauna will become similar and the regional differences blurred. So, even if introduced species may result in greater diversity locally, on a worldwide scale they may lead to the impoverishment of biodiversity.

## 5. TOOLS FOR MARINE BIODIVERSITY PRESERVATION: MMM-LAW AND MARINE PROTECTED AREAS

An important indirect threat to biodiversity is the weakness of legal systems and institutions. Contrary to nature conservation on land, the conservation of the marine environment and the marine life, e.g. the establishment of Marine Protected Areas (MPAs), started much later and was, until recently, difficult to implement. However, Belgium recently took several important initiatives to improve nature conservation at sea.

MPAs are an important tool for the conservation and restoration of ecological values that are needed to stop the loss of biodiversity and, where possible, to restore its natural values. To achieve these objectives, a whole battery of legal instruments, operating on a local or global scale, have been established.

A first impulse in the creation of marine protected areas was the Ramsar Convention (Iran, 1972 ratified by Belgium in 1975). Under this convention, the shallow coastal sandbanks in the western part of the Belgian coast, from the low water mark up to three nautical miles offshore, are protected as 'Wetland of International Importance for Bird Species' (figure 2). The area has an international importance for wintering sea birds, especially for the common scoter (*Melanitta nigra*).

At European level, two directives play a key role. The Birds Directive provides for the designation of Special Protection Areas (SPAs). Under the Habitats Directive, member states have to designate Special Areas of Conservation (SACs). Both SPA and SAC aim at the conservation of biodiversity by the protection and/or restoration of certain vulnerable

species and habitats. Together they will form a coherent European ecological network, called Natura 2000. The list of habitat types of Community importance for conservation (Annex 1 of the Habitats Directive) includes 'Coastal marine habitats consisting of permanently submerged shallow sandbanks'. Therefore, Belgium has proposed the entire three nautical miles zone along the Belgian western coast as a SAC to be included in the Natura 2000 network. Moreover, the proposed Natura 2000 Marine Protected Area is directly connected with ecologically valuable coastal habitats (intertidal beaches and IJzer-estuary, grey dunes and decalcified Atlantic dunes). In Belgian marine waters, no SPAs have been selected yet. A study on SPAs and the identification of sites is currently going on.

Another framework enabling the creation of MPAs is the OSPAR Convention. Protection of species and habitats is the subject of Annex V of the OSPAR Convention and the related strategy on the protection and conservation of the ecosystems and biological diversity of the maritime area. The OSPAR Convention makes it possible to establish MPAs inside and outside the territorial waters of the contracting parties. The marine protected areas in the framework of OSPAR should form an ecologically coherent network. By doing so, the benefits for the conservation of marine biodiversity will increase, especially for highly mobile species such as certain birds, mammals and fish.

The international framework formed the basis of the Law of 20 January 1999 on the protection of the marine environment in the marine areas under jurisdiction of Belgium (Wet / Loi Marien Milieu Marin, referred to as the MMM-law) published in the Belgian Official Journal on 12 March 1999. This law forms the legal framework that enables the Belgian government to take all necessary measures to execute the obligations resulting from international directives and conventions. In this law, some very important general guiding principles are mentioned, such as the precautionary principle, the principle of sustainable development, the principle of preventive action and the polluter-pays principle.

The MMM-law (which has to be implemented through Royal Decrees) provides for the creation of MPAs of five possible types, but none have been established yet:

- **integral marine reserves** created in order to let the natural phenomena evolve according to their own laws (without conservation or restoration management actions), and where every activity is forbidden, except for surveillance and control, monitoring and scientific research. Shipping, professional fisheries and military activities are not necessarily forbidden but they can be excluded or limited;
- **directed marine reserves** with an appropriate management for nature conservation and/or restoration purposes, and where every activity is forbidden, except for surveillance and control, monitoring and scientific research. Shipping, professional fisheries and military activities are again not necessarily forbidden but can be excluded or limited;
- **special protection areas** or special zones for nature conservation, established for the conservation of certain marine habitats or specific species, e.g. the proposed Natura 2000 network site;
- **closed areas** in which some activities are forbidden all year round or part of the year (seasonal prohibition);
- **buffer areas** designated to give additional protection to MPAs and in which prohibition and restriction measures are less stringent than in marine reserves.

