1 Nature and environment

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With an average water depth of 95 m, the North Sea is a rather shallow sea, which is mainly located on the European continental shelf. The seabed is predominantly characterised by sandy habitats. In the North Sea, water of the North Atlantic Ocean is mixed with fresh water from rivers of the surrounding countries (Norway, Sweden, Denmark, Germany, the Netherlands, Belgium, France and the United Kingdom) (OSPAR QSR 2010). The surface area of the North Sea amounts to approximately 670,000 km² (European Environment Agency 2015), of which the Belgian part of the North Sea (BNS) covers a modest 3,454 km², approximately 0.5% of the surface area of the North Sea (Dauwe et al. 2019, Verhalle and Van de Velde 2020). More geographical information about the BNS can be found on the Coastal Portal and the Marine Atlas. The current text elaborates on several natural and environmental characteristics of the BNS and its adjacent coastal area.

1.1 Characteristics of the marine and coastal environment

1.1.1 Sea

The marine ecosystem is a complex natural system of biotic (living organisms) and abiotic (physical and chemical) elements and consists of aquatic environments with high concentrations of dissolved salt. Marine organisms are highly dependent on each other and their abiotic environmental factors. The primary producers (phytoplankton and macroalgae) are the main food source of the zooplankton. Zooplankton and benthos are utilised as food by numerous organisms, including most fish species. Fish species, in turn, are an important food source for spcies of higher trophic levels such as seabirds, predatory fish and marine mammals. The marine food web is composed of a series of food chains that connect different trophic levels. This complex system is further enlarged by interactions with bacteria, microbiota and fungi, each of which plays an important role in the marine ecosystem, both in the soil and the water column (Herndl and Weinbauer 2003). These biotic interactions are additionally influenced by abiotic environmental factors. The highly dynamic nature of the marine environment causes organisms to be exposed to various natural stressors (salt stress, oxygen depletion, light penetration, currents, etc.). The biotic and abiotic elements of the marine ecosystem are further elaborated separately and at different levels below.

1.1.1.1 Abiotic elements of the marine ecosystem

Bathymetry and substrate

The BNS is a shallow part of the North Sea with a seabed that gradually deepens in a northwesterly direction up to a depth of 40 to 45 m. The relief of the seabed is characterised by the presence of a complex dynamic system of gullies and sandbanks. The sandbanks can be up to 30 m high in relation to the channels, 15 to 25 km long and 3 to 6 km wide. The orientation of the banks varies from parallel to the coast to southwest-northeast in the deeper parts of the BNS (figure 1). The substrate of the seafloor generally consists of non-consolidated Quaternary sediments with low thicknesses in the channels and up to 50 m at the level of the sandbanks (Le Bot et al. 2003 (BELSPO), Mathys 2009, Mathys 2010, Van Lancker et al. 2019 (TILES project BELSPO)). Underneath these Quaternary sediments is Paleogenic clay which is locally found at the seabed in the trenches. Often, this is accompanied by the occurrence of gravel (Lanckneus et al. 2001 (BUDGET project BELSPO), Le Bot et al. 2003 (BELSPO), Mathys 2009, Mathys 2010, De Clercq et al. 2016, Van Lancker et al. 2019 (TILES project BELSPO)). In general, the grain size distribution of the sediment on the seabed generally becomes coarser as the distance from the coast increases, and varies from silt-rich sediment close to the coast over fine to coarse sand in deeper waters, interspersed with gravel fields (Verfaillie et al. 2006, Van Lancker et al. 2007 (MAREBASSE project BELSPO), Van Lancker et al. 2015, Van Lancker et al. 2019 (TILES project BELSPO)).

Hydrodynamics and sediment transport

The currents in the BNS are dominated by semi-diurnal tides[1]. The tidal range can vary from 3 m at neap tide to over 4.5 m during spring tide, with a decreasing tidal range (between low and high tide) towards the northeast. Tidal currents can reach up to 1.2 m/s and are the main cause of sediment transport. In addition, currents caused by the wind can also play a role in this transport (Lanckneus et al. 2001 (BUDGET project BELSPO), Fettweis and Van den Eynde 2003, De Moor 2006, Van Lancker et al. 2012 (QUEST4D project BELSPO), Baeye 2012, Van Lancker et al. 2015). High concentrations of suspended sediment often occur along the Belgian coast, leading to zones of extremely turbid water (Fettweis and Van den Eynde 2003, Fettweis et al. 2007 (MOCHA project BELSPO), Baeye 2012, Fettweis and Baeye 2015, Fettweis et al. 2016, Fettweis and Lee 2017, Shen et al. 2018, Vanlede et al. 2019, Fettweis et al. 2019, Van Maren et al. 2020).

[1] Tidal type where there are two high tides and two low tides per day.

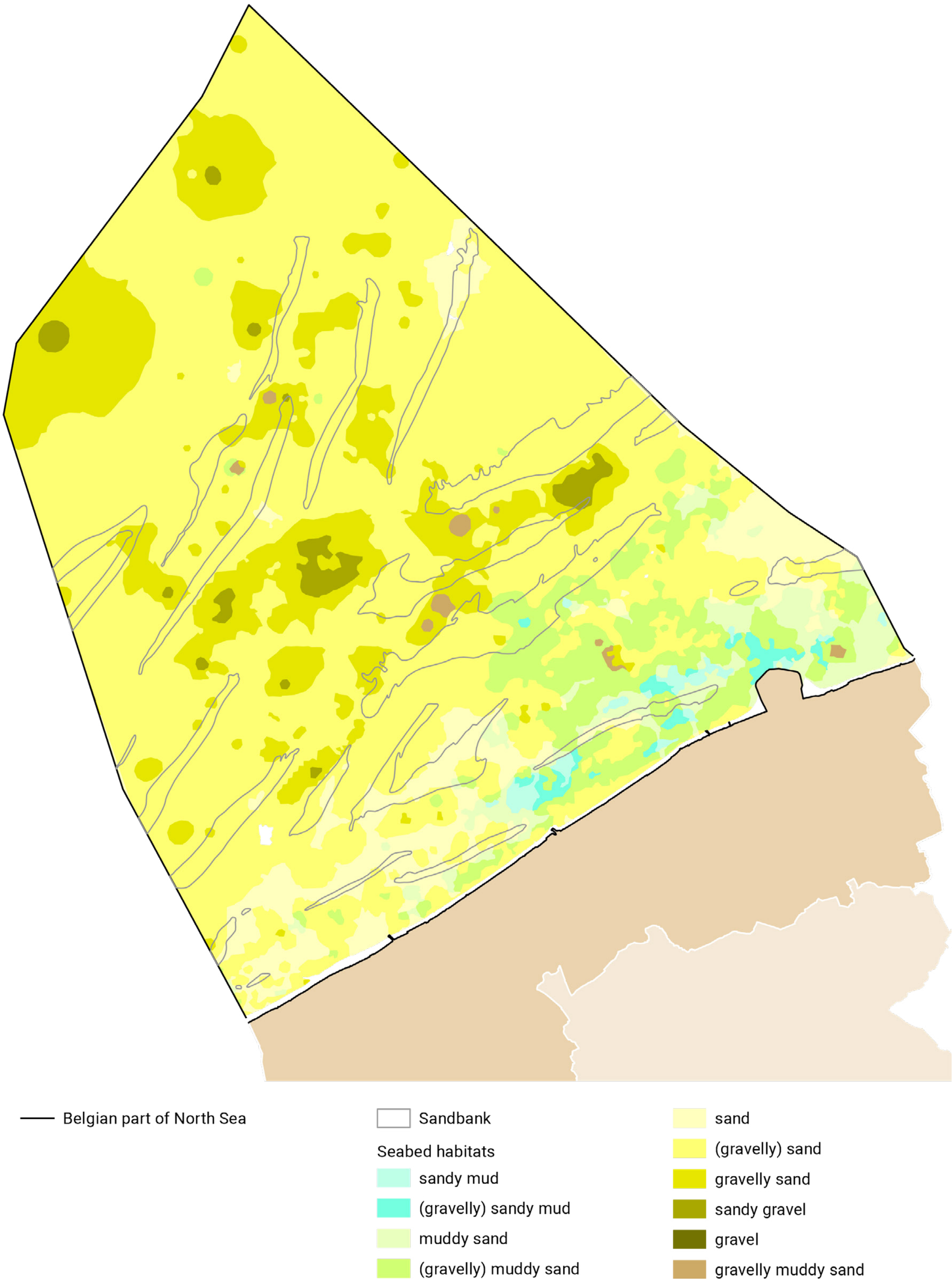

Figure 1. The sandbanks of the BNS, and the occurrence and distribution of seafloor habitat types mapped according to percentages of silt, sand, and coarse-grained sediments (Source: EMODnet Bathymetry, Van Lancker et al. 2013, Coastal Portal).

Measurement data and information on the hydrological and meteorological aspects (tides, currents, waves, wind, etc.) of the BNS can be consulted on the Flemish Banks Monitoring Network of the Flemish Hydrography. The administration also publishes the annual publication of the tide tables (Getijboekje 2021). Operational models using the hydro-meteorological data are available on the website of RBINS-Operational Directorate Natural Environment (OD Nature).

Seawater characteristics

The temperature of seawater in the BNS varies seasonally between 5°C and 20°C (Flemish Banks Monitoring Network). The seawater salinity in the BNS is strongly influenced by the river plumes[2] of the Scheldt, Rhine, Seine and Meuse rivers. This inflow of freshwater (salinity 0 PSU[3]) reduces the salinity of the water entering the BNS via the Channel (salinity 35 PSU) (Lacroix et al. 2004). The carbon chemistry of seawater has a seasonal variation and affects the acidity (pH) of the water, which fluctuates between 7.95 and 8.25 (Gypens et al. 2011, Le Quéré et al. 2015, Le Quéré et al. 2016, see also the Integrated Carbon Observation System (ICOS) and its entry in Schneiders et al. 2020 part E.7 Noordzee). Information about the nutrients and oxygen levels in the seawater was, *inter alia*, gathered in the context of the AMORE project (BELSPO), AMORE II project (BELSPO) and AMORE III project (phase 1 and phase 2 BELSPO) and the monitoring obligations for the OSPAR Commission (see also OSPAR IA 2017), the Water Framework Directive (WFD) and the Marine Strategy Framework Directive (MSFD) (see below **2.4 Protection of the marine and coastal environment**). The impact of climate change on the physical seawater characteristics in the BNS is discussed in Van den Eynde et al. (2011) (CLIMAR project BELSPO), Huthnance et al. 2016, the Coastal Vision project (formerly Flemish Bays, e.g. De Maerschalck et al. 2017) and in the CREST project (see also thematic chapter **Safety against flooding**).

1.1.1.2 Biotic elements of the marine ecosystem

Benthic life

The sandbanks and channels in the BNS (EU Habitats Directive Habitat Type 1110) are characterised by a rich benthic life (benthos). Given the high turbidity[4] of the seawater, microphytobenthos[5] is almost absent from the (subtidal) BNS. Benthic life here is dominated by zoobenthos. The benthos has been subject of intensive research since 1970 and tracked through biomonitoring (e.g. Cattrijsse and Vincx 2001, Van Hoey et al. 2004, Degraer et al. 2006, Degraer et al. 2008, Merckx et al. 2010, Vanaverbeke et al. 2011, Van Hoey et al. 2013, De Backer et al. 2014, Van Hoey et al. 2014, Vieren 2014, TROPHOS project (BELSPO), WESTBANKS project (BELSPO), ICES 2017, Hummel et al. 2017 (COST Action EMBOS ES1003), Van Hoey et al. 2019, Belgian State 2020). The benthos constitutes an important food source for fish, shrimps, crabs and even some birds, and actively influences the degradation and transport of organic matter and nutrients (e.g. Braeckman et al. 2010, Braeckman 2011, Van Ginderdeuren 2013, Courtens et al. 2017). The following section provides more details on the classification and spatial distribution of benthic organisms in the BNS:

- Just above the seabed of the North Sea, in the lowest meter of the water column, the hyperbenthos can be found, which mainly consists of fish larvae, crustaceans and mysid shrimps (e.g. Mees 1994, Beyst 2001, Dewicke 2002, Fockedey 2005, De Neve et al. 2020);
- On the seabed, large numbers of starfish (Asteroidea), serpent stars (Ophiuroidea), shrimp (Caridea), crabs (Brachyura), lobsters (Astacidea) and squids (Cephalopoda), as well as sea anemones (Anthozoa) like dead man's finger (*Alcyonium digitatum*) can be observed on the rocky substrates. Together with a number of less common species, they form the epibenthos, referring to their way of life just on the seabed (e.g. Hostens 2003, Calewaert et al. 2005, Vieren 2014, Vandendriessche et al. 2015, De Backer et al. 2016, Breine et al. 2018a);
- The bottom of the BNS serves as an important breeding ground for benthic[6], demersal[7] and bentho-pelagic fish[8] (Vieren 2014, Vandendriessche et al. 2015, De Backer et al. 2016, Degraer et al. 2019, Pecceu and Van Hoey 2020). The most common demersal flatfish in the BNS are plaice (*Pleuronectes platessa*), sole (*Solea solea*), dab (*Limanda limanda*), lemon sole (*Microstomus kitt*) and brill (*Scophthalmus rhombus*). Other dominant demersal fish species are the lesser weever (*Echiichthys vipera*), dragonet (*Callionymus*

[2] Fresh water discharge from rivers.
[3] Practical salinity unit.
[4] The turbidity level is a measure of relative clarity of a liquid.
[5] Microscopic primary producers living on and in the upper centimeters of benthic substrates.
[6] Fish that live and feed on or in the seabed.
[7] Fish that live and feed on or near the seabed.
[8] Fish that live and feed just above or near the seabed.

spp.), whiting (*Merlangius merlangus*), pouting (*Trisopterus luscus*) and hooknose (*Agonus cataphractus*) (Reubens 2013, Vieren 2014, Degraer et al. 2020);
- Most species of soil-dwelling organisms can be found among the sand grains (infauna or endobenthos), mainly to a depth of approximately 10 cm below the seabed: these are mainly bivalves, polychaete worms, small crustaceans (macrobenthos[9], Speybroeck et al. 2004, Degraer et al. 2006), nematodes and copepods (meiobenthos[10], Speybroeck et al. 2004);
- The bacterial community in the seabed is clearly different from that in the water column (De Tender et al. 2015). The highest richness and diversity of bacteria in the soil is recorded in June, linked to the breakdown of phytoplankton blooms, while β-AOB and AOA[11] peaks occur in September (Yazdani Foshtomi et al. 2015). Seasonal variations in the composition of the bacterial community are also stronger in fine sediments (Franco et al. 2007). The biogeochemistry of the seabed, including the carbon cycle, is described specifically for the Belgian coastal zone in Van de Velde et al. (2018);
- The spatial and seasonal variation in composition of microbial eukaryotes (protists) in the subtidal North Sea are described in Pede (2012). The diversity of protists is also associated with the grain size of the sediment, geochemistry and metal contamination.

