# Opportunities for nature restoration in the Dutch North Sea

Providing the foundation for the Nature Regeneration North Sea programme (NN)

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WAGENINGEN UNIVERSITY & RESEARCH

Deltares

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# Contents

# Summary


**Introduction and assignment**

This report by Wageningen Marine Research and Deltares provides a scientific foundation and structured overview (an eco-analysis) of opportunities and courses of action for nature regeneration in the Dutch North Sea. It forms a starting point of the scientific underpinning for the pioneering Nature Regeneration North Sea (NN) programme. The overarching goal of NN is to reverse the decline in ecological quality ("bending the curve") via targeted projects that complement existing protection, contributing to the recovery of the Dutch North Sea in particular, and the Greater North Sea in general. The eco-analysis offers a complete overview of the current status, trends and pressures acting on all relevant ecosystem components of the marine foodweb in the North Sea and explores opportunities for regeneration measures. For each ecosystem component, an action-oriented advice is formulated, focusing on how the NN programme can contribute to ecosystem recovery. A scale for restoration provides a structured way to assess the knowledge base and "maturity stage" of the regeneration measure, i.e. where large scale implementation is already feasible or where research or pilots are needed first. The document therefore serves as a building block for management decision making at programme level.

**NN programme context**

The primary goal of NN is to improve the ecological status of the North Sea by implementing active restoration measures. In doing so, the programme aligns with existing environmental policies and legislation such as the Marine Strategy Framework Directive (MSFD), Natura2000 and the Nature Restoration Regulation (NRR). Legal compliance to these directives and their subsequent management plans with protection measures are treated as a precondition. The NN programme focusses mainly on measures that reinforce and complement existing environmental policy and protection. Measures include those guided by natural processes to give the ecosystem as much chance as possible to improve autonomously (passive restoration).

**Restoration Readiness Level (RRL)**

For this assignment, a Restoration Readiness Level (RRL) framework was developed to assess the maturity of restoration and regeneration measures for ecosystem components. Inspired by the Technology Readiness Level (TRL) system, the RRL distinguishes four phases: research (RRL 1–3), focusing on ecological understanding and exploration of options; development (RRL 4–5), in which measures are tested in pilots and field experiments; demonstration (RRL 6–7), where effectiveness and feasibility are proven across multiple sites; and rollout (RRL 8–9), where measures are ready for large-scale application and policy integration. The framework also distinguishes between direct and indirect restoration, recognising that some components recover primarily indirectly through system-level improvements. The RRL provides a transparent, stepwise basis for prioritising measures and identifying pathways from knowledge development to large-scale ecological recovery.

**Explanation by ecosystem component**

Marine ecosystems are very complex; in order to produce a manageable guiding document, the report is structured along ecosystem components. The analysis covers habitats, phytoplankton and primary production, zooplankton, seaweed, cephalopods, benthos including biogenic reefs, vertebrate species groups comprising fish, birds and marine mammals. For each ecosystem component, an assessment of the current ecological situation, relevant policy context, and potential regeneration measures is included, and an action-oriented advice is formulated.

**Habitats**

Benthic soft sediment habitats have been impoverished by bottom trawling, long-term eutrophication, offshore infrastructure, and sediment extraction affecting soft substrate (covering the largest area of current benthic habitats in the Dutch part of the North Sea). Hard substrate habitats (abiotic and biogenic) have mostly been impacted negatively by bottom fisheries. Reef structures such as oyster beds have almost entirely disappeared which has led to an extensive loss of functions such as filtering and shelter.

Pelagic habitats are less easily defined than benthic habitats and are influenced by a combination of factors that define characteristics of the water column such as depth, salinity, riverine influence and stratification. The water column shows a mixed picture with offshore declines in algal concentrations and in coastal zones elevated productivity due to nutrient rich river outflows. Climate change intensifies stratification and alters nutrient availability.

For pelagic habitats there are few action perspectives targeted on drivers (stratification, nutrient loads, light climate) which fall under the remit of NN. The Habitats Directive (HD), Water Framework Directive (WFD) as well as the MSFD are already instrumental in improving pollution related issues. The current focus in NN is mainly on monitoring and small-scale pilots. The principle is recovery through pressure reduction and where needed targeted support using proven techniques.

Soft sediment and natural hard substate habitats are heavily disturbed by human activities, such as seafloor disturbing fisheries and sand extraction. The exclusion of seafloor disturbing activities (a policy measure implemented through a number of strategies and directives) is the most important passive restoration measure, before any active restoration (such as the restoration of biogenic reefs) can take place. Once protection is in place, hard substrates could be restored through active restoration of stone reefs. Artificial hard substrate can sometimes serve as foundation for the establishment of desired communities at suitable locations (e.g. oyster reefs on shipwrecks) however it is generally not recommended to deliberately add artificial hard substrates. Restoration of biogenic reefs and other benthic fauna are discussed further under benthic species and biogenic reefs.

**Phytoplankton and zooplankton**

Phytoplankton forms the base of the food web. Phytoplankton is not bound to specific habitats, but driven by light and nutrient availability. Due to declining nutrient loads primary production offshore has decreased while coastal zones under the influence of river run-off productivity show high values. Zooplankton (calanoid copepods, shellfish larvae, jellyfish) shows signs of a regime shift with lower densities large calanoid copepods and higher densities smaller species. Shellfish larvae of the European flat oyster (Ostrea edulis) are currently functionally extinct in the North Sea, due to overfishing and disease, whereas other shellfish larvae (e.g. mussels, Mytilus edulis) occur throughout the system with higher densities in coastal waters. Warmer water and changes in the food chain influence composition and availability. An increase in gelatinous plankton is linked with altered predation due to (over)fishing of natural predators and higher temperatures.

Direct intervention in plankton is not effective. There are a number of policy measures that can be taken to comply with the targets in directives such as curbing eutrophication by reducing nutrient run-off from land or deposition from the air. NN can contribute through knowledge development, long-term monitoring of changes in nutrient availability, turbidity and chlorophyll and through measures that strengthen food web relationships. Restoration of filtering reef builders and fish populations indirectly supports healthy plankton dynamics. Small scale experiments with, for instance, seaweed in coastal zones can be exploratory provided they are carefully tracked and evaluated. There seem to be no direct NN measures possible for zooplankton. In some cases, restoration of benthic habitats may be an indirect measure for benthic species with planktonic larvae. Such measures are currently not developed.

**Seaweed and kelp forests**

Natural kelp forests have always been limited in the Dutch North Sea due to a lack of natural hard substrate, reduced light conditions and competition by non-native species with local presence mainly on artificial structures and in sheltered waters. Only Saccharina latissima and Laminaria digitata are native to Dutch waters. In the wider North Sea context kelp habitats are relevant since they provide important ecosystem functions such as habitat for diverse marine species, enhanced biodiversity, improved water quality, and can contribute to climate mitigation. Restoration of kelp could therefore strengthen the ecological integrity and resilience of the ecosystem, in line with OSPAR and EU Nature Restoration objectives.

Active restoration of (endemic) kelp species could fall within the NN programme’s remit. Kelp recovery depends mainly on preconditions such as suitable substrate and better light conditions. Restoration readiness is low so a focus on small-scale, research-oriented projects in sheltered or structurally suitable sites could serve to advance knowledge on techniques for active planting.

**Cephalopods**

Cephalopods is a class including octopus, squid and cuttlefish. These are predators feeding on a large variety of fish and invertebrates. They are also a crucial part of the diet of many marine predators and the catch by commercial fisheries. Populations of cephalopods have increased in the Dutch North Sea, probably due to temperature rise under climate change. NN could focus on habitat restoration for egg deposition of cephalopod species. The first step, however, is to assess whether this is needed in the first place, because of the current natural increase of cephalopod numbers.

**Benthic species and biogenic reefs**

The focus is on four benthic species groups for which species protection plans are made under the MONS programme.

Biogenic reefs are structures created by the accumulation of living organisms such as reef-building polychaetes, bivalves, and corals. These structures provide valuable ecosystem services and can stabilize sediment and form biodiversity hotspots, contributing to the overall productivity, in an otherwise mostly sandy environment within the North Sea basin. Human impacts have significantly reduced biogenic reefs, such as the European flat oyster (*Ostrea edulis*) and reef-building Ross worm (*Sabellaria spinulosa*). While reef-building tube-dwelling worms are still present and will probably naturally recolonize areas once seafloor disturbing activities are reduced. The European flat oyster lacks a stable base population, making natural recovery unlikely.

Restoration of biogenic reefs has been a target in the MSFD for some time. Restoration of oyster beds is promising. Several oyster restoration pilots have already taken place successfully demonstrating that seeding and settlement are possible and that reproduction starts locally. To further restore oysters reefs, four areas for oyster restoration in the Frisian Front area have been defined under the North Sea Agreement. NN could develop plans to restore oysters and possibly other biogenic reef builders in these areas.

Long-lived shellfish and other burrowing megafauna are of high importance for the ecosystem functioning as they form an important trophic link in the food web and serve as a food source for many predators, ranging from other benthic species to fish and seabirds. Numbers and distribution area have declined due to bottom disturbing fisheries. Other direct pressure on long-lived shellfish in the North Sea include pollution and climate change. Active restoration of these species needs to be investigated but could include the creation of hard substrates for improved egg-deposition, during restoration of other ecosystem components.

Large mobile benthos encompasses a range of species that live on or near the seafloor and can freely move and/or swim near the sediment surface and includes mainly crustaceans such as lobster, crab and shrimps. While local populations are not doing well, overall numbers of European lobster and brown crab are increasing, possibly due to the continuing construction of offshore wind farms and associated infrastructure, which offer suitable habitat. Additional active restoration measures may not be needed.

Structure-forming benthic species comprise soft corals, sponges, sea anemones, and hydroids. They differ from biogenic reef-building species in that they do not form large scale abiotic reef systems by themselves. They are responsible for creating structures that can also function as habitat for a variety of other organisms. They are impacted by, in particular, seafloor disturbances such as bottom trawling. There are targets resulting from European directives to restore habitat H1170 and sponge and coral communities. It is therefore important to reduce human impact and offer opportunities for restoration through a combination of measures. NN could focus on restoration of natural boulder reefs and biogenic reefs as habitat for structure - forming species in closed areas where abiotic or biotic reefs used to be present in the past. Biotic reef restoration (oyster reefs) could help to create suitable habitat for these species.

**Fish**

Fish populations in the North Sea are subject to pressures throughout their life cycles, often spanning freshwater, estuarine and marine environments. Many species have declined due to a combination of habitat loss, fisheries-related pressures and broader environmental change. The focus is on fish groups for which species protection plans are made under the MONS programme.

Migratory fish are particularly affected by the degradation of riverine and estuarine habitats. The Netherlands has obligations to protect specific species under the EU Habitats Directive, the EU Marine Strategy Framework Directive (MSFD) and the North Sea Agreement. The conservation status of many migratory fish populations remains poor to moderate across Europe. The NN programme can contribute by supporting the restoration of (tidal) estuarine habitats and spawning and nursery areas, complementing policy-led measures such as barrier removal and fisheries management. However, knowledge of the marine life stages of many migratory species in the North Sea is still limited.

Elasmobranchs (skates and sharks) have declined mainly due to bycatch in combination with their slow life-history strategies. Most species occurring in the North Sea are classified by the IUCN as vulnerable or near threatened. NN-relevant measures focus on the restoration of feeding, reproductive and nursery habitats, potentially in combination with hard-substrate or biogenic reef restoration. The implementation of targeted measures, however, requires improved insight into habitat requirements for egg deposition and the spatial distribution of key nursery and feeding areas.

Pelagic and demersal fish populations show considerable variability, influenced by fisheries and habitat conditions. NN may focus on selected species that are currently in an unfavourable state. Species that play an important role as prey for seabirds may also be prioritised, strengthening ecosystem-level coherence Where sufficient ecological knowledge is available, NN can support active restoration of spawning and nursery habitats, including habitat enhancement through the addition of suitable substrates (e.g. gravel, sand, reefs or woody material) and the improvement of estuarine transition zones.

All interventions should follow a life-cycle approach, recognising that recovery depends on the availability and connectivity of habitats across different life stages. Where knowledge gaps limit action, NN can prioritise targeted knowledge development to identify critical habitats and feasible intervention options, ensuring that future measures are evidence-based and ecologically sound.

**Birds**

The focus is on bird groups for which species protection plans are made under the MONS programme.

Seabirds are highly mobile and use the North Sea as a feeding and resting area throughout the year. During the breeding season, coastal habitats are used for nesting. Selected species are considered vulnerable to offshore wind development and/or in need of protection in general, as agreed upon in international frameworks. Many seabird species are declining while some opportunistic species are more stable. Seabird recovery depends both on improvement of underlying ecosystem functions, such as prey abundance and habitat quality, and on direct management of breeding and foraging sites. Consequently, both policy-led (indirect) and active (direct and indirect) restoration measures that restore or create suitable breeding and foraging habitats are required. NN could enhance seabird colony resilience by supporting the protection of existing breeding sites through predator (e.g. foxes, rats) control, restoring or creating breeding habitats, and indirectly by improving prey availability.

Migratory birds are affected by offshore wind development when passing the North Sea during migration. Populations of some of the selected migratory bird species that use the North Sea and its coastal zones are under pressure, showing declining or unfavourable conservation status. NN can contribute to recovery by focusing on habitat-oriented and ecosystem-based measures that complement policy-level actions (such as spatial planning and fisheries regulation). The majority of direct restoration measures are limited to improving stopover and foraging habitat quality in estuarine systems such as the Wadden Sea, Delta region, and Lake IJssel, rather than in the open North Sea itself. Opportunities also lie in research and development of mitigation measures aimed at reducing mortality and disturbance from offshore activities caused by pressures like collision and displacement (by wind turbines). These measures would also benefit seabirds.

**Marine mammals**

Harbour porpoise, harbour seal and grey seal serve as key indicators of ecosystem health and play important roles in the marine food web. Although their populations in the North Sea remain relatively stable or are increasing over longer timescales, recent declines, especially in harbour seals, raise concern about prey availability, underwater noise, disturbance, and pollution. These species are vulnerable to bycatch, noise and possible fluctuations in food availability. The current status calls mainly for safeguarding habitat quality and reducing risks. Restoration opportunities for highly mobile marine mammals are inherently limited, but targeted measures can improve habitat conditions, reduce pressures, and enhance resilience. NN can complement existing policy measures mainly indirectly by enhancing food availability and ecosystem health.

**Conclusions and recommendations**

The primary goal of NN is to improve the ecological status of the North Sea by implementing active restoration measures, which should always be complemented by passive or policy-driven measures to achieve meaningful and lasting ecosystem improvements. Existing protection remains essential, while innovative, scalable restoration projects using a learning-by-doing approach can deliver visible results. Adaptive management, supported by robust monitoring and evaluation, enables upscaling of effective measures and reduces uncertainties.

Biogenic and geogenic reef restoration stands out as a high-impact measure, providing indirect benefits to many ecosystem components through enhanced habitat structure, food availability, and ecosystem functioning. Similarly, measures targeting prey fish (small pelagics) offer indirect benefits for seabirds and marine mammals, though further need assessments are required before specific interventions. While some measures, such as European flat oyster restoration, are relatively well developed, most others require research, piloting, and testing.

A structured evaluation and prioritisation framework, combining a decision tree with criteria on ecosystem functions, climate resilience, and holistic, area-based perspectives, guides project selection. Clearly defined objectives linked to measurable impact indicators, together with research and monitoring, are essential for assessing effectiveness. Pilot projects provide evidence to refine approaches and support upscaling, ensuring NN contributes meaningfully to long-term ecosystem recovery in the North Sea.

# Glossary

| | |
|---|---|
| 1110 | HD Annex I habitat type 1110 (sandbanks) |
| 1130 | HD Annex I habitat type 1130 (estuaries) |
| 1160 | HD Annex I habitat type 1160 (large shallow inlets and bays) |
| 1170 | HD Annex I habitat type 1170 (reefs) |
| BD | Birds Directive |
| BHD | Birds and Habitats Directive |
| BISI | Benthic Indicator Species Index |
| CCO | Cover, Characteristic species, Opportunistic species |
| CFP | Common Fisheries Policy |
| Chl a | chlorophyll a |
| CMS | Convention on the Conservation of Migratory Species of Wild Animals |
| CS | Conservation Status (CS) (Staat van Instandhouding, SvI) |
| DCS | Dutch Continental Shelf |
| EC | European Commission |
| EEZ | Exclusive Economic Zone |
| EU | European Union |
| EUNIS | European Union Nature Information System |
| GES | Good Environmental Status (GES) (under the MSFD) |
| HD | EU Habitats Directive |
| HD | Habitats Directive |
| ICES | International Council for the Exploration of the Sea (www.ices.dk) |
| IUCN | International Union for Conservation of Nature |
| KEC | Framework for Assessing Ecological and Cumulative Effects (Kader Ecologie en Cumulatie) |
| LNV | see LVVN |
| LVVN | Ministry of Agriculture, Fisheries, Food Security and Nature |
| MONS | Monitoring, Research, Nature Enhancement, and Species Protection programme |
| MPA | Marine Protected Area |
| MSFD | Marine Strategy Framework Directive |
| MSP | Marine Spatial Planning |
| MSY | Maximum sustainable yield |
| MWTL | Programme for Monitoring the Hydrological State of the Country (long-term monitoring programme for benthos, water quality and other parameters) |
| N2000 | Natura 2000 |
| NEM | Ecological Monitoring Network |
| NID | Nature Inclusive Design |
| NN | Regeneration North Sea program (Natuurherstel Noordzee) |
| NNDF | National Data bank Flora & Fauna |
| NOAA | National Oceanic and Atmospheric Administration |
| NRP | National Nature Restoration plan |
| NRP | National Restoration Plan (under the NRR) |
| NRR | Nature Restoration Regulation |
| OSPAR | Convention for the Protection of the Marine Environment of the North-East Atlantic |
| RRL | Restoration Readiness Level |
| SCANS | Small Cetaceans in European Atlantic waters and the North Sea |
| SIBES | Synoptic Intertidal Benthic Survey |

| | |
|---|---|
| SUBES | Synoptic Subtidal Benthic Survey |
| TNO | Netherlands Organisation for Applied Scientific Research |
| TRL | Technological Readiness Level |
| WFD | Water Framework Directive |
| WMR | Wageningen Marine Research |
| WOT | Statutory Research Tasks |
| Wozep | Offshore Wind Ecological Programme |

# 1 Introduction

## 1.1 The North Sea

The North Sea is one of the most utilised and exploited marine areas in the world, being surrounded by seven highly developed European countries. Human activities in both the present and past have impacted and continue to impact the North Sea Ecosystem. Humans have fished the North Sea for over 10,000 years (Van de Noort, 2012). Offshore oil and gas production has been a major economic activity in the North Sea since the late 1960s, and the North Sea contains some of the busiest shipping routes in the world. Many large rivers flow into the North Sea, discharging large volumes of fresh water laden with nutrients (from agricultural and urban origin) as well as pollutants from the many chemical plants situated along these rivers. Moreover, the OSPAR Quality Status Report 2023 has emphasized that additional efforts are needed to restore this ecosystem (OSPAR 2023).

## 1.2 The Nature regeneration North Sea (NN) programme

The Nature regeneration North Sea programme (NN) (2023–2030) is a Dutch national pioneering initiative aimed at achieving a healthy, resilient, and ecologically rich North Sea, one that allows space for natural processes while enabling sustainable human use. The programme seeks to ensure that recent and future developments in the North Sea can go hand in hand with nature development (Programmaplan, 2025).

The overarching goal of NN is to reverse the decline in ecological quality, contributing to the recovery of the Dutch North Sea in particular, and the Greater North Sea in general. Recent and future developments, such as the expansion of wind energy and climate change, will likely cause increasing pressure on the ecosystem in general and on protected species in particular (Programmaplan, 2025).To this end, the programme will initiate and finance a range of pilot projects and larger-scale activities focused on the restoration of species and habitats under pressure. This includes marine species such as fish, marine mammals, invertebrates, and seabirds associated with the North Sea ecosystem, as well as key ecological components at the base of the food web.

The NN programme is based on an Ecosystem Approach in accordance with the OSPAR definition[1]:

*'The comprehensive integrated management of human activities based on the best available scientific knowledge about the ecosystem and its dynamics, in order to identify and take action on influences which are critical to the health of the marine ecosystems, thereby achieving sustainable use of ecosystem goods and services and maintenance of ecosystem integrity'*

NN is designed to be complementary to existing nature and environmental policies and legislation, such as the Marine Strategy Framework Directive (MSFD), Natura 2000, the Common Fisheries Policy (CFP), OSPAR, and the Nature Restoration Regulation (NRR) (see 3.3). Measures required under these legal frameworks are considered guiding principles and are treated as given within the program. Where possible, NN's activities will also contribute directly to achieving these policy objectives. The national implementation of the Nature Restoration Regulation, together with the measures envisaged under NN, provides new opportunities for marine nature restoration. The NN programme is therefore grounded in the rationale of improving the impoverished ecological status of the North Sea and enhancing its biodiversity by supplementing the legally required protection measures with targeted restoration efforts.

[1] https://www.ospar.org/convention/principles/ecosystem-approach

## 1.3 Existing nature and environmental policy and legislation in the Dutch North Sea

In the North Sea Agreement (OFL, 2020) and the North Sea Policy Program 2022-2027 (Min I&W, Min LNV, Min EZK & Min BZK, 2022), the Dutch Ministries of Infrastructure and Water Management, and Economic Affairs and Climate agreed to let wind energy and nature development go hand in hand. The development of sustainable energy must fit within the ecological boundaries of the North Sea and comply with environmental policy and legislation. Among these policies and directives, are obligations by the Dutch government to comply with EU legislation, the most important of which are described in this section.

The **Natura2000** network is made up of Special Areas of Conservation and Special Protection Areas designated under the Habitats Directive (European Commission, 1992) and the Birds Directive (European Commission, 2009), respectively. The network includes both terrestrial and Marine Protected Areas. Current initiatives for Natura2000 areas in the North Sea are outlined in the North Sea Policy Program 2022-2027 (Min I&W, Min LNV, Min EZK & Min BZK, 2022). Management plans are developed for each Natura 2000 site which specify the conservation objectives for each area and measures required to achieve them. Each plan is drawn up for a period of six years. After this period, a review is conducted to determine whether the plan needs to be extended or adjusted. There are, however, no target years for achieving the conservation objectives, unlike the Nature Restoration Regulation (see below).

With respect to water quality and ecosystem health the **Marine Strategy Framework Directive (MSFD)** has entered into force in 2008 (European Commission, 2008), aiming to achieve a good environmental status for the marine environment by 2020 (Long 2011). Each Member State must prepare and implement its marine strategy, in cooperation with their neighbouring states sharing the same marine region and must review and update this strategy every 6 years. Currently, the MSFD is in its third implementation cycle (2024-2030). In the MSFD, the Good Environmental Status is supposed to be reached by 2020, but this target has not been met. In 2025 the European Commission launched a public consultation on and call for evidence on the upcoming revision to the MSFD, following an evaluation in 2025 which found that the directive has not managed to achieve its objective of gaining good environmental status. On land the **Water Framework Directive** has been operational since 2000 (European Commission, 2000). Its objective is to reach good status for all water bodies extending up to 1 nautical mile offshore, and it has played an important role in advancing reductions in pollutant and nutrient inputs to the North Sea.
**Species protection plans**: The North Sea Agreement (OFL, 2020) established a commitment to develop a number of species protection plans that are (1) most vulnerable to offshore wind development, (2) in need of protection in general, as agreed upon in international frameworks (EU Habitat Directive (HD), EU Bird Directive (BD), OSPAR, Red Lists, etc.), or (3) key to nature restoration and enhancement.
Each plan consists of two parts: a background document and an action plan. The background document compiles and evaluates the current and scientific information The background documents provide and evaluate information for the species regarding the following aspects: species descriptions, current species status, monitoring and research, evaluation of threats, effects and opportunities, existing national and international conservation measures, population status, knowledge gaps, and potential actions. In total 12 out of 12 background documents have been through stakeholder consultation. The action plans contain the measures to be taken by the Dutch government and will be developed and formalized by the ministry of LVVN after consultation of "Noordzeeoverleg" stakeholders.

**Nature Restoration Regulation (NRR)**: In August 2024 the EU adopted the Nature Restoration Regulation (NRR) (Office of the European Union, 2024) which establishes a framework to put in place restoration measures to restore degraded habitats. For the marine environment, it sets targets for restoration of amongst others seagrass beds, macroalgal forests, shellfish beds, and sponge communities. In addition, restoration measures can be focussed on the marine habitats of (protected) species. The member states are obliged to prepare national restoration plans and carry out the preparatory monitoring and research needed to identify restoration measures that are necessary to meet the targets. The Netherlands is currently in the process of developing this national restoration plan.

In the NRR the following example measures relevant for the marine habitats/species are mentioned (NRR Annex VII):

- (22) Improve connectivity across habitats to enable the development of populations of species, and to allow for sufficient individual or genetic exchange as well as for species' migration and adaptation to climate change.
- (23) Allow ecosystems to develop their own natural dynamics for example by abandoning harvesting and promoting naturalness and wilderness.
- (24) Remove and control invasive alien species and prevent or minimize new introductions.
- (25) Minimize negative impacts of fishing activities on the marine ecosystem, for example by using gear with less impact on seabed.
- (26) Restore important fish spawning and nursery areas.
- (27) Provide structures or substrates to encourage the return of marine life in support of the restoration of coral, oyster, or boulder reefs.
- (28) Restore seagrass meadows and kelp forests by actively stabilizing the sea bottom, reducing and, where possible, eliminating pressures or by active propagation and planting.
- (29) Restore or improve the state of characteristic native species populations vital to the ecology of marine habitats by conducting passive or active restoration measures, for example, introducing juveniles.
- (30) Reduce various forms of marine pollution, such as nutrient loading, noise pollution and plastic waste."

A distinction can be made between 'active restoration measures' (22, 24, 26, 27, 28, partly 29) and 'passive restoration measures' (23, 25, partly 29, 30). For this NN report, active restoration measures are more relevant. In 2025, WMR is preparing a report for the Ministry of LVVN on relevant habitat types and the habitats of selected species within the Dutch marine ecosystem, including the North Sea, as input for the National Restoration Plan under the NRR (de Froe et al., 2025). It contains, similar to this report, an overview of relevant habitat types (EUNIS) and species, including their historical and current distribution, ecological status, and an assessment of favorable reference areas needed for the re-establishment of habitats.

## 1.4 Nature restoration principles

To address and improve the impoverished ecological status of the North Sea, a range of different measures and approaches can be applied. Within the ULTFARMS programme, Degraer et al. (IN PRESS) have organised these measures into a mitigation (or intervention) hierarchy comprising: avoidance, mitigation, restoration and creation. While originally devised for nature-inclusive design solutions in wind farms, the underlying reasoning for assessing suitable measures is equally applicable to the NN programme.

**Avoidance**
In this step measures are taken to avoid negative impacts on nature from the outset of the human activity. This can include taking certain design choices and site selection options to minimise disturbance to marine species and habitats in the vicinity. This avoidance of damage to nature this falls outside the scope of NN.

**Mitigation**
The impoverished status of the North Sea can be attributed to human activities, either directly (energy infrastructure, (over)fishing, aggregate mining, pollution) or indirectly (climate change). Wherever possible, mitigating the negative consequences should always be attempted. Most mitigation measures are beyond the remit of NN.

**Restoration**
Where conditions are suitable and where appropriate policy measures are in place (such as exclusion of bottom trawling), passive and active restoration can take place. Measures can be taken guided by natural processes to give the ecosystem as much chance as possible to improve autonomously (passive restoration). Alternatively, active restoration measures can be considered, such as the reintroduction of species, (e.g. oysters) and providing settlement habitat for larvae. Both are within the remit of NN. Restoration can imply

restoring ecosystem functions, habitats and key species that were lost due to human activities in the past. However, restoration requires a clear understanding of what has been lost and why. Without this knowledge, there is a risk of shifting from ecological restoration to the creation of something entirely new, and possibly, undesirable. Therefore, before starting restoration projects the following questions should be considered (personal communication Jaap van der Meer):

1. **What can be restored?**
   Was there once an ecosystem feature or function that is now missing? And do we have reliable evidence of its former presence?
   (*Caution is needed to avoid idealized or overly optimistic assumptions*)
2. **Why is it no longer present?**
   What are the root causes behind its decline or disappearance?
   Understanding the underlying ecological mechanisms is essential — and may require further research.
3. **What is needed to restore it?**
   Are active interventions required, or could the ecosystem recover naturally if the right conditions are re-established?

This approach ensures that restoration efforts are grounded in ecological reality and focused on achievable and sustainable outcomes.

**Creation**
Humans have the capacity to fundamentally change the physical ecosystem. Building offshore wind farms is a good example. In theory we can create reef structures (e.g. stone reefs) in areas that in the past have never seen such structures; e.g. in the dynamic sand wave area of the Holland Coast. In these dynamic areas, stone reefs are naturally scarce and it is not favourable to most types of biogenic reefs (Herman and Van Rees, 2022). The question is to what extent it is desirable to create habitats that are not in keeping with the authenticity of the local environment and therefore measures aimed at creation should be approached with caution also within NN. As we currently do not fully understand the system functioning of our marine areas, creation may not be beneficial to the system. Our coastal systems are known for high production, not necessarily for high species diversity.

**Conclusion**

Among the different options (avoidance, mitigation, restoration and creation), restoration best aligns with the objectives of NN, as it directly contributes to strengthening and recovering marine ecosystems. As stated in the Programme's plan (Programmaplan, 2025) the measures to be taken are guided by natural processes and tailored to ecological dynamics, giving the ecosystem as many opportunities as possible to improve autonomously. Within NN the wording nature regeneration is used for restoration activities. This choice helps to avoid the recurring discussion on what historical reference state ecosystems should be restored to, as such reference conditions are often poorly defined or uncertain. In addition, marine systems have already changed substantially, making a return to former states unrealistic. NN Sea therefore focuses on restoration activities that are compatible with the current ecological conditions and functioning of the system, rather than aiming to recreate past situations. The objective is to realise the full natural potential of the North Sea within the current conditions and taking the authenticity of the local environment into account.

## 1.5 Assignment

This project is commissioned by the Dutch Ministry of LVVN as part of the Nature Regeneration North Sea (NN) programme (2023–2030). The programme aims to regenerate the ecosystem of the Dutch North Sea, complementing existing nature and environmental policy. A key principle of NN is that its approach is grounded in a solid scientific basis.

As strategic scientific partners of the NN programme, Deltares and Wageningen Marine Research were asked to develop this scientific foundation by providing an overview of the main opportunities and courses of action (in Dutch: handelingsperspectieven) for nature restoration in the North Sea.

### 1.5.1 Purpose

The objective of this assignment is to prepare a structured overview (eco-analysis) of opportunities and courses of action for all trophic levels with nature restoration in the Dutch North Sea. This eco-analysis forms the starting point of the scientific underpinning of the NN programme, providing an integrated description of the current ecological status, reference conditions, restoration goals, and potential measures for ecosystem recovery.

Rather than presenting fully developed plans, it offers science-based direction for future activities within the Nature Regeneration North Sea programme, grounded in existing knowledge and expert insights. The report synthesizes available literature and experiential knowledge to identify key ecological opportunities and practical action perspectives that can guide effective nature enhancement efforts in the marine environment. The report builds on related research, such as the findings from studies on the Nature Restoration Regulation and the development of species protection plans.

### 1.5.2 Scope of this study

This report provides an overview of the current status, trends, and pressures affecting all relevant ecosystem components in the Dutch North Sea. These insights and a summary of current (existing) policy and potential measures are used to formulate advice on opportunities for action for each ecosystem component. The advice outlines possible actions and identifies knowledge gaps that need to be addressed to enable effective implementation.

It is important to distinguish between passive/policy measures and active measures;

- Passive measures, such as the establishment of marine protected areas, or other measures like reduction of nutrients, fishery (catch limitation) measures or removing migration barriers, fall outside the scope of NN and are in this report referred to as policy measures.
- Active restoration measures, such as restoring bio- or geogenic reefs and spawning habitats, are within the scope of NN (but may also be initiated by policy).

## 1.6 References


De Froe, E., Asjes, A., Escaravage, V., Glorius, S.T., Hoogenstrijd, G., Husken, K.H.A., Jak, R. G., Nauta, R. W., Sandig, A., Smulders, F., Tamis, J.E., Troost, K., Wijnhoven, S. (2025). Natuurherstelverordening en het Nederlandse mariene ecosysteem; Stand van zaken voor de relevante habitattypen en habitats van soorten.Wageningen Marine Research rapport C082.25. https://doi.org/10.18174/703569

Degraer, S., L. Cornacchia, A. Ziemba, T. Agardy, S. van den Burg, K. van de Braak, L. A. van Duren, A. Declercq, M. Eggermont, A. Van Gerve, T. R. H. Kerkhove, I. Moulaertt, T. Patel, J. K. Petersen, M. Poelman, V. Stratigaki, E. Strothotte, J. Vanaverbeke, and G. Y. El Serafy. 2026. Rethinking the responsible application of nature-inclusive design in marine infrastructure to restore ecosystems and enhance biodiversity. ICES Journal of Marine Science in press.

European Commission (1992). Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora [Habitats Directive]. *Official J. of the European Communities*, *206*(L), 7–50.

European Commission (2000). Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for community action in the field of water policy. Off. J. Eur. Communities, 2000 (2000)

European Commission (2008). Directive 2008/56/EC of the European Parliament and of the Council, of 17 June 2008, establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive). *Official J. of the European Union*, *164*, 19–40. http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2008:164:0019:0040:EN:PDF

European Commission (2009) Directive 2009/147/Ec Of The European Parliament and of the Council of 30 November 2009 on the conservation of wild birds (https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:02009L0147-20190626)

Herman, P.M.J., and F.F. Van Rees. (2022). Mapping Reef forming North Sea Species. 11207716-000-ZKS-0001, Deltares, Delft.

Long, R. (2011). The Marine Strategy Framework Directive: a new European approach to the regulation of the marine environment, marine natural resources and marine ecological services. Journal of Energy & Natural Resources Law 29:1-44.

Ministerie van Infrastructuur en Waterstaat, Ministerie van Landbouw Natuur en Voedselveiligheid, Ministerie van Economische Zaken en Klimaat, & Ministerie van Binnenlandse Zaken en Koninkrijksrelaties (2022). *Programma Noordzee 2022 – 2027. Bijlage van het Nationaal Water Programma 2022-2027* (p. 164). https://open.overheid.nl/repository/ronl-eb6f03952fb18a506920ac95e4cd232c8d368b64/1/pdf/bijlage-programma-noordzee-2022-2027.pdf

Office of the European Union (2024). *Regulation (EU) 2024/1991 of the European Parliament and of the Council of 24 June 2024 on nature restoration and amending Regulation (EU) 2022/869 (Text with EEA relevance)*. http://data.europa.eu/eli/reg/2024/1991/oj

OFL (2020). *The North Sea Agreement*. https://doi.org/10.1080/00139157.1974.9928424

OSPAR (2023). *Quality Status Report 2023*. https://oap.ospar.org/en/ospar-assessments/quality-status-reports/qsr-2023/

Van de Noort, R. (2012). North Sea archaeologies: a maritime biography, 10,000 BC-AD 1500. Oxford University Press.

# 2 Materials and Methods

## 2.1 Ecosystem components

### 2.1.1 Selection of ecosystem components

Marine ecosystems are very complex and every attempt at subdividing them in functional groups has pros and cons. However, in order to produce a manageable guiding document, we have opted for a reporting structure along components of the marine food web, starting at the basis with the primary producers, going up to the apex predators. This includes a description of habitats, the current status, trends and pressures acting on all relevant ecosystem components in the North Sea, together with a first analysis on the potential measures where the programme NN can logically contribute. In doing so the following ecosystem components are identified which are covered in this report.

- Habitats$^{\$}$
- Phytoplankton and primary production
- Zooplankton
- Seaweed – kelp forests$
- Cephalopods
- Benthic species and biogenic reefs*
    - Biogenic reefs*$^{\$}$
    - Soft substrate benthos: (long lived) shellfish and burrowing megafauna*
    - Large mobile benthos*
    - Hard substrate benthos: structure forming benthos*
- Fish*
    - Migratory fish*
    - Sharks and rays*
    - Pelagic (forage) fish*
    - Demersal fish*
- Marine Mammals+
    - Harbour porpoise$^{+}$
    - Grey and harbour seals$^{+}$
- Birds*
    - Seabirds*
    - Migratory birds*

**Ecosystem component for which (background documents for) species protection plans are prepared.*
$^{\$}$*Ecosystem components for which restoration plans will be made under the EU Nature Restoration Regulation*
$^{+}$ *Existing (porpoise and seal) protection plans*

For each ecosystem component, only a selection of the most relevant species will be covered. Where appropriate (see *), we will base the selection on the selection that was made for the species protection plans.

Not included in the scope:

- Wadden Sea and Delta habitat types as such, e.g. salt marches, mudflats, intertidal mussel beds, etc.: These components are part of the Wadden Sea or Delta only and not in the scope of the NN program. However, activities in these areas may be considered where there is a clear and substantiated ecological link to the North Sea, for example through species that depend on both systems during their life cycle.

- Bats: Bats are highly protected species that use the North Sea as a migratory route and are known to be affected by offshore wind developments. Some species migrate across the North Sea and partially forage over marine areas. While these interactions are recognised, bats are not considered further in this document. They are not an integral component of the marine food web, nor do they play a clearly defined functional role within the marine ecosystem. Consequently, the Natuurversterking Noordzee (NN) programme currently sees limited scope to meaningfully contribute to conservation or restoration measures for bats within its mandate.Description of ecosystem components

For each ecosystem component in Chapters 5 - 12 the following topics are described:

Ecosystem component description and species selection: The ecosystem component description highlights one or more selected species. It begins with the identification and rationale for the species selection species, based on ecological relevance, sensitivity to human activities, or its importance for monitoring purposes. Where species protection plans are also developed for a specific ecosystem component, the same species selection has been applied (see also paragraph 2.3).

Habitat preference: The habitat preferences of the species are then described, explaining how the species interacts with different habitat types in the North Sea. For bird species in particular, the importance of the Dutch part of the North Sea is discussed, especially in terms of feeding, breeding, or migration.

Ecosystem function: The next section outlines the ecosystem function of the species, such as its role in the food web, its influence on other species, or its contribution to ecological processes.

Status and trends: This is followed by an overview of the current status and trends of both the ecosystem component and the selected species. It includes population trends over time, spatial distribution and, where available, visual maps illustrating these patterns.

Pressures and impacts: pressures and impacts are identified next, highlighting the most significant human-induced or natural stressors affecting the component and/or species. These may include direct pressures such as disturbance, habitat loss, pollution, or indirect pressures resulting from climate change. Pressures emanating directly from human activities as well as (semi)autonomous, longer-term trends are indicated.

Current policies: Existing policy frameworks relevant to the ecosystem component or the identified species group are summarized, covering national and international frameworks. Also, an inventory is made of (suggested) policy measures (not within the remit of NN), such as establishing MPAs, removing migration barriers and reduction pollution.

## 2.2 Advice

For each ecosystem component, an action-oriented advice is formulated, focusing on how the *Nature Regeneration North Sea* (NN) programme can contribute to ecosystem recovery. This includes an assessment of the current ecological situation, relevant policy context, and potential restoration measures to determine the most meaningful opportunities for NN to take action. Policy measures that are not within the remit of the NN programme are left out. The advice consists of the following elements:

### 2.2.1 Rationale

First, it is assessed whether action is needed for the ecosystem component in question (or if it is not needed). This assessment is based on two main aspects:

- **Ecological status and trends:** How are the species and habitats within this component currently doing? Are populations stable, declining, or improving compared to historical or reference conditions?
- **Policy context:** Do existing policies or frameworks (e.g. MSFD, Natura 2000, North Sea Agreement) indicate that action is required?

In addition, it is important to evaluate whether sufficient knowledge is available to make a well-founded judgement on these points. If both the ecological and policy assessments indicate a need for intervention — and the knowledge base is adequate — this forms the rationale for further action within NN.

### 2.2.2 Action Perspective for NN

For each ecosystem component, it is assessed which measures and actions are within the remit of NN and which are not (such as policy measures). The focus is on actions that directly support ecological recovery, following the restoration principles (see section 1.4). Where possible, the restoration readiness level (see 2.2.4) is indicated: is there sufficient evidence to implement restoration now, or is further research needed to increase the restoration readiness level?

### 2.2.3 Demonstration of Impact

For those ecosystem components applicable, the report outlines how NN can demonstrate ecological impact through measurable outcomes. It also evaluates whether the current knowledge base is sufficient to define meaningful indicators and identifies what additional monitoring, research, or pilot studies are needed to underpin evidence-based restoration.

### 2.2.4 Restoration Readiness Level (RRL)

To identify realistic opportunities to improve the ecological status of ecosystem components, it is essential to assess the available knowledge and practical experience with restoration measures for specific ecosystem components.

Therefor the so called Restoration Readiness Level (RRL) framework was designed for this project, providing a structured way to assess the knowledge base and "maturity stage" of the regeneration measure. The RRL is inspired by the Technology Readiness Level systematics (TRL), The concept of Technology Readiness Levels (TRLs) was originally developed by NASA in the 1970s to assess the maturity of emerging technologies (Sadin et al. 1989). It has since been widely adopted by research and policy organizations, including the European Commission, as a standardized framework for evaluating the development stage of technologies.

The RRL describes the progression from basic ecological understanding of an ecosystem component to proven large-scale restoration practice. In this way, proposed measures can be built up step by step: from knowledge projects and pilot locations to scaling up and broad application once the effects have been proven. This approach supports a careful and evidence-based way of working, in which uncertainties are explicitly addressed. It helps to identify where knowledge gaps remain, where pilots are needed, and where conditions are suitable for upscaling.

Importantly, the framework also recognizes that not all ecosystem components require direct intervention. Some components primarily benefit from measures targeting other, functionally linked parts of the ecosystem (for example, seabirds benefiting from improved fish stocks, or predators responding to prey recovery). In such cases, the RRL indicates the level of understanding and indirect recovery potential rather than readiness for direct restoration.

The RRL framework helps to determine for each ecosystem component:

- How well restoration processes are understood,
- What experience exists with restoration and the measure in question,
- Whether the component requires direct or indirect restoration, and
- How projects that propose certain measures can contribute to system-wide ecological recovery.

Each proposed measure is assigned a Restoration Readiness Level (1-9, see Table 4.1), reflecting its stage of knowledge and restoration maturity. To clarify whether this readiness concerns direct or indirect recovery each component is also assigned a code (see Table 4.2.1).

***Table 4.2.1.*** *Regeneration Readiness Levels (RRL)– Overview a framework designed for this study to provide a structured way to assess the knowledge base and "maturity stage" of the regeneration measures. Inspired on the Technology Readiness Level systematics (TRL) originally developed by NASA (Sadin et al. 1989).*

| **Phase** | **Level** | **Description** |
|---|---|---|
| Research phase | 1. Initial exploration | Basic knowledge is limited, and it is unclear whether restoration/regeneration is needed. There is a suspicion that restoration is needed or possible, but no substantiation or concrete approach. |
| | 2. Species and system knowledge | Understanding of the species (group) ecology is being developed (e.g., migration patterns, spawning habitat). Hypotheses about restoration measures are formulated. |
| | 3. Bottleneck analysis & opportunity exploration | Initial assessments of where and how restoration measures could be effective. Exploratory research into locations and constraints (e.g., micro-siting, functional fit). |
| Development phase | 4. Small-scale pilots / laboratory trials | Initial implementation of measures in a controlled or limited setting. Effects are monitored; uncertainties are mapped. |
| | 5. Field experiments and monitoring | Measures are tested in realistic (field) conditions, with attention to ecological effects, feasibility, and possible side effects. |
| Demonstration phase | 6. Proven effectiveness at pilot scale | Repeatable results from multiple projects or locations. Effectiveness is quantitatively substantiated. Applicability is further explored. |
| | 7. Demonstration projects | Measures have been applied in an operational context. Effectiveness, scalability, and social feasibility are demonstrated to stakeholders. |
| Roll out phase | 8. Preparation for rollout | Measures for ecosystem component are ready for broad application. Guidelines, design principles, or standards are available. Policy integration has begun. |
| | 9. Standard application (rollout phase) | The measure is widely accepted, embedded in policy, and applied at larger scale in restoration programmes or spatial development. |

| **Code** | **Description** | **Explanation** |
|---|---|---|
| D | Direct restoration | The component is suitable for direct restoration actions or pilots (e.g., reef construction, habitat creation, transplantation). |
| I | Indirect restoration | The component primarily benefits from restoration measures aimed at other components or system-level improvements (e.g., prey recovery, water quality, habitat protection). |
| DI | Direct + Indirect | Both direct restoration measures and indirect pathways are relevant for the component's regeneration. |
| NA | Not applicable | Restoration or regeneration is not a relevant at this stage (e.g., naturally dynamic or healthy component). |

RRL 1–3: Research Phase

Ecological functioning of the ecosystem component is only partly understood. Regarding restoration measures there is still uncertainty about ecological effectiveness, technical feasibility, or social acceptance. There is a need for:

- Basic species knowledge (distribution, ecology, habitat requirements)
- Hypothesis development on restoration measures
- Exploration of potential locations or bottlenecks (e.g., migration barriers)
- Example: Where are suitable spawning grounds for herring still found? Is reintroduction of allis shad ecologically and genetically responsible?

RRL 4–5: Development Phase

The measure has been tested at small scale or in pilots. There are indications the intervention works, but effectiveness must be further demonstrated. This requires:

- Practical experiments at limited scale
- Monitoring of ecological response (e.g., fish recruitment, habitat use)
- Development of technical implementation knowledge

  Example: Pilot using artificial reefs to create nursery areas for demersal fish; fish passages tested at small weirs.

RRL 6–7: Demonstration Phase
The measure has been successfully applied in multiple situations. Ecological effects are predictable and measurable. The approach can be widely demonstrated to stakeholders and policymakers. Key activities include:

- Demonstration projects at multiple locations
- Support with cost-effectiveness analyses
- Preparation for policy or regulatory integration
  Example: Demonstration of a successful fish migration route at the Haringvliet sluices; seabed protection around wind turbines with positive fish response.

RRL 8–9: Rollout Phase
The measure is proven effective, technically feasible, and socially accepted. A broad action perspective is available. The measure can:

- Be applied at larger scale
- Be integrated into standard management and development plans
- Be linked to financing instruments
  Example: Structural design of spawning areas for pelagic fish in marine reserves; standardization of habitat measures in wind farms.

### 2.2.5 Synthesis table

In the synthesis table (see **Table 11.1**), we have summarised for each of the ecosystem components potential measures that can be taken in order to improve the status of the component. These measures do not cover 'policy' measures, but only measures within the remit of NN. Colour codes indicate whether potentially actionable measures for ecosystem recovery are available (green), no or limited measures are available (orange), or if it is unknown if measures are available (mainly due to knowledge gaps) (yellow).

## 2.3 Desk study

The ecosystem components were described based on a desk study of scientific papers, grey literature, relevant websites and model outputs. An important document is the OSPAR Quality Status Report, which has assessed the status for ecosystem components for the greater North Sea published in 2023 (https://www.ospar.org/work-areas/cross-cutting-issues/qsr2023). Two additional and highly relevant (group of) report(s) to highlight are the Species protection plans and the National Restoration Plan under the NRR:

Species protection plans
For some species groups, summaries were prepared based on the information provided in the background documents for the Dutch species protection plans, developed by Wageningen Marine Research (WMR) and other parties commissioned by the Ministry of LVVN). These background documents compile and evaluate the current scientific knowledge. Background documents of the following species groups (published or in preparation) were used:

- Flying and/or shallow diving foraging birds of the coastal waters (Jongbloed et al. 2023)
- Offshore foraging/residing seabirds (Bos et al. 2023)
- Remaining KEC birds (max. 17 species) (Leopold et al. 2025)
- Migratory birds/Red List status birds (Jongbloed et al. 2025)
- Migratory fish (van Rijssel et al. 2025)
- Sharks and rays (Leurs et al. 2026)
- Pelagic fish (Tamis et al. 2026)
- Demersal fish (Tulp et al. 2026)
- Reef forming species (Sas et al. 2023)
- Structure forming species (Kingma et al. 2025)
- Large mobile benthic fauna (Rozemeijer et al. 2026 in prep)

- Long-lived shellfish and burrowing megafauna (Kingma et al. 2026 in prep)

National Restoration Plan under the NRR – report
As part of the desk study, the WMR report developed in preparation of the National Restoration Plan under the NRR (de Froe et al. 2025) was reviewed. This report identifies restoration needs for marine habitats and habitat of species and provides relevant input within the broader policy context of the NRR. Other existing policies and frameworks (e.g. the Marine Strategy Framework Directive, Habitats Directive/Natura 2000, and the North Sea Agreement) will also be reviewed to assess where action is required.

## 2.4 References

Asjes, J., Merkus, H., Bos, O. G., Steenbergen, J., Stuijfzand, S., van Splunder, I., Kooten, T. van, Rivero, S., & Vis, G. A. J. (2021). Monitoring en Onderzoek Natuurversterking en Soortenbescherming (MONS) (Issue 4 October 2021). https://www.noordzeeloket.nl/publish/pages/196778/mons-rapport-noordzeeoverleg-2021.pdf

De Froe, E., Asjes, A., Escaravage, V., Glorius, S.T., Hoogenstrijd, G., Husken, K.H.A., Jak, R. G., Nauta, R. W., Sandig, A., Smulders, F., Tamis, J.E., Troost, K., Wijnhoven, S. (2025). Natuurherstelverordening en het Nederlandse mariene ecosysteem; Stand van zaken voor de relevante habitattypen en habitats van soorten.Wageningen Marine Research rapport C082.25. https://doi.org/10.18174/703569

Kingma, E., Jongbloed, R. H., Clarisse, M., & Bos, O. G. (2025). *Structure-Forming Benthos Species in the Dutch North Sea. Background document for a protection plan.* Wageningen Marine Research report C106/25. https://doi.org/10.18174/705505

Sadin, S. R., Povinelli, F. P., & Rosen, R. A. (1989). *The NASA technology push towards future space mission systems.* Acta Astronautica, 20(1), 73–77.

Sas, H., van Duren, L., Herman, P., van der Have, T., Kamermans, P., Bos, O., Kingma, E., Bouma, T., & Kardinaal, E. (2023). *Reef-building species and biogenic reef enhancement in the Dutch North Sea. Background documents*. https://edepot.wur.nl/633785

Leurs, G., K. Bleeker, H.V. Winter & R.H. Jongbloed (2026). Sharks and Rays in the Dutch North Sea: Background document for a protection plan. Wageningen Marine Research report, no. C003/26. https://doi.org/10.18174/707647

Tamis, J.E., R. van Hal & R.H. Jongbloed (2026). Pelagic fish in the Dutch North Sea. Background document for a protection plan. Wageningen Marine Research report C005/26. https://doi.org/10.18174/708208

Tulp, I.Y.M., R. van Hal, J.E. Tamis & R.H. Jongbloed (2026). Demersal fish in the Dutch North Sea. Background document for a protection plan. Wageningen Marine Research report C006/26. https://doi.org/10.18174/708265

Kingma, E.M., A. Hamer, O.G. Bos, R. Witbaard & R.H. Jongbloed (2026 in prep.). Longlived shellfish and burrowing megafauna cummunities in the Dutch North Sea. Background document for a protection plan. Wageningen Marine Research report xxx.

Rozemeijer, M.J.C., J.E. Tamis & R.H. Jongbloed (2026 in prep.). Large mobile benthic fauna in the Dutch North Sea. Background document for a protection plan. Wageningen Marine Research report xxx.

Bos, O, Schekkerman, H, Kingma, E, Tamis, J, Goutbeek, A, van Oijen, T & Jongbloed, R (2023). Offshore birds in the Dutch North Sea: Background document for a protection plan. Wageningen Marine Research report, no. C087/23, Wageningen Marine Research, Den Helder. https://doi.org/10.18174/644064

Jongbloed, R., H. Schekkerman, E. Kingma, J. Tamis, A. Goutbeek, T. van Oijen, O. Bos (2023): Surface-feeding birds of the coastal waters in the Dutch North Sea. Background document for a protection plan. Wageningen Marine Research report C097/23. https://doi.org/10.18174/644517

Jongbloed, R.H., J. Karagicheva, J.E. Tamis, H. Schekkerman, T. van Oijen & M.J.M. Poot (2025). Migratory birds and Red List birds of the Dutch North Sea. Background document for a protection plan. Wageningen Marine Research report C090/25. https://doi.org/10.18174/704363

Leopold, M., M. Poot, J. Tamis, H. Schekkerman, A. Goutbeek, T. van Oijen, R. Jongbloed (2025). Seabirds in the Dutch North Sea. Background document for a protection plan for seabirds potentially vulnerable to offshore wind farms. Wageningen Marine Research report C047/25. https://doi.org/10.18174/695037

Leurs, G., K. Bleeker, H.V. Winter, R.H. Jongbloed (2026). Sharks and rays in the Dutch North Sea. Background document for a protection plan. Wageningen Marine Research report C003/26. https://doi.org/10.18174/707647

Van Rijssel. J.C, H.V. Winter, T. van der Hammen, J.E. Tamis, R.H. Jongbloed (2025). Migratory fish in the Dutch North Sea: Background document for a protection plan. Wageningen Marine Research report, no. C035/25, Wageningen Marine Research, Den Helder. https://doi.org/10.18174/693304

# 3 Habitats

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## 3.1 Pelagic habitats

Pelagic habitats are less easily defined on maps than benthic habitats (see Chapter 3.2). Pelagic 'habitats' can be defined using a combination of factors that define characteristics of the water column such as depth, salinity, riverine influence and stratification. OSPAR has divided the North-Western Atlantic area into pelagic assessment areas (OSPAR 2023) to assess the state of the North Sea in terms of eutrophication and chemical pollution. The areas are largely separated based on depth, salinity and stratification regime.

### 3.1.1 Depth

As with benthic habitats (see Chapter 3.2), depth also influences pelagic habitats, as it firstly influences the light climate. In shallow water, light penetrates easily to the seabed and primary production can take place throughout the water column. In deeper water, there are zones where light is insufficient for photosynthesis even in summer. The ratio between the 'photic zone' (with sufficient light for photosynthesis) and the layer below is an important factor in determining the depth integrated primary production (Tett 1990). The depth of the photic zone is strongly influenced by the amount of suspended and dissolved material, organic and inorganic (van Leeuwen et al. 2013).

### 3.1.2 Riverine influence

The discharge from rivers into the sea creates not only an area where salinity tends to be lower than in full oceanic conditions but also creates areas with high nutrient concentrations and sometimes high turbidity. By definition, river plumes (see various plumes in Figure 3-1) tend to be coastal, hence relatively shallow. However, river plumes also tend to carry substantial amounts of suspended solids. Dynamics of regions of freshwater influence (ROFI) can be very complex (Simpson 1997, de Boer et al. 2009) and determine productivity in the coastal regions. As freshwater has a lower density than seawater these regions are often characterised by a certain level of stratification, i.e. layers of water with different densities between which limited mixing takes place (De Vries et al. 2014).

### 3.1.3 Stratification

Both salinity and temperature can influence stratification. In shallow, highly dynamic areas the water column is virtually completely mixed most of the time, apart from directly in river plumes. Further offshore, where water is deeper and flow velocities are often lower, the upper water layers heat up in summer and can form a layer on top of colder (and hence denser) water, separated by a pycnocline (a thin layer with a rapid change in density). As there is sufficient light in the upper layer, phytoplankton can grow here, but growth can be limited due to the fact that the amount of nutrients in the upper layer is limited. In the North Sea in most places the area below the pycnocline does not receive enough light for photosynthesis and hence nutrients that are available here cannot be used. The onset of stratification is often strongly linked to the onset of the spring bloom of phytoplankton (Sharples et al. 2006). Stratification is one of the most important driving forces for ecological processes in the North Sea. In strongly seasonally stratified areas such as the Eastern North Sea and Northern North Sea (Figure 3-1), stratification limits primary production, as well as limits the transport of phytoplankton to the seabed, resulting in quite low food conditions in near-bed layers for benthos. Conversely, frontal areas, such as the Frisian Front, with similar nutrient loads, are much more productive and are often ecological hot-spots for ecology (Dewicke et al. 2002). Both climate change and large-scale infrastructure, such as offshore wind farms, affect this process. Even if NN-measures are not directly influencing stratification, it is important to be aware of the process and how this may change in the future.

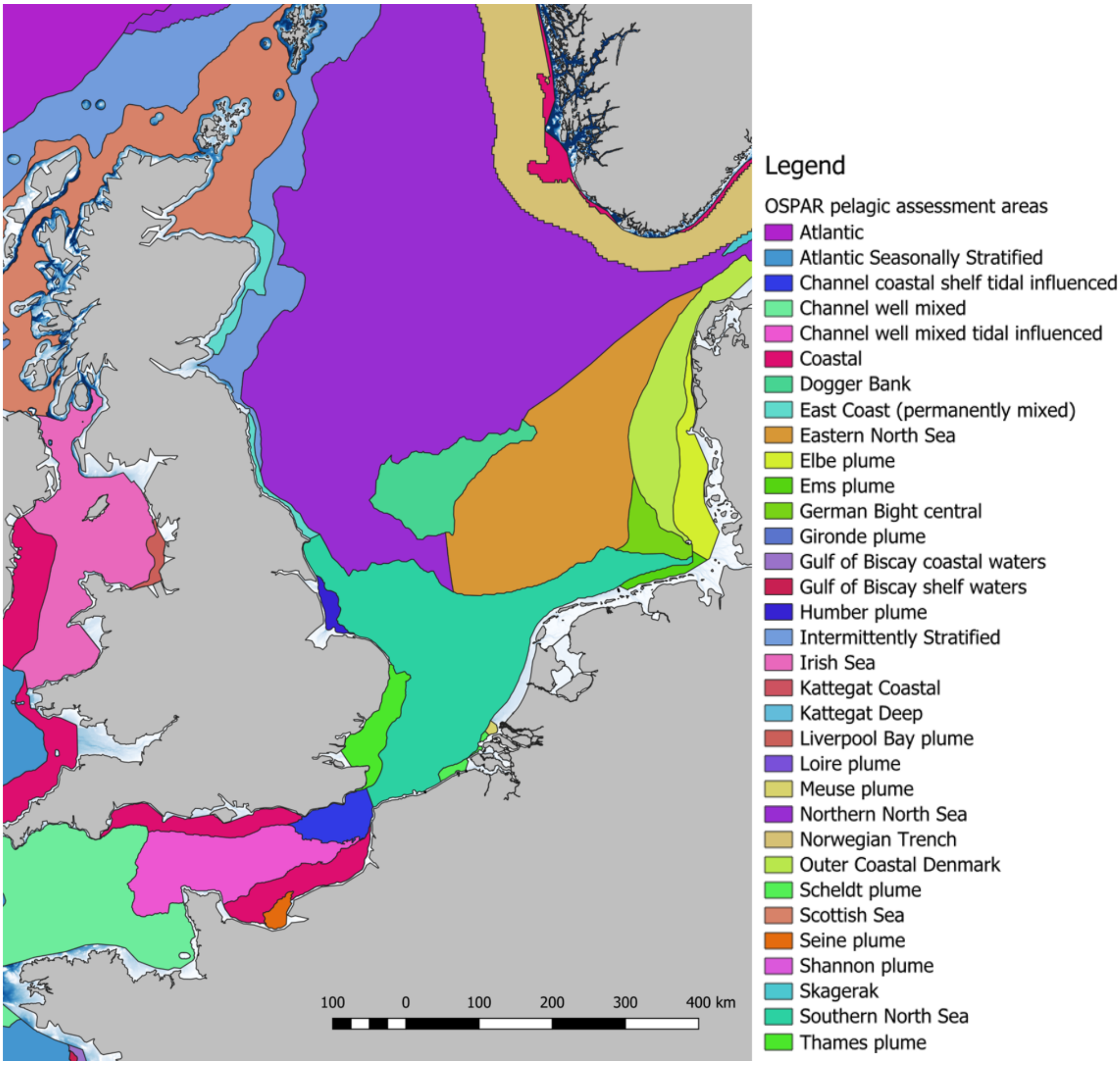


***Figure 3-1*** *OSPAR pelagic assessment areas in and around the North Sea (OSPAR 2023).*

## 3.2 Benthic habitats

The seafloor of the North Sea contains a wide variety of different habitats. A comprehensive classification has been established by the European Union, as part of the EUNIS habitat classification system. This system groups marine habitats based on their geographic location (e.g. Atlantic, Baltic), depth (e.g. infralittoral, circalittoral), substrate type (e.g. rock, mud), and further distinguishing factors such as dominant species (https://eunis.eea.europa.eu; viewer at https://emodnet.ec.europa.eu/geoviewer/). For the MSFD, broad habitat types are used to assess the status of marine ecosystems. EUNIS Level 3 can be translated directly into the MSFD benthic Broad Habitat Types classification.

Furthermore, OSPAR defines 18 threatened and/or declining habitats, 13 of which are located in the North Sea and only a handful in the Netherlands (intertidal *Mytilus edulis* beds on mixed and sandy sediment, intertidal mudflats, *Ostrea edulis* beds, *Sabellaria spinulosa* reefs, sea-pen and burrowing megafauna communities, *Zostera* beds; Bos et al. 2012). In this chapter, we will discuss two large groups of North Sea benthic habitats: soft substrate and hard substrate habitats.

### 3.2.1 Soft substrate

The vast majority of current benthic habitats in the Dutch part of the North Sea, comprising a large share of the marine biodiversity, is composed of soft substrate. This encompasses both sand and mud, in mixtures of varying compositions and sometimes also containing gravel. Biogenic material, such as organic matter or shells and shell fragments, occurs intermixed with the inorganic sediment. Sand is the dominant sediment in much of the Southern Bight and coastal zone, as well as on the Dogger Bank. The Oyster Grounds are covered with finer sediment. That also counts for the Wadden Sea and Southwestern Delta, where intertidal flats are formed in the littoral zone. Soft sediment hosts a wide range of species living below or on top of the surface (the endo- end epibenthos, respectively) and provides habitat for many other species that move freely over the sediment surface (the hyperbenthos). The soft-sediment benthos forms a crucial part of the marine food web, serving as food for larger animals such as fish, birds or marine mammals, and feeding on smaller organisms or detritus. Sediment reworking by benthic fauna buries organic matter below the oxic zone and leads to carbon sequestration in undisturbed sediments.

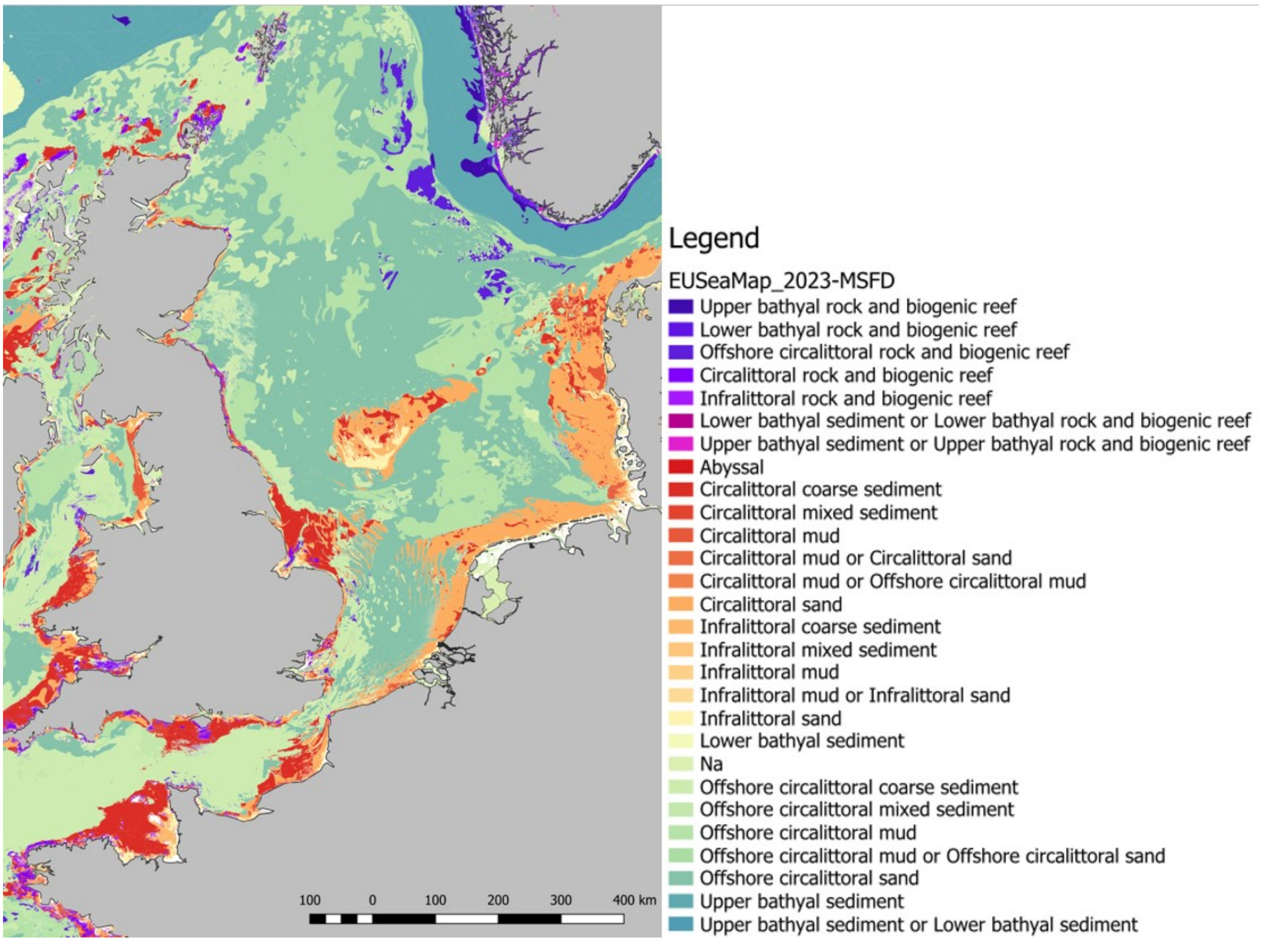


***Figure 3-2*** *EUNIS benthic habitats in and around the North Sea. Source: EMODnet. An update of this classification, based on more recent data, is currently being developed.*

According to the most recent OSPAR Quality status Report (OSPAR 2023), the benthic habitats of the Southern North Sea are impoverished. The most important factors affecting these habitats are eutrophication, bottom trawling, offshore infrastructure, and sediment extraction. Not all areas within the Dutch part of the North Sea suffer equally from all pressures. For example, eutrophication is mostly an issue along the coast, while disturbance from bottom trawling is highest on the Oyster Grounds (due to both high fishing intensity and the sensitivity of local habitats). Apart from directly impacting benthos, trawling, offshore infrastructure, and sediment extraction can lead to sediment changes in the soft-sediment habitats. As a result of the high anthropogenic pressures, diversity in most habitats is low to moderate.

As an indicator to assess the quality of the benthos in the Dutch North Sea, BISI (Benthic Indicator Species Index; Wijnhoven 2023a) was developed, which quantifies benthic quality based on community data. The quality thus assessed differs between habitats. In deep muddy habitats, quality started to improve slightly in

2021 after a fifteen-year period of decrease until 2018, but remains low. The quality of deep sandy habitats has stabilised over the past decade after a long decrease. In shallow muddy and sandy habitats, quality is low and fluctuating, with small improvements in some areas. For habitat type H1110 (sandbanks permanently covered by seawater), targets are not met. However, recent closures of some areas (among which the Dogger Bank) may reverse this situation in the future. The shallow habitats with coarse sediment are located within shallow sandy areas and show similar trends, albeit with a seemingly better recent improvement (Wijnhoven 2023b).

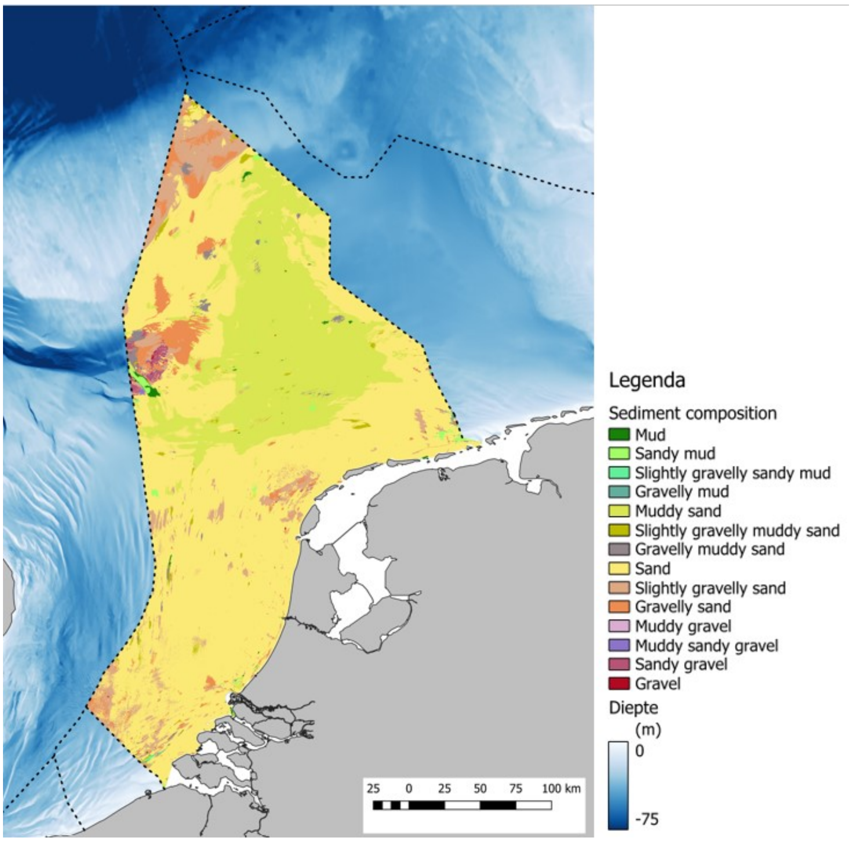


***Figure 3-3*** *Distribution of different sediment types in the Dutch part of the North Sea. Source: TNO,* *[https://www.dinoloket.nl/zeebodemsedimentkaart](https://www.dinoloket.nl/zeebodemsedimentkaart). This map is not yet used as a basis for the EUNIS benthic habitat classification in Figure 3.2, but will be integrated in the near future.*

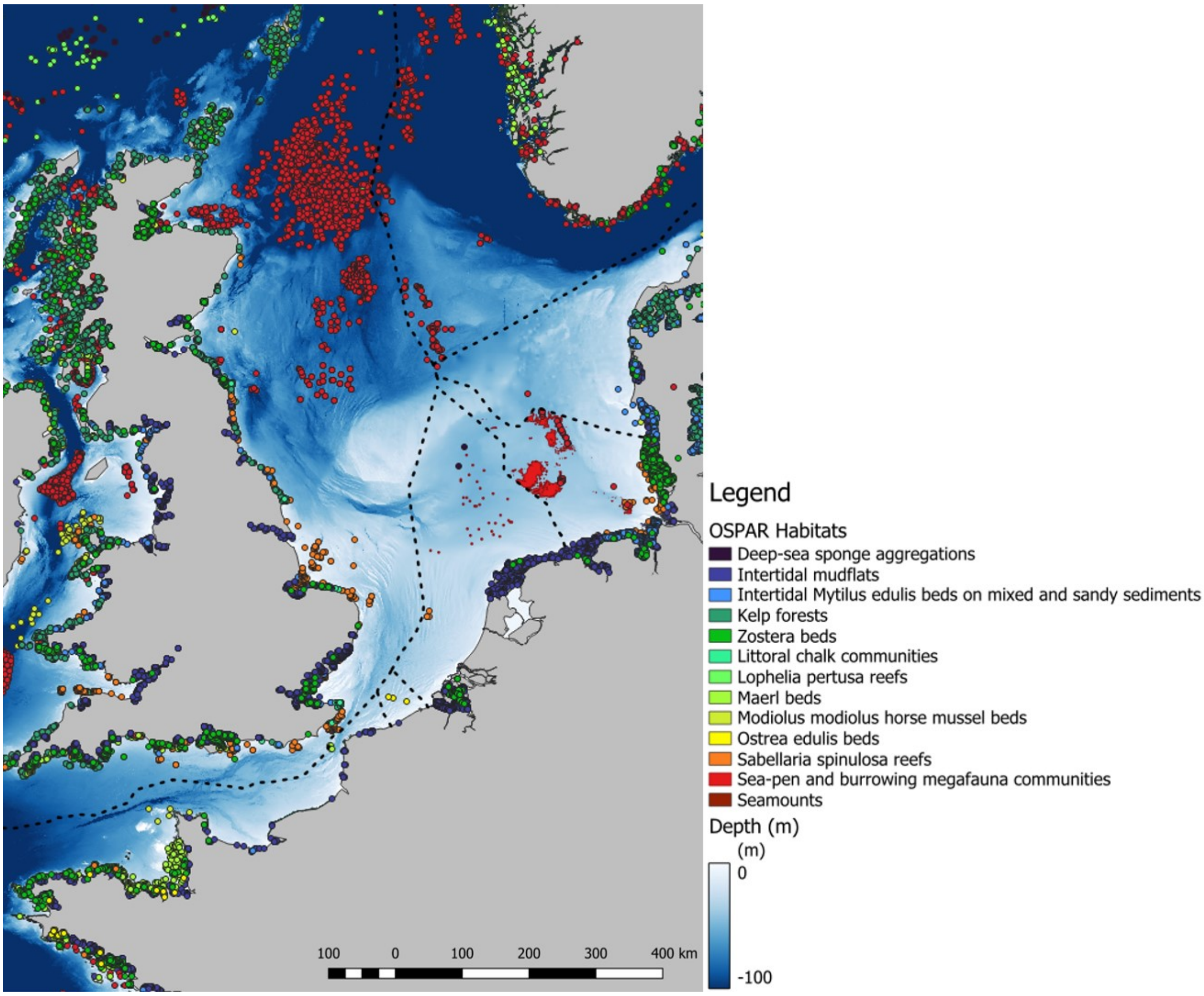


***Figure 3-4*** *OSPAR threatened and/or declining habitats in and around the North Sea. Source: OSPAR. Round dots, point sources; other shapes, polygons.*

The only existing measure currently in place to protect and/or restore soft-sediment benthic habitats is the establishment of areas protected against bottom-disturbing activities. Such closures are already in place at the Central Oyster Grounds (protected under the Marine Strategy Framework Directive), the Frisian Front (Natura2000 and MSFD), the Dogger Bank (Natura2000) and partly at the Cleaver Bank (Natura2000), North Sea Coastal Zone (Natura2000), Voordelta (Natura2000) and Vlakte van de Raan (Natura2000). The sediment around offshore wind turbines is *de facto* protected by a general ban on bottom trawling in wind farms. Measures to restore biogenic reefs are at present only being deployed at small scales. Large-scale implementation is needed for the restoration of these biogenic habitats.

### 3.2.2 Hard substrate (abiotic and biogenic)

Natural geogenic hard substrate habitats are relatively scarce in the southern North Sea. Only at the Cleaver Bank and at some locations near the coast (e.g. Borkum Reef Grounds, Texel Rough) relatively large-scale gravelly sediments are found (Figure 3.3). It is possible that some smaller hard substrate areas still remain to be discovered. The material in these deposits originated from Scandinavia and was deposited in what is now the southern North Sea during one of the last two glacial periods (Veenstra 1969). Biogenic materials such as wood, shell beds, biogenic reefs or moorlog (surfacing peat layers) can also form hard substrate habitats. Historically, large areas were covered by biogenic reefs of, mostly, European flat oysters (Thurstan et al. 2024) (see Section 7.1 Biogenic reefs). However, much of the geogenic hard substrate was likely destroyed and removed by fishing and the most widespread category of hard substrate in the present-day southern North Sea is probably anthropogenic hard substrate. This category consists of shipwrecks, offshore drilling rigs, wind turbines, scour protection layers, coastal infrastructure etc. and is believed to increase more than any other habitat type in the near future.

In the mostly soft-sediment southern North Sea, hard substrate harbour specific communities of epibenthic species. As this habitat is structurally more diverse than soft sediment, many non-burrowing species are often attracted for shelter from predation or adverse environmental conditions. The resulting communities tend to be species-rich and productive. It is unknown to what extent natural hard substrate has decreased in historic times. Oyster reefs are known to have covered a large part of the Oyster Grounds (Olsen, 1883), but along with much other hard substrate, they were destroyed, fragmented, or covered by sediment due to persistent bottom trawling, sediment extraction and dredging (Bennema, 2022).

Currently, the hard substrate habitats of the Cleaver Bank and Borkum Reef Grounds are protected under Natura 2000 and the Marine Strategy Framework Directive, respectively. Next to the hard substrates, soft sediment can be inhabited by biogenic reefs, such as bivalve beds, which to some extent offer similar opportunities for attachment or shelter (see Section 7.2 Long-lived shellfish and burrowing megafauna). A range of projects, among which several No-regret projects (e.g. Frisian Front Micrositing), and studies into habitat suitability mapping of reef- or other habitat-forming species, are already on the way. Restoring hard substrate through the addition of stones and boulders can also be deployed in protected areas, where communities are allowed to form without being affected by bottom-disturbing activities.

### 3.2.3 Artificial hard substrate

In the North Sea artificial hard substrate is present in the form of scour protection of offshore windfarms, offshore wind turbines, oil and gas platforms, scour protection of these platforms, cable crossings, shipwrecks and buoys (**Figure 3-8**), and along the edges of the North Sea in the form of coastal defence (dikes, dams). With the growth of offshore wind, the amount of artificial hard substrate will increase in the future. To make the artificial hard substrates more attractive to certain species, Nature Inclusive Design (NIDs) can be applied to create more attractive habitats, nursery areas, feeding areas or e.g. spawning habitat (Hermans et al. 2020).

Because artificial hard substrates are often structurally and/or compositionally different from natural substrates (e.g. wind turbines occupy the entire vertical depth of the water column and have different surface characteristics than natural stones), they cannot be considered perfect alternatives. Studies have indicated that the taxonomic or functional composition of communities on these surfaces is often significantly different from those on natural substrates (Smith & Rule, 2002; Brzana et al. 2024).