One of the difficult issues with which nature conservation at sea has to deal with is the management of fishery activities. Marine reserves have been proposed as an efficient and inexpensive way to maintain and manage fisheries while simultaneously preserving biodiversity. MPAs have not the same status as marine reserves with which they are often confused. Several activities will still be possible provided that they are in agreement with natural values and carried out in a sustainable way. In integral and directed marine reserves, professional fishing activities can only be restricted when the Minister responsible for marine environmental protection and the Minister responsible for fisheries agree on this matter. In the same way, the Federal Council of Ministers can restrict shipping by installing special obligatory routing systems. For the management of both types of marine reserves, the framework law provides the obligation to establish a heterogeneous management commission. This commission can make suggestions for management and conservation measures to the federal Minister of the Environment and will be charged with the execution of these measures.

The MMM-law also provides for the active protection of a number of species and forbids the intentional introduction of non-indigenous species in the marine environment, unless permission is given. Thus, the Royal Decree of 21 December 2001 on the protection of species in the marine areas under Belgian jurisdiction, published in the Belgian Official Journal (BOJ) on 14 February 2002, gives a list of protected species and regulations. The same Royal Decree also sets out the procedure to obtain permission for the intentional introduction of non-indigenous species.

Concerning the issue of the protection of species and habitats, Belgium is also actively involved in the OSPAR Convention for the designation of threatened and declining species and habitats. The establishment of such a list is in many cases hampered by the lack of data documenting the decline. This is especially the case for formerly common, but non-commercially important, species. This situation makes it more difficult to persuade some parties, involved in the process, of the need to protect the 'questionable' species. Even so, as illustrated above, some habitats have disappeared or declined in quality, often without being noticed or studied. This stresses once more the need for long-term and reliable data. But if we do not restore our coastal environments, monitoring will simply document the change of coastal ecosystems, which are already devoid of larger animals and scattered with plenty of opportunistic species, making these ecosystems more and more similar all over the world.

## 6. CONCLUSION

The role of biodiversity in ecosystem functioning is poorly documented in marine ecosystems as compared to terrestrial and freshwater ecosystems. As it became clear when compiling data of chapters 3 and 4 and from the overview of marine biodiversity, our knowledge of the occurrence and distribution of many taxa in the Belgian marine areas is still incomplete. This is due to the fact that the intensity of research is not evenly distributed over the Belgian marine areas. In particular, investigations of special habitats (e.g. wrecks) and areas further offshore (e.g. Hinder Banks) have only recently started. Moreover, biodiversity research at the genetic level is still in its infancy. There is a need to identify which anthropogenic threats cause changes in genetic biodiversity and to what extent these cause long- and short-term changes in the local fauna.

Gaps in knowledge represent an indirect but real threat to marine biodiversity. Indeed, biodiversity preservation (and restoration) through jurisdictional constraints completely relies on our actual knowledge of structure and functioning processes. Consequently, the management actions undertaken in order to protect the environment may lead to ineffective measures if they are based on inadequate information. A striking example of this is the worldwide decline of several shark and ray species, due to overfishing and a lack of fundamental life history data for the identification of appropriate management measures. On the other hand, insufficient knowledge is generally used to argue that the environmental impact of human activities is minimal. This has recently been acknowledged and corrected in environmental regulations that were based on an abusive interpretation of the 'principle of precaution'.

The definition of a 'sustainable biodiversity level' in Belgian marine areas requires a revisitation of older research, the gathering of data on poorly understood compartments and an increase in sampling effort in poorly documented areas. This has recently been undertaken and will certainly provide key information for the future management of the area. As has been emphasised many times, there is also a need for long-term, standardised monitoring activities in order to enable one to detect changes over a long period. So far, such studies have remained scarce because they are thought to be expensive, and hence are not a priority to policy and decision-makers. But how is it possible to discern between natural and anthropogenic causes of changes, in the absence of long-term data? The concept of 'sustainable development' defined within the Convention on Biological Diversity however acknowledges the need for an integration of environmental concern within socio-economic policies. This principle is now fully integrated in national marine research programmes. Research on marine 'ecosystem functioning', and in particular on the role played by biodiversity, as well as the implementation of an 'ecosystem approach' in marine environmental management are increasing worldwide and will probably allow to fill important gaps in our knowledge.