The distribution of bottom-dwellers is not uniform and is strongly linked to the physical characteristics of the seabed (e.g. grain size of the sediment) and to the lower part of the water column (for more information on distribution and numbers of species, see Degraer et al. 2008). Firstly, the seabed of the BNS is mainly characterised by soft substrates (from silt to fine to coarse sand). Five typical macrobenthic communities are found in the soft mobile substrates of the subtidal sandbanks (Van Hoey et al. 2004, Breine et al. 2018a). In the intertidal zone on the beach, a sixth community is found:

- The *Limecola balthica* community (subtidal);
- The *Abra alba* community (subtidal);
- The *Magelona-Ensis leei* community (subtidal);
- The *Nephtys cirrosa* community (subtidal);
- The *Hesionura elongata* community, before *Ophelia borealis-Hesionura elongata* community (subtidal);
- The *Eurydice pulchra-Scolelepis squamata* community (intertidal).

These communities, characterised by distinctive species with a certain diversity and density, are each observed in a specific and relatively well-defined environment (Degraer et al. 2003, Van Hoey et al. 2004, Degraer et al. 2008, Breine et al. 2018a).

In addition to the soft substrates, geogenic and biogenic reefs also occur in the BNS (EU Habitats Directive Habitat Type 1170). Geogenic[12] reefs host a typical fauna that lives on top of the gravel beds (so-called hard substrate epifauna) with e.g. sponges, soft corals, bryozoans and sea anemones (Van Lancker et al. 2007, Houziaux et al. 2008, Van Lancker 2017). Given the importance of these hard substrates for biodiversity, the evolution of natural gravel beds is being monitored (Van Lancker et al. 2016, De Mesel et al. 2017, Montereale-Gavazzi et al. 2018, Belgian State 2018a, Fettweis et al. 2020 (INDI67 project BELSPO), Van Lancker et al. 2020). Biogenic reefs are mainly shaped by the sand mason worm (*Lanice conchilega*) (Rabaut et al. 2009).

The increasing use of artificial hard substrates (e.g. wind turbines and artificial reefs) creates new opportunities for benthic organisms (Degraer et al. 2020). The dense coverage of the structures with a typical fauna of rocky substrates is striking: e.g. the mussel (*Mytilus edulis*) and the sea anemone (De Backer et al. 2020, Coolen et al. 2020). In addition, the scour protection of wind turbines provides opportunities for various species: e.g. the European lobster (*Homarus gammarus*) and the North Sea crab (*Cancer pagurus*) (Krone et al. 2017), macro algae, fish such as pouting (*Trisopterus luscus*) and cod (*Gadus morhua*) (Degraer et al. 2013, Reubens et al. 2013, Kerckhof et al. 2018, Vanaverbeke and Coolen 2019, Degraer et al. 2020), etc. Braeckman et al. (2020) showed that the species composition of the macrobenthic community varies according to the distance to the wind turbines. In general, a higher density and diversity was observed closer to the wind turbines. In addition, the structures provide space for an intertidal flora and fauna in the open sea in Belgian waters, which consists for a considerable part of non-indigenous species (Kerckhof et al. 2016, Kerckhof et al. 2018, Verleye et al. 2020). The effects of these hard substrates on the structure and activity of the biological communities in and on the surrounding soft substrates are monitored in the framework of several projects (e.g. Coates et al. 2013, Baeye and Fettweis 2015, FaCE-IT project (BELSPO), PERSUADE project (BELSPO), OUTFLOW project (BELSPO), Derweduwen et al. 2016, Mavraki 2020, Degraer et al. 2020).

[9] Organisms living on or in the seabed and larger than 1 mm.
[10] Organisms living in or on the seabed and between 0.063 and 1 mm in size.
[11] Ammonium oxidising bacteria (AOB) and ammonium oxidising archaea (AOA).
[12] Reefs whose topographic expression is the result of geological phenomena such as the gravel beds of the Hinderbanks.

Pelagic organisms

The pelagic zone or 'water column' (the ecological zone consisting of open water) mainly houses the floating phytoplankton, zooplankton, bacterioplankton and the actively swimming nekton (including specific fish species) and marine mammals (see below). The pelagic zone is the largest habitat in the world but, unlike the benthic ecosystem, has not been subject to a long research tradition in Belgian waters. The different components of the pelagic habitat are discussed below:

- Phytoplankton constitutes an important aspect of the marine food web (Castellani and Edwards 2017, Amadei Martinez et al. 2020). Changes in phytoplankton dynamics can strongly influence the zooplankton dynamics (Lancelot et al. 2007). The LifeWatch observatory is making efforts to map these phytoplankton communities. (Nohe 2019, Amadei Martinez et al. 2020, Lagaisse 2020, VLIZ 2021). The phytoplankton concentration, which typically achieves high concentrations in the coastal waters, is analysed on the basis of satellite images and chlorophyll a concentrations (Rousseau et al. 2006). In the last few decades, there have been strong changes in the phytoplankton of the BNS. In the period 1970-2000 the concentration of diatoms and dinoflagellates increased. After the turn of the century, however, the total phytoplankton biomass decreased and the annual phytoplankton bloom occurred earlier in spring. These changes are linked to a combination of de-eutrophication and climate warming. Furthermore, the number of potentially toxic phytoplankton species increased (Nohe et al. 2020, Desmit et al. 2020). During the summer months, a strong bloom of the dinoflagellate sea sparkle (*Noctiluca scintillans*) is often observed in Belgian waters. This bloom causes beautiful luminescent effects in warm and calm weather, but can lead to local oxygen deficiency due to the high oxygen consumption (Van Mol et al. 2007, Ollevier et al. 2020, AMORE II project (BELSPO)). In addition, it is important that the problems (structural and functional changes in ecosystems, habitat and biodiversity loss) related to the annual seasonal change in phytoplankton composition (e.g. Phaeocystis blooms) as a result of eutrophication are monitored properly (see thematic chapter **Agriculture**) (Vasas et al. 2007);
- The zooplankton community[13] of the BNS has a typical coastal nature, but is occasionally influenced by introduced species originating from the inflow of Atlantic water (Van Ginderdeuren 2013). The crustaceans (Crustacea), and more specifically the calanoid copepods (holoplankton[14], 66%), dominate the zooplankton with *Temora longicornis, Euterpina acutifrons, Acartia clausi, Paracalanus parvus* and *Centropages typicus* being the most common species (Van Ginderdeuren et al. 2012a, Deschutter et al. 2017, Semmouri et al. 2020). In addition, meroplanktonic[15] larvae of polychaetes, echinoderms, fish and barnacles are abundant in the BNS. May and June are the months with the highest mean zooplankton densities, followed by a smaller autumn peak in September. Zooplankton densities vary from 150 to 15,000 ind.m^{-3} and reach their peak a few kilometres off the coast, in the transition zone from coastal to offshore waters (Van Ginderdeuren et al. 2014a). Since 2012, the LifeWatch observatory has been monitoring zooplankton communities both nearshore (monthly) and offshore (seasonally) (Mortelmans et al. 2019, VLIZ 2020);
- Within the zooplankton community, specific attention has been paid to jellyfish (e.g. the non-indigenous warty comb jelly (*Mnemiopsis leidyi*) (Van Ginderdeuren et al. 2012b, Vansteenbrugge et al. 2015a, 2015b) and the common jellyfish (*Aurelia aurita*) (Dulière et al. 2014)), and copepodes (e.g.. the invasive *Caligus brevicaudatus* (Mortelmans et al. 2017) and *Pseudodiaptomus marinus* (Deschutter et al. 2018)). Zooplankton is generally considered to be one of the better bio-indicators to demonstrate environmental changes (e.g. ICES WGZE Report 2017, ICES WGZE Report 2021);
- The bacterioplankton, which is dominated by Proteobacteria and Bacteroidetes, is also a sensitive ecological indicator. Since 2012, the bacterial communities in the seawater of the BNS have been studied using DNA-based techniques (De Tender et al. 2015, Kopf et al. 2015, ten Hoopen et al. 2015, De Tender 2017, Micro B3 project, LifeWatch observatory);
- In the pelagic zone, floating macroalgae (besides drifting debris) provide a special habitat for numerous organisms. These organisms can originate from rocky shores where the macroalgae were detached (e.g. various species of marine isopods) and from colonising species at sea (e.g. by larval stages of many crustaceans). In North Atlantic waters, mainly *Himanthalia elongata*, *Ascophyllum nodosum*, *Fucus vesiculosus*, *Chorda filum* and *Laminaria* spp. were studied (Vandendriessche 2007);
- The research on pelagic fish in the BNS is limited, mainly due to the fact that the BNS is relatively shallow, so that both the typical pelagic fishing nets and sonar images can only be used to a limited extent. Van Ginderdeuren et al. (2014b) revealed that herring and sprat are common in the BNS. It mainly concerns immature individuals (0- and 1-year class) in coastal waters. Adult herring (*Clupea harengus*) is only observed in autumn when the fish are migrating to the spawning areas in the Channel. In summer, two

[13] A collective term for heterotrophic organisms which float, drift or swim in water.
[14] Organisms that are planktonic throughout their entire life cycle.
[15] Organisms that are planktonic only at a certain stage of life.

other pelagic species appear, namely mackerel (*Scomber scombrus*) and horse mackerel (*Trachurus trachurus*). Young horse mackerels are present in the offshore pelagic fish community (Van Ginderdeuren et al. 2012a). The initial assessment of Belgian marine waters (Belgian State 2012a) indicates that several anadromous fish[16] (such as twait shad (*Alosa fallax*)), that were included in the Habitats Directive Annex II, are recovering (Breine et al. 2017).

Birds and marine mammals

Marine mammals constitute a separate group, which is elaborated below together with the occurrence of seabirds in Belgian marine waters:

- The BNS is an important wintering and foraging area for seabirds (Seys 2001, Stienen and Kuijken 2003, Haelters et al. 2004, Stienen et al. 2007, Degraer et al. 2010, Belgian State 2018a). During the winter months, internationally important numbers (i.e. more than 1% of the biogeographic population) of the grebe (*Podiceps cristatus*) and the great black-backed gull (*Larus marinus*) reside here. Furthermore, important numbers of the red-throated loon (*Gavia stellata*) and the common scoter (*Melanitta nigra*) are often recorded in the BNS during winter. The red-throated loon is included in Appendix I of the Birds Directive, while the common scoter is protected by the RAMSAR Convention (see **1.4.2 Policy instruments**). The BNS is also important for the common guillemot (*Uria aalge*) and the black-legged kittiwake (*Rissa tridactyla*) (Waggitt et al. 2019), but these species do not have a special protection status. The beaches, the groynes and piers along the coast constitute resting places for internationally significant numbers of herring gull (*Larus argentatus*) and the ruddy turnstone (*Arenaria interpres*) (Adriaens and Ameeuw 2008). In spring and summer, the coastal zone is an important foraging area for terns that mainly breed in the port of Zeebrugge, the Sluice Dock of Ostend and in the Zwin. Although three tern species used to regularly exceed the 1% standard (sandwich tern (*Thalasseus sandvicensis*), common tern (*Sterna hirundo*) and little tern (*Sternula albifrons*)) (Degraer et al. 2010), the populations of terns and black-headed gulls in Zeebrugge-Heist and the western outer port of Zeebrugge declined sharply after 2008 (Stienen et al. 2019). In 2016, terns did not even breed in Zeebrugge. With the help of sound and dummies, several coastal breeding birds were lured back to the tern peninsula in Zeebrugge in 2017 and 2018. Some of the common terns moved to the newly constructed islands in the Sluice Dock at Ostend and in the Zwin, but the great tern and little tern (almost) disappeared in Flanders (Stienen et al. 2018, Stienen et al. 2019, Vermeersch et al. 2020, Faveyts and Stienen 2020). An important trend in recent years is the sharp and steady decline of the common scoter, which is probably related to a decreasing availability of suitable shellfish. Most other seabirds show fluctuating trends. What is remarkable, however, is the very similar trend of the razorbill (*Alca torda*), the little gull (*Hydrocoloeus minutus*) and the black-legged kittiwake, with increased numbers around 2010. These species are all highly dependent on the presence of sand eels and often occur together (Stienen and Vanermen 2018);
- The BNS functions as an important migration corridor used by more than one million seabirds each year. During the migration period, internationally significant numbers of lesser black-backed gull (*Larus fuscus*), sandwich tern and common tern are regularly observed (Stienen et al. 2007) and the BNS is also a fairly important migration route for gannets (*Morus bassanus*) (Waggitt et al. 2019). Incidentally, songbirds also migrate in large numbers across the North Sea;
- Research shows that seabirds are also affected by the wind farms in the BNS (Vanermen et al. 2020). For example, between 2013 and 2019, the gannet, common guillemot and razorbill were observed less often on the Thornton Bank, while the great black-backed gull and cormorant (*Phalacrocorax carbo*) were recorded more frequently (Vanermen et al. 2019). Furthermore, the collision risk of six seabird species in the Belgian wind farms was examined (Brabant and Vanermen 2020) and a first assessment was made of the possible loss of seabirds by the installation of wind turbines, as a result of habitat loss (Stienen and Vanermen 2020). In the latter publication, a decrease of several tens of percent is expected for the red-throated diver, common guillemot, razorbill and gannet after the completion of the second zone for renewable energy on the Hinderbanks;
- Furthermore, Belgian marine waters are considered to be important for four species of marine mammals listed in Annex II of the Habitats Directive (see **1.4.2 Policy instruments**), namely the harbour porpoise (*Phocoena phocoena*), the bottlenose porpoise (*Tursiops truncatus*), the harbour seal (*Phoca vitulina*) and the grey seal (*Halichoerus grypus*) (Degraer et al. 2010, Haelters et al. 2016, Buyse 2018, Haelters et al. 2020). In the period February-April, the number of harbour porpoise in the BNS can increase to more than 1% of the estimated North Sea population (Haelters et al. 2011, Waggitt et al. 2019). The number of strandings of harbour porpoises along the Belgian coast also differs seasonally. A first peak is observed

[16] Fish that live in the sea and migrate into fresh water to spawn.

in spring (March-May) followed by a second, less pronounced, peak in September. Furthermore, there are indications that the number of strandings could be higher in months with prolonged periods of intermittent high-intensity impulse noise from the construction of wind farms (Rumes et al. 2019). Finally, within the framework of the LifeWatch project, a passive acoustic network was set up to monitor the presence of harbour porpoises and dolphins in the BNS;

- In addition to marine mammals, several species of bats have been observed along the coast and above the BNS. The species most frequently observed at sea is Nathusius' pipistrelle (*Pipistrellus nathussii*). However, other species also occur above the sea, such as the common pipistrelle (*Pipistrellus pipistrellus*), Daubenton's bat (*Myotis daubentonii*), the parti-coloured bat (*Vespertilio murinus*) and the common noctule (*Nyctalus noctula*). These species undertake seasonal migrations between northern and southern Europe and also pass through the southern North Sea coasts (Brabant et al. 2016a, Brabant et al. 2016b, Lagerveld et al. 2017, Gillebert 2018). In the BNS, bats are mainly observed close to shore, but some bats also migrate across the channel. Therefore, the potential risks of offshore wind turbines for migrating bats are also investigated (Brabant et al. 2016a, Brabant et al. 2018). In order to study the distribution of bats along the coast and at sea, the LifeWatch observatory has set up an acoustic network.