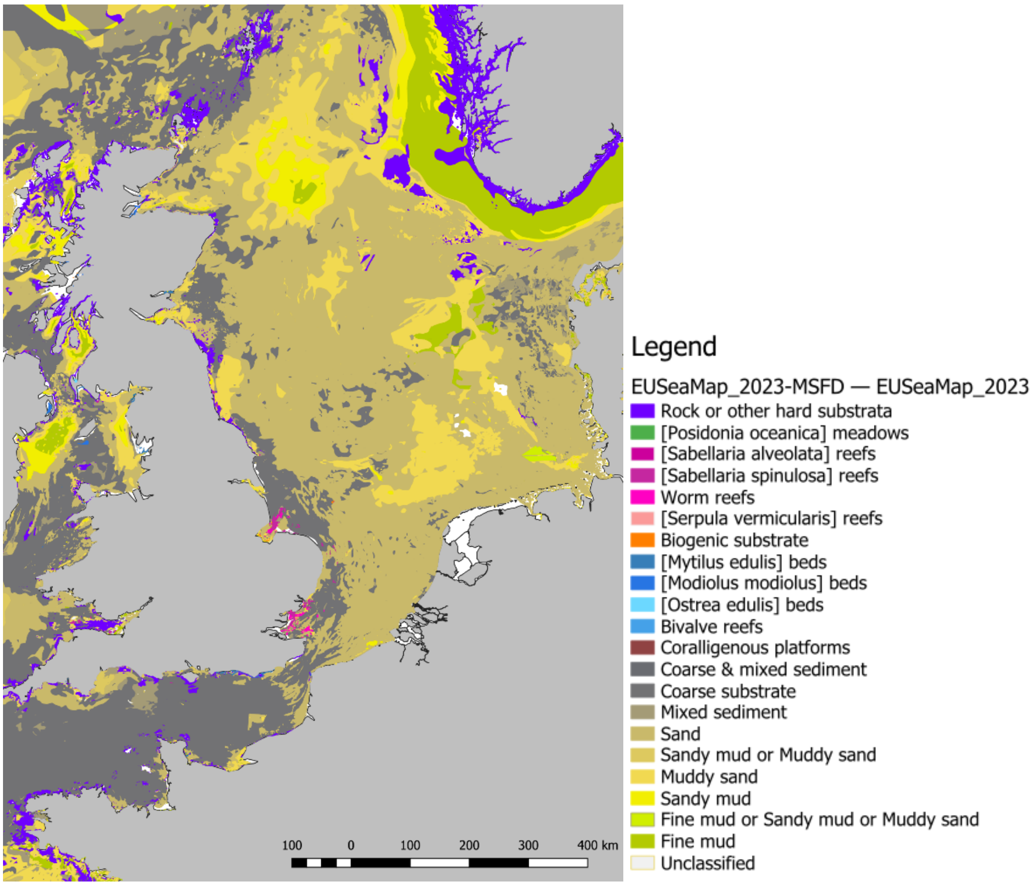


***Figure 3-5*** *Distribution of different substrate types in and around the North Sea. Source: EMODnet.*

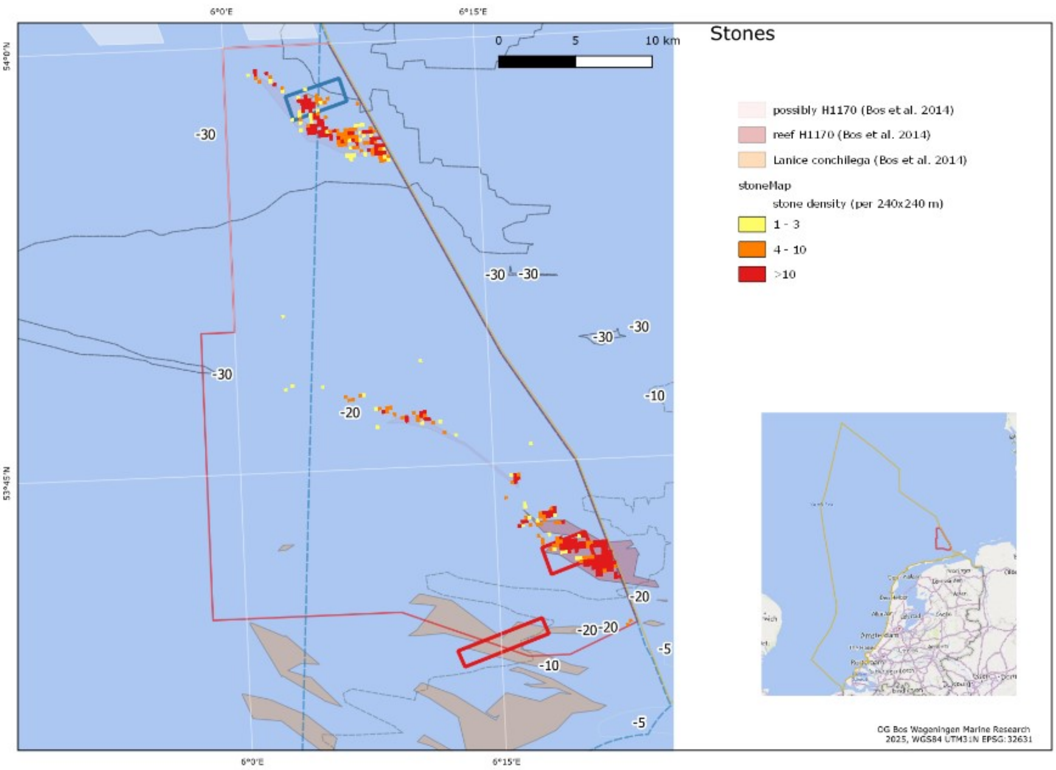


***Figure 3-6*** *Stone coverage density map of the Borkum Reef Grounds. The classes indicate the number of stones (visible on SSS images, size ~ >15 cm elevation) within an area of 240 x 240 m. The map is produced via manual selection of stones using the processed and ground projected historic data (Bos et al. 2025).*


***Figure 3-7*** *Habitat Directive Annex I habitat type H1170 (abiotic reefs) at the Cleaver Bank and locations of Hamon grabs in 2021 of the N2000/MSFD sampling program (Leewis & Dzon, 2022).*

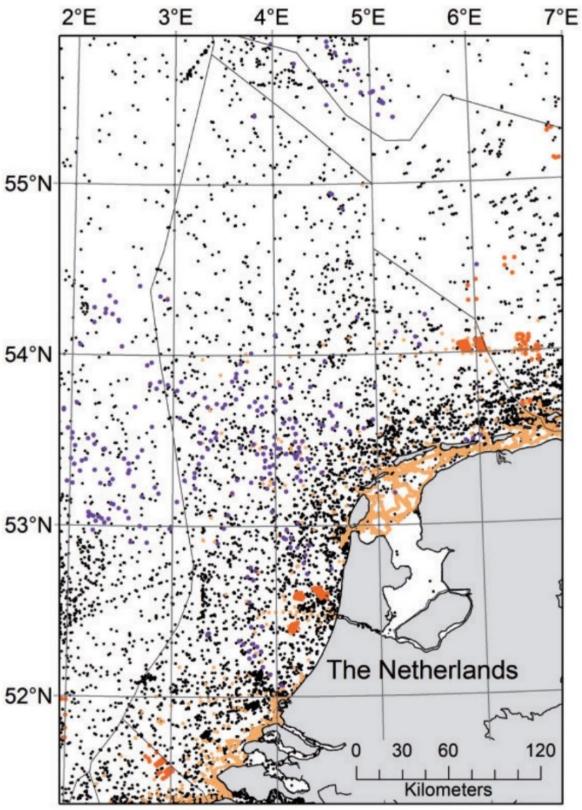


***Figure 3-8*** *Artificial hard substrate (2020): Shipwrecks (black dots), platforms (purple), wind farms (dark orange), buoys (light orange) present on DCS (outlined with black line) (Coolen et al. 2020).*

## 3.3 Current policy

For pelagic habitats the Habitats Directive (HD), as well as the Water Framework Directive (WFD) and the Marine Strategy Framework Directive (MSFD) are relevant. The latter is also instrumental in improving pollution related issues such as regulations surrounding plastic pollution (macro, micro and nano plastics). Furthermore, the Paris agreement and the national measures to reduce greenhouse gas emissions, are instrumental in limiting climate change being a major factor determining changes in temperature and stratification.

For benthic habitats a number of strategies and directives are important. Under the EU Biodiversity Strategy targets are set to protect 30% of the seabed, and 10% under strict protection. Implementing and enforcing seabed protection in these areas is the remit of national governments. Different EU policies help to protect benthic habitats: the HD via Natura 2000, the MSFD and the NRR. Fishery management measures, such as bans on bottom trawling, are implemented via the CFP. Mining of sand, gravel and shells is described in the Sandmining Strategy.

### 3.3.1 Policy measures

- Water quality: With respect to the pelagic habitats, water quality is one of the main issues. Measures to improve water quality and reduce the eutrophication status are covered partially by policies focussed on land / freshwater systems as agricultural run-off is a major contributor.
- Marine protected areas (MSFD/N2000 areas) and fishery measures in MPAs:
  - Since March 2023 the Cleaver Bank (H1170), the Frisian Front (MSFD area) and Central Oyster Grounds (MSFD area) have been partially closed for seafloor disturbing fisheries via the Art 11 procedure of the CFP. BD area Frisian Front is closed for gillnet fisheries for half a year per year.

- In November 2023 the Natura 2000 management plans[2] for Cleaver Bank, Frisian Front and Dogger Bank were put into operation by the Dutch Government. In these management plans, measures are listed for activities under national jurisdiction (oil and gas, pipelines, cables, etc). The management documents mainly focus on measures to minimise impact of activities.
- Since November 2025 the Dogger Bank (H1110C) has been partially closed for seafloor disturbing fisheries via the Art 11 procedure of the CFP[3].
- Additional MPAs or areas within MPAs will be closed to seafloor disturbing fisheries in the future. The Dutch government aims to close 15% of the Dutch North Sea for seafloor disturbing fisheries before 2030 in MPA's.

- Sand mining
  Sand and gravel mining takes place between the -20 m depth contour and the 12Nm border (14 Nm in the future: partiële herziening Programma Noordzee (Ministerie van Infrastructuur en Waterstaat, 2025) (Figure 3-10- up to the 12Nm border - and Mining Strategy).

- EU Nature Restoration Regulation (NRR):
  - EU Member States have to deliver a National Restoration Plan (NRP) by 2026 including restoration of marine habitats.
  - EU Member States have to implement restoration measures for at least 30% of the total area of all habitat types listed in Annex II of the NRR that are not in good condition (increasing to 60% in 2040 and 90% in 2050; article 5.1 NRR). To determine what these restoration targets mean, Member States must first establish Favourable Reference Areas for each habitat. Furthermore, the NRR states that for targets of broader habitats, group 7, (most of the soft sediment seafloor in the North Sea), Member States have to set a percentage themselves (see WMR report of De Froe et al. (2025)).
  - The WMR report of De Froe et al. (2025) indicates that most of the soft sediment is not in good ecological quality according to the BISI score, and therefore restoration needs to focus on improving quality.

## 3.4 Advice, action perspectives and possible measures

### 3.4.1 Pelagic habitats

*Rationale*
Recovery largely depends on system-level drivers (water quality, nutrient inputs, climate/temperature) and ecological drivers (stratification, nutrient loads, light climate). These are well understood in parts, but direct habitat-forming interventions are limited.

*Action perspective for NN*
There is little direct action perspective for NN. NN could add value by locally targeted pilots that test indirect pathways (e.g., localized nutrient buffering, nature-inclusive designs that alter local stratification near infrastructure). This will then be mainly indirect measures that can improve water quality, that are closely linked to the remit of NN. The measures targeting nutrient buffering or NiD that change local hydrodynamics sufficiently to change mixing are classified as RRL1-2.

*Demonstration of impact*
Demonstration of impact should be largely done through local water quality measures coupled with background information from long-term monitoring programmes, such as MWTL. Certain aspects will be very difficult to link directly to measures, e.g. changes in primary production. Firstly, there are relatively few primary production measurements available and secondly this is a parameter which is highly variable on

[2] https://www.rwsnatura2000.nl/gebieden/eez/eez_documenten/default.aspx#folder=2577424
[3] Doggersbank gedeeltelijk gesloten vanaf 18 november | Nieuwsbericht | Rijksoverheid.nl

many temporal scales (weather, season, annual variability, climate). Factors such as impact of measures on local turbidity and chlorophyll levels may be easier to attribute to specific measures.

### 3.4.2 Benthic habitats

*Rationale*
Soft sediment, biogenic reefs and natural hard substate habitats including their benthic fauna are heavily disturbed by human activities, such as through seafloor disturbing fisheries and sand extraction. Parts of these habitats are protected via fishery measures in MPAs.

*Action perspective for NN*
For benthic soft sediment and natural hard substrate habitats, the exclusion of seafloor disturbing activities (a policy measure) is the most important passive restoration measure, before any active restoration (such as the restoration of biogenic reefs) can take place. Once protection is in place, hard substrates could be restored as follows:

Active restoration of stone reefs (RRL 4-5): Natural hard substrates (abiotic reefs) are relatively rare in the Dutch part of the North Sea. The naturally occurring large boulders, remnants from the last ice age have probably partly been removed over the course of the 20$^{th}$ century to facilitate bottom trawling. In areas that historically had such features, such as the Borkum Reef Grounds and the Texel Roughs, there may be good arguments to aim for habitat restoration similar to boulder reef restoration efforts in Denmark (ICES 2025; Dahl et al. 2024; Helmich et al. 2020), following thorough guidelines connecting historic information on site specific occurrence to restoration practice.

Artificial hard substrate (RRL 6-7): While natural hard substrate is rare in the Dutch EEZ, there are substantial amounts of artificial hard substrate (wind farms, wrecks, buoys, coastal infrastructure etc.). Although most artificial structures are located in soft-sediment environments and therefore provide unnatural settings for the local ecosystem, they can sometimes serve as a foundation for the establishment of some desired communities, such as oyster reefs on shipwrecks. However, due to their different properties from both soft and natural hard substrates, it is generally not recommended to deliberately add artificial hard substrates.

Note that restoration of biogenic reefs and other benthic fauna are discussed elsewhere (see Chapter 3.2).

*Demonstration of impact*
To demonstrate the impact of the measures, monitoring will be set-up, in line with regular national monitoring (N2000/MSFD MWTL) and best practices (e.g. on boulder reef restoration, Denmark).

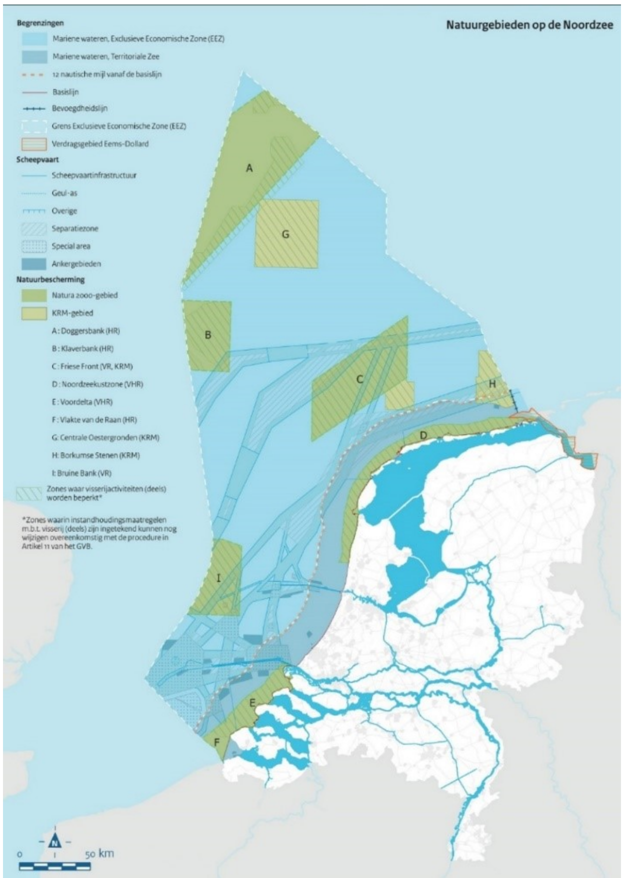


***Figure 3-9*** *Natura2000 and MSFD MPAs on the Dutch North Sea (https://www.noordzeeloket.nl/beheer/beschermde-natuurgebieden/)*


***Figure 3-10*** *Sand and gravel extraction areas on the Dutch North Sea (https://www.noordzeeloket.nl/functies-gebruik/zand-grindwinning/).*

## 3.5 References


Bennema, F.P. (2022). North Sea benthos 1902 – 1912 – Distribution based on Huxley, Wodan and Poseidon surveys data, Second edition. MarHis.

Bos, O.G., R. van Hal, R. van Bemmelen, A.J. Paijmans, and M.T. van der Sluis. (2012). OSPAR threatened and/or declining species and habitats in the Netherlands. IMARES Wageningen UR.

Bos, O.G., Bittner, O., van der Weide, B., Cuperus, J., Wijnhoven, S., Gaida, T., & Binnerts, B. (2025 in prep). Borkum Reef Grounds: inventory of biodiversity and habitats. MONS ID49 Effectivity of Marine Protected Areas ID. Wageningen Marine Research. Waardenburg Ecology. Ecoauthor. TNO. Wageningen Marine Research report.

Brzana, R., M. B. Peschke, and U. Janas. (2024). Biodiversity and functioning of benthic macrofauna associated with natural and artificial hard substrate in the Gulf of Gdansk (Baltic Sea). Marine Environmental Research 199: 106592.

Dahl, K., Stæhr, P.A.U., Göke, C., Svendsen, J.C., Steinfurth, R.C.H. and Jørgensen T.B. (2024) Best practice for boulder reef restoration. Scientific report from the National Centre for Marine Nature Restoration. https://www.danishmarinerestoration.com/media/72639/stenrev-best-practice.pdf

de Boer, G.J., J.D. Pietrzak, and J.C. Winterwerp. (2009). SST observations of upwelling induced by tidal straining in the Rhine ROFI. Cont. Shelf Res. 29:263-277.

Coolen, J. W. P., van der Weide, B. E., Cuperus, J., Blomberg, M., van Moorsel, G. W. N. M., Faasse, M. A., Bos, O. G., Degraer, S., & Lindeboom, H. J. (2020). Benthic biodiversity on old platforms, young wind farms and rocky reefs. *ICES J. Mar. Sci.*, *77*(3), 1250–1265.

De Vries, J.J., J.J. Nauw, H. Ridderinkhof, and H.M. van Aken. (2014). An exploratory study of the variability of currents and density in the Marsdiep. Cont. Shelf Res. 84:70-83.

Dewicke, A., V. Rottiers, J. Mees, and M. Vincx. 2002. Evidence for an enriched hyperbenthic fauna in the Frisian front (North Sea). Journal of Sea Research 47:121-139.

Helmig, S.A., Nielsen, M.M. & Petersen, J.K. (2020). Andre presfaktorer end næringsstoffer og klimaforandringer – vurdering af omfanget af stenfiskeri i kyst-nære marine områder. DTU Aqua-rapport nr. 360-2020. Institut for Akvatiske Ressourcer, Danmarks Tekniske Universitet. 24 pp.

Hermans, A., Bos, O.G., & Prusina, I. (2020). Nature-Inclusive Design: a catalogue for offshore wind infrastructure (Report 114266/20-004.274). Witteveen + Bos, Wageningen Marine Research. https://edepot.wur.nl/518699

ICES (2025). *Workshop on Nature Restoration and Recovery (WKREST). ICES Scientific Reports. 7:46. 172 pp.* https://doi.org/10.17895/ices.pub.28759463

Leewis, L., & Dzon, B. (2022). Macrozoöbenthos monitoring op de Klaverbank 2021 - Hamon happer. www.eurofins.nl/milieu

Ministerie van Infrastructuur en Waterstaat (2025). Ontwerp Partiële Herziening Programma Noordzee 2022-2027 *(Concept)*.

Olsen, O.T. (1883). The piscatorial atlas of the North Sea, English Channel, and St. George's Channels: illustrating the fishing ports, boats, gear, species of fish (how, where, and when caught), and other information concerning fish and fisheries. Taylor and Francis, London.

OSPAR. (2023). Eutrophication Thematic Assessment. OSPAR, 2023: Quality Status Report 2023.

Sharples, J., O.N. Ross, B.E. Scott, S.P.R. Greenstreet, and H. Fraser. (2006). Inter-annual variability in the timing of stratification and the spring bloom in the North-western North Sea. Continental Shelf Research 26:733-751.

Simpson, J.H. (1997). Physical processes in the ROFI regime. Journal of Marine Systems 12:3-15.

Smith, S.D.A., and M.J. Rule. (2002). Artificial substrata in a shallow sublittoral habitat: do they adequately represent natural habitats or the local species pool? J. Exp. Mar. Biol. Ecol. 277: 25-41.

Tett, P. (1990). The photic zone. Light and Life in the Sea:59-87.

van Leeuwen, S. M., J. van der Molen, P. Ruardij, L. Fernand, and T. Jickells. (2013). Modelling the contribution of deep chlorophyll maxima to annual primary production in the North Sea. Biogeochemistry 113:137-152.

Veenstra, H. J. (1969). Gravels of the southern North Sea. Marine Geology 7: 449-464.

Wijnhoven, S. (2023a). Protocol Benthic Indicator Species Index (BISI): Protocol BISI for generic application (BISI v3). Version v170424. Ecoauthor Report Series 2023-01, Heinkenszand, the Netherlands.

Wijnhoven, S. (2023b). Beoordeling kwaliteitstoestand Nederlandse deel Noordzee op basis van de Benthische Indicator Soorten Index (BISI). Toestand en ontwikkelingen van benthische habitats en HR-/KRM-gebieden gedurende 2016-2021 in vergelijking tot voorgaande jaren. Ecoauthor Report Series 2023-02, Heinekenszand, the Netherlands.

# 4 Plankton

*Auteur: Luca van Duren*

## 4.1 Phytoplankton

### 4.1.1 Description of the ecosystem component

Phytoplankton consists of small, mostly unicellular 'plant-like' organisms, that float in the water column. They are autotrophic, i.e. they use inorganic nutrient (such as nitrogen compounds and phosphate) and produce biomass by photosynthesis, under the influence of light (Reynolds 2006). In the marine environment three groups are dominant:

1) Diatoms
2) Dinoflagellates
3) Haptophytes

Of these groups the diatoms and haptophytes are dominant in shelf seas, such as the North Sea. In the more open ocean, also green algae (chlorophytes) are common and can dominate (Simon et al. 2009).

Photosynthesis is mediated via pigments, chlorophyll being the most important of them. Chlorophyll-*a* is relatively easy to measure, either *in situ*, or using earth observation (De Cauwer et al. 2004, Blauw et al. 2018). Hence, chlorophyll is often used as a proxy to measure phytoplankton biomass.

### 4.1.2 Species selection

For phytoplankton we will not consider individual species but mainly treat the entire complex of species as a whole. Due to their specific nutritional value to 'grazers' we will pay attention to the group of diatoms, and we will briefly address some nuisance and toxic groups, such as *Phaeocystis* sp. and certain groups of dinoflagellates.

### 4.1.3 Habitat preferences

Phytoplankton is driven by light and nutrient availability. Although light availability is influenced by depth and seabed composition, phytoplankton is not directly linked to specific benthic habitats. Certain species are adapted to e.g. low phosphate concentrations, low nitrogen concentrations or low light availability. In the different pelagic habitats identified by OSPAR different average phytoplankton biomass concentrations occur as well as different species compositions tend to dominate (OSPAR 2023a).

Occurrence of certain species is linked to the drivers of primary production. Close to the coast where the water is shallow and light penetrates a large part of the water column and nutrient concentrations are high, phytoplankton biomass and primary production is highest (Joint and Pomroy 1993, Ruardij et al. 1997, Llope et al. 2009). In shallow areas with high densities of benthic filter feeders, phytoplankton densities can also be influenced by filtration pressure.

### 4.1.4 Ecosystem function

Marine phytoplankton organisms account for more than 45% of the photosynthetic net primary production on Earth (Simon et al. 2009). Phytoplankton is the foundation of all life in the marine food web. Very few larger animals eat phytoplankton directly, but through intermediate food web links (zooplankton and zoobenthos) phytoplankton biomass ultimately ends up in the apex predators.

The growth of phytoplankton is termed 'primary production'. This is the production of phytoplankton biomass, generally expressed in grams carbon per unit surface area per time unit (most often per day). Primary production is determined directly by 1) the availability of macro-nutrients, such as nitrogen compounds (ammonia, nitrite and nitrate), phosphate and specifically for diatoms also silicate and 2) the availability of light in the water column. In most areas primary productivity is limited either by specific nutrients or by light, with differences in the limiting factor per region and per season. Indirectly, the availability of nutrients in the photic zone (the upper zone of the water column with sufficient light for primary production) can be governed by horizontal and vertical transport processes, and phenomena, such as stratification (Ruardij et al. 1997, Sharples et al. 2006, Wiles et al. 2006). Generally, in the North Sea, light is limiting in winter and certain nutrients are limiting in summer. In areas that are overstocked with grazers (mainly lagoons and bays with extensive shellfish farming) primary production can be limited by overgrazing, i.e. when the grazing rate on phytoplankton exceeds the maximum primary production rate (McKindsey et al. 2006).

Phytoplankton is the main food for herbivorous marine animals, such as copepods and krill in the water column and shellfish and worms on the seabed. However, the palatability and digestibility differ among types and species of phytoplankton. Generally, diatoms are considered the most nutritionally valuable (De Wilde et al. 1992), although certain diatom species appear to reduce egg viability in copepods (Ianora et al. 2003). Colony formation may be a defence mechanism for phytoplankton against predation. Certainly, colonies of e.g. *Phaeocystis* sp. (the foam alga) tend to be superfluent, allowing this species to bloom nearly uncontrolled under certain conditions (Rousseau et al. 2000, Tang 2003).

There are a number of phytoplankton species (mainly dinoflagellates and certain diatom species) that can produce toxins. Often the primary grazers (zooplankton of shellfish) are relatively immune for these toxins, but accumulation in e.g. shellfish can cause severe problems when consumed by higher trophic levels, including humans (Steidinger and Baden 1984, Camacho et al. 2007).

### 4.1.5 Status and trend ecosystem component

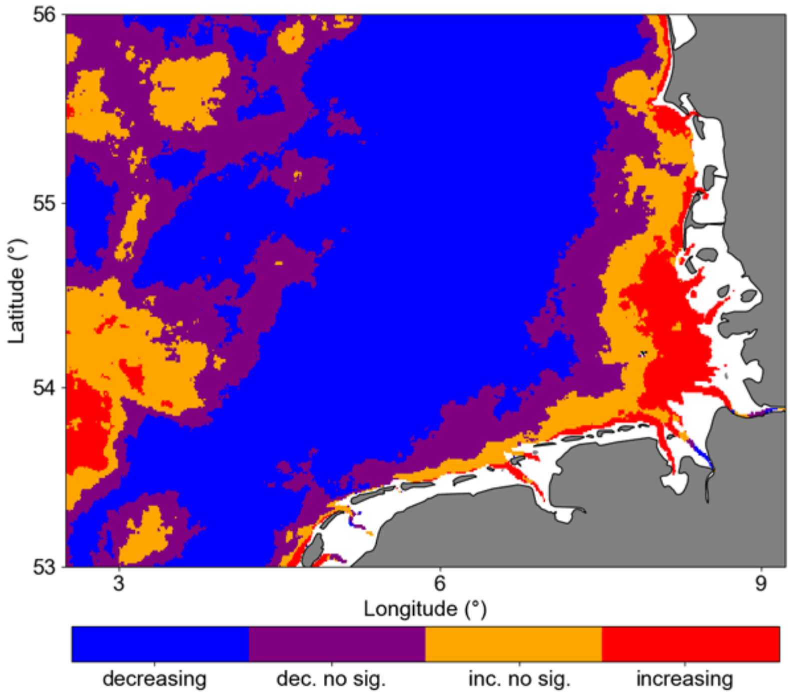


***Figure 4-1*** *Increases and decreases in North Sea chlorophyll a between 1998 and 2020 (de Luca Lopes de Amorim et al. 2024).*

Status and trends of phytoplankton are evaluated under the MSFD. Overall, most studies predict overall decreasing productivity with climate change in the North Sea (Capuzzo et al. 2018). However, this can change markedly, depending on areas. De Luca Lopes de Armorim (2024) found that over the most part of the North Sea, primary production declined between 1998 and 2020, while in coastal areas under the influence of river run-off productivity increased (see Figure 4.1). Prior to this, the North Sea was under the influence of severe eutrophication since the mid-seventies (Desmit et al 2020).

### 4.1.6 Pressures and impacts

#### 4.1.6.1 Nutrient availability

Eutrophication has been a major issue in European waters, including the marine environment, since the nineteen eighties (Stegert et al. 2021). The WFD was adopted to safeguard ecosystem health, including water quality (European Commission 2000). In pristine marine areas, usually nitrogen compounds are limiting, while in freshwater areas phosphate tends to be the limiting nutrient. In recent years nutrient loads from land to sea have been reduced, mainly due to the WFD (Prins et al. 2012). Phosphate loads have been reduced much more than nitrogen, leading to regular phosphate limitation in near-shore environments (Prins et al. 2012, Lenhart and Große 2018). This appears to have affected the composition of near-shore phytoplankton groups (Groß et al. 2022). Over longer time-scales changes in nutrient loads appear to be the dominant factor in the Southern North Sea (Clark and Frid 2001).

#### 4.1.6.2 Climate change

Climate change is also affecting phytoplankton. Firstly, the changes in temperature and acidity can impact growth and composition. Secondly, increasing temperatures will also increase summer stratification, which imposes limitations on primary production, as free nutrients in deeper water layers cannot be utilised in the photic zone (Sharples et al. 2006). An earlier onset of stratification can also lead to an earlier spring bloom, leading to potential mismatches for animals timing migration or spawning to the spring bloom. (Sharples et al. 2006). On the other hand, increased CO2 concentrations have a fertilizing effect that stimulates primary production (Tortell et al. 2008), phytoplankton growth and biomass (Egge et al. 2009), and the efficiency of phytoplankton in using limiting nutrients (Paul et al. 2015).

#### 4.1.6.3 Energy transition

In recent years the development of offshore wind farms has increased dramatically (WindEurope 2019). The interaction of currents and waves with support structures, as well as the impact on the wind field is likely to affect several fundamental oceanic processes, leading to impacts on primary production (Boon et al. 2018). The impact appears to differ per region of the North Sea, depending on depth, stratification regime, bed composition etc., according to numerical modelling exercises (Van Duren et al. 2021, Dorrell et al. 2022). Impacts are becoming visible in field surveys (Floeter et al. 2017).

#### 4.1.6.4 Food transition

There is also a trend in food production on the North Sea shifting from wild harvesting (mainly fisheries) to more aquaculture. Fed aquaculture (such as finfish) is limited in the Dutch North Sea (Jansen et al. 2016). However, there is a drive towards developing offshore extractive aquaculture such as seaweed and shellfish (Jansen et al. 2016, Jansen et al. 2023). In particular seaweed cultivation (if rolled out at a large scale) has the potential to deplete nutrient levels and negatively impact phytoplankton production (Vilmin and Van Duren 2021, Jansen et al. 2023). However, the current level of technological development for offshore seaweed is still very much in its infancy.

### 4.1.7 Current policy

With respect to phytoplankton, as well as the drivers for primary productivity (nutrients) the EU Marine Strategy Framework offers the direct legal framework for targets in the marine environment (Piroddi et al. 2021). Note that the background of the MSFD with respect to nutrients comes from the historic problems with eutrophication (Ferreira et al. 2011). Limits for potential over-extraction of nutrients (e.g. through seaweed cultivation) are less clearly defined.

OSPAR has set Ecological Quality Ratios for the different Eutrophication assessment areas in the North Sea (https://odims.ospar.org/en/submissions/ospar_chlorophyll_eqrs_2020_01_001/). The MSFD also uses chlorophyll as a proxy for the base of the food web, as eutrophication indicator. Targets are defined based on reconstructions of nutrient and chlorophyll concentrations in the pre-industrial era (roughly corresponding to the late nineteenth century (Stegert et al. 2021). With respect to *primary production* there are no clear targets.

4.1.7.1 Policy measures

There are a number of policy measures that can be taken to comply with the targets in the MSFD. Curbing eutrophication by reducing nutrient run-off from land (urban and agricultural areas) or deposition from the air are the most important ones. Also measures to reduce run-off of herbicides from land may be important in some areas. Such measures are basically the remit of the Water Framework Directive, or legal frameworks such as the "Nitrogen Law" (stikstofwet) regulating nitrogen emissions. Furthermore, measures to safeguard seabed integrity and reduce resuspension of fine sediments (e.g. when establishing concessions for offshore sand mining or when implementing fisheries exclusions zones) can be effective to improve water quality and the light climate.

### 4.1.8 Advice, action perspectives and possible measures

*Rationale*

There are no obvious direct measures to be taken with respect to phytoplankton, which would fall under the remit of NN. In some countries, such as China and in IMTA systems worldwide seaweed cultivation is used to reduce eutrophication (Chung et al. 2002, Roleda and Hurd 2019).

*Action perspective for NN*

For certain near-shore areas with eutrophication problems that are shallow enough to allow seaweed *meadows* to occur, this may be an option to investigate as an indirect measure. However, this needs to be approached with caution as seaweed meadows have never been a common feature near the Dutch coast (See Section 5). Hence, nutrient remediation using near-shore seaweed bed creation should be indicated as RRL 1-2. Further offshore, there are currently efforts to set up commercial seaweed farms. Most of these areas do not score poorly in the OSPAR eutrophication assessment anyway (OSPAR 2023a) and with the emergence of commercial farms, the risk over overextraction of nutrients is something to be aware of. Near-shore off-bottom seaweed farms as remediation measure may conflict with the offshore efforts of commercial attempts to produce seaweed and may also contravene N2000-directives. Also, the farms themselves are very much artificial structures. Hence, establishing offshore seaweed farms for nutrient remediation purposes seems far-fetched as a bona fide NN-measure.

There may be some other indirect measures that can improve water quality, that are closely linked to NN. These consider e.g. restoration of shellfish beds or otherwise improve benthic habitats. These potential NN measures may also have an indirect positive impact on phytoplankton.

*Demonstration of impact*

As phytoplankton is the foundation of the whole marine food web it is mainly an important boundary condition to take into account. To attribute water quality and phytoplankton changes to specific measures, long-term measurements are required. Hence primary production, although important to measure, might be a parameter which cannot be used to assess impacts of certain measures. Changes in nutrient availability, turbidity and chlorophyll are better candidates, due to the quicker responses and larger availability of background measurements.

## 4.2 Zooplankton

### 4.2.1 Description of the ecosystem component

**Definition**

Zooplankton is a crucial link in the marine foodweb. This group consists of many different animal groups. The word "plankton" is derived from the Greek word "planktos", which means "wanderer". Basically, any pelagic, aquatic organism that is not able to swim independently of the main current is called plankton. Mostly, planktonic organisms are very small, many microscopic, but also the Lion's mane jelly fish, with a bell diameter of 2 metres, still counts as plankton. There are many ways to classify zooplankton: by size (macro-,

meso- or microzooplankton) or by diet (herbivores, omnivores and carnivores). In this chapter we use the distinction holoplankton vs. meroplankton. Holoplankton are organisms that spend their whole life as plankton. Meroplankton spend either part of their life cycle as benthos or spend their adult life as "nekton" i.e. organisms that can swim independent of the current, such as fish.
Plankton consists of many phylogenetically very diverse groups. Note: the genetic differences between e.g. copepods, such as *Temora longicornis* and dinoflagellates such as *Noctiluca scintillans* are larger than the genetic difference between chordates such as *Oikopleura dioica* (part of the North Sea plankton) and human beings (*Homo sapiens*). Humans belong to the same phylum! Below is an overview of the most important holoplanktonic and meroplanktonic groups and some of the most conspicuous individual species. Only describing those groups which are in terms of production and biomass the most important would not do justice to the enormous diversity of the zooplankton. Note: this is not exhaustive, but it would go too far to give a complete and/or exhaustive overview. For a more elaborate overview see e.g. Conway (2012).

#### 4.2.1.1 Holoplankton

*Unicellular organisms (protists)*

Among the holoplanktonic unicellular groups, there are organisms such as: dinoflagellates, foraminifera and radiolarians. Dinoflagellates are a planktonic group that can be autotroph (i.e. phytoplankton), mixotroph or heterotroph (Hackett et al. 2004).
Foraminifera is a group of protist organisms, most of which are benthic, but a smaller number are planktonic (Hemleben et al. 2012). Foraminifers often have a kind of shell-like structure built from calcium carbonate. In some parts of the world, they can contribute significantly to the carbon flux towards the seabed (Meilland et al. 2018). Another group of protists are the radiolarians (Biard 2022). Also, single-cell organisms with multiple body compartments, surrounded by a mineral skeleton. Relatively little is known about their ecology

*Cnidaria and Ctenophora (jellyfish and comb jellies)*

The most recognised jellyfish are Scyphomedusae. Most Scyphomedusaeare are meroplanktonic and have sessile adult stages, with the exception of *Pelagia noctiluca*, a holoplanktonic small jelly, known for its bioluminescence. It also occurs in the North Sea (Ferraris et al. 2012). There is a second large group of jellyfish, i.e. comb jellies (Ctenophora) which are holoplanktonic. The most common species of comb jelly are the sea gooseberry, *Pleurobrachia pileus* (Fraser 1970), and species from the genus *Beroe* (Johansson et al. 2018). In recent years there are also common sightings of an invasive species, *Mnemiopsis leidyi*, which may in some cases pose a competitive threat for food to larval fish (Hamer et al. 2011).

*Chaetognaths (arrow worms)*

Most worms are benthic (often with a planktonic larval stage, which makes them meroplankton). However, a few groups are holoplanktonic. Chaetognaths (arrow worms) are a phylum of marine predatory worms, most of which are holoplanktonic (Khan and Williamson 1970). They can make up to 10-30% of the planktonic biomass and are the second-most common component of the zooplankton. They are mostly ambush predators, feeding on copepods, cladocerans, krill and fish larvae. The common species *Parasagitta elegans* was the first species of which the genome was fully mapped (Peijnenburg et al. 2004).

*Crustaceans*

In terms of both numbers and biomass the order of copepoda is by far the most important group of zooplankters. Copepods are the most numerous multicellular organisms in the world (Huys and Boxshall 2000). In the marine environment, particularly calanoid copepods are the most numerous and also the most important direct link between primary producers and higher trophic levels, although many species are omnivorous or predatory (Kleppel 1993). In the near coast of the North Sea predominantly smaller species are observed, such as *Acartia clausi, Temora longicornis, Centropages hamatus, C. typicus* and *Pseudocalanus spp.* (Halsband and Hirche 2001). Further offshore larger species are more dominant such as *Calanus finmarchicus* and *Calanus helgolandicus* (Jónasdóttir and Koski 2011).

Other holoplanktonic crustaceans are e.g. the Euphausiids (krill), with species such as *Meganyctiphanes norvegica* and *Euphausia superba* (Tarling et al. 2010). Particularly in northern parts of the North Sea schools of krill are an important food source for baleen whales, such as minke whales (*Balaenoptera acutorostrata*), and hence form a very short food chain between primary producers and apex predators.

*Chordata*
There are a number of holoplanktonic chordata in the North Sea, such as *Oikopleura dioica* and species of the genus *Fritilaria (Gordetckaia 2024)*. These species feed by producing a mucus net and pumping water into this. These species are therefore able to feed on very tiny picoplankton and bacteria, which are often too small for other filter feeders to consume (Dadon-Pilosof et al. 2023).

#### 4.2.1.2 Meroplankton
Meroplankton consists of animals that have a planktonic life stage and either a benthic stage or have an adult stage that counts as nekton. Those meroplankters that have a benthic life stage, can either have a planktonic larval stage and a benthic adult stage or the other way round.

*Species with larval planktonic stages and adult benthic stages*
This group can consist of very diverse phylogenetic groups such as Annelid worms, such as ragworms, that as adults live endobenthically, but also the larvae of reef building species, such as *Sabellaria spinulosa* and *Lanice conchilega* are planktonic. Nearly all benthic crustacea (barnacles, crabs, langoustines, lobsters) have planktonic larval stages. The same is true for the larvae of shellfish (Mollusca), such as mussels, oysters and horse mussels. Also, the larvae of the group echinoderms, which comprises the starfish, brittle stars, sea cucumbers and sea urchins all have planktonic larvae. At certain times of the year, these larval stages may comprise a substantial part of total plankton biomass (Vincx et al. 2004).

*Species with larval planktonic stages and adult nektonic stages*
This group consists predominantly of fish larvae, although a few chaetognaths also grow large enough and with sufficient swimming capabilities that they count as nekton. In fact, nearly all fish larvae are planktonic, only a few fish (e.g. most shark and ray species) hatch at such a size that they are sufficiently strong swimmers to move independent of the current.

*Species with adult planktonic stages and larval benthic stages*
This group consists nearly exclusively of Cnidaria, i.e. jelly fish. These animals have adults (medusae) that float around in the water column, where they are mainly transported by currents. The medusae reproduce sexually and the larvae settle, mostly on hard substrate, where they reproduce asexually by budding (Thorson 1950).

### 4.2.2 Species selection

Due to the enormous variety of species, we have selected only three groups that have most significance for the functioning of the ecosystem in general and for conservation specifically: calanoid copepods, shellfish larvae, jellyfish.

#### 4.2.2.1 Holoplankton
Calanoid copepods, as indicated in the previous section are by far the most important link between primary production and higher trophic levels. Despite their ecological significance they do not have any conservation status.

#### 4.2.2.2 Meroplankton
The two meroplanktonic groups selected are:

- Shellfish larvae, specifically the larvae of the European flat oyster *Ostrea edulis*. Due to its important function as an ecosystem engineer and its historically large abundance, there is a great deal of effort to recover this species. As it is functionally extinct in the North Sea, larval connectivity is of prime interest.
- Jellyfish. As the sessile life stages of these animals is often related to the presence of hard substrate, the habitat in the North Sea is going to change in their favour.

### 4.2.3 Habitat preferences

#### 4.2.3.1 Holoplankton

Calanoid copepods inhabit the water column, and as such are not bound to any specific benthic habitat. On average, the smaller species (up to 1.5 mm) inhabit the more coastal waters, while the larger species, such as *C. helgolandicus* and the closely related *C. finmarchicus,* are more offshore and open ocean species (Jónasdóttir and Koski 2011). These species tend to be larger (around 3-3.5 mm) (Båmstedt and Ervik 1984).

#### 4.2.3.2 Meroplankton

##### *4.2.3.2.1 Larval oysters (also see chapter 7.1)*

The habitat of larval oysters is linked to that of the adults. In the 10 – 14 days they spend in the water column, they are transported by the ambient currents (Robert et al. 2017, Kamermans et al. 2018). When they are competent to settle, they have strong preferences for calcareous and microtextured substrate (Potet et al. 2021).

##### *4.2.3.2.2 Jellyfish*

Habitat mapping for jellies indicated that occurrence is linked to temperature, salinity and prey index across the North Atlantic (Kennerley et al. 2021). This study also indicated that many of the areas that had a high probability of bloom occurrence were areas that were highly impacted by anthropogenic activities. The sessile (not planktonic) life stages of many jellyfish depend on the availability of hard substrate. This can be natural (stone, shell material) or artificial substrate. For the most common species in the North Sea, the moon jelly *Aurelia aurita*, the preferred locations for the polyps is relatively sheltered, with low to moderate flow velocities, while for many other species this is not well known (van Walraven et al. 2016).

### 4.2.4 Ecosystem function

#### 4.2.4.1 Holoplankton

##### *4.2.4.1.1 Calanoid copepods*

Many calanoid copepods are filter feeders (Paffenhöfer 1984). The majority is herbivorous and feeds on phytoplankton, although some species are predatory. Some common species such as *Acartia tonsa* can switch between filter feeding on phytoplankton and ambush predation (Jonsson and Tiselius 1990). While some adult copepods are omnivorous or carnivorous, the larval stages (nauplii) are nearly all herbivorous, feeding on phytoplankton (Paffenhöfer and Lewis 1989, Rey et al. 2001).

Their prime collective ecosystem function is being the link between primary production and higher trophic levels such as fish. Some fish species remain planktivorous throughout their lives (such as herring and mackerel), but virtually all fish species predate on copepods and other zooplankton in their early life stages. Which means that also all fisheries ultimately depend on these creatures (Roff et al. 1988).

The smaller calanoid copepod species and the nauplii, are the most important food for fish larvae. The larger species have also better abilities to escape predation. They tend to be important food sources for faster swimming adult fish (e.g. herring and mackerel) as well as being food sources for certain baleen whales. In the North Sea, predominantly minke whales, although for these species krill is the preferred food source (Anderwald et al. 2012). Due to the impact of zooplankton on the density and distribution of fish, there are also knock-on impacts on the predators of fish.

#### 4.2.4.2 Meroplankton

##### *4.2.4.2.1 Larval oysters (also see chapter 7.1)*

*Ostrea edulis* is a shellfish species that once was very abundant in the North Sea (Olsen 1883). The benthic adults covered around 17000 $km^2$ of soft-sediment habitat (Bennema et al. 2020; Thurstan et al. 2024), turning it into a hard substrate, thereby providing habitat for a range of organisms (Korringa 1954). *Ostrea edulis* was a keystone species in the North Sea, converting soft substrate into hard complex substrate, enhancing biodiversity by providing habitat to many species. After spawning, larvae are formed in the water column and remain planktonic for about 10-14 days, depending on temperature (Maathuis et al. 2020). The larvae are basically the dispersal vectors for these important ecosystem engineers (Chapman et al. 2021).

*4.2.4.2.2 Jellyfish*

Jellyfish tend to be predators, feeding on other zooplankton and juvenile fish. They are therefore direct competitors with other planktivores, including commercially important species such as herring (Lynam et al. 2005). Jellyfish have faster life cycles than most fish species and can therefore often react faster than many fish species to changes in food availability. They can suddenly occur in very large blooms (Gambill 2015). These blooms may be caused by blooms in zooplankton prey, but as they are plankton themselves, they may also aggregate due to converging currents, such as eddies and gyres (Schnedler-Meyer et al. 2018). Jellyfish themselves are prey to certain bird species, such as fulmars and certain cetaceans, such as humpback whales. Fulmars appear to forage selectively on the jellyfish gonads, which can form in certain times of the year a substantial part of their diet (Byrkjedal and Langhelle, 2019) For most these predators, jellyfish are a relatively small part of their diet. Very few fish species eat jellies; the ocean sunfish, *Mola mola* is one of the few, for which jellyfish are the main part of the diet. This oceanic species occasionally wanders into the North Sea (Breen et al. 2017).

### 4.2.5 Status and trend ecosystem component

4.2.5.1 Holoplankton

*4.2.5.1.1 Copepods*

There are several reports of regime shifts in the North Sea with an overall decline in total copepod biomass and shifts from larger to smaller species (Mortelmans et al. 2021, Deschamps et al. 2024). Much of these trends are likely linked to climate change. The increase of marine heatwaves seems to have negative consequences for dominant North Sea copepod species, such as *Temora longicornis, Acartia clausi*, *Centropages* spp. and *Calanus helgolandicus* (Semmouri et al. 2023). In other parts of the world, observed declines in calanoid copepod taxa may be linked to an increase in gelatinous plankton, particularly blooms of comb jellies (Pierson et al. 2020). The decline in copepod biomass in the North Sea may also be linked to changes in primary production (Capuzzo et al. 2018). The study by Capuzzo et al (2018) used indirect techniques to argue that primary productivity over the past 25 years has diminished, with profound effects, particularly on smaller copepod species in the southern North Sea and knock-on effects for fish larvae. The ultimate cause for the decline in primary production appeared to be a combination of lower nutrient run-off and increased stratification due to climate change (Capuzzo et al. 2018). The recent OSPAR quality status report found that negative trends were more profound offshore than nearshore (OSPAR 2023b). Continuous temporal observations of North Sea zooplankton production only exist since 1958. Based on long term reconstructed climate records and historic Dutch herring fisheries records Scherer et al. (2024) reconstructed a historic plankton index for the North Sea, going back to 800 CE. This index indicated that current levels are indeed historically low (Figure 4-2).

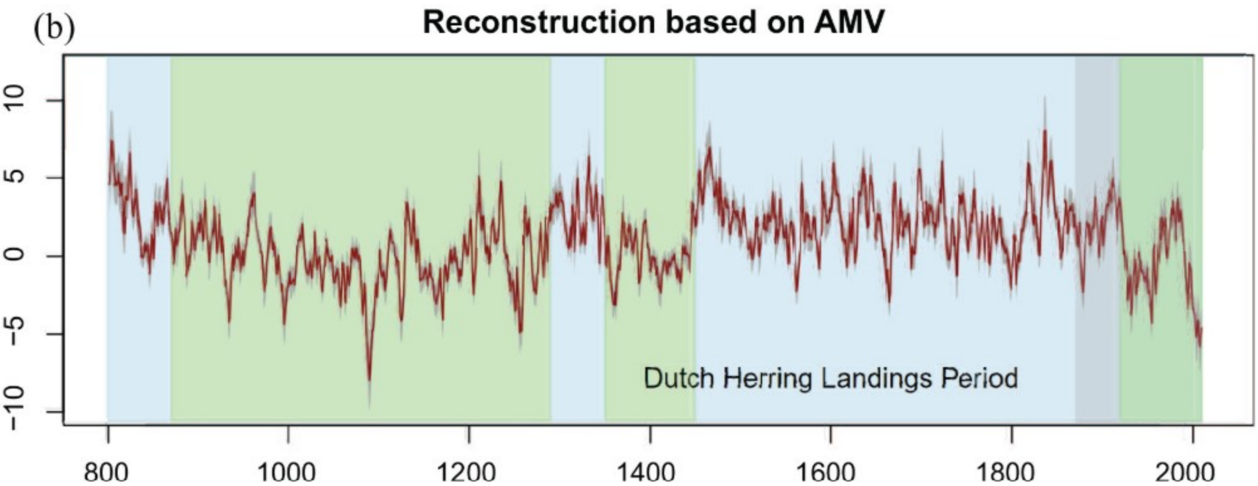


***Figure 4-2*** *Reconstruction of a historic plankton index for the North Sea, based on palaeoceanographic reconstructions of the Atlantic Multidecadal Variability (AMV; Scherer et al 2024). Green shaded periods indicate warmer periods and light blue shaded periods indicate cooler climatic periods).*

#### 4.2.5.2 Meroplankton

##### *4.2.5.2.1 Shellfish larvae (also see chapter 7.1)*

The European flat oyster (*Ostrea edulis*) is currently functionally extinct in the North Sea, due to overfishing and disease (Pogoda et al. 2019). Planktonic larvae are currently predominantly found either near inlets, where the species is cultivated (Kamermans et al. 2023) or near sites where oysters have been deployed for restoration purposes (Bos et al. 2020, Bos et al. 2023). There are a few locations where oyster larvae have been found without a clear source being known. Other shellfish larvae (e.g. mussels, *Mytilus edulis*) occur throughout the system, with higher densities in coastal waters.

##### *4.2.5.2.2 Jellyfish (cnidaria)*

Over the past decades there has been a marked increase in the occurrence of gelatinous zooplankton (Vansteenbrugge et al. 2015, Bosch-Belmar et al. 2020, Pierson et al. 2020). This has been attributed to four different factors, all partly anthropogenic. Firstly, (over)fishing removes important competitors for food. Many jellyfish feed on copepods and other zooplankton species and they can therefore benefit from the reduction of fish stocks that decreases fish predation on copepods (Roux et al. 2013). Climate change is the second cause cited as a main cause (Van Walraven et al. 2015, Lee et al. 2023). Jellyfish thrive in warmer waters and the asexual part of their reproductive cycle occurs more rapidly under these conditions (Purcell 2005, Attrill et al. 2007, Van Walraven et al. 2015, Lee et al. 2023). The third cause is eutrophication, however, this was more important in the North Sea in the 1980s and 1990s (Van Walraven et al. 2015), but is clearly diminished in recent years due to European measures under the Water Framework Directive (Baretta-Bekker et al. 2009). Also, eutrophication can in severe cases lead to low oxygen levels. Jellyfish can survive in low oxygen environments, giving them a competitive advantage (Purcell 2005). The fourth factor is the increase of artificial hard substrate in the North Sea as well as other waters (Holst and Jarms 2007, Janßen et al. 2013).

### 4.2.6 Distribution

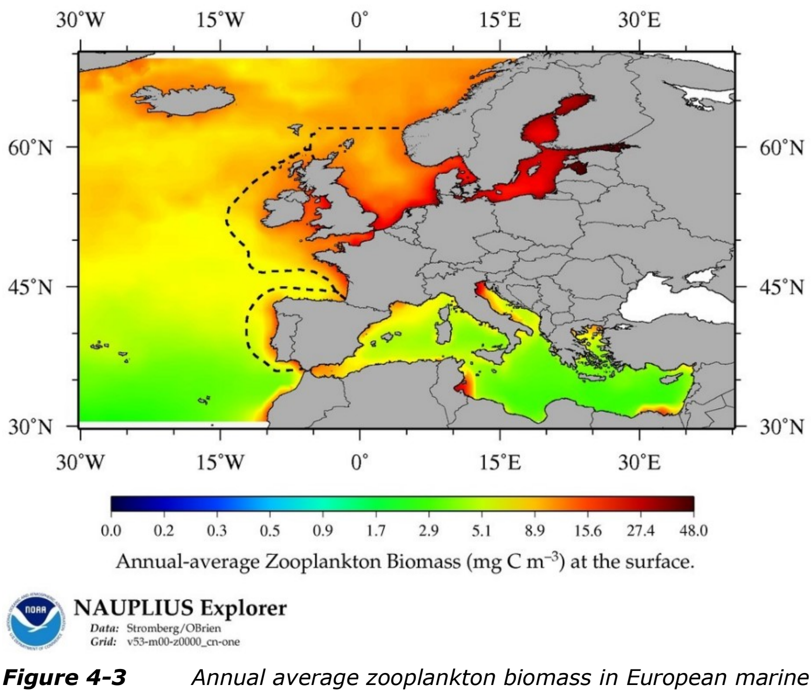


***Figure 4-3*** *Annual average zooplankton biomass in European marine waters. Data from the NOAA Nauplius database (https://www.st.nmfs.noaa.gov/copepod/naupex/europe-main/).*

Overall, the distribution of zooplankton biomass distribution is similar to phytoplankton biomass distribution. The North Sea is a very productive system and hence has relatively large biomasses of zooplankton in comparison to the open Atlantic Ocean or the Mediterranean Sea. Biomasses are highest near the coast, where primary production is highest due to high abundance in nutrients (Figure 4-3).

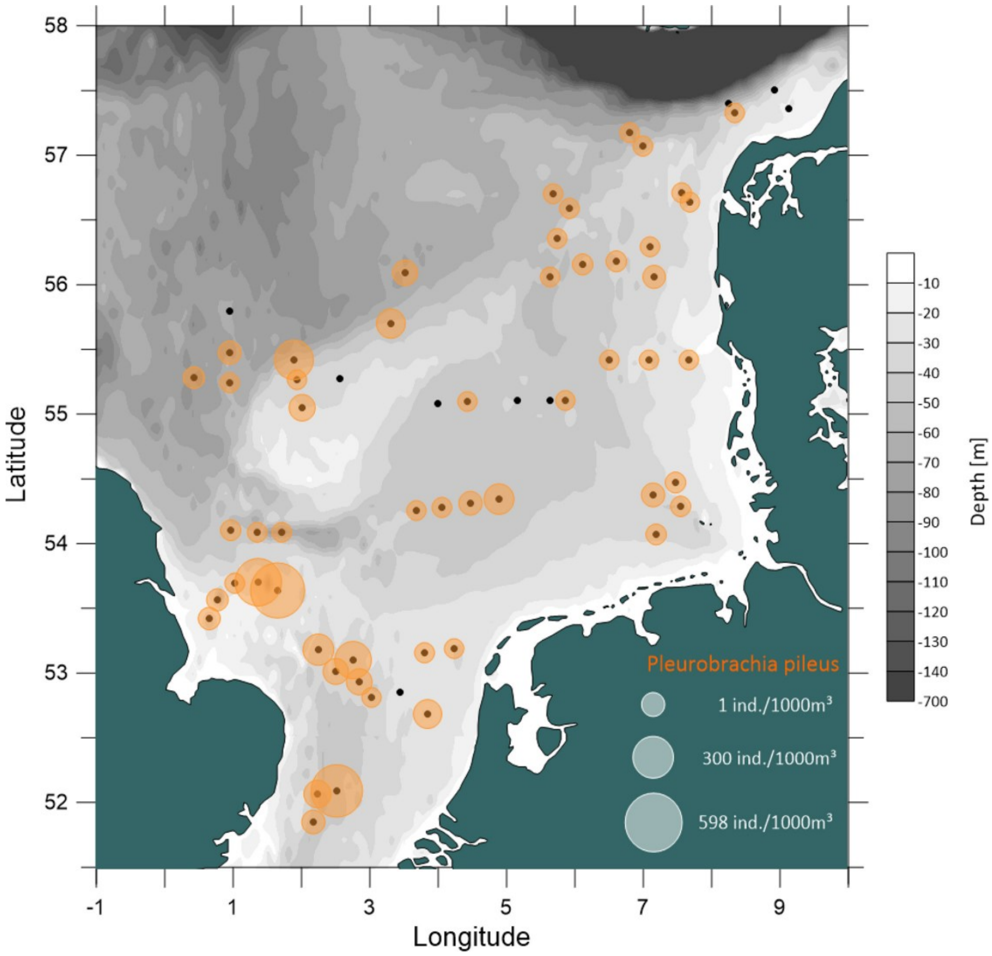


***Figure 4-4*** *Occurrences of Pleuropbrachia pileus in August 2018. Figure from Gawinsky et al. (2019).*

The bulk of the biomass data belongs to pelagic copepods (Figure 4-3). With regards to jellyfish, comb jellies such as *Pleurobrachia* are found throughout the North Sea, with higher abundances in the southern North Sea (Gawinski et al. 2019 and Figure 4.4).

### 4.2.7 Pressures and impacts

#### 4.2.7.1 Climate change

With respect to copepods the downward trends are partially attributed to climate change. For the gelatinous zooplankton the relation with climate change appears to be opposite – climate change is likely to be a contributing factor in the recently observed blooms.

For deep-living benthic species such as *Ostrea edulis* the most relevant impact of climate change is increasing stratification, leading to reduced food availability near the seabed. There may also be increased risks for disease with climate change, as in lake Grevelingen, the occurrence of *Bonamia ostrae* in autumn was linked to higher temperatures in the previous year (Engelsma et al. 2010).

#### 4.2.7.2 Presence of infrastructure (wind farms)

With respect to copepods, the impact of wind farms will largely follow the impact of offshore wind farms on primary production. In seasonally stratified areas this may be an increase, due to higher availability of nutrients in the upper layers, while in shallower, not or intermittently stratified areas we will likely see decreases (Zijl et al. 2024). For gelatinous plankton with a sessile stage, the increased availability of hard substrate is likely positive. Due to the lack of bottom trawling, wind farms in areas with appropriate habitat may be suitable to kick-start the return of the native flat oyster by placing adult oysters or spat on shell or spat on a substrate. This may also lead to a local increase in oyster larvae, which also may find additional habitat for settlement.

### 4.2.8 Current policy

Although zooplankton is an important component in the OSPAR Quality Status Reports, and the most recent report was negative on zooplankton trends in most of the North Sea (OSPAR 2023b), there are no clear policy targets with respect to zooplankton. Under the MONS programme research into trends is initiated, which may in future lead to policy objectives.

#### 4.2.8.1 Policy measures

There are no conservation measures to e.g. boost copepods or reduce extreme jellyfish blooms, other than measures relating to reducing climate change and improving water quality, such as reduction of eutrophication. Such measures may be advisable but are not within the remit of the NN programme.

### 4.2.9 Advice, action perspectives and possible measures

*Rationale*

Most impacts of human beings on zooplankton populations (holoplanktonic or meroplanktonic) are indirect. Measures to reduce (over)fishing, measures to reduce climate change and changes in availability of hard substrate will impact zooplankton stocks, production and distribution. Given the pivotal role of zooplankton in the marine foodweb, knowledge on the trends, occurrence and ecology of zooplankton is a boundary condition for successful measures for other ecosystem components.

*Action perspective for NN*

There seem to be no direct NN measures possible. In some cases, restoration of benthic habitats may be an indirect measure for benthic species with planktonic larvae (meroplankton). Such measures are currently not developed and assessed for efficacy, hence these will be RRL 1-3.

*Demonstration of impact*

Due to the importance as boundary condition for other ecosystem components it is advisable to measure zooplankton biomass and diversity trends. Part of this is done within MONS, but for NN specific impact monitoring for measures may be advisable. Measuring the presence of certain larval stages (e.g. of European flat oysters, *O. edulis* using plankton samples, will demonstrate reproduction success of oyster restoration projects. However, as there are no specific measures targeting zooplankton within the remit of NN, the impact demonstration is also limited.

## 4.3 References


Anderwald, P., P.G. Evans, R. Dyer, A. Dale, P.J. Wright, and A.R. Hoelzel. (2012). Spatial scale and environmental determinants in minke whale habitat use and foraging. Mar. Ecol. Prog. Ser. 450:259-274.

Attrill, M.J., J. Wright, and M. Edwards. (2007). Climate-related increases in jellyfish frequency suggest a more gelatinous future for the North Sea. Limnology and Oceanography 52:480-485.

Båmstedt, U., and A. Ervik. 1984. Local variations in size and activity among *Calanus finmarchicus* and *Metrida longa* (Copepoda, Calanoida) overwintering on the west coast of Norway. Journal of Plankton Research 6:843-857.

Baretta-Bekker, J.G., J.W. Baretta, M.J. Latuhihin, X. Desmit, and T.C. Prins. (2009). Description of the long-term (1991-2005) temporal and spatial distribution of phytoplankton carbon biomass in the Dutch North Sea. J. Sea Res. 61:50-59.

Bennema, F. P., G. H. Engelhard, and H. Lindeboom. 2020. *Ostrea edulis* beds in the central North Sea: delineation, ecology, and restoration. ICES Journal of Marine Science.

Biard, T. (2022). Diversity and ecology of Radiolaria in modern oceans. Environmental Microbiology 24:2179-2200.

Blauw, A.N., E. Benincà, R. W.P.M. Laane, N. Greenwood, and J. Huisman. (2018). Predictability and environmental drivers of chlorophyll fluctuations vary across different time scales and regions of the North Sea. Progress in Oceanography 161:1-18.

Boon, A.R., S. Caires, I.L. Wijnant, F. Zijl, J.J. Schouten, S. Muis, T. Van Kessel, L.A. Van Duren, and T. Van Kooten. (2018). Assessment of system effects of large-scale implementation of offshore wind in the southern North Sea. 11202792-002-ZKS-0006, Deltares, Delft.

Bos, O.G., P. Kamermans, M. Schutter, M.A.M. Maathuis, A. van Gool, T. Van der Have, J. H. Bergsma, T. Raaijmakers, L.A. Van Duren, and H. Sas. (2020). Monitoring of oyster bank restoration Gemini Offshore windfarm and Borkum Reef 2019. IJmuiden.

Bos, O.G., Duarte-Pedrosa, S., Didderen, K., Bergsma, J.H., Heye, S., & Kamermans, P. (2023). Performance of European oysters (*Ostrea edulis* L.) in the Dutch North Sea, across five restoration pilots. Front. Mar. Sci, *10*. https://doi.org/10.3389/fmars.2023.1233744

Bosch-Belmar, M., G. Milisenda, L. Basso, T.K. Doyle, A. Leone, and S. Piraino. (2020). Jellyfish Impacts on Marine Aquaculture and Fisheries. Reviews in Fisheries Science & Aquaculture 29:242-259.

Breen, P., A. Cañadas, O.Ó. Cadhla, M. Mackey, M. Scheidat, S.C. Geelhoed, E. Rogan, and M. Jessopp. (2017). New insights into ocean sunfish (Mola mola) abundance and seasonal distribution in the northeast Atlantic. Scientific Reports 7:2025.

Byrkjedal, I., and G. Langhelle. 2019. Selective feeding on jellyfish organs by Northern Fulmars Fulmarus glacialis. Ornis Norvegica 42:15-18.

Camacho, F.G., J.G. Rodríguez, A.S. Mirón, M.C. García, E. Belarbi, Y. Chisti, and E.M. Grima. (2007). Biotechnological significance of toxic marine dinoflagellates. Biotechnology advances 25:176-194.

Capuzzo, E., C.P. Lynham, J. Barry, D. Stephens, R.M. Forster, N. Greemwood, A. McQuatters-Gollop, T. Silva, S.M. van Leeuwen, and G.H. Engelhard. (2018). A decline in primary production in the North Sea over 25 years, associated with reductions in zooplankton abundance and fish stock recruitment. Global Change Biology 24:e352-e364.

Chapman, E.C.N., A. Rodriguez-Perez, T. Hugh-Jones, C. Bromley, M. A. James, K. Diele, and W. G. Sanderson. (2021). Optimising recruitment in habitat creation for the native European oyster (Ostrea edulis): Implications of temporal and spatial variability in larval abundance. Marine Pollution Bulletin 170:112579.

Chung, I.K., Y.H. Kang, C. Yarish, G.P. Kraemer, and J.A. Lee. (2002). Application of seaweed cultivation to the bioremediation of nutrient-rich effluent. Algae 17:187-194.

Clark, R.A., and C.L. Frid. (2001). Long-term changes in the North Sea ecosystem. Environmental Reviews 9:131-187.

Conway, D.V. (2012). Marine Zooplankton of Southern Britain-Part 1: Radiolaria, Heliozoa, Foraminifera, Ciliophora, Cnidaria, Ctenophora, Platyhelminthes, Nemertea, Rotifera and Mollusca. Occasional Publication of the Marine Biological Association 25.

Dadon-Pilosof, A., K. Conley, F. Lombard, K.R. Sutherland, A. Genin, M. Richter, F.O. Glöckner, and G. Yahel. (2023). Differential clearance rates of microbial phylotypes by four appendicularian species. Mar. Ecol. Prog. Ser. 706:73-89.

De Cauwer, V., K. Ruddick, Y.-J. Park, B. Nechad, and M. Kyramarios. (2004). Optical remote sensing in support of eutrophication monitoring in the southern North Sea.

de Luca Lopes de Amorim, F., A. Balkoni, V. Sidorenko, and K. H. Wiltshire. (2024). Analyses of sea surface Chlorophyll-a trends and variability in a period of rapid Climate change, German Bight, North Sea. EGUsphere 2024:1-36.

Desmit, X., A. Nohe, A.V. Borges, T. Prins, K. De Cauwer, R. Lagring, D. Van der Zande, and K. Sabbe. (2020). Changes in chlorophyll concentration and phenology in the North Sea in relation to de-eutrophication and sea surface warming. Limn. Oceanogr. 65:828-847.

De Wilde, P., M. Jenness, and G. Duineveld. (1992_. Introduction into the ecosystem of the North Sea: hydrography, biota, and food web relationships. Neth. J. Aquat. Ecol. 26:7-18.

Deschamps, M., M. Boersma, C. Meunier, I. Kirstein, K. Wiltshire, and J. Di Pane. (2024). Major shift in the copepod functional community of the southern North Sea and potential environmental drivers. ICES J. Mar. Sci. 81:540-552.

Dorrell, R.M., C.J. Lloyd, B.J. Lincoln, T.P. Rippeth, J.R. Taylor, C.-c.P. Caulfield, J. Sharples, J.A. Polton, B. D. Scannell, D.M. Greaves, R.A. Hall, and J.H. Simpson. (2022). Anthropogenic Mixing in Seasonally Stratified Shelf Seas by Offshore Wind Farm Infrastructure. Frontiers in Marine Science 9.

Egge, J., T. Thingstad, A. Larsen, A. Engel, J. Wohlers, R. Bellerby, and U. Riebesell. (2009). Primary production during nutrient-induced blooms at elevated $CO_2$ concentrations. Biogeosciences 6:877-885.

Engelsma, M. Y., S. Kerkhoff, I. Roozenburg, O. L. Haenen, A. Van Gool, W. Sistermans, S. Wijnhoven, and H. Hummel. (2010). Epidemiology of Bonamia ostreae infecting European flat oysters Ostrea edulis from lake grevelingen, the Netherlands. Mar. Ecol. Prog. Ser. 409:131-142.

European Commission, E. (2000). Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy. Official Journal of the European Communities 327:1-72.

Ferraris, M., L. Berline, F. Lombard, L. Guidi, A. Elineau, J. M. Mendoza-Vera, M. K. S. Lilley, V. Taillandier, and G. Gorsky. (2012). Distribution of *Pelagia noctiluca* (Cnidaria, Scyphozoa) in the Ligurian Sea (NW Mediterranean Sea). J. Plankt. Res. 34:874-885.

Ferreira, J.G., J.H. Andersen, A. Borja, S.B. Bricker, J. Camp, M.C. da Silva, E. Garcés, A.-S. Heiskanen, C. Humborg, and L. Ignatiades (2011). Overview of eutrophication indicators to assess environmental status within the European Marine Strategy Framework Directive. Est. Coast. Shelf Sci. 93:117-131.

Floeter, J., J.E. van Beusekom, D. Auch, U. Callies, J. Carpenter, T. Dudeck, S. Eberle, A. Eckhardt, D. Gloe, and K. Hänselmann. (2017). Pelagic effects of offshore wind farm foundations in the stratified North Sea. Progr. in Oceanogr. 156:154-173.

Fraser, J. (1970). The ecology of the ctenophore *Pleurobrachia pileus* in Scottish waters. ICES J. Mar. Sci. 33:149-168.

Gambill, M. (2015). Ecophysiology and life cycle dynamics of North Sea gelatinous zooplankton. Staats-und Universitätsbibliothek Hamburg Carl von Ossietzky.

Gawinski, C., B. Huwer, P. Munk, and C. Jaspers. (2019). Biodiversity of gelatinous macrozooplankton: Quantitative assessment of data and distribution patterns in the southern and central North Sea during August 2018. Data in Brief 25:104186.

Gordetckaia, O. (2024). A survey of the biodiversity of Tunicata with a focus on Ascidiacea in the waters of Heligoland Island, North Sea.

Groß, E., J. Di Pane, M. Boersma, and C.L. Meunier. (2022). River discharge-related nutrient effects on North Sea coastal and offshore phytoplankton communities. Journal of Plankton Research 44:947-960.

Hackett, J.D., D.M. Anderson, D.L. Erdner, and D. Bhattacharya. (2004). Dinoflagellates: a remarkable evolutionary experiment. American J. Botany 91:1523-1534.

Halsband, C., and H.-J. Hirche. (2001). Reproductive cycles of dominant calanoid copepods in the North Sea. Mar. Ecol. Prog. Ser. 209:219-229.

Hamer, H.H., A.M. Malzahn, and M. Boersma (2011). The invasive ctenophore *Mnemiopsis leidyi*: a threat to fish recruitment in the North Sea? J. Plankt. Res. 33:137-144.

Hemleben, C., M. Spindler, and O.R. Anderson. (2012). Modern planktonic foraminifera. Springer Science & Business Media.

Holst, S., and G. Jarms. (2007). Substrate choice and settlement preferences of planula larvae of five Scyphozoa (Cnidaria) from German Bight, North Sea. Mar. Biol. 151:863-871.

Huys, R., and G.A. Boxshall. (2000). Copepod Evolution. Pages -. the Ray Society, London.

Ianora, A., S.A. Poulet, and A. Miralto (2003). The effects of diatoms on copepod reproduction: a review. Phycologia 42:351-363.

Jansen, H.M., S. Van Den Burg, B. Bolman, R.G. Jak, P. Kamermans, M. Poelman, and M. Stuiver. (2016). The feasibility of offshore aquaculture and its potential for multi-use in the North Sea. Aquac. Int. 24:735-756.

Jansen, H.M., S.W.K. van der Burg, L.A. van Duren, P. Kamermans, M. Poelman, N. A. Steins, and K.R. Timmermans. (2023). Food for thought: A realistic perspective on the potential for offshore aquaculture in the Dutch North Sea. J. Sea Res. 191:102323.

Janßen, H., C. Augustin, H.-H. Hinrichsen, and S. Kube. (2013). Impact of secondary hard substrate on the distribution and abundance of *Aurelia aurita* in the western Baltic Sea. Mar. Pollution Bull. 75:224-234.

Johansson, M.L., T.A. Shiganova, H. Ringvold, A.N. Stupnikova, D.D. Heath, and H.J. MacIsaac. (2018). Molecular insights into the ctenophore genus Beroe in Europe: new species, spreading invaders. J. Heredity 109:520-529.

Joint, I., and A. Pomroy. (1993). Phytoplankton biomass and production in the southern North Sea. Mar. Ecol. Prog. Ser. 99:169-169.

Jónasdóttir, S. H., and M. Koski. (2011). Biological processes in the North Sea: comparison of *Calanus helgolandicus* and *Calanus finmarchicus* vertical distribution and production. J. Plankt. Res. 33:85-103.

Jonsson, P.R., and P. Tiselius. (1990). Feeding behaviour, prey detection and capture efficiency of the copepod *Acartia tonsa* feeding on planktonic ciliates. Mar. Ecol. Prog. Ser. 60:35-44.

Kamermans, P., E. Kingma, K. Didderen, and W. Lengkeek. (2023). Monitoring platte-oesterbank Voordelta 2022. Wageningen Marine Research.

Kamermans, P., B. Walles, M. Kraan, L. van Duren, F. Kleissen, T. van der Have, A. Smaal, and M. Poelman. (2018). Offshore Wind Farms as Potential Locations for Flat Oyster (*Ostrea edulis*) Restoration in the Dutch North Sea. Sustainability 10:3942.

Kennerley, A., I. Lorenzoni, T. Luisetti, L. Wood, and N. Taylor. (2021). Mapping habitats for the suitability of jellyfish blooms around the UK and Ireland. Hydrobiol. 848:1535-1552.

Khan, M., and D. Williamson. (1970). Seasonal changes in the distribution of Chaetognatha and other plankton in the eastern Irish Sea. J. Exp. Mar. Biol. Ecol. 5:285-303.

Kleppel, G.S. (1993). On the diets of calanoid copepods. Mar. Ecol. Prog. Ser. 99:183-195.

Korringa, P. (1954). The Shell of *Ostrea edulis* as a Habitat. Archives Néerlandaises de Zoologie 10:32-146.

Lee, S.-H., L.-C. Tseng, Y. Ho Yoon, E. Ramirez-Romero, J.-S. Hwang, and J. Carlos Molinero. (2023). The global spread of jellyfish hazards mirrors the pace of human imprint in the marine environment. Env. Int. 171:107699.

Lenhart, H.J., and F. Große. (2018). Assessing the effects of WFD nutrient reductions within an OSPAR frame using trans-boundary nutrient modeling. Front. Mar. Sci 5.

Llope, M., K.-S. Chan, L. Ciannelli, P. Reid, L.C. Stige, and N.C. Stenseth. (2009). Effects of environmental conditions on the seasonal distribution of phytoplankton biomass in the North Sea. Limn. Oceanogr. 54:512-524.

Lynam, C.P., M.R. Heath, S.J. Hay, and A.S. Brierley. (2005). Evidence for impacts by jellyfish on North Sea herring recruitment. Mar. Ecol. Prog. Ser. 298:157-167.

Maathuis, M.A.M., J.W.P. Coolen, T. van der Have, and P. Kamermans. (2020). Factors determining the timing of swarming of European flat oyster (*Ostrea edulis* L.) larvae in the Dutch Delta area: Implications for flat oyster restoration. J. Sea Res. 156.

McKindsey, C.W., H. Thetmeyer, T. Landry, and W. Silvert. (2006). Review of recent carrying capacity models for bivalve culture and recommendations for research and management. Aquacult. 261:451-462.

Meilland, J., R. Schiebel, C. Lo Monaco, S. Sanchez, and H. Howa. (2018). Abundances and test weights of living planktic foraminifers across the Southwest Indian Ocean: Implications for carbon fluxes. Deep Sea Research Part I: Oceanographic Research Papers 131:27-40.

Mortelmans, J., A. Aubert, J. Reubens, V. Otero, K. Deneudt, and J. Mees. (2021). Copepods (Crustacea: Copepoda) in the Belgian part of the North Sea: Trends, dynamics and anomalies. J. Mar. Systems 220:103558.

Olsen, O.T. (1883). The piscatorial atlas of the North Sea, English and St. George's Channels, illustrating the fishing ports, boats, gear, species of fish (how, where, and when caught), and other information concerning fish and fisheries. Taylor and Francis, London.

OSPAR (2023a). Eutrophication Thematic Assessment. OSPAR, 2023: Quality Status Report 2023.

OSPAR (2023b). OSPAR Quality Status Report 2023.

Paffenhöfer, G.A. (1984). Calanoid copepod feeding. Pages 75-96 *in* D. G. Meyers and J. R. Strickler, editors. Westview Press, Boulder.

Paffenhöfer, G.A., and K.D. Lewis. (1989). Feeding behavior of nauplii of the genus *Eucalanus* (Copepoda, Calanoida). Mar. Ecol. Prog. Ser. 57:129-136.

Paul, C., B. Matthiessen, and U. Sommer. (2015). Warming, but not enhanced CO2 concentration, quantitatively and qualitatively affects phytoplankton biomass. Mar. Ecol. Prog. Ser. 528:39-51.

Peijnenburg, K.T., J.A. Breeuwer, A.C. Pierrot-Bults, and S.B. Menken. (2004). Phylogeography of the planktonic chaetognath Sagitta setosa reveals isolation in European seas. Evolution 58:1472-1487.

Pierson, J., E. Camatti, R. Hood, T. Kogovšek, D. Lučić, V. Tirelli, and A. Malej. (2020). Mesozooplankton and gelatinous zooplankton in the face of environmental stressors. Coastal Ecosystems in Transition: A Comparative Analysis of the Northern Adriatic and Chesapeake Bay:105-127.

Piroddi, C., E. Akoglu, E. Andonegi, J.W. Bentley, I. Celić, M. Coll, D. Dimarchopoulou, R. Friedland, K. De Mutsert, and R. Girardin. (2021). Effects of nutrient management scenarios on marine food webs: a Pan-European Assessment in support of the Marine Strategy Framework Directive. Front. Mar. Sci. 8:596797.

Pogoda, B., J. Brown, B. Hancock, J. Preston, S. Pouvreau, P. Kamermans, W. Sanderson, and H. V. Nordheim. (2019). The Native Oyster Restoration Alliance (NORA) and the Berlin Oyster

Recommendation: Bringing back a key ecosystem engineer by developing and supporting best practice in Europe. Aquatic Living Resources 32.

Potet, M., A. Fabien, S. Chaudemanche, N. Sebaibi, T. Guillet, S. Gachelin, H. Cochet, M. Boutouil, and S. Pouvreau. (2021). Which concrete substrate suits you? Ostrea edulis larval preferences and implications for shellfish restoration in Europe. Ecological Engineering 162:106159.

Prins, T.C., X. Desmit, and J.G. Baretta-Bekker. (2012). Phytoplankton composition in Dutch coastal waters responds to changes in riverine nutrient loads. J. Sea Res. 73:49-62.

Purcell, J.E. (2005). Climate effects on formation of jellyfish and ctenophore blooms: a review. Journal of the Mar. Biol. Assoc. UK 85:461-476.

Rey, C., R. Harris, X. Irigoien, R. Head, and F. Carlotti. (2001). Influence of algal diet on growth and ingestion of *Calanus helgolandicus* nauplii. Mar. Ecol. Prog. Ser. 216:151-165.

Reynolds, C. S. (2006). The ecology of phytoplankton. Cambridge University Press.

Robert, R., J. Vignier, and B. Petton. (2017). Influence of feeding regime and temperature on development and settlement of oyster *Ostrea edulis* (Linnaeus, 1758) larvae. Aquacult. Res. 48:4756-4773.

Roff, J.C., K. Middlebrook, and F. Evans (1988). Long-term variability in North Sea zooplankton off the Northumberland coast: productivity of small copepods and analysis of trophic interactions. Journal of the Marine Biological Association of the United Kingdom 68:143-164.Roleda, M. Y., and C. L. Hurd. (2019). Seaweed nutrient physiology: application of concepts to aquaculture and bioremediation. Phycologia 58:552-562.

Roleda, M. Y., and C. L. Hurd. 2019. Seaweed nutrient physiology: application of concepts to aquaculture and bioremediation. Phycologia 58:552-562.

Rousseau, V., S. Becquevort, J. Y. Parent, S. Gasparini, M.H. Daro, M. Tackx, and C. Lancelot. (2000). Trophic efficiency of the planktonic food web in a coastal ecosystem dominated by Phaeocystis colonies. J. Sea Res. 43:357-372.

Roux, J.-P., C.D. van der Lingen, M.J. Gibbons, N.E. Moroff, L.J. Shannon, A.D. Smith, and P.M. Cury. (2013). Jellyfication of marine ecosystems as a likely consequence of overfishing small pelagic fishes: lessons from the Benguela. Bull. Mar. Sci. 89:249-284.

Ruardij, P., H. Van Haren, and H. Ridderinkh. (1997). The impact of thermal stratification on phytoplankton and nutrient dynamics in shelf seas: A model study. J. Sea Res. 38:311-331.

Schnedler-Meyer, N.A., T. Kiørboe, and P. Mariani. (2018). Boom and bust: life history, environmental noise, and the (un)predictability of jellyfish blooms. Front. Mar. Sci. 5:257.

Semmouri, I., K.A. De Schamphelaere, J. Mortelmans, J. Mees, J. Asselman, and C. R. Janssen. (2023). Decadal decline of dominant copepod species in the North Sea is associated with ocean warming: Importance of marine heatwaves. Marine Pollution Bulletin 193:115159.

Sharples, J., O.N. Ross, B.E. Scott, S.P.R. Greenstreet, and H. Fraser. (2006). Inter-annual variability in the timing of stratification and the spring bloom in the North-western North Sea. Continent. Shelf Res. 26:733-751.

Simon, N., A.-L. Cras, E. Foulon, and R. Lemée. (2009). Diversity and evolution of marine phytoplankton. Comptes Rendus Biologies 332:159-170.

Stegert, C., H.-J. Lenhart, A. Blauw, R. Friedland, W. Leujak, and O. Kerimoglu. (2021). Evaluating uncertainties in reconstructing the pre-eutrophic state of the North Sea. Frontiers in Marine Science 8:637483.

Steidinger, K. A., and D.G. Baden. 1984. Toxic marine dinoflagellates. Academic Press New York.

Tang, K. W. (2003). Grazing and colony size development in Phaeocystis globosa (Prymnesiophyceae): the role of a chemical signal. J. Plankt. Ress. 25:831-842.

Tarling, G.A., N.S. Ensor, T. Fregin, W.P. Goodall-Copestake, and P. Fretwell. (2010). An introduction to the biology of Northern krill (Meganyctiphanes norvegica Sars). Advances in marine biology 57:1-40.

Thorson, G. (1950). Reproductive and larval ecology of marine bottom invertebrates. Biol. Reviews 25:1-45.

Tortell, P.D., C.D. Payne, Y. Li, S. Trimborn, B. Rost, W.O. Smith, C. Riesselman, R.B. Dunbar, P. Sedwick, and G.R. DiTullio. (2008). CO2 sensitivity of Southern Ocean phytoplankton. Geophyc. Res. Letters 35.

Van Duren, L.A., F. Zijl, V.T.M. van Zelst, L.M. Vilmin, J. Van der Meer, G.M. Aarts, J. Van der Molen, K. Soetaert, and A.W. Minns. (2021). Ecosystem effects of large upscaling of offshore wind on the North Sea - Synthesis report. 11203731-004-ZKS-0010, Deltares, Delft.

van Walraven, L., F. Driessen, J. van Bleijswijk, A. Bol, P. C. Luttikhuizen, J. W. P. Coolen, O. G. Bos, A. Gittenberger, N. Schrieken, V. T. Langenberg, and H. W. van der Veer (2016). Where are the polyps?

Molecular identification, distribution and population differentiation of *Aurelia aurita* jellyfish polyps in the southern North Sea area. Mar. Biol. 163.

Van Walraven, L., V. Langenberg, R. Dapper, J.I. Witte, A. F. Zuur, and H. Van der Veer. (2015). Long-Term patterns in 50 years of scyphomedusae catches in the western Dutch Wadden Sea in relation to climate change and eutrophication. J. Plankt. Res. 37:151-167.

Vansteenbrugge, L., T. Van Regenmortel, M. De Troch, M. Vincx, and K. Hostens. (2015). Gelatinous zooplankton in the Belgian part of the North Sea and the adjacent Schelde estuary: Spatio-temporal distribution patterns and population dynamics. J. Sea Res. 97:28-39.

Vilmin, L.M., and L.A. van Duren. (2021). Modelling seaweed cultivation on the Dutch continental shelf. 11205769-002-ZKS-0001, Deltares, Delft.

Vincx, M., W. Bonne, A. Cattrijsse, S. Degraer, A. Dewicke, M. Steyaert, J. Vanaverbeke, G. Van Hoey, E. Stienen, and J. VanWaeyenberghe (2004). Structural and functional biodiversity of North Sea ecosystems: species and their habitats as indicators for a sustainable development of the Belgian continental shelf. Belgian Science Policy: scientific support plan for a sustainable development policy (SPSD-I).

Wiles, P.J., L.A. van Duren, C. Haese, J. Larsen, and J.H. Simpson. (2006). Stratification and mixing in Limfjorden in relation to mussel culture. J. Mar. Syst. 60:129-134.

WindEurope. (2019). Our energy, our future; How offshore wind will help Europe go carbon-neutral.

