Paper

SEEA Ocean Ecosystem Accounting for the Dutch North Sea: towards a first full implementation

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1. Summary

The North Sea is the largest natural area in the Netherlands, but it is also intensively used. To catch fish; to navigate and trade, and recently to provide sustainable wind energy. This intense use puts the North Sea under pressure. One of the key challenges for policy development is how to find a good balance between the biodiversity of the North Sea and the use of it as a source for food, energy, minerals and other natural resources.

In order to support both the development and monitoring of policies regarding the North Sea, and to support the associated societal debate, there is a clear need for reliable and neutral data on the various elements of the North Sea and it's use.

This report describes the (experimental) compilation of an ecosystem account for the Dutch North Sea, according to the guidelines of the UN System of Economic-Environmental Accounting — Ecosystem Accounting (SEEA-EA), which is the statistical standard in this field.

In short, SEEA-EA accounts describe the North Sea environment as ecosystems, in terms of size (*extent*) and quality (*condition,* including *biodiversity*). The human interaction with the North Sea is described bi-directional. In terms of our use of the sea (*ecosystem services*) and vice versa (*as pressures*). This use can be described both in *physical* terms, but can in most cases also be assigned a *monetary* value. Because the economic actors involved are the same as defined in the System of National Accounts, these values can be related to other macro-economic descriptors such as the UN Global Biodiversity Framework or sectoral statistics.

It should be noted, though, that ecosystem accounting is, despite the status of 'statistical standard', still experimental in the practical sense, especially when applied to the marine realm. Therefore, the value of the current report is as much in the exploration of data sources and options, and the development of methodologies, as in the numbers themselves.

1.1 Brief overview of the contents

Chapter 2 provides an introduction, by setting the policy context, including the Marine Strategy Framework Directive (MSFD) and OSPAR, and introduces the SEEA-EA framework.

Chapter 0 describes the delineation of the Dutch North Sea in individual ecosystem assets. A series of classification systems is described and evaluated, and eventually the EU-wide EUSeaMap is used as a data source to compile an *extent account* for the Dutch North Sea, and some sub-areas of interest.

Chapter 4 focuses on the *condition* of the North Sea and its constituent ecosystems. Since MSFD and OSPAR are important data sources for information of the state of biodiversity of the North sea, and the pressures upon it, a significant part of this chapter deals with cross walks between the various condition typologies of MSFD, OSPAR and SEEA-EA, resulting in a (largely) qualitative condition account based on the MSFD assessments.

Chapter 5 discusses the various *pressures* on the North Sea. Because many of the MSFD pressure descriptors have already been discussed in Chapter 4 on the condition account, more attention is given to the pressures as identified for the protected nature of the North Sea, under the Bird and Habitat Directive. The resulting (experimental) pressure account uses these pressures as links between economic sectors (causing the pressures) and the individual species and habitats. Additional attention is given to some specific types of pressures of interest, such as bottom trawling and wind energy.

Chapter 0 describes in depth the trends in biodiversity of the Dutch North Sea, using the same multi-species indicator methodology as the Living Planet Index. Indicators are defined for benthic macrofauna, fish, birds and all species groups together, including mammals such as porpoises.

Chapter 0 deals with the use of the North Sea by economic sectors (including households and the government) for a suite of ecosystem services, ranging from provisioning services (fish) and regulating services (including climate and waste regulation, and coastal protection) to cultural services (such as recreation and tourism) and abiotic services (e.g. mineral extraction and wind energy). For most of these ecosystem services an economic value could be established

Chapter 8 integrates all monetary valuations into the *asset account*, representing the monetary value of our use of the natural capital of the Dutch North Sea. For the basket of ecosystem services considered, it is approximately 50 billion euro.

Chapter 9, finally, presents a discussion on many of the issues encountered in this work, accompanied by a series of recommendations for future work.

2. Introduction

The Dutch Ministry of Infrastructure and Water Management has commissioned Statistics Netherlands (CBS) to develop a series of Ecosystem Accounts for the Dutch part of the North Sea, based on the United Nations (UN) System of Environmental-Economic Accounting (SEEA) guidelines. With this study, the ministry would like to explore the potential use of these accounts as an instrument to monitor and support sustainable development in the Dutch part of the North Sea, as part of a series of national and European policies.

This report provides an overview of how a full marine account, structured as a SEEA ecosystem account, can be setup. Emphasis is given to the alignment with the work done and the re-use of data collected on behalf of the European Marine Strategy Framework Directive (MSFD) and the OSPAR Convention for the Protection of the marine Environment of the North-East Atlantic, and the translations of concepts from the MSFD and OSPAR to make them suitable for use in the SEEA ecosystem accounting framework. The report build upon earlier pilot (Schenau et al., 2019).

The aim of this study is to present full SEEA ecosystem accounts; it should be emphasized that it is not in all cases possible yet, generally due to a lack of data, or missing characteristics – such as location – of the data available. In other cases there is too much data available, or a multitude of classifications schemes that one has to choose from. This report therefore also describes the search for data and the process of setting up ecosystem accounts.

2.1 Policy context

The Dutch North Sea policy is articulated in the North Sea Programme 2022–2027[1], which in turn is part of the wider National Water Programme 2022–2027, According to the North Sea Programme 2022–2027, "Attention for the economic importance of the North Sea is rising. In addition to the existing and sometimes centuries old uses such as shipping and fishing, innovative new uses are emerging, e.g. energy generation and marine aquaculture. At the same time, the need to further improve the environment of the North Sea and to maintain and recover the ecological system increases."[2]

The Dutch policy on the Dutch part of the North Sea is linked to, and organized within, several integrated, (inter)national, legal, spatial and administrative frameworks. The most important are:

2.1.1 Global Scale

Relevant international agreements and obligations are the Paris Climate agreement[3], the UN Convention of Biological Diversity (CBD) Kunming-Montreal Global Biodiversity Framework[4], and the UN Sustainable Development Goals[5], most importantly, SDG 14 *Life Below Water*.

[1] https://www.noordzeeloket.nl/en/policy/north-sea-programme-2022-2027/
[2] Quoted text in this section is taken verbatim from: https://www.noordzeeloket.nl/en/policy/
[3] https://unfccc.int/process-and-meetings/the-paris-agreement
[4] https://www.cbd.int/gbf/
[5] https://sdgs.un.org/goals

2.1.2 European Scale: MSFD and Natura 2000.

European Marine Strategy Framework Directive

The EU Marine Strategy Framework Directive (MSFD) is a comprehensive policy framework established by the European Union to ensure the sustainable use and protection of marine environments[6]. Adopted in 2008, the directive aims to achieve Good Environmental Status (GES) of EU marine waters by 2020 and maintain it thereafter. Member states are required to develop strategies and programs of measures to address pressures on marine ecosystems, monitor their progress, and take necessary actions to prevent deterioration and restore marine biodiversity, habitats, and ecosystem functions. The MSFD promotes integrated, science-based management for healthier seas and balanced maritime activities.

In the Netherlands the MSFD is implemented through the North Sea Programme 2022-2027 (see below in Section 2.1.4)

Natura 2000

The EU Bird Directive[7] and Habitat Directive[8] form the cornerstone of the EU's nature conservation policy. Together, these directives contribute to the establishment of the Natura 2000 network, which is one of the largest and most comprehensive networks of protected areas in the world. The Natura 2000 network plays a vital role in preserving Europe's biodiversity and ensuring the sustainable use of natural resources.

EU Biodiversity Strategy for 2030

The EU Biodiversity Strategy aims to halt the loss of biodiversity and ecosystem services in the EU by 2030[9]. It sets a target to safeguard at least 30% of the EU's marine areas, contributing to global ocean conservation. The strategy addresses threats such as overfishing, pollution, the control of invasive species and habitat degradation, promoting sustainable fisheries, marine protected areas, and ecosystem restoration for healthier seas. It also promotes nature-based solutions and stakeholder involvement in conservation efforts.

Marine ecosystem services play a crucial role in the EU Biodiversity Strategy. These services, provided by marine ecosystems, include things like seafood production, coastal protection, carbon sequestration, and recreational opportunities. The strategy aims to protect and restore marine biodiversity to ensure the continued provision of these services. By preserving healthy marine ecosystems, the EU seeks to sustain livelihoods, enhance resilience to climate change, and promote the overall well-being of both nature and people.

As part of their “integrated and whole-of-society approach”, the Biodiversity Strategy will also focus on measuring and integrating the value of nature, including the development of methods, criteria and standards to describe the essential features of biodiversity, its services, values, and sustainable us. The upcoming Eurostat regulation for ecosystem accounting[10] should be seen in this light.

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[6] See https://environment.ec.europa.eu/topics/marine-environment_en for an overview and https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32008L0056 for the legal text.

[7] Directive 2009/147/EC, see https://environment.ec.europa.eu/topics/nature-and-biodiversity/birds-directive_en

[8] Directive 92/43/EEC , see https://environment.ec.europa.eu/topics/nature-and-biodiversity/habitats-directive_en

[9] https://environment.ec.europa.eu/strategy/biodiversity-strategy-2030_en

[10] https://knowledge4policy.ec.europa.eu/news/european-commission-proposes-introduction-ecosystem-accounts_en

2.1.3 Regional Scale: OSPAR

The OSPAR Convention for the Protection of the marine Environment of the North-East Atlantic is the mechanism by which the European Union and 15 of their Member States cooperate to protect the marine environment of the North-East Atlantic[11].

The vision of OSPAR is "*a clean, healthy and biologically diverse North-East Atlantic Ocean, which is productive, used sustainably and resilient to climate change and ocean acidification*" (OSPAR, 2021). In order to deliver this vision, the current "2030" North-East Atlantic Environment Strategy ,NEAES [12] (OSPAR, 2021) sets out a set of 12 strategic objectives, organized along the four themes of the vision (Table 1)[13].

Table 1. OSPAR Strategic objectives (OSPAR, 2021)

Vision	Strategic objective	
Clean Seas		
	1	Tackle eutrophication
	2	Prevent pollution by hazardous substances
	3	Prevent pollution by radioactive substances
	4	Prevent inputs of and significantly reduce marine litter
Biologically diverse and healthy seas		
	5	Protect and conserve marine biodiversity
	6	Restore degraded habitats
Productive and sustainably used seas		
	7	Ensure sustainable use of the marine environment
	8	Reduce anhropogenic underwater noise
	9	Safeguard the structure and function of marine ecosystems
Resilience to impacts of climate change and acidification		
	10	Raise awareness of climate change and ocean acidification
	11	Facilitate adaptation to the impacts of climate change and ocean acidification
	12	Mitigate climate change and ocean acidification

Monitoring and assessment

Under each theme, work is undertaken in relation to the monitoring and assessment of the status of the marine environment, the results of which are used to follow up implementation of the strategies and the resulting benefits to the marine environment. The themes fit together to underpin the ecosystem approach.

The status of the marine environment is monitored through the OSPAR Joint Assessment & Monitoring Programme (JAMP). The key deliverable in this context is the publication of the Quality Status Report (QSR), which provides a picture of the overall state of the North-East Atlantic and its ecosystems, including pressures from human activities.

Ecosystem approach

OSPAR is guided by an ecosystem approach, defined as

> "the comprehensive integrated management of human activities based on the best available scientific knowledge of the ecosystem and its dynamics, in order to identify and take action on drivers, activities and pressures that adversely affect the health of marine

[11] https://www.ospar.org

[12] https://www.ospar.org/convention/strategy

[13] The previous 2010–2020 NEAES focused on five thematic strategies: Biodiversity and ecosystems; Eutrophication; Hazardous substances; Offshore oil and gas industry; Radioactive substances.

> ecosystems. The ecosystem approach thereby achieves the sustainable use of ecosystem goods and services and the maintenance of ecosystem integrity. (OSPAR, 2021)

This ecosystem approach takes into consideration the (cumulative) effects of human activities and is implemented through a continuous cycle of (i) setting and coordinating ecological objectives and associated targets and indicators, (ii) ongoing management and (iii) regular updates of ecosystem knowledge, research and advice. (OSPAR, 2021)

International engagement and the EU MSFD

When developing their marine strategies, EU Member States are required to coordinate with each other and third countries though the existing Regional Sea Conventions [such as OSPAR], which aim to protect the marine environment and bring together Member States and neighbouring countries that share marine waters[14]. Thus, within the EU, OSPAR provides a framework for cooperation that contributes to defining and achieving good environmental status under the EU Marine Strategy Framework Directive (MSFD).