However, it is feared that one 'species' necessary to undertake such integrated research might become extinct soon, i.e. the marine taxonomist. Indeed, just as it is the case for taxonomists in general, its population is growing so old that questions arise as to how future generations will benefit from their expertise and knowledge in biodiversity assessments...

#### *Acknowledgements*

The authors wish to warmly thank the following persons for providing information, support and/or peer-review: D. CASEAU, C. CLAES, M.H. DARO, F. FRANCKEN, S. DEGRAER, B. GODDEERIS, S. JANS, Th. JACQUES, J. HAELTERS, Cl. MASSIN, A. NORRO, G. VAN HOEY, H. VAN LOEN, L. VIGIN, as well as the editors of the book for their patience.

#### *References*

- BAETEMAN, C., 1999. The holocene depositional history of the IJzer paleovalley (western Belgian coastal plain) with reference to the factors controlling the formation of intercalated peat beds. *Geologica Belgica*, 2 (3-4): 39-72.
- BAETEMAN, M., 1982. Ecologische toestandbeschrijving van de zandexploitatie voor de Belgische kust 1977-1980. *Mededelingen van het Rijksstation voor Zeevisserij (Centrum voor Landbouwkundig Onderzoek, Gent)*, 184: 65 pp.

- BONNE, W., 2003. Benthic copepod communities in relation to natural and anthropogenic influences in the North Sea: sediments, sand extraction and phytoplankton blooms. PhD thesis Ghent University: vi + 289 pp.
- BROWN, C.J., HEWER, A.J., MEADOWS, W.J., LIMPENNY, D.S., COOPER, K.M., REES, H.L. & VIVIAN, C.M.G., 2001. Mapping of gravel biotopes and an examination of the factors controlling the distribution, type and diversity of their biological communities. Centre for environment, fisheries and aquaculture science, Lowestoft. DEFRA research project AE908. Science series technical report n°114: 43 pp.
- CADÉE, G.C., 1986. Increased phytoplankton primary production in the Marsdiep area (Western Dutch Wadden Sea). *Netherlands Journal of Sea Research*, 20: 285-290.
- CADÉE, G.C. & HEGEMAN, J., 2002. Phytoplankton in the Marsdiep at the end of the 20<sup>th</sup> century: 30 years monitoring biomass, primary production, and *Phaeocystis* blooms. *Netherlands Journal of Sea Research*, 48: 97-110.
- CATTRIJSE, A. & VINCX, M., 2001. Biodiversity of the benthos and avifauna of the Belgian coastal waters. Summary of data collected between 1970 and 1998. Federal Office for Scientific, Technical & Cultural Affairs, Brussels: 48 pp.
- DAAN, N., BROMLEY, P.J., HISLOP, J.R.G. & NIELSEN, N.A., 1990. Ecology of North Sea Fish. *Netherlands Journal of Sea Research*, 26 (2-4): 343-386.
- DARO, M.H., 1969. Etude écologique d'un brise-lames de la côte belge: 1. Description et zonation des organismes. *Annales de la Société royale zoologique de Belgique*, 99 (3-4): 111-152.