Zijl, F., L. Leummens, N. Alexandrova, T. van Kessel, L. Jaksic, V.T.M. van Zelst, L.M. Vilmin, S. Heye, and L.A. van Duren. (2024). Impact of offshore wind farms on the North Sea ecosystem. Scenario study for the partial revision of the Dutch offshore wind planning. 11209248-007-ZKS-0001, Deltares, Delft.

# 5 Seaweed - Kelp forests

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## 5.1 Description of the ecosystem component

Kelp forests, composed primarily of large brown (macro)algae, are foundational marine ecosystems providing structure and function comparable to terrestrial forests. These systems are biodiversity hotspots and are essential for ecosystem health in temperate coastal waters (Reed et al. 2008; Smale et al. 2013; Wernberg, 2019; de Bettignies et al. 2021b). These "forests of macroalgae" (kelp, seaweeds) are part of the EUNIS habitats[4] within NRR and are linked to Natura 2000 habitat types[5] 1130 (estuaries), 1160 (large shallow inlets and bays), 1170 (reefs) and in a lesser extend H1110. Despite the common usage of the word 'kelp', it is a rather general term which is used to refer to large brown seaweed that consist of three parts, a holdfast used as an anchor to substrates, a flexible stipe and a rather flat blade (Figure 5.1). Kelp is mostly found in the sublittoral zone where it can form forests that house a broad diversity of organisms. In the North Sea there are a few species of kelp found which all belong to the order of *Laminariaceae*. The number of kelp species in the North Sea is limited and involves around five native species: sugar kelp (*Saccharina latissima*), oar weed (*Laminaria digitata*), tangle kelp (a.k.a. forest kelp, *Laminaria hyperborea*), Dabberlocks (a.k.a. winged kelp, *Alaria esculenta*) and furbellows (*Saccorhiza polyschides*) (Van der Loos et al. 2021; Bunker et al. 2017). However, in the Dutch part of the North Sea we solely find the species *Laminaria digitata* and *Saccharina latissima*. The other species have all been found stranded on the beach but not attached to fixed substrates making them non-native for the Dutch part.

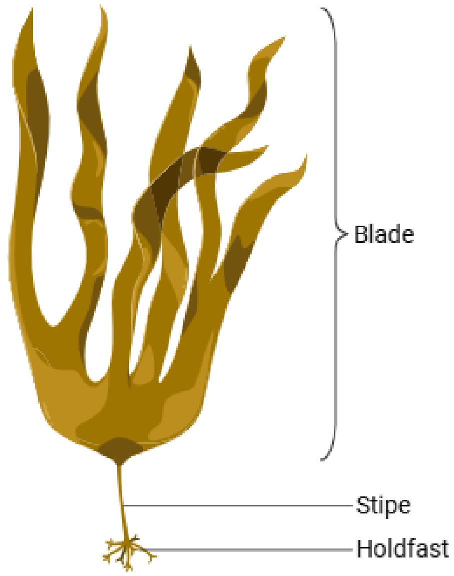


***Figure 5-1*** *Generic overview of a kelp. (source: R. Nauta, ChatGPT)*

While kelp forests are mostly found sublittoral, other species are found in the littoral zone and making up a substantial different habitat (see also Figure 5-3). Along the Dutch coast the dikes form a suitable habitat for littoral species of which most belong to the group of *Fucales*, also known as wracks. In addition to sessile seaweeds, there are floating seaweed species which can form temporal (micro) habitats for different organisms. The most common species in the North Sea area with this characteristic are: thong weed (*Himanthalia elongata*), wire weed (*Sargassum muticum*, invasive), egg wrack (*Ascophyllum nodosum*) and multiple other wrack species (*Fucus spp.*). The majority of these species are only present during certain periods of time mostly after the growing season (species dependent) and when species start reproduction. Exemplary is *Himanthalia elongata*, this species has sessile mushroom-shaped thalli of 1-3 cm but produces reproductive tissue which are elongated blades that can reach up to 1,5 m of length. When the tissue is fertile, it is detached from the sessile part and set adrift. This is the way to disperse its offspring. These reproductive tissues are commonly found on the Dutch coast, however sessile individuals are not found in the Netherlands coastal waters.

[4] European Environment Agency (EEA). EUNIS Habitat Classification: https://eunis.eea.europa.eu/

[5] https://ec.europa.eu/environment/nature/natura2000/

## 5.2 Species Selection / Focus Species

***Figure 5-2*** *Fucus spp (photo: Oscar Bos)*

In the EUNIS habitat classification[6] other groups of seaweeds are included such as fucales (sea oaks, wracks) and coralline red algae. For the Dutch coastal zone, the most commonly found fucales species are egg wrack (*Ascophyllum nodosum*), serrated wrack (*Fucus serratus*), spiraled wrack (*F. spiralis*) and bladder wrack (*F. vesiculosus*). Noteworthy species from this family are thong weed (*Himanthalia elongata*) and the invasive species wireweed (*Sargassum muticum*). *H. elongata* is not found living on the Dutch coast but is native to the North ea. Individuals from adjacent countries (e.g. France and the UK) do get beach casted on our coast. For this reason, the species is not listed as native for the Netherlands. *Sargassum muticum* is as stated an invasive species. Due to these characteristics these two latter species are not selected.

Under OSPAR, maerl beds are listed on the OSPAR threatened and/or declining habitats (OSPAR, 2008). "Maerl" is a collective term for several species of calcified red seaweed (e.g. *Phymatolithon calcareum, Lithothamnion glaciale, Lithothamnion corallioides and Lithophyllum fasciculatum*) which live unattached on sediments in beds or as fragmented nodules. However, none of these species are found in the Dutch part of the North Sea and/or along the coast. They are therefore not considered in this evaluation.

### 5.2.1 Rationale for selection

As only *S. latissima* and *L. digitata* are native to Dutch waters, these two species are the focus of this eco-analysis. Other kelp species such as *L. hyperborea*, *S. polyschides*, and *A. esculenta* are not found in the Dutch part of the North Sea but could still be of potential interest. Their absence is most likely related to environmental conditions in the Dutch coastal zone being unsuitable for their establishment.

For the fucales species, it is highly unlikely that these species can play a role in restoration projects as these are littoral species or, in some cases, are found on the upper edge of the sublittoral zone. This makes them not suitable to be developed into new seaweed communities at open sea. However, they have potential for expansion in the coastal zone where hard substrates are present. Nonetheless, these species are common and settle naturally, no additional action is therefore needed in perspective of restoration.

## 5.3 Habitat preferences

Kelp forests are predominantly found in the sublittoral zone. The selected kelp species (*S. latissima* and *L.* digitata) show a strong preference for hard substrates, including natural rocky reefs, artificial reefs, and potentially scour protection structures. In the North-East Atlantic, kelp forests dominate shallow subtidal rocky

[6] https://eunis.eea.europa.eu/habitats-code-browser-revised.jsp?expand=30000#level_30000

reefs, except in the most sheltered or highly turbid areas of northern-central Europe (Smale et al. 2013; Araújo et al. 2016). They typically occur at depths shallower than 20 meters, where moderate water movement and sufficient light levels enable optimal photosynthesis.

These preferred habitats overlap considerably with several designated Natura 2000 habitat types, including 1130 (estuaries), 1160 (large shallow inlets and bays) and 1170 (reefs). Fucales species also require hard substrates; however, as noted earlier, they primarily thrive in the littoral zone rather than the sublittoral environment.

## 5.4 Ecosystem function

Kelp species play a vital ecological role in supporting biodiversity and regulating nutrient and carbon cycles within the North Sea ecosystem. As primary producers, kelps and other seaweeds/algae convert sunlight, carbon dioxide, and nutrients such as nitrogen and phosphorus into organic matter through photosynthesis. In doing so, they remove nutrients from the surrounding water, thereby contributing to mitigate eutrophication and ocean acidification. Beyond their role in nutrient cycling, kelp forests also influence key physical parameters such as water flow and sedimentation dynamics (Kosek & Kukliński, 2023; Zhu et al. 2021; Zou, 2005). Moreover, these habitats support high levels of biodiversity, providing shelter and feeding grounds for a wide range of marine organisms, including fish, invertebrates, and mammals (Schoenrock et al. 2018; Port et al. 2016; Steneck et al. 2002).

## 5.5 Status and trend ecosystem component

Overall, there is a decline in kelp forests in Western Europe according to Araújo et al.(2016) & Eger et al. (2023). According to the latest OSPAR case report, kelp forest habitat is not rare in the overall OSPAR area (de Bettignies et al. 2021a, **Figure 5-3**), but strongly declining. Some species that are dominant in certain OSPAR regions are patchy or scarcely documented in other regions (e.g., *S. latissima* is rare on the northwest coast of Spain).

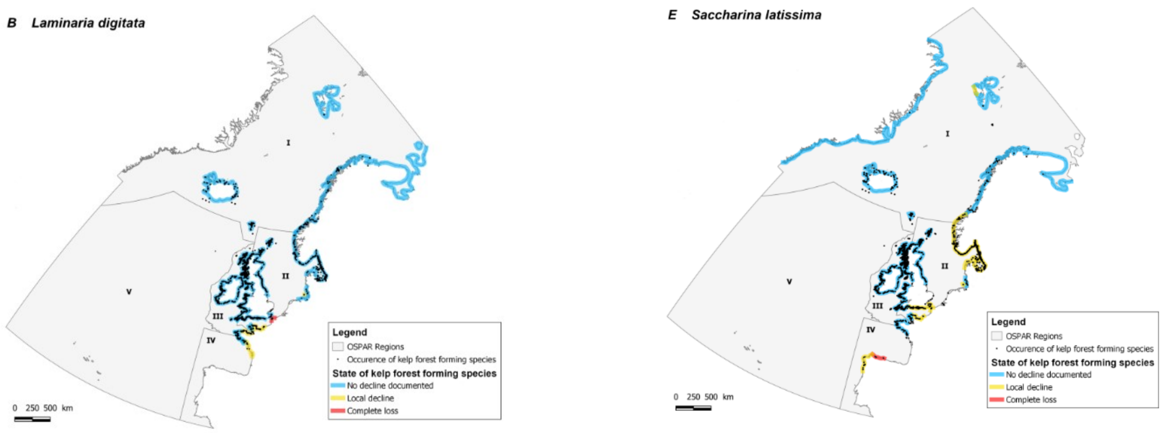


***Figure 5-3*** *Distribution maps of the kelp forest habitat-forming species oar weed (Laminaria digitata) and sugar kelp (Saccharina latissima). Colour lines display the status of kelp forests. Blue lines show kelp forest habitat ranges with no documented evidence of decline, yellow lines show regions of local decline and red lines show complete loss of kelp forest habitat (from de Bettignies et al. 2021a).*

The Dutch coast is a soft sediment delta and thus largely unsuitable for kelps. The maps in Figure 5-3 show very limited (reported) presence of kelps in the Netherlands and historical data for the Netherlands is largely lacking. Mol & Stegenga (1983) do mention the presence of sugar kelp (*S. latissima*) more inshore and nearshore, at some places in the Eastern Scheldt, the Marsdiep and near West-Terschelling and the presence of oar weed (*L. digitata*) at some places in the Marsdiep (Huisduinen, Den Helder and 't Horntje, Texel). Some anecdotal information from fishermen do mention the catch of 'sigars', which are likely to be stipes of different kelp species suggesting prior presence of kelp. At present, the locations where these kelp species are found is reduced to even fewer spots along the Dutch coast (Figure 5-4), the fucus species however are much more abundant and found on artificial hard structures like dikes, but also on mussel beds. Despite the presence of sugar kelp (*Saccharina latissima*) is depicted at the southern tip of the island of Texel (R.W. Nauta, pers. obs.) it is known this species is no longer present at this location after the reinforcement of the dike. Nonetheless, three individuals of oar weed (*L.* digitata) were found in this area on the tip of the island by WMR (R.W. Nauta, pers. obs.). In biodiversity monitoring campaigns on oil rigs, wracks and other artificial hard substrates further offshore in the North Sea no kelps are found. In herbaria archives in Dutch museums there are some *Laminariaceae* specimens conserved. To a few of these there are notes attached which state that at some places the seaweeds were found commonly. This implies that the species were more spread in history compared to the present state and were most found in the Scheldt estuary and near the city of Den Helder (De Froe et al. 2025). It is highly likely that they were found on (artificial) hard substrates.

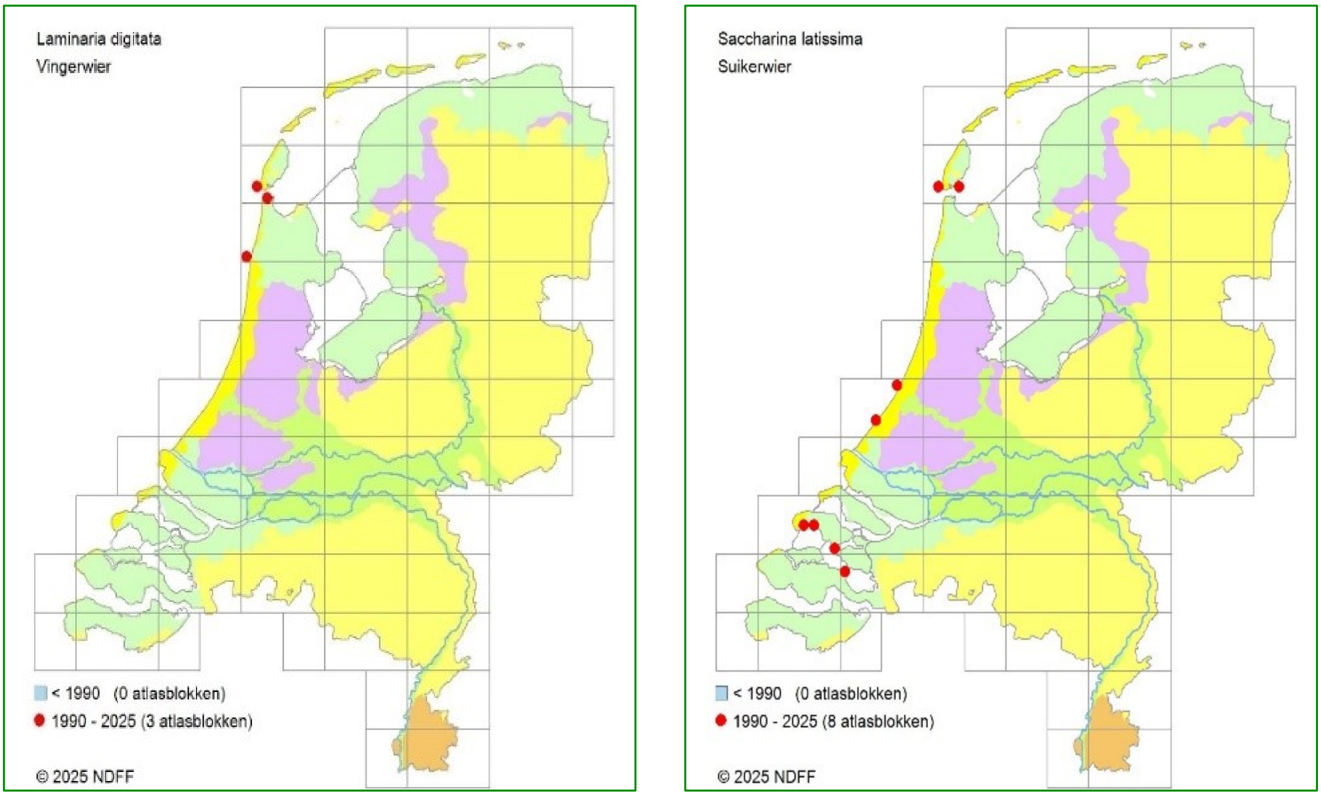


***Figure 5-4*** *Present locations of the two kelp species L. digitata (left panel) and S. latissimi (right panel) along the Dutch coast (source: Nationale Databank Flora & Fauna - www.verspreidingsatlas.nl ©NNDF).*

Here again, the southwestern Delta forms an exception as large areas are covered by the kelp *U. pinnatifida*. This species has however taken over the habitats of native kelp species which are now rarely found. Restoration of the presence of native kelp species like *S. latissima* can be a suitable approach in restoring native kelp forests.

## 5.6 Pressures and impacts

Kelp species in the North Sea are subject to multiple pressures that affect their distribution, growth, and ecological functioning. A key limiting factor is the scarcity of suitable hard substrates required for attachment. This shortage is exacerbated by bottom trawling and other forms of seabed disturbance, which remove natural hard substrates (biogenic and/or geogenic reefs) and hinder the recovery of biogenic reefs (Žuljević et al. 2016; Marques et al. 2024). Next to this, Žuljević et al. (2016), Marques et al. (2024) and OAP (2025) give other factors that affect the presence of kelp:

Excess nutrient input from agriculture and wastewater discharge leads to eutrophication and increased turbidity in coastal waters. The resulting decline in light availability reduces photosynthetic efficiency and recruitment success of seaweeds, especially in deeper or more marginal habitats.

Ocean warming driven by climate change poses an additional threat, particularly to cold-adapted kelp species such as *S. latissima* and *L. digitata*. If thermal tolerance limits are exceeded, these species may undergo range shifts or local declines, especially in the southern parts of their current distribution.

Coastal construction and offshore infrastructure, such as harbors, energy installations, and sea defenses, can alter hydrodynamic and sedimentation patterns, occasionally creating conditions unfavorable for natural seaweed growth. However, when appropriately designed and managed, and given that the environmental conditions are suitable its is expected that these structures can also provide substrate that support seaweed colonization.

Finally, invasive species such as *Sargassum muticum* and *Undaria pinnatifida* represent a growing concern. These non-native macroalgae can outcompete native species for space and light, altering community composition and reducing local biodiversity.

Together, these pressures constrain the natural extent of distribution and resilience of seaweed forests in the North Sea and should be carefully considered in conservation, restoration, and marine spatial planning initiatives.

## 5.7 Current policy

OSPAR lists kelp forests as a habitat of concern (threatened/declining)[7] and includes kelp in its Quality Status Report and biodiversity work programme (OSPAR, 2023). OSPAR has adopted recommendations for protection and is developing guidance on restoring and protecting important habitats (including carbon-sequestering habitats such as kelp).

The EU Nature Restoration Regulation (NRR) aims to put restoration measures in place across a significant share of EU land and sea and to restore ecosystems by 2050. The Regulation requires national restoration plans and prioritisation of ecosystems with high climate change resilience and biodiversity value. Under the NRR, Member States must define restoration measures for macroalgal forests (including kelp) and maerl beds and set restoration targets based on favourable reference areas. De Froe et al. (2025) were assigned to make a proposal for favourable reference areas for macroalgal forests. However, from this report, for kelp-related EUNIS habitat types, there appears to be insufficient information on both historical and current distribution to establish these reference areas at present. Only an indicative area has been established with major assumptions.

### 5.7.1 Policy measures

OSPAR recommends the following actions/measures to strengthen the protection of kelp forest habitat as a threatened and/or declining habitat to recover the habitat, to improve its status and to ensure it is effectively conserved:

- Legally protect kelp habitats — introduce legislation for threatened or declining kelp forests.
- Monitor — track kelp distribution, condition, and pressures (e.g. habitat loss, eutrophication, species removal, invasive species, physical damage).
- Designate MPAs — include kelp forests within the OSPAR Marine Protected Areas network.
- Manage existing MPAs — add targeted conservation measures for kelp habitats already within MPAs.
- Control pressures — reduce impacts from:
    - poor water quality (eutrophication, turbidity),
    - hazardous substances,
    - non-indigenous species.
- Reduce physical disturbance — avoid or minimise seabed damage and habitat loss.

[7] https://www.ospar.org/work-areas/bdc/species-habitats/list-of-threatened-declining-species-habitats/habitats/kelp-forest

- Restore habitats — support local kelp restoration programmes.
- Support research — on climate refuges, population genetics, cumulative stressors, ecological status, and restoration potential.
- Raise awareness — inform the public about the ecological value of kelp forests.
- Inform stakeholders — provide guidance to planners, developers, and marine industries about kelp habitat functions and how activities can hinder recovery.

## 5.8 Advice and action perspectives

*Rationale*
Kelp forests and other seaweeds provide important ecosystem functions such as primary production, nutrient and carbon cycling, and habitat for diverse marine species. They can enhance biodiversity, improve water quality, and contribute to climate mitigation. Restoration of kelp could therefore strengthen the ecological integrity and resilience of the North Sea ecosystem, in line with OSPAR and EU Nature Restoration objectives.

*Action perspective for NN*
Active restoration of (endemic) kelp species fall within the NN programme's remit. As it appears that *Saccharina latissima* used to occur more frequently along parts of the Dutch coast, although the exact historical distribution remains unknown, restoration of native kelp species such as *Saccharina latissima* could be a suitable measure. However, since the Dutch coastal zone is predominantly sandy and lacks natural hard substrates, restoration is generally not feasible unless artificial structures are used. Therefore, this type of restoration is not recommended on a large scale. To assess the feasibility of kelp restoration in the Dutch part of the North Sea coastal areas and the inshore waters, a scoping study should first identify suitable areas and determine whether natural recovery is possible or if active planting is required (RRL 1–3). For offshore opportunities, it is worthwhile to examine existing artificial structures, such as scour protection around wind farms, and evaluate whether local conditions are suitable for the targeted kelp species. It is also recommended to explore synergies with biogenic reef restoration initiatives within the NN programme, such as oyster reef recovery, where combined habitat development could enhance ecosystem functions (multi-species approach to habitat restoration, McAfee et al. 2020).

Small-scale, research-oriented projects in sheltered or structurally suitable sites could serve as valuable pilots to advance knowledge on techniques for active planting with the aim to kickstart the settlement of kelp. Lessons learned from such pilots may also have broader international relevance if the Dutch coastal system proves less suitable for larger scale kelp restoration (RRL 4-5).

Larger scale restoration (RRL 6–7) should only be considered once suitable locations have been identified, considering abiotic conditions, existing habitat values, current uses and users, and ecological carrying capacity, and when active planting has proven technically feasible.

*Measuring impact*
The impact of activities under the NN program can be assessed through the following recommended steps and their associated outputs:

1. Identification of suitable areas for kelp recovery, taking into account environmental conditions, existing habitat values, ecological carrying capacity, and current uses.
2. Demonstration of technical feasibility, showing that kelp restoration is both achievable and ecologically safe.
3. Assessment of restoration outcomes, where the impact can ultimately be measured by the number and area (in hectares) of successfully established, self-sustaining kelp forests. In addition, targeted project monitoring, combined with ecological modelling, can help evaluate the contribution of restored habitats to local biodiversity and translate these findings to the broader North Sea ecosystem context.

# 5.9 References


Araújo, R.M., Assis, J., Aguillar, R. et al. (2016). Status, trends and drivers of kelp forests in Europe: an expert assessment. Biodiversity and Conservation. Vol 25: 1319–1348. https://doi.org/10.1007/s10531-016-1141-7

Bunker, F, StP. D., Maggs, C.A., Brodie, J.A. & Bunker, A.R. (2017). Seaweeds of Britain and Ireland. Second edition. Wild nature Press, Plymouth, UK. ISBN 978-0-9955673-3-7.

de Bettignies T., Hébert C., Assis J., Bartsch I., Bekkby T., Christie H., Dahl K., Derrien-Courtel S., Edwards H., Filbee-Dexter K., Franco J., Gillham K., Harrald M., Hennicke J., Hernández S., Le Gall L., Martinez B., Mieszkowska N., Moore P., Moy F., Mueller M., Norderhaug K.M., Parry M., Ramsay K., Robuchon M., Russel T., Serrão E., Smale D., Steen H., Street M., Tempera F., Valero M., Werner T., La Rivière M. (2021a). Case Report for kelp forests habitat. OSPAR 787/2021, 39 pp. ISBN 978-1-913840-16-7

de Bettignies T., de Bettignies F., Bartsch I., et al. (2021b). Background Document for Kelp Forests habitat. OSPAR 788/2021, 66 pp. ISBN 978-1-913840-15-0.

De Froe, E., A. Asjes, V. Escaravage, S.T. Glorius, G. Hoogenstrijd, K.H.A. Hüsken, R.G. Jak, R.W. Nauta, A. Sandig, F. Smulders, J.E. Tamis, K. Troost, S. Wijnhoven*, 2025. Natuurherstelverordening en het Nederlandse mariene ecosysteem; Stand van zaken voor de relevante habitattypen en habitats van soorten. Wageningen Marine Research rapport C082/25.

Eger, A.M., Marzinelli, E.M., Beas-Luna, R. et al. (2023). The value of ecosystem services in global marine kelp forests. Nature Communications. Vol. 14 (1894). https://doi.org/10.1038/s41467-023-37385-0

Filbee-Dexter, K., Wernberg, T., Grace, S.P. et al. (2020). Marine heatwaves and the collapse of marginal North Atlantic kelp forests. Scientific Reports. Vol: 10 (13388). DOI: https://doi.org/10.1038/s41598-020-70273-x

Fredriksen, S., Filbee-Dexter, K., Norderhaug, K.M. et al. (2020). Green gravel: a novel restoration tool to combat kelp forest decline. Scientific Reports. Vol. 10 (3983). DOI: https://doi.org/10.1038/s41598-020-60553-x

Hohman, R., Hutto, S., Catton, C. & Koe, F. (2019). Sonoma-Mendocino Bull Kelp Restoration Plan. Plan for the Greater Farallones National Marine Sanctuary and the California Department of Fish and Wildlife. Greater Farallones Association. San Francisco, CA.

Kosek, K. & Kukliński, P. (2023). Impact of kelp forest on seawater chemistry – A review. Marine Pollution Bulletin. Vol. 196. DOI: https://doi.org/10.1016/j.marpolbul.2023.115655

Marques, A.F.S., Sanchéz-Gallego, Á., Correia, R.R., et al. (2024). Assessing Atlantic Kelp Forest Restoration Efforts in Southern Europe. Sustainability, 16(21), 9176. DOI: https://doi.org/10.3390/su16219176

McAfee,D., Larkin, C. & Connell, S.D. (2020). Multi-species restoration accelerates recovery of extinguished oyster reefs. Journal of applied Ecology, Vol. 58(2): Special feature: Citizen science, p286-294.

NZG. (2023). New Zealand Government, Fisheries Neew Zealand. A Summary of New Zealand mussel and seaweed restoration initiatives.

OAP, 2025. OSPAR Assessment Portal: https://oap.ospar.org/en/versions/2645-en-1-0-0-impact/. Accessed on April 30th, 2025.

OSPAR Commission. (2008). *OSPAR List of Threatened and/or Declining Species and Habitats*.

OSPAR, 2023. *Benthic Habitats Thematic Assessmen*t. In: OSPAR, 2023: Quality Status Report 2023. OSPAR Commission, London. Available at: https://oap.ospar.org/en/ospar-assessments/quality-status-reports/qsr-2023/thematic-assessments/benthic-habitats/

Port, J.A., O'Donnell, J.L., Romero-Maraccini, O.C., Leary, P.R., et al. (2015). Assessing vertebrate biodiversity in a kelp forest ecosystem using environmental DNA. Molecular Ecology. Vol. 25(2): 527-541. DOI: https://doi.org/10.1111/mec.13481

Reed, D.C., Rassweiler, A. & Arkema, K.K. (2008). Biomass rather than growth rate determines variation in net primary production by giant kelp. Ecology. 89(9): 2493-2505. DOI: https://doi.org/10.1890/07-1106.1

Schoenrock, K. M., Vad, J., Muth, A., et al. (2018). Biodiversity of Kelp Forests and Coralline Algae Habitats in Southwestern Greenland. Diversity, 10(4), 117. DOI: https://doi.org/10.3390/d10040117

Smale, D.A., Burrows, M.T., Moore, P., et al. (2013). Threats and knowledge gaps for ecosystem services provided by kelp forests: a northeast Atlantic perspective. Ecology and Evolution 2013; 3(11): 4016–4038. DOI: https://doi.org/10.1002/ece3.774

Steneck, R.S., Graham, M.H., Bourque, B.J., Corbett, D., et al. (2002). Kelp forest ecosystems: biodiversity, stability, resilience and future. Environmental Conservation. Vol. 29(4):436-459. DOI: https://doi/org/10.1017/S0376892902000322

Van der Loos, L., Karremans, M. & Perk, F. (2021). Veldgids zeewieren. KNNV Uitgeverij. ISBN 978 90 5011 8019.

Wernberg, T., Krumhansl, K. A., Filbee-Dexter, K., & Pedersen, M. F. (2019). Status and trends for the world's kelp forests. In World Seas: An Environmental Evaluation. Vol. 3: 57–78. Academic Press. DOI: https://doi.org/10.1016/B978-0-12-805052-1.00003-6

Zhu, Q., Zhu, Z., Nauta, R., Timmermans, K. R., et al. (2021). Impact of off-bottom seaweed cultivation on turbulent variation in the hydrodynamic environment: A flume experiment study with mimic and natural Saccharina latissima thalli. Science of the Total Environment, 797, Article 149048. DOI: https://doi.org/10.1016/j.scitotenv.2021.149048

Zou, D. (2005). Effects of elevated atmospheric $CO_2$ on growth, photosynthesis and nitrogen metabolism in the economic brown seaweed, *Hizikia fusiforme* (Sargassaceae, Phaeophyta). Aquaculture. Vol 250(3-4): 726-735. DOI: https://doi.org/10.1016/j.aquaculture.2005.05.014

Žuljević, A., Peters, A.F., Nikolić, V. *et al.* (2016). The Mediterranean deep-water kelp *Laminaria rodriguezii* is an endangered species in the Adriatic Sea. Marine Biology. Vol. 163(69). DOI: https://doi.org/10.1007/s00227-016-2821-2

# 6 Cephalopods

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## 6.1 Description of ecosystem component

Cephalopods is a class belonging to the phylum of *Mollusca* (Sweeney and Roper 1998). They are characterised by a prominent head and a set of tentacles, and most are capable of squirting ink when threatened, with the exception of *Nautilidae*. Cephalopods can be divided in four main categories:

- Cuttlefish
- Squid
- Octopus
- Nautilus

Only the *Nautilidae* have an external shell (Oesterwind et al. 2010). Since this type of cephalopod does not occur in the North Sea (Drerup and Cooke 2019, Lai et al. 2025), they are not considered further here. Octopus, squid and cuttlefish are all predators, but differ in anatomy. Virtually all cephalopod species are attributed with significant intelligence (Amodio et al. 2019). The life span of most cephalopod species in the North Sea varies from several months up to 2 years. Some bigger species can grow older. After hatching, the larvae float through the water feeding on a.o. zooplankton and grow up to adults. Most squid species die soon after mating.

### 6.1.1 Cuttlefish and bobtail squid

Cuttlefish are characterised by a unique internal shell, the 'cuttlebone' which is used for buoyancy control (Cadman et al. 2012). Bobtail squid (*Sepiolida*), a subgroup which is more related to cuttlefish than to squid, are similar in anatomy, but lack the cuttle bone and are on average smaller (Oesterwind et al. 2010). Cuttlefish appear to have the largest brain-to-body size ratio of all invertebrates (Ponte et al. 2021). Cuttlefish and bobtail squid have eight arms and two additional elongated tentacles that are used to grasp prey (Nixon 1985) (https://en.wikipedia.org/wiki/Cuttlefish). When escaping, cuttlefish use jet propulsion by contractions of the mantle (Gladman and Askew 2023). However, standard propulsion is through the lateral fins (Helmer et al. 2017).

### 6.1.2 Squid

Squid in the North Sea are often migratory, with common species such as European squid Loligo *Loligo forbesi* arriving in the spring via the English Channel from the Atlantic Ocean (Sims et al. 2001). Their anatomy also includes 8 arms and 2 longer tentacles. The largest species, the giant squid *Architeutis dux*, is an ocean dwelling species that occasionally makes its way into the North Sea, but then usually confined to the Northern British Isles. This species can grow up to 12-13 m. Squid are fast swimmers and most live in open water. Most squid species have a life span of less than 2 years.

### 6.1.3 Octopus

Octopus are soft-bodied organisms and as the name implies have eight muscular arms. When swimming the appendage trails behind the animal. They are masters of camouflage, not only able to adapt their colour but often also their skin texture to their surroundings (Hanlon 2007). They use their arms to move over the seabed and make use of jet propulsion when swimming fast.

# 6.2 Species selection

### 6.2.1 Cuttlefish and bobtail squid

*Sepia officinalis* (European common cuttlefish) is the dominant species of cuttlefish in the North Sea. For the bobtailed squid the most dominant species is *Sepiola atlantica*, but also *Sepietta owenia* and the small dwarf bobtail squid (*Sepiola rondeleti*) are relatively common.

***Figure 6-1*** *Picture of cuttle fish in the Eastern Scheldt (from IVN)*

### 6.2.2 Squid

Various squid species occur in the North Sea, the most common is the European common squid *Allotheuthis subulata.* Also, *Loligo forbesi* and *Loligo vulgaris* are common species. The North Sea is also the home range of the lesser flying squid (*Todaropsis eblanae*) and the broad-tail shortfin squid (*Illex coindetii*.)

### 6.2.3 Octopus

*Eledone cirrhosa*, the lesser octopus or the curled octopus is the most common octopus species in the North Sea (Drerup and Cooke 2019). It is also occasionally seen in the Dutch part of the North Sea. Spawning takes place from July to September (Boyle 1983), with females dying once they have deposited their eggs (Guerra 1992, cited in Hastie *et al*. 2008). The eggs hatch between April and July. The common octopus (*Octopus vulgaris*) occurs in the North Sea but is rarely seen in the Dutch part (Hiemstra 2015). This species is substantially larger than the lesser octopus.

# 6.3 Habitat preferences

### 6.3.1 Cuttlefish and bobtail squid

Both *S. officinalis* as well as *S. atlantica* can tolerate relatively low salinities and some individuals spend part of their time in estuaries. *S. officinalis* is usually found in coastal areas, while the bobtail squid *S. atlantica* lives in the entire central and southern North Sea (De Heij and Baayen 2005). Cuttlefish prefer sandy and muddy substrates covered by seaweed and seagrasses (Drerup and Cooke 2019). The Delta Area (Southwestern part of The Netherlands) is probably an important breeding territory for *S. officinalis* (Paullij et al. 1990). Mating occurs in deeper water. A single pair can mate several times and males have been observed to guard their mate post-insemination (Hanlon et al. 1999). Females deposit clutches of eggs on natural and artificial hard substrate including stones, seaweed, reed, wood, fykes and shipwrecks. Spawning in cuttlefish appears to be restricted to the southern part of the North Sea, mostly at depths around 10 m. (Laptikhovsky et al. 2023). Cuttlefish inhabit warmer, southern waters in winter and migrate to shallow, warm coastal waters in summer (De Heij and Baayen 2005).

The common bobtail squid *S. owenia* appears to spawn year-round off the Portuguese coast (Czudaj et al. 2012). This species is found in a wide depth range (8-1000 m) while migrating to shallower depths in winter / early spring. It prefers soft muddy bottoms (Drerup and Cooke 2019). *S. atlantica* seems to have varying regional depth ranges. In Scottish waters it is mainly found at 50-120 m depth, while in Iberian waters it appears to prefer shallower depths (6-50 m), Both species seem to attach eggs to hard substrates (Yau and Boyle 1996, Rodrigues et al. 2011).

### 6.3.2 Squid

*A. subulata* inhabits sandy and muddy bottoms, ranging from shallow coastal areas to a depth of 500 m, but is also commonly found on hard substrata. Seasonal migration consists of mature animals arriving in coastal onshore waters in spring/summer. This species is known to form dense aggregations (Drerup and Cooke 2019).

*L. forbesi* and *L. vulgaris* are open water species with overlapping ranges. Where their ranges overlap, *L. forbesii* tends to occur mainly in deeper regions whereas *L. vulgaris* is often observed near coasts with abruptly sloping seabeds. *L. vulgaris* has a preference for coarse sand habitats but can also be found over other sediment and even seagrass meadows (Drerup and Cooke 2019). All most common squid species spawn egg masses and attach them to rocks and other objects (including e.g. lobster pots and fishing creels) on the seabed (Stephen 2001).


***Figure 6-2*** *(left) Eggs of a squid on submarine wreck U97 and (right) eggs of Loligo vulgaris (European squid) on a wreck on the Dogger Bank.*

### 6.3.3 Octopus

The lesser octopus *E. cirrhosa* occurs throughout the entire North Sea, while the common octopus *O. vulgaris,* is restricted to the southern part of the North Sea (Oesterwind et al. 2022). *E. cirrhosa* is a sedentary species, mostly found on soft substrate. It appears to prefer habitats deeper than 30 m. but can occasionally also be found in rock pools (Drerup and Cooke 2019). The female attaches strings of 800 to 1500 grapelike eggs to the roof of a rock shelter and sits guard and tends them for about 100 days (at 16° C). When these eggs hatch as miniature adults they drift in the plankton before settling the following year (Boyle and Knobloch 1983). Hence, rocky substrate is required for reproduction. *E. cirrhosa* has been reported in Dutch waters, particularly in years with relatively high salinities (De Heij and Baayen 2005). The lesser octopus prefers temperatures around 12 °C. It survives in cooler water but does not tolerate temperatures exceeding 15 °C. *O. vulgaris* is also sedentary, but prefers areas with a large abundance of solid material (Drerup and Cooke 2019). They also deposit eggs in a rocky crevice and guard the eggs (Garci et al. 2016).

# 6.4 Ecosystem function

All cephalopods are predators feeding on a large variety of fish and invertebrates. They are also a crucial part of the diet of many marine predators and of commercial fisheries.

### 6.4.1 Cuttlefish and bobtail squid

*S. officinalis* feeds mainly on crustaceans, demersal fish, cephalopods and polychaetes (Castro and Guerra 1990). Cuttlefish have a number of different hunting techniques. On soft bottoms they often squirt jets into the sand to uncover prey. In other areas they mimic their surroundings, adapting the colour and patterns on their skin and with that ambush their prey (Drerup and Cooke 2019). Bobtail squid, such as *S. atlantica,* tend to feed on small crustaceans such as mysids and shrimp (Yau and Boyle 1996).

Cuttlefish such as *S. officinalis* are relatively large when adult. Their main predators are dolphins and larger fish (including sharks and other cuttlefish).

### 6.4.2 Squid

Squid are active pelagic hunters. They are rapid swimmers and locate prey by sight. They feed predominantly on fish, crustaceans and cephalopods, but are mainly piscivores (Pierce et al. 1994). Juveniles feed on zooplankton, such as copepods, mysids etc.

Numerous species prey on squid, including fish, sharks, marine mammals and many seabirds (Clarke 1996). The annual quantity of squid in the Eastern North Atlantic consumed by birds is estimated as 40000 tonnes (Furness 1994). Main consumers are fulmars and Manx shearwaters. Squid are also fished by humans. The landings for squid were estimated to be around 150 tonnes in 2003-2005 (Van der Kooij et al. 2016). Since 2018, the squid fishery has grown remarkably, with catches of 1700 tonnes in 2023-2024 by the flyshoot fisheries and 652 tonnes in 2023-2024 by the otter trawl fisheries. Also beam trawlers catch squid, but as bycatch (WMR data: Visserijnieuws, 17 Jan 2025).

### 6.4.3 Octopus

*O. vulgaris* feeds on various demersal prey, including many molluscs and crustaceans. Most is known on the diet of this species from the Mediterranean, where it is much more common than in the North Sea (Ambrose and Nelson 1983). The more common lesser octopus, often feeds on crustaceans (Boyle et al. 1986, Grisley et al. 1999). However, its diet also includes fish, cephalopods, gastropods, annelids, and echinoderms (Pierce et al. 2024). This species is prey to large fish and in particular marine mammals (Pierce et al. 2024).

# 6.5 Status and trend ecosystem component

Cephalopod trends are difficult to ascertain correctly. As all cephalopod species are opportunists, they likely benefit from (over) exploitation of key predators (Rodhouse et al. 2014).

### 6.5.1 Cuttlefish and bobtail squid

Over the past 30 years cuttlefish landings have slightly decreased in the North-East Atlantic, while they seem to have risen in Dutch waters (Moreno et al. 2022). As the North Sea represents the northernmost range of this species distribution, climate change is likely to push cuttlefish further north into the North Sea.

### 6.5.2 Squid

Regarding squid, most species have shown increasing trends over the past decades (Van der Kooij et al. 2016). Over a 35-year period, squid distribution across the North Sea has expanded. *Loligo* expanded southward from a predominantly north-easterly distribution, compared to northward expansions by *Alloteuthis* from their core distributions in the southern and central North Sea respectively. Climate change is most likely the cause of these shifts (Van der Kooij et al. 2016).

### 6.5.3 Octopus

Octopus landings have increased over the past decades. In terms of global trends, *O. vulgaris* was projected to undergo considerable reductions in habitat suitability (Borges et al. 2022). For the North Sea declines are expected under the most extreme climate scenarios (RCP8.5, Borges et al. 2022).

For *E. cirrhosa* there are few trend data and predictions available. Given its apparent temperature intolerance above 15 °C (De Heij and Baayen 2005), climate change will likely affect its distribution, certainly making shallow coastal areas less suitable. Given its fairly specific preference for temperatures around 12 °C, perhaps this indicates increasing suitability in more northern central areas of the North Sea.

## 6.6 Current policy

With squid having become a more lucrative fishing resource, the need for sustainable management is becoming increasingly important (Oesterwind et al. 2022). There is little or no fisheries management, apart from local management for small-scale fisheries e.g. for the common octopus, but this is generally outside the North Sea (Bobowski et al. 2023). However, currently there are few policy restrictions. Also, with respect to conservation the whole species group of cephalopods appears to be a gap in the Marine Strategy Framework Directive (MSFD) (Bobowski et al. 2023), despite their importance in the marine food web.

### 6.6.1 Policy measures

There are no formal protection or fishery targets for cephalopods in the Dutch North Sea. Whether targets are warranted for certain species, requires further research. Under the MSFD, the assessment of the environmental status of cephalopods needs to be improved.

## 6.7 Advice, action perspectives and possible measures

*Rationale*
Populations of cephalopods have increased in the Dutch North Sea, probably due to temperature rise under climate change. The most important species for the Dutch fisheries are the European squid (*L. vulgaris*) and the long-finned squid (*L. forbesii*). The southern North Sea is known as a spawning area for the European squid.. Since 2018, there is a targeted fisheries on squid, with highest catches in November/December. Under the MSFD, the assessment of the environmental status of cephalopods needs to be improved. Currently, bycatch, population size and demographical characteristics are not yet assessed. Fisheries management and studies of the effects of fisheries is outside the remit of the NN programme, but is also highly recommended. The same applies to studies on the effects of climate change on cephalopod populations.

*Action perspective for NN*
NN could focus on habitat restoration for egg deposition of cephalopod species. The first step, however, is to assess whether this is needed in the first place, because of the current natural increase of cephalopod numbers. Next, it is recommended to get more insight in important reproduction and foraging areas and structures used by cephalopods to deposit their eggs on (RRL 1-3). For example, In Zeeland, SCUBA divers have placed bamboo sticks or willow branches for a long time for cuttlefish to deposit their eggs on. As all cephalopods need (hard) substrate for egg deposition (Figure 6-2) this is something that can be addressed.

Locations to do so should however be carefully selected (RRL 4-6). Octopus species appear to like crevices in rocks. With their enormous flexibility they are generally capable of squeezing through very narrow gaps, being limited only by the size of their beaks. Whether they have requirements for gap sizes in terms of e.g. cavities for eggs needs further investigation.

The most obvious opportunities for measures, involving habitat provision are e.g. Nature-inclusive Design measures, e.g. adaptations to offshore wind turbine foundations, or Nature-inclusive anchors. These are in most cases the remit of developers and users of these infrastructures. However, research into such measures can be carried out within NN, if research indicates that extra measures for this group are required, either to comply with MSFD requirements or if iconic individual species are not doing well.

*Demonstration of impact*
To demonstrate the actual contribution of NN activities to copepods, restoration sites should be monitored, preferably in such a way that the knowledge base for MSFD assessments improves.

## 6.8 References

Ambrose, R.F., and B.V. Nelson. (1983). Predation by Octopus vulgaris in the Mediterranean. Marine Ecology 4:251-261.

Amodio, P., M. Boeckle, A. K. Schnell, L. Ostojíc, G. Fiorito, and N. S. Clayton. (2019). Grow smart and die young: why did cephalopods evolve intelligence? Trends in ecology & evolution 34:45-56.

Bobowski, B. T., A. M. Power, G. J. Pierce, A. Moreno, A. Iriondo, J. Valeiras, I. M. Sokolova, and D. Oesterwind. (2023). Cephalopods, a gap in the European marine strategy framework directive and their future integration. Mar. Biol. 170:26.

Borges, F.O., M. Guerreiro, C.P. Santos, J.R. Paula, and R. Rosa (2022). Projecting future climate change impacts on the distribution of the 'Octopus vulgaris species complex'. Front. Mar. Sci 9.

Boyle, P., M. Grisley, and G. Robertson. (1986). Crustacea in the diet of Eledone cirrhosa (Mollusca: Cephalopoda) determined by serological methods. J. Mar. Biol. Assoc. UK 66:867-879.

Boyle, P.R., and D. Knobloch. (1983). The female reproductive cycle of the octopus, Eledone cirrhosa. J. Mar. Biol. Assoc. UK 63:71-83.

Cadman, J., S. Zhou, Y. Chen, and Q. Li. (2012). Cuttlebone: characterisation, application and development of biomimetic materials. J. Bionic Engineering 9:367-376.

Castro, B.G., and Á. Guerra (1990). The diet of *Sepia officinalis* (Linnaeus, 1758) and Sepia elegans (D'Orbigny, 1835)(Cephalopoda, Sepioidea) from the Ria de Vigo (NW Spain).

Clarke, M.R. (1996). The role of cephalopods in the world's oceans: general conclusions and the future. Philosophical Transactions of the Royal Society of London. Series B: Biological Sciences 351:1105-1112.

Czudaj, S., J. Pereira, A. Moreno, A.M. Costa, U. Saint-Paul, and R. Rosa. (2012). Distribution, abundance, reproduction and ageing of the common bobtail squid *Sepietta oweniana* (Sepiolidae, Cephalopoda) from the Portuguese Coast. Mar. Biol. Res. 8:74-86.

De Heij, A., and R. Baayen. (2005). Seasonal distribution of cephalopod species living in the central and southern North Sea. Basteria 69:91-119.

Drerup, D., and G. Cooke. (2019). Cephalopod ID Guide for the North Sea.

Furness, R.W. (1994). An estimate of the quantity of squid consumed by seabirds in the eastern North Atlantic and adjoining seas. Fish. Res. 21:165-177.

Garci, M.E., J. Hernández-Urcera, M. Gilcoto, R. Fernández-Gago, Á.F. González, and Á. Guerra. (2016). From brooding to hatching: new insights from a female Octopus vulgaris in the wild. Journal of the J. Mar. Biol. Assoc. UK 96:1341-1346.

Gladman, N. W., and G. N. Askew. (2023). The hydrodynamics of jet propulsion swimming in hatchling and juvenile European common cuttlefish, *Sepia officinalis*. J. Exp. Biol. 226:jeb246225.

Grisley, M., P. Boyle, G. Pierce, and L. Key. (1999). Factors affecting prey handling in lesser octopus (*Eledone cirrhosa*) feeding on crabs (*Carcinus maenas*). J. Mar. Biol. Assoc. UK 79:1085-1090.

Hanlon, R. (2007). Cephalopod dynamic camouflage. Current Biology 17:R400-R404.

Hanlon, R., S. Ament, and H. Gabr. (1999). Behavioral aspects of sperm competition in cuttlefish, *Sepia officinalis* (Sepioidea: Cephalopoda). Mar. Biol. 134:719-728.

Helmer, D., B. R. Geurten, G. Dehnhardt, and F. D. Hanke. (2017). Saccadic movement strategy in common cuttlefish (*Sepia officinalis*). Front. Physiol. 7:660.

Hiemstra, A.-F. (2015). Recognizing cephalopod boreholes in shells and the northward spread of Octopus vulgaris Cuvier, 1797 (Cephalopoda, Octopodoidea). Vita Malacologica 13:53-56.

Lai, X., L. Zhao, W. Huang, L. Meilana, T. Li, K. Liu, B. Wang, B. Cong, and S. Liu. (2025). Distribution and Conservation Gaps of *Nautilus pompilius*: A study based on species distribution models. Diversity 17:243.

Laptikhovsky, V., G. Cooke, C. Drerup, A. Jackson, E. MacLeod, and J.-P. Robin. (2023). Spatial and temporal variability of common cuttlefish, *Sepia officinalis*, L. spawning grounds off North Europe. Fish. Res. 263:106688.

Moreno, A., D. Oesterwind, G. Pierce, and E. Abad. (2022). ICES Working Group on Cephalopod Fisheries and Life History (WGCEPH; Outputs from 2022 meeting).

Nixon, M. (1985). Capture of prey, diet and feeding of *Sepia officinalis* and *Octopus vulgaris* (Mollusca: Cephalopoda) from hatchling to adult. Vie Et Milieu/life & Environment:255-261.

Oesterwind, D., C.J. Barrett, A.F. Sell, I. Núñez-Riboni, M. Kloppmann, U. Piatkowski, K. Wieland, and V. Laptikhovsky. (2022). Climate change-related changes in cephalopod biodiversity on the North East Atlantic Shelf. Biodiv. Cons. 31:1491-1518.

Oesterwind, D., R. ter Hofstede, B. Harley, H. Brendelberger, and U. Piatkowski. (2010). Biology and meso-scale distribution patterns of North Sea cephalopods. Fish. Res. 106:141-150.

Paulij, W.P., Bogaards, R.H. & Denucé, J.M. Influence of salinity on embryonic development and the distribution of *Sepia officinalis* in the Delta Area (South Western part of The Netherlands). *Mar. Biol.* 107, 17–23 (1990). https://doi.org/10.1007/BF01313238.

Pierce, G. J., P. R. Boyle, L. C. Hastie, and M. B. Santos (1994). Diets of squid Loligo forbesi and Loligo vulgaris in the northeast Atlantic. Fisheries Research 21:149-163.

Pierce, G. J., S. Ivaylova, F. L. Matos, S. S. Monteiro, K. Roumbedakis, S. Lourenço, and F. Lishchenko. (2024). *Eledone cirrhosa*, horned octopus. pp 311-357. Octopus Biology and Ecology. Elsevier.

Ponte, G., M. Taite, L. Borrelli, A. Tarallo, A.L. Allcock, and G. Fiorito. (2021). Cerebrotypes in cephalopods: brain diversity and its correlation with species habits, life history, and physiological adaptations. Front. in neuroanatomy 14:565109.

Rodhouse, P. G. K., G. J. Pierce, O. C. Nichols, W. H. H. Sauer, A. I. Arkhipkin, V. V. Laptikhovsky, M. R. Lipiński, J. E. Ramos, M. Gras, H. Kidokoro, K. Sadayasu, J. Pereira, E. Lefkaditou, C. Pita, M. Gasalla, M. Haimovici, M. Sakai, and N. Downey (2014). Chapter Two - Environmental Effects on Cephalopod Population Dynamics: Implications for Management of Fisheries. Pages 99-233 in E. A. G. Vidal, editor. Advances in marine biology. Academic Press.

Rodrigues, M., M.E. Garcí, J.S. Troncoso, and Á. Guerra. (2011). Spawning strategy in Atlantic bobtail squid *Sepiola atlantica* (Cephalopoda: Sepiolidae). Helgol. Mar. Res. 65:43-49.

Sims, D.W., M.J. Genner, A.J. Southward, and S.J. Hawkins. (2001). Timing of squid migration reflects North Atlantic climate variability. Proc. Roy. Soc. London. Ser. B: Biol. Sci. 268:2607-2611.

Stephen, C. (2001). Environmental conditions and yolk biochemistry: factors influencing embryonic development in the squid *Loligo forbes*i (cephalopoda: Loliginidae) Steenstrup 1856. Univ. Aberdeen.

Sweeney, M., and C.F. Roper (1998). Classification, type localities, and type repositories of recent Cephalopoda. Smithsonian Contributions to Zoology 586:561-599.

Van der Kooij, J., G.H. Engelhard, and D.A. Righton. (2016). Climate change and squid range expansion in the North Sea. J. Biogeography 43:2285-2298.

Yau, C., and P. Boyle. (1996). Ecology of *Sepiola atlantica* (Mollusca: Cephalopoda) in the shallow sublittoral zone. J. Mar. Biol. Assoc. UK:733-748.

# 7 Benthic species and biogenic reef builders

The focus of this chapter is on the benthic species (groups) for which species protection plans are made under the MONS programme (see ☐). Benthos refers to the diverse group of sediment-dwelling animals that are retained on a sieve with a mesh size of 1 mm. The macrobenthos of the North Sea is mainly composed of mollusks (mostly bivalves and gastropods), crustaceans, annelid worms, and echinoderms, but also comprises a range of smaller taxonomic groups such as *sipunculans*, *nemerteans*, and a few chordates (e.g. the lancelet *Branchiostoma lanceolatum*).

Other important benthos groups are the meiobenthos (retained on a 64 µm mesh sieve and comprised of many phyla, but in the North Sea mostly nematodes and copepods; Huys et al. 1992) and microbenthos (not retained, even on a 64 µm mesh sieve and comprising a wide variety of mostly unicellular organisms). Another way of classifying benthos, rather than based on body size, is based on their primary habitat. Endobenthos live inside the sediment; epibenthos is attached to the sediment surface; and hyperbenthos moves freely above the surface.

The focus of this chapter is on the groups of ‘biogenic reefs’, ‘long-lived shellfish and burrowing megafauna’, ‘large mobile benthos’, and ‘structure-forming benthic species’. Meio- and microbenthos, although ecologically very important to, for example, the marine food web and biogeochemistry, are beyond the scope of this report. Action perspectives on their restoration are poorly understood and are probably similar to those for macrobenthos and benthic habitats.

## 7.1 Biogenic reefs

*Authors: Enzo Kingma (*based on the background report for the species protection plan: *Sas et al. 2023)*

### 7.1.1 Description of ecosystem component

Biogenic reefs are complex, three-dimensional structures created by the accumulation of living organisms such as reef-building polychaetes, bivalves, and corals. In the North Sea, most important biogenic reef-forming species include the Ross worm (*Sabellaria spinulosa*), the sand mason worm (*Lanice conchilega*), the European flat oyster (*Ostrea edulis*), the horse mussel (*Modiolus modiolus*), and the blue mussel (*Mytilus edulis*). These reef structures provide valuable ecosystem services and can form biodiversity hotspots in an otherwise mostly sandy environment within the North Sea basin (Sas et al. 2023).

### 7.1.2 Species selection

#### 7.1.2.1 Rationale for selection

Biogenic reefs serve as important habitats that support a diverse range of marine life, contributing to the overall productivity of the North Sea. The North Sea is however, a highly dynamic and heavily used environment that has experienced significant habitat degradation due to industrial activities, fishing pressures, climate change, diseases, and (past) overexploitation. These impacts have significantly reduced the presence and distribution of biogenic reefs, which reflects the need for conservation and restoration efforts.

#### 7.1.2.2 Focus species

Several species of marine bivalves and annelid worms are relevant for biogenic reef formation in the North Sea and are therefore considered within the scope of this report. The selection of species is based on their historical presence, ecological significance, and potential for restoration. Also, only native species are considered.

Reef-building marine bivalves

- European oyster (*O. edulis*): This species was once widespread in the North Sea, forming extensive reef structures and are considered important ecosystem engineers. Due to overexploitation, habitat destruction, and diseases, its populations have declined significantly and reef structures almost completely disappeared. As a result, *O. edulis* is the primary focus of current reef restoration projects in the North Sea (Bennema et al. 2020; Houziaux et al. 2011; Olsen, 1883).
- Horse mussel (*M. modiolus*): Horse mussels are capable of forming extensive reefs (beds). However, while horse mussel beds have been recorded in deeper areas of the North Sea, they are generally absent in the Dutch Exclusive Economic Zone (EEZ) (Dinesen & Morton, 2014).
- Blue mussel (*M. edulis*): Mostly recognized as an intertidal reef builder, *M. edulis* is also found throughout the North Sea, especially on (vertical) artificial structures higher in the water column. Recent studies have shown that the species may also form reef structures on or near the seabed, presenting potential opportunities for future restoration projects (Baden et al. 2021).

Reef-building annelid worms

- Sand mason worm (*L. conchilega*) and Ross worm (*S. spinulosa*): Both species contribute to biogenic reef formation by stabilizing sediments and providing structural habitat complexity (OSPAR, 2013; Rabaut et al. 2009). *S. spinulosa* is particularly important, as it forms dense aggregations that enhance benthic biodiversity also in the deeper Dutch North Sea regions.

Other potential reef-building species

- Other species, such as *Loimia ramzega*, *Owenia fusiformis*, and *Owenia borealis*, also show reef-forming potential in the North Sea. Additionally, hydroids may play a role in reef development by providing structural support. However, within the scope of this report, it is assumed that conservation and restoration efforts targeting the previously mentioned species will have broader benefits for reef-building organisms as a whole.

*Table 7.1. Biogenic reef building species*

| **English name** | **Scientific name** | **Dutch name** |
|---|---|---|
| Sand mason worm | *Lanice conchilega* | Schelpkokerworm |
| Ross worm | *Sabellaria spinulosa* | Gestekelde zandkokerworm |
| European flat oyster | *Ostrea edulis* | Gewone oester |
| Horse mussel | *Modiolus modiolus* | Paardenmossel |
| Blue mussel | *Mytilus edulis* | Gewone mossel |

### 7.1.3 Habitat preferences

Different reef-building species have distinct habitat requirements, influencing their distribution and potential for restoration in the North Sea.

- *O. edulis*: oysters settle on hard substrates such as rocks, loose stones, and shells, typically found on sandy or muddy seabeds from the low water mark to depths of several tens of meters (OSPAR Commission, 2009). Successful larval settlement depends on the availability of suitable substrate, and the species is sensitive to excessive sedimentation. Additionally, they can be found in the depressions of sandbanks, in channels within deltas and the Wadden Sea, and on gravel banks in Belgium, which differ from the traditional flat oyster beds.
- *M. modiolus*: Typically inhabits deeper North Sea regions with strong currents, high salinity, and coarse sand or gravel but also settles on bedrock and offshore structures. Juveniles attach to hard substrates using byssus threads. *M. modiolus* beds are common at 25–40 m depths but can occur up to 200 m deep (Anwar et al. 1990; OSPAR Commission, 2009; de Bruyne & van Leeuwen, 2013). However, beds of this species are mostly absent in the Dutch North Sea.
- *M. edulis*: Typically found in intertidal and shallow subtidal zones, attached to hard substrates like rocks, artificial structures, and shells. Mussel beds occur in the North Sea near Sweden and the UK, down to 20 meters, but are largely absent from the Dutch EEZ sandy seafloor due to physical disturbance, lower suspended organic material concentrations, and predation, though present on offshore hard substrates in a sort of “Mytilus zone” (Olsen, 1883; Coolen et al. 2020; Baden et al. 2019; Tillin & Mainwaring, 2016; Sas et al. 2023). At the Voordelta they have been recorded in the subliteral zone within the flat oyster reef. Furthermore, they have been observed at the Frisian Front, Central oyster grounds, and the Dogger Bank (Bakker et al. 2023).

- *S. spinulosa*: Forms reefs in fine sand areas with moderate to strong water movement. Requires large amounts suspended sediment for tube building and relies on initial hard substrate for reef development (Maddock, 2008).
- *L. conchilega*: Found in sandy and muddy seabeds, often alongside seagrass and benthic algae. Prefers areas with moderate bottom shear stress and wave influence, occurring from the shoreline to several tens of meters deep (Callaway et al. 2010; Herman & van Rees, 2022).

### 7.1.4 Ecosystem function

Biogenic reefs contribute to ecosystem functioning in several ways:

- Biodiversity: They create stable and complex heterogenous habitats that support a wide range of marine species, including fish, crustaceans, and other benthic invertebrates.
    - They provide shelter and breeding grounds.
    - They increase species richness and biomass in comparison to surrounding soft-bottom habitats.
    - They function as connectivity hubs that facilitate larval dispersal and recruitment at a larger North Sea basin scale.
- Nutrient cycling: These species filter (in)organic matter from the water column, thereby also improving water quality.
- Sediment stabilization: The reef structures help trap and stabilize sediments, reducing turbidity and preventing erosion.
- Carbon sequestration: Reef associated bivalves may contribute to carbon fixation. They incorporate $CO_2$ into their shells as calcium carbonate ($CaCO_3$). However, various processes also lead to $CO_2$ release, making the net impact on carbon sequestration uncertain.

### 7.1.5 Status and trend

Up until the 19th and early 20th centuries, extensive offshore and coastal beds of *O. edulis* were widespread along European shorelines (Thurstan et al. 2025). However, a combination of overfishing, pollution, disease outbreaks (*Bonamia ostreae*), and harsh winters led to the near total disappearance of flat oyster reefs in the North Sea. Today, a flat oyster reef mixed with a mussel bed exists in the Voordelta near the Brouwersdam. Some individuals are also recorded further offshore on shipwrecks (Figure 7-1).

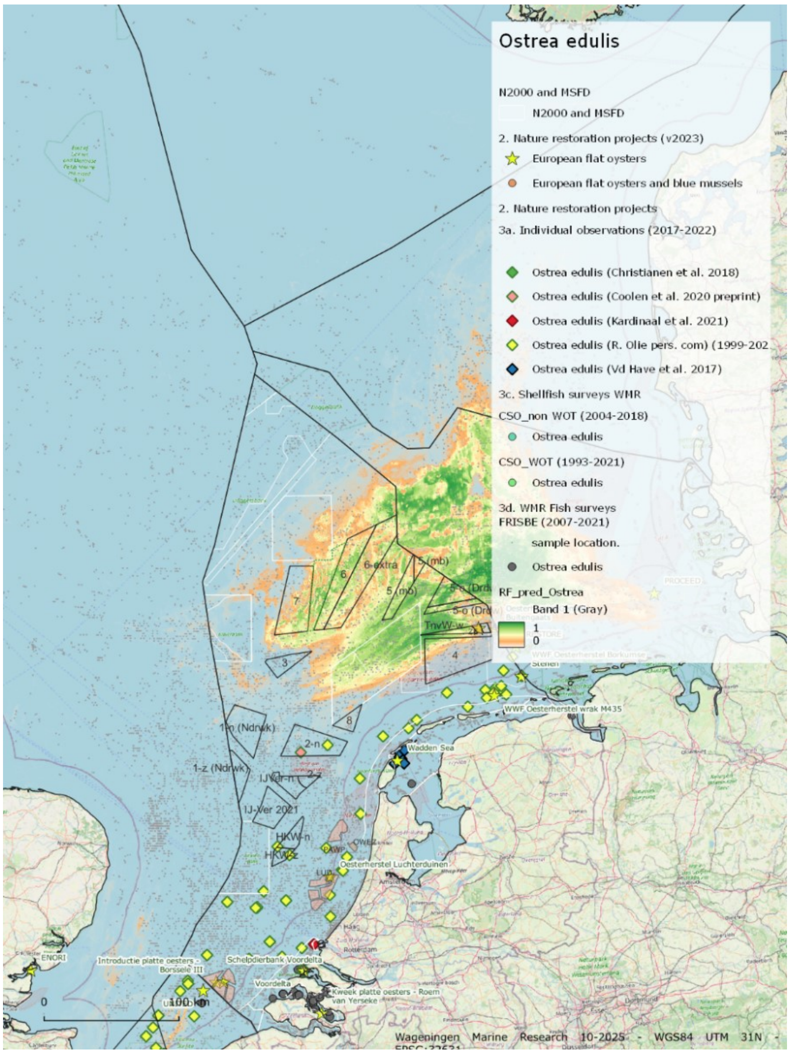


***Figure 7-1*** *Distribution of European flat oyster Ostrea edulis (point data) and predicted probability of occurrence (random forest regression) (Bos et al. 2024) with updated locations of wreck findings (R. Olie pers com).*

In the North Sea, sublittoral offshore mussel beds of *M. edulis* are mostly found in the intertidal and shallow subtidal zones. However, they have also been observed in deeper areas such as the Voordelta, Frisian Front, Central Oyster Grounds, and the Dogger Bank (Bakker et al. 2023). Dense mussel populations have also been recorded on artificial hard substrates, such as offshore wind farms (Figure 7-2).

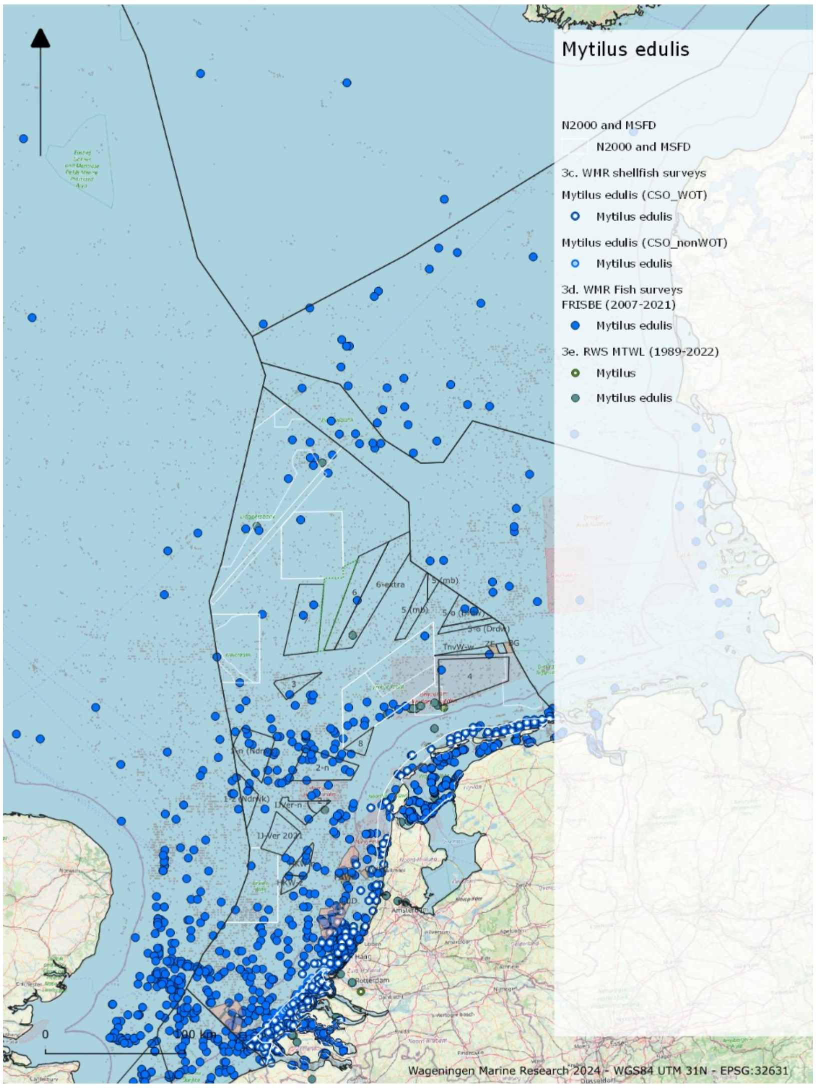


***Figure 7-2*** *Distribution of blue mussel Mytilus edulis (point data) and predicted probability of occurrence (random forest regression) (Bos et al. 2024).*

*M. modiolus* beds in the OSPAR region[8] are typically found in scattered patches across cold-temperate coastal regions of the northeast Atlantic shelf. They inhabit both natural and artificial substrates, from the lower intertidal zone to depths of approximately 200 meters. Their distribution ranges from the southern Barents Sea and White Sea down to the North Sea and Irish Sea (some beds observed around Iceland and the Faeroes) (OSPAR, 2009) (Figure 7-3). In the Dutch North Sea however, the species (individuals) is mostly absent and horse mussel beds do not seem to occur.

[8] https://oap.ospar.org/en/ospar-assessments/committee-assessments/biodiversity-committee/status-assesments/modiolus-modiolus-beds/

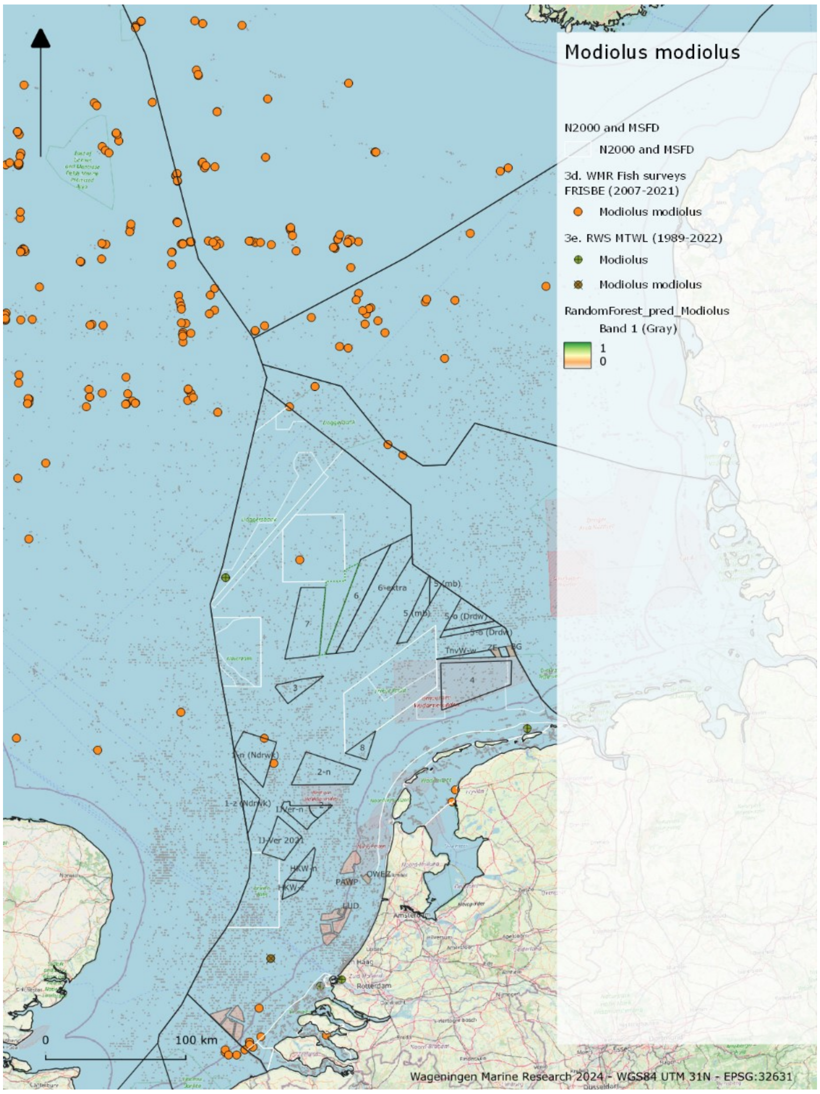


***Figure 7-3*** *Distribution of (individual) horse mussel Modiolus modiolus (point data) and predicted probability of occurrence (random forest regression) (Bos et al. 2024).*

*S. spinulosa* is widely distributed along European coastlines and in offshore waters, occurring both as individuals and in reef-forming aggregations (Figure 7-4). However, the formation of dense reefs is more limited and restricted to areas with high turbidity, strong bottom shear stress, and abundant sand supply. These conditions support reef development, particularly in regions with high gravel content in the sediment (Herman & Van Rees, 2022). The species relies on hard substrates to support reef formation, providing stable surfaces for larvae to settle and grow. *S. spinulosa* reef formations have been well documented in the UK and the southern North Sea (OSPAR Commission, 2013). Within the Dutch EEZ, reef formation by S. spinulosa is less common (van Duren et al. 2017), though reefs have been recorded at the Brown Ridge and possibly in the Frisian Front (van der Reijden et al. 2019). Additionally, a recent survey (Bakker et al. 2023) confirmed the presence of S. spinulosa in the Frisian Front and the area to its south. Moreover, small patches of *S. spinulosa* have been observed on artificial structures in the Dutch EEZ (Bos et al. 2019).

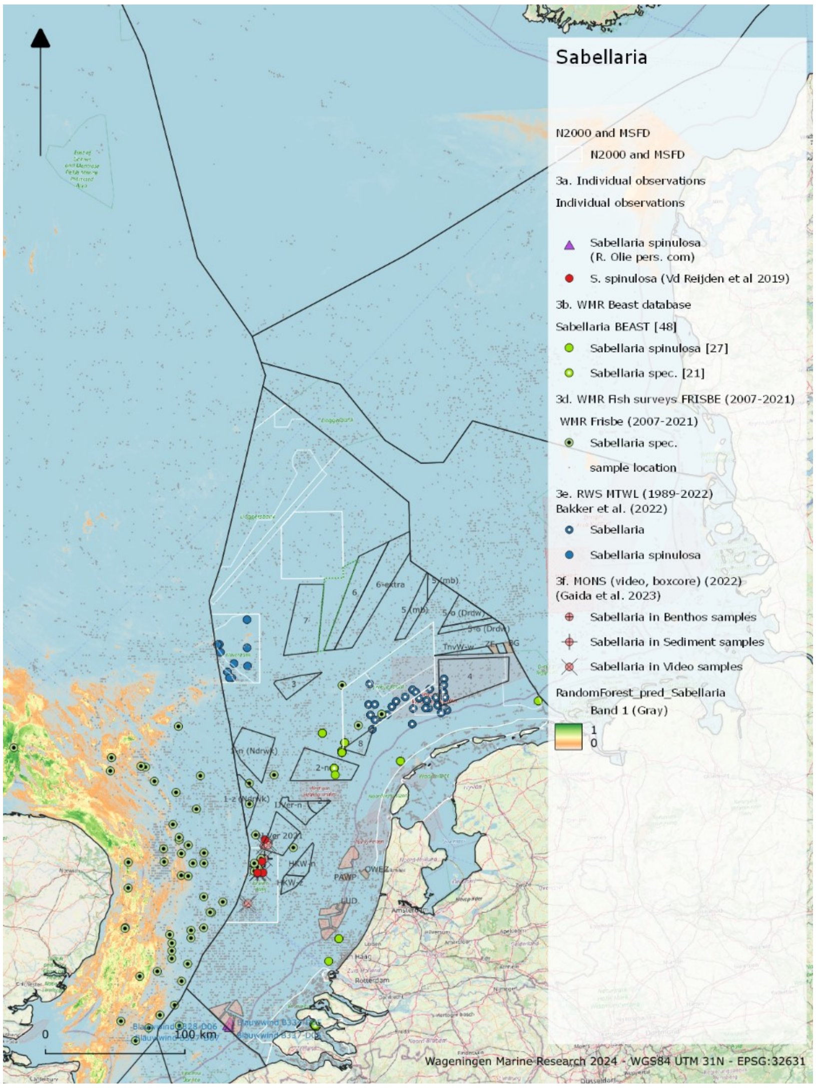


***Figure 7-4*** *Distribution of Sabellaria spp. based on point data and predicted probability of occurrence (random forest regression) (Bos et al. 2024).*

*L. conchilega* has a broad distribution across the northeast Atlantic, occurring along the entire European coastline, excluding the Arctic region (Callaway et al. 2010). It typically forms dense clusters on flats with medium fine to muddy sand (Mcquillan & Tillin, 2006). In the Netherlands, this species is found in tidal estuaries up to the Dogger Bank, with densities at times exceeding 4,700 individuals per $m^2$ (Coolen et al. 2015). The highest concentrations in the Dutch EEZ are observed north of the Wadden Islands, spanning from Terschelling to the eastern limits of the Dutch North Sea section, including the Borkum Reef Grounds (Figure 7-5).

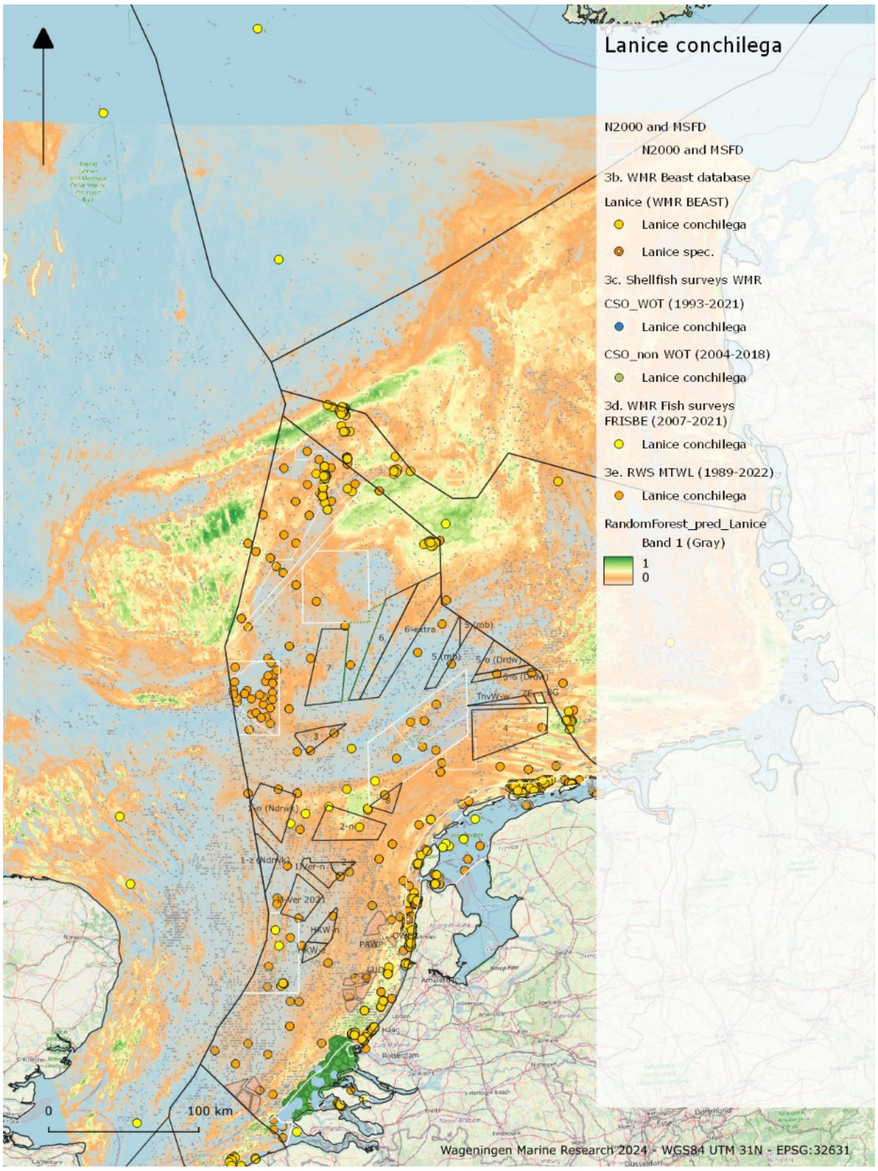


***Figure 7-5*** *Distribution of Lanice conchilega (point data) and predicted probability of occurrence (random forest regression) (Bos et al. 2024).*

### 7.1.6 Pressures and impacts

Despite their ecological significance, biogenic reefs face multiple threats:

- (Historical) overharvesting (e.g. flat oyster)
- Bottom trawling and dredging: Physical disturbance from fishing gear can degrade reef structures and hinder recovery
- Climate change: Rising sea temperatures can affect reef distributions and resilience
- Pollution

### 7.1.7 Current policy

None of the reef-building species (or their associated reefs) described in this chapter are currently directly protected under the Dutch implementation of the Natura 2000/Habitats Directive. Unlike other North Sea countries, such as Germany, the Netherlands has not yet classified biogenic reefs as part of Habitat Directive (HD) habitat type H1170 reefs, as outlined in the H1170 profile document (Min LNV, 2014). However, *S. spinulosa* is identified as a characteristic species for H1170, while *M. edulis* is considered a typical species for intertidal zones of H1140 and H1110, and *L. conchilega* is listed as a characteristic species for both intertidal and North Sea coastal areas of H1140 and H1110 (Min LNV, 2008; 2014). Intertidal mussel beds play a crucial role in maintaining the structure and function of habitat type H1140, though the role of sublittoral mussel beds in the North Sea is probably not crucial, since have historically been considered absent from offshore Dutch waters and have not yet been prioritized for conservation. De Froe et al. (2025) provide an overview of nearshore historical mussel beds, such as in the mouth of the Haringvliet area.

The OSPAR Commission includes several reef-building species and habitats on its list of 'threatened and declining species and habitats' in need of protection (OSPAR, 2008). This list covers *O. edulis* and *O. edulis* beds, intertidal mussel beds (excluding sublittoral/offshore beds), and *S. spinulosa*. Additionally, the MSFD acknowledges the return and recovery of biogenic reefs as part of Descriptor 6, Target 5 (D6T5) (Marine Strategy Part 1; IenW & LNV, 2018).

In the Netherlands, conservation objectives under the Environment and Planning Act of the Netherlands (formerly Nature Conservation Act) also indirectly safeguard shellfish populations, as they are essential food sources for protected bird species such as oystercatchers. As a result, mussels and mussel beds hold legal protection as critical ecosystem components. Moreover, the production and harvesting of *M. edulis* and *O. edulis* are regulated under the Dutch Fisheries Act, article 1.2 Staatscourant 1982, 253.

Due to the low relevance of *M. modiolus* in the southern North Sea, they do not have a protection status in Dutch waters.

#### 7.1.7.1 Policy measures

Restoration of biogenic reefs has been a target in the Dutch Marine Strategy for some time. In addition, since 2024, under the Nature Restoration Regulation (NRR), Member States have to put restoration measures in place for at least 30% in 2030 of the total area of all habitat types listed in Annex II of the NRR that are not in good condition (increasing to 60% in 2040 and 90% in 2050). Under the NRR, Member States must define restoration measures for shellfish beds. A proposal for favourable reference areas for littoral as well as sublittoral (a.o. flat oysters) shellfish beds is presented in a report by WMR (De Froe et al. 2025). Preliminary findings from this WMR report indicate a potential need for restoration of sublittoral shellfish beds, with the greatest potential in the North Sea and the Wadden Sea.