Apart from their engagement with the MSFD, OSPAR is strongly involved in in the relevant international frameworks, policies and other platforms, such as the UN sustainable development Goals (SDGs) and the International Maritime Organization (IMO).

OSPAR and Natural Capital

The current OSPAR North-East Atlantic Environment Strategy (NEAES) explicitly links to ecosystem services and ecosystem accounting:

Strategic objective 5: Protect and conserve marine biodiversity, ecosystems *and their services* to achieve good status of species and habitats, and thereby maintain and strengthen ecosystem resilience.

Strategic Objective 7: Ensure that uses of the marine environment are sustainable, through the integrated management of current and emerging human activities, including addressing their cumulative impacts

The link with ecosystem accounting is implemented through one of the underlying operational objectives:

S7.O3 By 2025 OSPAR will start accounting for ecosystem services and natural capital by making maximum use of existing frameworks in order to recognize, assess and consistently account for human activities and their consequences in the implementation of ecosystem-based management.

The NEAES does not make explicit which “existing” frameworks they refer to. SEEA(-EA), IPBES, GOAP and the Natural Capital Protocol are the most relevant of these.

Recently, experimental OSPAR NCA accounts have been compiled (Alarcon Blazquez, 2021; Alarcon Blazquez et al., 2023), on which the currently study builds.

2.1.4 National Scale

North Sea Programme 2022–2027

The North Sea Programme 2022-2027 describes the spatial planning in the Dutch part of the North Sea, the measures to achieve good environmental status and the management required

[14] https://environment.ec.europa.eu/topics/marine-and-coastal-environment_en

for this. The legal framework for this consists of the statutory obligations under the Water Act, which also implements the obligations of the European Maritime Spatial Planning Directive (MSP) and the Marine Strategy Framework Directive (MSFD). The central task for the North Sea 2022–2027 Program is to find the right social balance in the spatial development of the North Sea. This development must be efficient and safe and fit within the preconditions of a healthy ecosystem.[15]

North Sea Policy in the National Water Programme. The National Water Programme describes the measures to be taken to guarantee a safe and liveable Netherlands for future generations and to take advantage of the opportunities that water offers. The North Sea policy defines the general frameworks for (spatial) coordination between the users of the sea themselves and in relation to the marine ecosystem.

European Maritime Spatial Planning Directive. The North Sea programme 2022-2027 mentioned above is the Dutch implementation of the requirements of the European Maritime Spatial Planning Directive.

Update of the European regulation on environmental economic accounting. In 2023, Regulation (EU) No 691/2011 (Environmental Accounts) is expected to be extended with a module for ecosystem accounts. This means that all European countries must start working on implementation ecosystem accounts. For the Netherlands, this means that the aim in the coming years is to be able to comply with Eurostat's (voluntary) data deliveries before the implementation date, which will probably be at the end of 2027.

2.2 The structure of SEEA ecosystem accounts

The UN System of Environmental-Economic Accounting — Ecosystem Accounting (SEEA-EA) is a series of linked accounts, which each describe aspects of ecosystem assets and the ecosystem services they provide (Figure 1).

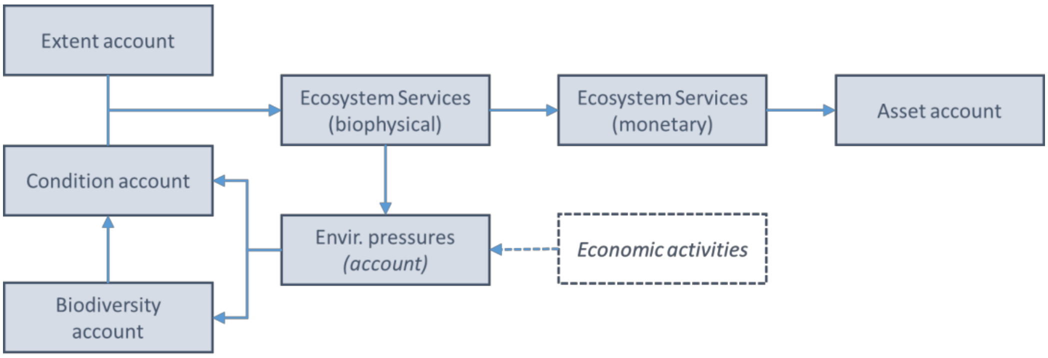


Figure 1. Structure of the SEEA ecosystem accounts. The dashed box around "Economic activities" indicate that this information is not part of the accounting structure, but conceptually drives the environmental pressures. The italics used in Environmental pressure pressures account indicate that a formal accounting structure for these pressures is not formally part of the SEEA framework

The ecosystem assets are described in two separate accounts. The **ecosystem extent account** is concerned with tiling the areas of interest (the ecosystem accounting area) into individual spatial units of unique ecosystem types. The ecosystem extent account tabulates the total size of each ecosystem type and changes thereof within a specified accounting period. The **ecosystem condition account** describes a series of relevant characteristics of each ecosystem type and/or asset. These characteristics are primarily focused on the *quality* of ecosystems in

[15] https://www.noordzeeloket.nl/en/policy/opinion-procedure-north-sea-program-2022-2027/

terms of both intrinsic ecological functioning, and their ability to generate ecosystem services. The **biodiversity account** provides in-depth additional information on trends in abundance of selected species groups.

Ecosystem services are described in a set of **supply and use tables**, which are compiled in both *biophysical* (volume) and *monetary* (value) terms. Each ecosystem is assumed to be supplied by specific ecosystem types or assets, and used by specific economic sectors (including households and the government). The **monetary asset account** records a monetary value of ecosystem assets in terms of the net present value of the ecosystem services supplied by the asset (the stock of ‘natural capital’). The asset account also records the changes in the monetary value of ecosystem assets over an accounting period including changes due to e.g. ecosystem degradation.

The environmental **pressures account** can best be described as the inverted version of ecosystem service accounts, with a flow from economic sectors (‘supplying’ pressure) to ecosystems (‘using’ these pressures).

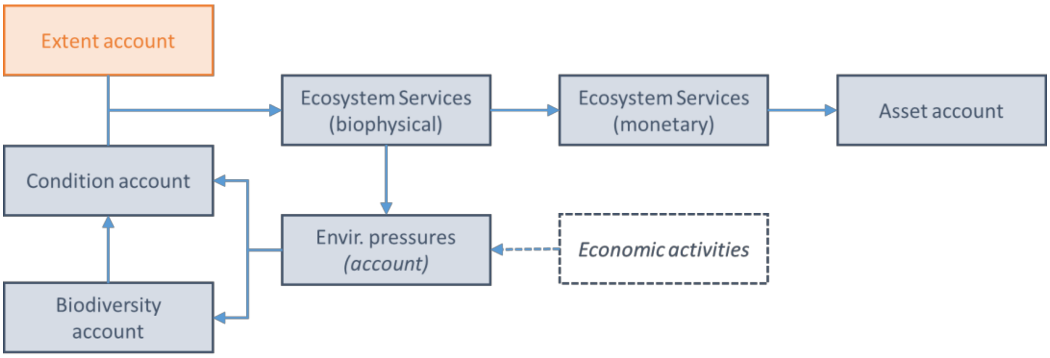
The next chapters describe how these individual accounts can be compiled. Attention is given to the previous pilot accounts by Statistics Netherlands (Schenau et al., 2019); the gaps therein, and options for completion based on available data sets and external developments such as accounts abroad, the EU MSFD, OSPAR etc.

Table 2 describes how the various elements of the ecosystem account can be linked with elements of the North Sea Policy.

Table 2. Links between ecosystem accounts and policies

Topic	Policy decisions	Treatment within ocean account
Marine ecosystem	The conservation and recovery of the marine ecosystem are assessed when making spatial planning decisions on activities. Natura 2000 areas at sea: [...]. Programme of measures for Marine Strategy: - Existing measures, including in terms of the marine ecosystem, invasive exotic species, eutrophication, pollutants, litter and underwater noise; - New measures with regard to litter; - New measures with regard to seabed protection	Condition account Extent account Pressure account Pressure account Extent account
Renewable energy	Generating renewable energy (from the wind or otherwise) is an activity of national interest. Space for operational capacity of 4,450 MW of wind energy at sea by 2023. Wind energy areas: [...]. Search areas: [...]. . Development in harmony with other uses of the North Sea: - design criterion 'distance between shipping routes and wind farms'; - design process 'distance between mining sites and wind farms'; - policy with regard to 'passage and multiple use'.	Ecosystem service (abiotic) None (future development) Extent account (potentially) Ecosystem condition (potentially) Ecosystem condition (potentially)
Surface minerals	Sand extraction for coastal defences and filling is an activity of national interest. Sand extraction strategy with preferred routes for cables and pipelines.	Ecosystem service (provisioning)
Oil and gas extraction	Oil and gas extraction • Activity of national interest. Making the most of the potential of the oil and gas reserves.	Ecosystem service (abiotic)
CO2 Storage	Activity of national interest. Sufficient space for CO2 storage as a temporary tool in the process of developing a fully renewable energy supply.	None (no link with current ecosystems)
cables and pipelines	The activities (wind) energy, oil and gas extraction and CO2 transport, including requisite cables and pipelines, are of national interest. Bundling cables and pipelines; removal obligation for cables and pipelines no longer in use. Tighten up removal obligation for pipelines. Checklist for determining removal obligation for cables or pipelines revised.	Ecosystem pressure (construction/removal disturbance; risks)
Shipping	Activity of national interest. Maintaining a system of traffic separation schemes, clearways and anchoring areas capable of accommodating vessels safely and swiftly. Implementing measures to reduce pollution caused by shipping (merchant vessels, fishing vessels, offshore, supply and recreation).	Ecosystem service (Spatial); Ecosystem pressure (noise; spills)
Defence	Activity of national interest. Sufficient exercise zones in the North Sea.	Extent account (special EAA); Pressure account (Noise)
Fishing, aquaculture and mariculture	Fostering responsible fishing and aquaculture practices and balanced use of fish stocks, striving towards a state of equilibrium between fishing and nature and a different division of responsibilities between government and industry. Continuing to contribute to the primary objectives of the Common Fisheries Policy (CFP) and implementing measures with regard to the marine ecosystem.	Ecosystem service (provisioning); Pressure
Underwater Cultural Heritage	The conservation of underwater cultural heritage is assessed when making spatial planning decisions on activities.	None (no link with current ecological processes)
Tourism and recreation	Facilitating and encouraging the tourism and recreation sector as a network partner in a partnership between entrepreneurs, market institutions and research institutes. Engaging in dialogue with local and regional government authorities and other parties where spatial planning or other policy developments in terms of the North Sea impact marine and coastal recreation.	Ecosystem Service (cultural)
Interaction between land and sea	When formulating spatial planning policy, specific attention needs to be paid to the interaction between land and sea, having due regard for the implementation of the Maritime Spatial Planning Directive	Indirect (ES for coastal users; pressures from terreitrial activities)
International cooperation	Thematic approach to partnerships with neighbouring countries.	Indirect, through alignment of ocean Accounts (GOAP; Ospar)

3. Ecosystem Extent



3.1 Introduction

A common starting point for ecosystem accounting is the organization of information on the extent of different ecosystem types within a country or other ecosystem accounting area (EAA), and how that extent is changing over time. This information is summarized in an ecosystem extent account (UN, 2021)

Ecosystem extent accounts are relevant for four reasons:

1. a common basis for discussion among stakeholders on the composition (mix/combination) of, and changes in, ecosystem types within a country (or any other accounting area).
2. a common framing through which other data about ecosystems can be presented. For example, where relevant data are available, maps of ecosystem condition and ecosystem service flows can be tabulated using a common classification of ecosystem types.
3. to provide a time series narrative, in this case through the estimation of opening and closing balances for an accounting period. Showing a time series of change is particularly important to reveal the degree to which the extent and composition of ecosystem types has changed, and the nature of conversions between ecosystem types.
4. the spatial data most commonly used to compile an ecosystem extent account provides an underlying infrastructure for the measurement of ecosystem condition and for the measurement and modelling of many ecosystem services.

SEEA ecosystem extent accounts are compiled for *ecosystem accounting areas* that are exhaustively and non-overlapping tiled into *ecosystem assets*, which are contiguous areas of a single *ecosystem type*.

In the next sections we first explore the options to define an appropriate ecosystem accounting area for the North Sea marine ecosystem account and then explore options for ecosystem type classification. Additional sections focus on available data sets, and a methodology to arrive at an extent account, presented in Section 3.8.