- DARO, M.H., 1970. Etude écologique d'un brise-lames de la côte belge: 2. Biologie et développement saisonnier des espèces. *Annales de la Société royale zoologique de Belgique*, 100 (3): 159-189.
- DAVOULT, D., DEWARUMÉZ, J.M., PRYGIEL, J. & RICHARD, A., 1988. Carte des peuplements benthiques de la partie française de la Mer du Nord. Station Marine de Wimereux, Ifremer, Région Nord / Pas-de-Calais: 30 pp. + map.
- DE SMET, W.M.A., 1974. Inventaris van de walvisachtigen (Cetacea) van de Vlaamse kust en de Schelde. *Bulletin van het Koninklijk Belgisch Instituut voor Natuurwetenschappen*, 50 (1): 156 pp.
- DE SMET, W.M.A., 1981. Gegevens over de walvisachtigen (Cetacea) van de Vlaamse kust en de Schelde uit de periode 1969-1975. *Bulletin van het Koninklijk Belgisch Instituut voor Natuurwetenschappen*, 54 (4): 34 pp.
- DE VOS, D., 1979. Zonatiestudie van de wiervegetatie van de pier van Zeebrugge. *Jaarboek Verenging voor het Onderwijs in de Biologie*, 2: 33-45.
- DELEU, S., 2002. Tide-topography interactions near the kink in the Westhinder sandbank (Southern North Sea). M.Sc. Thesis, Ghent University: 43 pp.
- DEGRAER, S., 1999. Macrobenthos of shallow marine habitats (Belgian coast) and its use in coastal zone management. PhD thesis Ghent University: iv, 158 pp.
- DEGRAER, S., VAN LANCKER, V., MOERKERKE, G., VAN HOEY, G., VINCX, M., JACOBS, P. & HENRIET, J.-P., 2002. Intensive evaluation of the evolution of a protected benthic habitat: HABITAT. Final report 01/02. Federal Office for Scientific, Technical and Cultural affairs (OSTC) - Ministry of the Flemish Community, Environment and Infrastructure. Department Waterways and Marine Affairs Administration, Coastal Waterways: 124 pp.
- DEGRAER, S., VOLCKAERT, A. & VINCX, M., 2003. Macrobenthic zonation patterns along a morphodynamical continuum of macrotidal low tide bar/rip and ultra-dissipative sandy beaches. *Estuarine, Coastal and Shelf Science*, 56: 459-468.
- DEWICKE, A., CATTRIJSE, A., MEES, J. & VINCX, M., 2003. Spatial patterns of the hyperbenthos of subtidal sandbanks in the southern North Sea. *Journal of Sea Research*, 49 (1): 27-45.
- DUMOULIN, E. & DE BLAUWE, H., 1999. Het Bruinwier *Undaria pinnatifida* (HARVEY) SURINGAR (Phaeophyta: Laminariales) aangetroffen in de jachthaven van Zeebrugge: met gegevens over het voorkomen in Europa en de wijze van verspreiding. *De Strandvlo*, 19 (4): 182-188.
- ENGLEDOW, H., SPANOGHE, G., VOLCKAERT, A., COPPEJANS, E., DEGRAER, S., VINCX, M. & HOFFMANN, M., 2001. Onderzoek naar de fysische karakterisatie en de biodiversiteit van strandhoofden en andere harde substraten langs de Belgische kust. Eindrapport in opdracht van het Ministerie van de Vlaamse Gemeenschap, Departement Leefmilieu en Infrastructuur, Afdeling Waterwegen en Zeewezen: 109 pp.