Restoration of biogenic reefs requires seabed protection measures, such as management measures to exclude bottom disturbing fishing and sand/gravel extraction. In the Voordelta, the mixed oyster reef is protected under a national fisheries management measure since 4 years[9]. In the Frisian Front area, 2 areas of 4 km2 and 2 areas of 50 km2 are designated for future oyster restoration activities. The 2 areas of 4 km2 are located in the Frisian Front MSFD area that was closed to bottom disturbing fisheries in 2023. Other fishery management measures under the CFP are in the pipeline and expected to be in place in the near future (2026/2027). These include enlargements of the Cleaver Bank (HD), Central Oyster Grounds (MSFD) and Frisian Front (MSFD) area closures and closure of the Borkum Reef Grounds (MSFD), Southern Dogger Bank (MSFD). In addition, BD area Brown Ridge will be closed for gillnet fisheries for half a year. These measures offer more opportunities for oyster restoration.

### 7.1.8 Advice and action perspectives, possible measures

*Rationale*

Biogenic reefs serve as important habitats that supports a diverse range of marine life, contributing to the overall productivity of the North Sea. Human impacts have significantly reduced the presence and distribution of biogenic reefs, such as the flat oyster (*O. edulis*) and reef-building Ross worm (*S. spinulosa*). While reef-building tube-dwelling worms are still present and will probably naturally recolonize areas once seafloor disturbing activities are not taking place anymore, the European flat oyster *O. edulis* lacks a stable base population, making natural recovery unlikely. Other species such as horse mussel (*M. modiolus*) are of little importance in the Dutch North Sea but may be restored in an international context.

*Action perspective for NN*

Although the NRR is to be implemented by the ministry of LVVN as a part of their regular policy, NN can help to contribute to these targets. NN can contribute to restoration of biogenic reefs by focussing on:

[9] https://www.natura2000.nl/gebieden/zeeland/voordelta/voordelta-aanwijzing

Active habitat restoration: Several oyster restoration pilots have already taken place successfully (Bos et al. 2023) and other pilots are ongoing e.g. pilots with remote setting (i.e. letting the larvae settle on the material before applying them at the seabed). To further restore oyster reefs, four areas (2 times 4 $km^2$ and 2 times 50 $km^2$) for oyster restoration in the Frisian Front area have been defined under the North Sea Agreement. NN is developing plans to restore oysters and possibly other biogenic reef builders in these areas. Other measures at other locations could involve providing suitable hard substrates for larvae to settle on (e.g. large-scale deployment of rocky material or shells on the seabed), where possible in combination with remote setting when proven successful. (RRL 4-5/6-7).

Improving restoration techniques: Effective and scalable restoration techniques are important for restoring reef-building species. Such methods should aim at creating self-sustaining reef systems over large areas, allowing for long-term recovery and ecological resilience (RRL 4-5).

- NN could help scaling up of the production of hatchery-raised, disease (*bonamia*)-free and tolerant European flat oyster spat that can be used for restoration.
- Habitat mapping / micro siting studies: In areas with strong spatial heterogeneity, such as the Frisian Front 2x2 km oyster restoration areas, and the Borkum Reef Grounds, more detailed mapping of the seafloor habitat is needed. This would help identify suitable conditions for reef restoration and where restoration efforts would be most effective.

*Demonstration of impact*

To demonstrate the impact of the measures, monitoring should be set-up, in line with regular national monitoring and best practices (NORA monitoring guide for oyster restoration).

### 7.1.9 References


Anwar, N.A., Richardson, C.A., & Seed, R. (1990). Age determination, growth rate and population structure of the horse mussel *Modiolus modiolus*. J. Mar. Biol. Assoc. UK, *70*(2), 441-457.

Baden, S., Hernroth, B., & Lindahl, O. (2021). Declining Populations of Mytilus spp. in North Atlantic Coastal Waters—A Swedish Perspective. J. Shellf. Res., 40(2), 269–296. https://doi.org/10.2983/035.040.0207


Baden, S., Hernroth, B., & Lindahl, O. (2021). Declining Populations of Mytilus spp. in North Atlantic Coastal Waters—A Swedish Perspective. J. Shellf. Res., 40(2), 269–296. https://doi.org/10.2983/035.040.0207


Bakker, E. G. R., de Jong, J., Middelveld, R., & Kruijt, D. B. (2022). *Macrozoöbenthos bemonstering Noordzee met de Bodemschaaf. Rapportage 2021 en 2022. Rapport22-0306.* https://open.rijkswaterstaat.nl/publish/pages/183829/bm_23-10_macrozo_benthos_bemonstering_noordzee_met_de_bodemschaaf_rapportage_2021_en_2022.pdf

Bennema, F. P., Engelhard, G. H., & Lindeboom, H. (2020). Ostrea edulis beds in the central North Sea: delineation, ecology, and restoration. *ICES J. Mar. Sci. (*https://doi.org/10.1093/icesjms/fsaa134)

Bos, O. G., Duarte-Pedrosa, S., Didderen, K., Bergsma, J.H., Heye, S., & Kamermans, P. (2023). Performance of European oysters (*Ostrea edulis* L.) in the Dutch North Sea, across five restoration pilots. Front. Mar. Sci., 10. https://doi.org/10.3389/fmars.2023.1233744

Bos, O.G., Kingma, E.M., & Van der Wal, J.T. (2024). Biogenic reefs in the Dutch North Sea in relation to Offshore Wind Energy locations: Actual and predicted probability of occurrence of reef forming shellfish and worms in new wind farm zones and search areas for wind farm zones. Wageningen Marine Research report C091/24. https://doi.org/10.18174/683402

Bos, O. G., Bittner, O., van der Weide, B., Cuperus, J., Wijnhoven, S., Gaida, T. C., & Binnerts, B. (2025). Borkum Reef Grounds: inventory of biodiversity and habitats. MONS ID49 Effectivity of Marine Protected Areas. Wageningen Marine Research, Waardenburg Ecology, Ecoauthor, TNO. C054/25 (https://doi.org/10.18174/697930).

Callaway, R., Desroy, N., Dubois, S. F., Fournier, J., Frost, M., Godet, L., Hendrick, V. J., & Rabaut, M. (2010). Ephemeral bio-engineers or reef-building polychaetes: How stable are aggregations of the tube worm *Lanice conchilega* (Pallas, 1766)? Integrative and Comparative Biology, 50(2), 237–250. https://doi.org/10.1093/icb/icq060

Coolen J.W.P., van der Weide B., Cuperus J., Blomberg M., van Moorsel G.W.N.M., Faasse M.A., Bos O.G., Degraer S., Lindeboom H.J. (2020) Benthic biodiversity on old platforms, young wind farms, and rocky reefs. *ICES J. Mar. Sci. 77*(3): 1250–1265 https://doi.org/10.1093/icesjms/fsy092

Coolen, J.W.P., Bos, O. G., Glorius, S., Lengkeek, W., Cuperus, J., van der Weide, B.E., & Agüera, A. (2015). Reefs, sand and reef-like sand: A comparison of the benthic biodiversity of habitats in the Dutch Borkum Reef Grounds. J. Sea Res, 103(1), 84–92.

De Bruyne, R., van Leeuwen, S., Gmelig Meyling, A., Daan, R. (Ed.) (2013). Schelpdieren van het Nederlandse Noordzeegebied: ecologische atlas van de mariene weekdieren (Mollusca). Tirion Natuur/Stichting Anemoon: Utrecht en Lisse. ISBN 978-90-5210-821-6.

Dinesen, G.E., & Morton, B. (2014). Review of the functional morphology, biology and perturbation impacts on the boreal, habitat-forming horse mussel Modiolus modiolus (Bivalvia: Mytilidae: Modiolinae). *Mar. Biol. Res.*, 10(9), 845–870. https://doi.org/10.1080/17451000.2013.866250

Gaida, T.C., Binnerts, B., & Bos, O. (2025). Semi-Automated Classification of Side-Scan Sonar Data for Mapping Sabellaria spinulosa Reefs in the Brown Bank, Dutch Continental Shelf. *J. Mar. Sci & Engin.*, *13*(1). https://doi.org/10.3390/jmse13010074

Herman P.M.J. & van Rees F.F. (2022) Mapping Reef forming North Sea Species. Deltares report 11207716-000-ZKS-0002

Houziaux, J. S., Fettweis, M., Francken, F., & Van Lancker, V. (2011). Historic (1900) seafloor composition in the Belgian-Dutch part of the North Sea: A reconstruction based on calibrated visual sediment descriptions. *Cont. Shelf Res.*, 31(10), 1043–1056. https://doi.org/10.1016/j.csr.2011.03.010

IenW & LNV. (2018). Marine Strategy (part 1). Update of current environmental status, good environmental status, environmental targets and indicators. 2018-2024 (Issue part 1). https://www.government.nl/documents/reports/2015/07/07/the-dutch-maritime-strategy015-2025

Maddock, A. (2008). UK Biodiversity Action Plan, Priority Habitat Descriptions; *Sabellaria spinulosa* Reefs.

Mcquillan, R., & Tillin, H. (2006). MarLIN Dense *Lanice conchilega* and other polychaetes in tide-swept infralittoral sand and mixed gravelly sand. MarLIN-Marine Life Information Network Marine Evidence-based Sensitivity Assessment (MarESA) Review. https://doi.org/10.17031/marlinhab.116.1

Ministerie LNV. (2008). Bij eb droogvallende slikwadden en zandplaten (H1140). (versie 18 dec 2008). https://www.natura2000.nl/sites/default/files/profielen/Habitattypen_profielen/Profiel_habitattype_1140.pdf

Ministerie LNV. (2014). Permanent overstroomde zandbanken (H1110). (versie 2014). https://www.natura2000.nl/sites/default/files/profielen/Habitattypen_profielen/Profiel_habitattype_1110_2014.pdf

Ministerie LNV. (2014). Riffen (H1170). (versie 2014). https://www.natura2000.nl/sites/default/files/profielen/Habitattypen_profielen/Profiel_habitattype_1170_2014.pdf

Olsen, O.T. (1883). The piscatorial atlas of the North Sea, English and St. George's Channels, illustrating the fishing ports, boats, gear, species of fish (how, where, and when caught), and other information concerning fish and fisheries. Taylor and Francis.

OSPAR Commission. (2009). Background Document for Modiolus modiolus beds. Biodiversity Series (425/2009). OSPAR. https://www.ospar.org/documents?v=7193

OSPAR Commission. (2009). Background document for Ostrea edulis and Ostrea edulis beds. Biodiversity Series (428/2009). OSPAR. https://www.ospar.org/documents?v=7183

OSPAR Commission. (2013). Background document on Sabellaria spinulosa reefs. Biodiversity Series (614/2013). OSPAR. https://www.ospar.org/documents?v=7342

OSPAR Commission. (2013). Background document on Sabellaria spinulosa reefs. Biodiversity Series (614/2013). OSPAR. https://www.ospar.org/documents?v=7342

OSPAR. (2008). List of Threatened and/or Declining Species and Habitats (OSPAR Agreement 2008-06). OSPAR.

Rabaut, M., Guilini, K., Van Hoey, G., Vincx, M., & Degraer, S. (2007). A bio-engineered soft-bottom environment: The impact of Lanice conchilega on the benthic species-specific densities and community structure. *Estuarine, Coastal and Shelf Science*, 75(4), 525–536. https://doi.org/10.1016/J.ECSS.2007.05.041

Sas, H., van Duren, L., Herman, P.M.J., van der Have, T., Kamermans, P., Bos, O.G., Kingma, E.M., Bouma, T., & Kardinaal, E. (2023). *Reef-building species and biogenic reef enhancement in the Dutch North Sea: Background documents*. https://edepot.wur.nl/633785

Thurstan, R.H., McCormick, H., Preston, J., Ashton, E.C., Bennema, F.P., Cetinić, A.B., Brown, J.H., Cameron, T.C., da Costa, F., Donnan, D.W., Ewers, C., Fortibuoni, T., Galimany, E., Giovanardi, O., Grancher, R., Grech, D., Hayden-Hughes, M., Helmer, L., Jensen, K.T., … zu Ermgassen, P.S.E (2024).

Records reveal the vast historical extent of European oyster reef ecosystems. *Nature Sustainability*. https://doi.org/10.1038/s41893-024-01441-4.
Tillin, H. & K. Mainwaring (2016) *Mytilus edulis* beds on sublittoral sediment. In Tyler-Walters H. and Hiscock K. (eds) Marine Life Information Network: Biology and Sensitivity Key Information Reviews, [on- line]. Plymouth: Mar. Biol. Assoc. UK. DOI https://dx.doi.org/10.17031/marlinhab.36.1
Van der Reijden, K.J., Koop, L., O'Flynn, S., Garcia, S., Bos, O., van Sluis, C., Maaholm, D.J., Herman, P.M. J., Simons, D.G., Olff, H., Ysebaert, T., Snellen, M., Govers, L.L., Rijnsdorp, A.D., & Aguilar, R. (2019). Discovery of *Sabellaria spinulosa* reefs in an intensively fished area of the Dutch Continental Shelf, North Sea. *J. Sea Res.*, 144(November 2018), 85–94. https://doi.org/10.1016/j.seares.2018.11.008
Van Duren, L. A., Gittenberger, A., Smaal, A. C., van Koningsveld, M., Osinga, R., Cado van der Lelij, J. A., & de Vries, M. B. (2017). Rich reefs in the North Sea, Deltares publication 1221293-000-ZKS0013

## 7.2 Long-lived shellfish and burrowing megafauna

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*(*based on the background report for the species protection plan: Kingma *et al.* 2026 in prep).

### 7.2.1 Description of the ecosystem component

The focus of this chapter is on long-lived shellfish species, defined as benthic shellfish with relatively slow growth rates and a long lifespan (>10y), and on the burrowing megafauna community, for which the OSPAR definition (2010) is used (see Box 1). This community is present in plains of fine mud, typically found at depths of 15–200 meters or more, where the sediment is extensively bioturbated by the burrowing activities of larger benthic organisms. The resulting burrows and mounds form prominent features of the seabed.

### 7.2.2 Species selection / Focus species

The selected species and habitat are part of the species protection plans that are being developed within the MONS programme. They concern ocean quahog (*Arctica islandica*), whelk (*Buccinum undatum*), red whelk (*Neptunea antiqua*) and the OSPAR habitat type 'burrowing megafauna and seapen communities' (see Box 1). The latter are communities often associated with sea pens and comprising, among others, large burrowing crustaceans such as *Nephrops norvegicus* or *Callianassa subterranea* (OSPAR 2010).

***BOX 1*** *Definition of the OSPAR habitat type Sea-pen and Burrowing Megafauna Communities (OSPAR, 2008).*

"***Plains of fine mud****, at water depths ranging from 15–200 m or more, which are heavily bioturbated by burrowing megafauna; burrows and mounds may form a prominent feature of the sediment surface with conspicuous populations of sea-pens, typically Virgularia mirabilis and Pennatula phosphorea. The burrowing crustaceans present may* ***include Nephrops norvegicus, Calocaris macandreae or Callianassa subterranea****. In the deeper fjordic lochs which are protected by an entrance sill, the tall sea-pen Funiculina quadrangularis may also be present. The burrowing activity of megafauna creates a complex habitat, providing deep oxygen penetration. This habitat occurs extensively in sheltered basins of fjords, sea lochs, and in deeper offshore waters such as the North Sea and Irish Sea basins and the Bay of Biscay.*

#### 7.2.2.1 Rationale for selection

The long-lived shellfish species (whelk *Buccinum undatum*, red whelk *Neptunea antiqua* and ocean quahog *Arctica islandica*) were selected because of their policy relevance. *Buccinum undatum* (common whelk) is a HD typical species for H1110ABC, H1140A and H1170. *Arctica islandica* (ocean quahog) and *Neptunea antiqua* (red whelk) are HD typical species for H1110C (Dogger Bank). Measures aimed to protect these species should also help to protect and restore other long lived shellfish species.

The burrowing megafauna species were selected on the basis of the definition of the OSPAR habitat "Burrowing megafauna communities and seapens" (Box 1). The main focus is on mud plains that are typically found in low energy environments, such as lochs and fjords. In undisturbed situations, seapens and other epifauna (e.g. brittlestars) thrive, inbetween large burrows created by different burrowing megafauna species. The habitat is also found in the deeper parts of the North Sea, but then usually in absence of seapens. As a working definition, Bos & Van der Wal (2025) used the 10% silt content threshold to delineate the habitat.

### 7.2.3 Habitat preferences

In the Dutch EEZ, the ocean quahog mostly occurs in the deeper and calmer environments of the Oyster Grounds (Herman & Witbaard 2023). There is no clear relation between its distribution in the North Sea and the sediment composition. However, its absence from the southern North Sea may be due to temperature effects on adult or larval survival (Witbaard & Bergman, 2003).

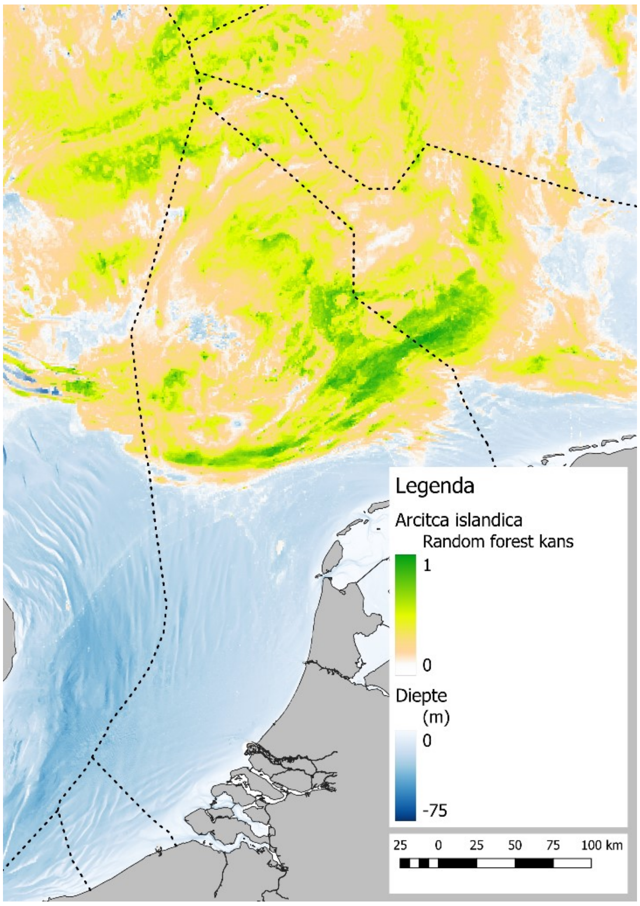


***Figure 7-6*** *Habitat suitability map of the ocean quahog in the southern North Sea. This prediction is for the period before 2004; habitat suitability has meanwhile been reduced due to fishing pressure SOURCE: Deltares.*

The common whelk (*Buccinum undatum*) is a demersal species with a broad substrate tolerance, occurring on muddy sand, coarse sand, gravel, and rocky bottoms, from shallow subtidal to continental shelf depths (to ~200 m, occasionally deeper) (SOURCE: Marlin). For reproduction, however, hard substrates are likely essential as females attach egg capsules to firm objects on the seabed, such as stones, shells, or artificial structures (Cadée, 1995). In the Dutch North Sea*, B. undatum* formerly thrived in coastal sandy habitats and around shellfish beds, but following its decline, remaining individuals are mostly found in undisturbed offshore areas (de Vooys & van der Meer, 2010).

The red whelk is a subtidal, epibenthic species typically found in colder deeper waters, ranging from ~15 m-1,200 m (Avant, 2003). Although often found on soft sediment areas, it needs the presence of hard substrate or structures such as gravel, rocks or shells, for its reproduction as females attach their eggs capsules to these hard surfaces (Smith et al. 2011; Power & Keegan, 2001[a]). The species is commonly observed on the Dutch Cleaver Bank in the northwestern Dutch North Sea, a gravelly bank which provides such habitat.

The burrowing megafauna community inhabits sandy and muddy substrates, creating complex, multi-branched burrow systems. This OSPAR habitat occurs north of the Frisian Front and south of the Dogger Bank, in the Oyster Grounds and in the Botney Cut (Figure 7-7).

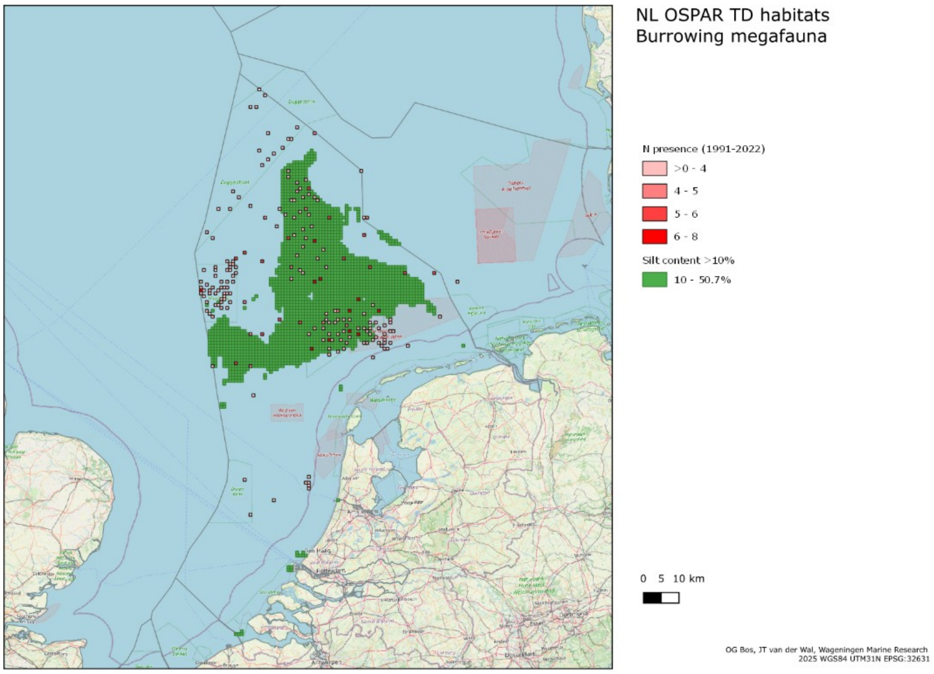


***Figure 7-7*** *Muddy areas (>10% silt) and records of burrowing megafauna species (Bos & Van der Wal, 2025). The green area is the focus area for this report as the habitat for burrowing megafauna. Data were aggregated in 2500mx2500m grid cells, since sampling does not occur at exactly the same spot and because of the different sampling methods. The burrowing megafauna was considered to be present in a grid cell if any of the selected taxa was present in 1 or more years from the available years (for details, see Bos & Van der Wal, 2025).*

### 7.2.4 Ecosystem function

Shellfish and other burrowing megafauna are of high importance for the ecosystem functioning of all marine regions. They form an important trophic link in the food web and serve as a food source for many predators, ranging from other benthic species to fish and seabirds. As many species are deposit feeders, which ingest sediment containing living and nonliving organic matter, they are considered a crucial component of the detritic food web (Lopez & Levinton 2011).

Common whelks are opportunistic feeders, and are both predator on living bivalves as well as scavengers (de Vooys and van der Meer, 2010; Hallers-Tjabbes et al. 1996) on dead animals lying on the sea floor like fishery discards and animals damaged by trawling. This scavenging behavior aids in the rapid removal of carrion from the seafloor, facilitating nutrient recycling and energy transfer within benthic food webs (Evans et al. 1996). Common whelks are themselves preyed upon by various predators, including cod, dogfish, skates, lobsters, and crabs (Ten Hallers-Tjabbes et al. 1996), most likely in their juvenile stage or when they are still small.

The red whelk occupies a broadly similar ecological niche as *Buccinum undatum*, functioning as both a scavenger and predator, but is a more northern species, occurring in colder waters such as the Dogger Bank and the Oyster Grounds (De Bruyne et al. 2013). It is known to feed on benthic invertebrates such as bivalves and polychaetes and may also consume carrion (Power & Keegan, 2001; Smith et al. 2011). By scavenging on animal remains on the seabed, the red whelk contributes to energy transfer and nutrient cycling in the benthic food web.

Burrowing shrimps are considered important ecosystem engineers, particularly in sandy seabed environments (Tempelman et al. 2013; Nickell & Atkinson, 1995; Stamhuis, 1997). Their burrowing activity results in bioturbation, which oxygenates the sediment, redistributes organic material, and enhances nutrient cycling (Witbaard & Duineveld, 1989; Tempelman et al. 2013). Moreover, these species and their associated burrow systems create conditions (microhabitats) for various (symbiotic) benthic species such as other bivalves and certain fish species. In addition to their role as habitat engineers, burrowing shrimps are an important food source for demersal fish and other predators. *Upogebia*, for example, is the most abundant decapod crustacean in the diet of the plaice (*Pleuronectes platessa*) and also contributes to the diet of the thornback ray (*Raja clavata*) (Rijnsdorp & Vingerhoed 2001; De Vooys et., 1991).

Bioturbation

One of the most important functions of the endobenthos is its role in solute transfer and sediment biogeochemistry. Virtually all species perform bioturbation in one way or another. Bioturbation is an umbrella term for all transport processes that affect the sediment matrix (Kristensen et al. 2012). This includes burrow ventilation (bioirrigation), in which water is transported into the sediment, and particle reworking, in which the sediment particles are transported due to the movement of the animal. Species usually bioturbate using one or several bioturbation modes, which determine to what extent the sediment is reworked. This can range from biodiffusors (which mix the sediment homogeneously), over up- or downward conveyors (which transport sediment particles up or down a tube or burrow), to regenerators (which excavate burrows that can subsequently collapse). An important consequence of bioturbation is the so-called benthic-pelagic coupling: the exchange of solutes (oxygen, nutrients and other substances) between the sediment and the water column. This results in a more oxygenated and nutrient-rich sediment than would be the case without bioturbation, but also transports organic matter to deeper anoxic layers, effectively sequestering the carbon into the seafloor. Although organic matter in surface layers is quickly broken down by the presence of oxygen in most of the North Sea, regional differences in degradation rates have been observed due to differences in bioturbation rates (De Borger et al. 2021).

In the Baltic Sea, the ocean quahog was found to highly contribute to the community bioturbation potential in fine sands (as a surficial biodiffusor). As a result of both its relative absence from the southern North Sea and the presence of more bioturbating species there, the local importance for bioturbation is rather low (Gogina et al. 2020). The ecological importance of the species probably lies more in its value as a food source for fish (Brey et al. 1990). As an extremely long-lived species with a high resistance to oxygen deficiency and pollution, ocean quahogs can also accumulate high levels of potential contaminants throughout their life cycle, making them valuable indicators of historical pollution (Liehr et al. 2005).

### 7.2.5 Status and trend ecosystem component

The whelk has virtually disappeared from Dutch coastal waters, following a historical collapse due to overfishing, dredging impacts, and the effects of tributyltin (TBT) pollution. For the red whelk, the status is not clear. For the habitat type ‘Burrowing megafauna’ the status in the latest OSPAR assessment[10] was assessed as ‘poor’.

The status and trends of the ocean quahog in the Dutch EEZ show reason for concern. Despite a higher chance of being sampled due to advancements in sampling equipment, its area of distribution has decreased over the past decades, and it has recently disappeared altogether from the Frisian Front. As it is a long-lived and largely sessile species, it is highly sensitive to bottom-disturbing fisheries, which is therefore the most likely cause of this disappearance. In addition, the population structure in the Dutch EEZ is possibly not sustainable, with densities of both adults and juveniles that are considered too low for self-sustainability. However, small and thus far undetected high-density populations may still exist and provide the necessary spat for long-term survival of the species (Herman & Witbaard 2023).

### 7.2.6 Pressures and impacts

Many studies have found links between the density, biomass, diversity or functioning of macrobenthos, and environmental changes linked to, for example, climate change, offshore wind farm construction, fisheries, or sediment disposal.

[10] https://oap.ospar.org/en/ospar-assessments/committee-assessments/biodiversity-committee/status-assesments/sea-pen-and-burrowing-megafauna-communities/

#### 7.2.6.1 Fisheries

The most direct pressure on long-lived shellfish in the North Sea stems from activities that disrupt the seabed, most significant bottom-contact fishing. Beam trawling, widely practiced in Dutch waters, places considerable strain on benthic ecosystems. By towing heavy gear across the seafloor, this method alters habitats through sediment disturbance and the damage of species present.

Long-lived shellfish species are vulnerable to shell damage and increased mortality caused by beam trawl fisheries. These species either live on top of the seabed (whelks) or just beneath the surface layer of sediment (ocean quahog) making them vulnerable for being fished or damaged by the passing gear (Witbaard & Klein 1994; Rumohr & Krost, 1991). Studies have shown a clear spatial overlap between areas of intense bottom trawling and the distribution of *A. islandica* (Herman & Witbaard, 2023; Craeymeersch et al. 2000).

The effects on the burrowing megafauna community are more complex. Bottom disturbing fisheries can lead to the collapse of the shallow parts of the burrows (the tunnel systems) and to damage of the associated epifauna, while the burrowing fauna itself may escape damage by hiding in the deeper parts of the tunnels. In some cases, *Nephrops* may even become dominant in areas following trawling activities (Vergnon & Blanchard, 2006; OSPAR Commission, 2010).

#### 7.2.6.2 Pollution

The use of tributyltin (TBT), once a common component in antifouling paints on ships, has left a long-lasting mark on marine gastropod populations in the North Sea. This chemical is harmful to marine organisms, with one of its most detrimental consequences being the development of imposex; a disorder in which female gastropods acquire male sexual traits. Such disruptions often lead to infertility and, in turn, population declines. Long-lived, slow-reproducing species like the common whelk and the red whelk are particularly at risk from this pollutant in the North Sea. Current regulations have significantly reduced TBT use, however the absence of previously common whelk populations in high-traffic zones suggests long-term or possibly irreversible impacts driven by this TBT pollution (in combinations with bottom-contact fisheries).

Other pollutants (PCBs, PAKs, PBDEs, pesticides, mercury) have been monitored by OSPAR in blue mussels and Pacific oysters and are declining at many sites. However, mercury consistently remains at levels above the environmental quality standards. Contamination by the toxic PFAS and BPA is a newer phenomenon, but equally a reason for concern. Due to bioaccumulation, these compounds may persist in the biota for the foreseeable future. Volatile regulation makes it unclear what the standards are for maximum exposure (Dogruer et al. 2024; Kingma et al. 2026 in prep.).

#### 7.2.6.3 Climate change

Weinert et al. (2022) modelled bioturbation of key species in the southern North Sea under a climate change scenario and projected that the bioturbation potential of many of these species is likely to decrease in the coming century, driven by northward range expansions. As these expansions do not always keep track with temperature shifts, it is not unlikely that benthic diversity in the North Sea will decrease due to the warming seawater (Hiddink et al. 2015). Ocean acidification as a result of greenhouse gas emissions can also significantly alter the composition of benthic communities, since not all species have the same sensitivity to decreases in seawater pH (Birchenough et al. 2015).

Long-lived shellfish and burrowing megafauna are particularly vulnerable to these changes, with species-specific tolerances determining their resilience to warming waters. For example, the ocean quahog *Arctica islandica* shows strong thermal limits around 16 °C, suggesting that its southern distribution in the North Sea (around the Frisian Front) will shift northwards as summer bottom temperatures rise (Herman & Witbaard, 2023; Mann, 1989; Merrill et al. 1969). In contrast, the common whelk *Buccinum undatum* has a broader tolerance but still faces reproductive constraints at higher temperatures, with recent declines in southern stocks raising concern (ICES 2025). Similarly, the red whelk *Neptunea antiqua* is predicted to undergo severe habitat loss, with modelling studies estimating near-complete disappearance from current southern ranges by 2099 (Avant, 2003; Weinert et al. 2016). Burrowing megafauna such as *Callianassa subterranea* may also lose substantial habitat (up to 31%), with cascading consequences for benthic ecosystem functioning (OSPAR Commission, 2010; Weinert et al. 2016). Overall, projections under IPCC scenario A1B suggest bottom water temperatures in the North Sea could rise by 0.15–5.4 °C this century, leading to widespread northward shifts and in some cases near-total habitat loss for key benthic species. In addition, ocean acidification may exacerbate these impacts, as shown by physiological stress responses in *Nephrops* *norvegicus* larvae (Hernroth et al. 2012; Wood et al. 2015), further threatening recruitment and population stability.

### 7.2.7 Current policy

Long-lived shellfish and burrowing megafauna communities are not listed as protected species. However, the three shellfish species (ocean quahog, whelk, red whelk) are listed as 'typical species' (indicators for a good quality of the habitat) for among others habitat type HD habitat type 1110c (Dogger Bank). This means that improving their status helps to reach targets under Habitats Directive/Natura 2000.

Furthermore, the burrowing megafauna community and the ocean quahog (*Arctica islandica*) are listed as 'threatened and/or declining species/habitats' under OSPAR (OSPAR, 2008). Protection is achieved through fishery measures in marine protected areas (Natura 2000 areas and MSFD areas). Protection of these species will take place through the implementation of fishery closures under the EU Common Fisheries Policy (CFP) in the relevant MSFD areas (Frisian Front, Central Oyster Grounds, Borkum Reef Grounds, Southern Dogger Bank).

Both the long-lived shellfish and the burrowing megafauna community are not listed specifically in the EU Nature Restoration Regulation.

Norway lobster (*Nephrops norvegicus*) and whelk (*Buccinum undatum)* are also commercial species and hence fall under the national fisheries act. For Norway lobster European TACs are set. There is no landing obligation for undersized Nephrops. For whelk no quota are set in the Netherlands.

#### 7.2.7.1 Policy measures

Obvious measures to protect these species and this habitat are the creation of marine protected areas with relevant fishery measures in place. This is a policy process under the EU Common Fisheries Policy (CFP) that is ongoing with new fishery measures expected in 2026/2027 in a number of areas. Other policy measures include reducing pollution levels to avoid harming marine life.

### 7.2.8 Advice and possible measures

*Rationale*

In the past decades, long-lived shellfish have declined in their numbers and distribution due to bottom disturbing fisheries resulting in loss and damage. Also, pollution by tributyltin (antifouling paint for ships) has caused population declines in whelks due to imposex (disturbance of reproduction).

*Action perspective for NN*

Focus points for NN could be: active restoration potential of these species such as the ocean quahog could be investigated. In addition, for whelk hard substrates could be created as egg-deposition material, during restoration of other ecosystem components (e.g. biogenic reefs) (RRL 4-5)

*Demonstration of impact*

The impact of restoration measures on long-lived shellfish species can be demonstrated by long-term monitoring of their distribution and population demographics. The current national Natura 2000/MSFD MWTL monitoring programme should be able to pick up such signals.

The impact of restoration measures on the OSPAR burrowing megafauna community may be more challenging to measure, since this concerns both the epifauna and the burrowing species, where the burrowing species may show increased numbers at higher fishing pressures. Apart from the national monitoring, visual inspections (video) of this burrowing community would be helpful.

### 7.2.9 References

Avant, P. (2003). *Neptunea antiqua* Red whelk. In Tyler-Walters H. and Hiscock K. *Marine Life Information Network: Biology and Sensitivity Key Information Reviews*, [on-line]. Plymouth: Mar Biol Ass United Kingdom. [cited 23-06-2025]. Available from: https://www.marlin.ac.uk/species/detail/1792

Beauchard, O., S. Mestdagh, L. Koop, T. Ysebaert, P. Herman. (2022). Benthic synecology in a soft sediment shelf: habitat contrasts and assembly rules of life strategies. Mar. Ecol. Prog. Ser. 682: 31-50.

Birchenough, S.N. R., H. Reiss, S. Degraer, N. Mieszkowska, Á. Borja, L. Buhl-Mortensen, U. Braeckman, J. Craeymeersch, I. De Mesel, F. Kerckhof, I. Kröncke, S. Parra, M. Rabaut, A. Schröder, C. Van Colen, G. Van Hoey, M. Vincx, and K. Wätjen. (2015). Climate change and marine benthos: a review of existing research and future directions in the North Atlantic. Wiley Interdisciplinary Reviews: Climate Change 6: 203-223.

Boon, A.R., and J. van Dalfsen. (2022). Long-term changes in the macrobenthic assemblages at a harbour sediment disposal site in the southern North Sea. Marine Environmental Research 178: 105663.

Bos, O.G., & van der Wal, J.T. (2025). Mapping habitats on the OSPAR List of threatened and/or declining species and habitats. Data submitted in 2025 to OSPAR by The Netherlands. Wageningen University & Research report C070/25. (https://doi.org/10.18174/702458)

Brey, T., W. Arntz, D. Pauly, and H. Rumohr. *Arctica (Cyprina) islandica* in Kiel Bay (Western Baltic): growth, production and ecological significance. J. Exp. Mar. Biol. Ecol.136: 217-235.

Cadée, G.C., Boon, J.P., Fischer, C.V., Mensink, B.P., & Ten Hallers-Tjabbes, C.C. (1995). Why the whelk (*Buccinum undatum*) has become extinct in the Dutch Wadden Sea. Neth J. Sea Res. 34(4): 337–339 (https://doi.org/10.1016/0077-7579(95)90044-6).

Coolen, J., J. Vanaverbeke, J. Dannheim, C. Garcia, S. Birchenough, R. Krone, and J. Beermann (2022). Generalized changes of benthic communities after construction of wind farms in the southern North Sea. J. Env. Management 315: 115173.

De Borger, E., U. Braeckman, and K. Soetaert. (2021). Rapid organic matter cycling in North Sea sediments. Continental Shelf Research 214: 104327.

De Bruyne, R.H., Van Leeuwen, S., & Meyling, A.G. (2013). Schelpdieren van het Nederlandse Noordzeegebied: ecologische atlas van de mariene weekdieren *(Mollusca)*.

de Fouw, J., P.W. van Horssen, J. Craeymeersch, M.F. Leopold, J. Perdon, K. Troost, I. Tulp, J. van Zwol, and C.J.M. Philippart. (2024). Spatio-temporal analysis of potential factors explaining fluctuations in population size of *Spisula subtruncata* in the Dutch North Sea.

De Vooys, C.G.N & Van der Meer, J. (2010). The whelk (*Buccinum undatum* L.) in the western Dutch Wadden Sea in the period 1946–1970: Assessment of population characteristics and fishery impact. J Sea Res 63 (1), 11-16 (https://doi.org/10.1016/j.seares.2009.08.005)

Dogruer, G., Sneekes, A. C., Kemenes van Uden, T., Kwadijk, C. J. A. F., de Hart, M. R., Dao, Q., van Barneveld, E., & Kotterman, M. J. J. (2024). Biotamonitoring Rijkswateren tot en met 2023: Deel I, Toestand en Trends conform KRW, KRM en OSPAR. (Wageningen Marine Research rapport; No. C040/23). Wageningen Marine Research. https://doi.org/10.18174/675201

Gogina, M., M.L. Zettler, J. Vanaverbeke, J. Dannheim, G. Van Hoey, N. Desroy, A. Wrede, H. Reiss, S. Degraer, V. Van Lancker, A. Foveau, U. Braeckman, D. Fiorentino, J. Holstein, and S.N.R. Birchenough. (2020). Interregional comparison of benthic ecosystem functioning: Community bioturbation potential in four regions along the NE Atlantic shelf. Ecological Indicators 110: 105945.

Heip, C., D. Basford, J. A. Craeymeersch, J.-M. Dewarumez, J. Dörjes, P. de Wilde, G. Duineveld, A. Eleftheriou, P. M. J. Herman, U. Niermann, P. Kingston, A. Künitzer, E. Rachor, H. Rumohr, K. Soetaert, and T. Soltwedel. (1992). Trends in biomass, density and diversity of North Sea macrofauna. ICES J. Mar. Sci. 49: 13-22.

Herman, P., & Witbaard, R. (2023). Mapping *Arctica islandica*. NIOZ Deltares report 11209797-002-ZKS-0002. (https://www.noordzeeloket.nl/publish/pages/234390/mapping-arctica-islandica-v2.pdf)

Hernroth, B., Sköld, H. N., Wiklander, K., Jutfelt, F., & Baden, S. (2012). Simulated climate change causes immune suppression and protein damage in the crustacean *Nephrops norvegicus*. *Fish & Shellfish Immunology*, *33*(5), 1095-1101 (https://doi.org/10.1016/j.fsi.2012.08.0110).

Hiddink, J.G., M.T. Burrows, and J. García Molinos. (2015). Temperature tracking by North Sea benthic invertebrates in response to climate change. Global Change Biology 21: 117-129.

Huys, R., P.M.J. Herman, C.H.R. Heip, and K. Soetaert. 1992. The meiobenthos of the North Sea: density, biomass trends and distribution of copepod communities. ICES J. Mar. Sci. 49: 23-44.

ICES (2025). Workshop on Whelk Fisheries (WKWF). ICES Scientific Reports. 07:32. 66 pp. (https://doi.org/10.17895/ices.pub.28566140)

Kingma, E.M., A. Hamer, O.G. Bos, R. Witbaard & R.H. Jongbloed (2026 in prep.). Long-lived shellfish and burrowing megafauna communities in the Dutch North Sea. Background document for a protection plan. Wageningen Marine Research report xxx.

Kristensen, E., G. Penha-Lopes, M. Delefosse, T. Valdemarsen, C. Quintana, and G. Banta. (2012). What is bioturbation? The need for a precise definition for fauna in aquatic sciences. Mar. Ecol. Prog. Ser. 446: 285-302.

Liehr, G., M. Zettler, T. Leipe, and G. Witt. (2005). The ocean quahog *Arctica islandica* L.: A bioindicator for contaminated sediments. Marine Biology 147: 671-679.

Lopez, G. R., and J. S. Levinton. 2011. Particulate organic detritus and detritus feeders in coastal food webs. Pages 5-21 *in* Treatise on Estuarine and Coastal Science. Wolanski, E., and D. McLusky, editors. Academic Press, London.

Mann, R. 1989. Larval ecology of *Arctica islandica* on the inner continental shelf of the eastern United States. J. Shellfish Res. 8: 464

Merrill, A.S. and J.W. Ropes (1969). The general distribution of the surf clam and ocean quahog. Proc. Natl. Shellfish. Assoc. 59: 40-45.

OSPAR Commission (2010). Background Document for Seapen and Burrowing megafauna communities. Biodiversity Series, OSPAR Commission, London, 1-27 pp. Available from: https://www.ospar.org/documents?v=7261

OSPAR. (2023). OSPAR Quality Status Report 2023.

Power A.J., Keegan B.F. (2001). Seasonal patterns in the reproductive activity of the red whelk, *Neptunea antiqua* (Mollusca: Prosobranchia) in the Irish Sea. J Mar Biol Assoc. UK. 2001;81(2):243-250. (doi:10.1017/S0025315401003708)

Ridgway, I. D., and C. A. Richardson. (2011). *Arctica islandica*: the longest lived non colonial animal known to science. Reviews in Fish Biol. Fish. 21: 297-310.

Rijnsdorp, A.D., & Vingerhoed, B. (2001). Feeding of plaice Pleuronectes platessa L.and sole Solea solea (L.) in relation to the effects of bottom trawling. *Journal of Sea Research*, *45*, 219-229. https://doi.org/10.1016/S1385-1101(01)00047-8

Rijnsdorp, A., J.G. Hiddink, P.D. van Denderen, N.T. Hintzen, O.R. Eigaard, S. Valanko, F. Bastardie, S.G. Bolam, P. Boulcott, J. Egekvist, C. Garcia, G. van Hoey, P. Jonsson, P. Laffargue, J.R. Nielsen, G.J. Piet, M. Sköld, and T. van Kooten (2020). Different bottom trawl fisheries have a differential impact on the status of the North Sea seafloor habitats. ICES J. Mar. Sci. 77: 1772-1786.

Smith, K.R., Mcconnaughey, R.A., & Armistead, C.E. (2011). NOAA Technical Memorandum NMFS-AFSC-231 Benthic Invertebrates of the Eastern Bering Sea: A Synopsis of the Life History and Ecology of Snails of the Genus Neptunea. (repository.library.noaa.gov/view/noaa/3983/noaa_3983_DS1.pdf)

Tempelman, D., Van Moorsel, G.W.N.M., & Faasse, M.A. (2013). De molkreeften *Upogebia deltaura* en *U. stellata* en geassocieerde soorten in de Noordzee (Decapoda: Upogebiidae). *Ned Faunistische Mededelingen*, *41*, 15-29 (https://natuurtijdschriften.nl/pub/1002132/NFM41__02__015-030_Tempelman_et_al.pdf).

Tillin, H.M., J.G. Hiddink, S. Jennings, and M.J. Kaiser. (2006). Chronic bottom trawling alters the functional composition of benthic invertebrate communities on a sea-basin scale. Mar. Ecol. Prog. Ser. 318: 31-45.

Troost, K., M. van Asch, S. Cornelisse, S. Glorius, D. van den Ende, Y. van Es, M. Keur, K. J. Perdon, J. van der Pool, W. Suykerbuyk, C. van Zweeden, and J. van Zwol. (2023). Schelpdierbestanden in de Nederlandse kustzone, Waddenzee en zoute deltawateren in 2022. Wageningen Marine Research.

Weinert M, Mathis M, Kröncke I, Neumann H, Pohlmann T, Reiss H. (2016). Modelling climate change effects on benthos: distributional shifts in the North Sea from 2001 to 2099. Estuarine, Coastal and Shelf Science. 2016;175:157–168. doi: 10.1016/j.ecss.2016.03.024.

Weinert, M., I. Kröncke, J. Meyer, M. Mathis, T. Pohlmann, and H. Reiss. (2022). Benthic ecosystem functioning under climate change: modelling the bioturbation potential for benthic key species in the southern North Sea. PeerJ 10: e14105.

Witbaard, R., & Duineveld, G.C.A. (1989). Some aspects of the biology and ecology of the burrowing shrimp *Callianassa subterranea* (Montagu)(Thalassinidea) from the southern North Sea. *Sarsia*, *74*(3), 209-219 (https://doi.org/10.1080/00364827.1989.10413430)

Wijsman, J.W.M., T.C. Prins, J.J.S. Moons, and P.M.J. Herman. (2023). Changed sediment composition prevents recovery of macrobenthic community four years after a shoreface nourishment at the Holland coast. Estuarine, Coastal and Shelf Science 293: 108521.

Witbaard, R., & Bergman, M.J.N. (2003). The distribution and population structure of the bivalve *Arctica islandica* L. in the North Sea: what possible factors are involved?. J Sea Res 50(1), 11-25. (https://doi.org/10.1016/S1385-1101(03)00039-X)

Wood, H.L., Eriksson, S.P., Nordborg, M., & Styf, H.K. (2015). The effect of environmental stressors on the early development of the Norway lobster *Nephrops norvegicus* (L.). *J Exp Mar Biol Ecol*, *473*, 35-42. (https://doi.org/10.1016/j.jembe.2015.08.009).

# 7.3 Large mobile benthos

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## 7.3.1 Description of the ecosystem component

Under the large mobile benthos, we consider the large hyperbenthos, encompassing a range of species that live on or near the seafloor and can freely move and/or swim near the sediment surface. This group is mainly composed of crustaceans such as the European lobster (*Homarus gammarus*), many species of crabs and brown shrimps (*Crangon crangon*), but also of demersal fish. These latter are discussed in a different section (section 0). Many species of hyperbenthos are economically relevant because they are targeted by fisheries. Hyperbenthos species can have a preference for hard substrate (e.g. lobsters), or live predominantly on soft sediments (e.g. brown shrimps).

## 7.3.2 Species selection / Focus species

Species protection plans are being developed for the European lobster (*H. gammarus*), the brown crab (*Cancer pagurus*) and the great spider crab (*Hyas araneus*). The brown crab and European lobster will be discussed here as focus species.

#### 7.3.2.1 Rationale for selection

- Of the three species for which protection plans are being developed, only the great spider crab is not directly targeted by fisheries. With 455.89 tonnes live weight in 2023, catches by Dutch fishermen are much higher for the brown crab, compared to 37.33 tonnes live weight for the European lobster (https://ec.europa.eu/eurostat/databrowser). Next to their economic importance, both species are also believed to be ecologically significant. Potentially regulating the structure of benthic communities by predation, brown crabs and European lobsters could be considered keystone species, influencing biodiversity and habitat structure through predation and competition (Boudreau & Worm 2012), although as of yet, hard evidence to support this claim is limited (Tonk & Rozemeijer 2019; Jurrius & Rozemeijer 2022).
- The great spider crab is less studied in the North Sea than the other two species and will not be further discussed here.

## 7.3.3 Habitat preferences

The brown crab and European lobster have similar habitat preferences. Young individuals of both species often bury themselves in soft sediment during their search for hard substrate, where they find shelter in crevices (Howard & Bennett 1979; Hall et al. 1991). However, juvenile lobsters seem to prefer coarser sediments than crabs (Ball et al. 2001). Adults of both species prefer to hide in rock crevices to reduce their exposure to predators, but brown crabs can also escape predation by burying in muddy sediment. Densities of lobsters were shown to be positively correlated with the amount of crevices in their environment (Rozemeijer & van de Wolfshaar 2019). European lobsters and juvenile brown crabs can survive extended periods of low salinities (down to 10 ppt), albeit with increased metabolic costs. Adult brown crabs do not tolerate salinities below 17 ppt (Wanson et al. 1983; Linley et al. 2007).
Artificial structures such as wrecks, scour protection around offshore wind farms and oil & gas platforms provide suitable habitat for both species (Tonk & Rozemeijer 2019; Krone et al. 2017).

### 7.3.4 Ecosystem function

Large decapods such as European lobsters and brown crabs take up an intermediate position in the food web. While they feed on smaller benthic species, lobsters and crabs are themselves prey for larger top predators such as marine mammals, fish, and humans. Crabs have a wider prey base than lobsters. Other important functions are competition for food and habitat, and the provision of habitat for suspension feeding epibionts (Boudreau & Worm 2012). Burrowing juveniles (and adults) effectively become part of the endobenthos and contribute to the community bioturbation (see chapter "shellfish and burrowing megafauna"). They are, however, much more mobile than most endobenthos and are therefore able to transport matter over larger distances. Both European lobster and brown crab may act as keystone species by controlling smaller predators and influencing reef development (Jurrius & Rozemeijer 2022).

### 7.3.5 Status and trend ecosystem component

The brown crab and European lobster can be found along the European Atlantic coasts, including the North Sea and English Channel, from Morocco to northern Norway. The European lobster also occurs in low densities in the Mediterranean Sea, whereas no recent observations of brown crabs have occurred in these waters (Prodöhl et al. 2006; Woll et al. 2006). European lobster occurs in low densities in the Dutch part of the North Sea, but with higher densities in the Eastern Scheldt. Detailed data on their distribution are scarce, but it is known that their densities in the Scottish part of the North Sea can be substantially higher than in the Netherlands (Rozemeijer & van de Wolfshaar 2019). Compared to European lobsters, brown crabs are more widely present offshore and especially in the German Bight (Steenbergen et al. 2012; Tonk & Rozemeijer 2019). However, a lack of stock assessments in Dutch waters means that population trends are uncertain (Mesquita et al. 2025).

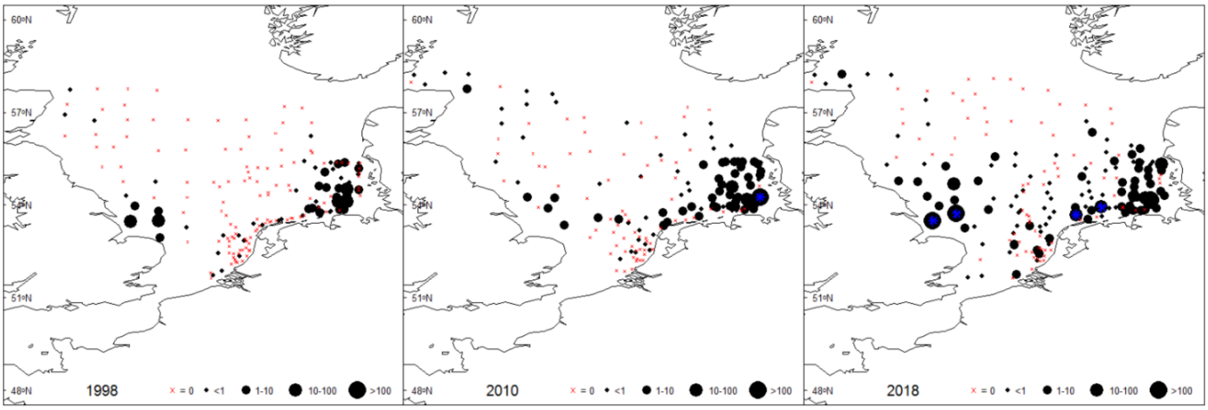


***Figure 7-8*** *Number of brown crabs per hectare based on two surveys in 1998, 2010 and 2018 in the North Sea. Source: Tonk & Rozemeijer (2019).*

Since the early 2000s, landings of European lobster by fishermen in Northwest Europe have increased significantly, mostly due to increases in the United Kingdom (Rozemeijer & van de Wolfshaar 2019) In the Eastern Scheldt, an as of yet unexplained mortality of lobsters since 2023 has drastically reduced the population (Schotanus et al. 2024). Recent increases in the population of brown crabs have been observed all over the southern North Sea (Tonk & Rozemeijer 2019). Due to a lack of monitoring, it is unclear whether the increase of offshore wind farms in the North Sea, with high amounts of crevices in the scour protection layers, will benefit the spread of both species, although it is suggested by sparse observations (Tonk & Rozemeijer 2019; Jurrius & Rozemeijer 2022). Wehkamp and Fischer (2012) showed that a potential increase in coastal defence structures in the southern North Sea may be beneficial to the European lobster but have little effect on brown crabs (and affect other decapod species negatively).

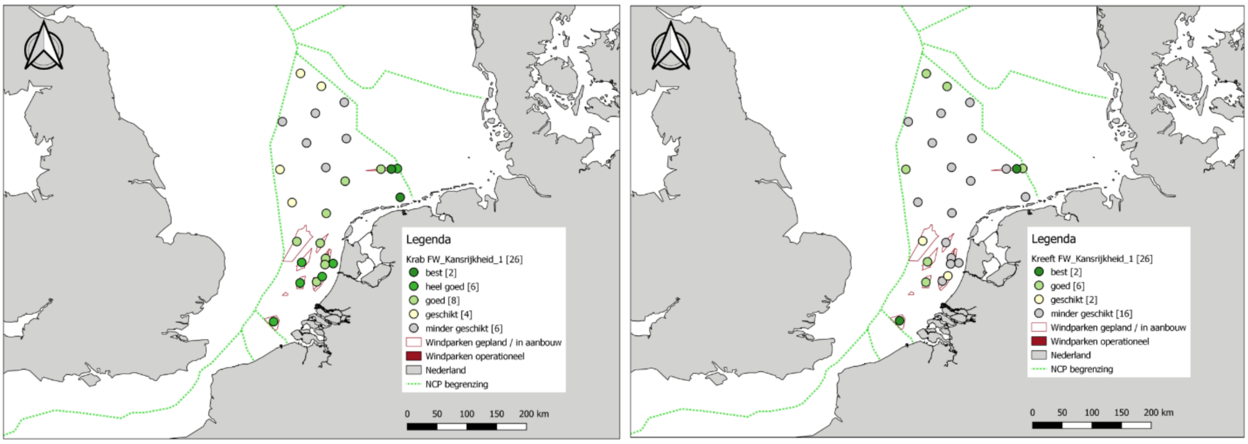


***Figure 7-9*** *Opportunity maps for the harvest of brown crab (left) and European lobster (right) in Dutch offshore wind farms. Source: van den Boogaart et al. (2019).*

### 7.3.6 Pressures and impacts

The European lobster and the brown crab are barely mentioned in the most recent OSPAR Quality Status Report, although crabs and lobsters as a group are mentioned with regard to ocean acidification, and lobsters with regard to the accumulation of radioactive substances. There is also a reference to injured brown crabs due to bottom trawling (OSPAR 2023).

#### 7.3.6.1 Long-term impacts

Studies have shown that climate change may affect the larval development of European lobster, potentially leading to a decreased recruitment success due to a decoupling between the timing of crucial development phases and food availability (Schmalenbach & Franke 2010). The larval development of brown crabs seems much more sensitive to temperature increases (Weiss et al. 2009). Ocean acidification also affects larval development, imposing stress and reduced growth, and reduce food intake in adults (Rato et al. 2017; Wang et al. 2018). Matić-Skoko et al. (2022) suggest that in the northern Adriatic Sea, European lobster catches increased after ocean warming due to increased mobility of the lobsters, leading to indirect mortality of temperature rise. Historic fisheries have destroyed large amounts of suitable habitat (oyster beds, gravel banks) and ongoing seafloor disturbance can likewise reduce natural shelter availability for lobsters and crabs (Olsen 1883; de Groot 1984).

#### 7.3.6.2 Short-term impacts

Since both species are commercially harvested, fisheries put pressure on their respective populations in the North Sea. For European lobster, it is suggested that overfishing resulted in the collapse of Swedish and Norwegian population in the 1960s (Sündelof et al. 2013). Fishing has been linked to injuries in brown crabs (Davies et al. 2021). Elevated levels of pollutants and radioactive substances have been found in brown crabs in the North Sea (Swift et al. 1994; Barrento et al. 2009), but the literature often only discusses human health effects, rather than effects on the crab physiology and ecology.
Other short-term pressures include underwater noise, which can alter antipredator behaviour in juvenile lobsters and potentially increase mortality (Leiva et al. 2021). Non-target impacts from bottom-disturbing fisheries also degrade habitat quality for both species (ICES 2023). In addition, recent mass mortality events in European lobster and brown crab populations have been reported in the UK and Eastern Scheldt, with unknown causes possibly linked to pathogens of pollution (Schotanus et al. 2024; ICES 2023).

### 7.3.7 Current policy

Both the European lobster and brown crab are commercially harvested species in Dutch waters. Most legislation concerning the species is therefore related to fisheries and not to protection or restoration. However, EU regulations do prohibit the landing of berried female lobsters in the Mediterranean (European

Commission 2006), but Dutch rules furthermore require the release of freshly moulted lobsters, besides imposing seasonal closures. Both species are believed to benefit from the absence of bottom-disturbing fisheries in offshore wind farms, providing that they can establish populations there.

#### 7.3.7.1 Policy measures

There are currently no policy targets for large mobile benthos.

### 7.3.8 Advice and action perspectives / possible measures

*Rationale*

While local populations of European lobster and brown crab, most particularly of European lobster in the Eastern Scheldt, are not doing well, overall numbers of European lobster and brown crab are increasing, possibly due to the continuing construction of offshore wind farms and associated infrastructure, which offer suitable habitat. Except for the specific case of the Eastern Scheldt, additional active restoration measures may not be needed. Restoration of the Eastern Scheldt population is only opportune after deeper research into the cause of the local population collapse.

Reports have also pointed out that the success of such populations does not only depend on the presence of sufficient habitat, but also on food availability, competition and other environmental factors (Tonk & Rozemeijer 2019; Jurrius & Rozemeijer 2022). If populations are established in new areas, there is a risk that targeted fisheries will also increase, potentially cancelling the positive effects of new habitat creation. A thorough monitoring of both the populations and fisheries is recommended.

*Action perspective for NN*

Active restoration of (hard substrate) habitats could benefit the establishment of populations of large mobile benthos, as studies into the potentially beneficial effects of offshore infrastructure suggest (RRL 4-5/6-7).

*Demonstration of impact*

Increased monitoring of large mobile species to understand their distribution. The creation of suitable habitat in the form of hard substrate (e.g. offshore wind farms) may benefit European lobster and brown crab. Studies have so far mostly focused on the establishment of populations in wind farms for fisheries. Cooperation with the fishing industry could be beneficial to a guaranteed population of lobsters and crabs in wind farms, although frequent monitoring is needed (Deetman 2023).

### 7.3.9 References


Barrento, S., A. Marques, B. Teixeira, P. Anacleto, M.L. Carvalho, P. Vaz-Pires, and M.L. Nunes. (2009). Macro and trace elements in two populations of brown crab *Cancer pagurus*: Ecological and human health implications. J. Food Composition and Analysis 22: 65-71.

Boudreau, S. A., and B. Worm. (2012). Ecological role of large benthic decapods in marine ecosystems: a review. Mar. Ecol. Prog. Ser. 469: 195-213.

Davies, C. E. (2021). Invertebrate health in marine protected areas (MPAs). Journal of Invertebrate Pathology 186: 107524.

Deetman, B. (2023). Win-Wind, Visserij op Noordzeekrab in windparken op zee, Markt en Economie. Wageningen Marine Research.

de Groot, S. J. (1984). The impact of bottom trawling on benthic fauna of the North Sea. Ocean Management 9: 177-190.

European Commission (2006). Council Regulation (EC) No 1967/2006 of 21 December 2006 concerning management measures for the sustainable exploitation of fishery resources in the Mediterranean Sea, amending Regulation (EEC) No 2847/93 and repealing Regulation (EC) No 1626/94. Official Journal of the European Communities.

Hall, S.J., D.J. Basford, M.R. Robertson, D.G. Raffaelli, and I. Tuck. (1991). Patterns of recolonisation and the importance of pit-digging by the crab *Cancer pagurus* in a subtidal sand habitat. Mar. Ecol. Prog. Ser. 72: 93-102.

Howard, A. E., and D. B. Bennett. (1979). The substrate preference and burrowing behaviour of juvenile lobsters (*Homarus gammarus* (L.)). J Nat. Hist. 13: 433-438.

ICES (2023). Working Group on the Biology and Life History of Crabs (WGCRAB; outputs from 2020–2022 meetings). ICES Scientific Reports. 5:110. 123 pp. https://doi.org/10.17895/ices.pub.24720936

Jurrius, L. H., and M.J.C. Rozemeijer. (2022). The role of European lobster (*Homarus gammarus*) in the ecosystem. An inventory as part of a feasibility study for passive fisheries on European lobster *Homarus gammarus* in offshore wind farms. Wageningen Marine Research.

Krone, R., G. Dederer, P. Kanstinger, P. Krämer, C. Schneider, and I. Schmalenbach. 2017. Mobile demersal megafauna at common offshore wind turbine foundations in the German Bight (North Sea) two years after deployment – increased production rate of *Cancer pagurus*. Marine Environmental Research. 123: 53-61.l

Leiva, L., S. Scholz, L. Giménez, M. Boersma, G. Torres, R. Krone, and N. Tremblay. (2021). Noisy waters can influence young-of-year lobsters' substrate choice and their antipredatory responses. Environmental Pollution. 291: 118108.

Linley, E., T. Wilding, K. Black, A. Hawkins, and S. Mangi. (2007). Review of the reef effects of offshore wind farm structures and their potential for enhancement and mitigation. Report to the Department for Business, Enterprise and Regulatory Reform.

Matić-Skoko, S., M. Pavičić, J. Šepić, I. Janeković, D. Vrdoljak, I. Vilibić, N. Stagličić, T. Šegvić-Bubić, and A. Vujević. (2022). Impacts of sea bottom temperature on CPUE of European lobster *Homarus gammarus* (Linnaeus, 1758: Decapoda, Nephropidae) in the Eastern Adriatic Sea. Front. Mar. Sci 9: 891197.

Mesquita, C., Tully, O., Martin, G., Marcussen, J. B., Zimmermann, F., Kozák, J.-L., et al. 2025. An overview of the brown crab (Cancer pagurus) fisheries and stock trends in the Northeast Atlantic. ICES Cooperative Research Reports Vol. 360. 37 pp. https://doi.org/10.17895/ices.pub.30009562

Olsen, O. T. (1883). The piscatorial atlas of the North Sea, English and St. George's Channels, illustrating the fishing ports, boats, gear, species of fish (how, where and when caught), and other information concerning fish and fisheries. Taylor and Francis: London. 50 pp.

OSPAR. (2023). OSPAR Quality Status Report 2023.

Prodöhl, P.A., K.E. Jørstad, A. Triantafyllidis, V. Katsares, and C. Triantaphyllidis. (2006). European lobster – *Homarus gammarus*. Genetic Impact of Aquaculture Activities on Native Populations. Final Scientific Report: 91-98.

Rato, L.D., S.C. Novais, M.F.L. Lemos, L.M.F. Alves, and S.M. Leandro. (2017). *Homarus gammarus* (Crustacea: Decapoda) larvae under an ocean acidification scenario: responses across different levels of biological organization. Comparative Biochemistry and Physiology Part C: Toxicology & Pharmacology 203: 29-38.

Rozemeijer, M.J.C., J.E. Tamis & R.H. Jongbloed (2026 in prep.). Large mobile benthic fauna in the Dutch North Sea. Background document for a protection plan. Wageningen Marine Research report xxx.

Rozemeijer, M.J.C., and K.E. van de Wolfshaar. (2019). Desktop study on autecology and productivity of European lobster (*Homarus gammarus*, L) in offshore wind farms. Wageningen Marine Research.

Schmalenbach, I., and H.-D. Franke. (2010). Potential impact of climate warming on the recruitment of an economically and ecologically important species, the European lobster (*Homarus gammarus*) at Helgoland, North Sea. Marine Biology 157: 1127-1135.

Schotanus, J., M. Engelsma, C. Dirks, E. Faassen, and N. Steins. (2024). Kreeftensterfte in de Oosterschelde: Een verkenning van mogelijke oorzaken. Wageningen Marine Research.

Steenbergen, J., M.M.M. Rasenberg, T. van der Hammen, and S.M. Bierman. (2012). Gerichte visserij op Noordzeekrab. IMARES.

Sündelof, A., V. Bartolino, M. Ulmestrand, and M. Cardinale. (2013). Multi-annual fluctuations in reconstructed historical time-series of a European lobster (*Homarus gammarus*) population disappear at increased exploitation levels. PLoS ONE 8: e58160.

Swift, D.J., D.L. Smith, D.J. Allington, and M.J. Ives. (1994). The $^{210}$Po content of North Sea edible crab, *Cancer pagurus* L., and common shrimp *Crangon crangon* L. and the potential radiological impact. Journal of Environmental Radioactivity 23: 213-230.

Tonk, L., and M.J.C. Rozemeijer. (2019). Ecology of the brown crab (*Cancer pagurus*) and production potential for passive fisheries in Dutch offshore wind farms. Wageningen Marine Research.

van den Boogaart, L., M. Poelman, L. Tonk, S. Neitzel, J. T. van der Wal, J. W. P. Coolen, and M. Machiels. (2019). Geschiktheid zeewindparken voor maricultuur en passieve visserij. Wageningen Marine Research.

Wang, Y., M. Hu, F. Wu, D. Storch, and H.-O. Pörtner. (2018). Elevated $pCO_2$ affects feeding behavior and acute physiological response of the brown crab *Cancer pagurus*. Frontiers in Physiology 9: 1164.

Wanson, S., A. Pequeux, and R. Gilles. (1983). Osmoregulation in the stone crab *Cancer pagurus*. Mar. Biol. Letters 4: 321-330.

Wehkamp, S., and P. Fischer. (2013). The impact of coastal defence structures (tetrapods) on decapod crustaceans in the southern North Sea. Mar. Env. Res. 92: 52-60.
Weiss, M., S. Thatje, O. Heilmayer, K. Anger, T. Brey, and M. Keller. (2009). Influence of temperature on the larval development of the edible crab, *Cancer pagurus*. J. Mar. Biol. Assoc. UK 89: 753-759.
Woll, A. K., G. I van der Meeren, and I. Fossen. (2006). Spatial variation in abundance and catch composition of *Cancer pagurus* in Norwegian waters: biological reasoning and implications for assessment. ICES J. Mar. Sci. 63: 421-433.

# 7.4 Structure-forming benthic species

Author: Enzo Kingma (based on the background report for the species protection plan: Kingma et al. 2025)

### 7.4.1 Description of ecosystem component

Structure-forming species enhance the complexity of benthic environments by creating three-dimensional structures that can support marine biodiversity. In the North Sea, these species groups include soft corals, sponges, sea anemones, and hydroids. They differ from biogenic reef-building species (see 7.1) in that they generally do not form large scale reef systems, even in areas of high local density. Although, some of the characteristics might overlap.
A background document for a species protection plan in the Dutch North Sea (Kingma et al. 2025) identified the Dead man's fingers (*Alcyonium digitatum*), Dahlia anemone (*Urticina felina*), Mermaid's glove (*Haliclona oculata*), and Sea fir (*Abietinaria abietina*) as representative species for these groups. These organisms are commonly found on hard substrates such as rocky outcrops, biogenic reefs, artificial structures, and shipwrecks, where they contribute to the overall structural complexity of benthic ecosystems.

### 7.4.2 Focus species

The selection of structure-forming representative species is based on their ecological function, prevalence, status in the North Sea, sensitivity to disturbances and listing in European legal frameworks such as the Habitats Directive and the Nature Restoration Regulation (Kingma et al.2025). Furthermore, the selection of these representative species is based on the reasoning that their protection will likely have a positive impact on structure-forming benthic species as a whole:

- Dead man's fingers (*A. digitatum*): A soft coral species commonly found on rocky substrates, wrecks, and artificial reefs in the North Sea. It provides habitat for various invertebrates and foraging/ shelter ground for small fish.
- Dahlia anemone (*U. felina*): A large anemone species that thrives on hard substrates and offers shelter to small marine organisms.
- Mermaid's glove (*H. oculata*): A branching sponge that can serve as habitat for microfauna and small fish species.
- Sea fir (*A. abietina*): A colonial hydroid that contributes to the structural complexity of benthic ecosystems, several smaller organisms can be found at this species.

***Table 7.2*** *Selected structure-forming species (umbrella species).*

| English name | Scientific name | Dutch name |
|---|---|---|
| Dead man's fingers* | *Alcyonium digitatum* | Dodemansduim |
| Dahlia anemone* | *Urticina felina* | Zeedahlia |
| Mermaid's glove / Eyed finger sponge* | *Haliclona oculata* | Geweispons |
| Sea fir | *Abietinaria abietina* | Zeedennetje |

*Typical species for H1170 and/or H1110 in the Netherlands (Min LNV, 2014; 2014)

### 7.4.3 Rationale for selection

Structure-forming species are an important benthic group within the North Sea responsible for creating three-dimensional structures that can also function as habitat for a variety of other organisms. However, their presence and ecological functions are impacted by human activities, particularly seafloor disturbances such as bottom trawling. Therefore, actions should be taken to conserve and restore this group.

Structure-forming species are commonly found on hard substrates, which include geogenic reefs, biogenic reefs, and artificial structures (such as shipwrecks, oil and gas production platforms, offshore wind turbine foundations, and scour protection layers). Occasionally, they are observed on soft substrates, but these species mostly require a hard substrate for attachment.

Some of the selected species are typical species of the HD habitat types H1170 (Reefs of the open sea) and, to some extent, H1110 (Permanently submerged sandbanks), both of which are recognized under European conservation frameworks (Min. LNV, 2014; 2014). Despite their ecological importance, these species currently lack direct legal protection in the Dutch North Sea, leaving them vulnerable to habitat degradation and loss. Considering their role in enhancing habitat complexity, supporting marine biodiversity, and contributing to the overall ecosystem health, there is need to integrate these species into conservation and restoration efforts/initiatives.

### 7.4.4 Habitat preferences

The distribution of structure-forming species depends on the availability of suitable hard substrates and hydrodynamic conditions:

- *A. digitatum*: Prefers areas with strong water movement (mostly sublittoral zones), attaching to rocks, shells, stones, wrecks, and other artificial structures (Wood,2013; Stichting ANEMOON, n.d.). The species has been recorded along nearly the entire Atlantic European coast, from Portugal to Norway, including Iceland (Budd, 2008).
- *U. felina*: Found on hard substrates such as boulders, shipwrecks, and artificial reefs from the lower shoreline to subtidal regions (>30 m deep) with strong water movement. The species has a boreal-arctic distribution and is commonly observed in the North Sea (Jackson & Hiscock, 2008).
- *H. oculata*: Occurs in areas with moderate current flow along open coastlines and in the outer regions of estuaries, typically on submerged hard substrates (Ackers et al. 2007; Mayhew, 2006). The species has a widespread distribution across the North Atlantic, occurring from North America and Canada down to Portugal. It is also thought to be present throughout Arctic and sub-Arctic waters (Mayhew, 2006). In the Netherlands, *H. oculata* is found along the entire coastline and within the Wadden Sea, where it inhabits hard substrates. In Zeeland, it is frequently observed in both the Oosterschelde and Lake Grevelingen (Stichting ANEMOON, n.d.).
- *A. abietina*: Found attached on different substrates: rocks, shells, algae, and artificial structures. The species has a bipolar distribution that covers the Arctic, Atlantic, and Pacific Oceans (Cornelius, 1995; Ronowicz et al. 2019)

### 7.4.5 Ecosystem function

Structure-forming species provide several ecosystem services:

- Biodiversity enhancement: Their complex structures offer habitat and protection for various species, such as: bryozoans, other hydroids, crustaceans, tubeworms, foraminifera, nudibranchs, and juvenile fish (Kingma et al.2025; Buhl-Mortensen et al. 2010; Miller et al. 2012).
- Environmental stability: Structure-forming species such as *A. digitatum* are important species in epibenthic communities on hard substrates, serving as an indicator of environmental stability (Lengkeek et al. 2013; Min LNV, 2014).
- Water filtration: many structure-forming species, particularly sponges and hydroids, filter organic material from the water column, improving water quality and contributing to the benthic-pelagic coupling (Sebens et al. 2017).
- Aesthetic value: Structure-forming species are often visually distinctive, featuring characterizing structures and sometimes vibrant colours.

### 7.4.6 Status and trend

The distribution and abundance of structure-forming species in the North Sea have been influenced by habitat availability and human activities. Artificial structures, such as offshore wind farms and wrecks, provide opportunities for the spread of these species by offering additional hard substrate. However, bottom trawling, coastal development, and climate change pose threats to their presence. In general, the precise status of the individual representative species remains unknown. However, the conservation status of habitat type H1170, where these species are commonly found, has been classified as ‘very unfavourable’.

### 7.4.7 Pressures and impacts

Structure-forming species face various threats, listed below. Their sensitivity varies by species. Some (e.g. *A. digitatum*: Budd, 2008) have a high recovery potential, while others (e.g. *U. feline*: Jackson & Hiscock, 2008) recover much more slowly due to their low growth rate, long lifespan, and limited larval dispersal.

- Fishing and bottom trawling: These activities cause physical disturbances that can lead to damage or removal of marine organisms. Bottom trawling, in particular, can break, dislodge, or bury soft corals, sponges, anemones, and hydroids. (Hinz et al. 2011; Lambert et al. 2017; Lengkeek et al. 2017).
- Sand and gravel extraction: Many structure-forming species rely on hard substrates for attachment. The removal of these substrates would lead to habitat loss. Additionally, sediment resuspension can smother sensitive epifauna. Not much studies have been conducted on the effect on structure-forming species, however, it is found that *A. digitatum* is impacted by gravel extraction (Van Moorsel & Waardenburg, 1991).
- Offshore construction: While artificial structures provide new habitats, construction activities can cause habitat destruction.
- Climate change: Ocean warming may affect the distribution and resilience of the species. However, structure-forming species such as *A. digitatum* and *U. felina* have a widespread distribution within the North Sea and therefore likely can withstand a range of temperature conditions (Budd, 2008b; Jackson & Hiscock, 2008; Jenkins & Stevens, 2022).
- Pollution: Some structure forming species, such as *A. digitatum* (Gittenberger & Van Loon, 2013; Stamp, 2015), are considered highly sensitive to pollution/organic enrichment/eutrophication.

### 7.4.8 Current policy

The Netherlands has obligations to protect habitat type H1170 under the Habitats Directive (HD) and to restore habitats under the Nature Restoration Regulation (Office of the European Union, 2024). Furthermore, there are obligations to protect seabed integrity under the Marine Strategy Framework Directive.

Under the HD, a number of structure-forming benthic species are listed as 'typical species' present in reefs (HD habitat type 1170: Cleaver Bank, Borkum Reef Grounds) and sand banks H1110C (Dogger Bank).
In Annex II of the Nature Restoration Regulation habitats are listed that may be relevant in the context of this report: 'MD121 Sponge communities on Atlantic offshore circalittoral rock' and 'bivalve reefs' (MA227, MA222 and MA223), which may serve as substrate for structure forming species.

#### 7.4.8.1 Policy measures

In natural reef areas, policy measures need to be in place before active restoration measures can be implemented. Policy measures include legal protection of species and habitats and implementation of seabed protection measures such as exclusion of bottom disturbing fishing and sand/gravel extraction. Currently, under the CFP, the N2000 area Cleaver Bank is partly closed to bottom disturbing fisheries, to protect H1170.

In the Frisian Front, 2 areas of 2x2 km and 2 areas of 50 km2 each are designated for future oyster restoration (oysters may provide habitat to corals and sponges). The areas of 2 km2 each, are located in an area closed for bottom disturbing fisheries since 2023. In the Voordelta, the mixed oyster reef is protected under a national fisheries management measure since 4 years. Other fishery management measures under the CFP are in the pipeline and expected to be in place in the near future (2026/2027). These include enlargements of the Cleaver Bank (HD), Central Oyster Grounds (MSFD) and Frisian Front (MSFD) area closures and closure of the Borkum Reef Grounds (MSFD), Southern Dogger Bank (MSFD). In addition, BD area Brown ridge will be closed for gillnet fisheries for half a year. The restoration of for instance flat oyster beds can help provide suitable habitat for the structure-forming species listed in this document, such as *A. digitatum*[11].

Furthermore, under the Nature Restoration Regulation (NRR), EU Member States must implement restoration measures for at least 30% of the total area of all habitat types listed in Annex II of the Regulation that are not in good condition, increasing to 60% by 2040 and 90% by 2050. Under the NRR, Member States are

[11] https://weblog.wur.eu/spotlight/european-flat-oysters-back-in-the-north-sea/

required to define restoration measures for sponge, coral and coralligenous beds. A proposal for favourable reference area and assessment of area not in good ecological condition are presented in a report prepared by WMR (De Froe et al. 2025).

### 7.4.9 Advice, action perspectives, possible measures

*Rationale*
Structure-forming species such as soft corals, structure forming sponges or larger anemones contribute to biodiverse habitats but are vulnerable to seafloor disturbing activities. In the Dutch North Sea, they are mostly observed on natural geogenic reefs, biogenic reefs (e.g. oyster beds), introduced hard substrates and on coarse soft substrate. The status of the individual species remains unknown, but the conservation status of habitat type H1170, where these species are commonly found, has been classified as 'very unfavourable'. Under the HD and the NRR there are targets to restore H1170 and sponge and coral communities. It is therefore important to reduce human impact and offer opportunities for restoration through a combination of measures, as identified in the background document of the species protection plan (Kingma et al. 2025) and summarized below.

*Action perspective for NN*
In addition to the Cleaver Bank and the Borkum Reef Grounds, there are other areas with known occurrences of hard substrate, such as the Texel Rough area, that remain to be investigated and are not protected. Identifying the occurrence of other hard substrate areas and combine them with existing data on the distribution of hard substrates, as a basis for habitat suitability maps for coral and sponge species, is already commissioned under the NRR. Structure-forming species also occur on artificial hard substrates, such as regular scour protection around offshore wind turbines, elements that are designed to enhance nature (nature-inclusive designs NIDs), or on shipwrecks and production platforms.

NN could focus on restoration of natural boulder reefs and biogenic reefs as habitat for structure-forming species in closed areas where abiotic or biotic reefs used to be present in the past, but have now declined or disappeared (see also section 3.2). The RRL level for abiotic reef restoration is assessed as "6 Proven effectiveness at pilot scale", mainly because in Denmark, abiotic reef restoration is common practise and guidelines and expertise are available (see section 3.2). The larvae of structure-forming species are probably readily available, so that passive restoration by restoring their habitat could be sufficient. Biotic reef restoration (oyster reefs) could help to create suitable habitat for these species[12], and is discussed in the chapter on Biogenic reefs (see section 7.1). If NN should focus on NIDs and other artificial reefs as well to restore habitat forming species remains a question.

*Demonstration of impact*
To demonstrate the actual contribution of NN activities to the recovery of structure-forming benthic species, restoration sites should be monitored, where possible using similar methodology as used in the MSFD/N2000 MWTL monitoring.

### 7.4.10 References


Ackers, R. G., Moss, D., Picton, B. E., Stone, S. M. K., & Morrow, C. C. (2007). *MARINE CONSERVATION SOCIETY SPONGES OF THE BRITISH ISLES ("SPONGE V") A Colour Guide and Working Document 1992 EDITION, reset with modifications, 2007*.

Budd, G. (2008). *Dead man's fingers (Alcyonium digitatum)*. https://doi.org/10.17031/marlinsp.1187.1

Buhl-Mortensen, L., Vanreusel, A., Gooday, A.J., Levin, L.A., Priede, I.G., Buhl-Mortensen, P., Gheerardyn, H., King, N.J., & Raes, M. (2010). Biological structures as a source of habitat heterogeneity and biodiversity on the deep ocean margins. Mar. Ecol, *31*(1), 21–50. https://doi.org/10.1111/j.1439-0485.2010.00359.x

Cornelius, P.F.S. (1995). *North-West European Thecate Hydroids and their Medusae* (R. S. K. Barnes & J. H. Crothers, Eds.; Vol. 50). Field Studies Council.

De Froe, E., Asjes, A., Escaravage, S. T. , Glorius, S., Hoogenstrijd, G., Hüsken, K. H. A., Jak, R. G., Nauta, R. W., Sandig, A., Smulders, F., Tamis, J. E., Troost, K., & Wijnhoven, S. (2025).


12 https://weblog.wur.eu/spotlight/european-flat-oysters-back-in-the-north-sea/

*Natuurherstelverordening en het Nederlandse mariene ecosysteem. Stand van zaken voor de relevante habitattypen en habitats van soorten. Wageningen Marine Research Rapport C082/25*. https://doi.org/10.18174/703569

Gittenberger, A., & van Loon, W. M. G. M. (2013). Sensitivities of marine macrozoobenthos to environmental pressures in the Netherlands. *Nederlandse Faunistische Mededelingen*, *41*, 79-111.