3.2 Ecosystem Accounting Area

The ecosystem accounting area (EAA) is defined as the geographical territory for which an ecosystem account is compiled. Most often this will be an administrative unit, such as a state or a province. The EAA therefore determines which ecosystem assets are included in an ecosystem account. It is a two-dimensional construct, providing an accounting boundary around a set of ecosystem assets represented by their two-dimensional footprints, such that the sum of the areas of the ecosystem assets is equal to the total area delineated by the EAA. (SEEA-EA; 3.22–23). See Figure 2 for an illustration of the relationship between ecosystem assets and the ecosystem accounting area. The discussion (Section 9.1, 'Pelagic habitats') provides some suggestions to account for the intrinsic 3D nature of the ocean realm

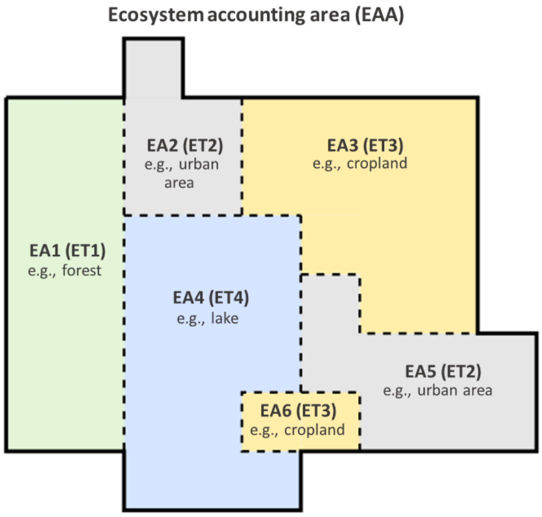


Figure 2. Relationships between spatial units in ecosystem accounts. Each of the colored boxed represents an *ecosystem asset* (EA) of a certain *ecosystem type* (ET; indicated by color). The outer outline enclosed the *ecosystem accounting area* (EEA) Source: UN (2021)

Ecosystem accounting areas are thus basically the areas used for the compiling and reporting of ecosystem accounts. While in principle they can be set up for any arbitrarily geographical areas, in practice they are aligned with well-established political or policy zonations, such as the subdivision of the Dutch Continental Shelf, the Exclusive Economic Zone (EEZ, up to 200M from the coastal *baseline*), the territorial sea (up to 12 M), delineations used for reporting on MSFD and WFD, OSPAR regions (Figure 4), or zones associated by the EU Common Fishery Policy.

These coastal baselines are usually defined as either physiographic features (low tide water line) or political, usually as straight base lines between landmarks or defined coordinates. For the Netherlands, straight base lines are defined for the Westerschelde estuary and the inlets in between the Wadden islands.

Because the EEZ and similar zones over neighbouring countries overlap, the formal zone boundaries are usually defined by treaties, and are located approximately "halfway" the overlap. As a result, the farthest point of the Dutch EEZ is no more than approx. 155 M from the baseline (NW Terschelling), where it borders the EEZ of the UK and Germany (Figure 3).

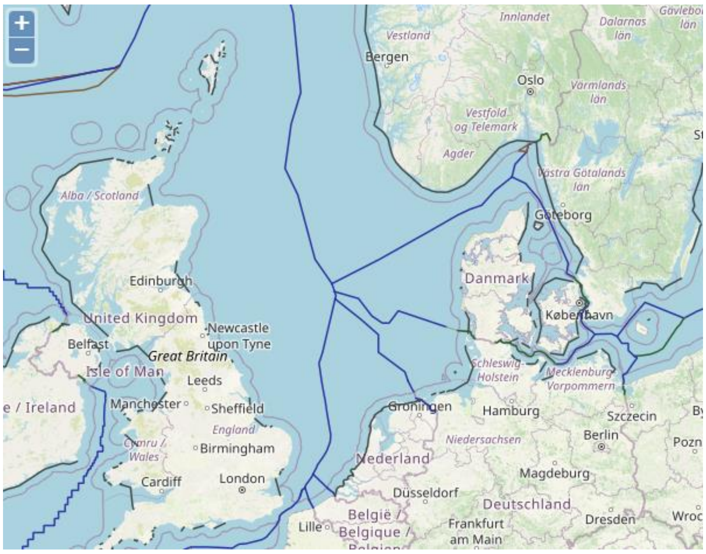


Figure 3. Exclusive economic Zones in the North Sea (and surroundings). Source: marineregions.org

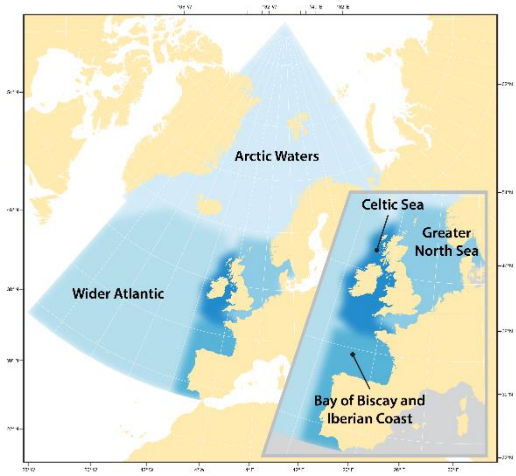


Figure 4. OSPAR regions. The Dutch Continental Shelf is part of OSPAR region II (Greater North Sea)

3.3 Ecosystem type classifications

As explained in the introduction to this chapter, ecosystem accounts organize information on the supply of ecosystem services by ecosystem type. The ecosystem accounting area is therefore subdivided into ecosystem assets, where the following principles should apply (SEEA-EA 3.37):

- *Ecosystem assets should represent ecosystems*. The spatial units should align with the definition of ecosystems following the Convention on Biological Diversity (CBD) in which there is consideration of organisms, their environmental setting and ecosystem processes. It is accepted that the delineations cannot be perfect representations of the complex ecological reality.
- *Ecosystem assets should be capable of being mapped.* Ecosystem accounting is commonly implemented using a spatially-based approach, in which case it is necessary that ecosystem assets can — in principle — be mapped and identified for a specific location.
- *Ecosystem assets should be geographically and conceptually exhaustive across ecological realms.* The ‘exhaustive’ criterion is understood as reflecting

comprehensiveness, both spatially and conceptually, including built environments. The set of ecosystem assets should allow for an EAA to be fully filled.

- *Ecosystem assets should be mutually exclusive, both conceptually and geographically*. Thus, EAs should not overlap, neither conceptually nor geographically, and any area on the land or the sea floor, or any horizontal depth layer in the ocean, should be occupied by one and only one ecosystem asset. As long as the ecosystem assets are mutually exclusive, there can be no "double-counting" of the same space.

Ecosystem assets are classified into ecosystem types. Thus, any ecosystem classification to be used for ecosystem accounting should ideally satisfy the definition of ecosystem types, i.e., a distinct set of abiotic and biotic components and their interactions, and enable application of the principles for delineating ecosystem assets listed above. (SEEA-EA 3.52)

In order to maximize consistency between (marine) reporting activities it seems logical to aim at using existing classification schemes where possible. For (global) international comparisons the SEEA-EA proposes the recently developed IUCN Global Ecosystem Typology, which has been designed in such a way that national (or, for that matter, European) classification schemes can be adopted as well.

In the next sections, we describe a few relevant classification schemes, discuss some issues associated with them, and propose a methodology to adapt them for the compilation of the North Sea marine ecosystem account.

3.3.1 IUCN Global Ecosystem Typology

The IUCN Global Ecosystem Typology (GET; Keith et al, 2022) is a recently developed comprehensive classification framework for Earth's ecosystems that integrates their functional and compositional features.

The GET is a hierarchical system and comprises six hierarchical levels. The three upper levels – realms, functional biomes and ecosystem functional groups – classify ecosystems based on their functional characteristics (such as structural roles of foundation species, water regime, climatic regime or food web structure), rather than based on which species live in them.

Realm: Major components of the biosphere that differ fundamentally in ecosystem organisation and function: terrestrial, freshwater, marine, subterranean and atmospheric.

Biome: A component of a realm united by one or a few common major ecological drivers that regulate major ecosystem functions and ecological processes, derived from the top-down by subdivision of realms, e.g. marine shelf; pelagic ocean waters (both within the marine realm); shorelines; supralittoral coastal (both within the marine-terrestrial transitional realm).

Ecosystem Functional Group: A group of related ecosystems within a biome that share common ecological drivers promoting convergence of ecosystem properties that characterise the group. Derived from the top-down by subdivision of biomes, e.g. seagrass meadows and subtidal and beds (both within the marine shelf biome).

The three lower levels of the typology — regional ecosystem subgroups, global ecosystem types and sub-global ecosystem types — distinguish functionally similar ecosystems based on biotic composition, but are not yet fully developed within the GET (although many of the European classifications discussed later in this chapter are expected to take up that role).

The (upper levels of the) GET has been adopted within the SEEA-EA as their reference classification. It can be used as a starting point when no local classification is available, but the main use is as a standard classification for international comparisons. To this end, local (national) ecosystem classifications can be linked to the GET units, preferably in an n:1 fashion (each local ecosystem type belongs to a single GET type).

In total the IUCN GET recognizes 4 core realms and 6 transitional realms. For marine ecosystem accounting of the North Sea 4 of these 10 are relevant. Out of the total of 8 biomes and 34 ecosystem functional groups (EFGs) within these 4 realms, 7 biomes and 16 EFG's are of interest (see Table 3).

Table 3. IUCN Global Ecosystem Typology (top 3 levels; partially). Realms that are not found within the North Sea region are not shown. Biomes and Ecosystem Functional Groups that are not found are shown in gray. Based on global-ecosystems.org

Realm	Biome	Ecosystem Functional Group	Occurence
M Marine	M1 Marine shelf biome	M1.1 Seagrass meadows	Major
		M1.2 Kelp forests	Minor?
		M1.3Photic coral reefs	None
		M1.4 Shellfish beds and reefs	Major
		M1.5 Photo-limited marine animal forests	Minor
		M1.6 Subtidal rocky reefs	Yes
		M1.7 Subtidal sand beds	Yes
		M1.8 Subtidal mud plains	Yes
		M1.9 Upwelling zones	None
	M2 Pelagic ocean waters biome	M2.1 Epipelagic ocean waters	Major
		M2.2 Mesopelagic ocean water	None
		M2.3 Bathypelagic ocean waters	None
		M2.4 Abyssopelagic ocean waters	None
		M2.5 Sea ice	None
	M3 Deep sea floors biome	(7 EFGs)	None
	M4 Anthropogenic marine biome	M4.1 Submerged artificial structures	Yes
		M4.2 Marine aquafarms	Yes
MT Marine-Terrestrial	MT1 Shorelines biome	MT1.1 Rocky Shorelines	None
		MT1.2 Muddy Shorelines	Yes
		MT1.3 Sandy Shorelines	Major
		MT1.4 Boulder and cobble shores	None
	MT2 Supralittoral coastal biome	MT2.1 Coastal shrublands and grasslands	Yes
FM Freshwater-Marine	FM1 Semi-confined transitional waters	FM1.1 Deepwater coastal inlets	None
		FM1.2 Permanently open riverine estuaries and bays	Yes
		FM1.3 Intermittently closed and open lakes and lagoons	None
MFT Marine-Freshwater-Terrestrial	MFT1 Brackish tidal biome	MFT1.1 Coastal river deltas	Yes
		MFT1.2 Intertidal forests and shrublands	None
		MFT1.3 Coastal saltmarshes and reedbeds	Major

3.3.2 EUNIS

One of the most comprehensive ecosystem type classifications used within Europe is the EUNIS (European Union Nature Information System) habitat classification, which is a comprehensive pan-European system for habitat identification. The classification covers all types of habitats from natural to artificial, from terrestrial to freshwater and marine.[16]

Recently, the hierarchical EUNIS classification has been revised. In the older (2012) classification 10 broad habitat types, labeled "A" to "J" were recognized, 1 marine and 9 terrestrial / freshwater, of which mainly "A" (marine habitats) and "B" (coastal habitats) are of relevance here:

A: Marine habitats are directly connected to the oceans, i.e. part of the continuous body of water which covers the greater part of the earth's surface and which surrounds its land masses.

B: Coastal habitats are those above spring high tide limit (or above mean water level in non-tidal waters) occupying coastal features and characterised by their proximity to the sea, including coastal dunes and wooded coastal dunes, beaches and cliffs.