The impact of human activities (e.g. fishing and offshore wind energy) on the distribution of seabirds and marine mammals is further discussed in table 1, chapter **1.3 Impacts on the Marine and Coastal Environment** and the thematic chapters **Fisheries** and **Energy (including cables and pipes)**.

Biological valuation of the sea

Within the framework of the BWZee project (BELSPO), the spatial distribution data of all components of the marine ecosystem were integrated and biological valuation maps were drawn up for the BNS (figure 2) (Derous et al. 2007). This includes benthos, demersal fish and seabirds. A complete overview of the species lists in the BNS is available within the Belgian Register of Marine Species (BeRMS, Vandepitte et al. 2010). In addition, many non-indigenous organisms are found in Belgian waters. The website 'Non-indigenous species' provides an overview of the 'established' non-indigenous marine and coastal species in the BNS and adjacent estuaries (Verleye et al. 2020).

1.1.2 Beach

1.1.2.1 Abiotic elements of the beach ecosystem

Beaches are relatively narrow, elongated strips that follow the boundary between land and sea, part of which is alternately situated above and below water due to tidal changes in the water level. They occur in coastal areas exposed to waves, resulting in deposits of mainly sandy sediments. On the beaches along the Belgian coast, this concerns medium fine quartz sand with a lot of shell grit. The beaches are generally characterised by a micro-relief of smaller shapes: low, elongated, longitudinal sand ridges separated by shallow, trench-shaped depressions (*zwinnen*), as well as other smaller features such as *wallen* and *hoornen* (rhythmic shapes). Waves and currents shape all sorts of ripple marks on the beach. The coast is subject to a semi-diurnal tide with tidal currents almost parallel to the coast. An elaborated overview of the geomorphology, processes and dynamics along the Flemish beaches is given in De Moor (2006) (see also Deronde 2007, Van Lancker et al. 2015).

1.1.2.2 Biotic elements of the beach ecosystem

The beach is a unique habitat where large numbers of organisms are present. In Speybroeck et al. (2005), Speybroeck et al. (2008) and Van der Biest et al. (2017a), an overview is given of the principal habitats, species and their interactions:

- Near the high water mark, on the dry beach, vascular plants can be found that are generally short living and dispersed by the sea (the most common species are the European searocket (*Cakile maritima*) and prickly glasswort (*Salsola kali* subsp. *kali*)). The establishment of the perennial species sand couch (*Elymus farctus* subsp. *boreoatlanticus*) or sea sandwort (*Honckenya peploides*) marks the starting point for the development of embryonic dunes because the sand deposited around these plants can accumulate permanently. The flood marks[17] are also the habitat for several terrestrial arthropods (the most common

[17] A landscape marking left by the high water mark.

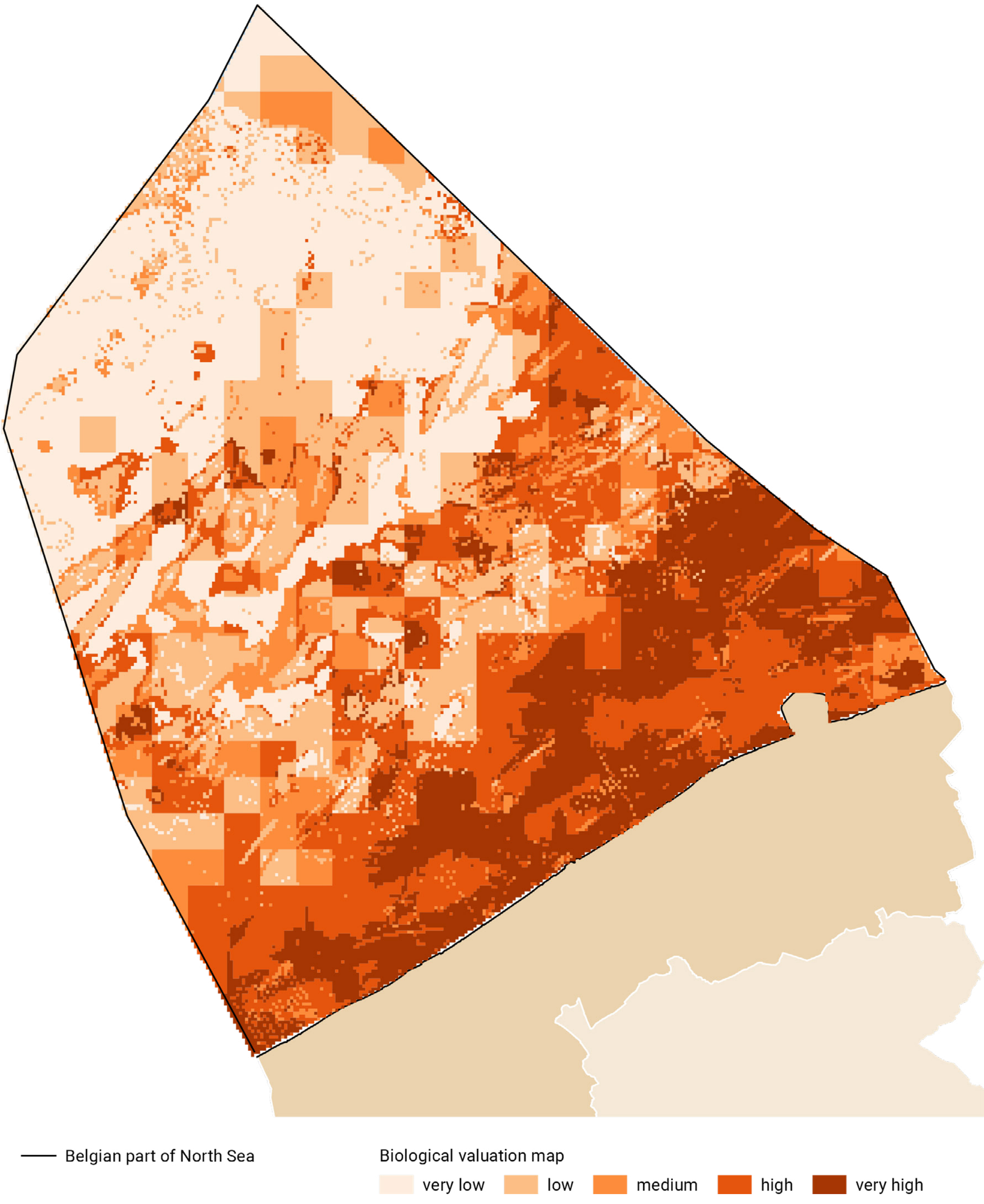

Figure 2. The biological valuation map of the BNS in which the valuation maps for macrobenthos, epibenthos, demersal fish and seabirds were combined (Source: BWzee project (BELSPO), Coastal Portal).

species being the sand hopper (*Talitrus saltator*) and a number of specialised fly species (Grootaert and Pollet 2004));

- Microphytobenthos, especially diatoms, constitutes an important primary producer at the Belgian coast (Speybroeck et al. 2005). The biomass of the microphytobenthos on sandy beaches is, however, much lower than in silty sediments (such as mudflats). The highest biomass is observed in summer and consists mainly of diatoms, to a lesser extent dinoflagellate and occasionally Euglenophyta. About 120 species have been observed so far, but this is probably a strong underestimation (van der Ben 1973, Blondeel 1996, Speybroeck et al. 2004, Speybroeck et al. 2005, Speybroeck et al. 2007);

- The meio- and macrobenthos on the beach include specific communities such as the macrobenthic (*Scolelepis squamata-Eurydice pulchra*) community. The geomorphology of the beaches, including their grain size and slope, determines to a significant extent the distribution of the (marine) benthic life on beaches. Beaches with gentle slopes and fine grain are generally richer than steep-sloped beaches with coarse sand particles (Degraer et al. 2003, Speybroeck et al. 2004, Vanden Eede et al. 2014a);
- The aforementioned beach fauna is an important food source for higher trophic levels of the marine environment, such as juvenile fish (e.g. plaice) and brown shrimp (*Crangon crangon*) (Beyst et al. 1999, Heindler et al. 2019). It is possible that the beach morphology has an impact on the breeding ground function of the intertidal beach sections for juvenile flatfish (Breine et al. 2018b);
- Birds only breed in the quiet beach reserve of Heist, where they are hardly disturbed by recreation, the tern peninsula in Zeebrugge and the edges of the new breeding islands in the Zwin and the Sluice Dock in Ostend (e.g. little tern, common tern, common ringed plover (*Charadrius hiaticula*) and Kentish plover (*Charadrius alexandrinus*)). However, the beaches remain an important resting and foraging area for all kinds of gulls and waders (Speybroeck et al. 2005, see also **Birds and marine mammals**).

Biological valuation of the beach

Based on the available biological information of macro-, epi- and hyperbenthos and birds, biological valuation maps have been created in Vanden Eede et al. (2014b) for a number of beaches along the Belgian coast. Scientific knowledge on coastal processes and dynamics, including the occurring species and their interactions, is crucial to assess the impact of human activities on the coastal environment and the maintaining of a healthy coastal ecosystem (Van der Biest et al. 2017a, Van der Biest et al. 2017b).

1.1.2.3 Artificial hard substrates

Along the Belgian coast, various artificial substrates have been constructed to protect the beaches, buildings and harbours from storms. From the French border to the Dutch border, more than 100 groynes and several dikes have been constructed (Engledow et al. 2001, Mertens 2009). In addition, the pier of Blankenberge and the Belgian ports also provide a lot of artificial hard substrates such as harbour walls, jetties (Nieuwpoort, Blankenberge and Ostend) and breakwaters (Ostend and Zeebrugge). Besides coastal safety, these hard substrates also form a unique habitat for many indigenous and non-indigenous species (Volckaert et al. 2002, Bouwens 2019). There are three communities on the groynes and in the harbours depending on their position in relation to the lowest astronomical tide (LAT) (Engledow et al. 2001, Volckaert et al. 2003, Volckaert et al. 2004). These communities consist of various fauna and flora:

- The most common epilithic fauna[18] are the polychaeta worms (Polychaeta), molluscs (Mollusca) and crustaceans (Crustacea). The latter group, including barnacles, is particularly well represented (Engledow et al. 2001, Volckaert et al. 2002);
- Various species of green algae (Chlorophyta), red algae (Rhodophyta) and brown algae (Phaeophyceae) can be found in the BNS on the artificial hard substrates in the intertidal zone (at the coastline and on the windmills). *Fucus* spp. and *Ulva* spp. are dominant genera along the Belgian coast and form a substrate on which other epiphytic seaweeds[19] can grow. These seaweeds can be obligate epiphytic (e.g. *Elachista* spp.) or can equally grow on the hard substrate itself (e.g. *Ulva* spp. or *Porphyra* spp.) (Engledow et al. 2001, Volckaert et al. 2004).

1.1.3 Dunes

The dune area of the Belgian coast, together with the mudflats and marshes and the upper beach are considered to be part of the 'Ecoregion of the Coast Dunes' (Sevenant et al. 2002). This area covers an area of 76.7 km². Based on pedology, this zone is characterised by the presence of sand that has been deposited by the wind (Kust en Klimaat 2020). These deposits date from after the last ice age, but are generally not older than a few hundred years. The oldest dunes at the Belgian coast are situated between Adinkerke and Ghyvelde in the North of France. They supposedly originated 5,000 years ago (De Ceunynck 1992, De Clercq and De Moor 1996). The largest part of the dunes, however, originated in the early Middle Ages and is referred to as 'young dunes'.

[18] Fauna living on hard substrates.
[19] Seaweeds growing on other seaweeds without extracting nutrients from them.

At present, dune formation and geomorphodynamics are generally limited to the dunes bordering the beach (*zeereep*[20]). A good dynamic in this zone is important for the formation of new dunes and the resilience of the coastal protection. Shifting sand is trapped on the high beach by specialised sand-binding grass species, such as sand couch (*Elytrigia juncea*) and especially European marram grass (*Ammophila arenaria*). Marram grass dunes can grow several metres along with shifting sand and form a robust protection against marine flooding (Provoost and Bonte 2004). Only in *De Westhoek* (De Panne) and *Ter Yde* (Oostduinkerke) inland dunes still show a certain dynamic. These are remnants of former migrating dunes, unvegetated dune ridges that move in the direction of the dominant winds. As in all of NW-Europe, migrating dunes in Belgium tend to stabilise (Provoost al. 2011).

The age of the dunes determines the degree of decalcification of the sand and is an important ecological determinant (Ampe 1999, Ampe et al. 2015). Deeply decalcified soils can be found in the old dunes of Adinkerke, the inner dunes of Westende and Bredene-De Haan and locally in the inner dunes of Knokke. Quantitatively, the ecological diversity is mainly determined by the soil moisture, which is in turn related to the dune relief in combination with the hydrology. A freshwater supply has built up below the dunes as a result of the percolation[21] of excess precipitation. The volume of this supply mainly depends on the width of the dunes. In the subsoil, this water body rests on an impermeable Paleogene clay layer of tens of metres thick. At the level of deep dune valleys (dune pans) or low-lying former beach plains, this groundwater can periodically rise above ground level[22] and be subject to ecological conditions that can lead to the development of swamp vegetation (Provoost et al. 2004, Provoost et al. 2020).