Hinz, H., Tarrant, D., Ridgeway, A., Kaiser, M.J., & Hiddink, J.G. (2011). Effects of scallop dredging on temperate reef fauna. *Mar. Ecol. Prog. Ser.*, *432*, 91–102. https://doi.org/10.3354/meps09166

Jackson, A., & Hiscock, K. (2008). *MarLIN Dahlia anemone (Urticina felina)*. https://doi.org/10.17031/marlinsp.1392.1

Jenkins, T.L., & Stevens, J.R. (2022). Predicting habitat suitability and range shifts under projected climate change for two octocorals in the north-east Atlantic. *PeerJ*, *10*. https://doi.org/10.7717/peerj.13509

Kingma, E.M., Jongbloed, R., Clarisse, M., Bos, O.G. (2025). Structure-forming species in the Dutch North Sea: Background document for a species protection plan. Wageningen Marine Research report C106/25. https://doi.org/10.18174/705505

Lambert, G.I., Murray, L.G., Hiddink, J.G., Hinz, H., Lincoln, H., Hold, N., Cambiè, G., & Kaiser, M.J. (2017). Defining thresholds of sustainable impact on benthic communities in relation to fishing disturbance. *Scientific Reports*, *7*(1). https://doi.org/10.1038/s41598-017-04715-4

Lengkeek, W., Bouma, S., Waardenburg, H.W.W., & Didderen, K. (2013). Voorbereidingen voor een Natura 2000 monitoringsplan voor Habitattype H1170 op de Klaverbank. Een verkennende veldexpeditie en aanzet voor een meetnetontwerp. Rapport 13-032. Bureau Waardenburg, Culemborg.

Lengkeek, W., Coolen, J.W.P., O.G. Bos, Bergsma, J.H., Driessen, F., & Spierenburg, M. (2017). *Notitie: Waarneming effect bodemberoering op de Klaverbank*.

Mayhew, E. M. (2006). *Haliclona (Haliclona) oculata Mermaid’s Glove.* https://www.marlin.ac.uk/species/detail/1865

Miller, R.J., Hocevar, J., Stone, R.P., & Fedorov, D.V. (2012). Structure-forming corals and sponges and their use as fish habitat in bering sea submarine canyons. *PLoS ONE*, *7*(3). https://doi.org/10.1371/journal.pone.0033885

Ronowicz, M., Peña Cantero, Á.L., Mercado Casares, B., Kukliński, P., & Soto Àngel, J.J. (2019). Assessing patterns of diversity, bathymetry and distribution at the poles using Hydrozoa (Cnidaria) as a model group. *Hydrobiologia*, *833*(1), 25–51. https://doi.org/10.1007/s10750-018-3876-5

Sebens, K., Sarà, G., & Nishizaki, M. (2017). Energetics, Particle Capture, and Growth Dynamics of Benthic Suspension Feeders. In *Marine Animal Forests* (pp. 1–42). Springer International Publishing. https://doi.org/10.1007/978-3-319-17001-5_17-3

Stamp, T. E. (2015). Alcyonium digitatum with dense Tubularia indivisa and anemones on strongly tide-swept circalittoral rock. sStichting ANEMOON. (n.d.). *Dodemansduim*. Https://Www.Anemoon.Org/Beheer/Bewaar/Soorten/Id/47/Dodemansduim.

Stichting ANEMOON. (n.d.). *Geweispons*. Retrieved July 15, 2024, from https://www.anemoon.org/beheer/website/bewaar/soorten/id/11/geweispons

Van Moorsel, G.W.N.M., & Waardenburg, H.W. (1991). *Short-term recovery of geomorphology and macrobenthos of the Klaverbank (North Sea) after gravel extraction*.

Wood, C. (2013). *Sea Anemones and Corals of Britain and Ireland* (Vol. 2). Princeton University Press.

# 8 Fish

*Authors: Ralf van Hal, Josien Steenbergen*

Fish are almost everywhere in the North Sea, from the shallow surf on the beach to the deepest parts off the Norwegian coast, and from the most undisturbed corner to the middle of the Rotterdam harbor. Fish are the main link between the base of the food web (phyto- and zooplankton, benthic invertebrates) and the higher trophic levels (piscivorous fish, birds, marine mammals and humans). Fish display a wide variety of traits. They range from short-lived gobies to long-lived sharks. Some species lay demersal eggs requiring specific sediments, stick their eggs to seaweed, produce free floating pelagic eggs, or in the case of tope are ovoviviparous. They are demersal (in, on or close to the seafloor) are pelagic (in the water column), or both like sandeel staying for long periods of time buried in the sediment while feeding as pelagic species in the water column. They can be sedentary, have large scale spawning/feeding migrations, or even migrate in land into the estuaries or up rivers. Owing to the large differences in traits, fish are grouped in migratory species, sharks and rays, forage fish and demersal fish.

## 8.1 Migratory fish

The migratory fish covered in this chapter are essentially diadromous species, which spend different stages of their life cycle in both freshwater and seawater. Anadromous species, such as salmon, migrate from the sea to freshwater to spawn, whereas catadromous species, such as eel, migrate from freshwater to the sea for spawning.

For migratory fish, a background document for a protection plan is published (van Rijssel et al. 2025). Unless stated different the text below is summarized from this document.

### 8.1.1 Description of the ecosystem component

Migratory fish typically are species of fish that undertake regular, often seasonal, movements between different habitats for purposes such as spawning, feeding, or overwintering. The migratory fish in this section are the so-called diadromous fish: fish that migrate between fresh water and saltwater. They exhibit a wide range of habitat preferences throughout their life cycles, often moving between marine, estuarine, and freshwater environments depending on their developmental stage.

### 8.1.2 Species selection / Focus species

The following species are selected in the background document for protection plans: Eel (*Anguilla anguilla*)*, Brown or Sea trout (Salmo trutta), Twaite shad (*Alosa fallax*), Allis shad (*Alosa alosa*), Sea lamprey (*Petromyzon marinus*), European river lamprey (*Lampetra fluviatilis*), Houting (*Coregonus lavaretus oxyrinchus* (Linnæus, 1758)), European sturgeon (**Acipenser sturio*), Salmon (*Salmo salar*).

*Rationale for selection*
The Netherlands has obligations to protect (specific) fish species under the EU Habitats Directive, the EU MSFD and the North Sea Agreement. This group includes all migrating fish species considered relevant for the North Sea and in need of protection in general, as agreed upon in international frameworks (HD, BD, OSPAR, Red Lists, etc.). Above that they are key to nature restoration and enhancement.

### 8.1.3 Habitat preferences

*Unless stated otherwise, these species descriptions are a summary of the description in van Rijssel et al (2025, using FishBase (Froese & Pauly, 2024 a.o. literature sources). Pictures of the species and distribution maps are available in van Rijssel et al. (2025).*

The **European eel** begins its life in the Sargasso Sea, drifting as larvae towards Europe. As glass eels, they enter estuarine habitats and later migrate into freshwater systems where they inhabit all types of benthic habitats from streams to shores of large rivers and lakes. Naturally they are found only in water bodies connected to the sea. Here they remain for years in their yellow eel stage before returning to the ocean as silver eels to spawn. They feed in both freshwater and marine environments, consuming macroinvertebrates and fish.

**Sea trout**, the anadromous form of brown trout, spawn in rivers and streams with strong currents. Their juveniles inhabit freshwater habitats including streams and lakes, while adults migrate to estuaries and coastal marine areas. Feeding takes place in both freshwater and marine environments, with juveniles primarily consuming insects and adults preying on mollusks, crustaceans, and small fish.

**Twaite shad** spawn in or just above the tidal reaches of rivers, where eggs are scattered over sandy or gravel riverbeds. Juveniles remain in estuaries and nearshore marine waters for over a year, while adults inhabit open coastal waters. Their diet includes small fish and crustaceans, mainly within marine feeding grounds.
Similarly, allis shad spawn in deep, slow-flowing parts of large rivers. Their juveniles stay in estuaries or river mouths, while adults are typically found in coastal and estuarine waters. Feeding occurs in marine habitats, where adults consume planktonic crustaceans and small fish.

Both **lamprey** species spawn in rivers and streams, on fast-flowing highly oxygenated areas with gravel, pebbles, and sand bottoms, sometimes traveling far inland. The larvae, known as ammocoetes, develop in freshwater sediments for several years and migrate to sea after metamorphosis. The larvae are filter feeders in freshwater, adults feed parasitically in marine waters, attaching to large fish or marine mammals and consuming their fluids and flesh.

**North Sea houting** spawns in rivers and uses large freshwater bodies such as the IJsselmeer and Southwest Delta for juvenile development. Although they occasionally occur in coastal waters, most of their life cycle unfolds in freshwater or transitional waters. They primarily feed on zooplankton and benthic invertebrates.

**European sturgeon** spawn in large rivers and their juveniles remain in estuaries for two to three years before migrating to sea. Adults occupy coastal and offshore marine waters and feed on benthic invertebrates and small fish. Historically widespread in Dutch rivers and estuaries, the species is now considered extinct in the Netherlands.

**Atlantic salmon** spawn in rivers and streams, with juveniles residing in freshwater for one to six years before migrating to coastal and oceanic waters. After several years at sea, adults return to their natal rivers to spawn. Juveniles feed in freshwater on insects and small invertebrates, while adults consume squid, shrimp, and fish in marine environments.

### 8.1.4 Ecosystem function

The migratory fish addressed in this report cover a wide range of species. Most are forage fish, i.e. they are preyed on by larger fish, birds and marine mammals (**Table 8.1**). The species themselves feed mainly on crustaceans and small fish. The lampreys form a specific feeding guild with the sea lamprey as a parasite (blood feeding) on cetaceans and large fish and river lamprey as predator (flesh feeding) of fish.

*Table 8.1* *Migratory species and their position in the marine ecosystem (van Rijssel et al. 2025.)*

| English name | Scientific name | Habitat | Food web position |
|---|---|---|---|
| European eel | *Anguilla anguilla* | Demersal | Multi |
| Brown trout | *Salmo trutta* | Pelagic | Forage fish, predator |
| Twaite shad | *Alosa fallax* | Pelagic | Forage fish, predator |
| Allis shad | *Alosa alosa* | Pelagic | Forage fish, predator |
| North Sea houting | *Coregonus oxyrinchus* | Pelagic | Forage fish |
| River lamprey | *Lampetra fluviatilis* | Demersal | Parasite |
| European sturgeon | *Acipenser sturio* | Pelagic | Top predator |
| Sea lamprey | *Petromyzon marinus* | Demersal/Pelagic | Parasite |
| Atlantic Salmon | *Salmo salar* | Pelagic | Forage fish, predator |

### 8.1.5 Status and trend ecosystem component

The current status of many migratory fish populations is poor to moderate, reflecting declines across Europe. Internationally, five species are of Least Concern (IUCN), while six of the nine species in this plan are protected under the EU Habitats Directive; five of these have an unfavourable or unfavourable-inadequate conservation status in the Netherlands (**Table 8.2**; van Rijssel et al. 2025).

The European eel is Critically Endangered internationally, with recruitment remaining very low. Though national populations are increasing since the 2007 eel regulation; silver eel escapement is still below target levels (van der Hammen et al. 2024). Atlantic salmon populations have declined to historically low levels, with near-threatened international status and poor/vulnerable conditions in OSPAR and EU assessments. Reintroduction and habitat improvements are ongoing.

Brown trout, Twaite shad, Allis shad, Sea lamprey, and European river lamprey are generally of Least Concern internationally, though OSPAR reports poor status for Allis shad and Sea lamprey. Brown trout populations persist but face habitat pressures, while Twaite and Allis shad are mostly extinct or sporadic in Dutch waters. Both lamprey species are rare and confined to suitable estuaries and rivers.

The international status of houting is marked as extinct (IUCN) and vulnerable (Red List), whereas nationally houting is in “favourable/increasing condition”, benefiting from reintroduction efforts. The European sturgeon remains critically endangered, with no natural reproduction observed; it is extinct in the Netherlands, though limited restocking has increased bycatch reports in the North Sea.

***Table 8.2*** *Current conservation status, showing the International status at the left (IUCN Status and trend, OSPAR Status regarding the Greater North Sea and European Red List status) and the national status at the right (Dutch Red List and Conservation Status (CS) in the Netherlands for the Habitats Directive) status and trend). NL: The Netherlands; NR: Not relevant (species is not included in the Red List, OSPAR list and/or not included as species of the Habitats Directive in the Netherlands); ?: Unknown / unspecified D: Decreasing/Decline; I: Increasing/Increase CR: Critically Endangered; LC: Least Concern; NT: Near Threatened; EX: Extinct: VU: Vulnerable; EN: Endangered; SvI: Staat van Instandhouding (Conservation status in the Netherlands for the Habitats Directive); U1: Unfavourable-inadequate; U2: unfavourable-bad; F: Favourable (table is copied from van Rijssel et al. 2025).*

| Species | International | | | | National | | | References |
|---|---|---|---|---|---|---|---|---|
| | IUCN Status | IUCN Trend | OSPAR | Red List EU | Red List NL | CS NL | Trend NL | |
| Eel | CR | D | Poor | CR | NR | NR | NR | (European Commission et al. 2011; OSPAR, 2022c; Pike et al. 2020) |
| Brown trout | LC | ? | NR | LC | NR | NR | NR | (European Commission et al. 2011; Freyhof, 2011b) |
| Atlantic salmon | NT | D | Poor | VU | NR | U2 | D | (Darwall, 2023; European Commission et al. 2015; OSPAR, 2022b; Winter et al. 2022c, Adams et al. 2020*) |
| North Sea houting | EX | ? | Not available | VU | NT | F | I | (European Commission et al. 2011; Freyhof & Kottelat, 2008c; OSPAR, 2020a; Staatscourant, 2015; Winter et al. 2022d, Adams et al. 2020*) |
| Twaite shad | LC | S | NR | LC | EX | U2 | S | (European Commission et al. 2011; I. Freyhof & Kottelat, 2008b; Staatscourant, 2015; Winter et al. 2022e) |
| Allis shad | LC | ? | Poor | LC | NR | NR | NR | (European Commission et al. 2011; Freyhof & Kottelat, 2008a; OSPAR, 2022a) |
| Sea lamprey | LC | S | Poor | LC | NT | U2 | D | (European Commission et al. 2011; NatureServe, 2013; OSPAR, 2022d; Staatscourant, 2015; Winter et al. 2022a, Adams et al. 2020*) |
| European river lamprey | LC | ? | NR | LC | NT | U1 | D | (European Commission et al. 2011; J. Freyhof, 2011a; Staatscourant, 2015; Winter et al. 2022b, Adams et al. 2020*) |
| European sturgeon | CR | D | Poor | CR | NR | NR | NR | (European Commission et al. 2011; Gessner et al. 2022; OSPAR, 2020b) |

**where applicable the status of the last assessment in 2025 is used, reports will be available in 2026.*

*Legend (status getting worse from left to right)*

| | | | | | | |
|---|---|---|---|---|---|---|
| **IUCN/ Red List** | LC | NT | VU | EN | CR | EX |
| **OSPAR** | Good | | | | | Poor |
| **CS NL** | FV | U1) | U2 | | | |
| **Trend** | I | S | D | | | |

### 8.1.6 Pressures and impacts

Migratory fish species are subject to multiple pressures, including barriers to migration, mortality from infrastructure, pollution, fishing, habitat degradation, and emerging stressors related to climate change and offshore developments (**Table 8.2**). Key pressures for the Greater North Sea can also be found in OSPAR status assessments of the different species (OSPAR, 2020a, 2020b, 2022a, 2022b, 2022c, 2022d) and for the Netherlands specific the so called "bouwsteen reports for N2000" were used (Winter et al. 2022a, 2022b, 2022c, 2022d, 2022e). Below a summary of the threats based on the van Rijssel rapport is provided.

**Barriers to migration** remain a major threat for all migratory fish species. These obstacles hinder movement between marine and freshwater habitats. For European eel, this pressure is decreasing in the Netherlands thanks to mitigation measures, but the problem of barriers for migration remains widespread.

**Mortality and injury from human infrastructure** — such as hydropower turbines — continue to affect several species, particularly European eel, allis shad, European sturgeon, and North Sea houting. While measures in the Netherlands have reduced this threat for eel, other species remain vulnerable, especially during their juvenile stages.

**Pollution** from synthetic and non-synthetic substances also poses a persistent threat, particularly for European eel, which shows signs of reproductive impairment linked to long-lived pollutants such as PCBs and dioxins.

**Fisheries-related pressures** — both legal and illegal, targeted or as bycatch — impact multiple species. European eel, Atlantic salmon, and allis shad are directly exploited, although legal fishing pressure on eel and salmon has decreased, illegal fishing and trade remain a concern. Bycatch affects all species to varying degrees, though eel and lampreys generally show higher survival rates.

**Predation** by both natural and non-native predators is an increasing concern. In marine environments, gulls, predatory fish (e.g. cod, whiting, pollack), and seals prey on salmonids. In freshwater, non-native species such as the Wels catfish (*Silurus glanis*) have become significant predators of several migratory fish.

**Habitat loss and degradation** in riverine, estuarine, and coastal systems continue to limit population recovery. European eel faces somewhat less pressure from freshwater habitat loss, but other species remain affected: brown trout by degraded conditions in the Wadden Sea and tributaries; shads and lampreys by loss of spawning and nursery grounds; houting by declining habitat quality in areas such as the IJsselmeer; and sturgeon and salmon by ongoing deterioration of freshwater spawning areas.

**Emerging pressures** include electromagnetic fields from subsea cables, particularly within and between offshore wind farms. Although effects are still uncertain, fish migrating near the seabed may be more exposed than pelagic species. As subsea cables often run perpendicular to the coast, and they may intersect migratory routes.

**Climate change** represents a growing overarching pressure, altering temperature regimes, salinity, and prey availability. It is expected to influence eel, shad, lamprey, and salmon through shifts in distribution, reproduction, and feeding conditions.

**Invasive and non-indigenous species** exert additional stress through predation, competition, and disease transmission. Eel, houting, and sturgeon are increasingly affected by non-native predators and parasites, while salmon also faces risks from pathogens and escaped aquaculture fish.

**Ship traffic** contributes to direct mortality through propeller strikes, posing risks particularly for large migratory species such as sturgeon, eel, and salmonids.

***Table 8.3*** *Overview of threats that have been identified for migratory fish: N = Threat relevant for North Sea; O = threat outside the North Sea (i.e. estuaries, brackish and/or freshwater habitats); - = no threat identified (Copied from van Rijssel et al. 2025).*

| **Pressure** | **European eel** | **Sea trout** | **Twaite shad** | **Allis shad** | **Sea lamprey** | **River lamprey** | **North Sea Houting** | **European Sturgeon** | **Atlantic salmon** |
|---|---|---|---|---|---|---|---|---|---|
| Barrier to species movement | N/O | N/O | N/O | N/O | N/O | N/O | N/O | N/O | N/O |
| Extraction of or mortality/injury to species (e.g. hydropower turbines) | O | O | - | O | O | O | O | - | O |
| Input of other substances (synthetic/non-synthetic) | O | - | - | - | - | - | - | - | - |
| Removal of target species (incl. illegal catch) | N/O | - | - | O | - | - | - | - | O |
| Removal of non-target species (e.g. bycatch) | N* | N | N | N | N* | N* | N | N | N |
| Habitat loss or alteration | O | O | O | O | O | O | O | O | O |
| Electromagnetic fields around power transport cables | N | N | - | - | - | - | - | N | N |
| Input or spread of non-indigenous species | O | O | O | O | O | O | O | O | O |
| Loss of / change to natural biological communities | N/O | N/O | N/O | N/O | N/O | N/O | N/O | N/O | N/O |
| Climate change | N/O | N/O | - | N/O | - | - | N/O | - | N/O |

### 8.1.7 Current policy

The Netherlands has obligations to protect (specific) fish species under the HD, MSFD and the North Sea Agreement. For all species a species protection plan will be developed as was agreed in the North Sea Agreement.

Habitat Directive species of migratory fish in the Dutch North Sea are twaite shad (H1103), salmon (H1106), sea lamprey (H1095), river lamprey (H1099) and allis shad (H1102). North Sea houting and European sturgeon occur in Dutch coastal and riverine waters but are not specifically mentioned for Natura 2000 for The Netherlands and only listed for the HD.

For two of the nine migratory fish species included in this protection plan, the Convention on the Conservation of Migratory Species of Wild Animals (CMS) applies: European eel has been added to Appendix II in 2014 (CMS, 2014) and European sturgeon has been listed to Appendix II in 1999 and Appendix I in 2005 (CMS, 2016).

Following the EU 'Eel Regulation' (EC 1100/2007) a national action plan for eel in the Netherlands is implemented in July 2009 and revised in 2011 and 2018. The measures in the Dutch Eel Management Plan include measures on the improvement of fish migration including eel, reduction of eel mortality at hydroelectric stations by at least 35%. Reduction of eel mortality through implementation of several fisheries measures. Restocking of glass eel and pre-grown eel from aquaculture (van Rijssel & van der Hammen, 2023).

In the Netherlands, there is a release obligation for any caught Atlantic salmon or brown trout since 2000. For the other migratory fish species, release measures are written down in Fisheries law. Thus, any caught migratory fish (with exception for river lamprey caught outside their migration period) has to be released immediately.
In 2019, the Netherlands partly opened up a large migration barrier important for many migratory fish species. The Haringvliet sluices which were installed in 1970 blocking an important migratory fish route towards the spawning grounds. During periods of high discharge freshwater is being led out into the sea, however, since 2019, when the conditions allow, seawater is also being let in for short periods of time in order to aid migratory fish species to enter the Rhine-Meuse system (van Rijssel et al. 2025).

Two EU LIFE projects are helping to bring allis shad back to the Rhine by re-introducing allis shad larvae into the river at various points (European Commission et al. 2021).

Sturgeon is protected in the Netherlands by national legislation and there are also conservation plans at European level: An action plan for the conservation and restoration of the European sturgeon was published by the Council of Europe in 2007 (Rosenthal, et al. 2007). A decade later, in November 2018, a Pan-European Action Plan for Sturgeons (Friedrich et al. 2018) was adopted by the Standing Committee of the Convention on the Conservation of European Wildlife and Natural Habitats (Bern Convention) and recommended for implementation under the Habitats Directive in May 2019.

For the Netherlands, the following measures for migratory fish have been implemented or are soon to be implemented.

- Fish migration river between the Wadden Sea and Lake IJsselmeer, to facilitate passing migratory fish species from the Wadden Sea towards Lake IJsselmeer.
- No fishing zones of commercial or recreational fishing around migration barriers. At the two major barriers in The Netherlands, Haringvliet sluices and the Afsluitdijk (Kornwerderzand), a no fishing zone is planned; 1.5 and 1 km respectively. Although bycatches of migratory fish species by commercial fisherman around these locations seem relatively low (van Rijssel et al. 2019; van Rijssel & Winter 2023)
- As a result of the recent Tac and Quota Regulation negotiations each member state has to close eel fisheries in marine waters for six months. Therefore, the closed period is extended from three to six months and is set from 1 of September to the 1 of March for the marine waters of the Netherlands covering the main migration period of silver eel.

#### 8.1.7.1 Policy measures

Below follows a summary of the measures that are listed and summarized in van Rijssel et al. (2025) (**Table 8.4**). In addition to reducing fishing pressure, measures aimed at reducing barriers and improving spawning areas are effective conservation measures. Most of these measures apply to freshwater stages of diadromous fish. Partly because here most threats take place during the freshwater stages. But also, because the ecological knowledge of the marine life stages in the North Sea for these species is much less well known.

***Table 8.4*** *Summary of possible actions and proposed priority measures to target the problems encountered by migratory fish (from van Rijssel et al. 2025).*

| Species | Objective | Action |
|---|---|---|
| Eel | Increase the number of successfully out-migrating silver eels and the number of glass eels successfully entering freshwater | Reduce fishing pressure Europe through specific measures |
| | | Reduce barrier mortality during migration by pumps (such as hydropower stations). |
| Brown (sea) trout | Restore spawning population | Improve the passage of the Afsluitdijk and barriers in the rivers (including Germany) |
| | | Improve and expand spawning area and nursery area (in Germany) by removing barriers and create suitable spawning habitat |
| Twaite shad | Reestablish spawning population | Reduce fishing in protected areas in the North Sea, especially Vlakte van de Raan, Voordelta, Wadden Sea and Ems-Dollard estuary |
| | | Restore tidal estuarine habitats |
| Allis shad | Increase spawning population | Mitigate barriers (Nederrijn, river Meuse) |
| | | Restore estuarine habitats |

**Table 8.4** *cont.*

| Species | Objective | Action |
|---|---|---|
| Sea lamprey | Increase spawning population | Remove barriers |
| | | Make fish ladders more passable |
| River lamprey | Increase spawning population | Remove barriers |
| | | Make fish ladders more passable |
| North Sea houting | Increase diadromous spawning population | Make the Afsluitdijk and Haringvliet sluices passable |
| | | During the migration period of North Sea houting (November-February) a restriction of the fisheries close to the inlet and outlet sites |
| European sturgeon | Reestablish spawning population | Decrease and adequate treatment of bycatch in coastal fisheries |
| | | Ensure good quality spawning habitat |
| Atlantic salmon | Restore spawning population | Improve and expand spawning area and nursery area (in Germany) by removing barriers and create suitable spawning habitat |
| | | Remove barriers or make them well passable |

### 8.1.8 Action perspective for NN

*Rationale*

Populations of most migratory fish species have declined sharply or disappeared from Dutch waters, as a result they are in an unfavourable or critical state, mainly due to habitat loss, migration barriers, altered river flows, and bycatch. Many species have lost access to their spawning and nursery habitats, while estuarine and coastal zones have become degraded. It is therefore crucial to strengthen the populations of these species through a combination of measures, as identified in the background document of the species protection plan and summarized below.

*Action perspective for NN*

Looking at the presented measures in the species background document, NN can play a key role through the measures that involve restauration of (tidal) estuarine habitats and spawning areas complementing more policy-led measures such as barrier removal and fisheries management. In that perspective NN initial focus should be on practical, scalable restoration projects and building knowledge for further implementation & upscaling (RRL4-6). It is recommended that, prior to implementing restoration projects, a comprehensive desk study is carried out—supplemented, where relevant, by targeted field surveys—to identify suitable locations for restoration and to determine, based on previous studies, which interventions are most appropriate. This assessment should also take into account how these measures relate to other necessary interventions that fall within the policy domain, ensuring alignment and complementarity.

The ecological knowledge of the marine life stages in the North Sea for most migratory fish species is poorly known. More specific it was advised by van Rijssel et al. (2025) to study the relative importance of marine habitats for growth during the yellow eel stages (RRL1-3). This could be taken up by NN as this might possibly lead to action perspective for the programme.

*Demonstration of impact*

To demonstrate the actual contribution of NN activities to the recovery of migratory fish populations, a solid knowledge base on the status of the stocks is required. Knowledge that is currently largely lacking. There is insufficient information on population size, distribution, and trends of most of the species. Moreover, the condition of these populations is influenced by a wide range of anthropogenic factors, including fishing, habitat alteration, pollution, and climate change.

Given these uncertainties, it is important that objectives for NN are defined at the level of habitat restoration and improvement—for example, the number of hectares of habitats or spawning grounds restored or enhanced—combined with monitoring to assess how successfully these habitats are used by the target species. This approach allows NN to demonstrate tangible ecological progress while contributing to the long-term recovery of migratory fish populations.

### 8.1.9 References

Main source:
Van Rijssel, J.C., Winter, H.V., van der Hammen, T., Tamis, J.E., Jongbloed, R.H., 2025. Migratory fish in the Dutch North Sea. Background document for a protection plan. Wageningen Marine Research report C035/25. https://doi.org/10.18174/693304

Sources used in the doc above:

Adams, A., Bijlsma, R.-J., Bos, G., Clerkx, S., Janssen, J., van Kleunen, A., Remmelts, W., van Rooijen, N., Schaminée, J., Schmidt, A., van Swaay, C., Wijnhoven, S., Woestenburg, M., (Ed.), & van Aar, M., (Ed.). (2020). Vogel- en Habitatrichtlijnrapportage 2019. WOT Natuur & Milieu. https://edepot.wur.nl/520728
CMS (2014). Proposal for the inclusion of the european eel (*Anguilla anguilla*) *ON CMS APPENDIX II*.
CMS (2016). Inclusion of the species *Acipenser sturio* on Appendix I of the Convention on the Conservation of Migratory Species of Wild Animals (CMS).
Darwall, W.R.T. (2023). Salmo salar. The IUCN Red List of Threatened Species 2023: E.T19855A67373433. https://dx.doi.org/10.2305/IUCN.UK.2023-1.RLTS.T19855A67373433.en.
European Commission, Directorate-General for Environment, Brooks, E., & Freyhof, J. (2011). European red list of freshwater fishes. Publications Office. https://doi.org/10.2779/85903
European Commission, Directorate-General for Environment, Carpenter, K., Karmovskaya, E., Gil de Sola, L., Stump, E., Delgado, J., Munroe, T., Clò, S., Allen, D., McCully Phillips, S., Papaconstantinou, C., Comeros-Raynal, M., Soldo, A., Pollard, D., Scott, J., Harvey, M., Fowler, S., Keskin, C., … Cook, R. (2015). European red list of marine fishes. Publications Office. https://doi.org/10.2779/082723
European Commission, Directorate-General for Environment, & Sundseth, K. (2021). The state of nature in the EU – Conservation status and trends of species and habitats protected by the EU nature directives 2013–2018. Publications Office of the European Union. https://doi.org/10.2779/5120
Freyhof, I., & Kottelat, M. (2008a). *Alosa alosa*. The IUCN Red List of Threatened Species 2008: E.T903A13091343. https://dx.doi.org/10.2305/IUCN.UK.2008.RLTS.T903A13091343.en.
Freyhof, I., & Kottelat, M. (2008b). *Alosa fallax* (errata version published in 2020). The IUCN Red List of Threatened Species 2008: E.T904A174776207. https://dx.doi.org/10.2305/IUCN.UK.2008.RLTS.T904A174776207.en.
Freyhof, I., & Kottelat, M. (2008c). *Coregonus oxyrinchus*. The IUCN Red List of Threatened Species 2008: https://dx.doi.org/10.2305/IUCN.UK.2008.RLTS.T5380A11126034.en
Freyhof, J. (2011a). *Lampetra fluviatilis* (errata version published in 2016). The IUCN Red List of Threatened Species 2011: E.T11206A97805807. https://dx.doi.org/10.2305/IUCN.UK.2008.RLTS.T11206A3263535.en.
Freyhof, J. (2011b). *Salmo trutta*. The IUCN Red List of Threatened Species 2011: E.T19861A9050312. https://dx.doi.org/10.2305/IUCN.UK.2008.RLTS.T19861A9050312.en.
Friedrich, T., Gessner, J., Reinartz, R., & Striebel-Greiter, B. (2018). PAN-EUROPEAN ACTION PLAN FOR STURGEONS. the World Sturgeon Conservation Society and WWF. T-PVS/Inf(2018)6. https://rm.coe.int/pan-european-action-plan-for-sturgeons/16808e84f3
Froese, R., & Pauly, D. (2024). FishBase. World Wide Web electronic publication. www.fishbase.org
Gessner, J., Williot, P., Rochard, E., Freyhof, J., & Kottelat, M. (2022). *Acipenser sturio* (errata version published in 2023). The IUCN Red List of Threatened Species 2022: E.T230A242530547. https://dx.doi.org/10.2305/IUCN.UK.2022-1.RLTS.T230A242530547.en.
NatureServe. (2013). *Petromyzon marinus*. The IUCN Red List of Threatened Species 2013: E.T16781A18229984. https://dx.doi.org/10.2305/IUCN.UK.2013-1.RLTS.T16781A18229984.en.
OSPAR. (2020a). Background Document for Houting—Wadden Sea population of Coregonus oxyrinchus.
OSPAR. (2020b). Status Assessment 2020—European Sturgeon. https://oap.ospar.org/en/ospar-assessments/committee-assessments/biodiversity-committee/status-assesments/european-or-common-sturgeon/
OSPAR. (2022a). Status Assessment 2022—Allis shad. https://oap.ospar.org/en/ospar-assessments/committee-assessments/biodiversity-committee/status-assesments/allis-shad/

OSPAR. (2022b). Status Assessment 2022—Atlantic salmon. https://oap.ospar.org/en/ospar-assessments/committee-assessments/biodiversity-committee/status-assesments/atlantic-salmon/

OSPAR. (2022c). Status Assessment 2022—European eel. https://oap.ospar.org/en/ospar-assessments/committee-assessments/biodiversity-committee/status-assesments/european-eel/

OSPAR. (2022d). Status Assessment 2022—Sea lamprey. https://oap.ospar.org/en/ospar-assessments/committee-assessments/biodiversity-committee/status-assesments/sea-lamprey/

Pike, C., Crook, V., & Gollock, M. (2020). Anguilla anguilla. The IUCN Red List of Threatened Species 2020: E.T60344A152845178. https://dx.doi.org/10.2305/IUCN.UK.2020-2.RLTS.T60344A152845178.en.

Rosenthal, H., Bronzi, P., Gessner, J., Moreau, D., & Rochard, E. (2007). Action Plan for the conservation and restoration of the European sturgeon (Acipenser sturio). Council of Europe Publishing Nature and environment, No. 152: 1-125.

Staatscourant. (2015). Besluit van de Staatssecretaris van Economische Zaken van 15 oktober 2015, DGAN-PDJNG / 15129301, houdende vaststelling van geactualiseerde Rode lijsten flora en fauna. Staatscourant 2015 nr. 36471 23 oktober 2015. https://zoek.officielebekendmakingen.nl/stcrt-2015-36471.pdf

van der Hammen, T., Volwater, J. J. J., Soudijn, F. H., van Rijssel, J. C., School J. J. M., van Daalen, S. F. (2024) European Eel (Anguilla anguilla) stock size, anthropogenic mortality and silver eel escapement in the Netherlands 2006-2023. CVO report: 24.023. DOI: https://doi.org/10.18174/675817.

van Rijssel, J., van den Puijenbroek, M., Schilder, K., & Winter, E. (2019). Impact van verschillende visserijvormen op trekvissen. Wageningen Marine Research rapport C046/19. https://edepot.wur.nl/476384

van Rijssel, J. C., & van der Hammen, T. (2023). Report on the eel stock, fishery and other impacts, in The Netherlands. ICES Scientific Reports.

van Rijssel, J.C., Winter, H.V. (2023). Inspannings- en vangstregistraties van trekvissen door beroepsvissers aan de buitenzijde van de Haringvlietsluizen in 2021 en 2022. Wageningen University & Research rapport C033/23. DOI: an https://doi.org/10.18174/632229.

Winter, E., de Leeuw, J., van Rijssel, J., & Janssen, J. (2022a). Bouwsteen ten behoeve van het Strategisch Plan Natura 2000. Soort 1095. Zeeprik (Petromyzon marinus).

Winter, E., de Leeuw, J., van Rijssel, J., & Janssen, J. (2022b). Bouwsteen ten behoeve van het Strategisch Plan Natura 2000. Soort 1099. Rivierprik (Lampetra fluviatilis).

Winter, E., de Leeuw, J., van Rijssel, J., & Janssen, J. (2022c). Bouwsteen ten behoeve van het Strategisch Plan Natura 2000. Soort 1106. Zalm (Salmo salar).

Winter, E., de Leeuw, J., van Rijssel, J., & Janssen, J. (2022d). Bouwsteen ten behoeve van het Strategisch Plan Natura 2000. Soort 1113. Noordzeehouting (Coregonus oxyrhynchus).

Winter, E., van Rijssel, J., de Leeuw, J., & Janssen, J. (2022e). Bouwsteen ten behoeve van het Strategisch Plan Natura 2000. Soort 1103. Fint (Alosa fallax).

## 8.2 Elasmobranchs

For Elasmobranchs a background document for a species protection plan is being prepared (Leurs et al. 2026). The report served as a basis for the preparation of this document.

### 8.2.1 Description of ecosystem component

Elasmobranchs are a diverse and evolutionarily ancient group of cartilaginous fishes within the subclass *Elasmobranchii*. Elasmobranchs play an important role as predators in the marine ecosystem (Batsleer et al. 2020; Heithaus et al. 2008). They are characterized by specific biological traits: they are long-lived and exhibit slow growth, late sexual maturity, and produce a small number of offspring per year. These traits make cartilaginous fishes vulnerable to fishing, pollution, and changes in essential habitats, particularly spawning and nursery areas (Batsleer et al. 2020; Stevens et al. 2000; Schindler et al. 2002; Heessen, 2010).

### 8.2.2 Species selection / Focus species

This analysis is based on the same selection of species as used in the background document for the species protection plans (Leurs et al.2026):

Sharks: small spotted catshark (*Scyliorhinus canicula*), starry smooth-hound (*Mustelus asterias*), tope (*Galeorhinus galeus*), spiny dogfish / spurdog (*Squalus acanthias*),
Skates: thornback skate (*Raja clavata*), blonde skate (*Raja Brachyura*), spotted skate (*Raja montagui*), starry skate (*Amblyraja radiata*), cuckoo skate (*Leucoraja naevus*), common stingray (*Dasyatis pastinaca*), flapper skate; common skate complex (*Dipturus intermedius/batis (complex)*).

*Rationale for selection*
The selection of species follows the same reasoning and approach as used in the species protection plans (Leurs et al.2026). The 11 priority species were selected based on their occurrence in Dutch waters, but also due to their status and listing on (inter)national protection measures. Other species that once were more common in the Dutch North Sea but have since disappeared or are only present sporadically, such as the angelshark (*Squatina squatina*), porbeagle (*Lamna nasus*), basking shark (*Cetorhinus maximus*) have not been included in this report. The flapper skate (*Dipturus intermedius*) is included as the 'common skate complex' as most of the information on this species from the North Sea originates from before this complex was resolved and split into two separate skate species.

### 8.2.3 Habitat preferences

**The small-spotted catshark** occurs on the continental shelf, mostly on soft-sediment habitats shallower than 450 meters. The small-spotted catshark moves over relatively short distances throughout its life cycle (Rodriguez-Cabello *et al.* 1997, Ferragut-Perello *et al.* 2024).

**The starry smooth-hound's** habitat ranges from the sandy/gravel intertidal to depths of <200 meters deep (Ebert *et al.* 2021). The species migrates inshore during the summer months and has been recorded to travel over 1.400 km (Brevé *et al.* 2016). The starry smooth-hound uses estuaries and shallow bays as nursery area and their distribution is segragated between males and females (Brevé *et al.* 2016, 2020). The starry smooth-hound is normally a specialist, feeding predominantly on crabs (McCully Phillips *et al.* 2015, Biton-Porsmoguer 2022).

**The Tope** uses inshore bays or estuaries as nursery area in which juveniles stay for up to two years (McMillan *et al*. 2021). In the North-East Atlantic, Thorburn et al. (2019) indicated that the shallow coastal habitats along Wales and the Northern Netherlands may be plausible pupping grounds, as evidenced for waters around the Wadden Sea islands (Edwards et al. 2025). The species is a known migrant that travels more than 4.600 km in total during seasonal migrations between feeding and reproductive areas (Holden and

Horrod 1979, Nosal *et al.* 2020, Schaber *et al.* 2022). This species is known to move between the North East Atlantic and the Mediterranean Sea (Colloca *et al.* 2019, Thorburn *et al.* 2019).

**The spiny dogfish's** feeds on teleosts, invertebrates and sometimes other elasmobranchs (Holden 1966, Ebert *et al.* 2021). It's prefered habitat is soft sediments on continental shelves at 0-600m deep (Ebert *et al.* 2021). Some populations of this species are resident, while others can undertake long-distance migrations of up to 1.600 km (Carlson *et al.* 2014, Ebert *et al.* 2021). Some populations are resident, while others can undertake long-distance migrations of up to 1.600 km (Carlson *et al.* 2014, Ebert *et al.* 2021).

**Thornback skates** feed on benthic crustaceans and includes fish in its diet ontogenetically (Holden and Tucker 1974, Farias *et al.* 2006). They occur at shallow to deep depths (5 to 1010 m; Last *et al.* 2016). Adults of this species move from deeper offshore waters to shallower waters during the summer months (Walker *et al.* 1997, Hunter *et al.* 2005). The species can move over long distances, as is witnessed in tagging studies (Bird *et al.* 2020).

**The blonde skate** occurs mostly in nearshore waters to a depth of 150 m, but possibly to depths of up to 900 m (Last *et al.* 2016). The species has been captured as far as 910 km from initial tagging locations (Bird *et al.* 2020). Blonde skate mainly feeds on shrimp and teleost fishes (Farias *et al.* 2006)

**The spotted skate** mostly occurs at depths between 10 to 150 meters (although recorded to at least 800 meters). Individuals of this species have traveled for up to 416 km from initial capture locations (Bird *et al.* 2020). It feeds on benthic habitats on polychaetes, amphipods, and teleosts (larger individuals; Farias *et al.* 2006).

**Starry skate** usually occurs in demersal habitats at depths between 25 to 440 meters (but occurs to 1.400 m). The movement ecology of this species is not well known, but previous tagging studies shows this species moves over distances of up to 486 km (Bird *et al.* 2010), but generally it is hypothesized that long-distance movements are limited in this species (Templeman 1984, Kneebone *et al.* 2020).

**The Cuckoo skate** occurs mostly on benthic sandy to gravel habitats at depths between 10-900 meters. Tagging studies show that this species travels for up to 425 km from initial capture locations (Bird *et al.* 2010).

**The common stingray** uses coastal bays and estuaries and occurs mostly shallower than 50 meters deep (although it has been recorded at depths of up to 140 m; Last *et al.* 2016). In the warmer Portuguese waters the common stingray remains within the vicinity of the coast, moving over short distances between coastal areas (Kraft *et al*. 2023).

**The flapper skate** occurs in mostly on demersal, soft-bottom habitats from the shallows to depths of up to 1.500 meters (Last *et al.* 2016).

### 8.2.4 Ecosystem function

Sharks and rays can have various roles in marine food webs and these roles can change during their lifecycle (e.g., ontogenetically or seasonally) (Flowers *et al.* 2021, Dedman *et al.* 2024). Larger shark species can act as top-predators, whereas smaller and young sharks and rays often have a more meso-predatory role (Flowers *et al.* 2021, Heithaus *et al.* 2022). Generally, as sharks and rays occupy the intermediate and top predatory positions in marine food webs, their presence or absence is considered to be a good indication of marine ecosystem health (e.g. Dedman *et al*. 2024).

The shark and ray species included in this protection plan predominantly occupy intermediate food web positions (i.e., meso-predatory role), except for large tope and spiny dogfish that may have higher positions in the food web (Table 3). A meso-predatory role means that these species exert predatory pressure on lower trophic levels (i.e., benthic invertebrates such as crabs, but also small fish), but are themselves also prey to larger predators (i.e., other sharks or marine mammals; Table 3).

Sharks and rays can also act as nutrient vectors. As predators that move over longer distances (e.g. moving between coastal and offshore areas seasonally), sharks and rays also connect ecosystems and transport nutrients between different areas (Papastimatiou *et al.* 2015, Leurs *et al.* 2023). In addition, benthic sharks and rays may dig up and rework the sediments while searching for prey or whole resting (Nauta *et al.* 2024, Leurs *et al.* 2023). This bioturbation of sediments, which is mostly done by rays, is known to turn over the top sediment layers frequently, by which nutrients trapped in sediments are resuspended in the water column and the rays change the biogeomorphology of (intertidal) marine habitats by creating a landscape of sediment depressions (O'Shea *et al.* 2012, Flowers *et al.* 2021, Nauta *et al.* 2024). These landscape-wide changes of sediment depressions can provide new habitat to lower trophic organisms, especially in the intertidal where these features act as tidepools and provide refuge for organisms during high tide (O'Shea *et al.* 2012).

### 8.2.5 Status and trend ecosystem component

*Distribution*

The eleven elasmobranch species discussed show broad distributions across the Northeast Atlantic and adjacent seas, with varying degrees of presence in Dutch waters. Most species occur from Norway to at least the Mediterranean Sea (Ebert et al. 2015; Jabado et al. 2020; Last et al. 2016), while some, such as the tope (*Galeorhinus galeus*) and spiny dogfish (*Squalus acanthias*), have near-global distributions in temperate and boreal waters (Ebert et al. 2021).

Within the North Sea, species richness and abundance are generally highest in the southern and central parts. The spiny dogfish and spotted skate (*Raja montagui*) are widespread across the North Sea, whereas the starry skate (*Amblyraja radiata*) is mainly found in the northern areas (Kulka et al. 2019; Leurs et al. 2026). Several species are common or seasonally present in Dutch waters, notably the small-spotted catshark (*Scyliorhinus canicula*), starry smooth-hound (*Mustelus asterias*), thornback skate (*Raja clavata*), and blonde ray (*Raja brachyura*) (Leurs et al.2026; Ellis et al. 2005, 2008). The starry smooth-hound is a seasonal visitor, with large females entering the Eastern Scheldt for parturition between April and September (Brevé et al. 2016, 2020). The tope likely uses Dutch and German waters as nursery areas (Thorburn et al. 2019; Edwards et al. in press).

The cuckoo skate (*Leucoraja naevus*) occurs mostly off the British coast and is rare in the Dutch EEZ (Ellis et al. 2014). The common stingray (*Dasyatis pastinaca*) is mostly confined to warmer coastal waters but is occasionally recorded in Dutch estuaries (Jabado et al. 2020; Leurs et al. 2026). The flapper skate (*Dipturus intermedius*) now occurs primarily off northern Scotland but historically inhabited Dutch waters and may recolonize in the future (Ellis et al. 2021; Bom et al. 2022).

Overall, Dutch waters provide important seasonal and nursery habitats for several demersal shark and ray species within the broader North Sea population context.

*Status*

Information on the population/stock status of sharks and rays in the North Sea originates from different sources, which we here used in a hierarchical manner due to differences in the underlying data and regional aspect of the assessments: (1) ICES stock assessments (based on landing data), (2) OSPAR assessments (often based on ICES or fishery-independent surveys), and (3) regional IUCN assessments (or description of the North Sea population in the global assessment of the species) (**Table 8.5**).

All sharks/rays with ICES advice are being commercially fished and of these species only Starry skate has a zero-catch advice due to the fact that the species has been declining since 2001 and is currently under the trigger limit. All other species that are being commercially fished are above the trigger limit according to ICES.

According to IUCN most of the species are in a vulnerable to near threatened stated. Exceptions are: Small-spotted catshark, spotted skate and cuckoo skate (Least concern). The international assessments are not always representative of the North Sea populations, as some species in the North Sea may be stable or recovering, while on a global scale these species are in decline (i.e., tope and spiny dogfish). The spotted skate, thornback skate, spiny dogfish and flapper skate have been assessed under OSPAR in 2021. The spotted ray population status was assessed to be 'Good' in OSPAR region II (North Sea), with this region showing an increase since 2009 (OSPAR, 2021a). The thornback ray shows a similar increase in biomass and stock size indicators (OSPAR, 2021b). The common skate was assessed to be 'Poor', with the species still infrequently captured or completely absent on locations in its former distribution (OSPAR, 2021c). Similarly, the spiny dogfish status in the North Sea was also assessed to be 'Poor' (OSPAR 2021d). Throughout its range stock size remains low, but according to latest ICES reports, published after the 2021 OSPAR assessment, this species shows an increase stock size and recruitment in the North Sea (ICES, 2024a,b). In the 2022 OSPAR report on the recovery of fishes in the Northeast Atlantic, almost all species included in this report were assessed to be recovering in the Greater North Sea (OSPAR, 2022). The tope and common stingray were assessed as having stable populations, whereas the starry skate is still declining, and the status of the common skate complex is unknown.

National status of the shark and ray species included in this study is only assessed as part of the national Red List (**Table 8.5**). The last assessment of sharks and rays for this list took place in 2004, in which the starry smooth-hound, tope and thornback skate were assessed to be Vulnerable, and the common stingray was assessed to be critically endangered. However, more recent assessments of their national conservation status are lacking. No national indicators exist for elasmobranch species to be assessed under the EU Marine Strategy Framework Directive. In addition, status assessments like the 'Staat van Instandhouding' as used for species listed in the EU Habitat Directive do not exist for elasmobranchs.

***Table 8.5*** *International and national conservation status of shark and ray species included in this document (copied from Leurs et al.2026).*

| Species | | International | | National |
|---|---|---|---|---|
| | | **IUCN** | **OSPAR*** | **NL Red List** |
| **Sharks** | Small-spotted catshark | Least Concern (2020) | Recovering | |
| | Starry smooth-hound | Near Threatened (2020) | Recovering | |
| | Tope | Critically Endangered (2020) | Stable | |
| | Spiny dogfish | Vulnerable (2019) | | Critically Endangered (2015) |
| **Rays** | Thornback skate | Near Threatened (2023) | Recovering | Endangered (2015) |
| | Blonde skate | Near Threatened (2023) | Recovering | |
| | Spotted skate | Least Concern (2023) | Recovering | Critically Endangered (2015) |
| | Starry skate | Vulnerable (2019) | Declining | |
| | Cuckoo skate | Least Concern (2014) | Recovering | |
| | Common stingray | Vulnerable (2020) | Stable | |
| | Common skate complex | Critically Endangered (2021) | Unknown | Extirpated (2015) |

**According to the 2022 OSPAR Recovery of Sensitive Fishes report (OSPAR 2022)*

### 8.2.6 Pressures and impacts

In general, sharks and rays are sensitive to anthropogenic threats due to their life history traits. Their growth is slow, maturity is reached at a relatively late age, their reproductive cycle is long, and fecundity generally low compared to other (commercial) fish species (e.g., Lucifora *et al*. 2004, Dulvy *et al*. 2014).

Sharks and rays are affected by multiple human pressures. They are sensitive to fishing pressure and recovery of exploited populations may be relatively slow (e.g. Dulvy *et al*. 2014, 2021). Bycatch in commercial and recreational fisheries is a major source of mortality, with impacts varying by gear type, handling practices and habitat overlap with target fish species. Bottom-disturbing activities (e.g. trawling, dredging, offshore wind development) can cause habitat loss but may also create new structures suitable for egg laying. Other threats listed in Leurs et al. (2026) are:

- Coastal development and defense works have reduced shallow habitats and altered food webs in key areas.

- Noise pollution can change behaviour and habitat use, though species-specific effects remain poorly understood. Especially the combination of the exposure to electromagnetic fields and noise associated with offshore windfarms need further investigation due to the rapid energy transition.
- Climate change is expected to shift distributions and habitats through warming and sea-level rise, while chemical pollution (e.g. PFAS, microplastics, heavy metals) poses long-term risks through bioaccumulation in these top predators.

### 8.2.7 Current policy

On a regional (European) level, conservation measures on sharks and rays include fisheries management under the CFP (EU 2022/109, 2019/1241), EU Shark Finning Regulation (EU 605/2013), the MSFD, HD, and the species assessments of OSPAR and ICES.

On a national level, seven shark (smooth-hound, tope, spiny dogfish) and ray species (thornback skate, spotted skate, common stingray, and flapper skate) have been included in the Fisheries Act of 1963 (Min. LNV 2023). This act is the basis for the implementation of fisheries agreements and CFP on a national level.

The national habitat approach (NL: "leefgebiedenbenadering") stimulates the protection of species through different projects. The spiny dogfish is included as 'green' species, meaning there are no protection measures needed. The thornback skate and flapper skate are included as 'orange' species, meaning that at least one or two conservation measures are needed for these species.

#### 8.2.7.1 Policy measures

For sharks and rays, it remains a challenge to develop meaningful management measures due to persistent knowledge gaps. Although knowledge of these species in the North Sea has increased substantially in recent years, several important uncertainties remain. These include limited information on the rarer species, insufficient understanding of migration patterns and spatial use, limited knowledge on selectivity in fisheries, uncertainties regarding discards and post-release survival, and limited insight into the role of (other) anthropogenic stressors.

Further research remains essential to support evidence-based management, given the limited knowledge about distribution, population structures, migration routes, and habitat use of many species. Many possible measures are probably policy or fishery management measures, and not in the remit of NN (**Table 8.6**). Research on spatial distribution and migration patterns is needed to better understand how sharks and rays use the North Sea, particularly in relation to areas with existing or future offshore wind farms. This knowledge will help to anticipate and mitigate potential conflicts between conservation objectives and human activities. It is also crucial to identify important areas or "hotspots" for sharks and rays, such as key feeding, nursery, or aggregation sites. Protecting these areas can provide direct spatial protection and support the recovery of local populations.

***Table 8.6*** *Policy measures for conservation of elasmobranchs (Leurs et al. (2026)).*

| Measures | Rationale |
|---|---|
| **Alternatives for group TACs for rays** | Prevent overexploitation of vulnerable stocks and improve fisheries management |
| **Selectivity in fisheries (e.g., "kiwi trawl")** | Increase survival rates |
| **Identify important areas for sharks and rays ("hotspots")** | Manage and protect areas so that species receive direct protection |
| **Develop indicators for status assessment under the MSFD** | Status assessment under the MSFD provides insight into monitoring and data collection, and helps identify possible measures under the MSFD |
| **Research on spatial distribution and migration patterns** | Ecological important areas prioritized in area-based management of sharks & rays. |

### 8.2.8 Advice, action perspectives / possible measures

*Rationale*

Sharks and rays are long-lived and exhibit slow growth, late sexual maturity, and produce a small number of offspring per year which make them vulnerable to fishing, pollution, and changes in spawning and nursery areas. In $20^{th}$ century, many populations have declined mainly due to bycatch in fisheries.
In this report eleven species are showcased as species in need of restoration. A range of direct and indirect measures that can contribute to improving the conservation status of sharks and rays in the North Sea were identified in the species protection background document and summarised here. Given the vulnerable conservation status of many species and their ecological importance, and slow population recovery, targeted measures to protect and restore shark and ray populations are essential. Actions may include habitat protection, bycatch reduction, monitoring programs, and research to fill knowledge gaps, all of which are critical to ensure the resilience and long-term sustainability of these species in the North Sea.

*Action perspective for NN*

Measures within the remit of NN could include restoration of feeding, reproduction (e.g. habitat for egg deposition) or nursery areas. A combination with other NN measures, such as hard substrate or biogenic reef restoration is possible. For example, restoration of an oyster reef could result in habitat for egg deposition. However in order to be able to implement targeted measures more insight in the specific requirements for egg deposition, (location of) important nursery areas or feeding areas is needed (RRL 1-3).
Re-introduction could also be an option, where species are grown from eggs to juveniles in a hatchery and released at restoration sites. An example is the re-introduction of thornback rays in the Eastern Scheldt and Western Scheldt areas which shows promising signs of success based on studies of juvenile behaviour (Verveld, 2024) (RRL 4-5).

*Demonstration of impact*

To demonstrate the actual contribution of NN activities to the recovery of shark and ray populations, monitoring is required. On a large scale, this could be done by the regular fish surveys that take place annually. On a small scale, visual monitoring can be done, e.g. to assess egg deposition, or the presence of species at restoration sites. Also monitoring of tagged animals can be considered, for which additional receiver stations should be placed at restoration sites, as part of the international network to detect tagged fish species.

### 8.2.9 References

Main source:
Leurs, G., K. Bleeker, H.V. Winter, R.H. Jongbloed (2026). Sharks and Rays in the Dutch North Sea: Background document for a protection plan. Wageningen Marine Research report C003/26. https://doi.org/10.18174/707647

*Sources in Leurs et al.(2026):*

Bird, C., Burt, G. J., Hampton, N., McCully Phillips, S. R., & Ellis, J. R. (2020). Fifty years of tagging skates (Rajidae): Using mark-recapture data to evaluate stock units. Journal of the Marine Biological Association of the United Kingdom, 100(1), 121–131. https://doi.org/10.1017/S0025315419000997
Biton-Porsmoguer, S. (2022). Diet strategies of starry smooth-hound Mustelus asterias and tope shark Galeorhinus galeus (Carcharhiniformes: Triakidae) in the Eastern English Channel: implication for conservation. https://doi.org/10.21411/CBM.A.8EF00B6F
Bom, R. A., Brader, A., Batsleer, J., Poos, J.-J., Van Der Veer, H. W., & Van Leeuwen, A. (2022). A long-term view on recent changes in abundance of common skate complex in the North Sea. Marine Biology, 169(11), 146. https://doi.org/10.1007/s00227-022-04132-w
Brevé, N. W. P., Winter, H. V., Van Overzee, H. M. J., Farrell, E. D., & Walker, P. A. (2016). Seasonal migration of the starry smooth-hound shark Mustelus asterias as revealed from tag-recapture data of an angler-led tagging programme. Journal of Fish Biology, 89(2), 1158–1177. https://doi.org/10.1111/jfb.12994

Brevé, N. W. P., Winter, H. V., Wijmans, P. A. D. M., Greenway, E. S. I., & Nagelkerke, L. A. J. (2020). Sex differentiation in seasonal distribution of the starry smooth-hound Mustelus asterias. Journal of Fish Biology, 97(6), 1870–1875. https://doi.org/10.1111/jfb.14548

Carlson, A. E., Hoffmayer, E. R., Tribuzio, C. A., & Sulikowski, J. A. (2014). The Use of Satellite Tags to Redefine Movement Patterns of Spiny Dogfish (Squalus acanthias) along the U.S. East Coast: Implications for Fisheries Management. PLoS ONE, 9(7), e103384. https://doi.org/10.1371/journal.pone.0103384

Colloca, F., Scannella, D., Geraci, M. L., Falsone, F., Batista, G., Vitale, S., Di Lorenzo, M., & Bovo, G. (2019). British sharks in Sicily: Records of long distance migration of tope shark (Galeorhinus galeus) from North-eastern Atlantic to Mediterranean Sea. Mediterranean Marine Science, 20(2), 309. https://doi.org/10.12681/mms.18121

Dedman, S., Moxley, J. H., Papastamatiou, Y. P., Braccini, M., Caselle, J. E., Chapman, D. D., Cinner, J. E., Dillon, E. M., Dulvy, N. K., Dunn, R. E., Espinoza, M., Harborne, A. R., Harvey, E. S., Heupel, M. R., Huveneers, C., Graham, N. A. J., Ketchum, J. T., Klinard, N. V., Kock, A. A., … Heithaus, M. R. (2024). Ecological roles and importance of sharks in the Anthropocene Ocean. Science, 385(6708), adl2362. https://doi.org/10.1126/science.adl2362

Dulvy, N. K., Fowler, S. L., Musick, J. A., Cavanagh, R. D., Kyne, P. M., Harrison, L. R., Carlson, J. K., Davidson, L. N., Fordham, S. V., Francis, M. P., Pollock, C. M., Simpfendorfer, C. A., Burgess, G. H., Carpenter, K. E., Compagno, L. J., Ebert, D. A., Gibson, C., Heupel, M. R., Livingstone, S. R., White, W. T. (2014). Extinction risk and conservation of the world's sharks and rays. eLife, 3, 1–35. https://doi.org/10.7554/elife.00590

Dulvy, N. K., Pacoureau, N., Rigby, C. L., Pollom, R. A., Jabado, R. W., Ebert, D. A., Finucci, B., Pollock, C. M., Cheok, J., Derrick, D. H., Herman, K. B., Sherman, C. S., VanderWright, W. J., Lawson, J. M., Walls, R. H. L., Carlson, J. K., Charvet, P., Bineesh, K. K., Fernando, D., … Simpfendorfer, C. A. (2021). Overfishing drives over one-third of all sharks and rays toward a global extinction crisis. Current Biology, 31(21), 4773-4787.e8. https://doi.org/10.1016/j.cub.2021.08.062

Ebert, D. A., Dando, M., Fowler, S. L., & Jabado, R. (2021). Sharks of the world: A complete guide (p. 609). Princeton University Press.

Edwards, J.E., Brevé, N.W.P., Walker, P., Buijse, A.D., Bijleveld, A.I., Winter, H.V. (2025). Evidence for a pupping area around the Dutch Wadden Islands for the critically endangered tope shark (Galeorhinus galeus). In: Edwards J.E. (2025). Life in the shallows: Tracking fish movement within and beyond the Dutch Wadden Sea. PhD-thesis, Wageningen University, the Netherlands.

Ellis, J. R., Cruz-Martínez, A., Rackham, B. D., & Rogers, S. I. (2005). The distribution of chondrichthyan fishes around the British Isles and implications for conservation. Journal of Northwest Atlantic Fishery Science, 35(November 2004), 195–213. https://doi.org/10.2960/j.v35.m485

Ellis, J. R., Dulvy, N. K., Jennings, S., Parker-Humphreys, M., & Rogers, S. I. (2005). Assessing the status of demersal elasmobranchs in UK waters: A review. Journal of the Marine Biological Association of the United Kingdom, 85(5), 1025–1047. https://doi.org/10.1017/S0025315405012099

Ellis, J. R., & Keable, J. (2008). Fecundity of Northeast Atlantic spurdog (Squalus acanthias). ICES Journal of Marine Science, 65(6), 979–981. https://doi.org/10.1093/icesjms/fsn080

Farias, I., Figueiredo, I., Moura, T., Gordo, L. S., Neves, A., & Serra-Pereira, B. (2006). Diet comparison of four ray species (Raja clavata, Raja brachyura, Raja montagui and Leucoraja naevus) caught along the Portuguese continental shelf. Aquatic Living Resources, 19(2), 105–114. https://doi.org/10.1051/alr:2006010

Ferragut-Perello, F., Sánchez-Zulueta, P., Ramírez-Amaro, S., Farriols, M. T., Pasini, N., Guijarro, B., Rodríguez-Cabello, C., & Ordines, F. (2024). Elasmobranch Mark–Recapture Experiment off the Balearic Islands: Insight into Scyliorhinus canicula Growth, Mobility, and Population Size. Fishes, 9(8), 315. https://doi.org/10.3390/fishes9080315

Flowers, K. I., Heithaus, M. R., & Papastamatiou, Y. P. (2021). Buried in the sand: Uncovering the ecological roles and importance of rays. Fish and Fisheries, 22(1), 105–127. https://doi.org/10.1111/faf.12508

Heithaus, M. R., Dunn, R. E., Farabaugh, N. F., Lester, E., Madin, E., Meekan, M., & Wirsing, A. J. (2022). Advances in our understanding of the ecological importance of sharks and their relatives. In J. C. Carrier, C. A. Simpfendorfer, M. R. Heithaus, & K. E. Yopak (Eds.), Biology of sharks and their relatives (3rd editio, pp. 486–522). CRC Press.

Heessen, H.J.L. (2010) State of the Art - Haaien en roggen in de Noordzee. Wageningen, IMARES Wageningen UR rapport C011/10: 30 pp.

Holden, M. J. (1966). The Food of the Spurdog, Squalus acanthias (L.). ICES Journal of Marine Science, 30(2), 255–266. https://doi.org/10.1093/icesjms/30.2.255
Holden, M. J., & Horrod, R. G. (1979). The migrations of tope, Galeorhinus galeus (L), in the eastern North Atlantic as determined by tagging. ICES Journal of Marine Science, 38(3), 314–317. https://doi.org/10.1093/icesjms/38.3.314
Holden, M. J., & Tucker, R. N. (1974). The food of Raja clavata Linnaeus 1758, Raja montagui Fowler 1910, Raja naevus Muller and Henle 1841 and Raja brachyura Lafont 1873 in British waters. ICES Journal of Marine Science, 35(2), 189–193. https://doi.org/10.1093/icesjms/35.2.189
Hunter, E., Buckley, A. A., Stewart, C., & Metcalfe, J. D. (2005). Migratory behaviour of the thornback ray, Raja clavata, in the southern North Sea. Journal of the Marine Biological Association of the United Kingdom, 85(5), 1095–1105. https://doi.org/10.1017/S0025315405012142
ICES. (2024a). Report of the Working Group on Elasmobranch Fishes (WGEF) (p. 78550907 Bytes, 994) [PDF]. ICES Scientific Reports. https://doi.org/10.17895/ICES.PUB.26935504
ICES (2024b). Spurdog (Squalus acanthias) in Subareas 1-10, 12 and 14 (the Northeast Atlantic and adjacent waters). ICES Advice: Recurrent Advice. Report. https://doi.org/10.17895/ices.advice.25019237.v1
Jabado, R.W., Chartrain, E., De Bruyne, G., Derrick, D., Dia, M., Diop, M., Doherty, P., Leurs, G.H.L., Metcalfe, K., Pacoureau, N., Pires, J.D., Ratão, S., Seidu, I., Serena, F., Soares, A.-L., Tamo, A., VanderWright, W.J. & Williams, A.B. 2021. Dasyatis pastinaca. The IUCN Red List of Threatened Species 2021: e.T161453A124488102. https://dx.doi.org/10.2305/IUCN.UK.2021-2.RLTS.T161453A124488102.en. Accessed on 18 August 2025.
Kneebone, J., Sulikowski, J., Knotek, R., McElroy, W. D., Gervelis, B., Curtis, T., Jurek, J., & Mandelman, J. (2020). Using conventional and pop-up satellite transmitting tags to assess the horizontal movements and habitat use of thorny skate (Amblyraja radiata) in the Gulf of Maine. ICES Journal of Marine Science, 77(7–8), 2790–2803. https://doi.org/10.1093/icesjms/fsaa149
Kraft, S., Winkler, A. C., & Abecasis, D. (2023). Small coastal marine protected areas offer recurring, seasonal protection to the common stingray (Dasyatis pastinaca). Ocean & Coastal Management, 246, 106891. https://doi.org/10.1016/j.ocecoaman.2023.106891
Last, P., White, W., Carvalho, M., Séret, B., Stehmann, M., & Naylor, G. (2016). Rays of the World. CSIRO Publishing.
Lucifora, L., Menni, R., & Escalante, A. (2004). Reproductive biology of the school shark, Galeorhinus galeus, off Argentina: Support for a single south western Atlantic population with synchronized migratory movements. Environmental Biology of Fishes, 71(2), 199–209. https://doi.org/10.1007/s10641-004-0305-6
McCully Phillips, S. R., & Ellis, J. R. (2015). Reproductive characteristics and life-history relationships of starry smooth-hound Mustelus asterias in British waters. Journal of Fish Biology, 87(6), 1411–1433. https://doi.org/10.1111/jfb.12826
McMillan, M. N., Semmens, J. M., Huveneers, C., Sims, D. W., Stehfest, K. M., & Gillanders, B. M. (2021). Grow or go? Energetic constraints on shark pup dispersal from pupping areas. Conservation Physiology, 9(1), coab017
Nauta, J., Leurs, G., Nieuwenhuis, B. O., Mathijssen, D. R. A. H., Olff, H., Bouma, T. J., Van Der Wal, D., Hijner, N., Regalla, A., Pontes, S. L., & Govers, L. L. (2024). Bioturbation by Benthic Stingrays Alters the Biogeomorphology of Tidal Flats. Ecosystems. https://doi.org/10.1007/s10021-024-00901-4
Nosal, A. P., Cartamil, D. P., Ammann, A. J., Bellquist, L. F., Ben-Aderet, N. J., Blincow, K. M., Burns, E. S., Chapman, E. D., Freedman, R. M., Klimley, A. P., Logan, R. K., Lowe, C. G., Semmens, B. X., White, C. F., & Hastings, P. A. (2021). Triennial migration and philopatry in the critically endangered soupfin shark Galeorhinus galeus. Journal of Applied Ecology, 58(8), 1570–1582. https://doi.org/10.1111/1365-2664.13848
O'Shea, O. R., Thums, M., Van Keulen, M., & Meekan, M. (2012). Bioturbation by stingrays at Ningaloo Reef, Western Australia. Marine and Freshwater Research, 63(3), 189–197. https://doi.org/10.1071/MF11180
OSPAR Commission. (2021a). Status Assessment 2021—Spotted ray. https://oap.ospar.org/en/ospar-assessments/committee-assessments/biodiversity-committee/status-assesments/spotted-ray/
OSPAR Commission. (2021c). Status Assessment 2021—Common skate. https://oap.ospar.org/en/ospar-assessments/committee-assessments/biodiversity-committee/status-assesments/common-skate/
OSPAR Commission. (2021b). Status Assessment 2021—Thornback ray. https://oap.ospar.org/en/ospar-assessments/committee-assessments/biodiversity-committee/status-assesments/thornback-ray/

OSPAR Commission. (2021d). Status Assessment 2021—Spurdog. https://oap.ospar.org/en/ospar-assessments/committee-assessments/biodiversity-committee/status-assesments/spurdog/
OSPAR Commission. (2022). Recovery of Sensitive Fish Species—Common Indicator Assessment [OSPAR Quality Status Report 2023]. OSPAR. https://oap-cloudfront.ospar.org/media/filer_public/b8/e9/b8e92fce-1bc8-4fbf-96f9-7f2b5c2d58b4/p00851_recovery_sensitive_fish_fc1_qsr23.pdf
OSPAR Commission. (2022). Recovery of Sensitive Fish Species—Common Indicator Assessment [OSPAR Quality Status Report 2023]. OSPAR. https://oap-cloudfront.ospar.org/media/filer_public/b8/e9/b8e92fce-1bc8-4fbf-96f9-7f2b5c2d58b4/p00851_recovery_sensitive_fish_fc1_qsr23.pdf
Papastamatiou, Y. P., Meyer, C. G., Kosaki, R. K., Wallsgrove, N. J., & Popp, B. N. (2015). Movements and foraging of predators associated with mesophotic coral reefs and their potential for linking ecological habitats. Marine Ecology Progress Series, 521, 155–170. https://doi.org/10.3354/meps11110
Rodríguez-Cabello, C., Fernández, A., Olaso, I., & Sánchez, F. (2001). SURVIVAL OF LESSER SPOTTED DOGFISH (Scyliorhinus canicula, L.) DISCARDED BY TRAWLERS. ICES, ICES CM 2001/N: 06.
Schaber, M., Gastauer, S., Cisewski, B., Hielscher, N., Janke, M., Peña, M., Sakinan, S., & Thorburn, J. (2022). Extensive oceanic mesopelagic habitat use of a migratory continental shark species. Scientific Reports, 12(1), 2047. https://doi.org/10.1038/s41598-022-05989-z.
Schindler, D. E., Essington, T. E., Kitchell, J. F., Boggs, C., Hilborn, R. (2002). Sharks and tunas: fisheries impacts on predators with contrasting life histories. Ecological Applications 12(3): 735-748.
Stevens, J. D., Bonfil, R., Dulvy, N.K., Walker, P.A., (2000). The effects of fishing on sharks, rays, and chimaeras (chondrichthyans), and the implications for marine ecosystems. ICES J. Mar. Sci. 57(3): 476-494
Templeman, W. (1984). [Details not provided in text].
Thorburn, J., Neat, F., Burrett, I., Henry, L.-A., Bailey, D. M., Jones, C. S., & Noble, L. R. (2019). Ontogenetic Variation in Movements and Depth Use, and Evidence of Partial Migration in a Benthopelagic Elasmobranch. Frontiers in Ecology and Evolution, 7, 353. https://doi.org/10.3389/fevo.2019.00353
Walker, P. (1997). Distribution, movement and stock structure of three ray species in the North Sea and eastern English Channel. ICES Journal of Marine Science, 54(5), 797–808. https://doi.org/10.1006/jmsc.1997.0223

*Other additional source:*
Verveld, J. (2024). "Moving back in" Assessing habitat suitability and space use for re-introduced Thornback Ray in the Western Scheld and Belgian Exculsive Economic Zone. GIMA, Final thesis Report. Template for the GIMA MSc

## 8.3 Pelagic fish

For pelagic fish a background document for a species protection plan is being prepared (Tamis et al. 2026). The report served as a basis for the preparation of this document.

### 8.3.1 Description of the ecosystem component

Forage fish, also called prey fish, are small pelagic fish that are mainly planktivorous, and form the lower tropic level fish in the food chain. They are preyed upon by other fish, marine mammals and birds and therefore considered key species of the food web. They have a relatively small maximum size and form large schools in the water column. In the Dutch (coastal) water they make up the largest part of the fish biomass (Couperus et al. 2016).

### 8.3.2 Species selection / Focus species

The focus species are lesser sandeel (*Ammodytes tobianus*), Raitt's sandeel (*Ammodytes marinus*), sprat (*Sprattus sprattus*), herring (*Clupea harengus*), European anchovy (*Engraulis encrasicolus*), and European smelt (*Osmerus eperlanus*).

#### 8.3.2.1 Rationale for selection

These species are selected as they form the major food source of fish-eating birds, but also of marine mammals. Besides that, European anchovy and European smelt are considered as indicators of estuarine quality. European smelt is on the Dutch Red List as "gevoelig" = vulnerable.

### 8.3.3 Habitat preferences

The forage fish are predominantly pelagic species that occur often as large schools in the water column. Despite that their preferred habitat is the marine water column, all the focus species require other habitat types throughout their life cycle.

Both sandeel species are buried for long periods of time as part of their daily behaviour as well for overwintering in the sandy seafloor. This requires well-oxygenated medium to coarse sands with medium grain sizes. Sediments with gravel, high silt and fine sand are avoided. Both species lay demersal eggs within the adult aggregations; the larvae are pelagic and as such disperse to other areas where they settle in adult aggregations. The impression is that adults have limited migration. Their spawning season differ in time with Raitt's spawning in Dec-Jan, while Lesser sandeel spawning in Feb-April and Sept-Nov.

Herring typically use gravel beds (Frost and Diele, 2022), mainly occurring along the UK coast into the Channel, to lay their eggs (Frost and Diele, 2022; *Figure 8-1*). Some herring population also use kelp, mearl, shells and even harbour walls to lay their eggs. Contrary to herring, sprat is an indeterminate multiple-batch spawner whose eggs are released in the water column. The larvae are known to be most abundant in the vicinity of tidal mixing fronts. Sprat is characterised by a tolerance to a wide range of salinities and is also abundant in estuarine habitats (ICES, 2005). Anchovy and smelt require freshwater runoff and migrate into the estuarine areas and even upriver to spawn, as smelt is an anadromous species which depends on fresh water for spawning.

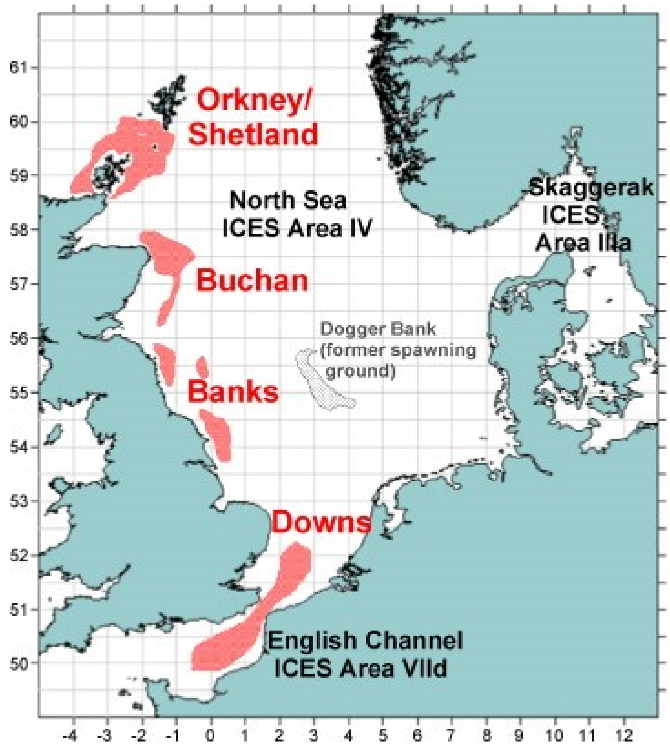


***Figure 8-1*** *Spawning grounds of North Sea herring. Major spawning components are indicated (Nash et al, 2009).*

### 8.3.4 Ecosystem function

The sandeel species are principal prey of many of the most abundant seabird species and several marine mammals feed intensively on sandeels during spring and summers. Both sandeel species occur in the open North Sea, the coastal waters, Wadden Sea and estuaries. They overlap in geographic distribution, the lesser sandeel tends to be closer to shore in shallow waters, while the Raitt's sandeel is found in more offshore waters.

The pelagic clupeid species sprat and herring (and pilchard (*Sardina pilchardus*)) occur in large schools in Dutch waters, being an important food source for higher trophic levels.

For herring mainly juveniles occur in the Dutch shallow coastal waters. The adults of the main populations in Dutch waters, North Sea autumn-spawning and the Downs herring, migrate to feed in the Norwegian Sea and return in summer along the UK coast and into the Channel. On multiple spawning grounds and in distinct spawning periods the different herring populations lay their demersal eggs typically on gravel beds (*Figure 8-1*) The pelagic larvae drift to the Dutch waters including the estuaries, the Wadden Sea, and the German Bight, where the juveniles form schools in their first years. Most of these juveniles come from the Downs spawning component in the Channel. However, recent studies in the Wadden Sea indicate mix spawning origins potentially including a coastal herring component potentially spawning in the (Dutch) Wadden Sea (Maathuis et al. 2024a, b).

For sprat the whole life cycle occurs in Dutch waters. In the coastal waters it is the most dominant pelagic species. A large part of the North Sea sprat population occurs in Dutch waters (Figure 8-2). The spawning of sprat most likely occurs offshore in the Channel, Southern Bight and German Bight. Eggs and larvae drift in Dutch waters in winter till early summer.

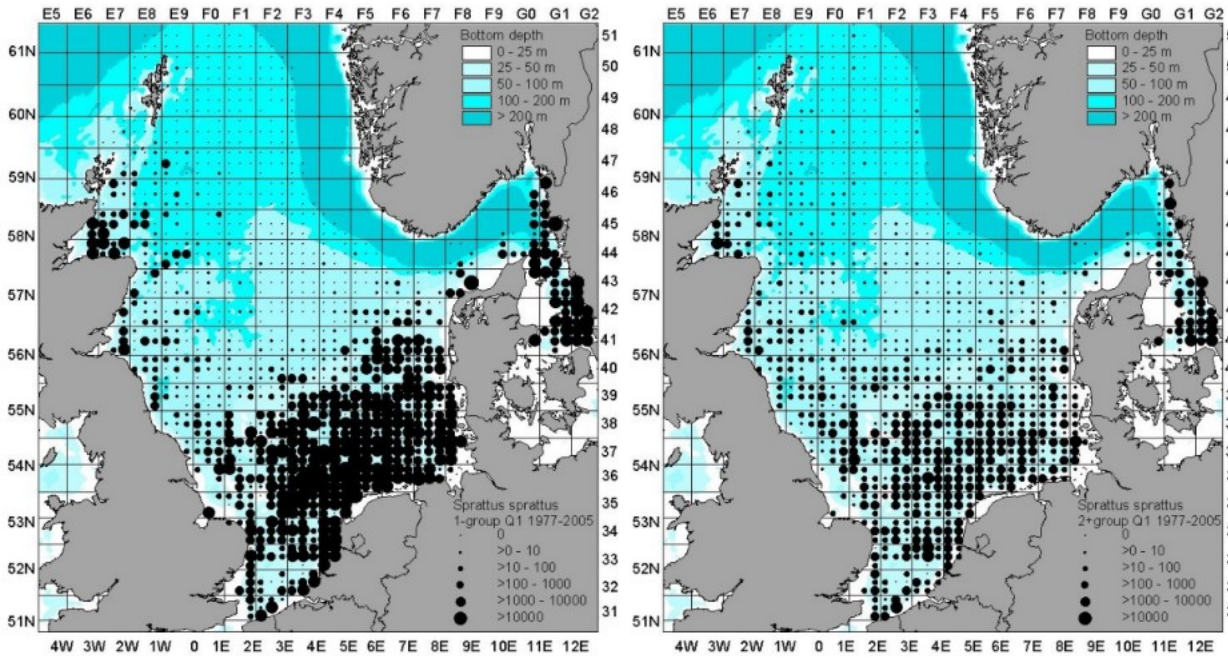


***Figure 8-2*** *Average annual catch rate (number per hour fishing) for 1-group and 2+ group sprat in the quarter 1 IBTS, 1977-2005 (ICES, 2005).*

European anchovy occurs in much lower abundances in the Dutch waters than the previously described species, with a main occurrence in the summer period. However, in some years substantial occurrences in winter are observed. It is expected that anchovy in the North Sea will benefit off increasing water temperatures due to climate change as much larger populations occur in southern waters and an increase in anchovy was observed since the 1990s (Alheit et al. 2012). However, genetic analyses indicate that North Sea and Channel fish are a distinct population from the one in the Bay of Biscay (Maathuis et al. 2024b). Anchovy, like sprat an indeterminate multiple-batch spawner that spawns pelagic eggs in the Scheldt and the Wadden Sea. Before the construction of the Afsluitdijk, large spawning aggregations occurred in the Zuiderzee. As it uses the estuarine waters for spawning it is considered an indicator for estuarine quality.

The smelt has two different life history strategies. One strategy depends fully on fresh water, occurring in the IJsselmeer, Markermeer, and other Dutch freshwater lakes. The other strategy migrates between salt and fresh water, occurring in the Wadden Sea, the North Sea coastal waters, and river estuary. The smelts occurring in the Wadden Sea likely depend mostly on spawning upstream the river Ems, as there is limited contribution of these migrating smelts to the Ijsselmeer population due to limited exchange possibilities. The smelt is a determinate single-batch spawner, like herring, depositing eggs on suitable substrates, like gravel, stones but also water plants. Silt concentrations can smother the eggs.

### 8.3.5 Status and trend ecosystem component

Forage fish are in high abundance presence in the Dutch waters (See IBTS, MONS Pel). The status and trend vary between the species.

The sandeel species, specifically Raitt's sandeel, are assessed by ICES as they are a target species of industrial fisheries. The ICES advice of early 2025, for sand eel in the central and southern North Sea, Dogger Bank, indicates low fishing pressure and a spawning stock biomass above the MSY biomass levels, without a clear trend in biomass. Specifically, focussing on the Dutch waters there is limited information on the sandeel status or trend. The regular monitoring programs all struggle to collect sensible data on these species and targeted activities have occurred too little to be able to determine trends.

For herring and sprat also, assessments are performed by ICES and some monitoring programs collect data on the populations in the Dutch waters. Herring status is however mainly defined by the adult population occurring outside the Dutch waters. The herring spawning stock is above the Biomass target limits of the assessments (ICES, 2024), the latest years recruitment is relatively low. This is observed in the Dutch waters by small catches of juvenile herring in the monitoring programs. The sprat adult biomass was assessed below the target levels (ICES, 2024), while recruitment of sprat was reasonable in latest years.

Anchovy in the North Sea is not assessed and the expectations in relation to climate change are considered prosperous. However, the only Dutch fishery targeting anchovy occurring in the Eastern Scheldt saw a reduction and even a complete absence of anchovy in recent years and also in the Wadden Sea abundances were not flourishing as might be expected with the increasing water temperatures. In the coastal and offshore water there is no clear trend in the surveys.