In the revised (2021-2022) classification nine different broad habitat types ("M" to "V") are recognized, four of which are marine. The three most relevant groups are:

M: Marine benthic habitats are the bed of seas directly connected to the oceans, i.e. part of the continuous body of water which covers the greater part of the earth

[16] Quoted text in this section is taken from https://www.eea.europa.eu/data-and-maps/data/eunis-habitat-classification

MH : Pelagic water column. The water column of shallow or deep sea, or enclosed coastal waters. Note that because of the strong temporal nature of the pelagic environment, the water column at a given location will be classified differently at different times of the year.

N : Coastal habitats are those above spring high tide limit (or above mean water level in non-tidal waters) occupying coastal features and characterised by their proximity to the sea, including coastal dunes and wooded coastal dunes, beaches and cliffs. Includes free-draining supralittoral habitats adjacent to marine habitats which are normally only very rarely subject to any type of salt water, in as much as they may be inhabited predominantly by terrestrial species, strandlines characterised by terrestrial invertebrates and moist and wet coastal dune slacks and dune-slack pools. Supralittoral sands and wracks may be found also in marine habitats (M). Excludes supralittoral rock pools and habitats, the splash zone immediately above the mean water line, as well the spray zone and zone subject to sporadic inundation with salt water in as much as it may be inhabited predominantly by marine species, which are included in marine (M).

In the next few paragraphs the typologies for these habitat groups are introduced.

Marine habitats

Marine benthic habitats (M) and marine pelagic habitats (MH) are separated into three distinct groups, each with a separate classification structure. This structure is described below:

Marine benthic habitats (M)

Definition: "Marine benthic habitats are the bed of seas directly connected to the oceans, i.e. part of the continuous body of water which covers the greater part of the earth".

Level 1 (realm) contains only the class "Marine benthic".

Level 2 (biological zone and substrate) crosses major substrate classes with major biological zones.

Substrates include rock, biogenic sediments (reefs etc), mud (>20% silt/clay); sand (<20% silt/clay); coarse sediment (gravel, pebbles, etc.) and mixed sediment (e.g. muddy gravelly sands)

Biological zones are strongly correlated with depth, and include *Littoral* (Intertidal); *Infralittoral* (plant dominated); (offshore) *Circalittoral* (animal dominated); upper and lower *bathyal* and *abyssal*. Note that the boundaries between these zone are not sharply defined in terms of depth, but rather the intensity of light reaching the seabed and other biophysiological factors. As continental shelfs, the deepest part of the North Sea are within the circalittoral zone.

Level 3 (bioregion) represents an oceanographic subdivision of the European seas. Each marine region is characterised by specific oceanographic features, e.g. salinity and temperature regime. The habitats treated in the levels below refer to the habitat classifications identified within the framework of the respective Regional Sea conventions.

The bioregions distinguished in EUNIS are Arctic, Baltic, Atlantic, Mediterranean and Black Sea. The North Sea is completely within the Atlantic biogeographical region, and associated with the OSPAR convention.

Level 4 (Biotope) represent the habitat defined by a dominant or characteristic species or by consistent multi-species characteristics or by an assemblage (community or biocenosis) and by distinctive habitat features, which together, allow distinction from neighbouring types.

Level 5 (Sub-biotope) represent habitat defined by variation in species composition, coupled with associated physical differences.

Level 6 (Variant) represent habitat defined by more subtle variation in species composition, coupled with associated physical differences

Table 4 lists the EUNIS benthic habitats (up to level 2). The full list of EUNIS marine habitats can be explored online.[17]

Table 4. EUNIS benthic habitats (level 2 only). Grey cells represents habitats that are not found in the Dutch North Sea.

Zone		**Substrate**					
		Hard/firm		**Soft**			
		Rock	**Biogenic**	**Coarse**	**Mixed**	**Sand**	**Mud**
Phytal gradient / hydrodynamic gradient	Littoral	MA1	MA2	MA3	MA4	MA5	MA6
	Infralittoral	MB1	MB2	MB3	MB4	MB5	MB6
	Circalittoral	MC1	MC2	MC3	MC4	MC5	MC6
Aphytal hydrodynamic gradient	Offshore circalittoral	MD1	MD2	MD3	MD4	MD5	MD6
	Upper bathyal	ME1	ME2	ME3	ME4	ME5	ME6
	Lower bathyal	MF1	MF2	MF3	MF4	MF5	MF6
	Abyssal	MG1	MG2	MG3	MG4	MG5	MG6

Marine Pelagic habitats

Definition: “The water column of shallow or deep sea, or enclosed coastal waters. Note that because of the strong temporal nature of the pelagic environment, the water column at a given location will be classified differently at different times of the year.”

Level 1 (Realm) contains only the class “Marine pelagic water column”.

Level 2 (Mixing and salinity) subdivides pelagic habitats based mainly on *stratification* and *salinity* of the water column. Separate classes are defined for *Neuston* habitats (at the water surface) and *fronts* (located at horizontal gradients). Table 5 lists the first two levels of the EUNIS pelagic habitats, and Table 6 illustrates the logical structure with respect to the two variables.

Table 5. EUNIS pelagic habitats (levels 1 and 2 only)

Code	**Name**
MH1	Neuston
MH2	Completely mixed water column with reduced salinity
MH3	Completely mixed water column with full salinity
MH4	Partially mixed water column with reduced salinity and medium or long residence time
MH5	Unstratified water column with reduced salinity
MH6	Vertically stratified water column with reduced salinity
MH7	Fronts in reduced salinity water column
MH8	Unstratified water column with full salinity
MH9	Vertically stratified water column with full salinity
MHA	Fronts in full salinity water column

[17] https://eunis.eea.europa.eu/habitats-code-browser-revised.jsp

Table 6. Logical structure of EUNIS MH Bentic waters (level 2)

Salinity	Mixing/Stratification				Front
	Mixed		Unstratified	Vertically	
	Complete	Partial			
Reduced	MH2	MH4	MH5	MH6	MH7
Full	MH3		MH8	MH9	MHA

Level 3 (biogeography) refers to the same biogeographical regions as benthic habitats

Level 4 (characteristics) enodes *temporal* aspects of the gradients are encoded: permanency of the neuston layer; residence time for partial or completely mixed water; duration of stratification or fronts; type of stratification (thermal; oxygen; salt); depth of unstratified waters.

level 6 (variants) lists further sub-types (currently used only to classify anoxic water)

3.3.3 Habitat directive

The EU Habitats Directive (92/43/EEC) is a key piece of European Union legislation aimed at conserving natural habitats and protecting wildlife species. The habitats that are targeted for conservation are listed in Annex I of the directive[18]. The Habitat directive is implemented through the establishment of the Natura 2000 network, comprising a.o. protected areas designated as Special Areas of Conservation (SACs) focusing on the conservation of these habitats.

For the overall Dutch marine Habitat Directive sites (see section 3.5) 12 of these habitat types are relevant (i.e. part of the site designation), 9 of which relate to the North Sea in the strict sense, i.e. excluding Schelde estuary and Wadden Sea. Table 7 lists the crosswalk of Annex I habitats with relevant Habitat Directive Sites.

These habitats are:

H1110: Sandbanks which are slightly covered by sea water all the time. Sublittoral sandbanks, permanently submerged. Water depth is seldom more than 20 m below Chart Datum[19]. Non-vegetated sandbanks or sandbanks with vegetation belonging to the *Zosteretum marinae* and *Cymodoceion nodosae.*[20]

H1130 Estuaries[*21)] Downstream part of a river valley, subject to the tide and extending from the limit of brackish waters.

1140: Mudflats and sandflats not covered by seawater at low tide. Sands and muds of the coasts of the oceans, their connected seas and associated lagoons, not covered by sea water at low tide, devoid of vascular plants, usually coated by blue algae and diatoms.

H1160: Large shallow inlets and bays[*)]**.** Large indentations of the coast where, in contrast to estuaries, the influence of freshwater is generally limited.

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[18] http://dd.eionet.europa.eu/vocabulary/biodiversity/n2000habitats/

[19] Reference sea level used as a datum for charting water depth, usually lowest astronomical tide or mean lower low water.

[20] Habitat descriptions taken from: https://eunis.eea.europa.eu/habitats-annex1-browser.jsp

[21] Habitats marked with an asteriks *) are not formally associated with the Nature 2000 sites within in the geographic scope (ecosystem accounting area) of this study, i.e. the North Sea in strict sense, but in other Dutch marine N2000 sites, such as the Wadden Sea and the Schelde estuary.

H1170: Reefs. Submarine, or exposed at low tide, rocky substrates and biogenic concretions, which arise from the sea floor in the sublittoral zone but may extend into the littoral zone where there is an uninterrupted zonation of plant and animal communities.

H1310: Salicornia[22] and other annuals colonizing mud and sand. Formations composed mostly or predominantly of annuals, in particular Chenopodiaceae of the genus *Salicornia* or grasses, colonising periodically inundated muds and sands of marine or interior salt marshes.

H1320: Spartina[23] swards (Spartinion maritimae). Perennial pioneer grasslands of coastal salt muds, formed by *Spartina* or similar grasses.

H1330: Atlantic salt meadows (Glauco-Puccinellietalia maritimae). Salt meadows of Baltic, North Sea, English Channel and Atlantic shores.

H2110: Embryonic shifting dunes. Formations of the coasts of the Atlantic, the North Sea, the Baltic Sea and the Mediterranean, representing the first stages of dune construction, constituted by ripples or raised sand surfaces of the upper beach or by a seaward fringe at the foot of the tall dunes.

2120: Shifting dunes along the shoreline with Ammophila arenaria ('white dunes'). Mobile dunes forming the seaward cordon or cordons of dune systems of the coasts of the North Sea [and other coasts].

H2130: Fixed coastal dunes with herbaceous vegetation ('grey dunes')[*)]. Fixed dunes, stabilised and colonised by more or less closed perennial grasslands and abundant carpets of lichens and mosses, from the North Sea [and other coasts].

2190: Humid dune slacks. Humid depressions of the dunal systems.

[22] Glasswort / Zeekraal
[23] Cordgrass / Slijkgras

Table 7. Presence of Annex I habitats in (peri) marine Habitat Directive sites in the Dutch part of the North Sea. Source: Natura 2000 reporting[24].

Anex I habitats			North Sea sites								Other marine sites				Non-marine sites										
			Doggersbank	Klaverbank	Bruine Bank	Friese Front	Noordzeekustzone	Vlakte van de Raan	Voordelta	Vlakte van de Raan	Waddenzee	Oosterschelde	Westerschelde & Saeftinghe	Zwin en Kievittepolder	Krammer-Volkerak	Grevelingen	Duinen en Lage Land Texel	Duinen Vlieland	Duinen Terschelling	Duinen Ameland	Duinen Schiermonnikoog	Duinen Goeree & Kwade Hoek	Overige duinen NH	Overige duinen ZH	Overig Zeeland
Coastal and Halophytic habitats																									
Open sea and tidal areas																									
H1110	Sandbanks which are slightly covered by sea water all the	Permanent overstroomde zandbanken	x				x	x	x	x	x		x									x			
H1130	Estuaries	Estuaria									x		x												
H1140	Mudflats and sandflats not covered by seawater at low tide	Slik en zandplaten					x		x		x		x	x			x					x			
H1160	Large shallow inlets and bays	Grote baaien										x													
H1170	Reefs	Riffen		x																					
Atlantic and continental salt marshes and salt meadows																									
H1310	Salicornia and other annuals colonizing mud and sand	Zilte pionierbegroeiingen					x		x		x	x	x	x	x	x	x	x	x		x	x			x
H1320	Spartina swards (Spartinion maritimae)	Slijkgrasvelden							x		x	x	x	x			x		x			x			
H1330	Atlantic salt meadows (Glauco-Puccinellietalia maritimae)	Schorren en zilte graslanden					x		x		x	x	x	x	x	x	x	x	x	x	x				x
Coastal sand dunes and inland dunes																									
Sea dunes of the Atlantic, North Sea and Baltic coasts																									
H2110	Embryonic shifting dunes	Embryonale duinen					x		x		x		x				x	x	x			x	x	x	x
H2120	Shifting dunes along the shoreline with Ammophila arenaria ('white dunes')	Witte duinen							x		x		x	x			x	x	x	x	x	x	x	x	x
H2130	Fixed coastal dunes with herbaceous vegetation ('grey dunes')	Grijze duinen									x	x	x	x		x	x	x	x	x	x	x	x	x	x
H2190	Humid dune slacks	Vochtige Duinvaleien					x				x		x	x	x	x	x	x	x	x	x	x	x	x	x

[24] https://www.natura2000.nl/gebieden/noordzee-nederlandse-exclusieve-economische-zone

3.3.4 Marine Strategy Framework Directive (Netherlands)

The Marine Strategy for the Dutch part of the North Sea 2012–2020 (Part I) notes that borders of benthic and pelagic habitats often coincide, and describes them together in a single classification. Only 7 units are recognized, based on substrate type and water depth (see Table 8).