The complex of soil and vegetation development and numerous biotic interactions cause further differentiation in ecotypes (Rappé 1996, Provoost en Bonte 2004). According to the European Habitats Directive (see **1.4.2 Policy instruments**), 14 more or less natural coastal ecotypes that are limited to the coastal area within Flanders can be distinguished (Decleer 2007, Provoost 2019) (see also Natura 2000 in Flanders website for more information). Six of the ecotypes are intertidal, the remaining eight belong to the dunes:

2110 - Embryonic shifting dunes;
2120 - Shifting dunes along the shoreline with European marram grass (*Ammophila arenaria*) ('white dunes');
2130 - Fixed coastal dunes with herbaceous vegetation ('grey dunes');
2150 - Atlantic decalcified fixed dunes (*Calluno-Ulicetea*);
2160 - Dunes with sea-buckthorn (*Hippophae rhamnoides*);
2170 - Dunes with creeping willow (*Salix repens* ssp. *argentea* (*Salicion arenariae*));
2180 - Wooded dunes of the Atlantic, continental and boreal coasts;
2190 - Humid dune slacks.

The ecological specificity of the dune ecosystem is mainly related to the geomorphological dynamics of the contact zone between land and sea, the typical microclimate and the environmental gradients of fresh-saline, dry-wet and calcareous-decalcified environments. In the dunes, the typical coastal species can almost all be found in the embryonic shifting dunes, the white dunes and the early stages of the grey dunes and dune valleys (Provoost and Bonte 2004). From the perspective of the European Habitats and Birds Directives (see **1.4.2 Policy instruments**), the following species deserve special attention (see also the website Natura 2000 in Flanders):

- Plant species in appendix II: creeping marshwort (*Apium repens*) and fen orchid (*Liparis loeselii*) (extinct at the Belgian coast);
- Bats in appendix IV: whiskered bat (*Myotis mystacinus*), brown long-eared bat (*Plecotus auritus*), Brandts' bat (*Myotis brandtii*) (hibernator), Daubenton's bat (hibernator), grey long-eared bat (*Plecotus austriacus*) (hibernator), common pipistrelle (during summer), Nathusius's pipistrelle (during summer), serotine bat (*Eptesicus serotinus*) (during summer) and common noctule (during summer) (De Maeyer and Velter 2004);
- Breeding birds in appendix I: black-crowned night heron (*Nycticorax nycticorax*), little egret (*Egretta garzetta*), European honey buzzard (*Pernis apivorus*), common tern, little tern, European nightjar (*Caprimulgus europaeus*), middle spotted woodpecker (*Dendrocoptes medius*), Sandwich tern, woodlark (*Lullula arborea*) and bluethroat (*Luscinia svecica*);
- Amphibians in appendix IV: northern crested newt (*Triturus cristatus*) (appendix II), natterjack toad (*Epidalea calamita*) and European tree frog (*Hyla arborea*);
- Snails in appendix II: narrow-mouthed whorl snail (*Vertigo angustior*) and Desmoulin's whorl snail (*Vertigo moulinsiana*).

[20] The part of the dune belt that borders the beach and functions as a seawall.
[21] The downward movement of water into the unsaturated zone of the soil.
[22] The interface between the ground and the air. The ground level is often specified in relation to a national zero-level (*Oostende Peil* or O.P.).

The human influence on the coastal ecosystem is substantial. Approximately half of the dune area has been urbanised in the last 150 years and the remaining areas have undergone drastic changes in the landscape. The sand dynamics of dunes (see also Provoost et al. 2016) have largely stopped, and thicket and forest development have profoundly altered the vegetation structure. Within the coastal dunes, other important triggers for biodiversity changes are atmospheric deposition of nitrogen, climate change, recreation, water extraction and expansion of exotic species (Provoost en Bonte 2004), putting the typical dune biodiversity under pressure (Provoost 2014). The reporting in the framework of the Habitats Directive reveals that only one of the eight different dune habitat types (sea-buckthorn thicket 2160) has a good conservation status (Paelinckx et al. 2019).

Despite the growing awareness of the role of dune dynamics in supporting human well-being and biodiversity, redynamisation of dunes is rarely implemented in coastal management due to the rather limited possibilities within the highly urbanised and fragmented landscape. A dynamic dune complex is not only of great ecological importance, but would also provide substantial economic added value in terms of coastal safety and recreation (Van der Biest et al. 2017c, De Bruyn et al. 2020, Provoost et al. 2020) (see also thematic chapter **Safety against flooding**). In *Ter Yde* and recently in *De Westhoek*, projects are ongoing to increase the sand dynamics (Provoost et al. 2019). Nature restoration is mainly done by cutting down thickets[23] and forest in favour of open dune biotopes such as grasslands, moss-dunes and low dune slack vegetation. Large parts of the dunes are grazed and locally mowed as part of conservation management. This management is generally successful, but afforestation and thicket formation remain major challenges (Provoost et al. 2010, Provoost et al. 2015, Provoost et al. 2020).

1.1.4 Estuaries, mudflats and marshes

Intertidal mudflats and marshes occur in the lee parts of the coast where reduced marine dynamics allow sedimentation of fine-grained silt. Along the Belgian coast, they can be found in the Yser Estuary, the Bay of Heist, the Zwin and the tern peninsula in Zeebrugge (see also Van der Biest et al. 2017a, De Bruyn et al. 2020), covering a total area of approximately 200 ha. Real estuarine nature is only present in the river mouth of the Yser. Outside the Belgian coast, mudflats and salt marshes also occur in the Scheldt estuary, but will not be covered here (see thematic chapter **Scheldt estuary**).

Mudflats and marshes are by nature dynamic systems. A healthy and dynamic system is characterised by the interaction between sedimentation and erosion processes. The trend and speed of habitat changes determines whether the dynamics in the system are too large, too small or in balance (Maris et al. 2014, Van der Biest et al. 2017a).

The Atlantic salt marshes and salt meadows are included in three European habitat types (Decleer 2007, Vandevoorde et al. 2019):

1310 – Salicornia and other annuals colonizing mud and sand;
1320 – Spartina swards (*Spartinion maritimae*);
1330 – Atlantic salt meadows.

Estuaries are considered as a separate habitat type (1130) and may include, in addition to the water biotopes, different habitat types of the mudflats and marshes.

The Zwin used to belong to an estuary reaching Bruges (see, *inter alia*, Claeys 1981, Termote 2012, De Bruyn et al. 2020). At present, the Zwin is a cross-border nature reserve (Belgium – The Netherlands) consisting of an interrupted dune belt with tidal mudflats and marshes behind it. The North Sea enters the area through a gully, creating a system of creeks. The protection of the habitat types and species occurring in the Zwin, by means of the European Habitats Directive, is described in Bot (2007a). The tidal area is an important place to rest, forage, moult, breed and migrate for several birds, including different species which are protected by the European Birds Directive (Bot 2007b). Several of these species make use of the food availability that is present in large numbers in the benthos (Van Colen et al. 2009, Verstraete en Verbelen 2014). Due to the siltation of the Zwin, measures have been taken in the context of the Development Sketch 2010 for the Scheldt estuary (see thematic chapter **Scheldt estuary**; ScheldeMonitor), to restore the mudflats and marshes and expand the nature reserve (Verhaegen et al. 2010, Van Nieuwenhuyse et al. 2016, see also Het Zwin in verandering). The expansion of the Zwin was extensively monitored in several projects (Cosyns et al. 2015, Slabbinck et al. 2017).

[23] Thicket is a form of vegetation dominated by shrubs that are not higher than five metres.

Within the Yser estuary, only the area between the river mouth in the North Sea and the *Ganzenpoot* lock complex is still under tidal influence. On the right bank, an intertidal zone that is part of the Flemish nature reserve of the Yser estuary is present (Hoffman 2006). Thanks to a nature restoration project, the natural transitions of the various components of the coastal ecosystem (including mudflats and salt marshes) have been restored (Hoffman et al. 2006). The nature protection in the Yser estuary by the European Habitats and Birds Directives is described in more detail in Spanoghe et al. (2003). In recent decades, a strong expansion of saline vegetation has been observed, including sea couch (*Elytrigia atherica*) establishing itself among the pioneer vegetation. Grassification is kept under control by extensive grazing management (Provoost et al. 2020). The composition of the fish stock of the Yser estuary was investigated in 2015 by Breine et al. (2016). Within the framework of the construction of the storm surge barrier, the benthic community of the harbour channel of Nieuwpoort was mapped during an ecological monitoring programme (Van Hoey and Van Colen 2018).

The Bay of Heist forms a wide 'green beach' with an increasing complexity of geomorphology and associated biotope types. The area of pioneer vegetation seems to have stagnated recently. This stabilisation and succession translates into a strong increase in saltwater plant species and lower lying macroalgae. With 43 species of interest, the Bay of Heist is considered a botanical hotspot. As in the Yser estuary, grassification is the main point of attention for management (Provoost et al. 2020).

1.1.5 Polders and Polder complex

The 'Polders' is the name of the former intertidal areas, which have been almost completely withdrawn from the marine influence by land reclamation since the early Middle Ages. It is a flat and low-lying landscape with inversion relief[24] caused by the consolidation of clay layers and the subsidence of peat (Baeteman 2007, Baeteman 2013, De Bruyn et al. 2020). It is also the name of the Habitats Directive area in the coastal zone (Decision of the Flemish Government of 24 May 2002) which overlaps with the birds directive area 'Polder complex' (Decision of the Flemish Government of 17 July 2000) (see **1.4.2 Policy instruments**) (more information on the Polders in the context of Natura 2000 can be found on the website of Natura 2000 in Flanders).

- These special protection areas (SPAs) have been designated for six European protected habitat types and 2 European protected animal species within the habitats directive area 'Polders' (Paelinckx et al. 2009, Decision of the Flemish Government of 24 May 2002). The habitat types include Salicornia and other annuals colonizing mud and sand (1310), Atlantic salt meadows (1330), Hydrophilous tall herb fringe communities of plains and of the montane to alpine levels (6430), *Molinia* meadows on calcareous, peaty or clayey-silt-laden soils (6410) and alluvial forests with *Alnus glutinosa* and *Fraxinus excelsior* (91E0). The species for which the habitats directive area has been established are the pond bat (*Myotis dasycneme*) and the northern crested newt. Recently, very few observations of the latter species have been made in the Polders;
- The birds directive area 'Polder complex' was established because the following European protected species breed or used to breed in this area: Eurasian bittern (*Botaurus stellaris*), little bittern (*Ixobrychus minutus*), ruff (*Philomachus pugnax*), short-eared owl (*Asio flammea*) and bluethroat. A number of non-breeding bird species are also relevant for the area: red-throated diver, Bewick's swan (*Cygnus bewickii*), whooper swan (*Cygnus cygnus*), the lesser white-fronted goose (*Anser erythropus*), barnacle goose (*Branta leucopsis*), red-breasted goose (*Branta ruficollis*), western marsh harrier (*Circus aeruginosus*), hen harrier (*Circus cyaneus*), merlin (*Falco columbarius*), golden plover (*Pluvialis apricaria*), wood sandpiper (*Tringa glareola*) and common kingfisher (*Alcedo atthis*) (Courtens and Kuijken 2004). The 'Polder Complex' has also been established because internationally significant numbers of geese stay in this area in the winter months. The pink-footed goose (*Anser brachyrhynchus*) and the greater white-fronted goose (*Anser albifrons*) annually exceed the 1% standard (Kuijken et al. 2005, Wetlands International 2006 – Waterbird Population Estimates, Devos and T'Jollyn 2016). The most recent status of breeding birds in Flanders is described in Vermeersch et al. (2020).

The Polders are also characterised by the occurrence of valuable historical permanent grasslands (HPGs). These were mapped by De Saeger et al. (2013). On 27 November 2015, the Government of Flanders definitely approved the map of the historically permanent grasslands (HPGs) in the agricultural region of the Polders (see thematic chapter **Agriculture**).

[24] Inversion of the relief whereby the soil that was initially lower than the surrounding land rises higher than its surroundings.

1.2 Ecosystem goods and services

The Millennium Ecosystem Assessment (MEA 2005) describes ecosystem services as the benefits that humans obtain from the ecosystem. They can be divided into goods, regulatory services, cultural services and support services. The concept of ecosystem services has been elaborated to also include the economic aspects of the ecosystem (The Economics of Ecosystems and Biodiversity, TEEB). The economic value of the services, which the marine and coastal ecosystems deliver, has been estimated by Costanza et al. (2014) at 660 and 8,944 US dollar per ha per year respectively. According to a study of the World Wide Fund (WWF) (Hoegh-Guldberg et al. 2015), the overall value of the ocean 'gross marine product' amounts to 24 billion US dollars. At European level, ecosystem services underpinning the EU blue economy are listed and documented with figures in The EU Blue Economy Report 2020.

For Belgium, the Belgian Ecosystems and Society community (BEES) network aims to map ecosystem services. The ECOPLAN toolbox has been developed to asses ecosystem services on land. For Flanders, Jacobs et al. (2010) published an exploratory inventory of ecosystem services (and potential ecosystem benefits). In addition, the nature report (NARA) is biannually drafted as an ecosystem assessment for Flanders, whereby the North Sea and the coastal dunes are analysed separately (Schneiders et al. 2020). In previous editions, 16 ecosystem services were developed (Stevens 2014). A separate chapter was dedicated to coastal protection (Provoost et al. 2014). Furthermore, nature valuation studies are also available (e.g. Hutsebaut et al. 2007). The calculation tool Natuurwaardeverkenner has been developed to support the quantification and economic estimation of the ecosystem services in a Social Cost-Benefit Analysis (SCBA) or other evaluations of (infrastructure) projects with an impact on nature (more information: Liekens et al. 2018).