The smelt population in IJsselmeer fluctuates highly since 2013 without a clear trend (de Leeuw & Volwater 2023). The trend of smelt in the Wadden Sea indicates a reduction since 2007, except for the Ems-Dollard where numbers seem constant. The numbers in the Weser and Elbe are higher, but in the Elbe strongly decreased in recent years (Tulp et al. 2022, 2024).

### 8.3.6 Pressures and impacts

There is targeted fishing on most of these species in and outside Dutch marine waters influencing the populations. Especially for herring but also sprat, sandeel and smelt the assessment targets and the related quota for the fisheries are trying to neutralize positive and negative trends by allowing more or less fishing. For smelt and anchovy access to and potentially quality of the estuarine areas are likely limiting factors. Other pressures and impacts that were mentioned in Tamis et al. (2026) are:

- Habitat degradation from bottom trawling, sand extraction and coastal infrastructure further reduces spawning and nursery areas.
- Climate change is the dominant long-term threat, driving warming, shifts in plankton and fish distributions, and reduced productivity of small pelagic fish, with cascading effects through the food web.
- Pollution and underwater noise add chronic pressure through bioaccumulation, behavioural disturbance and stress, although population-level effects are often uncertain.

Overall, multiple pressures act simultaneously and are likely to reinforce each other.

### 8.3.7 Current policy

Industrial fishing on sandeel occurs in central and northern North Sea, mainly outside the Dutch waters but also some activity occurs west of Den Helder. Sandeel catches are used mainly for aquaculture and are regulated based on stock assessment targets under the Common Fisheries Policy (CFP). The same applies to herring, sprat and smelt. Smelt fisheries in lake IJssel (IJsselmeer) have been prohibited based on the low biomass for some years; a court case end 2023 prohibited smelt fisheries in the Wadden Sea as well. However, some exemptions seem to be given for fisheries in the flushing basins of the Afsluitdijk. Smelt is on the Dutch Red List and classified as vulnerable.

**Marine Strategy Framework Directive (MSFD) – Good Environmental Status (GES)**
**Objective**: Fish is part of D1 Biodiversity and D3 commercial-fished species.

- D1C1: incidental bycatch: The mortality rate per species from incidental bycatch is below levels which threaten the species, such that its long-term viability is ensured. No specific GES has been adopted yet.
- D1C2: Population abundance: The population density of the species is not adversely affected due to anthropogenic pressures, such that its long-term viability is ensured. The GES is linked to D3 commercial species (see below). Furthermore, GES states rise in the proportion of vulnerable species of fish.
- D1C3: Demographic characteristics: size structure of fish community: The population demographic characteristics (e.g., body size or age class structure, sex ratio, fecundity, and survival rates) of the species are indicative of a healthy population which is not adversely affected due to anthropogenic pressures. The GES is an increase in the proportion of large fish in the fish community (using the Large Fish Indicator (LFI)). The selected pelagic fish are not part of this indicator as it is based on the data of the demersal fish surveys.

- D3C1 + D3C2: Fishing mortality rate and spawning stock biomass of commercially exploited species: the fishing mortality (F) rate of populations of commercially exploited species is at or below levels which can produce the maximum sustainable yield (MSY) and the spawning stock biomass (SSB) of populations of commercially-exploited species are above biomass levels capable of producing maximum sustainable yield (MSY). F and SSB are the results of the stock assessments performed under the Common Fisheries Policy, only available for the commercial species, e.g. herring, sprat and some sandeel stocks.

European Union (EU) Regulations on bycatch via incentives or obligatory technical measures (No 850/98) to reduce bycatch, are in place that should protect amongst other the selected pelagic species.

8.3.7.1 Policy measures
The concrete policy target for the commercial pelagic species is to maintain the commercial stocks within the reference levels set by the Common fisheries policy, which overlaps with the MSFD targets, so the stock can produce the maximum sustainable yield.

There is no specific GES target set for MSFD D1C1, nevertheless bycatch reduction is an overall policy target.

Additional possible policy measures, not within the remit of NN, include improvement of water quality to improve habitats, reduction of bottom fisheries to protect sandeel habitats, protection of spawning grounds (e.g. gravel beds for herring), and removal of migration barriers (Tamis et al. 2026).

### 8.3.8 Advice and possible measures

*Rationale*
Forage fish, also called prey fish, are small pelagic fish that are mainly planktivorous, and form the lower tropic level fish in the food chain, such as sandeels, sprat, herring, European anchovy, and European smelt. They are preyed upon by other fish, marine mammals and birds and therefore considered key species of the food web. They form large schools in the water column and make up the largest part of the fish biomass in the Dutch Coastal zone. In general, the species stocks are sustainably managed: the related quota for the fisheries are trying to neutralize positive and negative trends by allowing more or less fishing. Accessibility and quality of the estuarine areas is important for smelt and anchovy.

*NN Action perspective*

NN could focus on (sub)populations of the selected pelagic fish species that once inhabited the Dutch North Sea but that have disappeared or are in need of restoration. For example, herring in general in the North Sea is not threatened, but the remnant Zuiderzee herring, uncertain if it still exists, may need restoration. For this, the knowledge base on the requirements for spawning and optimal nursery quality for the different species and populations needs to be improved (RRL 1-3). When the knowledge base is sufficient, then NN can target specific species and areas and help actively restore relevant spawning and nursery habitats (RRL 4-5/6-7). Active habitat restoration may consist of adding substrate (gravel, sand, reefs, wood) to the seafloor. This may be done within protected areas, offshore windfarms and, sand/gravel extraction sites etc., but also in combination with other restoration efforts, such as restoration of biogenic reefs.

*Demonstration of impact*
To demonstrate the actual contribution of NN activities to the forage fish populations, a monitoring program is needed. It is important that objectives for NN are defined at the level of habitat restoration and improvement, for example, the number of hectares of habitats or spawning grounds restored or enhanced—combined with monitoring to assess how successfully these habitats are used by the target species. This approach allows NN to demonstrate tangible ecological progress while contributing to the long-term recovery of forage fish populations.

### 8.3.9 References


Alheit, J., Pohlmann, T., Casini, M., Greve, W., Hinrichs, R., Mathis, M., O'Driscoll, K., Vorberg, R., Wagner, C., (2012). Climate variability drives anchovies and sardines into the North and Baltic Seas. Prog. Oceanogr. https://doi.org/10.1016/j. pocean.2011.11.015.

Couperus, B. et al. (2016) Abundance and tidal behaviour of pelagic fish in the gateway to the Wadden Sea. J. Sea Res. 109 : 42-51.

de Leeuw, J.J., & Volwater, J.J.J. (2023). Spieringstand IJsselmeer en Markermeer 2023. (CVO rapport; No. 23.026). Centrum voor Visserijonderzoek (CVO). https://doi.org/10.18174/644255

Frost, M., Diele, K. (2022). Essential spawning grounds of Scottish herring: current knowledge and future challenges. Rev Fish Biol Fisheries 32, 721–744. https://doi.org/10.1007/s11160-022-09703-0

ICES (2005). ICES (2005). ICES-FishMap. Accessed January 2026 at: https://www.ices.dk/about-ICES/projects/EU-RFP/Pages/ICES-FIshMap.aspx

ICES (2024). Greater North Sea Ecoregion - Fisheries Overview. ICES Advice: Fisheries Overviews. Report. https://doi.org/10.17895/ices.advice.27879879.v2

Maathuis, M.A.M., Couperus, B., van der Molen, J., Poos, J., Tulp, I., Sakinan, S., (2024a). Resolving the variability in habitat use by juvenile small pelagic fish in a major tidal system by continuous echosounder measurements. Mar. Ecol. Prog. Ser. 741, 169–187. https://doi.org/10.3354/meps14368.

Maathuis, M.A.M., Berg, F., Couperus, B. Poos. J.J. and Tulp, I. (2025). The function of the Wadden Sea in the life cycle of small pelagic fish. Estuarine, Coastal and Shelf Science 313: 109043. https://doi.org/10.1016/j.ecss.2024.109043

Maathuis, M.A., Tulp, I., Valk, S., van den Brink, X., Couperus, A.S., Keur, M.C., Nijland, R., Sakinan, S., Van der Horst, V. and J.J. Poos. (2024b). Small pelagic fish in the shallow Wadden Sea show opportunistic feeding with a strong benthic link. ICES J. Mar. Sci., 81(8), 1521-1535.

Nash, R.D.M., M. Dickey-Collas, and L.T. Kell (2009). Stock and recruitment in North Sea herring (*Clupea harengus*); compensation and depensation in the population dynamics. Fish. Res. 95.1: 88-97.

Tamis, J.E., R. van Hal & R.H. Jongbloed (2026). Pelagic fish in the Dutch North Sea. Background document for a protection plan. Wageningen Marine Research report C005/26. https://doi.org/10.18174/708208

Tulp, I., Chen, C., & Vrooman, J. (2022). The nursery function of the Ems estuary for fish. (Wageningen Marine Research report C092/22. https://doi.org/10.18174/583972

Tulp, I., Griffioen, B., Winter, E., Couperus, B., van der Knaap, I., Huisman, J., Eriksson, K., Mathijssen, D., & Jager, Z. (2024). Het functioneren van het Eems estuarium voor vis: literatuurstudie en meerjarig onderzoeksplan. Wageningen Marine Research rapport C029/24. https://doi.org/10.18174/658456

# 8.4 Demersal fish

For demersal fish a background document for a species protection plan is being prepared (Tulp et al. 2026). The report served as a basis for the preparation of this document/section.

### 8.4.1 Description of the ecosystem component

Demersal fish live and feed near or on the seafloor. The group is divided in benthic and benthopelagic species. The first without or with reduced swim bladder have negative buoyancy so they can be on the bottom without effort, while the benthopelagic fish with swim bladder have neutral buoyancy allowing them the float near the bottom without spending much energy. The benthic species often bury themselves in the seabed preferring specific sediments.

### 8.4.2 Species selection / Focus species

The focus demersal species are the same species as selected for the species background documents: Cod (*Gadus Morhua*), Whiting (*Merlangus merlangus*) and Tadpole fish (*Raniceps raninus*), and the benthic species Lemon sole (*Microstomus kitt*), Greater weever (*Trachinus draco*), and Lesser weever (*Echiichthys vipera*).

#### 8.4.2.1 Rationale for selection

As argued in Tulp et al. (2026) the selected species are included because they are of conservation concern and/or play an important ecological role in the Dutch North Sea. Several species are listed on the Dutch Red List (from Near Threatened to Critically Endangered) Cod is also listed by OSPAR and was also selected based on the nature enhancement species argument (ecofriendly design OWP). In addition, some species were selected based on their sensitivity to other threats than offshore wind development, i.e. bycatch (tadpole fish, greater weever, lesser weever), water quality (tadpole) and sand nourishment (lesser weever). Many are affected by bycatch in demersal or pelagic fisheries and are therefore relevant for nature restoration and management measures.

### 8.4.3 Habitat preferences

As demersal species these fish species all have some connection with the seafloor, which is largely determined by sediment type and grain size.

Cod in the North Sea may be found from shallow coastal waters to the shelf edge (200 m depth) and even beyond. They are often found on wrecks, and near hard structures also artificial structures like the scour protection of wind turbines (van Hal et al. 2017). Whiting inhabits area ranging from shallow inshore water (<10 m depth) to depths of 550 m, primarily it inhabits continental shelf waters at depths of 30–200m, favouring sandy or muddy seabeds, but also on sand and rock. Eggs are produced in batches and are pelagic. The tadpole fish can be found especially in inshore waters where they hide between rocks and seaweeds often just below the tide mark. They lay demersal eggs that adhere to the seabed. The larvae develop near the bottom before settling into deeper habitats as juveniles. They were also found on the scour protection rocks in Belgian wind farms (Kerckhof et al. 2018). In the northern part of their distribution range, the tadpole fish mainly occur in coastal waters at a preferred depth between 10 and 20 m, while in the south (Bay of Biscay) they occur mainly in deeper water in areas of sand and mud. The burying species, both weevers prefer sandy and muddy areas. The lemon sole inhabits continental shelf waters at depths of 20–200 m, preferring sandy, muddy, or gravelly seabeds.

### 8.4.4 Ecosystem function

Cod is almost at the top of the food chain and therefore plays an important role in the ecosystem, although cod stocks in the Northwest Atlantic collapsed in the 1990 and have yet to recover. Its food consists in the juvenile stage largely on crustaceans and for older individuals for a large part of other commercial fish species, including its own kind. Depending on its life stage, predators of cod, apart from man, will be other fish-eating species.

Whiting occurs throughout the whole southern North Sea, the Wadden Sea and the Scheldt estuaries and is in most recent years one of the most dominant fish species in the Dutch marine waters. In most recent IBTS survey done by the Netherlands (van Hal and Volwater, 2025) whiting was caught in all hauls from the southern Scottish waters to the German Bight up to the Belgium waters. Owing to their wide distribution and high abundance they play a key role in the current food web both as prey for larger fish, birds and marine mammals and predators as they feed on shrimps, crabs, molluscs, small fish, polychaetes and cephalopods. In contrast, the tadpole fish is elusive with their solitary and sedentary behaviour they likely only have limited and very local impact on the ecosystem. They live solitarily and rather secretive. In Dutch waters, the tadpole fish is rarely observed mainly in the Scheldt and Grevelingen.

Lesser weavers occur in specifically clean sandy habitat where they can be caught in considerable amounts. An area where they occur(ed) in high abundance is the Brown Ridge. Here, their predatory pressure, mainly on small fish like gobies, can be high (Creutzberg & Witte, 1989).

Greater weevers only occur in low numbers in the North Sea. Prior to the cold winter of 1963 the abundances were higher, and they were even caught by rod fishing from the dyke of the Marsdiep. Due to their current low abundance their ecosystem impact is expected to be limited. They are not expected to be a preferred prey, owing to their venomous glands. Great weevers prey on crustaceans and fish. They still occur in higher abundances on the muddy and fine sands of the Kattegat, where they are buried in the sand during the day. Despite having pelagic eggs and larvae, they seem to form resident stocks with limited mixing. This might explain the lack of recolonization in the southern North Sea (Heessen et al. 2015).

Lemon sole is an opportunistic feeder and primarily consumes small invertebrates and polychaete worms. As lemon sole is not a common species, its role in the foodweb is likely limited. Based on catch data, they are widespread across the North Sea but are only infrequently caught off the Dutch coast. The highest catch rates occur on the inner shelf, mainly at depths of 50–125 m.

### 8.4.5 Status and trend ecosystem component

The latest available assessment of cod dates from 2024. The biomass of the Southern cod substock, occurring in Dutch waters remains well below reference points, Despite reduced fishing pressure. As recruitment has been very low since the mid-1990s, near-term recovery potential is limited. The ICES advice of 2024 of whiting in the North Sea indicated the highest spawning stock biomass and the lowest fishing pressure in the last 40 years, with an increasing trend in recent years. The ICES advice of 2024 of lemon sole (category 3 species, meaning not a fully analytical assessment can be performed due to limited data availability) indicates a decreasing trend in stock size, which recently fell below the biomass trigger reference point ($I_{trigger}$).

There are no stock assessments for the weevers or the tadpole fish. The greater weaver is rare, since its significant decrease in 1963 without a clear trend. Also, the tadpole fish is rare with limited data and no indication of a trend. The lesser weever is more abundant and showed over the period 1990-2022 a strong declining trend based on fish survey data (https://www.clo.nl/indicatoren/nl159602-fauna-in-de-kustzone-1990-2022).

At the international level, OSPAR assessed the status of marine fish in the Greater North Sea for 2015–2020 (**Table 8.7**). Of the species covered in this plan, only cod failed to meet the OSPAR threshold for good status and has long been listed as threatened or declining, with stocks still under pressure. Whiting and lemon sole met OSPAR biomass thresholds, while the other species were not assessed. According to the IUCN Red List, most species are classified as Least Concern, although cod was previously listed globally as Vulnerable and many assessments are outdated as it has been more than 10 years since the latest assessments.

***Table 8.7*** *International population status, according to the OSPAR population status of marine fish (OSPAR QSR 2023): NA: Not Available; Failed: population under the threshold; Achieved: population above the threshold; and the IUCN Status (https://www.iucnredlist.org/) CR: Critically Endangered; EN: Endangered; VU: Vulnerable; NT: Near Threatened; LC: Least Concer*n (copied from Tulp et al, 2026).

| | **OSPAR population status of marine fish** | | **IUCN Red List** | | |
|---|---|---|---|---|---|
| **Species name** | **Threshold** | **Assessment period** | **Status** | **Scope of assessment** | **Year of assessment** |
| Cod | Falied | 2015-2020 | VU | Global | 1996 |
| | | | LC | Europe | 2013 |
| Whiting | Achieved | 2015-2020 | LC | Global & Europe | 2013 |
| Tadpole fish | NA | - | LC | Global & Europe | 2014 |
| Lemon sole | Achieved | 2015-2020 | LC | Global | 2021 |
| | | | | Europe | 2014 |
| Greater weever | NA | - | LC | Global | 2014 |
| | | | | Europe | 2014 |
| Lesser weever | NA | - | LC | Europe | 2014 |

### 8.4.6 Pressures and impacts

Fisheries are the main pressure for the selected species particularly for the targeted commercial species. Cod, whiting, and lemon sole are directly targeted, while all focal species are affected by fisheries as bycatch, potentially altering population structures. Recreational fishing also contributes to cod removals. Other effects are caused particularly by bottom trawling, which damages seabed habitats. Other pressures mentioned in Tulp et al (2026):

- Climate change further pressures populations through warming, shifts in prey and predator distributions, and increased susceptibility to parasites, limiting natural recovery, especially for cod.
- Pollution from chemicals like PCBs, mercury, and PFAS remains a significant chronic threat, affecting growth, reproduction, and survival.
- Underwater noise from shipping, construction, and wind farms can disrupt behaviour, physiology, and larval dispersal, with cod particularly sensitive.
- Habitat degradation from coastal development, sand extraction, and offshore wind farms modifies shallow nursery areas, though some wind farm structures may provide shelter and enhance local cod and plaice abundance.

Overall, fishing, habitat loss, climate change, pollution, and noise interact as cumulative pressures on demersal fish populations.

### 8.4.7 Current policy

Management of demersal fish in the North Sea relies mainly on Total Allowable Catches (TACs), EU multiannual management plans, and spatial conservation measures (Tulp et al. 2026). TACs are set annually for cod, whiting and lemon sole and allocated as national quotas. The EU demersal management plan allows additional measures such as gear restrictions, seasonal or area closures and minimum sizes, while Real Time Closures can temporarily close areas when high numbers of juvenile fish are caught.

Area-based conservation is implemented through Natura 2000 sites and other marine protected areas, with increasing closures to bottom-disturbing fisheries under the North Sea Agreement, although current coverage still falls short of agreed targets. Among the fish species in the North Sea cod has the most extensive species-specific measures, including recovery plans, OSPAR protection and national avoidance and monitoring schemes. Whiting and lemon sole are mainly managed through TACs, while no specific measures exist for tadpole fish and weever species. **Marine Strategy Framework Directive (MSFD) – Good Environmental Status (GES)**
**Objective**: Fish is part of D1 Biodiversity and D3 commercial-fished species.

- D1C1: incidental bycatch: The mortality rate per species from incidental bycatch is below levels which threaten the species, such that its long-term viability is ensured. No specific GES has been adopted yet.
- D1C2: Population abundance: The population density of the species is not adversely affected due to anthropogenic pressures, such that its long-term viability is ensured. The GES is linked to D3 commercial species (see below). Furthermore, GES states rise in the proportion of vulnerable species of fish.
- D1C3: Demographic characteristics: size structure of fish community: The population demographic characteristics (e.g., body size or age class structure, sex ratio, fecundity, and survival rates) of the species are indicative of a healthy population which is not adversely affected due to anthropogenic pressures. The GES is an increase in the proportion of large fish in the fish community (using the Large Fish Indicator (LFI)).
- D3C1 + D3C2: Fishing mortality rate and spawning stock biomass of commercially exploited species: the fishing mortality (F) rate of populations of commercially exploited species is at or below levels which can produce the maximum sustainable yield (MSY) and the spawning stock biomass (SSB) of populations of commercially exploited species are above biomass levels capable of producing maximum sustainable yield (MSY). F and SSB are the results of the stock assessments performed under the Common Fisheries Policy, only available for the commercial species, e.g. whiting and lemon sole.

#### 8.4.7.1 Policy measures

The most impactful policy measure to support these populations, identified by Tulp et al. (2026) (either directly or through positive effects on size-structure) is the reduction or stop of bottom disturbing activities in wider regions. This would create conditions that allow for the natural restoration and recovery of species that are currently inhabiting heavily disturbed sediments. However, the extent to which these benthic fish communities will actually benefit, remains uncertain.

### 8.4.8 Advice and action perspectives / possible measures

*Rationale*

Demersal fish form a diverse group with distinct features and ecological characteristics and as a result, their responses to conservation efforts may vary considerably between species (Tulp et al. 2026). For the same reason identifying restoration measures for this group is very species dependent. Whiting is currently doing extremely well, requiring no measures for status improvement.

*NN Action perspective*

For cod and tadpole fish and other demersal fish species that are known to be associated with geogenic and biogenic reefs, maintaining or extending hard substrate could be beneficial (RRL4-5/6-7). Demersal fish species in general could benefit from reef restoration measures (see sections 3.2 and 7.1). Also offshore wind farms closed to fisheries can function similarly to marine protected areas, Cod is attracted to scour protection and monopiles and will likely benefit from the new feeding habitat, although population-level effects remain uncertain (RRL4-5, population effects RRL 1-3). For most focal species, the importance of spawning and nursery habitats is poorly understood, meaning no specific habitat enhancement measures can yet be recommended (RRL 1-3). Nature-based coastal protection, which allows space for natural sediment dynamics, can both strengthen coastal defense and enhance biodiverse tidal habitats in the Wadden Sea and Dutch delta, offering potential nursery benefits for fish, supported by opportunities under the Nature Restoration Law.

*Demonstration of impact*

To demonstrate the actual contribution of NN activities to demersal fish populations, a dedicated monitoring programme is needed. Objectives for NN should be defined at the level of habitat restoration and improvement, for example in terms of the area of habitats or spawning grounds restored or enhanced, combined with monitoring to assess how effectively these habitats are used by the target species. In addition, more insight is needed into how these measures translate to population-level effects. This approach allows NN to demonstrate tangible ecological progress while improving understanding of long-term population responses.

### 8.4.9 References


Creutzberg, F., and J. IJ Witte. (1989) An attempt to estimate the predatory pressure exerted by the lesser weever, Trachinus vipera Cuvier, in the southern North Sea." J fish biol 34.3: 429-449.

Heessen, H.J.L., Daan, N., & Ellis, J.R. (2015). Fish atlas of the Celtic Sea, North Sea, and Baltic Sea. Wageningen Academic Publishers.

Kerckhof, F., B. Rumes, and S. Degraer (2018). A closer look at the fish fauna of artificial hard substrata of offshore renewables in Belgian waters." Environmental Impacts of Offshore Wind Farms in the Belgian Part of the North Sea: Assessing and Managing Effect Spheres of Influence. Ed. by S. Degraer, R. Brabant, B. Rumes, and L. Vigin. Royal Belgian Institute of Natural Sciences, Brussels.

Tulp, I.Y.M., R. van Hal, J.E. Tamis & R.H. Jongbloed (2026). Demersal fish in the Dutch North Sea. Background document for a protection plan. Wageningen Marine Research report C006/26. https://doi.org/10.18174/708265

van Hal, R., A. B. Griffioen, and O. A. van Keeken. 2017. Changes in fish communities on a small spatial scale, an effect of increased habitat complexity by an offshore wind farm. Marine Environmental Research 126:26-36.

Van Hal, R., & Volwater, J.J.J. (2025). *Reisverslag IBTS-Q1 2025*. (CVO rapport; No. CVO rapport 25.011). Centrum voor Visserijonderzoek (CVO).

# 9 Birds

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*Summarized from the four background documents of the species protection plans for seabirds (*Bos *et al.* (2023), Jongbloed *et al.* (2023), Leopold et al. (2025) and migratory birds (Jongbloed et al. 2025).

## 9.1 Seabirds

*Summarized from three background documents for species protection plans for seabirds (Bos et al. 2023; Jongbloed et al. 2023; Leopold et al. 2025).*

### 9.1.1 Description of ecosystem component

Seabirds spend most of their time at sea, foraging plankton, arthropods, shellfish, fish, as well as carrion and discards. Some species also predate on other birds. Seabirds are highly mobile and use the North Sea as a feeding and resting area throughout the year. Some species can stay for long times at sea, other travel every day to land to sleep. During the breeding season, coastal habitats are used for nesting. This is the period, when movements become most restricted and foraging is limited to the flight range around the breeding colony, with some species flying a couple of hundred kilometre per day.

### 9.1.2 Species selection / Focus species

The selection of relevant seabird species is based on the recently developed species protection plans. For seabirds, three background documents for the protection plans have been developed:

1. Surface-feeding birds of the coastal waters in the Dutch North Sea (Jongbloed et al. 2023): Great black-backed gull (*Larus marinus*), Herring gull (*Larus argentatus*);
2. Offshore birds in the Dutch North Sea (Bos et al. 2023): Northern gannet (*Morus bassanus*), Black-legged kittiwake (*Rissa tridactyla*);
3. Other seabirds (Leopold et al. 2025): Lesser black-backed gull (*Larus fuscus*), Sandwich tern (*Thalasseus sandvicensis*), Common tern (*Sterna hirundo*), Great skua (*Stercorarius skua*), Arctic skua/ Parasitic jaeger (*Stercorarius parasiticus*), Common Guillemot (*Uria aalge*), Razorbill (*Alca torda*), Atlantic puffin (*Fratercula arctica*), Red-throated diver (*Gavia stellata*), Northern fulmar (*Fulmarus glacialis*), Common scoter (*Melanitta nigra nigra*) and the Common gull (*Larus canus*).

*Rationale for selection*
The selected species are considered vulnerable to offshore wind development and/or in need of protection in general, as agreed upon in international frameworks (HD, BD, OSPAR, Red Lists, etc.). Great black-backed gull, herring gull, northern gannet and black-legged kittiwake are considered priority species, as they are most vulnerable to offshore wind development in the Netherlands. The group described in the background document 'other seabirds' includes seabirds that are also considered vulnerable to offshore wind farms within the KEC 4.0 but are not indicated as priority species (Leopold et al. 2025). The common scoter and common gull are considered relevant because their populations are currently in an unfavourable status according to the report under the BD, and the Netherlands has pledged, in line with the EU Biodiversity Strategy 2030, that their status should improve or at least not deteriorate (Schmidt et al. 2023).

### 9.1.3 Habitat preferences

Seabirds in the Dutch North Sea occupy a wide range of habitats throughout their annual cycle. Outside the breeding season, seabirds spend most of their time at sea. Depending on prey and hunting style, some species remain offshore while others stay closer to the coast. Some seabirds also inhabit inland areas and for example forage inland, on landfills (large gulls) or in agricultural lands (common gull, black-backed gull).

During the breeding season, seabirds usually become more land-bound, nesting along the coast, on islands (natural as well as artificial), and sometimes inland. Nesting seabirds can be found in various habitats: dunes, cliffs, or human-made constructions. Gulls and terns breed in the Netherlands, although for common gull the Netherlands is situated near the southern limit of the distribution range (Leopold et al. 2025). The other species breed outside the Netherlands (**Table 9.1**). Additional information on distribution of species that are breeding in the Netherlands is provided in the three background documents for species protection plans for seabirds.

The **great black-backed gull** are seabirds with a wide distribution range. They occur at sea far from the coast as well as in coastal waters and on land. The species inhabits rocky or sandy coasts, estuaries and inshore and offshore waters (BirdLife International 2024) but are mostly recorded near the shores of the northern Atlantic Ocean breeding on the rocky coasts (Bos et al. 2023). The North Sea is particularly important as a migration area and wintering area (Skov et al. 1995). Northern breeders migrate south in winter to the Iberian Peninsula, while southern breeders remain resident (Cramp & Simmons 1983, Good 2020). In the Netherlands the great black-backed gulls breed in hard to access areas such as artificial islands, dams and salt marshes.

The **European herring gull** inhabits coastal and near-coastal areas but may also forage inland on large lakes and reservoirs, fields and refuse dumps (del Hoyo *et al.* 1996). Two subspecies are differentiated in Europe: breeding in Scandinavia and NW Russia and breeding in Western Europe (including The Netherlands) and Iceland. In the Netherlands, outside the breeding season, herring gulls can be found throughout the country, but they are particularly abundant in a wide strip along the coasts. Herring gulls nest on the ground in (often large) colonies in coastal dunes, harbors and industrial areas, but also on rooftops in industrial areas and increasingly in cities.

**The lesser black-backed gull** breeds colonially, often alongside other gull species such as the herring gull. It shows a preference for level-ground that is well covered with fairly close, short vegetation (e.g. heather, bracken; BirdLife International 2024). The species breeds from central northern Russia westwards and southwards, with breeding in the Netherlands concentrated mainly in the western part of the country. After the breeding season, lesser black-backed gulls disperse widely, occupying a variety of coastal and inland habitats along the Atlantic seaboard and further south to West Africa. The species forages extensively on sea, as well as on land.

In the Netherlands, the **common gull** is mostly a terrestrial bird, found in coastal areas all year round (Hornman et al. 2024). It breeds in a variety of sites along the coast and inland, including grass, rock, shingle, earth or floating marshy vegetation on the ground, as well as artificial structures such as nest-boxes and trees off the ground (Birdlife factsheet: Flint *et al*. 1984, Richards 1990, del Hoyo *et al.* 1996, Snow and Perrins 1998). The Netherlands lies near the southern edge of its breeding range (Leopold et al. 2025). During winter, common gulls are most abundant in inland grasslands and the Wadden Sea, with inland birds moving to coastal areas when freezing conditions limit food availability (Sovon 2018, Hornman et al. 2024).

**Sandwich terns** are mainly coastal birds, occurring in the Netherlands in both breeding and non-breeding. They nest on sandy islands, rocky calcareous islets, sand-spits, dunes, shingle beaches and extensive deltas with immediate access to clear waters with shallow sandy substrates rich in surface-level fish (Snow and Perrins 1998). The species prefers raised, open, unvegetated sand, gravel, mud or bare coral substrates for nesting (del Hoyo et al. 1996). In the Netherlands Sandwich terns breed in remote, undisturbed, highly dynamic coastal systems, with little to no vegetation (Leopold et al. 2025).

The **common tern** is a migratory coastal seabird (del Hoyo et al. 1996, Snow and Perrins 1998). It breeds either in solitary pairs or colonially in a wide range of habitats (del Hoyo et al. 1996). In the Netherlands, common terns breed in various places, including coastal areas (like the delta) as more inland, with notable concentrations in and around lake IJssel.

The black-legged kittiwake is abundant year-round in the North-East Atlantic (Waggitt et al. 2019). However, in Dutch waters the kittiwake is mainly a winter visitor. The species has a fairly northern (Holarctic) breeding distribution and is much scarcer in the southern part of the North Sea during breeding season. Recently, the black-legged kittiwake started breeding in small numbers on gas platforms in the North Sea on the southwestern side of the Frisian Front (Camphuysen & Leopold 2007, Fijn et al. 2023).

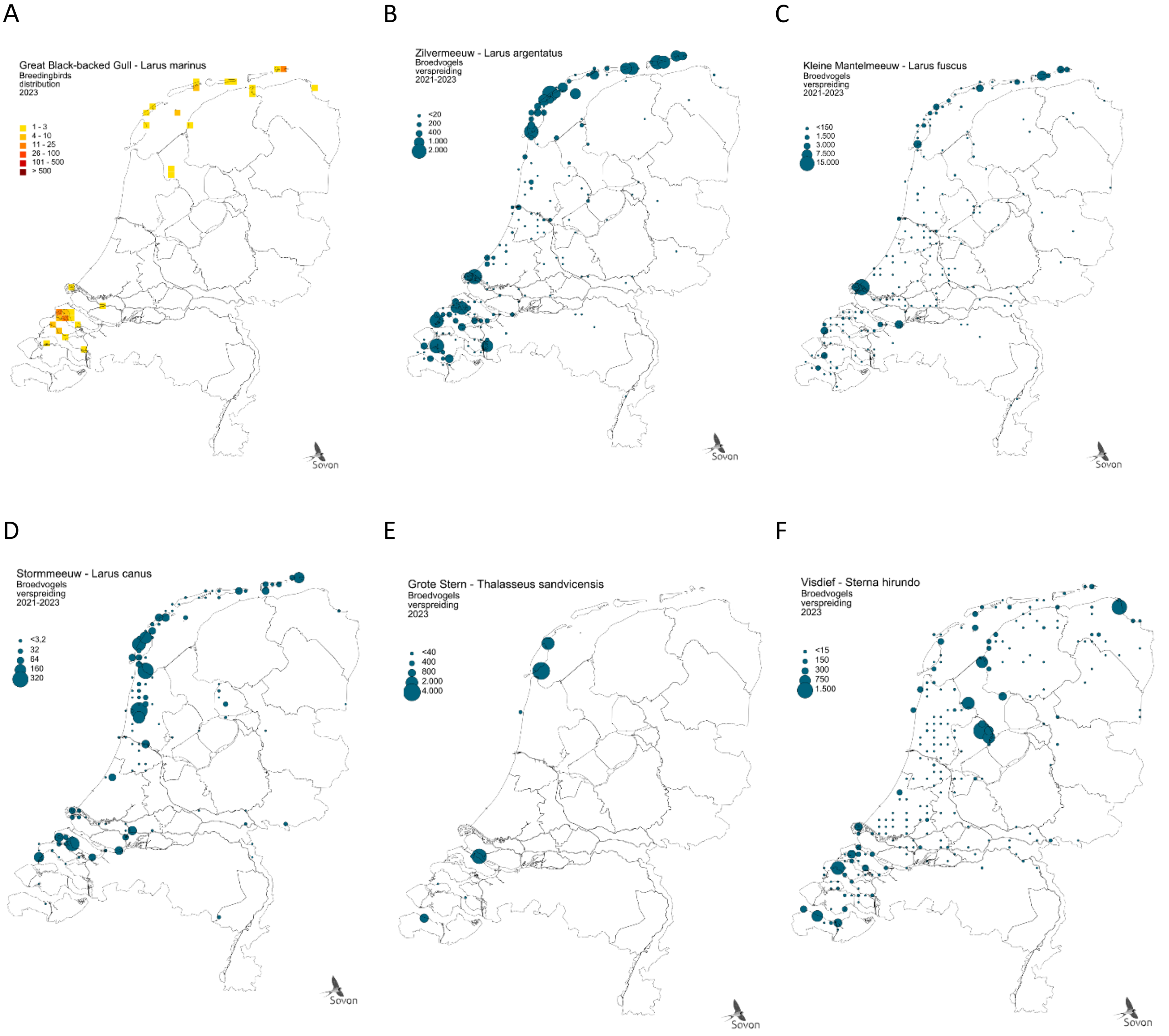


***Figure 9-1*** *Distribution maps of breeding birds (2021-2023) of A: great black-backed gull (Larus marinus, 2023 only), B: European Herring Gull (Larus argentatus), C: lesser black-backed gull (Larus fuscus), D: common gull (Larus canus), E: Sandwich tern (Thalasseus sandvicensis), Common Tern (Sterna hirundo). Numbers vs size of the bullet, vary per species: see legends of the various maps (maps from stats.sovon.nl).*

During the non-breeding season, seabirds in Dutch waters primarily use marine habitats, with many species concentrated in shallow, nearshore areas that provide accessible foraging opportunities. Red-throated divers and common scoters use coastal waters of the eastern North Sea, including the German Bight where the shallow zone of the North Sea is at its widest (Leopold et al. 1995b, Skov et al. 1995, 2007). Generally, they are found in waters less than 20 meters deep (Skov et al. 1995). These coastal waters serve as an important staging and feeding area. Northern fulmars occur in large numbers across the North Sea year-round, particularly in the northern half, with high-Arctic populations moving southward in winter (Skov et al. 2007, Burnell et al. 2023). Northern fulmars feed pelagically in all seasons by taking prey from the sea surface and is frequently present around fishing boats, particularly in the northern North Sea (Leopold et al. 2025). Black-legged kittiwakes are offshore surface feeders that show a seasonal distribution shift: in June, large groups concentrate around the Frisian Front, while in November and February they are more widely spread over the entire Dutch Continental Shelf (Bos et al. 2023). Parasitic jaegers and great skuas, pass through

Dutch waters respectively in autumn and winter. In the Netherlands parasitic jaegers are mostly seen close to the coastline peaking in August/September while great skuas are often found on the open sea, although coastal waters are not avoided (Platteeuw et al. 1994, Sovon 2022). The northern gannet is a subsurface feeder that spends most of its life at sea (Bos et al. 2023). It is a fairly common non-breeding visitor and may forage in the Dutch North Sea from colonies at the British east coast (Hamer 2007, Hamer 2001, Wakefield et al. 2013). Its occurrence along the Dutch coast depends on the prevailing wind direction, food availability and time of the year. Atlantic puffins are mostly offshore visitors, present in low numbers (Leopold et al. 2025). Common guillemots occur throughout the North Sea and large numbers of post-breeders visit Dutch waters after breeding (Leopold et al. 2025; Skov et al. 1995). It is a pursuit-diving marine bird.

***Table 9.1*** Seabird species' occurrence in the Netherlands, feeding ecology and habitat (based on *Bos* et al. *(2023), Jongbloed* et al. *(2023), Leopold* et al. *(2025) and pers. communication M. Poot*). * *spending winter season in NL ** stopover in NL during migration between the breeding and wintering grounds* Note, that a species can be 'breeding in NL' and 'Non-breeding (spending winter season in NL)' if it is represented by several populations with different breeding ranges or by one population that breeds and winters in the Netherlands. *** gas platforms.

| Bird species | Habitat | Feeding behaviour | Diet | Breeding in NL | Non-breeding (winter)* | Non-breeding (passage)** |
|---|---|---|---|---|---|---|
| Greater black-backed gull | Offshore, coastal, inland | Surface water | Variable | Yes | Yes | Yes |
| Herring gull | Offshore, coastal, inland | Surface water | Variable | Yes | Yes | Yes |
| Lesser black-backed gull | Offshore, coastal, inland | Surface water | Variable | Yes | No | Yes |
| Common gull | Coastal, inland | Surface water | Variable: small pelagic fish and earth-worms | Yes | Yes | Yes |
| Sandwich tern | Coastal | Diving | Fish | Yes | No | Yes |
| Common tern | Coastal | Diving | Fish | Yes | No | No |
| Red-throated diver (diver sp.) | Coastal | Diving | Fish | No | Yes | No |
| Common scoter | Coastal | Diving | Molluscs | No | Yes | No |
| Razorbill | Offshore, coastal | Diving, but mostly forage near the surface | Fish, krill | No | Yes | No |
| Common guillemot | Offshore, coastal | Diving | Fish | No | Yes | Yes |
| Northern fulmar | Offshore | Surface water | Fish, squid, plankton | No | Yes | Yes |
| Great skua | Offshore | Kleptoparasite | Fish, discards, carrion, birds | No | Yes | No |
| Parasitic jaeger | Offshore | Kleptoparasite | Fish | No | No | Yes |
| Black-legged kittiwake | Offshore | Surface water | Fish | Yes*** | Yes | Yes |

*Table 9.1. cont.*

| Bird species | Habitat | Feeding behaviour | Diet | Breeding in NL | Non-breeding (winter)* | Non-breeding (passage)** |
|---|---|---|---|---|---|---|
| Northern gannet | Offshore | Surface water | Fish | No | Yes | Yes |
| Atlantic puffin | Offshore | Diving | Fish | No | Yes | Yes |

### 9.1.4 Ecosystem function

Seabirds are top predators in the marine ecosystem. They play an important role in shaping marine food webs through top-down pressure on their prey populations such as fish and invertebrates, and by recycling nutrients through guano deposition (Hazen *et al.* 2019). Marine top predators often exhibit clear responses to environmental variability and anthropogenic impacts on ecosystems. As such, seabirds are among the most visible ecological indicators for the Good Environmental Status (GES) of the sea (Leopold et al. 2025).

Feeding ecology varies widely among species. Gulls and terns exploit a wide range of food sources both at sea and on land, varying from rodents, earthworms, fish, and marine invertebrates to even human refuse and discards (Arbouw & Swennen 1985, Vauk & Prüter 1987, Leopold et al. 2025). The diet of the common scoter is predominantly molluscs in the coastal zone. The great Skua and parasitic jaeger are both kleptoparasites: their behaviour is often raptor-like and many live on a diet of smaller seabirds, and on seabird-food that is obtained by often very aggressive kleptoparasitic behaviour. All other species dominantly feed on (small pelagic) fish and some species also have crustaceans and other marine invertebrates in their diet. Many seabirds became dependent on human activities: they consume large quantities of fisheries discards in Dutch waters and forage on food waste. Thereby also contributing towards waste breakdown back into marine and coastal ecosystems (Burdon et al. 2017). Through their foraging and movement patterns, seabirds connect offshore and coastal food webs.

### 9.1.5 Status and trend ecosystem component

The seabird community in the Dutch North Sea includes both breeding and non-breeding species with wide North Atlantic distributions. In the Greater North Sea region, the breeding productivity for common gull, lesser black-backed gull, common tern, northern fulmar, great skua, parasitic jaeger and puffin, is considered too low to prevent a decline of ≥30% over three generations if maintained at the same level (Leopold et al. 2025). As most selected seabirds have a very wide distribution area it is possible that the national status of the birds differs from the international status.

Among the breeding species in the Netherlands, the lesser black-backed gull is the most numerous, although numbers have declined since 2010 (Boele et al. 2024, Camphuysen 2013). Nevertheless, the current population size is still estimated well above the favourable reference value (Vogel et al. 2021, Sovon 2022). The great black-backed gull population, which established in the Netherlands after 1993 as breeding bird, shows contrasting trends regionally (Jongbloed et al. 2023). The numbers have been declining in the Greater North Sea region by about 45% since 1991 but seemed to have reached a stable level since around 2005. In the Netherlands the trend of great black-backed gull has showed significant increase, since establishing as a breeding bird since 1993 although the population is small, and status is favourable (Sovon 2023). The non-breeding population however shows a long-term decline, <5% per year in the Netherlands, marking an unfavourable status. Herring gull breeding populations have decreased by more than 50% since ca. 1990 partly due to reduced food availability and increased predation (Sovon 2023). Although the population trend outside the breeding season does not show significant change since 1980, average numbers are below the favourable reference value (Jongbloed et al. 2023). The breeding population of both common gulls, common terns and sandwich terns have an unfavourable status. For the first two breeding numbers have declined severely, and regarding sandwich terns have suffered additional losses from recent avian influenza outbreaks and habitat loss (Leopold et al. 2025).

Non-breeding assemblages in Dutch waters are dominated by migratory seabirds originating from breeding areas across northern Europe. Red-throated divers and common scoters occupy nearshore wintering grounds, whereas guillemots, razorbills, kittiwakes, northern fulmars, gannets and great skuas are distributed across the offshore Dutch Continental Shelf. The total abundance and seasonal distribution of these species are strongly influenced by food availability, weather, and anthropogenic pressures such as fisheries and offshore wind development (Leopold et al. 2025). For non-breeding species trends are mixed. Northern fulmar and great skua show declines in the Netherlands linked to food shortages, reduced fisheries discards, and bird flu (Vogel et al. 2021, Camphuysen et al. 2022, Leopold et al. 2025). The black-legged kittiwake population has been declining throughout the Greater North Sea, although the numbers on the Dutch Continental Shelf have increased at a moderate rate (<5% per year) in contrast to the European trend. They are increasingly observed breeding on oil and gas platforms in the vicinity of the Frisian Front. In contrast, common guillemot and razorbill populations have increased in Dutch waters possibly indicating that the southern North Sea now holds many birds that wintered further north in earlier decades (Leopold et al. 2025). Moreover, on the Dutch Continental Shelf a significant increase in the number of northern gannets has been observed since 1990 (Fijn et al. 2022). However, in 2022 an outbreak of highly bird flu spread through norther gannet breeding colonies throughout the North Atlantic, lead to mortality of the majority of chicks and unprecedented number of adult birds in 75% of all colonies (Bos et al. 2023). The common scoter, an important wintering species, has declined by about 50% since the 1990s, although distribution shifts complicate trend assessment and numbers might be in fact stable or increasing elsewhere, e.g., around the British Isles (Frost et al. 2021, BirdLife International 2022b, Sluijter & Wolf 2024, Poot et al. 2014), Numbers of red-throated divers in Dutch waters are at the level of the favourable reference value of 1600 birds (Sovon 2022) and often probably well above this number (van Bemmelen et al. 2022, 2024b). The trend in numbers is weakly increasing, suggesting that the conservation status is favourable, in Dutch Waters. The parasitic jaeger occurs in very low numbers on the Dutch Continental Shelf, with declining trends across the North-East Atlantic. It is *Endangered* in Europe but *Least Concern* globally; no national reference value is defined (Vogel et al. 2021). The Atlantic puffin is Vulnerable globally and declining across Europe. In Dutch waters, it occurs only in small wintering numbers (<1,000, occasionally up to 10,000), mainly around the Dogger Bank and Brown Ridge (van Bemmelen et al. 2021a).

The information on status of the seabird species in this report, was revised, based on the updated Acceptable Level of Impact (ALI) methodology (Schekkerman 2024). The summarized assessment of the conservation status is categorized as either 'Good' or 'Not good'.. Compared to Sovon's previous advice (Schekkerman 2022), the conservation status assessment for most of the 23 seabird species listed in **Table 9.2** has not changed. Overall, only for a few species, such as lesser black-backed gull, common guillemot, and razorbill, the summarized assessment of the conservation status is categorized as 'Good'. For most others, including herring gull, black-legged kittiwake, common scoter, and Sandwich tern, the conservation status remains 'Not good'. For the northern gannet, and great skua, the status has changed from 'Good' to 'Not good', mostly due to the observed high impact from the recent avian influenza outbreak.

**Table 9.2** *Conservation status of the selected seabird species (table from Schekkerman, 2024). The first column provides a summary assessment of the status as Good or Not Good (for guidance on how to translate this assessment into the X-threshold of the Acceptable Level of Impact, see (Schekkerman 2024), for the Acceptable Level of Impact, see (Hin et al. 2023, 2024). The following columns present the background information behind this assessment.*

| | **Summary** | **National** | | | | | | | **International** | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Species** | **Assessment of conservation status** | **Conservation Status (Staat van Instandhouding)** | | | | | | | **MSFD/OSPAR** | | **IUCN-status** | | **HPAI bird flu**[12] |
| | | season[1] | SvI[2] | GRP[3] | current pop. [4] | pop: GRP[5] | trend 1980[6] | trend 12 yr[7] | D1C2[8] | D1C3[9] | **Europa**[10] | **EU 28**[11] | |
| Great black-backed gull | Not good | br<br>nb | G<br>ZO | . 17,000* | .<br>11,000 | .<br>64% | ++<br>- | +<br>= | 0.57 | (EN) | LC | NT | †/†† |
| Hering gull | Not good | br<br>nb | ZO<br>MO | .<br>. | .<br>. | .<br>. | -<br>= | -<br>= | 0.61<br>0.68 | (CR)<br>. | NT | VU | † |
| Lesser black-backed gull | Good | br<br>nb | G<br>G | 46,000<br>. | 92,000<br>. | 200%<br>. | +<br>+ | -<br>++ | 1.29 | (EN) | LC | LC | † |
| Red-throated diver | Good | nb | G | 1600 | 1600 | 100% | ~ | = | . | . | LC | LC | - |
| Northern fulmar | Not good | Br<br>nb | .<br>MO | .<br>. | .<br>. | .<br>. | .<br>-- | .<br>- | 0.61 | (EN) | VU | EN | - |
| Northern gannet | Not good | br<br>nb | G | 17,000 | .<br>20,000 | .<br>118% | .<br>+ | .<br>= | 2.76 | (LC) | LC | LC | †† |
| Great skua | Not good | nb | G | 190 | 240 | 126% | = | = | 0.89 | (EN) | LC | LC | †† |
| Parasitic jaeger | Not good | nb | ZO | . | . | . | - | + | 0.15 | (CR) | EN | EN | - |
| Black-legged kittiwake | Not good | br<br>nb | G<br>G | .<br>. | .<br>. | -<br>- | +<br>+ | ~<br>= | 0.36 | (EN) | VU | EN | † |
| Sandwich tern | Not good | br<br>nb | ZO<br>G | 28,000*<br>. | 18,000 | 64 %<br>. | +<br>+ | -<br>+ | 1.02 | (LC) | LC | LC | †† |
| Common tern | Not good | br<br>nb | ZO<br>ZO | 29,000* | 15,000 | 52 % | -<br>+ | -<br>++ | 0.52 | (CR) | LC | LC | † |
| Common guillemot | Good | nb | G | 88,000 | 128,000 | 145 % | + | + | 0.96 | (LC) | LC | LC | † |
| Razorbill | Good | nb | G | 65,000 | 94,000 | 145 % | ? | ? | 1.41 | (LC) | NT | NT | - |
| Atlantic puffin | Not good | nb | MO | . | . | . | ~ | ~ | 0.91 | (VU) | EN | LC | -? |
| Common gull | | br<br>nb | ZO<br>G | .<br>. | .<br>. | .<br>. | -<br>+ | -<br>= | | | LC | LC | |

| | |
|---|---|
| **Season**: | The season relevant for the Dutch conservation status assessment: *br* = breeding birds, *nb* = non-breeding birds. |
| **SvI**: | Formal conservation status in the Netherlands: *G* = favourable, *MO* = moderately unfavourable, *ZO* = highly unfavourable. |
| **GRP**: | Favorable reference population size, expressed in breeding pairs (*br*) or seasonal average number of individuals (*nb*). |
| **Current Pop.**: | Recent population size (period 2014/15–2019/20); same units as in GRP (Sovon 2024). |
| **Pop:GRP**: | Recent population size as a percentage of the GRP. |
| **Trend 1980**: | Population trend in the Netherlands since 1980: **++** strong increase; **+** moderate increase; **=** stable; **~** unclear; **-** moderate decline; **--** strong decline (Source: Sovon statistics) |
| **Trend 12 years**: | Population trend in the Netherlands over the last 12 years (symbols and source as in Trend 1980). |
| **D1C2**: | Marine Strategy Framework Directive (MSFD) and OSPAR indicator for seabird abundance in the International North Sea: Favourable if ≥0.7 or ≥0.8, otherwise unfavourable (Dierschke et al. 2022). |
| **D1C3**: | MSFD and OSPAR indicator for seabird breeding productivity: Expressed as a hypothetical IUCN category the population would fall into if the current productivity remained unchanged for three generations (Frederiksen et al. 2022). |
| **Europe**: | IUCN status category for the European population: LC (Least Concern), NT (Near Threatened), VU (Vulnerable), EN (Endangered), CR (Critically Endangered) (BirdLife International 2024) |
| **EU 28:** | IUCN status category for the population within the 28 EU member states (BirdLife International 2021). |
| **HPAI**: | Mortality due to highly pathogenic avian influenza (HPAI) during outbreaks in 2022–2023, whose effects have not yet been incorporated into SvI and MSFD indicators: - No extraordinary mortality in Western Europe; † Above-average mortality due to HPAI, but not significant enough to cause a negative change in SvI or IUCN status; †† High mortality (tens of percent of the adult population), potentially leading to a negative change in SvI or IUCN status. |

### 9.1.6 Pressures and impacts

Seabirds are exposed to pressures throughout their entire annual cycle, both in the North Sea and elsewhere, as these species also spend considerable time in other marine areas or even on land (breeding and foraging (Busch & Garthe 2018, Gyimesi *et al.* 2016). For instance, if a population is already in decline due to low breeding success in other regions, even small increases in adult mortality could accelerate population collapse (e.g. Schippers et al. 2020). Therefore, population impacts from pressures within the North Sea should be evaluated within the broader context of threats occurring across the species' entire range, parts of which can lay outside the North Sea and the Netherlands (see e.g., Bagstad et al. 2019). Since not all pressures and threats affecting the seabirds discussed in this report are confined to the North Sea, we classify them below by geographic area.

**Pressures and threats acting across the geographic range**
Several types of pressures and threats may act across multiple regions and habitats. For instance, climate change works as a background pressure, sometimes exacerbating the effects of other pressures. It especially affects breeding birds, high in the Arctic, such as the parasitic skua, northern fulmar, Atlantic puffin, red-throated diver, and common scoter. The effects of the climate change on bird populations are still poorly studied (especially in the Russian part of the area) but become increasingly noticeable. For instance, Renner *et al.* (2024) reported that more than half of Alaska's population of common guillemots died during a marine heatwave event between 2014 and 2016, with an estimated loss of 4 million birds. Recent population abundance estimates since then have found no evidence of recovery, suggesting that the heatwave may have led to an ecosystem shift.

Stochastic pressures and threats with high impact, namely, spills of chemical substances, and disease outbreaks, as well as the mentioned above extreme weather events, are rare but can cause tremendous mortality, sometimes combined with breeding failure, in birds. These events are impossible to reliably predict. However, the risk of such events needs to be considered by impact assessments, especially regarding populations with vulnerable conservation status.

Chemical pollutants, such as PCB's are still affecting seabird reproduction (Sonne et al. 2020), while the effects of the growing number of other chemicals still largely need to be assessed (e.g. Davey et al. 2022).

**Pressures and threats in the North Sea**
All seabirds are exposed to pressures and threats in the North Sea. The threats in the North Sea are:
- collision with offshore wind turbines,
- light pollution and flaring by oil and gas platforms,
- possibly, barrier effects of OWFs,
- decrease in food availability (e.g. due to the climate change and fisheries),
- bycatch, i.e. occasional entanglement in fishing nets,
- oil spills,
- displacement by OWFs and shipping.

While oil spills, light pollution and flaring appear to be under reasonable control (Koeman et al. 1969, Camphuysen 2022), the effects of other pressures and threats require further research. Especially the impact from the growing offshore wind infrastructure is highly uncertain. Litter in the sea remains a problem: birds can die when they get entangled in plastic or ingest large pieces of it, but also the effects of ingested smaller or microplastic still need to be investigated (Wilcox et al. 2015, Bange et al. 2023, Leopold et al. 2025).

Food availability is likely a limiting factor for seabird populations in the North Sea. It can be affected by a decline in the populations of staple prey, the disappearance of alternative food sources (leading to increased competition for the staple prey), and reduced prey accessibility, for example due to disturbances in foraging areas. The ongoing decline in food availability is largely driven by climate change but can further be exacerbated by local activities such as fisheries, dredging, mining, and the construction of offshore infrastructure (e.g., wind farms) (Searle et al. 2023, Witbaard et al. 2024). The impact of fisheries on forage fish populations remains difficult to quantify due to the complex relationships within the North Sea ecosystem (Engelhard et al. 2014). The complex set of pressures on small pelagic fish and bivalves, including climate change, fisheries, harvesting and loss of nursery habitat can have cascading effects on their seabird predators. Disturbance by shipping, fishing and OWFs can lead to avoidance of foraging areas, some species such as common guillemot, razorbill, red-throated diver and common scoter are especially sensitive (Leopold et al. 2025, Grundlehner et al. 2025). Another pressure is reduction of alternative food sources, such as discard restrictions and landfill closures. This has affected some gull species, who used to heavily rely on this food source (Leopold et al. 2025, Bos et al. 2023, Sovon 2022, van Donk et al. 2019, Langley et al. 2021, Spelt et al. 2021).

**Pressures and threats outside the North Sea**

The main pressures and threats for the seabirds on land are related to the:

- breeding habitat loss (including predation of nests and chicks and disturbance or persecution by humans), and
- food availability decline (coastal zone, land)

Breeding habitats, such as small islands can become unsuitable for the nesting gulls and terns, when they get overgrown with tall vegetation due to natural succession (Sovon 2022). Another form of breeding habitat loss is predation. This can happen due to the predator population growth, but also due to the changes in habitat (such as low water levels), when it becomes accessible to predators (e.g. Sovon 2022). Ground-nesting birds, gulls and terns are especially vulnerable to predation by mammals, e.g. red foxes, and brown rats (Schwemmer *et al.* 2021, Bregnballe *et al.* 2022, Sovon 2022). In the Delta region, invasion of foxes has pushed the lesser black-backed gull to nest at breeding sites of other coastal birds elsewhere in the Delta and to cities in the surrounding area. Islands use to serve safe refuges for the breeding (sea)birds. However, brown rats can invade the islands being occasionally brought with the ships (Arts & Janse 2021, Sovon 2022). Pushed to nest at the colonies of other species, large gulls play the role of predators themselves, taking eggs and chicks. Additionally, they can compete for resources with the smaller-sized residents, such as common gulls and terns (Sovon 2022). High levels of predation, but also abandonment of nests and broods can also be caused by presence of humans and their pets.

The common, lesser black-backed and herring gulls, are known to forage on agricultural lands and in polders, where they mainly eat earthworms (Gyimesi *et al.* 2016), (Schwemmer *et al.* 2008, Camphuysen *et al.* 2022). These inland-foraging birds are likely to be affected by various pressures, such as overfertilization and other attributes of intensive agricultural practices (Schwemmer *et al.* 2008).

### 9.1.7 Current policy

The Netherlands has obligations to protect (specific) seabird species under the EU Birds Directive, the EU Marine Strategy Framework Directive (MSFD) and the North Sea Agreement. For all selected seabird species, a background document for the species protection plan was developed within the North Sea Agreement (Leopold et al. 2025, Bos et al. 2023, Jongbloed et al. 2023). These frameworks for seabird conservation in the Dutch North Sea put forward several targets that are described in the background documents as well as below.

**1. Marine Strategy Framework Directive (MSFD) – Good Environmental Status (GES)**

- Objective: Ensure that seabird populations reflect healthy ecological conditions, based on abundance, demographic trends, and reproductive success. Population Size (D1C2): For each functional group, at least 75% of species must maintain population levels above a threshold based on historical baselines (updated in OSPAR 2023).
- EU Birds Directive Compliance (D1C2): Populations must align with national targets set under the EU Birds Directive.
- Breeding Success (D1C3): Breeding performance should be sufficient to avoid population declines of ≥30% over three generations (updated in OSPAR 2023).
- D1T1: Improve assessment methods of bird populations and identifying key pressures at regional level.
- D1T2: Support recovery by reducing fishery impacts in designated Natura 2000 areas (e.g. “De Vlakte van de Raan” and “North Sea Coastal Zone”).
- D1T3: Achieve conservation objectives for habitats and species in the Natura 2000 areas.

- D1T7: Monitor bird collisions with offshore wind turbines (Wozep[13] programme).

Note: MSFD targets are formalized in *Marine Strategy Part I – Environmental Status* (2018) and are updated every six years. The most recent public consultation took place in summer 2025, and formal adoption of the revised Marine Strategy is planned for 2026.

**2. Natura 2000 and EU Birds Directive**

- Species Protection: All bird species are protected; Annex I species require special habitat conservation, and Annex II species may be hunted under specific conditions.
- Area Protection: Four marine Natura 2000 sites in the Dutch North Sea have been designated to safeguard key seabird and migratory bird species, including the species selected in this report:
    - *North Sea Coastal Zone*: red-throated diver and common scoter
    - *Voordelta*: Sandwich tern, common tern, red-throated diver and common scoter
    - *Brown Ridge*: great skua, common guillemot, razor bill, great black-backed gull, and northern gannet
    - *Frisian Front*: common guillemot

**Conservation Targets**:

- Maintain population size and habitat quality for designated species.
- Align with nationally defined targets, Favourable Reference Values (FRVs), and Natura 2000 targets.
    - No national target or favourable reference value for population size has been defined for the common gull (Vogel et al. 2021).
    - No offshore sites have been specifically designated for the black-legged kittiwake and no favourable reference value has been set.

9.1.7.1 Policy measures

BirdLife International made an overview of conservation actions for bird species (BirdLife International 2024). Although these actions vary per species, the overall aim is to strengthen seabird populations by securing safe and rich with food habitats (breeding and non-breeding) and decreasing human-induced mortality (due to e.g. hunting, bycatch, collisions with offshore structures) and breeding failure (e.g. due to egg collection, disturbance, predation). The background documents for the species protection plans (Leopold et al. 2025, Jongbloed et al. 2023, Bos et al. 2023) reviewed and pre-analysed the overview by BirdLife International, the OSPAR measures, and the *Bouwstenen* series by Sovon (2022). Based on these analyses, the impactful policy measures and restoration actions have been summarized in

**Table 9.3**. Measures to support breeding success, mitigate disturbance, maintaining healthy populations of key forage species, such as small pelagic fish and shellfish, are essential for supporting seabird populations in the North Sea. Although the exact prey stock sizes required to maintain seabird populations at healthy levels remain uncertain, the necessity of ongoing measures, such as current restriction of fisheries in Natura 2000 areas and in the IJsselmeer and the Wadden Sea and improvement of nursery habitats for the main forage fish species in coastal zone, is beyond doubts. However, knowledge of the status of forage fish for North Sea seabirds is largely lacking. Setting upper catch limits that explicitly consider seabird food requirements has also been proposed as a potential policy measure.

*Below, a generalized summary of these measures and actions is provided. They focus on reducing pressures through regulation, spatial management, or improved monitoring.*

1 [13] Wind op zee ecologisch programma (Wozep), see: https://noordzeeloket.nl/functies-gebruik/energietransitie-zee/windenergie-zee/ecologie/wind-zee-ecologisch-programma-wozep/

***Table 9.3*** *Possible policy measures from Leopold et al. (2025), Jongbloed et al. (2023) Bos et al. (2023) and Sovon bouwstenen complete overviews can be found in the reports.*

| Measure | Species | Rationale/objective |
|---|---|---|
| Restricting areas for building new wind farms, avoid key areas for feeding, resting, flying | Northern gannet, kittiwake, great black-backed gull, herring gull, guillemot, razorbill | Manage and protect areas |
| OWF collision-reducing measures | Northern gannet, kittiwake | Mitigate collision risk in offshore wind farms |
| Protection of nests from human disturbance during breeding season | Breeding species, (local or international e.g. gannet, guillemot) | Support breeding success |
| Creating disturbance free zones, by closures of high bird density and food base areas within the coastal zone for all shipping and fisheries | Red-throated diver, common scoter, razorbills and guillemots | Mitigating disturbance by shipping and fishery boats |
| Consider setting upper limits on catch by informed by research on the carrying capacity of the North Sea for fish consumption and interactions of fisheries and birds; banning and/or continued ban of bottom-trawl fisheries from N2000 areas suitable for sandeel | All selected species (except common scoter). | Safeguard availability of pelagic fish |
| Consider disturbance-free zones in key-foraging areas | Common scoter, red-throated diver | Mitigating disturbance by shipping and fishery boats |

**Resolving knowledge gaps**
Persistent knowledge gaps hinder the development of fully evidence-based management for seabirds in the North Sea. Monitoring and research on bycatch are especially relevant for red-throated diver, common scoter, common guillemot, razorbill, northern fulmar, northern gannet, and black-legged kittiwake (Leopold et al. 2025, Bos et al. 2023, BirdLife International 2024). Key monitoring actions could include on-board observer programmes as well as studies of stranded seabirds to assess bycatch levels in fisheries. Based on these findings, mitigation measures can be developed and implemented. Further research is also needed to assess and, where necessary, mitigate the impacts of offshore infrastructure and activities, including wind energy development through monitoring of seabirds corpses washing up on beaches, but also through observations of seabird behaviour and collisions in the windfarms with cameras. Finally, avian influenza represents an emerging threat, particularly for colonial breeding and roosting seabirds. Outbreaks can be mitigated by immediate removal of dead birds, but as the virus continues to evolve, the population-level impacts of future outbreaks remain unpredictable. Continuous monitoring and research into the epidemiology and ecological effects of avian influenza are therefore essential. Such monitoring can be done using telemetry tracking of individual birds (Talmon et al. 2025).

### 9.1.8 Advice and action perspective for NN

*Rationale*
Populations of several seabird species in the Dutch North Sea are in an unfavourable or declining state. Overall, seabird populations are under multiple cumulative pressures, including habitat loss at breeding sites, disturbance, incidental bycatch, pollution, and reduced food availability. Strengthening the ecological resilience of seabirds will therefore require a combination of spatial planning, habitat protection, and targeted mitigation measures to reduce mortality, increase breeding success and maintain adequate foraging

opportunities. Seabird recovery depends both on the improvement of underlying ecosystem functions, such as prey abundance and habitat quality, and on the direct management of breeding and foraging sites. Consequently, both policy-led (indirect) and active (direct) restoration measures are required.

As stated by Leopold et al. (*2025*), the Netherlands can be most effective with measures aimed at its breeding birds and for the species that winter in Dutch waters in internationally important numbers (red-throated diver, common scoter, guillemot, razorbill, but also northern gannet). The Dutch-breeding species include: lesser black-backed gull, herring gull, common gull, sandwich tern, common tern. Great black backed gulls and black-legged kittiwakes breed in the Netherlands in very low numbers, and the measures supporting these Dutch breeders are unlikely to have high impact at a population level. However, for species breeding outside of the Netherlands, there is also an option support measure focussing on breeding support abroad.

*Action perspective for NN*
A list of NN action perspective is given in

**Table 9.4**. NN can contribute to seabird recovery by facilitating targeted pilots or proven measures that restore or create suitable breeding and foraging habitats. This primarily applies to seabird species that breed in the Netherlands. For species that do not breed in the Netherlands, opportunities for international collaboration can be explored, with NN potentially supporting or co-facilitating projects at the international level. Promising opportunities include the restoration of dynamic sandbanks to support nesting of common and sandwich terns (Sovon Bouwstenen (2024), and the experimental manipulation of the seabed by the sand-mining industry to stimulate settlement of *Spisula subtruncata*, an important food source for common scoter, and potentially sandeel (Rozemeijer & Baptist, in prep.).

Further, NN could enhance colony resilience by supporting the management and protection of existing breeding sites through predator control, such as the exclusion of foxes by fencing, culling rats, and by the rapid removal of dead or sick birds during avian influenza outbreaks. Creating artificial breeding habitats also offers concrete opportunities. For example, common and Arctic terns at Eemshaven were successfully redirected to a newly constructed artificial island in the Eems–Dollard estuary, approximately four kilometres away. Similar initiatives could be explored for suitable coastal or offshore locations. In addition, new infrastructure associated with offshore wind expansion or carbon capture and storage developments could be designed to include features that support nesting or roosting seabirds, such as ledges or platforms. Note that relocations of breeding sites may not equal more breeding birds and studies on the breeding success at alternative sites should be conducted to evaluate the true effect of such measures.

Where possibilities for direct habitat restoration are limited, NN could promote research and field experiments aimed at reducing mortality and disturbance caused by offshore activities. There is a need to develop and test operational mitigation measures that reduce collisions at wind farms. These include turbine curtailment, increased lowest tip height, improved blade visibility and acoustic deterrence. Such research and experimentation fall within the exploratory phase (RRL 1–3). Similarly, studies could be conducted to assess whether colony establishment can be stimulated by behavioural cues such as playing colony sounds, placing decoy birds, or providing nesting material (RRL 1–3). Through these complementary activities, NN can help bridge the gap between knowledge development and large-scale ecological application.

NN should go hand-in-hand with other relevant conservation programs. OSPAR published the Regional Action Plan for Marine Birds in the North-East Atlantic (RAP-Bird) in 2024 (OSPAR Commission 2024). Building on the OSPAR Quality Status Report (2023), RAP-Bird outlines measures to reduce and eliminate key pressures on marine birds. It includes enhanced protection for at-risk species, conservation across migratory flyways, reduction of incidental bycatch in fisheries, best practices for mitigating impacts from offshore wind developments, and actions to secure and restore breeding colonies from invasive predators.

***Table 9.4*** *Possible NN measures for seabirds*

| Measure | Species | Rationale/objective |
|---|---|---|
| Restoration of dynamic water levels to create breeding habitat | Breeding species | Facilitates formation of new sandbanks and resets vegetation succession to facilitate good breeding habitat |
| Creating new/alternative breeding sites (for example artificial breeding habitats) | Breeding species | Safeguard sufficient good breeding habitat at sites |
| Protection of breeding areas from predators through reduced access (natural barriers, such as water or fencing) or eradication. | Breeding species | Enhance population resilience by supporting breeding success |
| Active control of predators or removal of nests of large gulls at colonies of smaller seabirds | Breeding species | Enhance population resilience by increasing breeding output |
| Collection of dead birds from breeding colonies | Breeding species | Reduce avian influenza transmission within colonies |

*Demonstration of impact*

To demonstrate the actual contribution of NN activities to the recovery of seabird populations, both ecological monitoring and targeted research are required. On a broad spatial scale, existing long-term monitoring programs provide valuable information on population trends, spatial distribution, and habitat use. These can be used to evaluate whether regional seabird populations show positive responses in areas where NN interventions take place. On a local scale, NN can implement project-specific monitoring at restoration or pilot sites to assess:

- Breeding success, including nest counts, clutch size, and hatching and fledging rates;
- Survival rates through colour-marking programmes;
- Colony establishment and persistence at newly created or restored sites;
- Disturbance levels: collecting representable samples of species-specific dose- and distance-dependent behavioural reactions: alertness, escape flight, time of return (experiments; tracking with animal-borne transmitters, visual observations).
- The effectiveness of predator exclusion or control measures;
- Use of created habitats by foraging birds (e.g. via direct observation, drones, or radar tracking);
- Food availability, such as prey fish density (e.g. sandeel, Spisula spp.) in proximity to breeding or foraging sites (tracking with animal-borne transmitters).

### 9.1.9 References


Arbouw G.J. & Swennen C. (1985). Het voedsel van de stormmeeuw Larus canus op Texel. Limosa 58: 7-15

Bagstad, K.J., Semmens, D.J., Diffendorfer, J.E., Mattsson, B.J., Dubovsky, J., Thogmartin, W.E., Wiederholt, R., Loomis, J., Bieri, J.A., Sample, C., Goldstein, J. & López-Hoffman, L. (2019). Ecosystem service flows from a migratory species: Spatial subsidies of the northern pintail. *Ambio* 48: 61–73.

Bange, A., Backes, A., Garthe, S. & Schwemmer, P. (2023). Prey choice and ingestion of microplastics by common shelducks and common eiders in the Wadden Sea World Heritage Site. Mar. Biol. 170: 54.

BirdLife International. (2024). *Data Zone*.

Bos, O., Schekkerman, H., Kingma, E., Tamis, J., Goutbeek, A., Van Oijen, T. & Jongbloed, R. (2023). Offshore birds in the Dutch North Sea: Background document for a protection plan. Wageningen Marine Research report, no. C087/23, https://doi.org/10.18174/644064

Boele, A., Vergeer, J. W., van Bruggen, J., Goffin, B., Koffijberg, K., van Oostveen, C., Schoppers, J., & Jansen, D. (2024). *Broedvogels in Nederland in 2023. Sovon-rapport 2024/40*. https://stats.sovon.nl/pub/publicatie/21771

Bregnballe, T., Sunde, P. & Kuhlmann Clausen, K. (2022). Occurrence of rats and their impacts on colonial waterbirds in a Danish fjord. Ornis Fenn. 00–00.

Burdon D., Potts T., Barbone C. & Mander L. (2017). The matrix revisited: A bird's-eye view of marine ecosystem service provision. Marine Policy, 77: 78–89. doi:10.1016/j.marpol.2016.12.015

Burnell, Daisy., Perkins, A. J., Newton, S., Bolton, M., Tierney, T. D., & Dunn, T. (2023). *Seabirds count : a census of breeding seabirds in Britain and Ireland (2015-2021)*. Lynx Nature Books.
Camphuijsen, C.J. (2013). A historical ecology of two closely related gull species (Laridae): Multiple adaptations to a man-made environment. [s.n.], Groningen.
Camphuysen, K. (C J.), Donk, S.C. van, Shamoun-Baranes, J. & Kentie, R. (2023). The Annual Cycle, Breeding Biology and Feeding Ecology of the Lesser Black-Backed Gull Larus fuscus. *Ardea* 112: 31–61.
Camphuysen, K.C.J. (2022). Mission accomplished: chronic North Sea oil pollution now at acceptable levels, with Common Guillemots *Uria aalge* as sentinels. *Seabird* 34: 1–32.
Camphuysen, C.J. & Leopold, M. (2007). Drieteenmeeuw vestigt zich op meerdere platforms in Nederlandse wateren. LIMOSA, 80(4), 153-156.
Cramp, S., and K. E. L. Simmons. (1983). Handbook of the Birds of Europe, the Middle East and North Africa. The Birds of the Western Palearctic. Vol III. Waders to Gulls. Vol. 3. Oxford University Press, Oxford.
Davey, C.J.E., Kraak, M.H.S., Praetorius, A., ter Laak, T.L. & van Wezel, A.P. (2022). Occurrence, hazard, and risk of psychopharmaceuticals and illicit drugs in European surface waters. Water Res. 222: 118878.
del Hoyo, J.; Elliott, A.; Sargatal, J. (1996). Handbook of the Birds of the World, vol. 3: Hoatzin to Auks. Lynx Edicions, Barcelona, Spain.
Dierschke, V., Marra, S., Parsons, M., Fusi, M. & French, G. (2022). *Marine Bird Abundance*.
Engelhard, G.H., Peck, M.A., Rindorf, A., C. Smout, S., van Deurs, M., Raab, K., Andersen, K.H., Garthe, S., Lauerburg, R.A.M., Scott, F., Brunel, T., Aarts, G., van Kooten, T. & Dickey-Collas, M. (2014). Forage fish, their fisheries, and their predators: who drives whom? ICES J. Mar. Sci. 71: 90–104.
Fijn, R., Poot, M.J.M., Arts, F., Bemmelen, R.S.A. van, Hornman, M., Jong, J. de, Schekkerman, H., Soldaat, L. & Troost, G. (2022). Dutch waters form an internationally important stopover for the Little Gull (*Hydrocoloeus minutus*). Limosa 95: 160–177.
Fijn R., van Bemmelen R.S.A., Verhoek L. & Schekkerman H. (2023). Drieteenmeeuwenonderzoek op de Nederlandse Noordzee. Limosa 96: 130-136.
Flint, V.E.; Boehme, R.L.; Kostin, Y.V.; Kuznetsov, A.A. (1984). *A field guide to birds of the USSR*. Princeton University Press, Princeton, New Jersey.
Frederiksen, M., Dierschke, V., Marra, S., Parsons, M., French, G., Fusi, M., Schekkerman, H., Anker-Nilssen, T. & Mitchell, I. (2022). *Marine Bird Breeding Productivity*.
Frost, T. M., Calbrade, N. A., Birtles, G. A., Hall, C., Robinson, A. E., Wotton, S. R., Balmer, D. E., & Austin, G. E. (2021). *Waterbirds in the UK 2019/20: The Wetland Bird Survey. BTO, RSPB and JNCC, in association with WWT*. https://www.bto.org/sites/default/files/publications/wituk1920forweb.pdf
Gyimesi, A., Boudewijn,Theo J., Buijs, Roland-Jan, Shamoun-Baranes, Judy Z., de Jong, Job W., Fijn, Ruben C., van Horssen, Peter W. & and Poot, M.J.M. (2016). Lesser Black-backed Gulls Larus fuscus thriving on a non-marine diet. Bird Study 63: 241–249.
Good, T. P. (2020). Great Black-backed Gull (Larus marinus). In S. M. Billerman (Ed.), *Birds of the World*. Cornell Lab of Ornithology. https://doi.org/10.2173/bow.gbbgul.01
Grundlehner, A., Leopold, M. F., & Kersten, A. (2025). This is EPIC: Extensive Periphery for Impact and Control to study seabird habitat loss in and around offshore wind farms combining a peripheral control area and Bayesian statistics. *Ecological Informatics*, *85*, 102981. https://doi.org/10.1016/J.ECOINF.2024.102981
Hamer, K. C., Phillips, R. A., Hill, J. K., Wanless, S., & Wood, A. G. (2001). Contrasting foraging strategies of gannets Morus bassanus at two North Atlantic colonies: foraging trip duration and foraging area fidelity. *Mar Ecol Prog Ser*, *224*, 283–290.
Hamer, K. C., Humphreys, E. M., Garthe, S., Hennicke, J., Peters, G., Grémillet, D., Phillips, R. A., Harris, M. P., & Wanless, S. (2007). Annual variations in diets, feeding locations and foraging behaviour of gannets in the North Sea: flexibility, consistency and constraint. *Mar Eco Prog Ser*, *338*, 295–305.
Hazen, E.L., Abrahms, B., Brodie, S., Carroll, G., Jacox, M.G., Savoca, M.S., Scales, K.L., Sydeman, W.J. & Bograd, S.J. (2019). Marine top predators as climate and ecosystem sentinels. *Front. Ecol. Environ.* 17: 565–574.
Heldbjerg, H., Fox, A.D., Lehikoinen, A., Sunde, P., Aunins, A., Balmer, D.E., Calvi, G., Chodkiewicz, T., Chylarecki, P., Escandell, V., Foppen, R., Gamero, A., Hristov, I., Husby, M., Jiguet, F., Kmecl, P., Kålås, J.A., Lewis, L.J., Lindström, Å., Moshøj, C., Nellis, R., Paquet, J.-Y., Portolou, D., Ridzoň, J., Schmid, H., Skorpilová, J., Szabó, Z.D., Szép, T., Teufelbauer, N., Trautmann, S., Turnhout, C. van, Vermouzek, Z., Voříšek, P. & Weiserbs, A. (2019). Contrasting population trends of Common Starlings (Sturnus vulgaris) across Europe. *Ornis Fenn.* 96: 153–168.

Hin, V., IJntema, G., Kooten, T. van & Potiek, A. (2024). A revised methodology for quantifying 'Acceptable Level of Impact' from offshore wind farms on seabird populations. doi: 10.18174/659871.

Hin, V., Kooten, T. van, Potiek, A. & Kraal, J. (2023). Further development of the 'Acceptable Level of Impact' framework for effects of offshore wind farms on seabirds : extended method development and sensitivity analysis. doi: 10.18174/644082.

Hornman M., Koffijberg K., van Oostveen C., van Winden E., Louwe Kooijmans J., Kleefstra R., Vergeer J.W. & Soldaat L. (2024). Watervogels in Nederland in 2021/2022. Sovon rapport 2024/22, RWS rapport BM 24.04. Sovon Vogelonderzoek Nederland, Nijmegen. pub.sovon.nl/pub/publicatie/21647

Jongbloed, R., Schekkerman, H., Kingma, E., Tamis, J., Goutbeek, A., Van Oijen, T. & Bos, O. (2023). Surface-feeding birds of the coastal waters in the Dutch North Sea : Background document for a protection plan. Wageningen Marine Research report C097/23. https://doi.org/10.18174/644517

Koeman, J.H., Ten Noever De Brauw, M.C. & De Vos, R.H. (1969). Chlorinated Biphenyls in Fish, Mussels and Birds from the River Rhine and the Netherlands Coastal Area. *Nature* 221: 1126–1128.

Langley, L.P., Bearhop, S., Burton, N.H.K., Banks, A.N., Frayling, T., Thaxter, C.B., Clewley, G.D., Scragg, E. & Votier, S.C. (2021). GPS tracking reveals landfill closures induce higher foraging effort and habitat switching in gulls. Mov. Ecol. 9: 56.

Leopold, M., Skov, H. & Hüppop, O. (1993). Where does the Wadden Sea end? Links with the adjacent North Sea. *WSNL* 5–9.

Leopold, M. F., Skov, H., & Durinck, J. (1995). The distribution and numbers of red-throated divers Gavia stellata and black-throated divers Gavia arctica in the North Sea in relation to habitat characteristics. *Limosa*, *68*, 125.

Leopold, M.F., Poot, M., Tamis, J., Schekkerman, H., Goutbeek, A., van Oijen, T. & Jongbloed, R. (2025). *Seabirds in the Dutch North Sea*. Background document for a protection plan for seabirds potentially vulnerable to offshore wind farms. Wageningen Marine Research report C047/25. https://doi.org/10.18174/695037

OSPAR Commission. (2024). OSPAR's regional action plan for marine birds in the north-east Atlantic (2024 – 2030).

Platteeuw, M., van der Ham, N. F., & den Ouden, J. E. (1994). *Zeetrektellingen in Nederland in de jaren tachtig*.

Poot, M., Heunks C., Boudewijn T.J., Leopold M.F., & van Bemmelen R. (2014). *Species of interest: birds-common scoter. Ch. 4 in: Prins T.C., van der Kolff G.H., Bon A.R., Reinders J., Kuijper C., Hendriksen G., Holzhauer H., Langenberg V.T., Craeymeersch J.A.M., Tulp I.Y.M., Poot M.J.M., Seegers H.C.M. & Adema J. (eds).*

Renner, H.M., Piatt, J.F., Renner, M., Drummond, B.A., Laufenberg, J.S. & Parrish, J.K. (2024). Catastrophic and persistent loss of common murres after a marine heatwave. Science 386: 1272–1276.

Richards, A. (1990). Seabirds of the northern hemisphere. Dragon's World Ltd, Limpsfield, U.K.

Schekkerman, H. (2022). Invulling van parameterwaarden voor Acceptable Levels of Impact van sterfte van vogels door windparken op zee.

Schekkerman, H. (2024). Invulling van parameterwaarden voor herziene Acceptable Levels of Impact van sterfte van vogels door windparken op zee | Sovon Vogelonderzoek.

Schippers, P., Buij, R., Schotman, A., Verboom, J., van der Jeugd, H. & Jongejans, E. (2020). Mortality limits used in wind energy impact assessment underestimate impacts of wind farms on bird populations. Ecol. Evol. 10: 6274–6287.

Schmidt, A.M., Mathijssen P.J.H., Jongbloed R.H., Tamis J.E., Goutbeek A.B., Reinartz R., Vogel R., Sanders M.E., van der Wal J.T. &. Woltjer I. (2023). Advies over de Nederlandse pledges voor de Europese biodiversiteitsstrategie 2030; Toelichting op het advies van Wageningen Research en Sovon Vogelonderzoek aan het Ministerie van Landbouw Natuur En Voedselkwaliteit. Wettelijke Onderzoekstaken Natuur & Milieu, WOt-technical report 241. doi:10.18174/591181.