More important, though, is the explicit recognition of several special habitats:

- Coastal zone
- Frisian Front
- Central Oyster grounds
- Doggersbank
- Klaverbank

which are strongly associated with Natura 2000 sites (see Section 3.5.1).

Table 8. Ecosystem types used in the Dutch MSFD, part I[25]

Name	Substrate	Water depth	Salinity	Tidal current
Shallow fine sand		15–20	27–34‰	up to 1.0
Mid depth mixed sand	medium fine to coarse sand	20–30	>34‰	up to 1.0
Deep fine and coarse sand	Very fine to silty sand	40–50		weak
Deep Silty seabed		~50		
Frisian Front	sand to silt to silty sand	30–40		
Mid-depth gravel and stones, Klaver Bank	Gravel and stones	>40		
Dogger bank	fine sand	20–30		0.1–0.2

The 2018 update of the Dutch marine Strategy includes an updated habitat classification, which is largely based on the EUNIS habitat classification (Table 9; note the marked difference between Dutch and English language versions; the Dutch version is the authoritative one).

Table 9. Habitat classification as used in the Marine Strategy (2018 update)[25]

	EUNIS	Featurures	Depth	Median grain size	Tidal current
Dutch version					
	MB5	Infralittoral sand	ca. 0–20m	sand <1mm, <30% clay, silt (<63µm)	Strong
	MC1,2	Circalittoral sand and biogenic reefs	ca. 20–40m	Non-mobile rocks	Weak
	MC3	Circalittoral coarse sediment	ca. 20–40m	sand >1mm, >5% gravel, shells	Weak
	MC5	Circalittoral sand	ca. 20–40m	sand <1mm, <30% clay, silt (<63µm)	Weak to Strong
	MD5	Offshore circalittoral sand	ca. 40–70m	sand <1mm <30% clay silt (<63µm)	Weak
	MD6	Offshore circalittoral mud	ca. 40–70m	<30% clay, silt (<63µm)	Weak
English translation					
		Shallow to moderately deep, coarse sediment	0–30m	>500µm	Strong (up to 1 m/s)
		Shallow to moderately deep, mixed sediment	0–30m	>63µm (typ. <200% silt)	Strong (up to 1 m/s)
		Shallow to moderately deep, silt-rich sediment	0–30m	<63µm (typ. >20% silt)	Weak
		Deep coarse sediment	30–70m	>500µm	Strong (up to 1 m/s)
		Seep sandy sediment	30–70m	>63µm	Strong (up to 1 m/s)
		Deep silt-rich sediment	30–70m	<63µm	Weak

[25] English: https://www.noordzeeloket.nl/en/policy/marine-strategy/marine-strategy-part-1/ Dutch: https://www.noordzeeloket.nl/beleid/mariene-strategie-krm/deel-1-milieutoestand/

3.3.5 Natuurverkenning (Nature Lookout) 2010-2040

To support the development of the Nature Lookout 2010-2040 (van Oostenbrugge et al., 2011, 2012; Dammer et al., 2013) a new "nature type" classification for the North Sea was developed. This classification was based on the following ecologically relevant abiotic factors:

- Geographical area (North Sea; Wadden Sea; (former) Estuaria)
- Summer stratification of the water column
- Salinity (gradients)
- Water depth (in 10m increments)
- Bottom sediment (in 4 classes)

This classification was later used in the 2019 pilot ecosystem account (Schenau et al., 2019), mainly for pragmatic reasons (availability, and fitness for purpose at that time).

3.3.6 Eurostat

The European Union is currently (2023) proposing the extension of the regulation on environmental statistics to include ecosystem accounting. As part of this process, the EU proposes a European classification of ecosystem types, building upon both the earlier European classifications (MAES) and the international IUCN GET. It should be noted though, that this classification is not fully standardized yet; e.g. there are proposals to move 11.4 "coastal saltmarshes" to level 1 class "marine ecosystems" to improve alignment with EUNIS (where salt marshes are classified as littoral ecosystems)

Table 10. Ecosystem classification for the Eurostat Ecosystem accounts.

Level 1	Level 2	Level 3
10. Marine inlets and transitional waters (lagoons, fjords)	10.1 Coastal lagoons	10.1.1 Coastal lagoons
	10.2 Estuaries and bays	10.2.1 Estuaries and bays
	10.3 Intertidal flats	10.3.1 Intertidal flats (e.g., Wadden Sea)
	10.4 Deepwater coastal inlets (fjords)	10.4.1 Deepwater coastal inlets (fjords)
11. Coastal beaches, dunes and wetlands	11.1 Artificial shorelines	11.1.1 Artificial shorelines
	11.2 Coastal dunes, beaches and sandy and muddy shores	11.2.1 Coastal dunes
		11.2.2 Beaches and sandy shores
		11.2.3 Muddy shores
	11.3 Rocky shores	11.3.1 Coastal shingle
		11.3.2 Rock cliffs, ledges and shores
	11.4 Coastal saltmarshes and salines	11.4.1 Coastal saltmarshes
		11.4.2 Salines
12. Marine ecosystems	12.1.Marine macrophyte habitats	12.1.1 Kelp forests
		12.1.2 Seagrass meadows
	12.2 Coral reefs	12.2.1 Coral reefs
	12.3 Shellfish beds and reefs	12.3.1 Shellfish beds and reefs
	12.4 Subtidal sand beds and mud plains	12.4.1 Subtidal sand beds and mud plains
	12.5 Subtidal rocky substrates	12.5.1 Subtidal rocky substrates
	12.6 Continental and island slopes	12.6.1 Continental and island slopes
	12.7 Deepwater benthic and pelagic ecosystems	12.7.1 Deepwater benthic and pelagic ecosystems
	12.8 Sea ice	12.8.1 Sea ice

3.4 Available map products.

The previous section of ecosystem type classifications stressed that "*Ecosystem assets should be capable of being mapped"*, which implies that there is a need for geospatial data sources in order to compile ecosystem extent accounts. In this section we look at various data sources that are available.

3.4.1 EUSeaMap

To support the EU MSFD, the European Marine Observation and Data Network (EMODnet) has set up an extensive monitoring and data access program focused around themes such as bathymetry, biology, chemistry, geology, human activities and seabed habitats.

The seabed habitat map, fully named EUSeaMap (2021) is a broad-scale predictive habitat map[26], produced using a top-down modelling approach using classified habitat descriptors to determine a final output habitat.

Habitat descriptors are based on multiple variables: including:

- Biological (depth) zone and seabed substrate (as in EUNIS)
- Energy class (kinetic energy at the seabed due to waves)
- Oxygen and salinity levels (used in the Black Sea and Baltic Sea only)

See Table 11 for an overview of possible values.

Table 11. Descriptors and values for the EUSeaMap classsificaton (selection). Grey values are not mapped for the Dutch part of the North Sea

Biozone	Substrate	Energy	Oxygen	Salinity
Infralittoral	Seabed	High energy	Oxic	Euhaline
Shallow circalittoral	Sandy mud	Moderate energy	Suboxic	Polyhaline
Deep circalittoral	Muddy sand	Low energy	Anoxic	Mesohaline
Bathyal	Sandy mud			Oligohaline
Abyssal	Coarse substrate			
…	Mixed sediment			
	Ostrea edulis beds			
	Fine mud			
	Rock			
	Worm reefs			
	Musel beds			
	…			

It should be noted that the model includes the sublittoral zone only; due to the high variability of the littoral zone, a lack of detailed substrate data and the resolution of the model, it is difficult to predict littoral habitats at the scale of the map (100x100 m resolution).

The EUSeaMap is published in 2-3 years intervals, with official releases for 2016, 2019 and 2021, with the next release scheduled for 2023. It is also used as a data source to develop the marine habitats layer of the EEA *Ecosystems of Europe* (2012) map.[27]

3.5 Areas of special interest

The previous paragraphs were concerned with ecosystem type classification schemes that all aim at a spatially exhaustive mapping of the sea (bottom) of the Dutch part of the North Sea as a whole. In addition, there are some areas within the North Sea that are of relevance for specific reasons. Examples include the Natura 2000 network, aiming at the protection of (marine) habitats and species, the seabed protected sites designated under the MFSD, and

[26] Quoted text in this section is take from the EUSeaMap metadata website: http://gis.ices.dk/geonetwork/srv/eng/catalog.search#/metadata/01bf1f24-fdcd-4ee7-af8b-e62cf72fe2f9

[27] See https://www.eea.europa.eu/en/datahub/datahubitem-view/573ff9d5-6889-407f-b3fc-cfe3f9e23941

other areas of interest from a policy, economic, or biodiversity perspective. In this section a number of those areas will be presented, and the relationship with ecosystem accounting will be discussed, i.e., how they should be recorded in the various accounting tables.

3.5.1 Natura 2000 sites

Natura 2000 is the European network of core breeding and resting sites for rare and threatened species, and some rare natural habitat types which are protected in their own right. It stretches across all 27 EU countries, both on land and at sea. The aim of the network is to ensure the long-term survival of Europe's most valuable and threatened species and habitats, listed under both the Birds Directive and the Habitats Directive.[28]

The **Habitat Directive** (92/43/EEC) ensures the conservation of a wide range of rare, threatened or endemic animal and plant species. Some 200 rare and characteristic habitat types are also targeted for conservation in their own right.[29] These are listed in Annex I of the directive.

The implementation of the Habitat Directive involves the identification of Sites of Community Importance (SCIs) that, when approved by the Commission, can be designated as Special Area of Conservation (SAC).

The **Birds Directive** (2009/47/EC) is — despite its name — also concerned with habitats. While the primary aim is to protect all of the 500 wild bird species naturally occurring in the European Union, it is noted that habitat loss and degradation are the most serious threats to the conservation of wild birds. The Directive therefore places great emphasis on the protection of habitats for endangered and migratory species. It establishes a network of Special Protection Areas (SPAs) including all the most suitable territories for these species.[30]

Both the Special Area of Conservation (SACs; Habitats Directive) and the Special Protection Areas (SPAs; Bird Directive) are included in the Natura 2000 ecological network. In the Dutch part of the North Sea 7 Natura 2000 sites are designated as SAC or SPA, or both (Figure 5).

Doggersbank (Dogger bank)[31]

- Natura 2000 site (#164 ; code NL2008001 ; 4,735 km^2) under the Habitats directive (SAC since 2016)
- Protects 3 species of the Nature Directives: Grey seal (*Halichoerus grypus*); Common seal (*Phoca vitulina*); Common Porpoise (*Phocoena phocoena*)
- Protects 1 habitat types of the Habitats Directive: H1110: *Sandbanks which are slightly covered by sea water all the time* (394,613 ha).

Friese Front (Frisian Front)[32]

- Natura 2000 site (#166; code NL2016166 ; 2,882 km^2) under the Birds directive (SPA since 2016)
- protects 1 species of the Nature Directives: Guillemot (*Uria aalge*).

[28] https://ec.europa.eu/environment/nature/natura2000/
[29] https://ec.europa.eu/environment/nature/legislation/habitatsdirective/index_en.htm
[30] https://ec.europa.eu/environment/nature/legislation/birdsdirective/index_en.htm
[31] https://eunis.eea.europa.eu/sites/NL2008001
[32] https://eunis.eea.europa.eu/sites/NL2016166

Klaverbank (Cleaver bank)[33]

- Natura 2000 site (#165; code NL2008002 ; 1,539 km^2) under the Habitats Directive (SAC since 2016)
- Protects 3 species of the Nature Directives: Grey seal (*Halichoerus grypus*); Common seal (*Phoca vitulina*); Common Porpoise (*Phocoena phocoena*)
- Protects 1 habitat types of the Habitats Directive: H1170 *Reefs* (76,934 ha).