- ENO, N.C., CLARK, R.A. & SANDERSON, W.G. (eds), 1997. Non-native marine species in British waters: a review and directory. Joint Nature Conservation Committee, Peterborough: 152 pp.
- FETTWEIS, M. & VANDEN EYNDE, D., 2003. The mud deposits and the high turbidity in the Belgian-Dutch coastal zone, southern bight of the North Sea. *Continental Shelf Research*, 23: 669-691.
- FRANCKEN, F. & RUDDICK, K., 2003. Ontwikkeling van een dispersiemodel voor de evaluatie van de impact op het leefmilieu van toxische producten afkomstig van chemische wapens die zich bevinden op de bodem van de zee (Paardenmarkt site). BMM Brussel. Federale Leefmilieu Inspectie, contract INS-22472, intermediate report: 28 p.
- GASPARINI, S., DARO, M.H., ANTAJAN, E., TACKX, M., ROUSSEAU, V., PARENT, J.-Y. & LANCELOT, C., 2000. Mesozooplankton grazing during the *Phaeocystis globosa* bloom in the southern bight of the North Sea. *Journal of Sea Research*, 43: 343-356.
- GILSON, G., 1900. Exploration de la Mer sur les côtes de la Belgique en 1899. *Mémoires du Musée Royal d'Histoire Naturelle de Belgique*, 1: 81 pp., 3 maps.
- GILSON, G., 1914. Le Musée d'Histoire Naturelle moderne; sa mission, son organisation, ses droits. *Mémoires du Musée Royal d'Histoire Naturelle de Belgique*, 7 (1): 256 pp.
- GOVAERE, J.C.R., VAN DAMME, D., HEIP, C. & DE CONINCK, L.A.P., 1980. Benthic communities in the southern bight of the North Sea and their use in ecological monitoring. *Helgoländer Meeresuntersuchungen*, 33: 507-521.
- GRAY, J.S., 1997. Marine Biodiversity: patterns, threats and conservation needs. *Biodiversity and Conservation*, 6: 153-175.
- GULLENTOPS, F., MOENS, M., RINGELE, A. & SENGIER, R., 1976. Geologische kenmerken van de suspensie en de sedimenten. In: NIHOUL, J.C.J. & GULLENTOPS, F. (eds), *Projekt Zee: eindverslag*. Vol. 4: sedimentologie. Diensten van de Eerste Minister. Programmatie van het Wetenschapsbeleid, Brussel: 127 pp.
- GUNS, M., HOEYWEGEN, P., VINCKE, W. & DECLERCK, R., 1999. Zware metalen in grijze garnaal (*Crangon crangon*) van de Belgische kustwateren (1972-1997). *Mededelingen van het Departement Zeevisserij (Centrum voor Landbouwkundig Onderzoek, Gent)*, 251.
- HAMON, D., 1996. Peuplements benthiques des fonds meubles. Distribution de la faune benthique, distribution de la Crépidule (*Crepidula fornicata*). In: AUGRIS, C. & HAMON, D. (eds), *Atlas thématique de l'environnement marin en baie de Saint-Brieuc (Côtes d'Armor)*. Ifremer, Brest: 45-51.
- HECQ, J.H. & GOFFART, A., 1996. The pivotal role of zooplankton in the North Sea pelagic ecosystem. In: *Dialogue between scientists and users of the sea. Proceedings of a symposium held on the occasion of the 10<sup>th</sup> anniversary of the civil service oceanographic research vessel Belgica, Ostend, 17-19 October 1994*. Federal Office for Scientific, Technical and Cultural Affairs, Brussels: 21-32.
- HEESSEN, H.J.L. (ed.), 2003. Development of Elasmobranch Assessments - DELASS. EC project, DG Fish Study, contract 99/055, final report: 605 pp.
- IPCC, 2001. Climate Change 2001: The scientific basis. Contribution of the Working Group I to the 3<sup>rd</sup> assessment report of the Intergovernmental Panel on Climatic Change [HOUGHTON, J.T., DING, Y., GRIGGS, D.J., NOGUER, M., VAN DER LINDEN, P.J., DAI, X., MASKELL, K. & JOHNSON, C.A. (eds)]. Cambridge University Press, Cambridge, UK & New York, USA: 881 pp.
- JACKSON, J.B.C., KIRBY, M.X., BERGER, W.H., BJORNDAAL, K.A., BOTSFORD, L.W., BOURQUE, B.J., BRADBURY, R.H., COOKE, R., ERLANDSON, J., ESTES, J.A., HUGHES, T.P., KIDWELL, S., LANGE, C.B., LENIHAN, H.S., PANDOLFI, J.M., PETERSON, C.H., STENECK, R.S., TEGNER, M.J. & WARNER, R.R., 2001. Historical overfishing and the recent collapse of coastal ecosystems. *Science*, 293 (5530): 629-637.
- JAUNIAUX, T. & COIGNOUL, F., 2001. Pathologie des infections par les morbilivirus chez les mammifères marins. *Annales de Médecine Vétérinaire*, 145: 75-96.
- JOCQUÉ, R. & VAN DAMME, D., 1971. Inleidende oecologische studie van klei- en turfbanken in de getijdenzone te Raversijde (België). *Biologisch Jaarboek Dodonaea*, 39: 157-190.
- JOHNS, D.G. & REID, P.C., 2001. An overview of plankton ecology in the North sea. Technical report, Strategic Environmental assessment (SEA). SAHFOS: 29 pp.
- KERCKHOF, F., 1988. Over het verdwijnen van de Purperslak *Nucella lapillus* (LINNAEUS, 1758) langs de Belgische kust. *De Strandvlo*, 8 (2): 82-85.