Schwemmer, P., Garthe, S. & Mundry, R. (2008). Area utilization of gulls in a coastal farmland landscape: habitat mosaic supports niche segregation of opportunistic species. Landsc. Ecol. 23: 355–367.

Schwemmer, P., Weiel, S. & Garthe, S. (2021). Spatio-temporal movement patterns and habitat choice of red foxes (*Vulpes vulpes*) and racoon dogs (*Nyctereutes procyonoides*) along the Wadden Sea coast. Eur. J. Wildl. Res. 67: 49.

Searle, K.R., Regan, C.E., Perrow, M.R., Butler, A., Rindorf, A., Harris, M.P., Newell, M.A., Wanless, S. & Daunt, F. (2023). Effects of a fishery closure and prey abundance on seabird diet and breeding success: Implications for strategic fisheries management and seabird conservation. Biol. Conserv. 281: 109990.

Skov, H., Durinck, J., Leopold, M. F., & Tasker, M. L. (1995). *Important bird areas in the North Sea, including the Channel and the Kattegat*. Cambridge

Skov, H., Durinck, J., Leopold, M. F., & Tasker, M. L. (2007). A quantitative method for evaluating the importance of marine areas for conservation of birds. *Biological Conservation*, *136*(3), 362–371. https://doi.org/10.1016/J.BIOCON.2006.12.016

Sluijter, M., Lillipaly, S. J., & Wolf, P. A. (2024). *Midwintertelling van zee-eenden in de Waddenzee en Nederlandse kustwateren in november 2023, januari en maart 2024. Rapport RWS – Centrale Informatievoorziening. Rapport BM 24.36 / Deltamilieu Projecten rapport 2024-09*.

Snow, D.W.; Perrins, C.M. (1998). The Birds of the Western Palearctic, Volume 1: Non-Passerines. Oxford University Press, Oxford.

Sonne, C., Siebert, U., Gonnsen, K., Desforges, J.-P., Eulaers, I., Persson, S., Roos, A., Bäcklin, B.-M., Kauhala, K., Tange Olsen, M., Harding, K.C., Treu, G., Galatius, A., Andersen-Ranberg, E., Gross, S., Lakemeyer, J., Lehnert, K., Lam, S.S., Peng, W. & Dietz, R. (2020). Health effects from contaminant exposure in Baltic Sea birds and marine mammals: A review. Environ. Int. 139: 105725.

Sovon Vogelonderzoek Nederland. (2018). *Vogelatlas van Nederland*. Kosmos.

Sovon (2022). Bouwstenen voor het Strategisch Plan Natura 2000: factsheets van vogelsoorten die be trokken zijn bij de instandhoudingsdoelstellingen voor Natura 2000-gebieden.

SOVON. (2023). *European Herring Gull*. https://stats.sovon.nl/stats/soort/5920/?language=english

Sovon (2024). Species overview.

Spelt, A., Soutar, O., Williamson, C., Memmott, J., Shamoun-Baranes, J., Rock, P. & Windsor, S. (2021). Urban gulls adapt foraging schedule to human-activity patterns. Ibis 163: 274–282.

Talmon, I., Pekarsky, S., Bartan, Y., Thie, N., Getz, W. M., Kamath, P. L., Bowie, R. C. K., & Nathan, R. (2025). Using wild-animal tracking for detecting and managing disease outbreaks. Trends in Ecology & Evolution, 40(8), 760–771. https://doi.org/10.1016/J.TREE.2025.05.004

van Bemmelen, R., de Jong, J., Beuker, D., Rebolledo, E. B., Collier, M., Engels, B., Hoekstein, M., Jonkvorst, R. J., Lilipaly, S., Sluijter, M., van Straalen, D., Wolf, P., Roos, M., & Fijn, R. (2021). Groot aantal papegaaiduikers fratercula arctica in de nederlandse noordzee in februari 2020. *Sula*, *29*, 1–11. www.trektellen.nl

van Bemmelen, R., de Jong, J., Arts F.A., Beuker D., Engels B.W.R., Hoekstein M.S.J., van der Horst Y., Kuiper K., Leemans J., Sluijter M., van Straalen K.D., Wolf P.A., & Fijn R.C. (2022). *Verspreiding, abundantie en trends van zeevogels en zeezoogdieren op het Nederlands Continentaal Plat in 2021-2022. RWS Centrale Informatievoorziening BM 22.27. Waardenburg Ecology Rapportnr. 22-328.*

van Bemmelen, R. S. A., de Jong, J. W., Arts, F. A., Beuker, D., Engels, B. W. R., Hoekstein, M. S. J., van der Horst, Y., Kuiper, K., Leemans, J., Sluijter, M., van Straalen, K. D., Wolf, P. A., & Fijn, R. C. (2024). *Verspreiding, abundantie en trends van zeevogels en zeezoogdieren op het Nederlands Continentaal Plat in 2022- 2023. RWS-Centrale Informatievoorziening BM 23.32. Waardenburg Ecology Rapportnr. 23-443.*

van Donk, S., Shamoun-Baranes, J., van der Meer, J. & Camphuysen, K.C.J. (2019). Foraging for high caloric anthropogenic prey is energetically costly. Mov. Ecol. 7: 17.

Vauk G. & Prüter J. (1987). Möwen. Verein Jordsand, Jordsand-Bucht Nr. 6, 299p.

Vogel, R. L., Foppen, R., van Kleunen, A., van Roomen, M., & van Turnhout, C. (2021). *Methodiek voor de bepaling van de staat van instandhouding van vogels. Sovon-rapport 2021/26*. https://stats.sovon.nl/pub/publicatie/21323

Waggitt JJ, Evans PGH, Andrade J, et al. (2020). Distribution maps of cetacean and seabird populations in the North-East Atlantic. J Appl Ecol.; 57: 253–269. https://doi.org/10.1111/1365-2664.13525

Wakefield, E. D., Bodey, T. W., Bearhop, S., Blackburn, J., Colhoun, K., Davies, R., Dwyer, R. G., Green, J. A., Grémillet, D., Jackson, A. L., Jessopp, M. J., Kane, A., Langston, R. H. W., Lescroël, A., Murray, S., le Nuz, M., Patrick, S. C., Péron, C., Soanes, L. M., … Hamer, K. C. (2013). Space partitioning without territoriality in gannets. *Science*, *341*(6141), 68–70. https://doi.org/10.1126/science.1236077

Wilcox, C., Van Sebille, E. & Hardesty, B.D. (2015). Threat of plastic pollution to seabirds is global, pervasive, and increasing. Proc. Natl. Acad. Sci. 112: 11899–11904.

Witbaard, R., Parmentier, B. & Herman, P. (2024). Distribution of Sandeel (Ammodytes sp.) in the Dutch North Sea.

## 9.2 Migratory birds

*Summarized from the background document of a species protection plan (Jongbloed et al. 2025*).

### 9.2.1 Description of the ecosystem component

Migratory birds are a diverse group of birds with a range of flight strategies while traveling between their wintering and breeding areas. Some species even fly between hemispheres. Many migratory birds also make use of different ecosystems in different seasons. For instance, shorebirds inhabit intertidal areas in temperate and tropical zones, where they forage on benthos, but they spend their breeding season in dry Arctic tundra eating insects. The migratory birds are affected by offshore wind development when passing the North Sea during migration.

### 9.2.2 Species selection / Focus species

The selection of migratory bird species is based on the background document for the species protection plan that is currently being developed (Jongbloed et al. 2025). The following species are selected in the background document: common shelduck (*Tadorna tadorna)*, Bewick's swan (*Cygnus (columbianus) bewickii)*, brent goose (*Branta bernicla)*, red knot (*Calidris canutus)*, Eurasian curlew (*Numenius Arquata)*, little gull (*Hydrocoleus minutus*), black tern (*Chlidonias niger*), common starling (*Sturnus vulgaris*).

*Rationale for selection*
The selection of migratory bird species in this plan follows the background document prepared under the North Sea Agreement (Jongbloed et al. 2025). Species were included based on three main criteria: (1) vulnerability to offshore wind development, (2) conservation concern under international frameworks such as the EU Birds and Habitats Directives, OSPAR, and national Red Lists, and (3) key to nature restoration and enhancement. This group includes migratory birds identified as vulnerable to offshore wind farms within the KEC 4.0 assessment but not previously covered by protection plans 1, 2, or 3 (Leopold et al. 2025, Bos et al. 2023, Jongbloed et al. 2023). In addition, several breeding species were included due to their unfavourable or declining conservation status, as reflected in the Dutch Red List status.

### 9.2.3 Habitat preference

*Unless stated otherwise, these species descriptions are a summary of the description in Jongbloed et al. (2025). Pictures of the species and distribution maps are available in Jongbloed et al. (2025)*

The migratory birds considered here depend on a range of coastal and inland habitats across the North Sea region, using Dutch waters and coasts primarily as breeding, wintering, or stopover sites. Most species rely on shallow coastal and intertidal zones, while several also use inland freshwater or agricultural habitats during migration or winter.

*Wildfowl*
Common shelducks breed along the coast and further inland across central and northern Eurasia, including in the Netherlands, nesting in burrows or cavities (Sovon 2024). Large movements across the North Sea occur between the Wadden Sea and the UK during moulting and cold weather movements (Gyimesi et al. 2017). In the German Wadden sea they feed mainly on benthic organisms, green algae and plant seeds. In contrast to common shelducks, brent geese do not breed in the North Sea region, but in Arctic tundra habitats (Cramp & Simmons 1977, van Roomen *et al.* 2022). The North Sea is part of the flyway between the Wadden Sea and the UK, one of the important wintering sites, but also between the Wadden Sea and the staging sites in the Dutch Delta and France (Ebbinge *et al.* 2013, Gyimesi *et al.* 2017). In their staging and wintering sites, such as intertidal mudflats and salt marshes but also agricultural land, they feed on seagrass, saltmarsh plants and meadow grass (Bos & Stahl 2003, Dokter et al. 2018). In the Netherlands, pastures appear to be more attractive to brent geese, especially in spring, when they fuel up before spring migration (Dokter *et al.* 2018). Bewick's swan is another species that breeds in tundra habitat (Kouzov *et al.* 2024). The species

crosses the southern North Sea during spring and autumn migration, to winter in temperate western Europe among which the Netherlands. (Woodward et al. 2023). Tracking data show that the swans may fly in the vicinity of wind farms in UK, Dutch and German coastal waters (Griffin et al*.* 2016). During winter, the species uses freshwater lakes, but also grasslands and arable lands feeding on aquatic vegetation, grass and harvest remains (Sovon 2024, Nuijten & Nolet 2020).

*Waders*
Red knots heavily rely on intertidal flats in the Wadden Sea. The canutus subspecies uses the Wadden Sea as critical stopover on the way from their wintering grounds in Africa to the breeding sites in Russia (Davidson & Piersma 1992, van Gils et al. 2016). The islandica subspecies spends most of the year in Western Europe, among which the Netherlands, migrating to the polar desert in Greenland and NE Canada in spring (Wilson & Tomkovich 2017). In the Wadden sea they feed on benthic bivalves such as cockles and tellins (Piersma et al. 1994, Poot et al. 2014, Bijleveld 2015). The Eurasian curlew has breeding populations in the Netherlands, that mostly stay in Europe for the winter and use the North Sea to migrate across in large numbers (Woordward et al. 2023). In summer additional curlews arrive to the Wadden Sea from eastern Europe (Brown 2015). Curlews breed in open habits like peat bogs, floodplain meadows, arable fields and grasslands. They mainly use estuaries and coastal grassland where they feed on earthworms, beetles, woodlice, crustaceans and shellfish (Bocher et al. 2024, Stillman et al. 2005, Navedo et al. 2020).

*Gulls and terns*
The little gull breeds inland and although breeding cases in the Netherlands are sporadic and scarce, nearly the entire European population passes through the Duch part of the North Sea to make a refueling stopover during spring migration. In that period substantial numbers may also occur in large inland freshwater bodies, especially the IJsselmeer (Fijn *et al.* 2022). European breeding birds winter on and around the North Sea region, along the Atlantic coast as far as Morocco (del Hoyo et al. 1996). During migration and in winter the species occurs at sea, along shores, near moths of rivers and stream, and on freshwater, where they mainly feed on small fish and invertebrates (del Hoyo et al. 1996). Black terns breed in river landscapes, peat marshes and grasslands in the Netherlands and elsewhere in Europe. During late summer, large numbers stage in Lake Ijsselmeer and the Wadden Sea, where they forage over coastal and nearshore waters rich in small fish and flying insects (Beintema et al. 2010, Michael et al. 2024).

*Songbirds*
The common starling is a widespread species breeding and wintering in the Netherlands. The starling primarily uses inland and coastal grasslands for feeding on invertebrates, seeds and berries (Versluijs *et al.* 2016, Heldbjerg *et al.* 2019). Although not directly associated with offshore North Sea habitats, large migratory movements occur along the coast, and coastal zones provide foraging habitat during migration and winter (Sovon 2002).

***Table 9.5*** *Migratory bird species' occurrence in the Netherlands, feeding ecology and habitat (based on Jongbloed et al. (2025).* spending winter season in NL ** stopover in NL during migration between the breeding and wintering grounds Note, that a species can be 'breeding in NL' and 'Non-breeding (spending winter season in NL)' if it is represented by several populations with different breeding ranges or by one population that breeds and winters in the Netherlands.*

| **Bird species** | **Habitat** | **Feeding behaviour** | **Diet** | **Breeding in NL** | **Non-breeding (winter)*** | **Non-breeding (passage)**** |
|---|---|---|---|---|---|---|
| Common shelduck | Shore coastal | Mudflats | Benthos | Yes | Yes | No |
| Bewick's swan | Shore, inland | Shallow freshwater | Plants | No | Yes | No |
| Brent goose | Shore, inland | Land surface, mudflats | Plants | No | No | No |
| Red knot | Shore coastal | Mudflats | Benthos | No | Yes | Yes |
| Eurasian curlew | Shore, inland | Mudflats | Benthos | Yes | Yes | No |
| Little gull | Coastal | Water surface | Fish, insects | Yes | Yes | Yes |
| Black tern | Coastal | Water surface | Fish | Yes | No | Yes |
| Common starling | Inland | Land surface | Diverse | Yes | Yes | Yes |

### 9.2.4 Ecosystem function

Migratory birds form a dynamic link between the North Sea and distant ecosystems (Jongbloed et al. 2025). They connect breeding, staging and wintering areas across the globe and thus contribute to ecological connectivity (Lank & Ydenberg 2003, Dekker & Ydenberg 2004). However, their direct ecological influence within the North Sea might be limited, and largely confined to coastal and nearshore habitats. In these areas, species such as geese, waders and sea ducks can locally influence benthic communities, primary production, and nutrient turnover through grazing and excretion. Their temporary aggregation can also provide a seasonal food source for predators, contributing to the transfer of energy within the coastal food web. However, this is particularly of relevance in the Wadden Sea (Ly *et al.* 2014, Reijers *et al.* 2024). Most migratory birds use the offshore North Sea mainly as a migration corridor with brief residence time and wide dispersal.

Beyond their trophic role, migratory birds also act as biological connectors, transporting nutrients, propagules and occasionally pathogens between regions (e.g. Buehler *et al.* 2010, The Global Consortium for H5N8 and Related Influenza Viruses 2016, Viana *et al.* 2016, Zhou *et al.* 2016). Although these processes are difficult to quantify at the scale of the North Sea, they contribute to the broader ecological coupling between marine, coastal and terrestrial systems.

### 9.2.5 Status and trends

The current status and population trends of selected migratory bird species are summarized below and presented in

**Table 9.6**, which distinguishes between national and international conservation status. These trends are based on recent assessments (Sovon 2024, Schekkerman 2024, BirdLife International 2024) and indicate considerable variation among species in both their use of the North Sea and their population trajectories across Europe.

*Wildfowl*

Of the wildfowl species considered, only a small proportion of the Bewick's swan population uses the North Sea, while for the common shelduck and brent goose it is unknown what share of the population does so, although both species are known to migrate over the North Sea. The common shelduck shows a stable trend in the Netherlands after earlier growth until the early 2010s (Jongbloed et al. 2025). Bewick's swan numbers have declined since 1995, mainly due to low recruitment and a redistribution of the population north-eastwards, resulting in fewer birds migrating over the North Sea (Beekman *et al.* 2019, Linssen *et al.* 2023). The brent goose population has increased since 1980 and is currently stable (Koffijberg *et al.* 2013, Sovon 2024).

*Waders*

According to Schekkerman (2024) the portion of red knot population that uses the North Sea is unknown. The red knot population declined in the 1990s until early 2000s, which coincided with depletion of cockle population in the Wadden Sea but has partially recovered since 2010 (Kraan et al. 2007). The Eurasian curlew relies heavily on the North Sea region, with up to half the population using it in winter (Kleefstra et al. 2022). In contrast the Netherlands hosts a relatively small proportion of the total breeding population,2% as of 2015 (Brown 2015, Jongbloed et al. 2025). Breeding and wintering populations are declining throughout western Europe, including the Netherlands, mainly due to low reproductive success (AEWA Eurasian Curlew IWG 2022, SOVON 2024, Roodbergen *et al.* 2012, Cook *et al.* 2021).

*Gulls and terns*

The little gull depends strongly on the North Sea, where large spring aggregations can represent nearly the entire European population (Schekkerman 2024). The population trend of little gulls in the Netherlands shows no significant change (Sovon, 2024). Despite this, breeding populations, although marginal, have significantly decreased since the 1980s due to habitat loss in inland wetlands. Regarding the black tern only a small spart of the population uses the North Sea (Schekkerman 2024). The species is endangered in the Netherlands, with a >95% decline of roosting terns since the 1950s, caused by habitat degradation, food limitation, and disturbance (Jongbloed et al. 2025).

*Songbirds*

A very large part of the common starling population uses the North Sea (Schekkerman 2024). This species has an extremely large range and population size, and is categorised as Least Concern (BirdLife International 2024). Although European populations have declined due to agricultural intensification, recent trends in the Netherlands are stable (non-breeding) to slightly increasing (breeding) (PECBMS 2024).

**Table 9.6** *Conservation status of the selected migratory bird species (table from Schekkerman, 2024). The first column provides a summary assessment of the status as Good or Not Good (for guidance on how to translate this assessment into the X-threshold of the Acceptable Level of Impact, see (Schekkerman 2024), for the Acceptable Level of Impact, see (Hin et al. 2023, 2024). The following columns present the background information behind this assessment.*

| | Summary | National | | | | | | | International | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Species** | **Assessment of conservation status:** | **Conservation Status (Staat an Instandhouding)** | | | | | | | **MSFD/OSPAR** | | **IUCN-status** | | **HPAI bird flu[12]** |
| | | season[1] | SvI[2] | GRP[3] | current pop. [4] | pop: GRP[5] | trend 1980[6] | trend 12 yr[7] | D1C2[8] | D1C3[9] | Europa[10] | EU 28[11] | |
| Bewick's swan | Not good | nb | ZO | 2.800 | 1.700 | 61% | - | -- | . | . | VU | VU | - |
| Brent goose | Good | nb | G | 42.000 | 42.000 | 100% | + | = | 0.79 | . | LC | LC | - |
| Common shelduck | Good | br | G | . | . | . | = | = | 1.09 | . | LC | LC | † |
| | | nb | G | 41.000 | 65.000 | 158% | + | = | | | | | |
| Little gull | Good | br | ZO | . | . | . | -- | ~ | . | . | LC | LC | - |
| | | nb | G | 14.000 | 14.000 | 100% | = | = | | | | | |
| Red knot | Good | nb | G | 51.000 | 67.000 | 131% | + | = | 0.58 | . | LC | LC | † |
| Eurasian curlew | Not good | br | ZO | . | . | . | - | - | 1.01 | . | NT | NT | - |
| | | nb | G | 86.000 | 126.000 | 147% | + | = | | | | | |
| Black tern | Not good | br | ZO | 10.000* | 1.400 | 14% | + | - | . | . | LC | LC | - |
| | | nb | ZO | 71.000* | 15.000 | 21% | - | - | | | | | |
| Common starling | Not good | br | ZO | . | . | . | - | + | . | . | LC | LC | - |
| | | nb | ZO | . | . | . | - | = | | | | | |

**Season**: The season relevant for the Dutch conservation status assessment: *br* = breeding birds, *nb* = non-breeding birds.
**SvI**: Formal conservation status in the Netherlands: *G* = favourable, *MO* = moderately unfavourable, *ZO* = highly unfavourable.
**GRP**: Favorable reference population size, expressed in breeding pairs (*br*) or seasonal average number of individuals (*nb*).
**Current Pop.**: Recent population size (period 2014/15–2019/20); same units as in GRP (Sovon 2024).
**Pop:GRP**: Recent population size as a percentage of the GRP.
**Trend 1980**: Population trend in the Netherlands since 1980: **++** strong increase; **+** moderate increase; **=** stable; **~** unclear; **-** moderate decline; **--** strong decline (Source: Sovon statistics)
**Trend 12 years**: Population trend in the Netherlands over the last 12 years (symbols and source as in Trend 1980).
**D1C2**: Marine Strategy Framework Directive (MSFD) and OSPAR indicator for seabird abundance in the International North Sea: Favourable if ≥0.7 or ≥0.8, otherwise unfavourable (Dierschke et al. 2022).
**D1C3**: MSFD and OSPAR indicator for seabird breeding productivity: Expressed as a hypothetical IUCN category the population would fall into if the current productivity remained unchanged for three generations (Frederiksen et al. 2022).
**Europe**: IUCN status category for the European population: LC (Least Concern), NT (Near Threatened), VU (Vulnerable), EN (Endangered), CR (Critically Endangered) (BirdLife International 2024)
**EU 28:** IUCN status category for the population within the 28 EU member states (BirdLife International 2021).
**HPAI**: Mortality due to highly pathogenic avian influenza (HPAI) during outbreaks in 2022–2023, whose effects have not yet been incorporated into SvI and MSFD indicators: - No extraordinary mortality in Western Europe; † Above-average mortality due to HPAI, but not significant enough to cause a negative change in SvI or IUCN status; †† High mortality (tens of percent of the adult population), potentially leading to a negative change in SvI or IUCN status.

### 9.2.6 Pressures

Migratory birds rely on safe and suitable breeding, stopover, and wintering habitats, as well as unhindered connections between them. Migratory bird species are especially sensitive to the pressures "reduction of stopover areas and habitat quality", "disturbance, barriers", "barrier to species movement, and "additional mortality" caused by collision and hunting. As most species considered only migrate over the North Sea, the pressures within this region are likely less influential than those encountered elsewhere along their migratory routes. An exception is the little gull that makes several-week stopover in the North Seaduring spring and autumn migration. For the rest of the species considered here, the offshore North Sea is not part of the reproduction or feeding habitat and the air space above the North Sea only serves as a corridor between the breeding areas and wintering and/or stopover sites.

Among the selected migratory bird species, only the little gull is a seabird and is thus exposed to a number of threats in the North Sea, such as displacement caused by offshore infrastructures, oil spills, other pollution, and food (small pelagic fish) availability decline (Bradbury *et al.* 2014, Leopold *et al.* 2015, Potiek *et al.* 2022). However, all the species cross the North Sea during migration and can suffer from collisions with offshore wind turbines and from light pollution by industrial structures, vessels, oil and gas platforms (Leopold et al. 2015, Schwemmer et al. 2023, Green et al. 2019, Krijgsveld et al. 2009). The North Sea threats with their pressures relevant for migratory bird species are (Jongbloed et al. 2025):

- For all eight migratory bird species:
  - Collisions with offshore wind turbines
  - Barrier effects of offshore windfarms during migration
  - Light pollution and flaring by oil and gas platforms
- For little gull, in addition to the above:
  - Displacement by offshore wind turbines and shipping
  - Pollution
  - Food availability and accessibility decline

### 9.2.7 Current policy

The Netherlands has obligations to protect (specific) migratory bird species under the EU Birds Directive, the EU Marine Strategy Framework Directive (MSFD) and the North Sea Agreement. Recently a background document for the species protection plan was developed for migratory seabird species as was agreed in the North Sea Agreement (Jongbloed et al. 2025). These frameworks for migratory bird conservation in the Dutch North Sea put forward several targets that are described in the background document as well as summarized below.

**1. Marine Strategy Framework Directive (MSFD) – Good Environmental Status (GES)**
**Objective**: Ensure that seabird populations reflect healthy ecological conditions, based on abundance, demographic trends, and reproductive success.

- **Population Size (D1C2)**: For each functional group, at least 75% of species must maintain population levels above a threshold based on historical baselines (updated in OSPAR 2023).
- **EU Birds Directive Compliance (D1C2)**: Populations must align with national targets set under the EU Birds Directive.
- **Breeding Success (D1C3)**: Breeding performance should be sufficient to avoid population declines of ≥30% over three generations (updated in OSPAR 2023).
- **D1T1**: Improve assessment methods of bird populations and identifying key pressures at regional level.
- **D1T2**: Support recovery by reducing fishery impacts in designated Natura 2000 areas (e.g. "De Vlakte van de Raan" and "North Sea Coastal Zone").
- **D1T3**: Achieve conservation objectives for habitats and species in the Natura 2000 areas.
- **D1T7**: Monitor bird collisions with offshore wind turbines (Wozep[14] programme).

**Note**: MSFD targets are formalized in *Marine Strategy Part I – Environmental Status* (2018) and are updated every six years. The most recent public consultation took place in summer 2025, and formal adoption of the revised Marine Strategy is planned for 2026.

**2. Natura 2000 and EU Birds Directive**
**Protection Mechanisms**:

- **Species Protection**: All bird species are protected; Annex I species require special habitat conservation, and Annex II species may be hunted under specific conditions.

2 [14] Wind op zee ecologisch programma (Wozep), see: https://noordzeeloket.nl/functies-gebruik/energietransitie-zee/windenergie-zee/ecologie/wind-zee-ecologisch-programma-wozep/

- **Area Protection**: Three marine Natura 2000 sites in the Dutch North Sea have been designated to safeguard some of the migratory bird species selected in this report:
    - *North Sea Coastal Zone*: common shelduck, little gull, red knot, Eurasian curlew
    - *Voordelta*: common shelduck, little gull, Eurasian curlew
    - *Brown Ridge*: little gull

**Conservation Targets**:

- Maintain population size and habitat quality for designated species.
- Align with nationally defined targets and Favourable Reference Values (FRVs) (Sovon, 2022).

#### 9.2.7.1 Policy measures

Actions and measures for the migratory birds are suggested in background report (Jongbloed et al. 2025). Below, a selection of measures with the highest action perspective are listed. This includes the management and use of the North Sea through optimizing the spatial planning of offshore wind farms, minimizing collision and barrier effects, and reducing light and chemical pollution. Although offshore wind development will continue, improving impact assessment and integrating bird-sensitive design and operation (e.g. curtailment regimes, increased blade visibility) can help mitigate mortality and disturbance during migration. Such actions primarily aim to reduce anthropogenic pressures and maintain safe migration corridors. Furthermore, restricted fishing can also contribute to improved foraging conditions for the little gull. Restoration measures to enhance or create habitats that support feeding or resting birds, could be especially beneficial for species such as the little gull, black tern, Bewick's swan, Eurasian curlew, red knot, and brent goose, which depend on coastal and estuarine environments connected to the North Sea.

***Table 9.7*** *Overview of policy measures for migratory birds (Jongbloed et al. 2025).*

| **Measure** | **Species** | **Rationale/objective** |
|---|---|---|
| Improved offshore wind farm planning, including spatial optimization and curtailment regimes | All migratory species | Reduce collision risk, barrier effects, and mortality during migration |
| Engineering solutions (e.g. bladeless turbines) | All migratory species | Reduce collision risk |
| Reduction of artificial light and flaring at sea | All migratory species | Minimize disorientation and collision risk caused by light attraction |
| Designation of MPAs with restricted fishing, including nature transition | Little gull | Improve prey (small pelagic fish) availability and reduce disturbance |

### 9.2.8 Advice and action perspectives

*Rationale*

Populations of some of the selected migratory bird species that use the North Sea and its coastal zones are under pressure, showing declining or unfavourable conservation status. While species such as the brent goose and red knot are currently stable or recovering, others, including Bewick's swan, Eurasian curlew, and black tern, remain vulnerable due to various pressures at the breeding sites, wintering grounds and stopover sites along their migratory routes. For the little gull, the overall population is considered stable, yet the species remains of concern because a large proportion of the population depends on suitable conditions in the North Sea during migration and staging periods, making it sensitive to local pressures such as disturbance, displacement, and reduced food availability.

*Action perspective for NN*

Within this framework NN can contribute to migratory bird recovery by focusing on habitat-oriented and ecosystem-based measures that complement policy-level actions (such as spatial planning and fisheries regulation).

For migratory birds, the majority of direct restoration measures are limited to improving stopover and foraging habitat quality in connected estuarine systems such as the Wadden Sea, Delta region, and IJsselmeer, rather than in the open North Sea itself. These habitats provide essential resting and feeding opportunities during migration. Measures such as restoring shallow vegetated shorelines, dynamic water levels, and intertidal zones can improve prey availability for species like Bewick's swan, black tern, Eurasian curlew, red knot, and little gull.

Within the NN opportunities for migratory birds lie in research and development of mitigation measures similar to those described for seabirds, aimed at reducing mortality and disturbance from offshore activities caused by pressures like collision and displacement. This includes the development and testing of operational mitigation measures for offshore wind farms, such as turbine curtailment, increased lowest tip height, improved blade visibility, and acoustic deterrence (RRL 1–3).

*Demonstration of impact*

On a large scale, existing programmes such as Wozep and national bird counts can be used to track migration intensity, spatial use, and collision risk. On a smaller scale, NN could implement project-specific monitoring at offshore wind farms, similar to approaches for seabirds, such as radar or camera-based monitoring to assess the effectiveness of mitigation measures such as light reduction or curtailment. In coastal and estuarine areas, bird use and prey availability can be monitored to evaluate improvements in foraging and stopover habitat quality.

### 9.2.9 References


AEWA Eurasian Curlew IWG. (2022). *Rolling Work Plan 2023-2025 for Breeding Range States.* https://www.unep-aewa.org/sites/default/files/document/aewa_ec_iwg_workplan_rolling.pdf

Beekman, J., Koffijberg, K., Wahl, J., Kowallik, C., Hall, C., Devos, K., Clausen, P., Hornman, M., Laubek, B., Luigujõe, L., Wieloch, M., Boland, H., Švažas, S., Nilsson, L., Stipniece, A., Keller, V., Gaudard, C., Degen, A., Shimmings, P., … Rees, E. C. (2020). Long-term population trends and shifts in distribution of Bewick's swans cygnus columbianus bewickii wintering in northwest Europe. *Wildfowl*, *69*, 73–102.

Beintma, A.J., Winden, J. van der, Baarspul, T., Krijger, J.P. de, Oers, K. van & Keller, M. (2010). Black Terns Chlidonias niger and Their Dietary Problems in Dutch Wetlands. Ardea 98: 365–372. Bijleveld, A.I. 2015. Untying the knot: Mechanistically understanding the interactions between social foragers and their prey. University of Groningen.

BirdLife International. 2024. Data Zone. Accessed in 2024 at: https://datazone.birdlife.org/

Bocher, P., Donnez, M., Chenu, A., Sviridova, T., Fort, J., Garthe, S., Jiguet, F., Piha, M., Elts, J., Marja, R., Amélineau, F., Robin, F., Rousseau, P. & Schwemmer, P. (2024). Home ranges and hatching success of threatened Eurasian curlew in north-eastern Europe relates to habitat type: Natural vs. agricultural landscapes. Glob. Ecol. Conserv. 50: e02851.

Bos, D. & Stahl, J. (2003). Creating new foraging opportunities for dark-bellied brent Branta bernicla and barnacle geese Branta leucopsis in spring - insights from a large-scale experiment.

Bos, O., Schekkerman, H., Kingma, E., Tamis, J., Goutbeek, A., Van Oijen, T. & Jongbloed, R. (2023). Offshore birds in the Dutch North Sea: Background document for a protection plan. Wageningen Marine Research report, no. C087/23, https://doi.org/10.18174/644064

Bradbury, G., Trinder, M., Furness, B., Banks, A. N., Caldow, R. W. G., & Hume, D. (2014). Mapping Seabird Sensitivity to offshore wind farms. *PLoS ONE*, *9*(9). https://doi.org/10.1371/journal.pone.0106366

Brown, D.J. 2015. International Single Species Action Plan for the Conservation of the Eurasian Curlew (TS No. 58) | AEWA.

Buehler, D. M., Tieleman, B. I., & Piersma, T. (2010). How do migratory species stay healthy over the annual cycle? A conceptual model for immune function and for resistance to disease. *Integrative and Comparative Biology*, *50*(3), 346–357. https://doi.org/10.1093/ICB/ICQ055

Cook, A. S. C. P., Burton, N. H. K., Dodd, S. G., Foster, S., Pell, R. J., Ward, R. M., Wright, L. J., & Robinson, R. A. (2021). Temperature and density influence survival in a rapidly declining migratory shorebird. *Biological Conservation*, *260*, 109198. https://doi.org/10.1016/J.BIOCON.2021.109198

Cramp, S. & Simmons, K.E.L. (1977). The birds of the Western Palearctic. Oxford University Press, Oxford.

Davidson, N.C. & Piersma, T. (1992). The migrations and annual cycles of five subspecies of knots in perspective. Wader Study Group Bull. 187–197.

Dekker, D., & Ydenberg, R. (2004). Raptor Predation on Wintering Dunlins in Relation to the Tidal Cycle. *The Condor: Ornithological Applications*, *106*(2), 415–419. https://doi.org/10.1093/CONDOR/106.2.415

del Hoyo, J.; Elliott, A.; Sargatal, J. (1996). Handbook of the Birds of the World, vol. 3: Hoatzin to Auks. Lynx Edicions, Barcelona, Spain.

Dokter, A.M., Fokkema, W., Ebbinge, B.S., Olff, H., van der Jeugd, H.P. & Nolet, B.A. (2018). Agricultural pastures challenge the attractiveness of natural saltmarsh for a migratory goose. J. Appl. Ecol. 55: 2707–2718.

Ebbinge, B.S., Blew, J., Clausen, P., Günther, K., Hall, C., Holt, C., Koffijberg, K., Dréan-Quénec'hdu, S.L., Mahéo, R. & Pihl, S. (2013). Population development and breeding success of Dark-bellied Brent Geese Branta b. bernicla from 1991–2011. Wildfowl 74–89.

Fijn, R., Poot, M.J.M., Arts, F., Bemmelen, R.S.A. van, Hornman, M., Jong, J. de, Schekkerman, H., Soldaat, L. & Troost, G. (2022). Dutch waters form an internationally important stopover for the Little Gull (*Hydrocoloeus minutus*). Limosa 95: 160–177.

Green, R. M. W., Burton, N. H. K., & Cook, A. S. C. P. (2019). Migratory movements of British and Irish Common Shelduck Tadorna tadorna: a review of ringing data and a pilot tracking study to inform potential interactions with offshore wind farms in the North Sea. *Ringing and Migration*, *34*(2), 71–83.

Griffin, L., Rees, E. & Hughes, B. (2016). Satellite tracking Bewick's Swan migration in relation to offshore and onshore wind farm sites. WWT Final Report to the Department of Energy and Climate Change. WWT, Slimbridge 55pp.

Gyimesi, A., Evans, T., Linnebjerg, J., de Jong, J., Collier, M. & Fijn, R. (2017). Review and analysis of tracking data to delineate flight characteristics and migration routes of birds over the Southern North Sea. Bureau Waardenburg bv. Report nr 16-139. Culemborg, the Netherlands

Heldbjerg, H., Fox, A.D., Lehikoinen, A., Sunde, P., Aunins, A., Balmer, D.E., Calvi, G., Chodkiewicz, T., Chylarecki, P., Escandell, V., Foppen, R., Gamero, A., Hristov, I., Husby, M., Jiguet, F., Kmecl, P., Kålås, J.A., Lewis, L.J., Lindström, Å., Moshøj, C., Nellis, R., Paquet, J.-Y., Portolou, D., Ridzoň, J., Schmid, H., Skorpilová, J., Szabó, Z.D., Szép, T., Teufelbauer, N., Trautmann, S., Turnhout, C. van, Vermouzek, Z., Voříšek, P. & Weiserbs, A. (2019). Contrasting population trends of Common Starlings (*Sturnus vulgaris*) across Europe. *Ornis Fenn.* 96: 153–168.

Jongbloed, R., Schekkerman, H., Kingma, E., Tamis, J., Goutbeek, A., Van Oijen, T. & Bos, O. (2023). Surface-feeding birds of the coastal waters in the Dutch North Sea : Background document for a protection plan. Wageningen Marine Research report C097/23. https://doi.org/10.18174/644517

Jongbloed, R.H., J. Karagicheva, J.E. Tamis, H. Schekkerman, T. van Oijen & M.J.M. Poot (2025). Migratory birds and Red List birds of the Dutch North Sea. Background document for a protection plan. Wageningen Marine Research report C090/25. https://doi.org/10.18174/704363

Kleefstra, R., Bregnballe, T., Frikke, J., Günther, K., Hälterlein, B., Hansen, M. B., Hornman, M., Ludwig, J., Meyer, J., & Scheiffarth, G. (2022). *Trends of Migratory and Wintering Waterbirds in the Wadden Sea 1987/1988 - 2019/2020.*

Koffijberg, K., Winden, E. van, & Clausen, P. (2013). The Netherlands as a winter refuge for Light-bellied Brent Geese Branta bernicla hrota. *Wildfowl*, *Special Issue*(3), 40–56.

Kouzov, S.A., Kravchuk, A.V., Koptseva, E.M., Gubelit, Y.I., Zaynagutdinova, E.M. & Abakumov, E.V. (2024). Ecological and phylogenetic aspects of the spring diet of three palaearctic species of swans. BMC Ecol. Evol. 24: 17.

Kraan, C., Piersma, T., Dekinga, A., Koolhaas, A., van der Meer, J., Kraan, C., Dekinga, T., Koolhaas, A., van der Meer, A., Dekinga, A., & van der Meer, J. (2007). Dredging for edible cockles (Cerastoderma edule) on intertidal flats: short-term consequences of fisher patch-choice decisions for target and non-target benthic fauna. *ICES Journal of Marine Science*, *64*(9), 1735–1742. https://doi.org/10.1093/ICESJMS/FSM153

Krijgsveld, K. L., Akershoek, K., Schenk, F., Dijk, F., & Dirksen, S. (2009). Collision risk of birds with modern large wind turbines. *Ardea*, *97*(3), 357–366. https://doi.org/10.5253/078.097.0311

Lank, D. B., & Ydenberg, R. C. (2003). Death and danger at migratory stopovers: Problems with "predation risk." *Journal of Avian Biology*, *34*(3), 225–228. https://doi.org/10.1034/J.1600-048X.2003.03250.X

Leopold, M. F., Booman, M., Collier, M. P., Davaasuren, N., Fijn, R. C., Gyimesi, A., de Jong, J., Jongbloed, R. H., Jonge Poerink, B., Kleyheeg-Hartman, J., Krijgsveld, K. L., Lagerveld, S., Lensink, R., Poot, M. J. M., van der Wal, J. T., & Scholl, M. (2015). *A first approach to deal with cumulative effects on birds and bats of offshore wind farms and other human activities in the Southern North Sea.* https://library.wur.nl/WebQuery/wurpubs/482985

Leopold, M.F., Poot, M., Tamis, J., Schekkerman, H., Goutbeek, A., van Oijen, T. & Jongbloed, R. (2025). Seabirds in the Dutch North Sea. Background document for a protection plan for seabirds potentially vulnerable to offshore wind farms. Wageningen Marine Research report C047/25. https://doi.org/10.18174/695037

Linssen, H., van Loon, E. E., Shamoun-Baranes, J. Z., Nuijten, R. J. M., & Nolet, B. A. (2023). Migratory swans individually adjust their autumn migration and winter range to a warming climate. *Global Change Biology*, *29*(24), 6888–6899.

Ly, J., Philippart, C. J. M., & Kromkamp, J. C. (2014). Phosphorus limitation during a phytoplankton spring bloom in the western Dutch Wadden Sea. *Journal of Sea Research*, *88*, 109–120. https://doi.org/10.1016/J.SEARES.2013.12.010

Michael, P.E., Gleason, J.S., Haney, J.C., Hixson, K.M., Satgé, Y.G. & Jodice, P.G.R. (2024). Black Terns (*Chlidonias niger*) beyond the breeding grounds: Occurrence, relative density, and habitat associations in the northern Gulf of Mexico. Wilson J. Ornithol. 136: 220–236.

Navedo, J.G., Gutiérrez, J.S., Salmón, P., Arranz, D., Novo, M., Díaz-Cosín, D.J., Herrera, A.G. & Masero, J.A. (2020). Food Supply, Prey Selection and Estimated Consumption of Wintering Eurasian Curlews Feeding on Earthworms at Coastal Pastures. Ardea 107: 263–274.

Nuijten, R. & Nolet, B. (2020). Chains as strong as the weakest link: remote assessment of aquatic resource use on spring migration by Bewick's Swans. Avian Conserv. Ecol. 15.

PECBMS. 2024. European species trends accessed at: https://pecbms.info/

Piersma, T., Verkuil, Y. & Tulp, I. (1994). Resources for Long-Distance Migration of Knots *Calidris canutus islandica* and *C. c. canutus*: How Broad Is the Temporal Exploitation Window of Benthic Prey in the Western and Eastern Wadden Sea? Oikos 71: 393–407.

Poot, M., Roelen, B. & Piersma, T. (2014). Red Knots scavenging on large, dying cockles: opportunistic feeding by a sensory specialized mollusc-crushing shorebird. Wader Study Group Bull. 121: 33–42.

Potiek, A., Leemans, J. J., Middelveld, R. P., & Gyimesi, A. (2022). *Cumulative impact assessment of collisions with existing and planned offshore wind turbines in the southern North Sea Analysis of additional mortality using collision rate modelling and impact assessment based on population modelling for the KEC 4.0 Ecology & Landscape*. Report 21-205. Bureau Waardenburg, Culemborg

Reijers, V. C., van Rees, F., van der Heide, T., Oost, A. P., Ruessink, G., Koffijberg, K., Camphuysen, K. C. J., Penning, E., Hijner, N., & Govers, L. L. (2024). Birds influence vegetation coverage and structure on sandy biogeomorphic islands in the Dutch Wadden Sea. *Science of The Total Environment*, *950*, 175254. https://doi.org/10.1016/J.SCITOTENV.2024.175254

Roodbergen, M., van der Werf, B., & Hötker, H. (2012). Revealing the contributions of reproduction and survival to the Europe-wide decline in meadow birds: review and meta-analysis. *Journal of Ornithology*, *153*(1), 53–74. https://doi.org/10.1007/S10336-011-0733-Y

Schekkerman, H. (2024). Invulling van parameterwaarden voor herziene Acceptable Levels of Impact van sterfte van vogels door windparken op zee. Notitie bestemd voor Min LVVN. In *SOVON Notitie-nummer: 2024/53.*

Schwemmer, P., Pederson, R., Haecker, K., Bocher, P., Fort, J., Mercker, M., Jiguet, F., Elts, J., Marja, R., Piha, M., Rousseau, P., & Garthe, S. (2023). Assessing potential conflicts between offshore wind farms and migration patterns of a threatened shorebird species. *Animal Conservation*, *26*(3), 303–316.

Sovon (2022). Bouwstenen voor het Strategisch Plan Natura 2000: factsheets van vogelsoorten die be trokken zijn bij de instandhoudingsdoelstellingen voor Natura 2000-gebieden.

Sovon (2024). Species overview. Accessed in 2024 at: https://stats.sovon.nl/stats/soorten

Stillman, R., West, A., Goss-Custard, J., McGrorty, S., Frost, N., Morrisey, D., Kenny, A. & Drewitt, A. (2005). Predicting site quality for shorebird communities: a case study on the Humber estuary, UK. Mar. Ecol. Prog. Ser. 305: 203–217.

The Global Consortium for H5N8 and Related Influenza Viruses. (2016). Role for migratory wild birds in the global spread of avian influenza H5N8. *Science (New York, N.Y.)*, *354*(6309), 213–217. https://doi.org/10.1126/SCIENCE.AAF8852

Van Gils, J.A., Lisovski, S., Lok, T., Meissner, W., Ożarowska, A., De Fouw, J., Rakhimberdiev, E., Soloviev, M.Y., Piersma, T. & Klaassen, M. (2016). Body shrinkage due to Arctic warming reduces red knot fitness in tropical wintering range. Science 352: 819–821.

Van Roomen, M., Citegetse, G., Crowe, O., Dodman, T., Hagemeijer, W., Meise, K. & Schekkerman, H. (2022). East Atlantic Flyway Assessment 2020.The status of coastal waterbird populations and their sites. Sovon Vogelonderzoek.

Versluijs, M., Turnhout, C.A.M. van, Kleijn, D. & Jeugd, H.P. Van der (2016). Demographic Changes Underpinning the population decline of starlings *Sturnus vulgaris* in The Netherlands. Ardea 104: 153–165.

Viana, D. S., Santamaría, L., & Figuerola, J. (2016). Migratory Birds as Global Dispersal Vectors. *Trends in Ecology & Evolution*, *31*(10), 763–775. https://doi.org/10.1016/J.TREE.2016.07.005

Wilson, J.R. & Tomkovich, P.S. (2017). Spring migration of Red Knot *Calidris canutus* subspecies through N Europe. Wader Study 124: 125–133.

Woodward, I.D., Franks, S.E., Bowgen, K. & Davies, J.G. (2023). Strategic study of collision risk for birds on migration and further development of the stochastic collision risk modelling tool. Work Package 1: Strategic review of birds on migration in Scottish waters. Report by British Trust for Ornithology, Royal Society for the Protection of Birds and ECO-LG to The Scottish Government, Crown Estate Scotland and The Crown Estate.

Zhou, L. C., Liu, J., Pei, E. le, Xue, W. J., Lyu, J. M., Cai, Y. T., Wu, D., Wu, W., Liu, Y. Y., Jin, H. Y., Gao, Y. W., Wang, Z. H., & Wang, T. H. (2016). Novel Avian Influenza A(H5N8) Viruses in Migratory Birds, China, 2013-2014. *Emerging Infectious Diseases*, *22*(6), 1121–1123. https://doi.org/10.3201/EID2206.151754

# 10 Marine mammals

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## 10.1 Description of ecosystem component

Marine mammals are generally long lived high trophic level predators that play a vital role in maintaining ecosystem balance and can serve as key indicators of general ocean health. Their diet and body condition reflect long-term changes in food webs, and their decline can cause cascading effects, destabilizing marine ecosystems. Additionally, marine mammals bioaccumulate pollutants like persistent organic pollutants (POPs), and heavy metals making them valuable sentinels for assessing chemical contamination and its impacts on marine environments and human health.

As charismatic species, marine mammals hold significant societal value. Moreover, all marine mammal species that occur regularly in the North Sea are legally protected. Marine mammals are relatively well monitored, as they are observable either at the surface or at haul-out areas. Within the North Sea, marine mammal populations have undergone notable changes (Engelhard et al. 2014, ICES 2024). For seals, this was primarily due to overhunting until the 20th century, whereas harbour porpoises have experienced distributional shifts. Currently, pollution, (noise) disturbance, and bycatch are considered the major anthropogenic threats, while environmental changes, which can cause shifts in prey distribution, will define their distribution.

## 10.2 Focus species

This report focuses on three resident marine mammal species of the North Sea: the harbour porpoise (*Phocoena phocoena*), the grey seal (*Halichoerus grypus*), and the harbour seal (*Phoca vitulina*). The harbour porpoise is the most abundant cetacean species in the Greater North Sea, 2022 (Gilles et al. 2023). The other resident cetacean species, white-beaked dolphin (*Lagenorhynchus albirostris*) and minke whale (*Balaenoptera acutorostrata*) occur in lower numbers (Gilles et al. 2023). Though arctic pinnipeds are regularly observed, only two pinniped species are resident to the North Sea: the grey seal and the harbour seal (ICES 2024). In Dutch waters, harbour porpoises and then grey and harbour seals are the most abundant (CLO 2025).

### 10.2.1 Rationale for selection

Given their relatively high abundance, thus their importance for the ecosystem, harbour porpoises, harbour and grey seals are the most ecologically significant marine mammals for restoration measures. These species serve as key indicators of ecosystem health and play important roles in marine food webs. Their abundance and the availability of aerial survey and tracking data make them suitable for monitoring status and trend and assessing conservation measures. However, their highly mobile nature makes targeted restoration challenging. While restoring specific habitats or mitigating localized threats might be more straightforward for the haul out areas of seal species (where they haul out, breed and moult), efforts to restore habitats at sea are deemed more challenging. Nevertheless, restoring habitat at sea could benefit both seals and porpoises by improving overall ecosystem health.

# 10.3 Habitat preferences

### 10.3.1 Harbour porpoise

Harbour porpoises in European waters primarily inhabit shallow, dynamic marine environments characterized by complex bathymetry, diverse substrates, and variable oceanographic conditions (Hammond et al. 2002, Gilles et al. 2016, Waggitt et al. 2017). Their distribution is strongly influenced by prey availability, with higher densities found in areas with significant sea surface temperature variability, likely due to oceanographic fronts that concentrate prey (Gilles et al. 2016). In the southern North Sea, they are commonly found at depths of 25–40 meters and around 150 km offshore, with proximity to sand eel grounds being a key factor in their habitat selection (Gilles et al. 2016). Porpoise distribution varies seasonally, with hotspots shifting from inshore areas in spring to offshore regions in summer (Gilles et al. 2016).

### 10.3.2 Grey and harbour seals

Like all seals harbour and grey seals associate with both terrestrial and aquatic habitats, though clearly more time is spent at sea than on land. In line with their phenology seals require land to breed and moult. In the Netherlands this is predominantly (tidal) sandbanks, away from human reach. Grey seal pups born in November-January, require continuous dry areas during their nursing period (~21 days) and consecutive moult (1-4 weeks), while harbour seal pups (May-July) can swim immediately after birth, though they need land to suckle (~24 days). After breeding, the older seals moult (grey seals in March-April; harbour seals in July-September), then again land is needed to dry the pelt and insure circulation in the skin. Outside these periods seals spend most of their time offshore at sea, but return regularly to sandbanks to rest, then functioning as central-place foragers. Grey seals tend to aggregate in large numbers on haul-out sites, mostly located on the more exposed outer edges of the Wadden Sea and Delta region. Compared to grey seals, harbour seals are more spread out in often smaller aggregations over the available haul-out sites and are often found on inter-tidal sandbanks, including those further into the Wadden Sea (Figure 10-1).

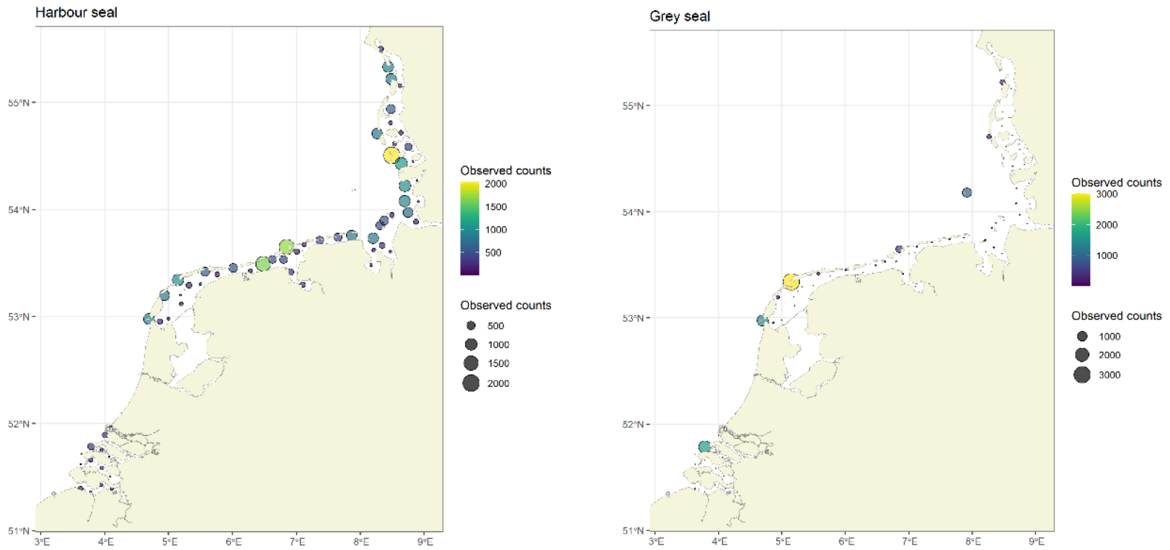



***Figure 10-1*** *Average (10 year) distribution of harbour seals (left panel) and grey seals (right panel) on the haul-out sites in the international Wadden Sea and Delta region during the moult season of each species. Note, haul-out sites are clustered to ensure proper visualisation.*

From the haul-out sites, seals make foraging trips to sea. Though harbour seals occasionally forage in the Wadden Sea, the vast majority (87%) of dive time is spent in the North Sea. Grey seals spend potentially even more time at sea. Since both seal species are central-place foragers, density of seals at-sea is highest near the proximity of the haul-out sites (Figure 10-2). While most of the trips are within approximately 50km from the haul-out site, harbour seals and particularly also grey seals make more distant trips offshore and may include distant areas such as the Dogger Bank, located more than 300km away. Seals depend on the North Sea for foraging and migration.

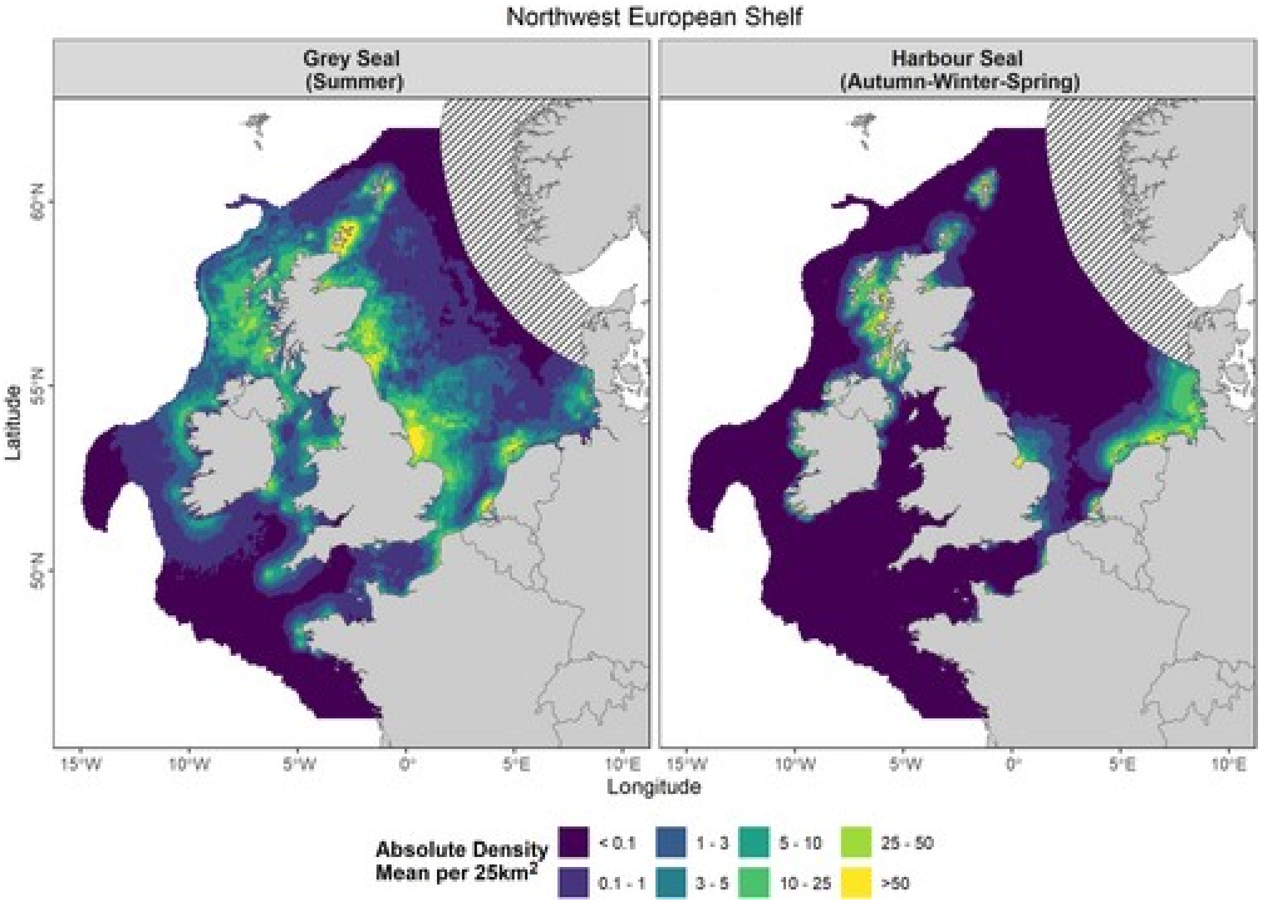



***Figure 10-2*** *At-sea distribution of grey and harbour seals, showing mean estimated densities per 5-km grid cell (from Carter et al. 2025). Grey seals (summer) occur in high densities in coastal waters near major haul-out sites, while substantial numbers are also present offshore. Harbour seals (autumn–winter–spring) are likewise concentrated near haul-out areas but display a more restricted, predominantly coastal distribution compared with grey seals.*

Data from tagged seals (2007–2019) in the Netherlands show habitat preferences based on depth, seabed structure, and proximity to resting sites (Figure 10-3).

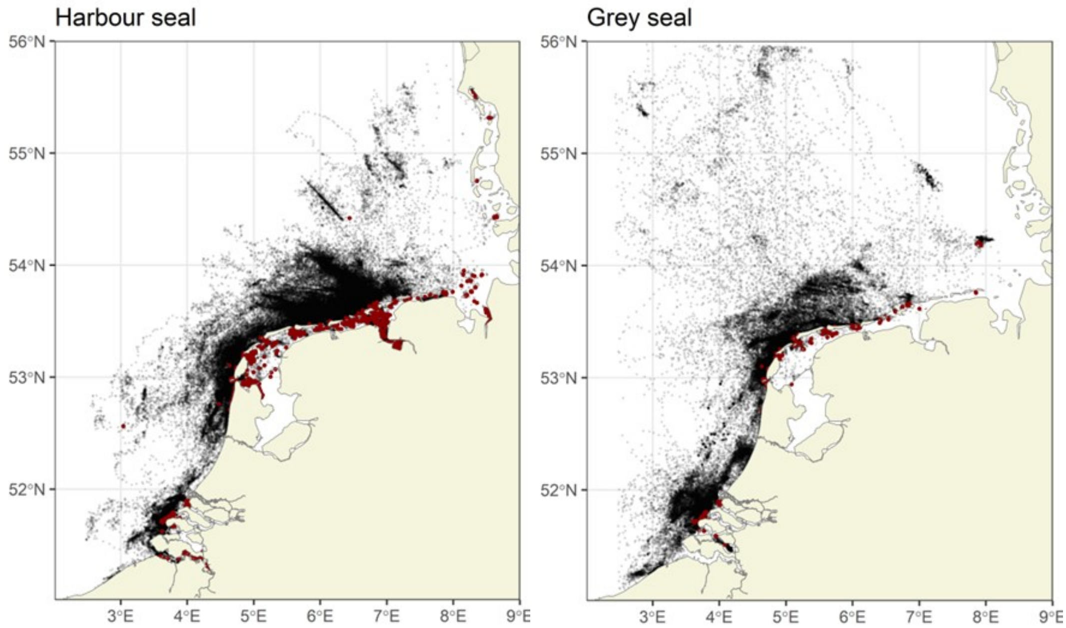



***Figure 10-3*** *Estimate of the mean density of harbour seals (left) and grey seals (right) in July (after Aarts et al. 2021).*

Both harbour and grey seals are predominantly benthic foragers, feeding on a variety of demersal fish species such as flat fish (plaice, sole, flounder and dab), sandeel, and other demersal species like five-bearded rockling, dragonet and bullrout, but also more mid-water species like cod and whiting. Both harbour and grey seal forage in areas with sandy and gravely substrate, and areas with high mud content (e.g. North of the Frisian Front) are generally avoided.

## 10.4 Ecosystem function

Marine mammals are long-lived, high trophic level predators that serve as key indicators of ecosystem health and they are widely distributed (Bestley et al. 2020). Their diet and body condition reflect long-term food web changes (Moore 2008). As apex predators, marine mammals play a crucial role in regulating marine ecosystems through top-down control, influencing prey populations and shaping trophic interactions. Many species have diverse diets, which helps maintain species diversity and ecosystem balance. The removal or decline of marine mammals can lead to cascading effects, such as prey population booms or shifts in species composition, potentially destabilizing entire food webs (Estes et al. 2011).

As high-level predators, marine mammals are also valuable indicators of ocean pollution. They accumulate persistent organic pollutants (POPs) and heavy metals through biomagnification, making them useful sentinels for assessing chemical contamination in marine ecosystems (Ross et al. 2000). The study of their tissue samples, blubber, and even exhaled breath can provide insights into long-term pollution trends and their potential impacts on marine food webs and human health.

## 10.5 Status and trend

### 10.5.1 Harbour porpoise

Large-scale North Sea wide SCANS surveys have provided consistent estimates of harbour porpoise abundance in the greater North Sea, with similar numbers recorded for 2022 (SCANS IV: 339,000, CV = 0.17), 2016 (SCANS III: 345,000, CV = 0.18), and 2005 (SCANS II: 355,000, CV = 0.22) (Gilles et al. 2023). The 1994 survey (SCANS I), the first in this series, recorded a somewhat lower estimate of 289,000 (CV = 0.14). These results suggest that harbour porpoise abundance in the North Sea has remained relatively stable over time.

The summer distribution of harbour porpoises has shifted significantly from northern regions to the south-western areas of the North Sea between 1994 and 2005, with this pattern persisting through 2016 (Hammond et al. 2002, 2013, 2021). This shift has resulted in a higher density of porpoises in Dutch parts of the North Sea. Although the precise causes are still uncertain, it is likely influenced by changes in prey availability and in particular sandeel abundance (Hammond et al. 2013, Sveegaard et al. 2012, Ransijn et al. 2021). It underscores the importance of understanding prey dynamics as a potential driver behind distribution changes.

Based on all available survey data from Belgium, Denmark, Germany and the Netherlands, density surface model outputs for harbour porpoise distribution in the southern North Sea were generated for spring, summer and autumn 2005-2013 and for summer 2014-2019 (Gilles et al. 2016, 2020; see Figure 10-4).

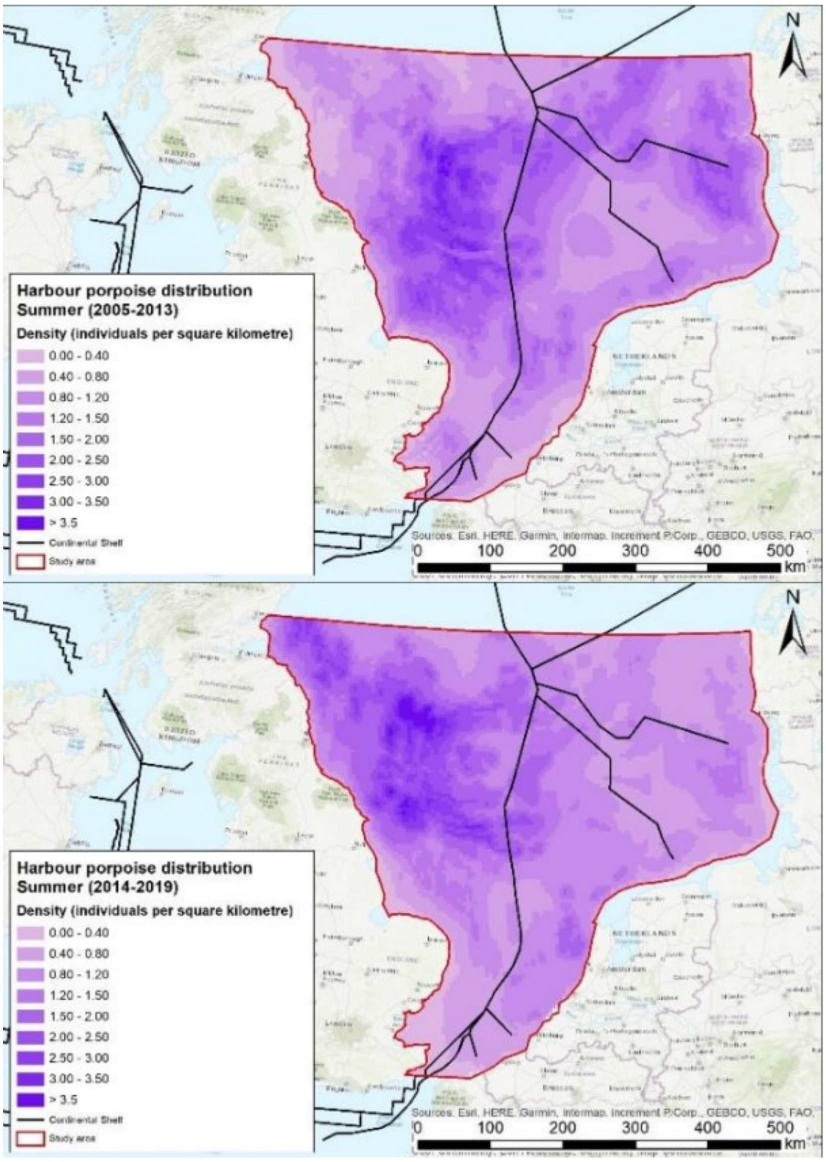



***Figure 10-4*** *Comparison of the updated distribution maps for harbour porpoise in summer based on 2005 – 2013 survey data (top) and 2014 – 2019 survey data (bottom). Source Gilles et al. (2016, 2020).*

Results from SCANS-II and SCANS-III show that the predicted core distribution in 2016 in the North Sea is very similar to that observed in 2005 (Figure 10-5). The SCANS-III distribution map also closely resembles the summer distribution map from surveys in the southern North Sea (Figure 10-4). However, the map for the southern North Sea includes more detail on distribution within the Dutch North Sea compared to the SCANS maps.

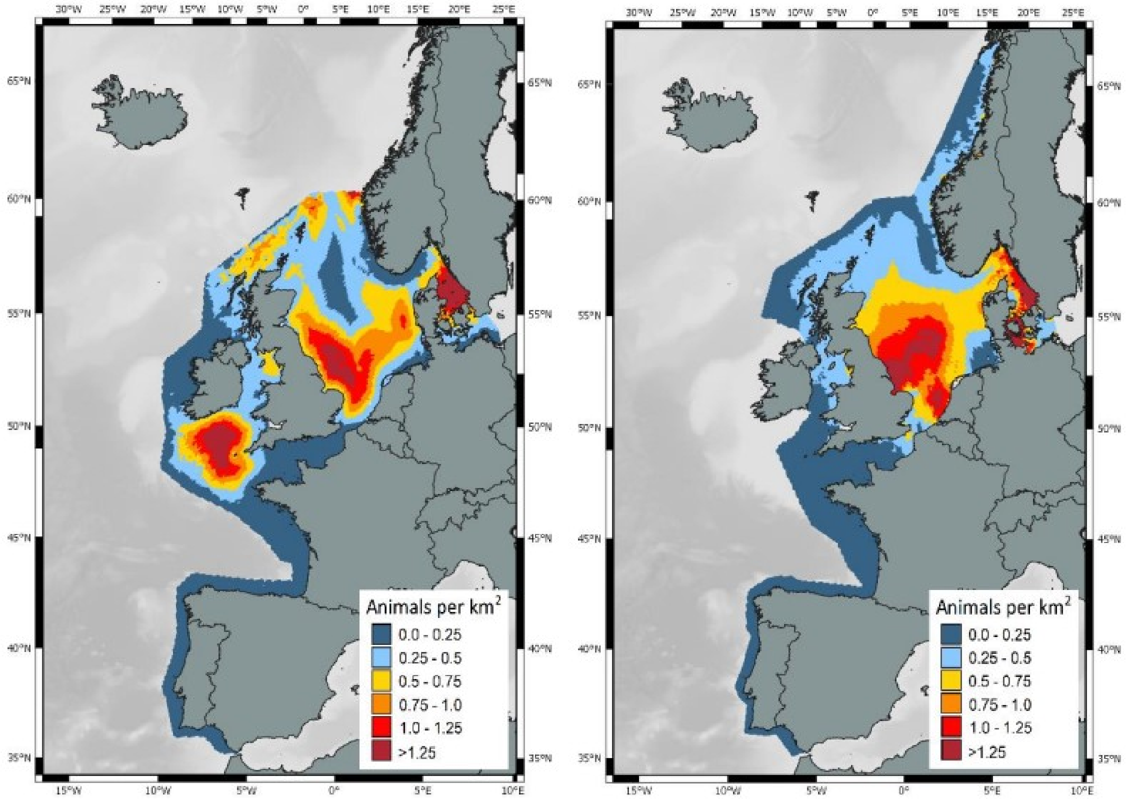



***Figure 10-5*** *Predicted surfaces of estimated density for harbour porpoise in SCANS-II (2005, left) and SCANS-III (2016, right).*

The SCANS maps complement the regional surveys by providing a broader greater North Sea basin perspective. The SCANS-IV density surface model results suggest a northward contraction of the 2005 and 2016 hotspot in the southern North Sea, between the Dutch mainland coast and the UK, and an extension from the northern part of the southern North Sea to the central North Sea (see Figure 10-6; Gilles et al. 2025).

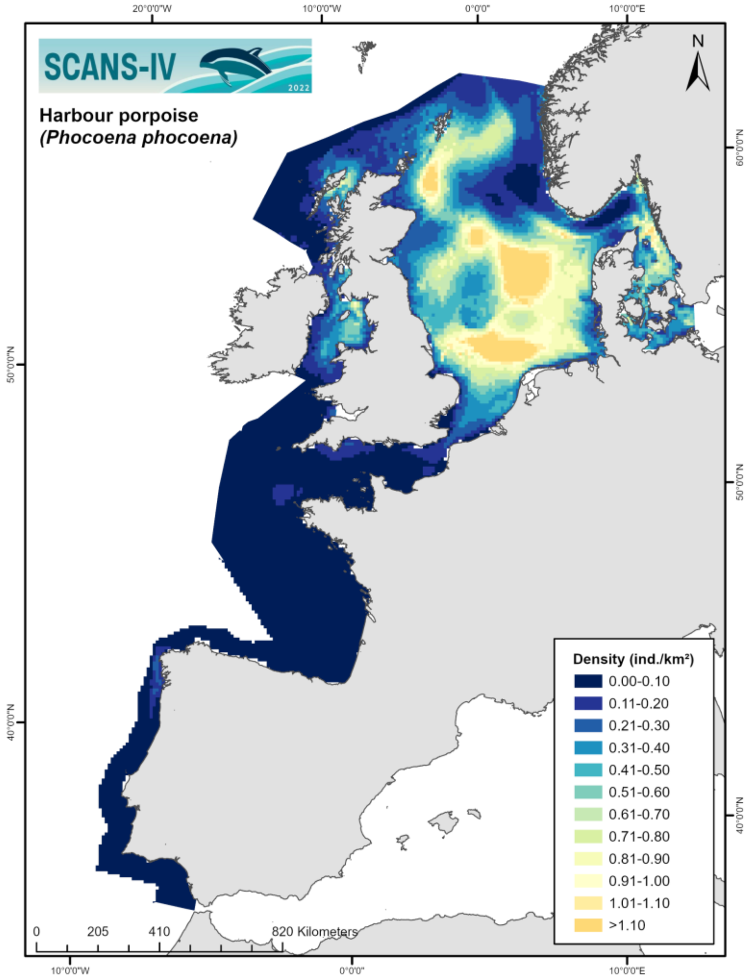



***Figure 10-6*** *Predicted surfaces of estimated density for harbour porpoise in SCANS-IV (2022).*

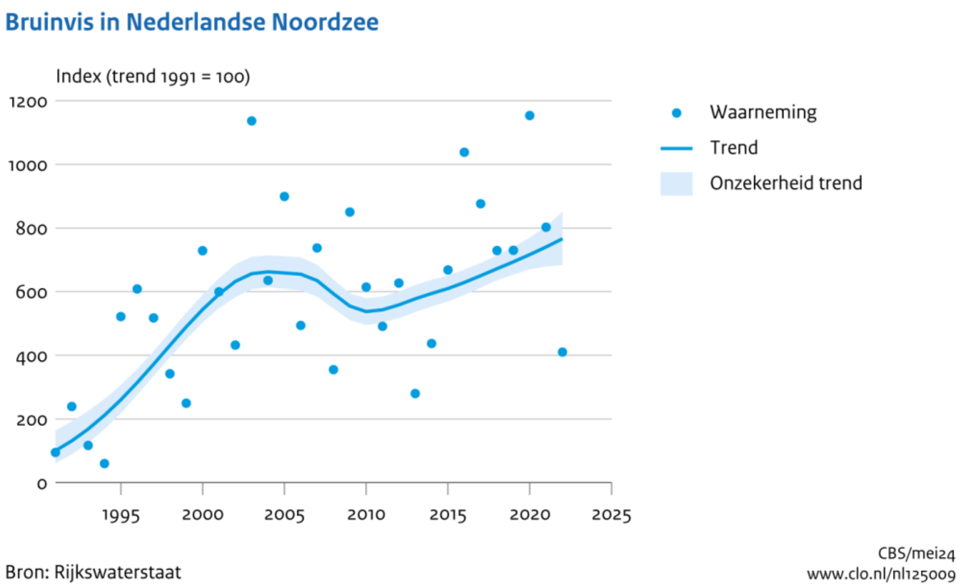



***Figure 10-7*** *Harbour porpoise trend during aerial surveys on the Dutch Continental Shelf, 1991-2022. Source: MWTL & WMR.*

Due to limited surveys on the Dutch Continental Shelf since 2019 and the pending analysis of the 2024 DCS summer survey, no firm conclusions can be drawn about porpoise distribution changes in Dutch waters. However, the SCANS-IV survey (2022; Gilles et al. 2025) and the 2024 summer survey indicate higher porpoise densities north of the Wadden Isles. In 2024, more porpoises were observed north of the Frisian Front, while very low numbers were recorded between the Wadden Isles and the Frisian Front. Offshore densities appeared higher than near the coast, aligning with SCANS-IV findings.

### 10.5.2 Grey and harbour seals

#### 10.5.2.1 Trends in areas adjacent to Dutch waters

Main haul out sites, which reflect abundance at sea, are found along the UK and the Wadden Sea area. In the UK, grey seal numbers (based on pup counts) remain stable around the Northern and Western Isles (the Atlantic coast) of the UK, and they have been generally increasing in the North Sea. Pup production seemed to stabilise recently in Scotland. While harbour seal populations remain stable or are growing in the Western Isles, in contrast, they are declining along Scotland's northeast coast, in the Northern Isles, and more recently along the northern North Sea coasts of the UK (Morris et al. 2021, Russell et al. 2019, SCOS 2022, 2024, Thomas et al. 2019, Thompson et al. 2019). Smaller colonies are seen in Norway: ~2000 harbour seals and <100 grey seals: trends are stable and France: ~1500 harbour seals and ~3200 grey seals; both growing trends (ICES 2024).

#### 10.5.2.2 Harbour Seal Population Trends in Dutch waters

In Dutch waters, the harbour seals in the Netherlands that belong to the international Wadden Sea population, also show a decreasing trend (Galatius et al. 2024). After the closure of the hunt in the 1960’s and 70's, the population showed an impressive recovery growing at a stable rate of 9% per year between 2002 and 2013 (Brasseur et al. 2018). However, after 2013 growth slowed to 1%, followed by a decline since 2021 of 5% per year. Recent counts of the total Wadden Sea area amount to 23,772 seals, 6,604 in the Netherlands (Galatius et al. 2024). Adjusted estimates, based on correction for animals estimated to be at sea, indicate a total population of 34,960 harbour seals in 2024 (Galatius et al. 2024), ~16% decline since 2021. In the Dutch part of the Wadden Sea, the numbers declined almost 20% since 2021. Interestingly, the changes observed in the Wadden Sea harbour seals from 2013 onwards did not seem to affect the pup production, which initially continued to grow annually. Pup numbers only started to decline in 2022. This leads to the conclusion that pup survival, or rather the lack of pup survival is thus the major cause of the observed decline (Galatius et al. 2024). In lack of additional data, it remains unclear what the mechanisms are of the decrease.

The harbour seal numbers in the Delta region have shown a slower recovery, potentially due to historical impacts (e.g., Delta Works). While total counts amounted to less than 20 animals in 1990-1995, annual growth (~100 seals/year) resulted in a maximum count of 1528 animals in 2022 (Hoekstein et al. 2024), which is attributed to migration rather than births, as annual stranding rapports show very high mortality in the region while pup numbers are relatively low (Brasseur 2018).

There is a lack of knowledge with regards to the habitat quality required by seals, particularly at sea. The "favourable" conservation status of the quality of habitat for seals reported in many assessments is based on population trends rather than on actual monitoring of habitat conditions. This lack of information on habitat quality and changes that might occur is of concern now, as at least the harbour seal population is declining.

#### 10.5.2.3 Grey Seal Population Trends in Dutch waters

Grey seals that had been practically absent before, recolonised the Wadden Sea, including the Dutch waters in the late 1980's (Reijnders et al. 1995, Brasseur et al. 2015). Increase in numbers is initially attributed to migration, though currently >1000 pups are born locally, contributing to this growth. In addition, regular visits of grey seals from the UK, contribute to the high numbers observed, obscuring the analysis of local developments. In 2025, a total of 12,064 grey seals were recorded throughout the Wadden Sea region, with 8,638 located in the Dutch part (Schop et al. 2025).

The grey seal numbers in the Delta region have shown a slower recovery, potentially due to historical impacts (e.g., Delta Works). While total counts amounted to less than 20 animals in 1990-1995, recent annual growth (~400 seals/year) resulted in a maximum count of almost 3.500 animals in 2023 (Hoekstein et al. 2024), here also growth in numbers is attributed to migration rather than births, and annual stranding rapports show very high mortality in the region while pup numbers are very low (Brasseur 2018). In 2024 a remarkable drop in numbers (-17%) was observed; the maximum count was 2901 (Hoekstein et al. 2025).

## 10.6 Pressures and impacts

The threats/pressures listed in **Table 10.1** represent those considered to have most relevance for marine mammals (OSPAR 2012, ICES 2015). Pressure and threat levels are classified as high, medium or low for each species-region combination, and are assessed on an individual to population level. Results reflect both regional differences in pressures and differences in species ecology or habitat. Thus, species feeding on cephalopods are more likely to ingest plastic bags, beaked whales are particularly susceptible to mid-frequency long-signal sonar sound, and coastal species are generally exposed to higher levels of pollutants.

The combined impact of various anthropogenic pressures, cumulative effects can threaten the overall conservation status of harbour porpoise, grey and harbour seals (Geelhoed et al. 2023). The main anthropogenic threats to harbour porpoises and grey and harbour seals are:

1. **Underwater noise**

This is primarily caused by activities such as shipping, construction of offshore wind farms, and seismic surveys, which can disrupt the natural behaviours of porpoises and seals.

Anthropogenic noise potentially has an adverse effect on marine mammals (Southall et al. 2008, 2019, Richardson et al. 2013), invertebrates (Murchy 2019), fish (Slabbekoorn 2010, Popper et al. 2014, Cox et al. 2018) and birds (Anderson Hansen et al. 2020). The effect is particularly likely for marine mammals which rely on hearing as their primary sense for foraging, orienting, detecting predators and communicating (Richardson et al. 1995). In the ocean the main source of anthropogenic noise is shipping, dominating the soundscape at all frequencies (Frisk et al. 2012, Malakoff 2010; Tournadre 2014). This effect is particularly visible in the North Sea which is one of the busiest seas in the world (Kaplan and Solomon 2016). Shipping noise disrupts essential behaviours in harbour porpoises, including foraging, communication, and predator avoidance (Richardson et al. 1995) and may alter distribution patterns (Pigeault et al. 2024). Key effects observed in studies include:

- Interrupted foraging: Reduced prey capture attempts when noise exceeds 96 dB (16 kHz) (Wisniewska et al. 2018).
- Stress behaviours: Vigorous fluking, bottom diving, and cessation of echolocation during high-noise events (Frankish et al. 2023, Wisniewska et al. 2018).
- Habitat avoidance: Lower porpoise densities in high-traffic zones compared to quieter areas (Pigeault et al. 2024).

These impacts are exacerbated by the porpoises’ high metabolic rates, requiring near-continuous feeding (e.g. Kastelein et al. 2019, Wisniewska et al. 2016). These signs of stress from harbour porpoises are directly correlated with a fast increase in ambient noise caused by the incoming vessel. An effective action to reduce this impact is vessel slowdown. Reducing ship speed directly lowers noise levels and exposure time (Findlay et al. 2023): Reducing vessel speed in high-traffic maritime areas like the North Sea can significantly mitigate the harmful effects of anthropogenic noise on harbour porpoises, a species critically impacted by underwater noise pollution (Barlow et al. 1988, Frankish et al. 2023, Goodwin 2007, Palka 2002, Wisniewska et al. 2018). For example, a voluntary slowdown trial in Vancouver Bay (11 knots) reduced acoustic source levels by 5.9–11 dB, cutting potential lost foraging time by 22% for killer whales (Joy et al. 2019, MacGillivray et al. 2019).

2. **Bycatch and fishing**

Marine mammals become accidentally caught in fishing gear, particularly in gillnets, which poses a significant risk to their population (Taylor et al. 2022). Fishing near resting sites (e.g., shrimp fishing) disrupts seals.