Noordzeekustzone (North Sea Coastal Zone)[34]

- Natura 2000 site (#7; code NL9802001; 1,445 km^2) under the Birds Directive (SPA since 2000) and the Habitats Directive (SAC since 2009)
- Protects 27 species of the Nature Directives (20 birds; 3 fishes; 1 flowering plant; 3 mammals)
- Protects 6 habitat types of the Habitats Directive: H1110: *Sandbanks which are slightly covered by sea water all the time* (144,474 ha); H1140: *Mudflats and sandflats not covered by seawater at low tide* (3,053 ha); H1310: *Salicornia and other annuals colonizing mud and sand* (195 ha); H1330: *Atlantic salt meadows (Glauco-Puccinellietalia maritimae)* (191 ha); H2110: *Embryonic shifting dunes* (462 ha); H2190: *Humid dune slacks* (2 ha).

Bruine Bank (Brown Ridge)[35]

- Recently assigned Natura 2000 site (#168; code NL2021168; 1,365 km2) under the Birds Directive (SPA since 2021).
- Protects 1 species of the Birds Directives (Little gull; *Hydrocoloeus minutus*[36]) and 5 other bird species.

Voordelta[37]

- Natura 2000 site (#113; code NL4000017; 835 km2) under the Birds Directive (SPA since 2000) and the Habitats Directive (SAC since 2008).
- Protects 37 species of the Nature Directives (30 birds; 4 fishes; 3 mammals)
- Protects 7 habitat types of the Habitats Directive: H1110 *Sandbanks which are slightly covered by sea water all the time* (81,260 ha); H1140 *Mudflats and sandflats not covered by seawater at low tide* (2,224 ha); H1310 *Salicornia and other annuals colonizing mud and sand* (47 ha); H1320 *Spartina swards (Spartinion maritimae)* (7 ha); H1330 *Atlantic salt meadows (Glauco-Puccinellietalia maritimae)* (41 ha); H2110 *Embryonic shifting dunes* (10 ha); H2120 *Shifting dunes along the shoreline with Ammophila arenaria ('white dunes')* (32 ha).

Vlakte van de Raan[38]

- Natura 2000 site (#163; code NL2008003 ; 17,521 ha) under the Habitats Directive (SAC since 2011)

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[33] https://eunis.eea.europa.eu/sites/NL2008002
[34] https://eunis.eea.europa.eu/sites/NL9802001
[35] https://eunis.eea.europa.eu/sites/NL2021168
[36] Formerly known as Larus minutus
[37] https://eunis.eea.europa.eu/sites/NL4000017
[38] https://www.natura2000.nl/gebieden/zeeland/vlakte-van-de-raan; https://eunis.eea.europa.eu/sites/NL2008003

- Protects 1 habitat type of the Habitats Directive: H1110: *Sandbanks which are slightly covered by sea water all the time* (17,521 ha) and 6 species (3 fishes; 3 mammals) of the Nature directives.
-

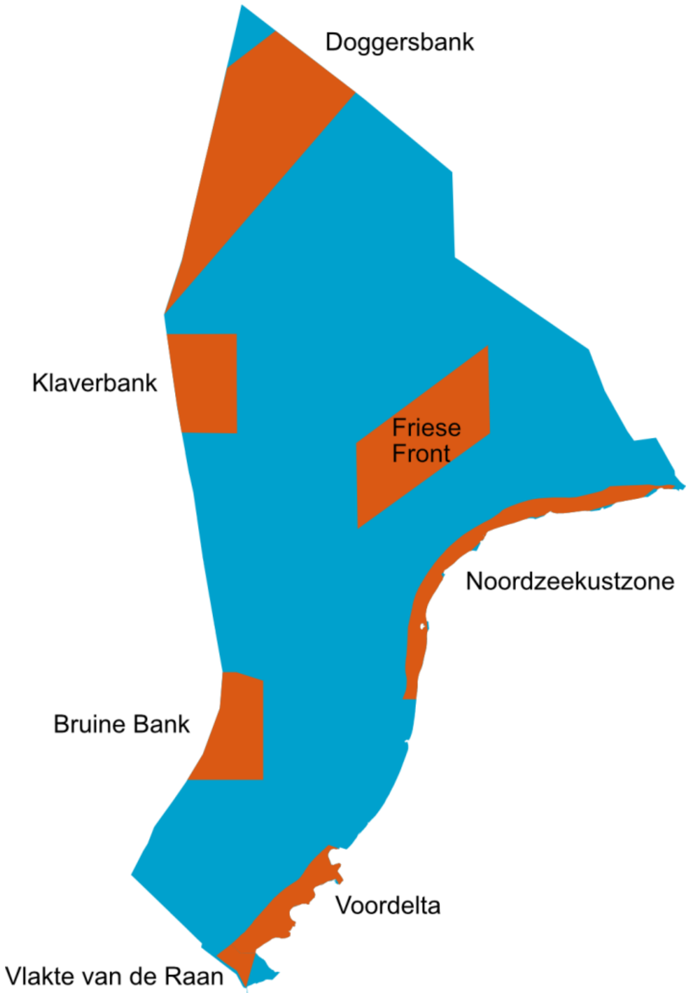


Figure 5. Natura 2000 areas within the Dutch part of the North Sea.

3.5.2 Seascapes

Ecosystem types often occur in specific spatial mixtures and juxtapositions. On the land these are often called landscape mosaics, or simply *landscapes*. Similarly, in the marine realm, using extensive bathymetric surveys, the North Sea as a whole can be subdivided into eight distinct *seascapes* (van der Reijden et al., 2018). Some of these seascapes corresponds clearly to established zones, such as the Doggersbank, the Cleaver Bank and the Central Oyster Grounds, and their international extensions.

As with the N2000 sites, the seascapes could be useful to regionalize the ecosystem accounts for the North Sea (i.e., ecosystem accounting areas nested within the (greater) North Sea Ecosystem Accounting Area. Because of the shown correlation between seascape and demersal fish densities distribution, there is an ecological argument to include the seascape boundaries in the delineation of ecosystem assets. In practice this means that the seascape map could be used as an additional intersection layer.

3.6 Existing extent accounts

Up until now, of the countries in the (southern) North Sea, only the Netherlands, the UK and Germany have developed extent accounts in some form. This section briefly introduces the approaches taken by these countries before further developing a full extent account for the Netherlands.

3.6.1 Netherlands (2019)

The 2019 pilot account for the Dutch part of the North Sea (Schenau et al., 2019) based the delineation of ecosystem assets on a map of "nature types" that was developed as part of the Nature Lookout 2010–2040 (van Hal et al, 2011; Also see section 3.3.5).

This map included as relevant variables:

- Water depth (4 classes: 0–10m, 10–20m, 20–30m; >30m;
- Summer stratification of the water column;
- Salinity (distinguishing marine waters from transitional waters);
- Sediment type;
- Protection status;

but excluded the spatial extent of immobile biota (reefs, oyster and mussel beds, sea grass meadows etc.), Natura-2000 and EUNIS habitats, and the anthropogenic habitats, although van Hal et al. (2011) mention the relevance of these habitats.

3.6.2 United Kingdom marine natural capital account (2021)

The UK marine natural capital accounts[39] includes a partial ecosystem extent account that is based on the EUNIS (2012) levels 2 and 3 habitats (e.g.: A5.3.Sublittoral mud), which are mapped using a combination of survey data and models in the UKSeaMap project, that is strongly related to the EUSeaMap data (Section 3.4.1).

3.6.3 Germany

Germany is currently developing ecosystem accounts for the whole of the country, using SEEA guidelines. Their extent account is based on a national classification (Bellingen et al., 2021), see Table 12.

Table 12. Ecosystem classification for marine ecosystem types, as used in the ecosystem extent account for Germany (Bellingen et al., 2021).

B02	Marine waters	B02.1	Coastal sea water	B02.21	Coastal sea macrophyte stocks
				B02.22	Coastal riffs
				B02.23	Coastal sandbanks
				B02.29	Other coastal seabed
		B02.2	Open sea	B02.31	Marine macrophyte stocks in the open sea
				B02.32	Riffs in the open sea
				B02.33	Sandbanks in thje open sea
				B02.39	Other seabed in the open sea
		B02.3	Tidal flats	B02.11	Tidal flats with macrophye stocks
				B02.12	Tidal flats with mussel stocks
				B02.19	Other tidal flats

[39] https://www.ons.gov.uk/economy/environmentalaccounts/bulletins/marineaccountsnaturalcapitaluk/2021

3.6.4 OSPAR

Alarcon Blazquez (2021) and Alarcon Blazques et al., (2023), in the first version of the ecosystem account for the whole OSPAR region, presented an extent account based on EUNIS levels 2 and 3 (i.e., the EUSeaMap, Section 3.4.1). They noticed that while the SEEA-EA endorses the use of the IUCN Global Ecosystem Typology, there currently are no suitable maps of the Ecosystem Functional Groups (the preferred level of ecosystem type for international comparisons). They further noted that many relevant ecosystem types are missing from the EUSeaMap data product, mainly littoral ecosystems, but also coastal (salt marshes; mangroves) and biogenic (coral reefs).

3.7 Methodology

The following topics require discussion and decision making in order to establish an ecosystem extent account for the North Sea.

3.7.1 Data Sources

The main data source for the extent account is the EUSeaMap (see section 3.4.1), which is a pan-European broad scale habitat map. The latest version was released in November 2021 and builds upon previous iterations[40]. The map is available in three Europe-wide classification systems (EUNIS habitat classification 2007, EUNIS marine habitat classification 2019 and MSFD Benthic Broad Habitat Types).

Because the EUSeaMap covers a wider area than the Dutch part of the North Sea, the Dutch Exclusive Economic Zone was used to delineate the ecosystem accounting area. Additionally, the topographic map was used to ensure that the areas close to the coast not included in the EU sea map were covered as well. Finally, areas of interest such as Natura 2000 areas were added as sub-accounting areas.

- Dutch Exclusive Economic Zone (EEZ) – april 2021
- Dutch Topographic map (Top10NL, 2021)[41].
- Natura 2000 areas (18 may, 2021)[42].

3.7.2 Ecosystem accounting area

For the purpose of marine ecosystem accounting, it seems appropriate to include the intertidal area as well, because this area is clearly part of the marine realm. Within the EUNIS habitat classification (section 3.3.2) it is covered by marine habitats. In other ecosystem accounts (e.g. the UK marine account) the high-water mark is used or preferred as delineation of the accounting area.

Many “marine” ecosystem services are supplied by marine ecosystem types, but used at terrestrial ecosystem types. E.g., beachgoers enjoy the sea (marine) but sunbath on the beach (terrestrial). It thus seems appropriate to account for this import / export of ecosystem services by including these coastal terrestrial ecosystem assets as well.

Thus, there are 3 options with respect to the inner boundary:

1. Align with MSFD area: outer boundary defined by the EEZ boundary; inner boundary by the coastal baseline.

[40] https://www.emodnet-seabedhabitats.eu/news/official-release-of-euseamap-2021/
[41] https://www.kadaster.nl/zakelijk/registraties/basisregistraties/brt
[42] https://ez.maps.arcgis.com/home/item.html?id=fa352a63853c48428240eccfd26a982d

2. Same as 1, but including intertidal areas.
3. Same as 2, but including “coastal” terrestrial ecosystems as well. These coastal systems should have a well-defined link with the marine realm: salt marshes; beaches; coastal dunes; artificial coastal defences, etc.

It is recognized that above three options are nested within each other, so if the associated assets are marked as to which definition they belong, a strict MSFD account can be extracted from a more broader account by subsetting the latter using these marks.

The major disadvantage of option 1 is that intertidal ecosystems, which are clearly marine in nature, would be out of scope. The major disadvantage of option 3 would be that a marine ecosystem account would overlap with the terrestrial account. Therefore, in this report, option 2 is adopted: the ecosystem accounting area for the North Sea is defined as the MSFD reporting area, plus adjacent intertidal areas, to the extent that they are located offshore with respect to the straight base lines separating the North Sea from the Westerschelde and Wadden Sea.

Additionally, for those ecosystem services that are closely linked to the coastal zone, such as recreation, some treatment of the coastal zone is required.

In the related study *Economic description of the Dutch North Sea and coast,* the coastal zone was defined to include both the coastal zone in a strict sense (e.g. beaches; coastal dunes) and a 1km buffer around (Walker et al., 2023).

Approach taken

The outline of the Ecosystem Accounting Area (EAA) is based on the Exclusive Economic Zone (EEZ) and the topographic map. The territorial boundaries of the EEZ are well defined, but the territorial boundaries closer to the coast, between the Netherlands and Germany, are not established. For this study, it was chosen to select the waters from the topographic map that are labelled ‘North Sea’ for this purpose. This results in an overestimation of the EAA because the topographic map includes a buffer zone of approximately 250m at the borders with Belgium and Germany[43]. Intertidal areas were included in the EAA, but coastal terrestrial ecosystems were excluded. Natura 2000- sites will be treated as sub-accounting areas.