Scientific knowledge about the ecosystem goods and services of the BNS (and the wider North Sea) and the adjacent coastal zone has been built up in various studies:

- A preliminary overview of the types of goods and services in the BNS delivered by marine biodiversity can be found in Beaumont et al. (2007);
- Within the renewed Ecosystem Vision Flemish Coast (Van der Biest et al. 2017a), an ecosystem service analysis was made, based on the CICES v4.3 classification[25] of ecosystem services for the purpose of developing a long-term vision 2100. Van der Biest (2018) presents the scientifically based methods for assessing and managing ecosystem services. For the coastal ecosystem, it was mentioned that the most important economic value in the dunes is created by recreation, and secondly by flood protection (Van der Biest et al. 2017c). The extraction of drinking water, for example, is also an important ecosystem service, although the net extraction of natural groundwater has a significant negative impact on biodiversity. The Ecosystem Vision emphasises that, despite the current scientific knowledge on the impact of human activities on the marine environment, it is a challenge to deal with uncertainties (e.g. carbon sequestration in the marine environment) and thus to preserve coherence between human activities and a healthy ecosystem. The determination of the cumulative effects of human activities remains a major challenge (Stelzenmüller et al. 2018).
- In the framework of the Marine Strategy Framework Directive (MSFD), a first socio-economic analysis of the use of Belgian marine waters and the costs associated with the degradation of the marine environment was prepared in 2012 (Belgian State 2012b, Börger et al. 2016). An update of this socio-economic analysis in the context of the MSFD was published in 2018 (Belgian State 2018b, Volckaert and Rommens 2018). In the context of this socio-economic analysis, the potential of an ecosystem service approach was also put forward (Belgian State 2018b, Volckaert and Rommens 2018). This approach provides information on the difference in value of the ecosystem that would be provided in the situation of a Good Environmental Status (GES as defined in the MSFD) compared to normal use. The focus was put on the Flemish banks for the aggregate extraction sector (see also thematic chapter **Sand and gravel extraction**). At present, the methodology and empirical application are not yet sufficiently developed to fully apply the ecosystem approach within the current reporting cycle of the MSFD;
- Although the socio-economic value of ecosystems is becoming increasingly important, it is not considered in spatial planning. Van der Biest et al. (2020) therefore wrote a method, based on two principles, that promotes the integration of ecosystem services and biodiversity in the spatial planning process. Firstly, the diversity of biotic and abiotic ecosystem processes must be considered. Secondly, these processes should be linked to biodiversity and socio-economic benefits to identify the interface between conflicting objectives;
- OSPAR is also taking action to establish an assessment framework for evaluating the economic and social value of the OSPAR maritime area (OSPAR IA 2017);

[25] A new version is now available: CICES v5.1.

- The MAES report (2018) (Mapping and Assessment of Ecosystems and their Services) proposed a list of policy-relevant key indicators to assess the pressure on marine ecosystem services and the state of the marine ecosystem;
- Within the SUMES project (2020-2023), in the framework of the Blue Cluster, a comprehensive model is being developed that assesses the capacity of the marine ecosystem to deliver certain goods and services. The project aims to use this model to identify the local, regional and global effects of (socio)-economic activities at sea and to gain more insight into cause-effect chains.

In addition, in recent decades, there has been a strong commitment to the sustainable use of the marine ecosystem within the framework of the blue economy and marine biotechnology. A broader perspective on the developments in the BNS is given in the thematic chapter **Blue Economy and Innovation**.

1.3 Impact on the marine and coastal environment

The marine and coastal environment described above host a region where various human activities take place, each of which has a specific impact on this environment (see thematic chapter **Integrated maritime policy**: figure 6). Several reports provide an overview of the human activities and the associated impact is provided: Maes et al. (2004) (MARE-DASM project BELSPO), Maes et al. (2005) (GAUFRE project BELSPO), Goffin et al. (2007), André et al. (2010), Belgian State (2012a), Belgian State (2018a), Kint et al. (2018), the third federal environmental report (2019a and 2019b), as well as European Environment Agency (2015) and OSPAR IA 2017 on a higher geographical scale. In addition, numerous studies exist on the (direct and indirect) impact of a specific user function. These publications are discussed in the thematic chapters of the different user functions under the section 'Impact'. In table 1, a list of the various thematic chapters of the **Knowledge Guide Coast and Sea 2022** (Dauwe et al. 2022) is given, in more information on a specific type of impact can be found. This table does not provide an exhaustive overview of the impacts on the marine and coastal environment, but serves as a readers' guide.

Table 1. Referral table with an overview of the type of impacts dealt with in the specific thematic chapters of the **Knowledge Guide Coast and Sea 2022** (Dauwe et al. 2022).

Impact	Thematic chapters
Impact on air quality	Maritime transport, shipping and ports; Tourism and recreation; Fisheries; Agriculture; Sand and gravel extraction; Safety against flooding; Energy (including cables and pipes).
Impact on the pelagic ecosystem (eutrophication, pollution, etc.)	Energy (including cables and pipes); Agriculture; Tourism and recreation; Aquaculture; Maritime transport, shipping and ports; Military use; Dredging and dumping; Fisheries; Sand and gravel extraction; Blue Economy and Innovation.
Impact on fish stocks	Fisheries; Marine aquaculture; Tourism and recreation; Energy (including cables and pipes).
Impact on seabirds and marine mammals	Energy (including cables and pipes); Maritime transport, shipping and ports; Fisheries; Aquaculture; Military use.
Impact on the seabed/ habitats	Sand and gravel extraction; Dredging and dumping; Energy (including cables and pipes); Military use; Safety against flooding; Fisheries; Marine aquaculture; Agriculture; Blue economy and innovation.
Impact on hydrographic properties	Energy (including cables and pipes); Maritime transport, shipping and ports; Military use; Safety against flooding; Marine aquaculture; Dredging and dumping; Sand and gravel extraction.
Impact on land use (including impact on nature area)	Social and economic environment; Tourism and recreation; Energy (including cables and pipes); Fisheries; Marine aquaculture; Agriculture; Safety against flooding; Sand and gravel extraction; Maritime transport, shipping and ports; Maritime and coastal heritage; Blue Economy and Innovation.
Impact on beach and dunes	Tourism and recreation; Safety against flooding; Marine aquaculture.
Impact on groundwater	Agriculture; Safety against flooding.

1.3.1 Litter

Given that the problem of marine litter is not specifically linked to one particular user function, its impact is described separately. Litter is caused by multiple activities and/or sectors, and also has a potential negative impact on multiple user functions. In Flanders, research on the presence and effects of litter and microplastics on the beach and in the sea has been carried out for twenty years (Devriese and Janssen 2021). In order to protect the marine environment, marine litter has been included in the OSPAR objectives and in the MSFD environmental targets (descriptor 10) (see further **1.4 Protection of the marine and coastal environment**). In this context, experts from the EU member states have collaborated to determine a threshold of 20 pieces of waste per 100 m of tide line (van Loon et al. 2020). The revision of the initial assessment for the Belgian marine waters (Belgian State 2018a) showed that on average, 136 objects of litter per 100 m of coastline was found at the Flemish beaches (of which about 80% are plastic), and an average of 126 objects per km² are observed on the seabed (of which about 90% are plastic). Furthermore, the OSPAR intermediate assessment confirmed that plastic is the most common material on the seabed and the beach (OSPAR IA 2017, ICES 2020). These pieces of plastic can further fragment into very small pieces of plastic, called micro- or nanoplastics. Not only large plastic objects, but also the microscopic plastic particles cause various forms of negative impact: socially, economically and ecologically (see overview Devriese and Janssen 2021). Both fundamental and applied scientific research, as well as in the context of (government) policy, there are clear needs to further study and tackle the problem of litter and microplastics in Flemish aquatic environments (Devriese and Janssen 2021). Action against (marine) litter is currently being taken at several (policy) levels (Devriese and Janssen 2020 (Annex 1)), including Belgium and Flanders (Devriese and Janssen 2021). The policy statement of the minister for the North Sea mentions the need for coordinated actions at different areas and levels to tackle the flow of waste into the sea (Van Quickenborne 2020). Both the Flemish (OVAM 2017) and federal (De Backer 2017) action plan focus on measures to reduce marine litter (incl. prevention). Part of the measures from the Flemish action plan will be further implemented within the Flemish Implementation plans for Plastics. In addition, the Coalition Agreement of the Flemish Government (2019-2024) also tackles the litter problem. Given the social importance of this problem, not only the Flemish researchers are committed, but there is also a growing awareness among players in the Blue Economy of the need to invest in innovative solutions for marine litter and microplastics (e.g. through the Blue Cluster) (Devriese and Janssen 2021). The PLUXIN project, for example, cooperates with actors from research institutes, industry, citizens and policy to compile innovative solutions to reduce plastic litter in Flanders.

1.4 Protection of the marine and coastal environment

1.4.1 Policy context: administrations and organisations

The environmental policy concerning the coast and sea is to a large extent steered by several international, European and regional organisations (see also thematic chapter **Integrated maritime policy**). In 2015, the Sustainable Development Agenda 2030 (United Nations - UN) was adopted, including 17 Sustainable Development Goals (SDG). SDG 14 addresses the conservation and sustainable use of the seas, oceans and marine resources and focuses on the threats such as climate change, overfishing and pollution. In order to support countries in achieving SDG 14, the United Nations Decade of Ocean Science for Sustainable Development (2021-2030) was announced. Under the umbrella of the UN, several (sectoral) organisations are involved in marine environmental and nature policy. The International Maritime Organisation (IMO) of the UN, is a specialised agency responsible for the safety and security of shipping and the prevention of marine pollution caused by ships (see also thematic chapter **Maritime transport, shipping and ports**). The United Nations Environment Programme (UNEP) aims to coordinate the development of environmental policy at global and regional level by bringing the environment to the attention of governments and the international community, while identifying new points of interest. Furthermore, through the Convention on Biological Diversity (CBD), the UN ensures the conservation of coastal and marine areas with considerable importance for biodiversity and ecosystem services, so called ecologically or biologically significant marine areas (EBSA).

At European level, the Directorate-General for the Environment (DG ENV) of the European Commission (EC) aims to protect, maintain and reinforce the European environment. Important European directives for this purpose are the Habitats and Birds Directives, which are relevant for both the marine and terrestrial environment. The European MSFD is an important umbrella instrument for the protection of the marine environment. The Directorate-General for Maritime Affairs and Fisheries (DG MARE) of the EC operates on multiple policy areas: the Common Fisheries Policy (CFP, see thematic chapter **Fisheries**), the Integrated Maritime Policy (IMP) and a sustainable blue economy (COM (2021) 240). The IMP aims to provide an integrated answer to the current challenges related to European seas: marine pollution, environmental protection, coastal development, job creation, etc. The European Environment Agency (EMA-EEA) of the European Union provides reliable and objective information on the environment to anyone involved or interested in environmental policy. In the OSPAR Commission, national governments from Western Europe (including Belgium) and the EU collaborate to protect the marine environment of the North-East Atlantic Ocean.

In Belgium, the Marine Environment division of the FPS Health, Food Chain Safety and Environment is competent for the environmental policy in the BNS. The division also chairs the advisory commission for marine spatial planning (MSP) in the Belgian maritime regions (RD of 13 November 2012). The scientific and technical support for the marine environmental policy is provided by the Management Unit of the North Sea Mathematical Model of the Royal Belgian Institute of Natural Sciences (RBINS-MUMM). The objectives of the the policy statement of the Deputy Prime Minister and minister for Justice and the North Sea include more focus on Blue Energy, Blue Economy, Blue Shipping, more Blue at Sea and the protection of Blue Nature (Van Quickenborne 2020).

The North Sea is also discussed as an element in the solution to climate change and the North Sea vision 2050. The North Sea Vision 2050 which was later renamed the Think Tank North Sea, set up two thematic focus groups in 2019-2020: Working with nature and Living with climate change. Together with stakeholders, a working group report was developed for each theme. In a new working group (2021-2022), the think tank will establish a vision on Environmentally sustainable blue growth.

The policy on nature and the environment with regard to the coast (landward of the baseline) is a competence of the Government of Flanders (Policy Memorandum on the environment 2019-2024). The Department of Environment and Spatial Development (OMG) is the environmental administration of the Government of Flanders and is responsible for the preparation, follow-up and evaluation of the Flemish environmental policy. OMG is also responsible for operational matters such as environmental enforcement, environmental permits and approvals, environmental impact and safety reports, nature and environmental education, and nature conservation and development. In addition to OMG, the following relevant entities are included in the policy area Environment: the Agency for Nature and Forests (ANB), the Research Institute for Nature and Forest (INBO), the Flemish Energy and Climate Agency (VEKA), the Public Waste Agency of Flanders (OVAM), the Flemish Environment Agency (VMM), the Flemish Land Agency (VLM) and the territorial development programme Kustzone (T.OP Kustzone) of OMG and the Province of West Flanders.

The Province of West Flanders acts an intermediary between the federal Government, the regions and the municipalities, and has competences with regard to the environment, as it is responsible for granting permits, spatial policy, parts of water management, the management of provincial domains and green corridors, and nature and environmental education.

The municipal environmental services are competent for the treatment of complaints concerning the environment and nature, local nature preservation, monitoring and advice on environmental permits, waste management, environmental policy planning, development of a sustainable policy and raising awareness on the themes of nature, environment and sustainability towards the citizens and other target groups.

1.4.2 Policy instruments

The intense activities at sea and in the coastal zone have led to an elaborate package of legislation and regulation with the aim of mitigating, reducing or avoiding the impact of certain user functions on the environment (see Verleye et al. 2018, Legislative module Compendium website). This legislation and regulation is mostly sector-specific (e.g. MARPOL Convention) and is further discussed in the thematic chapters of the relevant user functions in the sections ‘Policy Context’ and ‘Sustainable Use’. Hence, the most relevant nature and environment-related policy instruments for the BNS and the coastal zone are elaborated below (see also thematic chapter **Integrated maritime policy** for more information).

1.4.2.1 United Nations Convention on the law of the sea (1982)

The United Nations Convention on the law of the sea (UNCLOS 1982) can be considered as the first intergovernmental convention that creates an integrated legal framework for the use of the ocean. Notwithstanding the broad scope of this convention, part XII of UNCLOS (Protection and Preservation of the Marine Environment) specifically addresses the protection and preservation of the marine environment. The Intergovernmental Conference developed an international legally binding instrument (ILBI) under the UNCLOS on the conservation and sustainable use of Marine Biological Diversity of Areas Beyond National Jurisdiction (BBNJ). This was established under the UN General Assembly (UNGA) in 2017 (UN Resolution A/RES/72/249).

1.4.2.2 Convention on biological diversity (1992)

The Convention on biological diversity (CBD) was established at the UN Convention on Environment and Development (UNCED, 3-14 June 1992, Rio de Janeiro) and covers ecosystems, species and genetic resources. The convention has three main objectives: (1) the conservation of biological diversity, (2) its sustainable use and

(3) the fair and equitable sharing of benefits arising from of the utilisation of genetic resources. The national biodiversity strategies and action plans (Biodiversity 2020, Update of the Belgian national strategy 2013) provide a principal instrument for the conservation and sustainable use of biological diversity with contracting parties cooperating where there are bilateral interests or where there is no national jurisdiction over the matter.