3. **Chemical pollution**

Exposure to pollutants, such as polychlorinated biphenyls (PCBs), can affect the health and reproductive success of marine mammals. Pollutants can have a negative effect on marine mammal health and vital rates, ultimately affecting marine mammal populations. Numerous studies describe negative effects of polychlorinated biphenyls (PCBs) on marine mammal health and reproductive impairment, including implantation failure, abortion and sterility (Murphy et al. 2010, Murphy et al. 2015, Jepson et al. 2016). In addition, high PCB levels likely increase susceptibility to infectious diseases, leading to elevated mortality risk (Jepson et al. 2005). For some marine mammal species, sustained and elevated PCB burdens are likely to still have significant effects at the population level, despite the limitation on the use of PCBs in the 1970s (Jepson et al. 2016). Reducing risks of PCB exposure could be achieved by improving disposal of PCB materials and limiting the PCB bioavailability to marine food webs through improved management of dredging in harbours and improved containment of environmental PCB contamination (Jepson et al. 2016; van den Heuvel-Greve et al. 2024). Future research should not be limited to the analysis of PCBs, but include other legacy chemicals (e.g. PBDEs, OCPs, HBCDs, MeHg) or emerging persistent chemicals (PCNs, SCCPs) and aim at assessing potential interactions and potential synergic effects of these pollutants (Pinzone et al. 2023).

4. **Resource depletion**

The availability of prey can be affected by overfishing and changes in marine ecosystems, which can impact the marine mammal's food sources. Harbour porpoises have a high metabolic rate and a limited capacity for energy storage (Bjørge 2003, Kastelein et al. 2019, Wisniewska et al. 2016). As a result, there is concern that they may be more susceptible to starvation because of their limited ability to cope with reduced food availability.

5. **Climate change**

Climate change can affect marine mammals in several ways (Gulland et al. 2022); e.g. through shifting distributions in reaction to changing temperatures, indirectly through changes in the food web, and by increasing vulnerability to disease and pollution. Climate change is expected to significantly impact the population and distribution of harbour porpoises over time (Evans & Bjørge 2013, Fontaine et al. 2010, Gulland et al. 2022).

6. **Disturbance**

Tourism activities (e.g., recreational boating, kitesurfing) disturb seals at resting sites. Seasonal closures are insufficient as sandbanks shift over time. New activities like fast rubber boats have increased disturbances in previously inaccessible areas and could affect both seals and porpoises. Although direct research on these effects is currently limited, incidental reports indicate that these activities affect the species.

7. **Habitat loss**

Seabed alterations like dredging, sand extraction, and construction projects affect sandbank stability and accessibility and could influence seal haul out sites. For example: sandbank subsidence in the Oosterschelde may lead to habitat loss. However, as the effects of these activities on seals are not, yet, studied it remains a largely unaddressed issue.

***Table 10.1*** *OSPAR matrix of pressures and effects on marine mammals. High (H): evidence or strong likelihood of negative population effects, mediated through effects on individual mortality, health and/or reproduction. Medium (M): evidence or strong likelihood of impact at individual level on survival, health or reproduction but effect at population level is not clear. Low (L): possible negative impact on individuals but evidence is weak and / or occurrences are infrequent. No Information (NI): cases where there was little or no information on the impact on marine mammals and cases where the threat was absent or irrelevant for a particular region-species combination (OSPAR IA 2017).*

| **PRESSURE CATEGORY** | **PRESSURE** | | **Harbour porpoise** | **White-beaked dolphin** | **Minke whale** | **Harbour seal** | **Grey seal** |
|---|---|---|---|---|---|---|---|
| POLLUTION & OTHER CHEMICAL CHANGES | Contaminants | | H | M | L | H | H |
| | Nutrient enrichment | | L | L | L | L | L |
| PHYSICAL LOSS | Habitat loss | | NI | NI | NI | On land | On land |
| PHYSICAL DAMAGE | Habitat degradation | | L | L | L | | |
| OTHER PHYSICAL PRESSURES | Litter (including microplastics and discarded fishing gear) | | L | L | M | M | M |
| | Underwater noise changes | Military sonar | M | M | M | NI | NI |
| | | Seismic surveys | M | M | M | M | M |
| | | Pile-driving | M | M | M | M | M |
| | | Shipping | M | M | M | M | M |
| | Barrier to species movement (offshore windfarms, wave or tidal device arrays) | | L | L | L | M | M |
| | Death or injury by collision | With ships | L | L | M | L | L |
| | | With tidal devices | Risk of collision leading to death or injury is considered possible, but no evidence of such an event to date | | | | |
| BIOLOGICAL PRESSURES | Introduction of microbial pathogens | | L | L | L | M | M |
| | Removal of target and non-target species (prey depletion) | | M | L | M | M | M |
| | Removal of non-target species (bycatch) | | H | L | M | H | H |
| | Disturbance (e.g. wildlife watching) | | L | L | L | H | H |
| | Deliberate killing and hunting | | Does not occur | | L | | |

## 10.7 Current policy

Marine mammals are highly protected under European and national legislation, and under various treaties and guidelines in which targets and measures are formulated (see list). For the harbour porpoise there is a national protection plan (Min LNV, 2020). Several marine Natura 2000 sites in the Dutch North Sea have been designated to protect harbour porpoises and seals (e.g. Dogger Bank, Cleaver Bank, North Sea Coastal Zone, Vlakte van de Raan, Voordelta). For seals there is trilateral management plan as well as (seasonally) closed resting areas in the Delta and Wadden Sea and guidelines to keep distance to not disturb them. Seasonal closures in Dutch waters (in total 25 areas) protect some of the key areas for harbour seals during their breeding and moulting periods (May-September). For grey seals, the most important breeding sites are closed for the public, but there is little or no protection during the moult. Furthermore, the impression is that there are relatively few protected resting areas compared to the seal's population sizes.

- National guidelines
  - Framework for Assessing Ecological and Cumulative Effects (Kader Ecologie en Cumulatie), Updated Conservation Plan for the Harbour Porpoise,
- National legislation
  - Environmental Management Act (includes the formerly Nature Conservation Act).
- International guidelines

        - ASCOBANS Conservation Plan for Harbour Porpoises (*Phocoena phocoena* L.) in the North Sea, International Whaling Commission (IWC), Conservation and Management Plan for the Wadden Sea Seal Population 2023-2027 (SMP seal management plan).
    - International legislation
        - Habitats Directive, Marine Strategy Framework Directive, The Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR), Agreement on the Conservation of Small Cetaceans of the Baltic, North East Atlantic, Irish and North Seas (ASCOBANS), Common Fisheries Policy (CFP), Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), Bern-convention, Bonn-convention, Agreement on the Conservation of Seals in the Wadden Sea (WSSA).

### 10.7.1 Possible measures

Conservation strategies for seal haul-out areas can be complemented at sea by broader measures aimed at reducing noise, disturbance in general, pollution, and managing fisheries to protect against by-catch and ensure prey availability. Such measures could benefit all marine mammals, and other species like seabirds and fish. The following recommendations are rephrased but come from the recommendations for Nature Restoration Regulations by the Expert Group on Marine Mammals from the Trilateral Wadden Sea Cooperation. This group is mainly focused on activities in and adjacent to the Wadden Sea area.

#### 10.7.1.1 Seasonal closures

Harbour seal numbers have been declining in recent years, with lower pup survival rates probably contributing to this decline. It is not clear what the cause is. However, to ensure pups leave the Wadden Sea in good condition, disturbances at pupping sites must be avoided. While some closures exist, there is debate over the necessary distance to maintain during the pupping season and not all pups are protected. Suckling periods are very short (21-24 days), and even the loss of one day has significant effect on pup survival. Therefore, clear protected zones and proper enforcement during pupping seasons are essential for both harbour and grey seals.

#### 10.7.1.2 Bycatch mitigation and set nets

Bycatch poses a significant threat to the conservation of marine mammals and other aquatic species. Mitigation measures are crucial to address this issue, particularly for smaller fishing vessels under 15 meters in length (Min LNV, 2020). To protect the North Sea and Wadden Sea ecosystem and minimize the unintended consequences of both recreational and commercial fishing, it is essential to promote and enforce the adoption of bycatch reduction techniques across all vessel sizes. These efforts will help safeguard marine biodiversity and ensure the long-term sustainability of fishing practices in the region.

Set nets, including gillnets, have the highest bycatch rates, yet their use in Dutch waters is poorly documented. While attention often focuses on industrial, offshore fisheries, the impact of set nets used by commercial fishermen in the Wadden Sea and recreational fishermen in all Dutch waters are often overlooked. To mitigate this, it is crucial to require registration of all locations where nets are set and to define temporal and spatial limitations on their deployment, particularly near haul-out sites of seals. Implementing measures like those in Sweden would help reduce the risk of entanglement and protect marine mammals in this sensitive area. Harbour porpoise bycatch numbers exceed the (OSPAR) bycatch threshold in the Greater North Sea. For grey seal this threshold is not exceeded, and data are lacking for harbour seal (Taylor et al. 2022).

#### 10.7.1.3 Shipping noise

<u>Use of Autonomous vehicles</u>: Silent, cost-effective alternatives for accessing offshore wind farms, reducing cumulative noise. These measures are critical in the North Sea, where wind farm construction and shipping already intensify ambient noise. Here we propose a decrease in ship speeds in wind farms by 20 % and explore alternative methods to access the area. One method might be the increase in the use of autonomous vehicles that are known to be silent and cost-effective in the long term. Wind farms are areas already affected by a change in the marine habitat and an increase in ambient noise making it necessary to limit the effect of anthropogenic activities.

Monitoring**:** Wind farm monitoring should look at the changes in ambient noise and prey availability in relation to the occurrence of harbour porpoise with several hydrophones. The latter can be studied with passive acoustic monitoring, using hydrophones to detect and porpoise clicks as a proxy for their presence, at wind farm scale (acoustic monitoring. Another method to monitor harbour porpoise presence and effect are aerial surveys, preferably at a broader scale, e.g. at Dutch Continental Shelf.

10.7.1.4 Closure of coastal resting and breeding sites informed by ecological principles
Seals use terrestrial sites for breeding, moulting and resting. Disturbance may hinder animals from selecting the most optimal location. For example, many parts of the beach along the West Coast of the Netherlands are in proximity to foraging areas at sea; however, they are not used by seals because of the constant presence of humans. Consequently, seals may now use coastal areas that are sub-optimal and could conflict with current or future human activities. A systematic assessment could map suitable locations for coastal resting and breeding sites, evaluate existing sites and closures, and explore opportunities for designing new breeding and resting sites in collaboration with private and public partners. As illustrated in Figure 10-8, habitat suitability at sea derived from tracking ta can be used to predict the distribution and group sizes of seals at coastal resting areas. Initiatives such as the Noordpoort beach reserve illustrate how spatial management can balance wildlife needs with recreation.

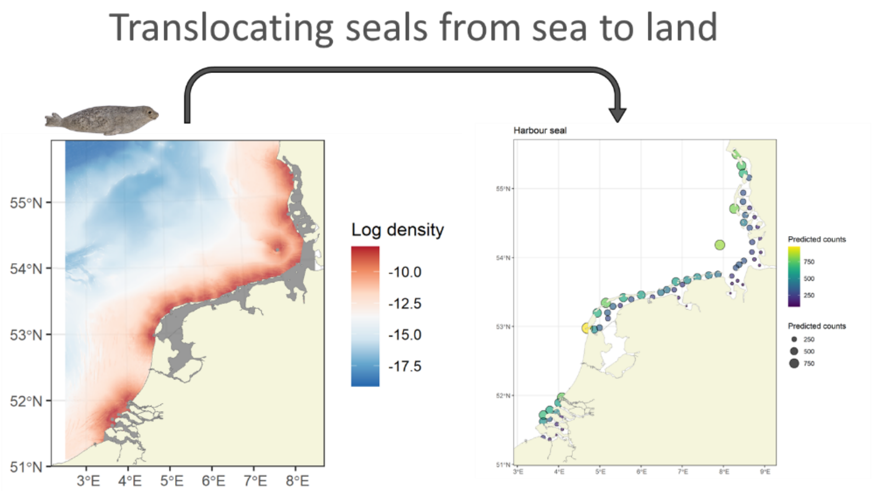



***Figure 10-8*** *An illustration demonstrating how habitat suitability at sea, derived from tracking data, can be used to predict the distribution and group sizes of seals at resting sites along the coast.*

10.7.1.5 Science based ocean education
Researchers emphasize that experiencing nature is essential for fostering pro-environmental behaviour, which is crucial in addressing the global environmental crisis (Cazalis et al. 2022). To enhance public engagement and ocean literacy, marine mammals can serve as compelling ambassadors in science-based educational programs that combine outreach ("taking the sea to them") and immersive field-based activities ("bringing them to the sea"). Interactive learning modules, such as marine mammal tracking simulations, mobile learning labs ('The Traveling Sea Lab'), immersive field experiences, educational toolkits and citizen science initiatives can help reconnect students with marine ecosystems and inspire stewardship. These initiatives align with UNESCO's 2025 call for integrating ocean-related topics into national curricula. These outputs will ensure a long-lasting impact by creating multiple ways for students to engage with marine science, whether in the classroom, through hands-on field experiences, or via digital platforms.

Potential partners include Radboud University's Centre Connecting Humans and Nature, EcoMare, IVN Natuureducatie, WNF, Staatsbosbeheer, and Outward Bound Nederland.

### 10.7.2 Monitoring & Research

1. Improve population monitoring by integrating data from all regions (Wadden Sea & Delta).
2. Improve habitat quality monitoring by integrating data from all sources (natural changes, abiotic and biotic, and anthropogenic activities).

3. Monitor effects of ambient noise levels on the behaviour of harbour porpoises and seals.
4. Investigate causes of declining juvenile seal survival rates since 2013.
5. Study habitat use and migration routes to identify critical EUNIS habitat types.
6. Study effect of pollutants.

## 10.8 Advice and action perspective

*Rationale*
Harbour porpoises and seals (harbour and grey) are key top predators and indicators of marine ecosystem health in the North Sea. Their abundance and wide-ranging behaviour link coastal, estuarine, and offshore ecosystems. Although their populations in the North Sea remain relatively stable or increasing over longer timescales, recent declines, especially in harbour seals, raise concern about prey availability, underwater noise, disturbance, and pollution. Restoration opportunities for highly mobile marine mammals are inherently limited, but targeted measures can improve habitat conditions, reduce pressures, and enhance resilience.

*Action perspective for NN*
Underwater noise, bycatch, chemical pollution, resource depletion, and disturbance from tourism and shipping are the dominant threats to marine mammals. These impacts cannot be "restored" in the traditional sense (e.g. by habitat creation or reintroduction) but instead require regulatory, spatial, and behavioural interventions. Examples include vessel speed slowdowns, fishing gear modifications, stricter controls on chemical emissions and dredging, and seasonal restrictions near haul-out or pupping sites. Such measures primarily reduce pressures rather than restore habitat.

Within the framework of NN, direct restoration actions for marine mammals should focus on improving habitat quality and reducing human pressures, rather than on species-specific interventions. NN can complement existing policy measures by:

- enhancing food availability and ecosystem health, such as projects improving fish nursery areas and prey base restoration, which indirectly benefit seals and porpoises (RRL6-7).
- filling key knowledge gaps, e.g. the ecological quality of foraging habitats, effects of underwater noise mitigation (e.g. ship speed slowdown or silent technologies), and links between prey dynamics and seal/porpoise distribution (RRL1-3).
- stabilizing or creating suitable resting areas, improving access to undisturbed coastal sites, or pilot projects combining habitat enhancement with nature-based coastal defence. These actions would have relatively low restoration readiness levels (RRL 1–3), as feasibility and ecological benefits require further research.

*Demonstration of impact*
To demonstrate the actual contribution of NN activities to the conservation of marine mammals, monitoring should focus on changes in prey availability, noise exposure, and habitat use. On a large scale, existing monitoring programmes (e.g. aerial surveys can be used to assess distribution and population trends. On a smaller scale, site-specific studies can evaluate the effectiveness of mitigation and habitat enhancement measures. Demonstrable results could include enhanced prey availability, reduced noise levels, and improved suitability of resting habitats, providing measurable ecological gains for marine mammals and the wider North Sea ecosystem.

## 10.9 References


Aarts, G., 2021, memo "Estimated distribution of grey and harbour seals" for KEC 4.0, Wageningen Marine Research.

Barlow, J., Oliver, C.W., Jackson, T.D., Taylor, B.L., (1988). Harbor porpoise, *Phocoena phocoena*, abundance estimation for California, Oregon, and Washington: II. Aerial surveys. Fish. Bull. 86 (3), 433–444.

Bestley, S., Ropert-Coudert, Y., Bengtson Nash, S., Brooks, C. M., Cotté, C., Dewar, M., Friedlaender, A. S., Jackson, J. A., Labrousse, S., Lowther, A. D., McMahon, C. R., Phillips, R. A., Pistorius, P., Puskic, P. S., Reis, A. O. de A., Reisinger, R. R., Santos, M., Tarszisz, E., Tixier, P., … Wienecke, B. (2020). Marine

Ecosystem Assessment for the Southern Ocean: Birds and Marine Mammals in a Changing Climate. *Front Ecol. Evol.*, *8*, 566936.
Bjørge, A. (2003). The harbour porpoise (*Phocoena phocoena*) in the North Atlantic: Variability in habitat use, trophic ecology and contaminant exposure. In *NAMMCO Scientific Publications* (Vol. 5).
Bowen W.D. & Siniff D.B. (1999). Distribution, population biology, and feeding ecology of marine mammals. In: Reynolds III J.E. & Rommel S.A. (eds). Biology of marine mammals: 423-484. Smithsonian Institution Press, Washington.
Bowen, W. D., Ellis, S. L., Iverson, S. J., & Boness, D. J. (2003). Maternal and newborn life-history traits during periods of contrasting population trends: implications for explaining the decline of harbour seals (*Phoca vitulina*), on Sable Island. J. Zoology, *261*(2), 155–163.
Brasseur, S. M., Reijnders, P. J., Cremer, J., Meesters, E., Kirkwood, R., Jensen, L. F., Jeβ, A., et al. (2018). Echoes from the past: regional variations in recovery within a harbour seal population. PLoS ONE, 13: e0189674.
Brasseur, S.M.J.M., van Polanen Petel, T.D., Gerrodette, T., Meesters, E.H.W.G., Reijnders, P.J.H., and Aarts, G. (2015). Rapid recovery of Dutch grey seal colonies fueled by immigration. Mar. Mammal Sci., 31: 405-426.
Burger, A.E., & Piatt, J.F. (1990). Flexible time budgets in breeding common murres: buffers against variable prey abundance. *Studies in Avian Biology*, *14*, 71–83.
Cazalis, V., Loreau, M., & Barragan-Jason, G. (2023). A global synthesis of trends in human experience of nature. *Frontiers in Ecology and the Environment, 21*(2), 85-93. https://doi.org/https://doi.org/10.1002/fee.2540
CLO (2025). Gewone en grijze zeehond in Waddenzee en Deltagebied, 1960-2025 (indicator 1231, versie 22, 18 augustus 2025), www.clo.nl. Centraal Bureau voor de Statistiek (CBS), Den Haag; PBL Planbureau voor de Leefomgeving, Den Haag; RIVM Rijksinstituut voor Volksgezondheid en Milieu, Bilthoven; en Wageningen University and Research, Wageningen.
Cox, K., Brennan, L. P., Gerwing, T. G., Dudas, S. E., and Juanes, F. (2018). Sound the alarm: A meta-analysis on the effect of aquatic noise on fish behavior and physiology. Global Change Biol. 24, 3105–3116. doi: 10.1111/gcb.14106
Croxall, J. P., Reid, K., & Prince, P. A. (1999). Diet, provisioning and productivity responses of marine predators to differences in availability of Antarctic krill. Mar. Ecol. Prog. Ser., 177, 115–131.
Engelhard, G.H., Peck, M.A., Rindorf, A., Smout, S.C., Deurs, M. Van, Raab, K., Andersen, K.H., Garthe, S., Lauerburg, R.A.M., Scott, F., Brunel, T., Aarts, G., Kooten, T. Van, & Dickey-Collas, M. (2014). Forage fish, their fisheries, and their predators: who drives whom? *ICES J. Mar. Sci.*, *71*, 90–104.
Estes, J.A., Terborgh, J., Brashares, J.S., Power, M.E., Berger, J., Bond, W.J., Carpenter, S.R., Essington, T. E., Holt, R.D., Jackson, J.B.C., Marquis, R.J., Oksanen, L., Oksanen, T., Paine, R.T., Pikitch, E.K., Ripple, W.J., Sandin, S.A., Scheffer, M., Schoener, T.W., … Wardle, D.A. (2011). Trophic downgrading of planet earth. *Science*, *333*(6040), 301–306.
Evans, P.G.H. & Bjørge, A. (2013). Impacts of climate change on marine mammals. MCCIP Science Review 2013: 134-148
Findlay, C.R., Rojano-Doñate, L., Tougaard, J., Johnson, M.P. and Madsen, P.T., 2023. Small reductions in cargo vessel speed substantially reduce noise impacts to marine mammals. *Science Advances*, *9*(25), p.eadf2987.
Frankish, C.K., von Benda-Beckmann, A.M., Teilmann, J., Tougaard, J., Dietz, R., Sveegaard, S., Binnerts, B., de Jong, C.A.F., Nabe-Nielsen, J. (2023). Ship noise causes tagged harbour porpoises to change direction or dive deeper. Mar. Pollut. Bull. 197, 115755 https://doi.org/10.1016/j.marpolbul.2023.115755.
Frisk, G.V., 2012. Noiseonomics: the relationship between ambient noise levels in the sea and global economic trends. Sci. Rep. 2 (1), 437. https://doi.org/10.1038/ srep00437.
Fontaine, M.C., Tolley, K.A., Michaux, J.R., Birkun Jr, A., Ferreira, M., Jauniaux, T., Llavona, Á., Öztürk, B., Öztürk, A.A., Ridoux, V. and Rogan, E., (2010). Genetic and historic evidence for climate-driven population fragmentation in a top cetacean predator: the harbour porpoises in European water. *Proc. Royal Soc. B: Biol. Sci.*, *277*(1695), pp.2829-2837.
Galatius A., Brasseur S., Hamm T., Jeß A., Meise K., Meyer J., Schop J., et al. (2024). Survey Results of Harbour Seals in the Wadden Sea in 2024.

Galatius, A., Brasseur, Hamm, T., Jeß, A., Meise, K., Meyer, J., Schop, J., Siebert, U., Stejskal, O., Teilmann, J., & Thøstesen, C.B. (2025). Survey Results of Harbour Seals in the Wadden Sea in 2025: Record high pup count despite recent decline in moult counts.

Geelhoed, S.C.V., Scheidat, M., van Bemmelen, R.S.A., & Aarts, G.M. (2013). Abundance of harbour porpoises (*Phocoena phocoena*) on the Dutch Continental Shelf, aerial surveys in July 2010 - March 2011. *Lutra*, *56*(1), 45-57. https://edepot.wur.nl/287394

Geelhoed, S.C.V., & Scheidat, M. (2018). Abundance of harbour porpoises (Phocoena phocoena) on the Dutch Continental Shelf, aerial surveys 2012-2017. *Lutra*, *61*, 127-136. https://edepot.wur.nl/498286

Geelhoed, S.C.V., Authier, M., Pigeault, R. and Gilles, A., 2023. Abundance and distribution of cetaceans. In: OSPAR, 2023: The 2023 Quality Status Report for the Northeast Atlantic. OSPAR Commission, London

Gilles, A., Viquerat, S., Becker, E.A., Forney, K.A., Geelhoed, S.C.V., Haelters, J., Nabe-Nielsen, J., Scheidat, M., Siebert, U., Sveegaard, S., Van Beest, F.M., Van Bemmelen, R., & Aarts, G. (2016). Seasonal habitat-based density models for a marine top predator, the harbor porpoise, in a dynamic environment. *Ecosphere*, *7*(6), e01367.

Gilles, A., Ramirez-Martinez, N.C., Nachtsheim, D. & Siebert, U. (2020). Update of distribution maps of harbour porpoises in the North Sea. Commissioned by Rijkswaterstaat. University of Veterinary Medicine Hannover, Institute for Terrestrial and Aquatic Wildlife Research.

Gilles, A., Authier, M., Ramirez-Martinez, N.C., Araújo, H., Blanchard, A., Carlström, J., Eira, C., Dorémus, G., Fernández-Maldonado, C., Geelhoed, S.C.V., Kyhn, L., Laran, S., Nachtsheim, D., Panigada, S., Pigeault, R., Sequeira, M., Sveegaard, S., Taylor, N.L., Owen, K., Saavedra, C., Vázquez-Bonales, J.A., Unger, B. & Hammond, P.S. (2023). Estimates of cetacean abundance in European Atlantic waters in summer 2022 from the SCANS-IV aerial and shipboard surveys. Final report published 29 September 2023. 64 pp.

Gilles, A., Authier, M., Pigeault, R., Ramirez-Martinez, N.C., Benoit, V., Carlstrom, J., Eira, C., Geelhoed, S. C.V., Laran, S., Sequeira, M., Sveegaard, S., Taylor, N.L., Saavedra, C., Bonales, J.A.V., & Hammond, P.S. (2025). *Spatial models of cetacean density in European Atlantic waters based on SCANS-IV summer 2022 survey data*. University of Veterinary Medicine Hannover. https://edepot.wur.nl/693476

Goodwin, L. (2007). The Ecology and Conservation of the Harbour Porpoise (*Phocoena phocoena*) Along the West Coast of the UK. Thesis. University of Plymouth. https://doi.org/10.24382/4175.

Goodwin L. (2008). Diurnal and tidal variations in habitat use of the harbour porpoise (*Phocoena phocoena*) in Southwest Britain. Aquatic Mammals 34: 44-53

Gulland, F.M., Baker, J. D., Howe, M., LaBrecque, E., Leach, L., Moore, S. E., ... & Thomas, P. O. (2022). A review of climate change effects on marine mammals in United States waters: Past predictions, observed impacts, current research and conservation imperatives. *Climate Change Ecology*, *3*, 100054.

Hammond, P.S., Berggren, P., Benke, H., Borchers, D. L., Collet, A., Heide-Jørgensen, M. P., Heimlich, S., Hiby, A. R., Leopold, M. F., & Øien, N. (2002). Abundance of harbour porpoise and other cetaceans in the North Sea and adjacent waters. *J. Applied Ecol. 39*(2), 361–376.

Hammond, P.S., Lacey, C., Gilles, A., Viquerat, S., Börjesson, P., Herr, H., Macleod, K., Ridoux, V., Santos, M.B., Scheidat, M., Tellmann, J., Vingada, J., & Olen, N. (2021). Estimates of cetacean abundance in European Atlantic waters in summer 2016 from the SCANS-III aerial and shipboard surveys. In *Sea Mammal Research Unite, University of St Andrews, UK*.

Hammond, P. S., Macleod, K., Berggren, P., Borchers, D.L., Burt, L., Cañadas, A., Desportes, G., Donovan, G.P., Gilles, A., Gillespie, D., Gordon, J., Hiby, L., Kuklik, I., Leaper, R., Lehnert, K., Leopold, M., Lovell, P., Øien, N., Paxton, C.G.M., … Vázquez, J. A. (2013). Cetacean abundance and distribution in European Atlantic shelf waters to inform conservation and management. *Biol. Cons.*, *164*, 107–122.

Morris, C.D., Duck, C.D., & Thompson, D. (2021). Aerial surveys of seals in Scotland during the harbour seal moult, 2016-2019. In *NatureScot Research Report 1256*.

Hoekstein, M., Janse, W., and Sluijter, M. (2023). Watervogels en zeehonden in de Zoute Delta in 2021/2022.

Hoekstein, M.S.J., F.A. Arts & W. Janse, 2025. Watervogels en zeehonden in de Zoute Delta in 2023/2024. Deltamilieu Projecten Rapportnr. 2025-01. Deltamilieu Projecten, Vlissingen. Rijkswaterstaat, Centrale informatievoorziening Rapport BM 25-03

Ries, E.H., Hiby, L.R., and Reijnders, P.J.H. (1998). Maximum likelihood population size estimation of harbour seals in the Dutch Wadden Sea based on a mark-recapture experiment. J. Applied Ecol., 35: 332-339.

ICES (2024). Working Group on Marine Mammal Ecology (WGMME). ICES Scientific Reports. 6:82. 239 pp. https://doi.org/10.17895/ices.pub.26997367

Jepson, P.D., P.M. Bennett, R. Deaville, C.R. Allchin, J.R. Baker, and R.J. Law (2005). Relationships between polychlorinated biphenyls and health status in harbor porpoises (*Phocoena Phocoena*) stranded in the United Kingdom. *Env. Toxicology and Chemistry* 24, 1: 238–48. https://doi.org/10.1897/03-663.1.

Jepson, P.D., R. Deaville, J.L. Barber, À. Aguilar, A. Borrell, S. Murphy, J. Barry, et al. (2016). PCB Pollution Continues to Impact Populations of Orcas and Other Dolphins in European Waters. *Sci. Reports* 6, 1: 18573. https://doi.org/10.1038/srep18573.

Joy, R., et al. (2019). Potential benefits of vessel slowdowns on endangered southern resident killer whales. Front. Mar. Sci. 6, 344. doi: 10.3389/fmars.2019.00344

Kaplan, M.B., Solomon, S. (2016). A coming boom in commercial shipping? The potential for rapid growth of noise from commercial ships by 2030. Mar. Policy 73, 119–121. https://doi.org/10.1016/j.marpol.2016.07.024.

Kastelein, R.A., Helder-Hoek, L., Jennings, N., Kester, R. & Huisman, R., (2019). Reduction in Body Mass and Blubber Thickness of Harbor Porpoises (*Phocoena phocoena*) Due to Near-Fasting for 24 Hours in Four Seasons. Aquat. Mammals 45: 37-47. 10.1578/AM.45.1.2019.37.

MacGillivray, A.O., Li, Z., Hannay, D.E., Trounce, K.B., and Robinson, O.M. (2019). Slowing deep-sea commercial vessels reduces underwater radiated noise. J. Acoustical Soc. America 146, 340–351. doi: 10.1121/1.5116140

Malakoff, D. (2010). A push for quieter ships. Science 328 (5985), 1502–1503. https://doi.org/10.1126/science.328.5985.1502.

MinLNV. (2020). Updated Conservation Plan for the Harbour Porpoise *Phocoena phocoena* in the Netherlands Maintaining a Favourable Conservation Status. Ministry of Agriculture, Nature and Food Quality. https://www.rijksoverheid.nl/documenten/rapporten/2020/11/16/updated-conservation-plan-for-the-harbour-porpoise-phocoena-phocoenain-the-netherlands

Moore, S.E. (2008). Marine mammals as ecosystem sentinels. *Journal of Mammalogy*, *89*(3), 534–540

Murchy, K. A.,Davies, H., Shafer, H., Cox,K., Nikolich,K., and Juanes, F. (2019). "Impacts of noise on the behavior and physiology of marine invertebrates: A meta-analysis," in Proceedings of Meetings on Acoustics (The Hague, the Netherlands: AIP Publishing).

Murphy, S, G.J. Pierce, R.J. Law, P. Bersuder, P.D. Jepson, J.A. Learmonth, M. Addink, et al. (2010). "Assessing the Effect of Persistent Organic Pollutants on Reproductive Activity in Common Dolphins and Harbour Porpoises." *J. Northwest Atlantic Fish. Sci.* 42: 153–73. https://doi.org/10.2960/J.v42.m658.

Murphy, S., J.L. Barber, J.A. Learmonth, F.L. Read, R. Deaville, M.W. Perkins, A. Brownlow, et al. (2015) "Reproductive Failure in UK Harbour Porpoises *Phocoena phocoena*: Legacy of Pollutant Exposure?" Edited by H.-J. Lehmler. *PLOS ONE* 10,7: e0131085. https://doi.org/10.1371/journal.pone.0131085.

Palka, D., (2002). Incorporating uncertainty into marine mammal management. Am. Fish. Soc. Symp. 27, 157–169. http://scholar.google.com/scholar?hl=en&btnG=Search &q=intitle:Incorporating+uncertainty+into+marine+mammal+management#5.

Pigeault, R., Ruser, A., Ramírez-Martínez, N. C., Geelhoed, S. C.V., Haelters, J., Nachtsheim, D. A., ... & Gilles, A. (2024). Maritime traffic alters distribution of the harbour porpoise in the North Sea. Mar. Poll. Bull., 208, 116925.

Pinzone, M., Parmentier, K., Siebert, U., Gilles, A., Authier, M., Brownlow, A., Caurant, F., Das, K., Deaville, R., Galatius, A., Geelhoed, S., Hernández Sánchez, M.T., Mendez-Fernandez, P., Murphy, S., Persson, S., Roos, A., van den Heuvel-Greve, M., Vinas, L., Williams, R. S. (2022). Pilot Assessment of Status and Trends of persistent chemicals in marine mammals. In: OSPAR, 2023: The 2023 Quality Status Report for the North-East Atlantic. OSPAR Commission, London.

Popper, A.N., Hawkins, A.D., Fay, R.R., Mann, D.A., Bartol, S., Carlson, T.J., et al. (2014). "Sound exposure guidelines," in ASA S3/SC1. 4 TR-2014 Sound Exposure Guidelines for Fishes and Sea Turtles: A Technical Report prepared by ANSI-Accredited Standards Committee S3/SC1 and registered with ANSI (Richmond, United States: Springer), 33–51.

Ransijn, J. M., Hammond, P. S., Leopold, M. F., Sveegaard, S., & Smout, S. C. (2021). Integrating disparate datasets to model the functional response of a marine predator: A case study of harbour porpoises in the southern North Sea. *Ecol. Evol.*, *11*(23), 17458–17470.

Reijnders, P. J. H., van Dijk, J., and Kuiper, D. (1995_. Recolonization of the dutch Wadden Sea by the grey seal *Halichoerus grypus*. Bio. Cons., 71: 231-235.

Richardson, W.J., Greene, C.R. Jr., Malme, C.I., and Thomson, D.H. (2013). Marine mammals and noise (San Diego, United States: Academic press).

Richardson, W.J., C.R. Greene Jr., C.I. Malme, D.H. Thomson (1995), Marine Mammals and Noise (Academic Press).

Ross, P.S., De Swart, R.L., Addison, R.F., Van Loveren, H., Vos, J.G., & Osterhaus, A.D. (2000). "Contaminant-induced immunotoxicity in marine mammals: A review." *Environmental Health Perspectives, 108(Suppl 1), 29–51.*

Russell, D.J.F., Morris, C.D., Duck, C.D., Thompson, D., & Hiby, L. (2019). Monitoring long-term changes in UK grey seal pup production. *Aquat. Cons.: Mar. Freshw. Ecosyst.*, *29*(S1), 24–39.

SCOS (2022). Scientific advice on matter related to the management of seal populations.

Schop J., Brasseur S., Galatius A., Hamm T., Jeß A., Meise K., Meyer J., et al. (2024). Grey Seal Numbers in the Wadden Sea and on Helgoland in 2023-2024.

Schop, J., Bönisch, A., Brasseur, S., Galatius, A., Hamm, T., Jeß, A., Meise, K., Meyer, J., Stejskal, O., Siebert, U., Teilmann, J., & Thøstesen, C.B. (2025). Grey Seal numbers in the Wadden Sea and Helgoland in 2024-2025.

Slabbekoorn, H., Bouton, N., van Opzeeland, I., Coers, A., ten Cate, C., and Popper, A.N. (2010). A noisy spring: the impact of globally rising underwater sound levels on fish. Trends Ecol. Evol. 25, 419–427. doi: 10.1016/j.tree.2010.04.005

Southall, B.L., Bowles, A.E., Ellison, W.T., Finneran, J.J., Gentry, R.L., Greene, C.R. Jr., et al. (2008). Marine mammal noise-exposure criteria: initial scientific recommendations. Bioacoustics 17, 273–275. doi: 10.1080/09524622.2008.9753846

Southall, B.L., Finneran, J.J., Reichmuth, C., Nachtigall, P.E., Ketten, D.R., Bowles, A.E., et al. (2019). Marine mammal noise exposure criteria: updated scientific recommendations for residual hearing effects. Aquat. Mammals 45 (2), 125–232. doi: 10.1578/AM.45.2.2019.125

Sveegaard, S., Nabe-Nielsen, J., Stæhr, K.J., Jensen, T.F., Mouritsen, K. N., & Teilmann, J. (2012). Spatial interactions between marine predators and their prey: herring abundance as a driver for the distributions of mackerel and harbour porpoise. Mar. Ecol. Prog. Ser., 468, 245–253.

Taylor, N., Authier, M., Banga, R., Genu, M., Macleod, K., Gilles, A. (2022). *Marine Mammal By-catch*. In: OSPAR, 2023: The 2023 Quality Status Report for the Northeast Atlantic. OSPAR Commission, London

Tournadre, J. (2014). Anthropogenic pressure on the open ocean: the growth of ship traffic revealed by altimeter data analysis. Geophys. Res. Lett. 41 (22), 7924–7932. https://doi.org/10.1002/2014GL061786.

Thomas, L., Russell, D. J. F., Duck, C. D., Morris, C. D., Lonergan, M., Empacher, F., Thompson, D., & Harwood, J. (2019). Modelling the population size and dynamics of the British grey seal. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *29*(S1), 6–23.

Thompson, D., Duck, C.D., Morris, C.D., & Russell, D.J.F. (2019). The status of harbour seals (*Phoca vitulina*) in the UK. Aquatic Conservation: Marine and Freshwater Ecosystems, 29(S1), 40–60.

Van den Heuvel-Greve, M., de Froe, E., Kotterman, M., Kwadijk, C., & Foekema, E. (2024). Hoofdlijnenrapport: impact van probleemstoffen (incl. PFAS) op natuur in de Westerschelde. Rapport C084/24. Wageningen Marine Research.

Van Heel, B.F., van den Born, R.J., & Aarts, N. (2023). Nature experiences in childhood as a driver of connectedness with nature and action for nature: A review. Ecopsychology, 15(4), 354-367.

Waggitt J.J., Dunn H.K., Evans P.G.H., Hiddink J.G., Holmes L.J., Keen E., Murcott B.D., Piano M., Robins P.E., Scott B.E., Whitmore J. & Veneruso G. (2017). Regional-scale patterns in harbour porpoise occupancy of tidal stream environments. ICES J. Mar. Sci. doi:10.1093/icesjms/fsx164.

Wisniewska, D.M., Johnson, M., Teilmann, J., Rojano-Donate, L., Shearer, J., Sveegaard, S., Miller, L.A., Siebert, U. and Madsen, P.T. (2016). Ultra-high foraging rates of harbor porpoises make them vulnerable to anthropogenic disturbance. *Current Biology*, *26*(11), pp.1441-1446.

Wisniewska, D.M., Johnson, M., Teilmann, J., Siebert, U., Galatius, A., Dietz, R. and Madsen, P.T. (2018). High rates of vessel noise disrupt foraging in wild harbour porpoises (*Phocoena phocoena*). *Proc. Royal Soc. B: Biol. Sci.*, *285*(1872), p.20172314.

Wilson, L.J., & Hammond, P.S. (2019). The diet of harbour and grey seals around Britain: Examining the role of prey as a potential cause of harbour seal declines. *Aquat. Cons.: Mar. Freshw. Ecosyst.*, *29*(S1), 71–85.

# 11 Synthesis and recommendations

## 11.1 Synthesis

For each ecosystem component, we have identified potential measures to improve its ecological status. As outlined in Section 1.4, the scope of NN focuses on initiating active restoration measures and therefore does not include passive or policy-based measures, such as the designation of MPAs, fisheries exclusion zones, bycatch reduction, measures to reduce land-based nutrient runoff, or the removal of infrastructural barriers in waterways. However, for many ecosystem components, such measures are often the most effective—or even the only—means to achieve ecological improvement. Table 11.1 summarises the measures described in Chapters 3–10 per ecosystem component, distinguishing between passive/policy measures and active (optional) NN measures.

NN measures can be either direct or indirect. Direct measures have an immediate effect on target species, for example through relocation or (re)introduction of (cultivated) individuals to enhance local populations, habitat regeneration, or by increasing spawning success (e.g. by reducing predation pressure on eggs or juveniles at spawning sites). Habitat regeneration can therefore be a direct NN measure for certain target species, such as the reintroduction of oyster reefs, while for other species that benefit from the newly created habitat (e.g. through increased shelter, food availability, or nursery functions) the same measure functions as an indirect NN measure. More generally, indirect NN measures target one ecosystem component but are expected to generate positive effects for other, functionally linked components, for example measures aimed at (small pelagic) fish stocks that simultaneously improve food availability for multiple predator species. Where relevant and/or known, potential NN measures have been classified as direct or indirect in Table 11.1.

When identifying potential active restoration measures, the availability and maturity of the underlying knowledge base is a key consideration. To systematically assess this, we developed Restoration Readiness Levels (RRLs), which provide a structured framework to evaluate the development stage, feasibility and knowledge gaps of possible active NN measures. These measures are therefore assessed based on their ecological effectiveness, technical feasibility, level of practical experience and potential interactions with other ecosystem components. Some of the NN measures listed in Table 11.1 are already relatively well developed. For example, restoration of the European flat oyster builds on a substantial history of research and practice in Europe, including initiatives within the Native Oyster Restoration Alliance. While site-specific studies may still be required (e.g. on the stability of deployment materials in particular restoration areas) and an overarching restoration masterplan remains under development, the overall roadmap for European flat oyster restoration is well established. For other measures, however, effectiveness, practical implementation and potential conflicts with other ecosystem components are far less clear. In many fish species, key bottlenecks have been identified in spawning or nursery habitats. While restoration of these habitats represents a promising high-level option, practical implementation will require careful design, piloting and testing before wider application. Some species depend on very specific habitat types that are currently rare in Dutch waters. Where such habitats have declined due to human activities (e.g. removal of large stones to facilitate fishing), there is a clear rationale for active restoration. In contrast, for species that require habitat types that are naturally scarce in the Dutch North Sea (such as gravel beds), more fundamental questions arise regarding the desirability and ecological implications of introducing non-native habitat elements, which need to be resolved before restoration can be considered.
Some of the measures proposed for NN also appear in the list of proposed measures for NRR, such as measures related to fish spawning areas. The measures for NRR are currently being developed, so it is recommended to ensure alignment with that process. The same applies to the species protection plan background documents and the associated action plans that are currently being developed by LVVN.

***Table 11.1*** *Overview of potential measures per ecosystem component. Green = potentially actionable measures for ecosystem recovery are available, red: no measures available, orange = only indirect measures are available, yellow = optional direct measures available, but there are knowledge gaps).*

| **Ecosystem component category** | **Ecosystem component sub-category** | **Passive / Policy measures (in brackets relevant policy or legislation)** | **Active measures: options for NN** |
|---|---|---|---|
| Habitats | Pelagic habitats | Water quality improvement (WFD, MSFD) | No direct measures. Indirect, local measures only e.g. NIDs, localised nutrient buffering, local stratification near infrastructure |
| | Benthic habitats | Seabed protection (N2000, MSFD and NRR) | Direct: Active restoration complementary to seabed protection: stone reef restoration, artificial hard substrate for certain key communities only |
| Plankton | Phytoplankton | Eutrophication reduction, water quality improvement (WFD, MSFD) | No direct/indirect measures |
| | Zooplankton | Indirect only: climate change reduction and water quality improvement only, eutrophication reduction (MSFD) | No direct options. Indirect measures for meroplankton: could benefit from biogenic/geogenic reef projects |
| Seaweed | | OSPAR list of recommendations. NRR restoration measures proposals. Kelp: knowledge gap assessment | Need assessment; Direct: possible kelp restoration (feasibility assessment) |
| Cephalopods | | No formal protection or measures in place | Need assessment. Direct: possible restoration with focus on reproduction, foraging areas and habitat restoration for egg deposition. Indirect: could benefit from biogenic/geogenic reef projects |
| Benthos | Reefbuilders (biogenic reefs) | Seabed protection e.g. fisheries measures / MPA / sediment management (MSFD, NRR, CFP) | Direct: Active habitat restoration: oyster & other biogenic reef builder restoration |
| | Shellfish / burrowing megafauna | Fisheries measures /new or improved MPA assessment/ sediment management via (N2000, MSFD, CFP) | Direct: Active restoration e.g. creation egg-deposition areas for welk. Indirect via biogenic reef restoration |
| | Large mobile fauna | No policy measures in place | Indirect: could benefit from biogenic/geogenic reef projects |
| | Structure forming / hard substrate benthos | Seabed protection measures: fisheries measures / new or improved MPA assessment/ sediment management (N2000, HD, CFP, NRR) | Active restoration of hard substrate, e.g. natural boulder reefs and biogenic reefs |

***Table 11.2*** *cont.:*

| Ecosystem component category | Ecosystem component sub-category | Passive / Policy measures (in brackets relevant policy or legislation) | Active measures: options for NN |
|---|---|---|---|
| Fish | Migratory fish | Fisheries measures / waterway management / removal migration barriers (HD, Eel & Sturgeon Management Plan) | Direct: reintroduction; improve nursery / spawning habitat; restore estuarine habitats; removal migration barriers |
| | Sharks and rays | Knowledge gaps. Fisheries measures / new or improved MPA assessment | Need assessment. Direct limited, potentially rewilding via reintroduction (e.g. thornback ray), indirect restoration of hard substrate or biogenic reef restoration |
| | Forage fish / prey fish | Fisheries measures / new or improved MPA assessment / sediment management / removal migration barriers (MSFD, CFP) | Need assessment. Potentially Direct: potentially restoration of spawning / nursery habitat |
| | Demersal fish | Fisheries measures / new or improved MPA assessment / sediment management (MSFD, CFP) | Direct (need assessment); possible nursery areas / indirect; could benefit from biogenic and geogenic projects (incl NiD) |
| Birds | Seabirds breeding (NL) | Spatial optimization OWF design, breeding habitat creation, control of predators, disturbance free zones, fishery discard policy, mitigation offshore activities | Direct: Restore / create suitable breeding and foraging habitats, predator control. Indirect: increase food availability |
| | Seabirds non-breeding (NL) | Spatial optimization OWF design, bycatch reduction, resting areas, protecting feeding, MSP international;; mitigation offshore activities | Direct: Restore / create suitable breeding habitats (through international collaborations) , Indirect: increase food availability |
| | Migratory birds | Spatial optimization OWF design, resting areas protection, protecting international breeding grounds; mitigation offshore activities | Largely out of scope of NN (no use of North Sea ecosystem except for little gull). Direct: improve resting and foraging habitats. Indirect through enhancing food availability (prey fish). |
| Marine mammals | Harbour porpoise | Bycatch reduction / mitigation offshore activities (e.g. noise), ocean literacy and reducing human pressure (chemical pollution, tourism, shipping) | Indirect only: enhancing food availability (improve fish nurseries, prey base restoration) |
| | Seals | Resting / nursing area seasonal closure; bycatch reduction techniques / mitigation offshore activities (e.g. noise), ocean literacy (developing public awareness) | Indirect only: enhancing food availability (improve fish nurseries, prey base restoration) |

## 11.2 Recommendations for follow up steps

This eco-analysis aims to form the scientific foundation for the course of action for nature restoration in the Dutch North Sea. The current ecological status, reference conditions, restoration goals (if any), and potential actionable measures for ecosystem recovery have been described in the previous chapters. To create and select projects and implement measures in e.g. pilots, suitable projects need to be selected based on certain criteria. We propose a decision tree as a means for selecting the suitable projects (Section 11.2.1), and subsequently apply a framework as a means of prioritising projects based on their added value in addition to other running projects and allocation of funds (Section 11.2.2). We conclude with some final recommendations (Section 11.2.3).

### 11.2.1 Evaluation framework for projects and measures

Figure 11-1 shows a proposal for a decision tree for selecting potential projects with proposed measures. The first criterion that needs resolving, is whether the proposed measure falls under the remit of the NN Programme. A second step is to ascertain if a measure can effectively be implemented without further policy measures, or in conjunction with conservation programmes, e.g. under the Nature Restoration Law. E.g. if a measure in a certain location depends on fisheries measures being implemented in that region first, it needs to be (temporarily) shelved. Also, with implementing a measure/action within NN it is important to consider "other bottlenecks/threats" for the species. In the example of migratory fish, there is no point in restoring spawning habitat in a certain area if sufficient connectivity is not guaranteed.

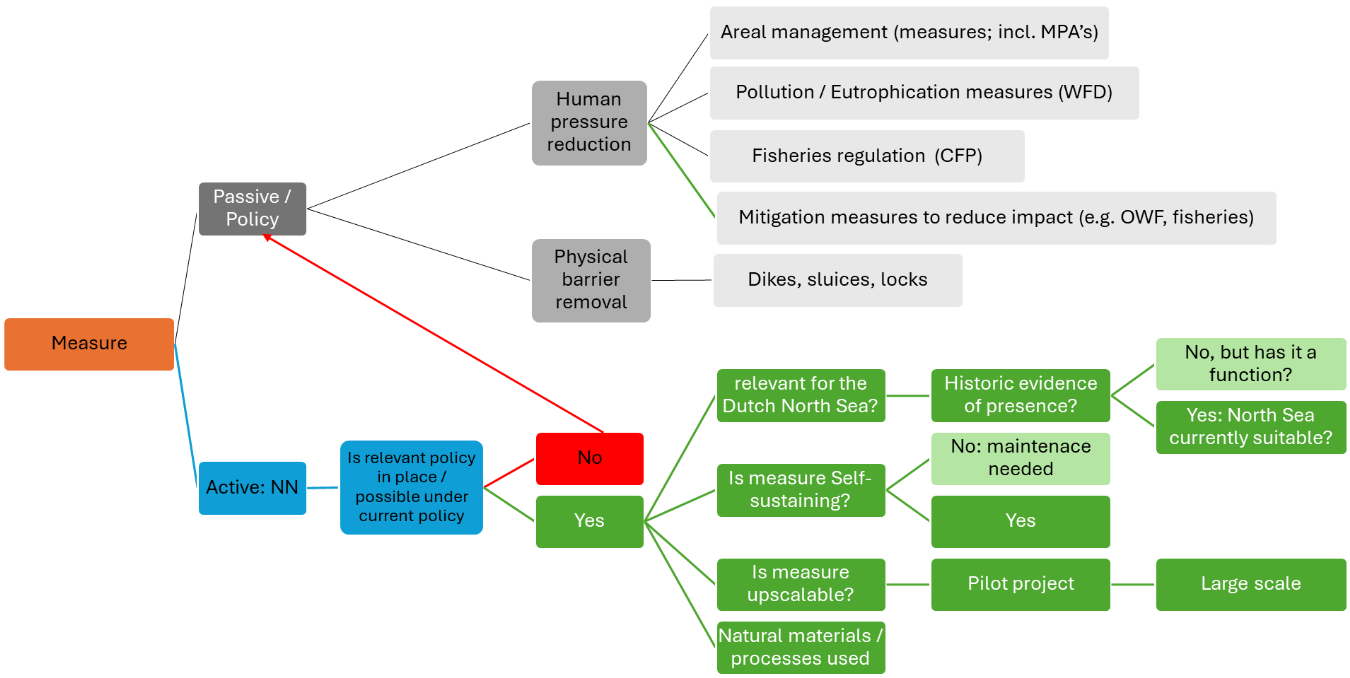


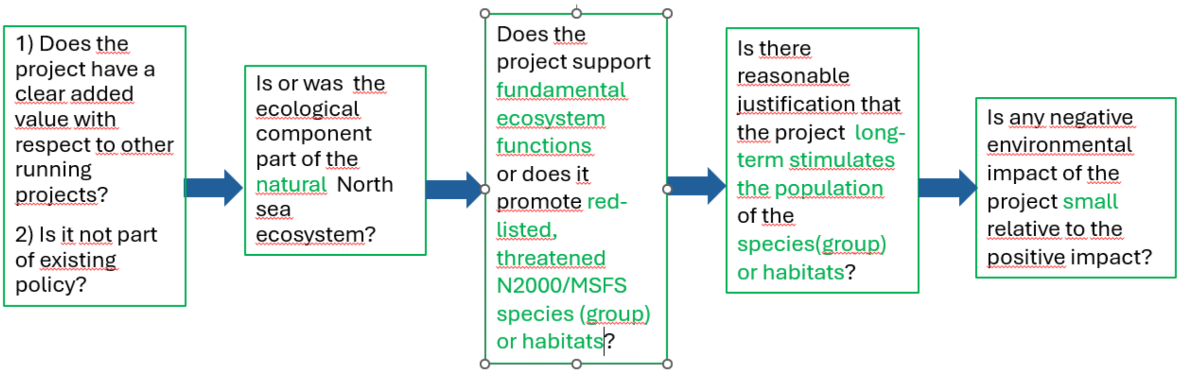

***Figure 11-1*** *Proposal for a decision tree for new project selection for the NN Programme; when a block is green, this indicates a positive recommendation to proceed within NN, with the understanding that light green blocks should be approached with some caution.*

Furthermore, criteria concern a measure's relevance for the North Sea, taking ongoing changes, such as climate change, into account. Historic presence of the species or habitat is an important point to consider but may not always be decisive. A species with demonstrable historic presence in the Dutch EEZ, which is being pushed northward out of the Dutch EEZ, may no longer be a sensible focal point for NN. Conversely species without historic presence, but currently present and fulfilling important ecosystem engineering functions may be considered. At a similar level, self-sustainability is a main criterion. If not, the desirability and feasibility of regular maintenance needs to be assessed. The main aim of NN is ecosystem scale enhancement of species, habitats and functions. In addition, measures without prospect of self-proliferation due to practical, legal, financial or other reasons and that can only be implemented at small-scale, should not be considered further. Finally, the use of natural materials and processes is a main consideration.

### 11.2.2 Prioritisation framework

Once a proposed measure has passed the decision tree as a first step, there are further arguments that can help with prioritisation as well as with allocating budget. These steps are highlighted in Figure 11-2 originally created by Hein Sas for the NN program. These criteria do need further elaboration and specification before they are fully applicable.

NN is a programme that is additional and complementary to standing policy, hence a check on whether there is any related and overlapping standing policy is part of the first step. In general NN is not responsible for the funding of current policy measures. However, in some cases there will be overlap with implementation projects under existing policy, particularly  with the recent adoption of the 'Nature Restoration Law'. Under this policy, it is likely that also activities such as oyster reef restoration will take place. So, on one hand it will take careful consideration to see if NN measures and projects brings something extra, on top of standing policy, while on the other hand delay of starting projects should be avoided in case these measures may become part of existing policy.




| Required elaboration | | | | |
|---|---|---|---|---|
| Define 'added value' and implementation of existing policy | Define 'natural part', based on this report and historical data | Definine 'foundation of the ecosystem', based on this report. Make an inventory of relevant N2000 species (groups) and habitats | Develop criteria for 'reasonable justification of a long-term impact on populations / habitats | Develop a benchmark for a 'relatively small negative environmental impact' |

***Figure 11-2*** *Scheme for decision and prioritisation of (active) measures for nature restoration (Source: Hein Sas; not published).*

With respect to the second criterion, the main focus of NN is the (Dutch) North Sea. However, ecological components currently or historically absent in the Dutch part, but present in neighbouring countries, and with potential suitable habitat in the Dutch part, can be taken into account. Also habitats outside the North Sea but critical for species during some part of the life history of that species can be taken into account. Think of spawning grounds and nursery areas for fish inshore or even upstream and breeding colonies for birds on land.

### 11.2.3 Final recommendations

#### 11.2.3.1 Additional criteria

Improved status of the North Sea ecosystem is the ultimate goal. It will be impossible to carry out measures on all species for which potential measures are possible. Apart from the relatively straightforward decisions in the decision tree there are more complex choices to be made. Factors involved in the choice of priorities are:

- **Focus on processes and ecosystem functions.** Priorities should be given to measures which may target specific species but have positive knock-on effects on other species beyond the direct target species. E.g. the loss of biogenic reefs has caused significant declines in habitat quality for many other species, sessile, as well as mobile. Therefore, expansion of biogenic reefs and other keystone species can be considered high priority.
- **Future-proof**. The North Sea is changing rapidly. Climate change is an important driver. We already see ecosystem shifts due to temperature changes. Other factors to be taken into account, specifically for benthic habitats, include the expected increase of stratification, which strongly influences the food availability on the seabed. Also measures that depend on locations such as frontal areas that may shift under climate change. E.g. the EU project FutureMARES has indicated that both climate change as well as large-scale shellfish cultivation may interact with large-scale shellfish restoration efforts FutureMARES (2024). The increasing and prolonged occurrence of temperature stratification can limit areas where oysters have sufficient growth potential. Hence, (semi)autonomic changes, such as climate change, as well as the influence of all other human activities need to be considered, to ensure success.
- **Holistic approach**. The increasing human use of the North Sea, such as the rapid realisation of the energy transition and offshore aquaculture, result in a rapid urbanisation of the North Sea. Fisheries has had a large impact on the ecology of the North Sea since well before living memory. Making sure that measures that require a high degree of seabed stability are not carried out in areas with high trawling activity, is obvious. Moreover, there are also interactions between ecosystem components that require a holistic approach. Large beds of *Lanice* may facilitate larval settlement of shellfish, but to what extent they facilitate or hamper shellfish reef formation may need to be investigated. For NN, activities that benefit multiple ecosystem components will be of higher value than activities that only boost a single species.

#### 11.2.3.2 Ecosystem component or areal approach

There are basically two different ways to approach restoration:

1. Focussing on requirements of ecosystem components and assess in which areas measures can be taken
2. Focussing on the ecological potential of manageable areas and assess which measures can be taken for ecosystem components that are significant for that area

Both approaches may be valid. E.g. for restoration of the European flat oyster, which is clearly one of the most important keystone species that has been lost in the North Sea, there are already international studies and restoration efforts ongoing on where and how to restore this species. For this species, approach 1 is probably the primary way to go.

In most other instances it may be more effective to work with a primary focus on the area. Firstly, this allows a more holistic approach, taking into account the interactions between ecosystem components (see criteria in previous section). Measures for multiple ecosystem components can be designed in conjunction with each other. Secondly, it would make sense to assess which stakeholders particularly use the area and involve these stakeholders from the beginning in plans for measures. If the area under consideration also contains windfarms, measures can be ensured to align with any nature-inclusive measures within the windfarm. Criteria for choosing certain areas for an integrated approach can include suitability for multiple ecosystem components, connectivity with other areas for mobile species.

Hence, we recommend that while further development of measures along the lines of ecosystem components (approach 1) should continue, the NN programme makes a start with areal assessments (approach 2), to design coherent measures.

#### 11.2.3.3 Impact, objectives and learning

For all NN measures, it is essential that implementation is preceded by a clear definition of objectives. Each measure should explicitly state what ecological improvement is targeted, at which spatial and temporal scale, and how success will be assessed. These objectives should be directly linked to measurable and testable impact indicators, forming the basis for a robust impact monitoring framework.

On another level, for measures implemented at pilot scale, well-designed research and monitoring is crucial to generate insight into the effectiveness and potential unintended impacts of a measure. As NN follows a learning-by-doing approach, outcomes from pilot projects should be systematically evaluated and when sufficient evidence is available on effectiveness, feasibility and trade-offs measures can progress to the next stage, including upscaling to larger spatial or operational scales.

In addition, attention should be given to gaining insight into current food webs and their interactions, for example through modelling approaches, as well as to understanding the expected influence of measures on food web structure and function. Modelling direct and indirect effects within food webs represents a complementary method to monitoring indicators and can provide valuable additional insight. Such modelling is also valuable to evaluate the impact of NN measures and the effectiveness of the NN programme in achieving its ultimate goals, and it is recommended to align these efforts with ongoing modelling studies under MONS and within the NWO NoRegrets project.

### 11.2.4 References

FutureMARES (2024). Mechanistic projections for changing species and ecosystems: preliminary projections and report. Deliverable Report 4.4, CEFAS, Lowestoft. https://www.futuremares.eu/_files/ugd/753771_21ca5f46e0034078b832a3b544cfa22c.pdf.

# 12 Quality Assurance

Wageningen Marine Research utilises an ISO 9001:2015 certified quality management system. The organisation has been certified since 27 February 2001. The certification was issued by DNV.

If the quality cannot be guaranteed, appropriate measures are taken.

# 13 Justification

Report: C018/26
Project Number: 4318100496

The scientific quality of this report has been peer reviewed by a colleague scientist and a member of the Management Team of Wageningen Marine Research

Approved: Ruud Jongbloed
Researcher

Signature:


Date: February 12th, 2026

Approved: Dr. ir. T.P. Bult
Director

Signature:


Date: February 12th, 2026

# Annex 1 Overview of data and models

*Author: Luca van Duren*

## Models

For restoration measures, insight is needed into where ecological potential of areas can be found. In order to assess the ecological potential of marine areas, models are indespensable. Various models and data(bases) exist that can be used for assessing restoration site selection potential, for identifying knowledge gaps, etc. This model and database inventory includes relevant global and European initiatives, Dutch initiatives and ecosystem specific databases which may be helpful for defining future NN projects.
In the marine environment there are, in comparison to terrestrial areas, far fewer measurements and observations on habitat characteristics, occurrence of species, variability of environmental parameters (seasonally, year-to-year) etc. Models can be used for the following purposes:

1. Simulating currents and waves. Hydrodynamic models simulating currents and waves are often at the basis of marine ecological models (Booij et al. 1996, Duran-Matute et al. 2014, Zijl et al. 2020).
2. Simulating the transport and cycling of nutrients, penetration of light, growth and dynamics of phytoplankton can be conducted using biogeochemical models coupled to abovementioned hydrodynamic models (Ruardij et al. 1997, van der Molen et al. 2013, Los et al. 2014, Van Duren et al. 2017).
3. Gaining area covering insight into habitat characteristics. With sparse measurements on abiotic parameters, data-driven models can be used to interpolate measurements to get an areal cover of parameters. An example is the use of a random forest model to construct a fine-resolution map of mud content of the seabed (Stephens and Diesing 2015). This study used observational data on mud content in the seabed, combined with modelled bed shear stress from hydrodynamics models and data on bathymetry, to construct maps for seabed composition.
4. Gaining insight in how the physical habitat characteristics link to habitat suitabilility for species and species groups. This can be achieved with statistical spatial models. Examples of this are the studies on habitat suitability based on underlying maps of presence / absence of species and maps of physical habitat characteristics (Tyberghein et al. 2012, Herman and Van Rees 2022).
5. Gaining insight into connectivity for planktonic organisms between areas (e.g. source populations and potential suitable settlement habitat (Bacher et al. 2016, Kamermans et al. 2018). Spatial distribution models as well as connectivity models can include behavioural traits. Such models are called agent-based models (Thorson et al. 2012, Pastor et al. 2018)
6. Gaining insight into connectivity between areas for birds and nekton. Such models require higher level behaviour (Stephens et al. 2003, Dean et al. 2013).
7. Gaining insight in the local growth potential of species and species groups, based on food availabilty. This can be achieved though models on species-specific energy budgets (e.g. dynamics energy budget models), coupled to hydrodynamic and biogeochemical models. (Vilmin and Van Duren 2021, Stechele et al. 2023).
8. Gaining insight in species demographics. Demographic models (estimating survival and/or reproduction rates changing over time, their dependence on environmental parameters and their relative contribution to population growth) are important for conservation of birds, mammals and at least some fish.

Depending on the questions at hand, combinations of models can be used. An example of a mixed-model approach is the work on oyster restoration potential under different climate scenarios carried out in the FutureMARES project (Vilmin et al. 2023). In this study oyster growth was simulated using a DEB model, nested in the DCSM-Delwaq modelling suite (coupled hydrodynamic-water quality model). In the model oysters were allowed to grow in areas of the North Sea that were both suitable according to the model of Herman and Van Rees (2022) as well as exempt from trawling (either wind farm areas or MPAs).

In general, hydrodynamic and biogeochemical models are *deterministic*, based on underlying knowledge of all the relevant physical and biochemical processes. For higher trophic levels, particularly when behaviour of animals comes into play, models have to be stochastic, i.e. driven by data and based on statistical relationships. The choice of model strongly depends on the question, on the availability of underlying knowledge of relationships and on the availability of data.
Models are the only tools that can be used to predict how ecological populations or habitats are going to develop in the future, when fundamental changes are expected to the environment, e.g. how the ecosystem is likely to change with the development of wind farms. One cannot measure what is not there. However, it is essential that we are aware of the model limitations, particularly if models are designed and calibrated for certain boundary conditions and the boundary conditions are changed. It is dangerous to use model predictions at face value. It does often take specialist interpretation to draw the right conclusions.

## Data

*Author: Sharon Tatman, Oscar Bos*
To assess, plan and prioritise interventions, monitoring data is needed in addition to other sources of data such as modelling data, in order to understand the current status and functioning of ecosystem components and the pressures acting on them. Thus, data is essential for understanding extent and locations of (degrading) habitats and/or species and populations.

Certain data and information is needed for NN. These could be maps that identify locations with opportunities for large or small scale nature restoration, or maps with ecological data on habitat preferences or sensitivities per species (groups). Combining these maps together to produce new data products can provide even more insightful information on e.g. optimally suited areas for certain species (groups) or habitat restoration.

This paragraph consists of a short overview of publicly available data (data and information made freely available through the internet by government bodies without conditions of use), that can provide quantitative information on the status and trends of the ecosystem elements (e.g. benthos, fish, etc) in the Dutch North Sea. Note that this overview is not complete but tries to capture the main data sources.

There are many different data platforms available as a source of data for viewing and/or retrieving data for the North Sea. They can be distinguished as (European Commission, 2017):

a. **Data Catalogues** (typically a listing of data, its availability and how to source);
b. **Data Platforms** (online direct access to data sets, using data from source with open data standards)
c. **Map Viewers** (tool which shows spatial data on a map, if possible, provides the option for a download)
d. **Information Services** (tool which can aggregate or run a process to create information)
e. **Assessment Tools** (method or specialised tool to support further analysis and interpretation)

Data platforms can have multiple classifications, meaning that they, for example, can be a Map Viewer as well as an Information Service.

The following are all key sources of data on habitats, species and environmental parameters in the North Sea, relevant to NN, to be found on European or national data platforms consisting mainly of data catalogues, platforms or map viewers.

## Global/European Initiatives

**EMODnet (European Marine Observation and Data Network)**: The European Marine Observation and Data Network (EMODnet) is a network of organisations supported by the EU's integrated maritime policy. These organisations work together to observe the sea, process data according to international standards and make that information freely available as interoperable data layers and data products. EMODnet offers access to a wide range of marine data, including species distribution and habitat preferences in European waters, including the Dutch North Sea. The platform provides access to pan-European marine data, has a data viewer as well as a metadata registry. The EMODnet catalog is grouped into several themes: Bathymetry, Biology, Chemistry, Geology, Human Activities, Physics, Seabed Habitats. Data is downloadable via (https://emodnet.ec.europa.eu/geoviewer/#!/).

**ICES Data Platform:** the International Council for the Exploration of the Sea (ICES) is an intergovernmental marine science organization, assessing societal needs for impartial evidence on the state and sustainable use of seas and oceans. The goal is to advance and share scientific understanding of marine ecosystems and to use the acquired knowledge to generate state-of-the-art advice for meeting conservation, management, and sustainability goals. The ICES platform is classified as a map viewer and data platform, with spatial data layers that can be viewed on a map. Besides the ICES platform has a full metadata catalogue. The data is grouped into themes, including Fishing, Fish, Marine mammals, Seabirds, Habitats. Data is downloadable via https://data.ices.dk/view-map

**WISE Marine:** WISE-Marine provides access to information and data on the state of Europe's seas, on the pressures affecting them, and on the actions being taken to protect and conserve the marine environment. This information is collected at the European level through implementation and reporting for the EU Marine Strategy Framework Directive (MSFD, Directive 2008/56/EC), as well as from other European legislation and initiatives that are relevant for the marine environment. The WISE-Marine platform is a partnership between the European Commission and the European Environment Agency (EEA). Data is downloadable via the map viewer https://discomap.eea.europa.eu/wise-marineviewer/. There is no central point to access all the available data and information. The website links to several dashboards on several subjects which are part of the MSFD.

**OSPAR Data & Information Management System (ODIMS):** The OSPAR Data and Information System (ODIMS) is an online platform providing a single point of access to all the data and information gathered through OSPAR's Joint Assessment and Monitoring Programme across the different thematic work areas of the Convention. The landing page shows multiple options to filter data and information. It is only possible to view one dataset at a time in a data viewer. It is possible to download data via webservice, if the service allows, but it is also possible to download shapefiles directly. Data is downloadable via https://odims.ospar.org/en/.

**Ocean Biodiversity Information System (OBIS):** the Ocean Biodiversity Information System (OBIS) is a global data and information platform on marine biodiversity. It provides a database of marine species distribution and abundance. OBIS is coordinated by the Intergovernmental Oceanographic Commission of UNESCO and integrates data from various sources worldwide. Data is downloadable via https://obis.org/data/access/. European node: EUROBIS

**SeaDataNet**: SeaDataNet is a pan-European infrastructure designed for the management and access of large and diverse sets of marine and oceanographic data. It connects over 110 national oceanographic and marine data centers from 35 countries, and hosts North Sea aggregated data. These datasets include measurements of temperature, salinity, and other oceanographic parameters. While SeaDataNet focuses on the standardisation and management of marine data, EMODnet is a better database since their main aim is to integrate and make a wide array of marine data products available.

**PANGAEA** (https://www.pangaea.de/): data warehouse. Contains datasets on the North Sea, mainly by AWI. Can be searched for target species, method, area, project, etc. It also contains photos and videos that can b downloaded, for example video inspections of oyster reefs.
(https://doi.pangaea.de/10.1594/PANGAEA.946721)

## Dutch initiatives

**Marine Information and Data Centre** (Informatiehuis Marien): the Marine Information and Data Centre (IHM) (Informatiehuis Marien) is managed by Rijkswaterstaat and the ministry of LVVN, consisting of a database providing comprehensive information on marine species, habitats, and ecological conditions in the Dutch North Sea. It is the location of data, information, and research information on the EEZ of the Dutch part of the North Sea, containing publicly available (government) data. It aims to be a platform which does not store data but keeps data at the source. IHM has an open data viewer, which is OGC compliant and therefore it is possible to download data. Besides, IHM has direct links to project pages (e.g. MONS, WOZEP) where the information is from. Data is downloadable via https://viewer.openearth.nl/ihm-viewer/?layers=85222873&layerNames=Maritime%20boundaries%20NCP%20%28INSPIRE%29.

Linked sites:

- Waterinfo extra: https://waterinfo-extra.rws.nl/ (collection of biological and abiotic data including MWTL collected by Rijkswaterstaat; partly displayed in IHM)
- Nationaal Georegister: www.nationaalgeoregister.nl. National georegister including data from the Hydrographical Office.

**Marine Information and Data Centre (Mijnbouw & wind op Zee):** The Mining and Wind Farm viewer is a data viewer which links to all relevant Dutch energy data. It provides options to view the data, but not to download them, allowing the user only to print a static map: https://experience.arcgis.com/experience/6e637f42374549329c46633afab17f58/page/Page/

**Offshore Wind Ecological Programme (WOZEP)** dataset: the WOZEP program provides datasets collected under the WOZEP program. The Datasets are arranged into themes: bats, benthos, birds, marine mammals, fish. Although the data is available (some data is embargoed) it is currently only available upon request through contacting the data manager at Witteveen+Bos.

## Ecosystem component specific datasets

We try to give an overview of useful databases for NN projects and tried to be as complete as possible. This overview can be used as a starting point for the programme to use and can be further updated where needed/relevant.

## Habitats

In addition to the EMODnet habitat maps, these datasets may also be helpful for NN projects:

- **Hydrographic Office (HO) side scan sonar (SSS) data:** The use of HO SSS data proved to be very powerful for fieldwork preparation and for habitat mapping (stone reefs H1170 and biogenic reefs) in The Borkum Reef Grounds. These data may be used for site selection studies (e.g. for native oyster restoration, *Sabellaria* restoration, etc.), and for habitat mapping (Bos et al. 2025).

- **Seafloor sediment map**: TNO Geological service (https://www.dinoloket.nl/zeebodemsedimentkaart). A new seafloor sediment map, with more resolution compared to the EMODnet habitat maps.

## Benthos

In addition to the data available through the Marine Information and Data Centre (benthic MWTL data and shellfish survey data), the following databases are of interest for NN projects:

- **BISAR** (Biodiversity Information System of benthic species at ARtificial structures): Dataset on hard substrate species. This large-scale/high-resolution North Sea information system combines diverse biological data with high resolution in terms of space, time and ecological structure (e.g., biodiversity and trophic relationships). Coverage: the area of the German Bight from 1969 to today (< 9000 stations, > 740 species). https://critterbase.awi.de/#projects-bisar

- **OneBenthic** (https://openscience.cefas.co.uk/): contains standardised UK dataset on benthos (grabs/core, trawl, imagery)

- **NIOZ TripleD dredge.** The NIOZ collects TripleD dredge data (larger benthos and benthic fish such as sandeel). Data have been published as an atlas but not online available (Witbaard et al. 2013).

- **MOO-project: scuba dive data** ('Het Duiken Gebruiken 4', Stichting Anemoon: Van der Loos et al. 2019). Data collected by volunteer scuba divers. For the North Sea, data are mainly collected during diving expeditions organized by the ''Duik De Noordzee Schoon'' foundation. For the Dutch delta area (Eastern Scheldt, Western Scheldt, Grevelingen) data are collected by individuals divers, and sometimes through groups of divers during dedicated monitoring days.

## Fish

In addition to the databases on commercial fish species and records of other species caught during various annual fish surveys, the following databases also provide useful data:

- **European Tracking Network (ETN)** tracks aquatic animals across Europe with the mission to better understand, protect and manage them (https://europeantrackingnetwork.org/en).

- **SharkATag program**: The SharkATag program targets smooth-hound sharks, tope, and common stingrays for catch-and-release in the Delta area. This program has yielded information on the seasonal migration, population structure and use of the Eastern Scheldt as a nursery area by smooth-hound sharks. No database online.

- **WMR Fresh water fish data**: Migratory and freshwater fish database (MWTL data). Trends per species. https://ecologie-van-zoetwatervis.wur.nl/soort/

- **Netherlands Database Flora and Fauna** (NDFF). Database for all plant and animal species occurring in the Netherlands, Relevant for a.o. migrating fish species. https://ndff.nl/ (200 million records)

- **MOO project (see benthos)**

- **Mijnvismaat**. Sizes of fish caught by recreational fishermen (https://www.mijnvismaat.nl/).

## Birds

In addition to the databases mentioned above, these databases may be helpful for NN projects:

- **European Seabirds At Sea (ESAS)**. Database of seabirds, mostly containing data from the North Sea and parts of the Northeastern Atlantic, and hosted by ICES (https://esas.ices.dk/inventory). A complete coverage of national sea areas is only achieved in The Netherlands, Belgium and Germany compared to other neighbouring countries. Elsewhere the coverage is incomplete and often project-related. For example, in the UK data are collected by the Crown estate and by offshore wind companies.
- **Bird tracking data**:
  - UvA-BitS (https://www.uva-bits.nl/),
  - Movebank (https://www.movebank.org/cms/movebank-content/audubon-mbi-collection).
  - Presence-absence for all species: eBird (https://ebird.org/home)
  - Marked individuals: EURING (https://euring.org/).

## Marine mammals

- **SCANS data**: not available online. Survey data for cetaceans in Northeastern Atlantic waters and the North Sea, initiated in 1994 and continued at approximately decadal frequency. Coordinated by the Sea Mammal Research Unit at the University of St Andrews (https://scans3.wp.st-andrews.ac.uk/).
- **Seal tagging data**: not available online. The transmitters register the geographical position and diving depth and regularly transmit all the data collected. This makes it possible to record individual behaviour and the use of space.

## Conclusion

Marine data collected through ecological or environmental surveys (e.g. biological or hydrographical data) are hosted by national authoritative data houses. They aggregate data into themes and often set their own national data standards. Many of these datasets from the individual national data authorities are ingested by European data authorities, such as those mentioned above. EMODNET for example collects the data from national level (on a voluntary basis by the member states) and subsequently aggregates and standardises the data into EMODNET's thematic groups, e.g. EMODNET Human Activities, Geology, Biology, Bathymetry (Fraschetti et al. 2024).

Although it seems that there is a plethora of data and online data platforms making data available for the North Sea, many datasets are not unique and hosted on multiple platforms (i.e. data can sometimes be recycled between data platforms). Furthermore, European data authorities have extensive data standardisation and harmonisation protocols which in practice means it can take a long time (even up to several years in some cases) to ingest data(sets) and aggregate into (basin-scale) data products or services. Although these protocols are necessary from a reliability and accuracy perspective, users should be aware of this lag in time of data availability.

## References

Bacher, C., R. Filgueira, and T. Guyondet (2016). Probabilistic approach of water residence time and connectivity using Markov chains with application to tidal embayments. Journal of Marine Systems 153:25-41.

Booij, N., L. Holthuijsen, and R. Ris. (1996). The" SWAN" wave model for shallow water. pp 668-676. Coastal engineering.

Bos, O.G., Bittner, O., van der Weide, B., Cuperus, J., Wijnhoven, S., Gaida, T. C., & Binnerts, B. (2025). Borkum Reef Grounds: inventory of biodiversity and habitats. MONS ID49 Effectivity of Marine Protected Areas. Wageningen Marine Research, Waardenburg Ecology, Ecoauthor, TNO. C054/25 (https://doi.org/10.18174/697930).

Dean, B., R. Freeman, H. Kirk, K. Leonard, R. A. Phillips, C. M. Perrins, and T. Guilford. 2013. Behavioural mapping of a pelagic seabird: combining multiple sensors and a hidden Markov model reveals the distribution of at-sea behaviour. Journal of the Royal Society Interface 10:20120570.

Duran-Matute, M., T. Gerkema, G. J. de Boer, J. J. Nauw, and U. Gräwe. (2014). Residual circulation and fresh-water transport in the Dutch Wadden Sea: a numerical modeling study. Ocean Science-Discussions 11:197-257.

Fraschetti, S., Strong, J., Buhl-Mortensen, L., Foglini, F., Gonçalves, J., González-Irusta, J., Lillis, H., Lindegarth, M., Martin, G., Menot, L., O'Keeffe, E., Pascoal, A., Salomidi, M., Schoening, T., Alexander, B. (2024). EMB Future Science Brief No. 11 'Marine habitat mapping'. 10.5281/zenodo.11203128.

Herman, P.M.J., and F.F. Van Rees (2022). Mapping Reef forming North Sea Species. 11207716-000-ZKS-0001, Deltares, Delft.

Kamermans, P., L.A. Van Duren, and F. Kleissen. (2018). European flat oysters on offshore wind farms: additional locations; Opportunities for the development of European flat oyster (Ostrea edulis) populations on planned wind farms and additional locations in the Dutch section of the North Sea Wageningen Marine Research, Yerseke (https://edepot.wur.nl/456358)

Los, F.J., T.A. Troost, and J.K.L. Van Beek. (2014). Finding the optimal reduction to meet all targets—Applying Linear Programming with a nutrient tracer model of the North Sea. Journal of Marine Systems 131:91-101.

*MSP data study – Evaluation of data and knowledge gaps to implement MSP*, Publications Office, (2017), https://data.europa.eu/doi/10.2826/25289

Pastor, A., P. Mariani, A.C. Erichsen, F.T. Hansen, and J.L. Hansen (2018). Modeling dispersal and spatial connectivity of macro-invertebrates in Danish waters: An agent-based approach. Regional Studies in Marine Science 20:45-59.

Ruardij, P., H. Van Haren, and H. Ridderinkhof. (1997). The impact of thermal stratification on phytoplankton and nutrient dynamics in shelf seas: A model study. J Sea Res 38:311-331.

Stechele, B., L. Barbut, G. Lacroix, L. A. van Duren, V. Van Lancker, S. Degraer, G. Montereale Gavazzi, P. Bossier, A. Declercq, and N. Nevejan. (2023). Northern Europe's suitability for offshore European flat oyster (Ostrea edulis) habitat restoration based on population dynamics. Frontiers in Marine Science 10.

Stephens, D., and M. Diesing. (2015). Towards Quantitative Spatial Models of Seabed Sediment Composition. PLoS ONE 10.

Stephens, K., B. Pham, and A. Wardhani. 2003. Modelling fish behaviour. Pages 71-78 in Proceedings of the 1st international conference on computer graphics and interactive techniques in Australasia and South East Asia.

Thorson, J.T., I.J. Stewart, and A.E. Punt. (2012). Development and application of an agent-based model to evaluate methods for estimating relative abundance indices for shoaling fish such as Pacific rockfish (Sebastes spp.). ICES J. Mar. Sci. 69:635-647.

Tyberghein, L., H. Verbruggen, K. Pauly, C. Troupin, F. Mineur, and O. De Clerck. (2012). Bio-ORACLE: a global environmental dataset for marine species distribution modelling. Global ecology and biogeography 21:272-281.

Van der Molen, J., J. Rees, and S. Limpenny. (2013). Modelling potential changes in marine biogeochemistry due to large-scale offshore wind farms. Pages EGU2013-7233 in EGU General Assembly Conference Abstracts.

Van der Loos, L.M., & Gmelig Meyling, A. W. (2019). *Het duiken gebruiken 4: Gegevensanalyse van het Monitoringproject Onderwater Oever (MOO). Fauna-onderzoek met sportduikers in Oosterschelde en Grevelingenmeer. Periode 1994 t/m 2018*. www.anemoon.org

Van Duren, L.A., T. Van Kessel, T.A. Troost, A.N. Blauw, L. Kramer, J.A. Van Gils, J.A.M. Craeymeersch, and P.M.J. Herman (2017). Scenariostudies ter ondersteuning van de MER-Zandwinning 2018-2027. 1230888-000-ZKS-0018, Deltares, Delft.

Vilmin, L.M., S. Heye, L.K. Schneider, F. Di Paola, P. Kamermans, J. Wijsman, and L.A. van Duren. (2023). Oyster restoration modelling in the North Sea using Delft3D FM. Deltares, Delft.

Vilmin, L.M., and L.A. Van Duren. (2021). Modelling seaweed cultivation on the Dutch continental shelf. 11205769-002-ZKS-0001, Deltares, Delft.

Zijl, F., S.C. Laan, and J. Groenenboom. (2020). Development of a 3D model for the NW European Shelf (3D DCSM-FM). report 11205259-015-ZKS-0003, Deltares, Delft.

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