3.7.3 Ecosystem classification

As explained in Section 3.3 there are multiple ecosystem classifications available, most notably the IUCN Global Ecosystem Typology (GET), the EUNIS habitat classification; the Habitat Directive Annex I Habitats and the ecosystem typology being developed for the Eurostat regulation on ecosystem accounting.

In the marine realm, spatial boundaries between ecosystem assets are much more fuzzy than in the terrestrial realm. For one, water itself is moving around. Thus, ideally, there should be a single classification for the whole of the North Sea, and by extension, all of OSPAR, or even globally.

While the Annex I habitats are especially relevant from an EU policy point of view, and the IUCN GET or the strongly related Eurostat classifications are the preferred ecosystem type classification from the SEEA-EA point of view, these are currently less suitable for compilation of an ecosystem extent account, mainly because of a current lack of spatially exhaustive data. Obviously, this may change in the future.

[43] Kadaster, 2021, Basisregistratie Topografie: Catalogus en Productspecificaties, v1.2.0.5

Thus, in this study, the North Sea ecosystem extent account will be based on the EUNIS level 1 and 2 habitats (EUSeaMap), optionally enriched with additional information on biotic communities (see below) and coastal ecosystems. These will be crosswalked with the IUCN GET level 3 types to reach maximum alignment and consistent international reporting.

This approach is in line with the experimental ecosystem account compiled for the OPSAR regions (Alarcon Blazques et al., 2021; 2023).

3.7.4 Pelagic ecosystems

Most, if not all, ecosystem classifications for the Dutch part of the North Sea have a strong focus on the sea floor and the benthic habitats found there. The EUNIS classification has separate sub-classifications for both benthic and pelagic ecosystems. However, the EUSeaMap broad-scale predictive habitat map includes only a few variables to represent the water column: water depth (biozone) and wave energy, while for instance gradients, such as associated with fronts, are not included at all.

Because currently there is no data set on pelagic habitats available, pelagic habitats cannot be explicitly represented in the extent account.

3.7.5 Protected areas

Five out of seven of the Natura-2000 areas in the North Sea are formally associated with habitats, which are themselves associated with ecosystem types (using the EUNIS classification). The N2000 sites, as spatially defined areas, do however not correspond with the spatial extent of these habitats. That is, the habitats are found *within* the site area, but the exact location of these habitats are not available. For this reason, the N2000 habitats are not suitable to be used in extent accounting.

However, because of their policy relevance, it is considered to be important to show the Natura 2000 areas and what is happening there. In order to enable the visibility of these areas in the eventual accounting tables, it seems logical to delineate these areas at least at the ecosystem sub-accounting area and preferably at the ecosystem asset level. Because of the close correspondence between Natura 2000 sites and specific habitats / ecosystems, these sites could also be taken as proxy for the corresponding ecosystems, but this seems to be more difficult to implement because of the differences in delineation between habitat presence and Natura 2000 site boundaries that are too large.

In this report, the designated Natura 2000 sites will be treated as separate ecosystem (sub) accounting areas (EEAs) within the Dutch part of the North Sea (which is the main EAA). Information on the presence of specific ecosystems and species within these areas could (if available) be recorded in the appropriate accounts.

3.7.6 Map construction

Using the above delineation the EUSeaMap was clipped to match the EAA. Near the coast the EUSeaMap did not completely cover the accounting area. For these areas, a classification of the biological zone was added using information from the topographic map. Intertidal areas were assigned the biological zone ‘Littoral’ and remaining areas were assigned biological zone ‘Infralittoral’. Since no additional information about energy class and substrate was available these were assigned “No energy information” and “Seabed” respectively.

3.8 Results

The total accounting area covers 59,211 km^2. This is a slight overestimation of the surface area that can be attributed to the Netherlands due to the buffer zone described above. To illustrate this, most often, the Dutch part of the North Sea is considered to be 58,500 km^2 (source: Rijkswaterstaat[44]). This means that the area used in this study is 711 km^2 larger due to a somewhat larger area in boundary regions with Germany and Belgium.

This section describes the ecosystems of the North sea based on the three different data layers that are present in the EUSeaMap: wave and current energy, depth / biological zone, and substrate. The distribution of these fields across the Dutch part of the North Seas will be analysed in isolation, in combination, and linked to the EUNIS typology. Additional analyses for the Natura 2000 sites (see Figure 5) are presented as well.

Energy

The attribute energy consists of combined current-and wave-induced energy at the seabed. Three levels are distinguished; high, medium and low energy. Current-and wave-induced energy are closely related to bathymetry. In general, the areas with higher energy are more shallow and thus often closer to the coast. Most of the North Sea is characterized by moderate and high energy at the seabed. Low energy occurs in the Cleaver Bank, which is split by a 60-metre deep channel called the Botney Cut. In this area, the bottom is rarely disturbed by natural causes[45] and the water is sufficiently clear that it enables the growth of calcareous red algae.

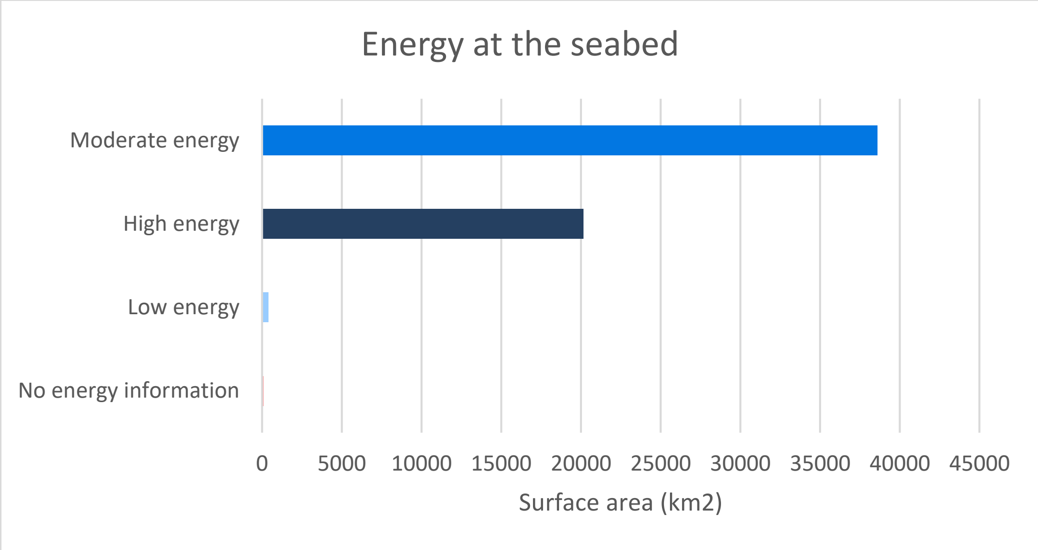
Biozone

Within the EEA four biological zones were distinguished. The littoral zone is the area close to the shore that includes the intertidal area. The infralittoral zone is the area of the seabed where photosynthetic algae are able to grow. The shallow circalittoral zone extends from the lower limit of the infralittoral zone to the depth at which the seafloor is no longer disturbed by wave action. The deep circalittoral zone extends from the lower limit of the shallow circalittoral zone to the shelf edge.

Substrate

The first characteristic of the North Sea ecosystems is the substrate. Most of the North Sea seabed consists of sand and muddy sand. Flat oyster (Ostrea edulis) beds were common until the late 19th century but have been reduced after intensive fisheries (Bennema et al., 2020). The substrate is also affected by sand and gravel extraction and bottom trawling.

[44] https://www.rijkswaterstaat.nl/water/vaarwegenoverzicht/noordzee
[45] Although (otter) bottom trawling will still disturb the bottom (WMR, pers. comm.)



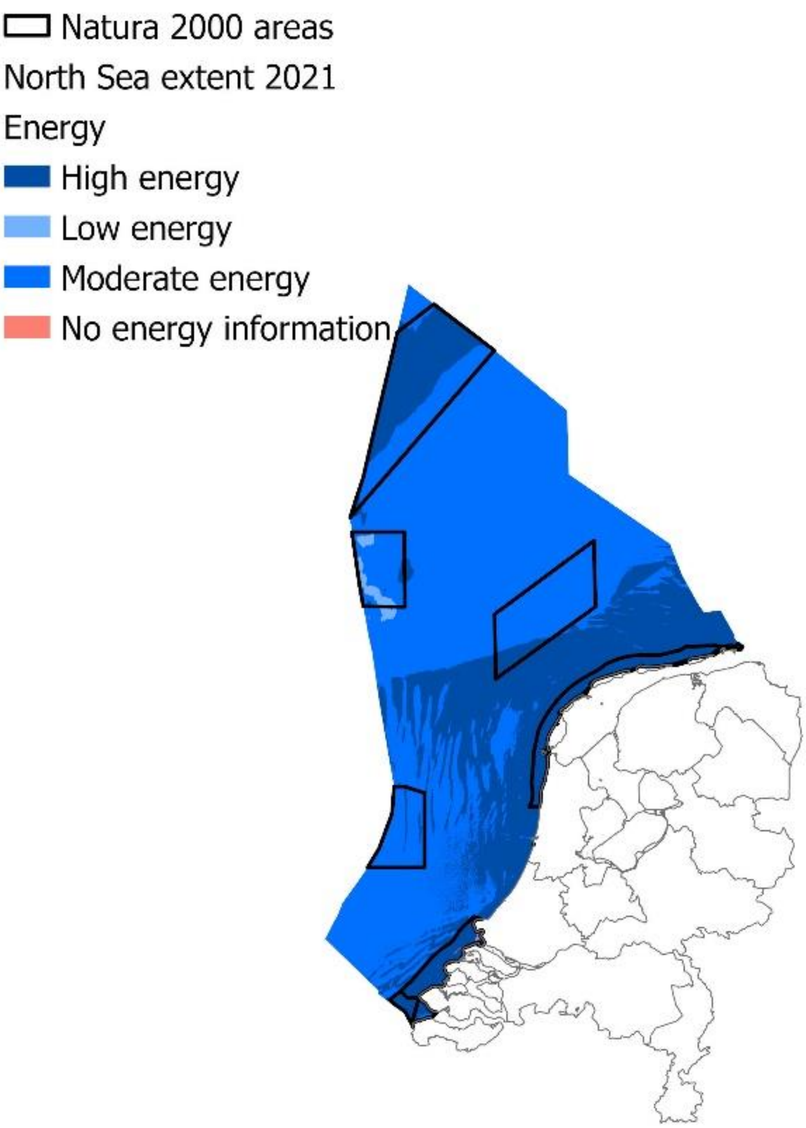
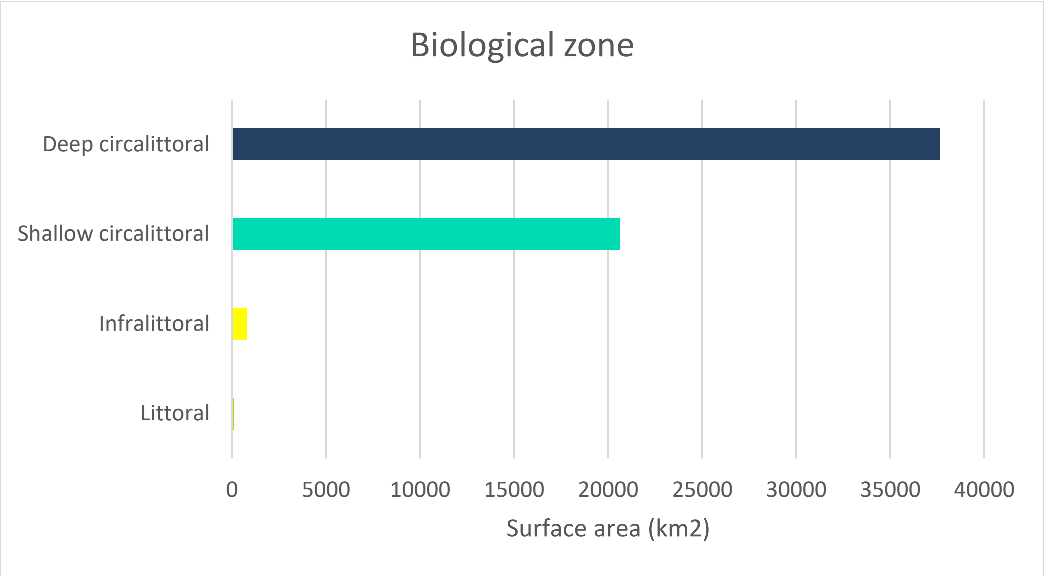


Figure 6. Subdivision and spatial distribution of the Dutch North Sea of Intensity of combined current-and wave-induced energy at the seabed.