1.4.2.3 RAMSAR Convention (1971)

The Ramsar Convention (Ramsar, Iran, 1971) is an intergovernmental treaty aimed at the global protection and sustainable management of wetlands with special attention to the conservation of habitats of water birds (Goffin et al. 2007). The convention attempts to achieve the protection and rational and sustainable use of wetlands of international importance (including marine waters where the depth of water at low tide is less than 6 metres) by means of local and national measures and international cooperation.

1.4.2.4 OSPAR Convention (1992)

The OSPAR Convention (1992) constitutes an overarching framework for the protection of the marine environment of the North-East Atlantic Ocean (including the North Sea) with a cooperation of 15 national governments and the EU (= the 16 contracting parties). The OSPAR Convention replaces the Convention of Oslo (1972) and the Convention of Paris (1974). The convention contains general regulations on the protection of the marine environment from specific sources of pollution, such as pollution from land, by disposal or combustion and by offshore activities. Furthermore, agreements on the evaluation of the quality of the marine environment (OSPAR QSR 2010, OSPAR IA 2017) and the protection and preservation of the ecosystems and biological diversity are part of the OSPAR Convention (Goffin et al. 2007).

Overall, the work of the OSPAR Commission is guided by the ecosystem approach towards an integrated management of human activities in the marine environment. This is supported by an obligation of contracting parties to apply the precautionary and polluter pays principle (see thematic chapter **Integrated maritime policy**), and the use of best available techniques (BAT) and best environmental practice (BEP), including clean technology. The implementation of the ecosystem approach is established in the OSPAR's North-East Atlantic Environment Strategy (NEAE Strategy). This NEAE Strategy was drawn up in 2010 based on the holistic approach in the OSPAR QSR 2010 and was revised (NEAES 2030) in 2021 with focus on the offshore industry (OSPAR 2021). The strategy focuses on three challenges that address the main threats for the ocean (biodiversity loss, pollution, including marine litter, and climate change). The OSPAR intermediate assessment (OSPAR IA 2017) updates the OSPAR QSR 2010 and can be integrated into national obligations for the assessment of marine waters in the context of the European MSFD (see below). The OSPAR Secretariat also acts as a secretariat for the Bonn Agreement (1969). This is the mechanism by which the North Sea States and the European Union (the contracting parties) collaborate in combating pollution in the North Sea Area from maritime disasters and chronic pollution from ships and offshore installations, as well as to carry out surveillance as an aid to detect and combat pollution at sea (Lagring et al. 2012, Schallier and Van Roy 2016).

1.4.2.5 Habitats Directive (1992) and Birds Directive (2009)

The European **Habitats Directive** (Directive 92/43/EEC) aims to maintain and restore the European natural habitats and wild fauna and flora. The member states need to designate special protection areas (SPA-H or habitats directive areas) for certain habitats and species of European importance which are listed in the Annexes I and II of the directive. Of the entire 3,190 ha of undeveloped dunes along the Belgian coast, 94% has been included within SPA-H. All intertidal mudflats and marshes (in total approx. 200 ha) are also designated as SPA-H. The Habitats Directive also applies to the BNS where two areas have been designated as SPA-H. The Flemish Banks (111,198 ha), bordering France, consists mainly of permanently flooded shallow sandbanks in which biogenic and geogenic reefs also occur. Near the border with the Netherlands, the *Vlakte Van De Raan* (6,492 ha) is designated as a SPA-H, which also consists of permanently flooded shallow sandbanks containing biogenic reefs.

The aim is to achieve a favourable conservation status (FCS) for the habitats listed in annex I and for the species listed in Annex II and IV to this directive. Conservation objectives (COs) determine the scientific standards against which the FCS must be assessed (see also Bot 2007 and Oosterlynck et al. 2020 (local conservation status)). For the marine protected areas, too, COs were determined in the context of the Birds and Habitats Directives (see also: Degraer et al. 2010). This study, together with the objectives of the MSFD, formed the basis of the MD of 2 February 2017 on the adoption of conservation objectives for marine protected areas. These conservation objectives are currently (2021) being re-evaluated.

According to the Habitats Directive (art. 17), the member states are obliged to report every six years to the EC about the conservation status of the habitat types and species as well as about the results of the policy pursued. For the landward side, the conservation status of the species and habitats of European importance was reported by Paelinckx et al. (2019). On the sea side, reporting to the EC was based on the evaluation of the FCS in Degraer et al. (2009) and the update of the initial assessment in the context of the MSFD (Belgian State 2018a).

The European **Birds Directive** (Directive 2009/147/EC) aims to protect all species of wild birds. Special protection measures have been taken for the habitats of the bird species listed in Annex I and all species occurring in internationally significant numbers as breeding, migratory or winter birds. Each member state is required to designate special protection areas (SPAs or birds directive areas). These birds directive areas, together with the habitats directive areas, are part of the European ecological Natura 2000 network. According to the Birds Directive (art. 12), the member states are obliged to report every six years about the conservation status of the species and on the outcome of the policy pursued to the EC. The MD of 2 February 2017 contains the conservation objectives (COs) that were adopted for the BNS in the context of the Birds and Habitats Directives. The most recent report under the Birds Directive covers the period 2013-2018 (see Vermeersch et al. 2019). In Paelinckx et al. (2009) and Degraer et al. (2010) the current conservation of the bird species of the Birds Directive at the level of Flanders and the North Sea (see also DG Leefmilieu 2010) has already been determined, in order to underpin the COs (Belgian State 2018d).

The implementation of the Habitats and Birds Directives in the federal legislation has been provided by several decrees under the Law of 20 January 1999: e.g. the RD of 21 December 2001, the RD of 27 October 2016 and the RD of 22 May 2019. The Decision of the Flemish Government of 23 March 2014 resulted in the definitive designation of the SPA on the (landward side of the) coast (Achterhaven Zeebrugge-Heist, Dune areas and Polders) and the associated COs (see additional information and approved COs at www.natura2000.vlaanderen.be). An overview of the European nature state, based on the reports of the member states in function of the nature directives (Habitats and Birds Directive) is given in European Environment Agency (2020).

1.4.2.6 Programmatic Approach to Nitrogen (PAN) (2014)

The atmospheric deposition of nitrogen from agriculture, traffic, industry and households is in certain cases a bottleneck for the realisation of the nature objectives set within the framework of the Habitats and Birds Directives (see also thematic chapter **Agriculture**). The Programmatic Approach to Nitrogen (PAN) was created to address this problem through both source- and effect-oriented measures (so-called recovery management). In the framework of the PAN, an area analysis was carry out in 2018 for the dune area (incl. Yser estuary and the Zwin) (Provoost et al. 2018) and polders (Vriens et al. 2018), which proposes specific recovery measures for each habitat type.

1.4.2.7 Water Framework Directive (2000)

The European Water Framework Directive (WFD, Directive 2000/60/EC) stipulates that all European 'natural' surface waters must have at least a good ecological status (GES) and a good chemical status (GCS) by 2015. For 'heavily modified' or 'artificial' surface waters/water bodies[26], the ecological objectives have been adjusted, and a good ecological potential (GEP) is mentioned. The deadline (2015) for achieving these objectives may be conditionally extended up to a maximum of two updates of the river basin management plan (2021/2027). For the purposes of the GES, the WFD extends to 1 nautical mile on the seaward side of the baseline and for the objectives of the GCS up to 12 nautical miles on the seaward side of the baseline.

In order to achieve the objectives of the WFD, member states are required to develop river basin management plans every six years. The first plans were drafted in 2009. In the Decree of 18 December 2015, the Government of Flanders adopted the second version of the river basin management plans for the rivers Scheldt and Meuse for the period 2016-2021, including the programme of measures for the river basin management plans (website Coordination Committee on Integrated Water policy, Programme of measures for the river basin management plans for Scheldt and Maas 2016-2021). All the surface waters of the coastal zone of Flanders belong to the international river basin district of the Scheldt: in accordance with the competences of the Flemish and federal authorities, the river basin management plans have been divided into a river basin management plan for the Scheldt (River basin management plan for the Scheldt 2016-2021) and a river basin management plan for the

[26] Artificial water bodies have been created by humans in places where no natural water was present. A heavily modified water body is a natural water body that has been severely modified by human activity.

Belgian coastal waters (River basin management plan for the Belgian coastal waters 2016-2021). The coordination between the managing authorities of the river basin district (the Netherlands, France, the three regions and the federal Government of Belgium) takes place via the International Scheldt Commission (ISC) and on the Belgian level via the Coordination Committee International Environment Policy (CCIEP). In September 2020, the public consultation of the third version of the Flemish river basin management plans for the period 2022-2027 was started. At the end of 2021, these plans were reviewed by the Flemish Government. The proposed plans contain measures and actions to improve groundwater and surface water and to protect against flooding and drought.

The WFD is supplemented by the Subsidiary Directive on Groundwater (Directive 2006/118/EC) (on the protection of groundwater against pollution and deterioration) and the Subsidiary Directive on Priority Substances (Directive 2008/105/EC) (on environmental quality standards in the field of water policy for surface water for a number of hazardous substances). Furthermore, the WFD is closely related to a number of other directives that are further discussed in the various thematic chapters. These include the Urban Waste Water Directive (Directive 91/271/EC), the Nitrates Directive (Directive 91/676/EC) (see thematic chapter **Agriculture**), the Bathing Water Directive (Directive 2006/7/EC) (see thematic chapter **Tourism and recreation**) and the Floods Directive (Directive 2007/60/EC) (see thematic chapter **Safety against flooding**).

The WFD is implemented by the RD of 23 June 2010 on the surface water status on a federal level and by the Decree Integral Water Policy (Decree of 18 July 2003), coordinated on 15 June 2018 (Water Code) on a Flemish level. The Flemish government is also making efforts to tackle water scarcity and droughts through the implementation of the Blue Deal.

1.4.2.8 Marine Strategy Framework Directive (2008)

The European Marine Strategy Framework Directive (MSFD, 2008/56/EC) is the environmental pillar of the European Union's Integrated Maritime Policy (IMP) (COM (2007) 575). The aim of the MSFD is to achieve a good environmental status (GES) of European marine waters by 2020 and to protect the resources on which economic and social activities depend. The GES is defined in Article 9 of this Directive on the basis of 11 descriptors (table 2) for which member states are required to develop indicators with associated environmental targets (DG Leefmilieu 2012, OD Nature). The European Union shall support member states in developing the methodology of the indicators through a technical report, scientific opinions by descriptor (table 2) and Decision (2017/848/EU) establishing criteria and methodological standards on GES of marine waters and specifications and standardised methods for monitoring and assessment. An overview of relevant legislation, guidelines, technical and scientific reports can be found on the website of the Directorate-General for Environment of the EC. Subsequent to the adoption of the MSFD, OSPAR assumed a key role in harmonising the environmental objectives and the programmes of measures drawn up and implemented by the EU Contracting Parties in the North Sea and the North-East Atlantic.

Table 2. An overview of the 11 descriptors and associated technical reports included in the MSFD.

Descriptors MSFD		
1	Biological diversity	Cochrane et al. (2010); 2017/848/EU
2	Non-indigenous species	Olenin et al. (2010); 2017/848/EU
3	Commercially exploited species of fish, crustaceans and molluscs	Piet et al. (2010); 2017/848/EU
4	Marine food webs	Rogers et al. (2010); 2017/848/EU
5	Eutrophication	Ferreira et al. (2010); 2017/848/EU
6	Seafloor integrity	Rice et al. (2010); 2017/848/EU
7	Hydrographical conditions	2017/848/EU
8	Contaminants	Law et al. (2010); 2017/848/EU
9	Contaminants in fish and other seafood	Swartenbroux et al. (2010); 2017/848/EU
10	Marine litter	Galgani et al. (2010); 2017/848/EU
11	Energy, including underwater noise	Tasker et al. (2010); 2017/848/EU

Following the implementation of the MSFD (RD of 23 June 2010 - marine strategy) and first six-yearly review, Belgium has prepared an update of the initial assessment of the state of the marine environment (Belgian State 2018a) for the BNS, including an actualisation of the socio-economic analysis of the users of the BNS (Belgian State 2018b) (OD Nature). Furthermore, the description of the good environmental status and determination of the environmental targets (Belgian State 2018c) was also updated. On this basis, an update of the monitoring programme (Belgian State 2020) was drawn up by MUMM to measure the evolution of the state of the environment's health. Subsequently, based on the analysis of the monitoring results during the first cycle, a programme of measures was developed by the Marine Environment division (Belgian State 2016), describing additional measures necessary to achieve a good environmental status. A new programme of measures is expected in 2022. In the meantime, studies are being carried out in this context to restore and strengthen the gravel beds and the (lost) oyster beds. Every six years (2024, 2030, etc.), the evaluation must be reviewed and, if necessary, revised in the light of the results obtained on the basis of the monitoring programme and the programme of measures (DG Leefmilieu 2012).

1.4.2.9 Law on the marine environment (1999) and marine spatial planning

The federal Law on the marine environment and marine spatial planning (MMM Law of 20 January 1999) aims to maintain the nature, biodiversity and integrity of the marine environment through protective measures (including the establishment of marine protected areas) and through measures to repair damage and environmental disturbance. In addition to a ban on a number of activities, this law introduces objective liability for damage and environmental disturbance (Goffin et al. 2007). The MMM Law also lists the activities that are subject to a prior licence or authorisation granted by the minister. Furthermore, the law links this licence or authorisation for existing and new activities at sea to a preceding environmental impact assessment (EIA). Since 20 July 2012, the law also regulates the organisation and procedure of marine spatial planning (MSP). Currently, the MSP is in a second cycle and valid from 2020 till 2026 (RD of 22 May 2019, see also Verhalle and Van de Velde 2020, Marine Atlas, Coastal Portal). The policy statement of the Deputy Prime Minister and minister for Justice and the North Sea announced the revision of the MMM Law followed by an evaluation of the procedures leading to the revision of the MSP (Van Quickenborne 2020).