- KERCKHOF, F., 1996. *Balanus amphitrite* (DARWIN, 1854), een nieuwe zeepok voor onze fauna? *De Strandvlo*, 16 (3): 100-109.
- KERCKHOF, F., 1998. De korfschelp *Corbula gibba* (OLIVI, 1792) nieuw voor de Belgische fauna. *De Strandvlo*, 18 (2): 80-89.
- KERCKHOF, F., 2002. Barnacles (Cirripedia, Balanomorpha) in Belgian waters, an overview of the species and recent evolutions, with emphasis on exotic species. In: PEETERS, M. & VAN GOETHEM, J.L. (eds), Belgian Fauna and Alien Species. Proceedings of the symposium held on 14.12.2001 in Brussels. *Bulletin of the Royal Belgian Institute of Natural Sciences, Biology*, 72, suppl.: 93-104.
- KERCKHOF, F., in prep. On the molluscan fauna on Belgian buoys.
- KERCKHOF, F. & CATTRIJSSSE, A., 2001. Exotic Cirripedia (Balanomorpha) from Buoys off the Belgian Coast. *Senckenbergiana maritima*, 31 (2): 245-254.
- KERCKHOF, F. & DUMOULIN, E., 1987. Eerste vondsten van de Amerikaanse Zwaardschede *Ensis directus* (CONRAD, 1843) langs de Belgische kust. *De Strandvlo*, 7 (2): 51-52.
- KERCKHOF, F. & DUMOULIN, E., 1988. Het voorkomen van *Ensis directus* (CONRAD, 1843) langs de Belgische en Noordfranse kust. *De Strandvlo*, 8 (2): 102-105.
- LANCELOT, C. & MATHOT, S., 1987. Dynamics of a *Phaeocystis*-dominated spring bloom in Belgian coastal waters. I. Phytoplanktonic activities and related parameters. *Marine Ecology Progress Series*, 37: 239-248.
- LANSZWEERT, E., 1868. Les bancs d'huitres devant Ostende. *Annales de la Société royale malacologique de Belgique, Bulletin des Séances*, 3: XVII-XVIII.
- LAVALEYE, M.S.S., LINDEBOOM, H. & BERGMAN, M.J.N., 2000. Macrobenothos van het NCP: rapport ecosysteendoelen Noordzee (Macrobenothos of the NCP: report Ecosystem Targets North Sea). NIOZ-rapport (NIOZ-report), 2000-4. Nederlands Instituut voor Onderzoek der Zee, Den Burg, Texel, The Netherlands: 65 pp.
- LINDEBOOM, H.J. & DE GROOT, S.J. (eds), 1998. IMPACT-II: the effects of different types of fisheries on the North Sea and Irish Sea benthic ecosystems. NIOZ report 1998-1, RIVO-DLO report C003/98: 404 pp.
- LOUIS, A., PETES, J., RAMBOER, T. & VANDERVEKEN, L., 1974. La végétation phytoplanktonique de l'Océan Atlantique N-E et de la Mer du Nord. *Studia algologica lovaniensa*, E. Stora-Scientia publisher, vol. I: 370 pp.
- LOUIS, A. & SMEETS, J., 1981. Etude écologique et algologique du secteur sud-est de la Mer du Nord: données de base. *Studia algologica lovaniensa*, E. Stora-Scientia publisher, vol. IX: 412 pp.
- M'HARZI, A., TACKX, M., DARO, M.H., KESALIA, I., CATURAO, R. & PODOOR, N., 1998. Winter distribution of phytoplankton and zooplankton around some sandbanks of the Belgian coastal zone. *Journal of Plankton Research*, 20 (11): 2031-2052.
- MAERTENS, D., 1989. Ecological monitoring of the new dumping area on the Belgian Continental Shelf. In: PICHOT, G. (ed.), Progress in Belgian Oceanographic Research 1989. Proceedings of the North Sea symposium held in Ghent, 14 February 1989. Prime Minister's Services. Science Policy Office, Brussels: 297-324.
- MAES, F., CLIQUET, A., SEYS, J., MEIRE, P. & OFFRINGA, H., 2000. Limited Atlas of the Belgian Part of the North Sea. Federal Office for Scientific, Technical and Cultural affairs: 31 pp.
- MANN, A., 1780. Mémoire sur l'Histoire-Naturelle de la Mer du Nord, & sur la Pêche qui s'y fait. *Mémoires de l'Académie Royale des Sciences, des Lettres et des Beaux-Arts de Belgique*, 2: 159-219, 1 map.
- MASSIN, Cl., NORRO, A. & MALLEFET, J., 2002. Biodiversity of a wreck from the Belgian Continental Shelf: monitoring using scientific diving. Preliminary results. *Bulletin de l'Institut royal des Sciences naturelles de Belgique, Biologie*, 72: 67-72.
- MC GLADE, J.M., 2002. The North Sea Large Marine Ecosystem. In: SHERMAN, K. & SKJOLDAL, H.R., Large Marine Ecosystems of the North Atlantic: changing states and sustainability. Elsevier: 339-412.
- MEUNIER, A., 1913. Microplankton de la Mer Flamande, première partie. Le genre *Chaetaceros*. *Mémoires du Musée Royal d'Histoire Naturelle de Belgique*, 7 (2): 1-49.
- MEUNIER, A., 1915. Microplankton de la Mer Flamande, deuxième partie. Les Diatomacées. *Mémoires du Musée Royal d'Histoire Naturelle de Belgique*, 7 (3): 1-118.
- MISSIAEN, T., HENRIET, J.-P., VAN LANCKER, V., CHARLET, F., MOERKERKE, G., LANCKNEUS, J., HALLEUX, L., COUVREUR, M. & DEGRAER, S., 2002. Paardenmarkt site evaluation. Federal Office for