1.4.2.10 Decree of the dunes - Flemish Ecological Network - Spatial Implementation Plans

Besides the aforementioned Ramsar Convention and the Habitats and Birds Directives, other policy instruments for the protection of nature areas in the coastal zone are of importance. At the Flemish level, the Decree of 21 October 1997 on nature conservation and the natural environment steers the overall objectives of the nature policy and the elaboration of policy instruments with regard to species as well as certain areas. The spatial basis for these instruments is constituted by the regional spatial plans of the seventies. In the context of the Dunes Decree (Decree of 14 July 1993 and following), additional areas have been protected, either as 'protected dune area' for the hard destinations or as 'agricultural area important for the dune area' for the agricultural land (Provoost 1999).

The Flemish Ecological Network (VEN) comprises valuable nature in Flanders, supplemented by areas with high potential as nature centres or as nature links. In these areas, nature is additionally protected and users and owners are given additional resources and opportunities to enable a nature- and people-friendly environment.

Finally, space for nature development is provided by spatial planning through the demarcation of the natural structures in the spatial structure plans (Spatial Structure Plan for Flanders, Provincial Spatial Structure Plan for West Flanders), subsequently implemented as spatial implementation plans (SIPs).

1.4.2.11 Long term vision of the Scheldt estuary (2001)

The policy and management of the Scheldt estuary is a cross-border matter in which both Flanders and the Netherlands are involved. For the policy context, including cross-border treaties and memorandums for the Scheldt estuary, we refer to the thematic chapter **Scheldt estuary** (and the website VNSC). Within the framework of the Long-Term Vision of the Scheldt estuary (LTV, Directie Zeeland and AWZ 2001), the Agenda voor de Toekomst of the Flemish-Dutch Scheldt Commission was established. The working group Research and Monitoring coordinates a long-term monitoring and research programme (MONEOS, Meire and Maris 2008) to support the policy and management of the Scheldt estuary. This includes the six-yearly evaluation of the estuary (evaluation method: Holzhauer et al. 2011, Maris et al. 2014, Barneveld et al. 2018). Within this evaluation method, each indicator is individually supported according to a pyramid structure in which the relevant test parameters, calculation parameters and explanatory variables are included (see also: Indicators for sustainable management in Goffin et al. 2015). The evaluation method a dynamic document that is reviewed after each evaluation report. The first evaluation report (T2009 report: Depreiter et al. 2014) serves as a reference for the subsequent evaluations, with T2015 evaluating data on the Scheldt estuary from 2010 to 2015 (Barneveld et al. 2018). A new update (T2021) of the evaluation methodology is expected by mid-2022. This update will focus on increasing the coherence between the various pyramids for 'nature', a broader interpretation based on narratives on ecology and the relevant human activities in the Scheldt estuary.

1.4.3 Protected areas

Belgium has several statutes for the protection of nature areas in the coastal and marine region: Wetlands or Ramsar areas, Natura 2000 areas, Flemish and recognised nature reserves, areas of the Dunes Decree, protected landscapes and the Flemish Ecological Network (VEN) (see **1.4.2 Policy instruments**). The working areas of two or more of the mentioned regulations often overlap. In total, more than 1,200 km² or about 37% of the BNS has been designated as a marine protected area (table 3, figure 3).

Table 3. An overview of the marine protected areas in the BNS, their surface, status and legal anchoring.

Protected area	Surface area	Status	Legislation
Special Protection Area SPA-1 (Birds Directive)	110.01 km²	Conservation objectives (COs) adopted Management plan drawn up and adopted on 19 January 2018	RD of 14 October 2005 - special protection zones and special zones for nature conservation RD of 27 October 2016 MD of 2 February 2017
Special Protection Area SPA-2 (Birds Directive)	144.80 km²	COs adopted Management plan drawn up and adopted on 19 January 2018	RD of 14 October 2005 - special protection zones and special zones for nature conservation RD of 27 October 2016 RD of 2 February 2017 RD of 22 May 2019 - nature conservation areas
Special Protection Area SPA-3 (Birds Directive)	57.71 km²	COs adopted Management plan drawn up and adopted on 19 January 2018	
Special Protection Area *Vlakte van de Raan* (Habitats Directive)	64.92 km²	Included in the MSP for the period 2020-2026	RD of 14 October 2005 - special protection areas and special zones for nature conservation RD of 22 May 2019 - nature conservation areas
Special Protection Area 'Flemish Banks' (Habitats Directive)	1,099.94 km²	COs adopted Management plan drawn up and adopted on 19 January 2018	RD of 14 October 2005 - special protection zones and special zones for nature conservation RD of 16 October 2012 amending the RD of 14 October 2005 RD of 27 October 2016 MD of 2 February 2017
Ramsar site Western Coastal Banks	19 km² (list Ramsar-areas)		

Natura 2000 comprises a European network of sites designated by the member states of the European Union as Special Protection Areas (SPAs) for the implementation of the Birds and Habitats Directives (see **1.4.2 Policy instruments**). The target date for achieving all nature objectives is 2050, for which six-yearly cycles are used. The Natura 2000 programme describes the actions within a single cycle and is included in the Nature Decree of 21 October 1997 (Pecceu et al. 2016, Belgian State 2018d).

On 27 October 2016, a new RD was adopted on the procedures for the designation and management of marine protected areas in the BNS (see **1.4.2 Policy instruments**, the Habitats and Birds Directives). As mentioned above, the MD of 2 February 2017 sets the conservation objectives of the marine protected areas. For activities that are likely to have a significant impact on marine protected areas, the impact should be determined through an appropriate assessment, and activities will only be allowed where there is no risk of negative impacts on marine protected areas. Activities that may have negative consequences may be authorised when there is a compelling motive of great public interest, but only when there are no alternatives available and if compensation is provided.

In the marine spatial plan (MSP) (RD of 22 May 2019, see also Verhalle and Van de Velde 2020, Marine Atlas, Coastal Portal) a new habitats directive area, *Vlakte of the Raan*, located on the Dutch border, was included (table 3, figure 3). The MSP aims to better align the activities in the BNS with the protection of the environment. For example, a number of subareas within the nature area of the Flemish Banks are delimited to improve soil integrity. Within these areas, zones can be defined in which certain restrictions for fisheries can be established. Currently, a study is being conducted to identify the most valuable areas for the introduction of fishery restricting measures (Visnat2 project). The current MSP is valid for a period of six years (2020-2026).

Furthermore, Belgium tries to contribute to the protection of the ocean at an international level. At the UN Climate Summit (COP26) in Glasgow (2021), Belgium, together with 12 other countries, launched the Blue Leaders Call for the Ocean. This declaration calls on heads of state worldwide to take action and commit to a new international goal of protecting at least 30% of the oceans by 2030 ("30x30").

Approximately 22% of the surface of the coastal communities has been assigned some kind of protection with regard to nature conservation (figures 4, 5 and 6). This share is higher compared to the hinterland (+/- 16%) and Flanders (+/- 14%) (Dauwe et al. 2019, Vriens et al. 2019). The maps and the surface area of the Natura 2000 sites in the coastal zone can be consulted on the website of Natura 2000 in Flanders and the Coastal Portal.

The remaining ecologically valuable dune areas, with a total surface area of approximately 2,830 ha, are almost entirely protected (Dauwe et al. 2019). Only 5% of these domains do not belong to nature areas of the regional spatial plan or are not protected by 'higher' protection statutes (protected dune area, nature protocol for military domains or nature reserves). It mainly concerns inner-dune areas and areas at the edge of the dunes, e.g. at Cabour (old dunes of Adinkerke), Sandeshoved (the 'dune tongue' of Nieuwpoort) and Oude Hazegraspolder in Knokke. However, these areas have been marked as special protection areas and belong to the 'agricultural areas important for the dune area' of the Dunes Decree (chapter 9 of the Law of 12 July 1973) (Dumortier et al. 2003). In 2013, the Provincial Spatial Implementation Plan (PSIP) 'Strand en Dijk' was approved. It indicates a division of the different beach zones, which allows a better licensing policy to be implemented and vulnerable zones to be better protected. These statutes only provide spatial protection, but do not guarantee that the natural values present will be safeguarded. This usually requires active nature management (Maelfait et al. 2012). The Nature Decree (Decree of 21 October 1997) provides an appropriate legal framework for this purpose, providing for the designation of nature reserves and the drafting of management plans.

According to De Saeger et al. (2013), there are approximately 12,000 ha of historical permanent grasslands (HPGs) in the coastal polders. The Nature Decree stipulates a prohibition or authorisation with regard to alterations of the vegetation and specific physical properties of these grasslands. In 2015, the Government of Flanders decided to protect 8,000 ha of grasslands of which a part being protected by nature legislation and the other by European agricultural policy (see thematic chapter **Agriculture**).

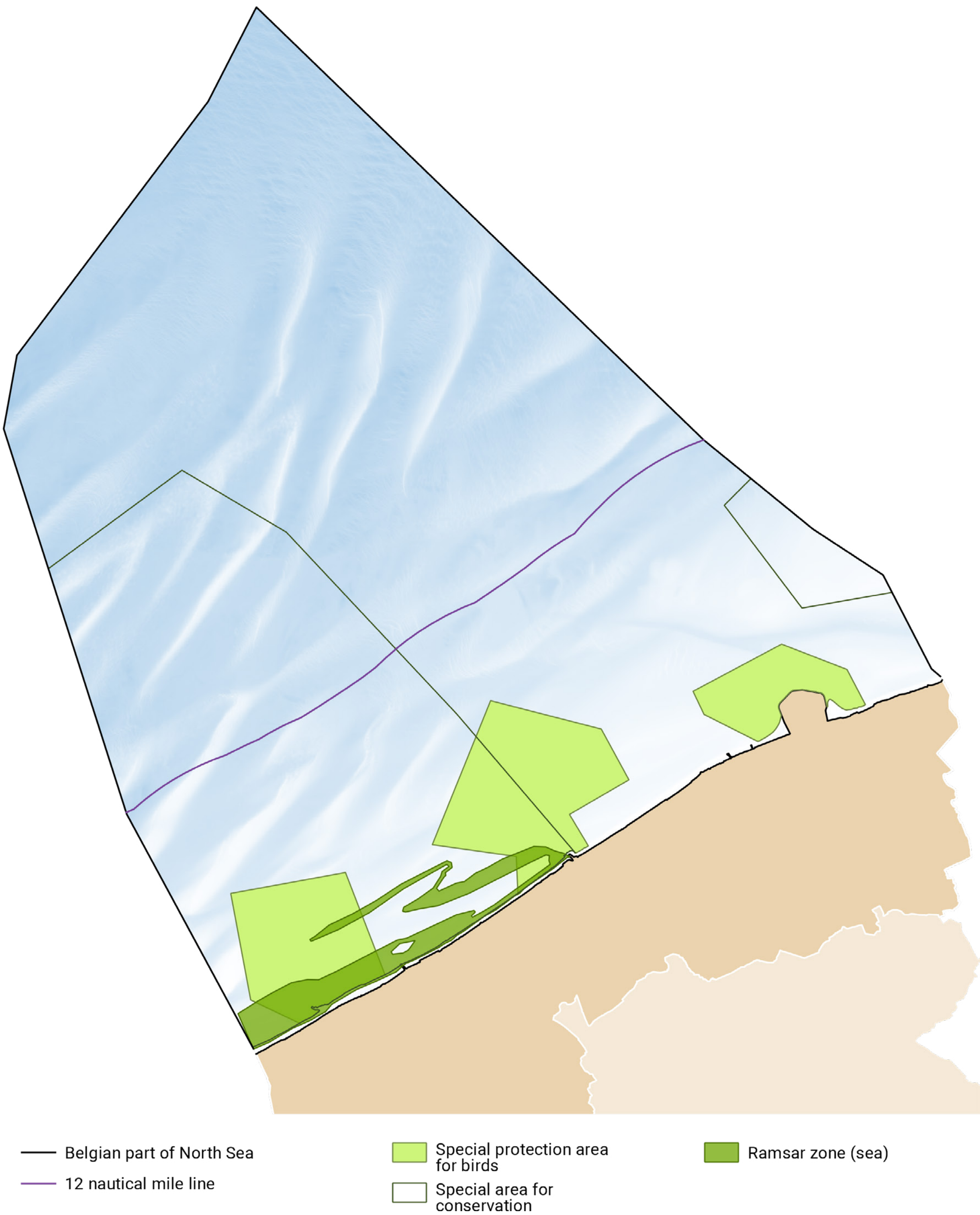

Figure 3. Demarcation of the protected areas in the BNS (Source: RBINS, MarineAtlas.be (based on RD 22 May 2019 (MSP 2020-2026)), Coastal Portal).

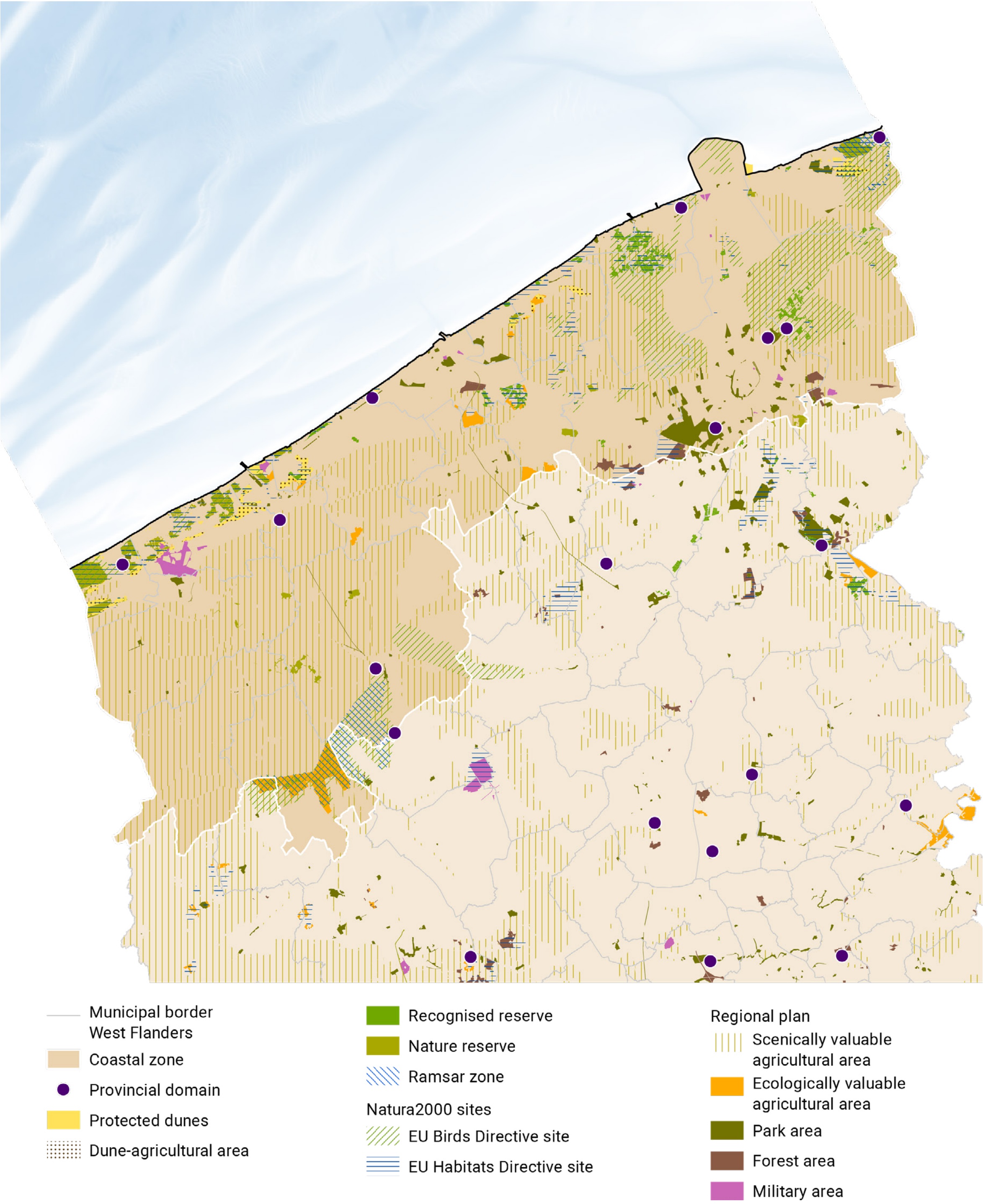

Figure 4. Protected areas and nature area in the coastal zone (Source: Province of West Flanders, Agency for Nature and Forest, Natura 2000, Flemish Department of Environment and Spatial Development – Section Vlaams Planbureau voor Omgeving, Coastal Portal).

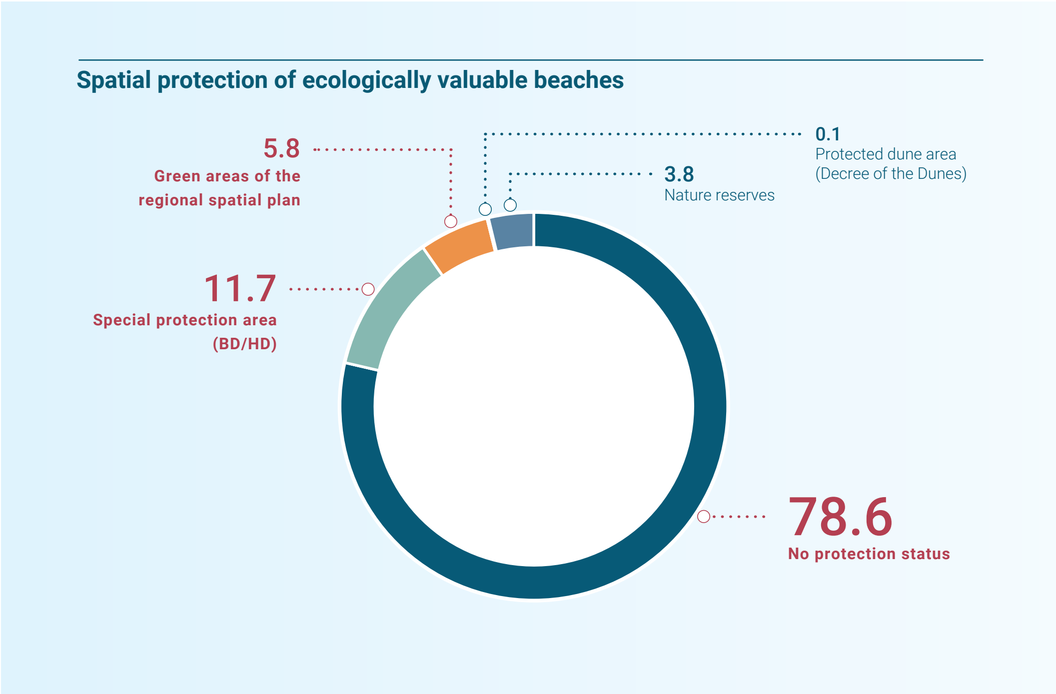

Figure 5. Area-based protection of ecologically valuable beaches according to different nature conservation statuses. Here, both protection categories under the Dune Decree were added to the analysis (Dumortier et al. 2003).

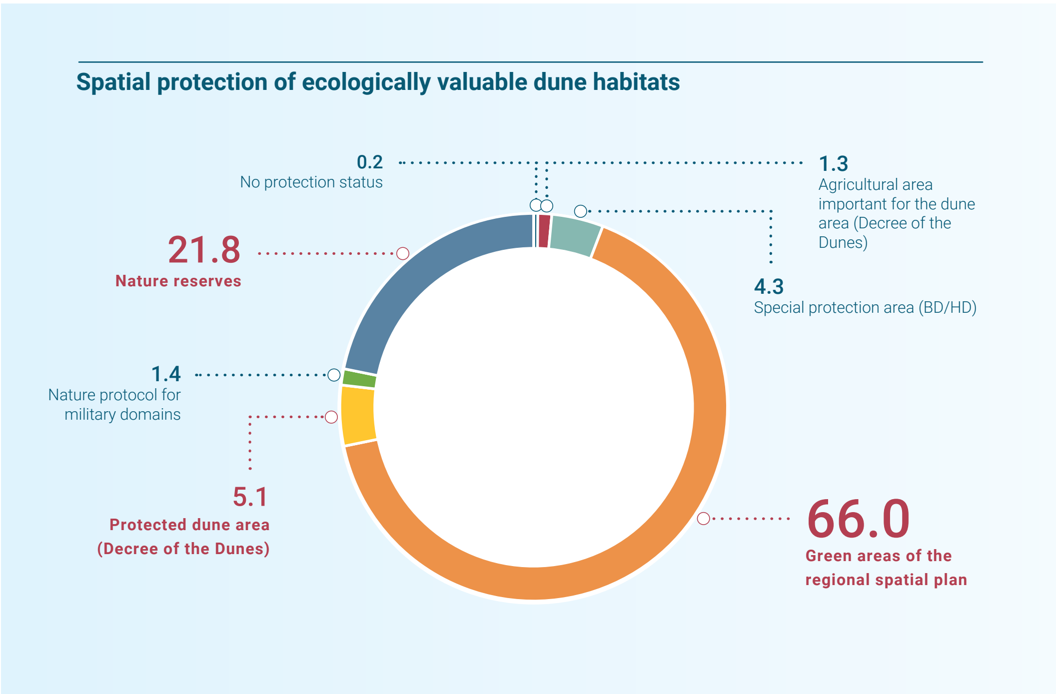

Figure 6. Area-based protection of ecologically valuable dune habitats according to different nature conservation statuses. Here, both protection categories under the Dune Decree were added to the analysis (Dumortier et al. 2003).

Legislation reference list

Overview of the relevant legislation on international ('Year A': adoption; 'Year EIF': entry into force), European, federal and Flemish level. For the consolidated European policy context see Eurlex. The national legislation can be consulted on the Belgian official journal and the Justel-database, the Flemish legislation is available on the Flemish Codex.

International conventions and agreements			
Acronyms	**Title**	**Year A**	**Year EIF**
RAMSAR	Convention on wetlands of international importance, especially as waterfowl habitat	1971	1975
MARPOL	International Convention for the prevention of pollution from ships, as modified by the Protocol of 1978	1973	1978
UNCLOS	United Nations Convention on the law of the sea	1982	1994
CBD	Rio de Janeiro Convention on biological diversity	1992	1996
OSPAR	Convention for the protection of the marine environment of the North-East Atlantic	1992	1998

European legislation and policy context			
Document number	**Title**	**Year**	**Number**
Decisions			
Decision (EU) 2017/848	Commission Decision laying down criteria and methodological standards on good environmental status of marine waters and specifications and standardised methods for monitoring and assessment, and repealing Decision 2010/477/EU	2017	848
Communications			
COM (2007) 575	Communication from the Commission - An Integrated Maritime Policy for the European Union	2007	575
COM (2021) 240	Communication from the Commission on a new approach for a sustainable blue economy in the EU Transforming the EU's Blue Economy for a Sustainable Future	2021	240
Directives			
Directive 91/271/EEC	Directive concerning urban waste water treatment	1991	271
Directive 91/676/EEC	Directive on the protection of waters against pollution caused by nitrates from agricultural sources (Nitrates Directive)	1991	676
Directive 92/43/EEC	Directive on the conservation of natural habitats and of wild fauna and flora (Habitats Directive)	1992	43
Directive 2000/60/EC	Directive establishing a framework for Community action in the field of water policy (Water Framework Directive)	2000	60
Directive 2006/7/EC	Directive concerning the management of bathing water quality and repealing Directive 76/160/EEC (Bathing Water Directive)	2006	7
Directive 2006/118/EC	Directive on the protection of groundwater against pollution and deterioration (Groundwater Directive)	2006	118
Directive 2007/60/EC	Directive on the assessment and management of flood risks (Floods Directive)	2007	60
Directive 2008/56/EC	Directive establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive)	2008	56
Directive 2008/105/EC	Directive on environmental quality standards in the field of water policy, amending and subsequently repealing Directives 82/176/EEC, 83/513/EEC, 84/156/EEC, 84/491/EEC and 86/280/EEC of the Council, and amending Directive 2000/60/EC (Priority Substances Directive)	2008	105

European legislation and policy context (continuation)			
Document number	**Title**	**Year**	**Number**
Directive 2009/147/EC	Directive on the conservation of wild birds (Birds Directive)	2009	147
Directive 2014/89/EU	Directive establishing a framework for maritime spatial planning (MSP Directive)	2014	89

Belgian and Flemish legislation		
Dates	**Title**	**File number**
Decisions of the Govt. of Flanders		
Decision of the Government of Flanders of 17 July 2000	Besluit van de Vlaamse regering tot wijziging van het besluit van de Vlaamse regering van 17 oktober 1988 tot aanwijzing van speciale beschermingszones in de zin van artikel 4 van de richtlijn 79/409/EEG van de Raad van de Europese Gemeenschappen van 2 april 1979 inzake het behoud van de vogelstand betreffende de speciale beschermingszone «3.2. Poldercomplex»	2000-07-17/70
Decision of the Government of Flanders of 24 May 2002	Besluit van de Vlaamse regering tot vaststelling van de gebieden die in uitvoering van artikel 4, lid 1, van Richtlijn 92/43/EEG van de Raad van de Europese Gemeenschappen van 21 mei 1992 inzake de instandhouding van de natuurlijke habitats en de wilde flora en fauna aan de Europese Commissie zijn voorgesteld als speciale beschermingszones	2002-05-24/44
Decision of the Government of Flanders of 27 November 2015	Besluit van de Vlaamse Regering houdende definitieve vaststelling van de kaarten van de historisch permanente graslanden in de landbouwstreek de Polders en houdende vaststelling van bijhorende beschermingsbepalingen	2015-11-27/19
Decision of the Government of Flanders of 18 December 2015	Besluit van de Vlaamse Regering houdende de vaststelling van de stroomgebiedbeheerplannen voor Schelde en Maas (2016-2021), met inbegrip van het maatregelenprogramma bij de stroomgebiedbeheerplannen, de herziene zoneringsplannen en de gebiedsdekkende uitvoeringsplannen	2015-12-18/41
Decision of the Government of Flanders of 20 January 2017	Besluit van de Vlaamse Regering tot wijziging van het besluit van de Vlaamse Regering van 18 december 2015 houdende de vaststelling van de stroomgebiedbeheerplannen voor Schelde en Maas (2016-2021), met inbegrip van het maatregelenprogramma bij de stroomgebiedbeheerplannen, de herziene zoneringsplannen en de gebiedsdekkende uitvoeringsplannen, wat betreft de herziene zoneringsplannen en de gebiedsdekkende uitvoeringsplannen voor Landen, Oostende, Sint-Katelijne-Waver en Zandhoven	
Decrees		
Decree of 14 July 1993	Decreet houdende maatregelen tot bescherming van kustduinen	1993-07-14/31
Decree of 21 October 1997	Decreet betreffende het natuurbehoud en het natuurlijk milieu	1997-10-21/40
Decree of 18 July 2003	Decreet van 18 juli 2003 betreffende het integraal waterbeleid	2018-06-15/23
Royal Decrees		
RD of 21 December 2001	Koninklijk besluit betreffende de soortenbescherming in de zeegebieden onder de rechtsbevoegdheid van België	2001-12-21/72
RD of 23 June 2010	Koninklijk besluit betreffende de vaststelling van een kader voor het bereiken van een goede oppervlaktewatertoestand	2010-06-23/04
RD of 23 June 2010	Koninklijk besluit betreffende de mariene strategie voor de Belgische zeegebieden	2010-06-23/05
RD of 13 November 2012	Koninklijk besluit betreffende de instelling van een raadgevende commissie en de procedure tot aanneming van een marien ruimtelijk plan in de Belgische zeegebieden	2012-11-13/07
RD of 27 October 2016	Koninklijk besluit betreffende de procedure tot aanduiding en beheer van de mariene beschermde gebieden	2016-10-27/11
RD of 22 May 2019	Koninklijk besluit tot vaststelling van het marien ruimtelijk plan voor de periode van 2020 tot 2026 in de Belgische zeegebieden	2019-05-22/23

Belgian and Flemish legislation (continuation)		
Dates	**Title**	**File number**
Ministerial Decrees		
MD of 2 February 2017	Ministerieel besluit betreffende de aanname van instandhoudingsdoelstellingen voor de mariene beschermde gebieden	2017-02-02/07
Laws		
Law of 12 July 1973	Wet op het natuurbehoud: Vlaamse Gewest	1973-07-12/35
Law of 20 January 1999	Wet ter bescherming van het mariene milieu en ter organisatie van de mariene ruimtelijke planning in de zeegebieden onder de rechtsbevoegdheid van België	1999-01-20/33
Law of 20 July 2012	Wet tot wijziging van de wet van 20 januari 1999 ter bescherming van het marine milieu in de zeegebieden onder de rechtsbevoegdheid van België, wat de organisatie van de mariene ruimtelijke planning betreft	2012-07-20/39