- Scientific, Technical and Cultural affairs, programme 'sustainable management of the North Sea', final report: 184 pp.
- NIHOUL, J.C.J., 1975. Effect of tidal stress on residual circulation and mud deposition in the Southern Bight of the North Sea. *Review of Pure and Applied Geophysics*, 113: 577- 581.
- NILSEN, H.-G., AAREFJORD, H., ØVERLAND, S. & RUKKE, J., 2002. Progress report: Fifth International Conference on the Protection of the North Sea. Conference held on 20-21 March 2002 in Bergen, Norway. Ministry of the Environment, Oslo: 210 pp.
- OFFRINGA, H., SEYS, J., VAN DEN BOSSCHE, W. & MEIRE, P., 1996. Seabirds on the Channel doormat. *De Giervalk*, 86: 3-71.
- OSPAR Commission, 2000. Quality Status Report. Region II: Greater North Sea. London: 136 pp.
- POLK, P., 1962. Bijdrage tot de kennis der mariene fauna van de Belgische kust. III. Waarnemingen aangaande het voorkomen, de voortplanting, de settling en de groei van *Crepidula fornicata* (L.). *Annales de la Société royale zoologique de Belgique*, 92 (1): 47-80.
- POLK, P., 1977. Inventarisatie plankton: fauna en flora. In: NIHOUL, J.C.J. & DE CONINCK, L., Projekt Zee: eindverslag. Vol. 7: inventaris van de fauna en flora. Diensten van de Eerste Minister. Programmatie van het Wetenschapsbeleid, Brussel: 233-311.
- POLL, M., 1947. Faune de Belgique: Poissons marins. Patrimoine du Musée Royal d'Histoire Naturelle de Belgique: 452 pp.
- PRYGIEL, J., DAVOULT, D., DEWARUMÉZ, J.M., GLAÇON, R. & RICHARD, A., 1988. Description et richesse des peuplements benthiques de la partie française de la Mer du Nord. *Comptes Rendus de l'Académie des Sciences*, Série III, 306: 5-10.
- ROOSE, P. & BRINKMAN, U.A.T., 2000. Volatile Organic Compounds in various marine organisms from the southern North Sea. *Marine Pollution Bulletin*, 40 (12): 1167-1177.
- ROOSE, P., COOREMAN, K. & VINCKE, W., 1998. PCBs in cod (*Gadus morhua*), flounder (*Platichthys flesus*), blue mussel (*Mytilus edulis*) and brown shrimp (*Crangon crangon*) from the Belgian continental shelf: relation to biological parameters and trend analysis. *Chemosphere*, 37 (9-12): 2199-2210.
- SEYS, J., 2001. Sea- and coastal bird data as tools in the policy and management of Belgian marine waters. PhD thesis Ghent University: 133 + lxix pp.
- SEYS, J., OFFRINGA, H., VAN WAHEYENBERGE, J., MEIRE, P. & KUIJKEN, E., 1999. Ornithologische belang van de Belgische maritieme wateren: naar een aanduiding van kensoorten en sleutelgebieden. Nota A74 Instituut voor Natuurbehoud, Brussel.
- SKOV, H., DURINCK, J., LEOPOLD, M.F. & TASKER, M.L., 1995. Important bird areas for seabirds in the North Sea including the Channel and the Kattegat. BirdLife International, Cambridge: 156 pp.
- TUNGARAZA, C., ROUSSEAU, V., BRION, N., LANCELOT, C., GICHUKI, J., BAYENS, W. & GOYENS, L., 2003. Contrasting nitrogen uptake by diatom and *Phaeocystis*-dominated phytoplankton assemblages in the North Sea. *Journal of Experimental Marine Biology and Ecology*, 292: 19-41.
- VAN BENEDEN, E., 1883. Compte rendu sommaire des recherches entreprises à la Station biologique d'Ostende pendant les mois d'été 1883. *Bulletin de la Classe des Sciences de l'Académie Royale de Belgique* (Sér. 3), 6: 458-483.
- VAN DER BEN, C., VAN DER BEN, D., VAN GOETHEM, J. & DARO, M.H., 1977. Inventaire et zonation des organismes sur les brise-lames de la côte belge. In: NIHOUL, J.C.J. & DE CONINCK, L., Projet Mer: rapport final. Vol. 7: inventaire de la faune et de la flore. Services du Premier Ministre. Programmation de la Politique scientifique: 313-332.
- VAN GOMPEL, J., 1991. Cetacea aan de Belgische kust, 1975-1989. *Lutra*, 34: 27-36.
- VAN GOMPEL, J., 1996. Cetacea aan de Belgische kust, 1990-1994. *Lutra*, 39: 45-51.
- VAN HOEY, G., DEGRAER, S., CATTRIJSE, A. & VINCX, M., subm. The macrobenthic communities of the Belgian Continental Shelf: a (re)analysis of combined data over six years. *Estuarine, Coastal and Shelf Science*.
- VAN LOEN, H., HOUZIAUX, J.-S. & VAN GOETHEM, J., 2002. The collection of G. GILSON as a reference framework for the Belgian marine fauna: a feasibility study. Federal Office for Scientific, Technical and Cultural Affairs, project MN/36/94, final report: 54 pp. + annexes.
- VAN MEEL, L.I.J., 1975. La mer du Nord méridionale, le Pas-de-Calais et la Manche. Essai d'écologie marine, principalement en ce qui concerne le microplankton. Vol. II - Etude planktonique: 655 pp. (unpublished).

- VAN MEEL, L.I.J., 1976. La mer du Nord méridionale, le Pas-de-Calais et la Manche. Essai d'écologie marine, principalement en ce qui concerne le microplankton. Vol. III - Phytoplankton, essai de systématique: 165 pp., 82 ill. (unpublished).
- VAN NEER, W., ERVYNCK, A., BOLLE, L.J., MILNER, R.S. & RIJNSDORP, A.D., 2002. Fish otoliths and their relevance to archaeology: an analysis of medieval, post-medieval and recent material of plaice, cod and haddock from the North Sea. *Environmental Archaeology*, 7: 61-76.
- VANAVERBEKE, J., GHESKÏÈRE, T. & VINCX, M., 2000. The meiobenthos of subtidal sandbanks on the Belgian Continental Shelf (Southern Bight of the North Sea). *Estuarine, Coastal and Shelf Science*, 51: 637-649.
- VINCKE, W., ROOSE, P., GUNS, M., VAN HOEYWEGEN, P. & HOENIG, M., 1999. Zware metalen in mosselen van de Belgische kust (1979-1997). *Mededelingen van het Departement Zeevisserij (Centrum voor Landbouwkundig Onderzoek, Gent)*, 250.
- VOLCKAERT, A., ENGLEADOW, H., BECK, O., DEGRAER, S., VINCX, M., COPPEJANS, E. & HOFFMANN, M., 2003. Onderzoek van de ecologische interacties van macroalgen, macrofauna en vogels geassocieerd met intertidal harde constructies langsheen de Vlaamse kust. Eindrapport in opdracht van het Ministerie van de Vlaamse Gemeenschap, Departement Leefmilieu en Infrastructuur, Afdeling Waterwegen en Zeewezen: 101 pp.
- WALKER, P., 1998. Fleeting images: Dynamics of North Sea ray populations. PhD thesis, University of Amsterdam and Royal Netherlands Institute for Sea Research: 145 pp.

Francis KERCKHOF  
Marine Ecosystem Management  
Royal Belgian Institute of Natural Sciences  
2de en 23ste Linierregimentsplein  
8400 Ostend

Jean-Sébastien HOUZIAUX  
Department of Invertebrates  
Royal Belgian Institute of Natural Sciences  
Rue Vautier 29  
1000 Brussels