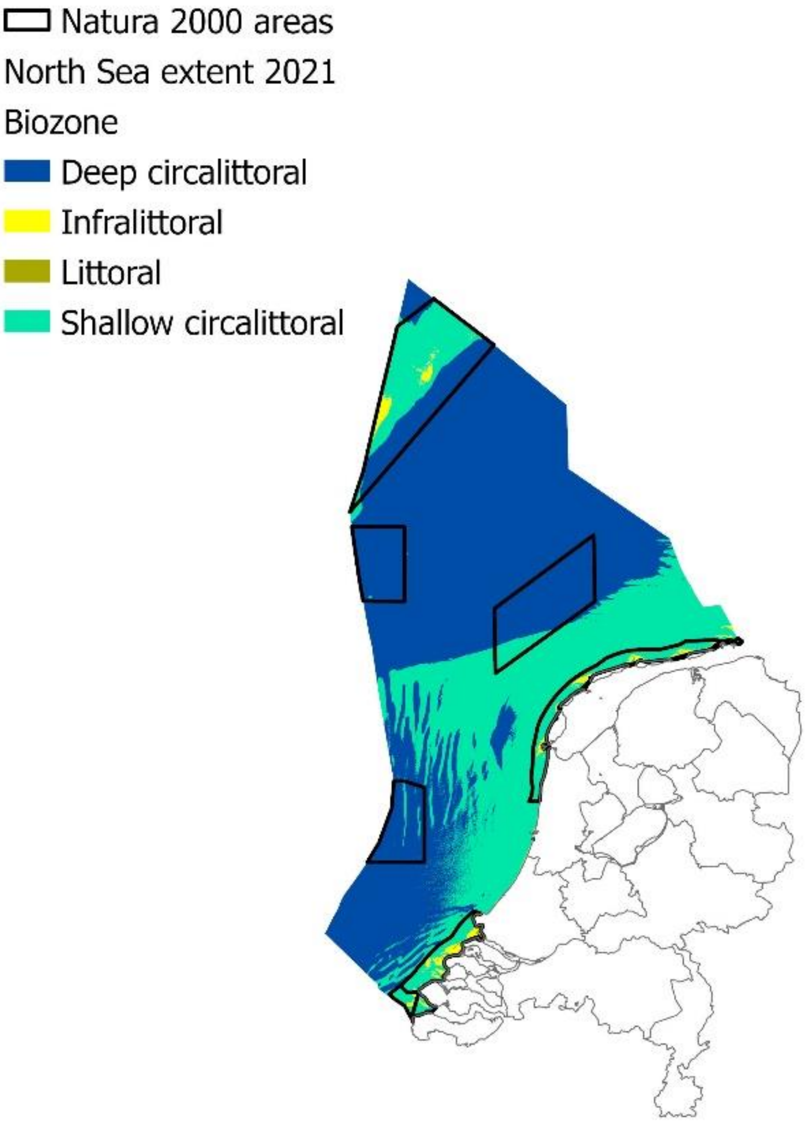


Figure 7. Subdivision and spatial distribution of biological zone in Dutch North Sea.

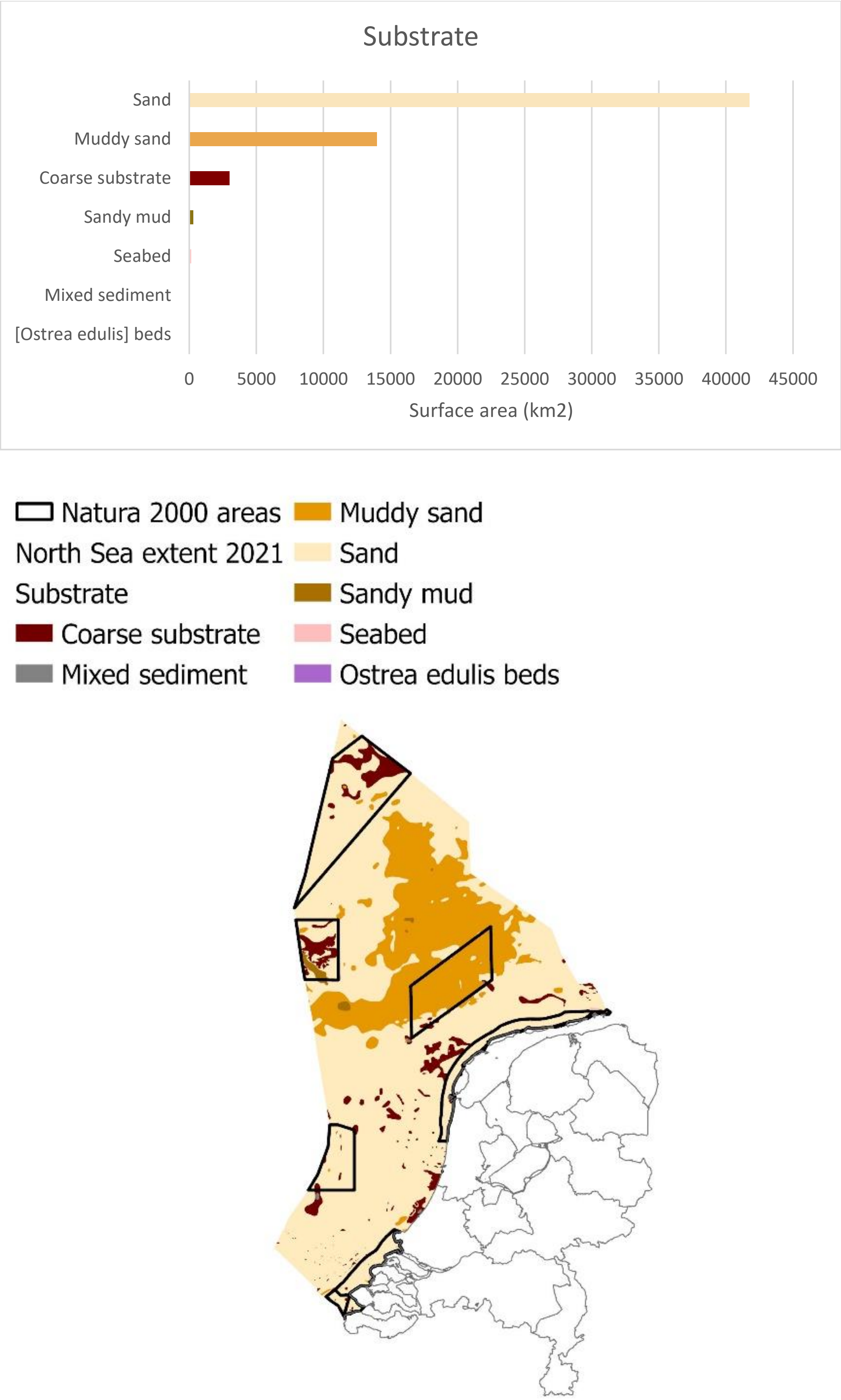


Figure 8. Subdivision and spatial distribution of substrate types for the Dutch North Sea.

Combining the three characteristics energy, biological zone and substrate yields separate ecosystem types as displayed in the accounting table below. The corresponding EUNIS classification is included as well. Three ecosystem types make up the majority of the accounting area, namely deep circalittoral sand, shallow circalittoral sand and deep circalittoral mud.

Table 13. Ecosystem Extent table for the Dutch part of the North Sea.

Energy	Biozone	Substrate	EUNIS 2019	km2	%
Moderate energy	Deep circalittoral	Sand	MD52: Atlantic offshore circalittoral sand	21858	36.9
High energy	Shallow circalittoral	Sand	MC52: Atlantic circalittoral sand	15973	27.0
Moderate energy	Deep circalittoral	Muddy sand	MD62: Atlantic offshore circalittoral mud	13339	22.5
Moderate energy	Shallow circalittoral	Sand	MC52: Atlantic circalittoral sand	2070	3.5
High energy	Shallow circalittoral	Coarse substrate	MC32: Atlantic circalittoral coarse sediment	1831	3.1
High energy	Deep circalittoral	Sand	MD52: Atlantic offshore circalittoral sand	918	1.6
Moderate energy	Deep circalittoral	Coarse substrate	MD32: Atlantic offshore circalittoral coarse sediment	903	1.5
High energy	Infralittoral	Sand	MB52: Atlantic infralittoral sand	695	1.2
High energy	Shallow circalittoral	Muddy sand	MC62: Atlantic circalittoral mud	402	0.7
Low energy	Deep circalittoral	Sandy mud	MD62: Atlantic offshore circalittoral mud	177	0.3
Other combinations				1044	1.8
			Total	**59211**	**100**

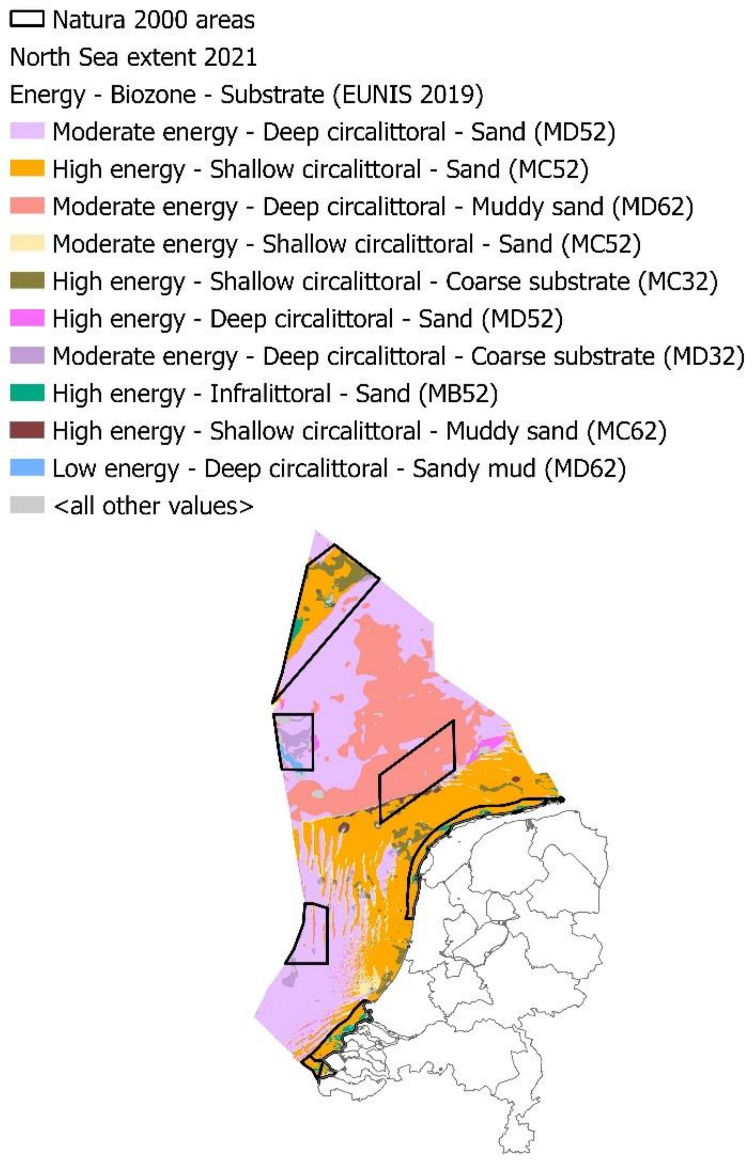


Figure 9. Ecosystem types of the Dutch part of the North Sea.

3.8.1 Crosswalk with IUCN Global Ecosystem Typology

As mentioned before (Section 3.3.1, Table 3), several *Ecosystem Functional Groups* from the Global Ecosystem Typology are relevant for the North Sea. Most prevalent are M1.7 subtidal sand beds and M1.8 subtidal mud plains (Keith et al., 2022). Table 14 shows a crosswalk with the corresponding EUNIS classifications within the Ecosystem Accounting Area. Though much smaller in area there are also shellfish beds and reefs present (M1.4), which used to be more widespread in the past. The same holds for sea grass, which used to occur close to the coast, but has now disappeared. Remnants are found in the Wadden Sea, where efforts are made to restore this habitat.

Table 14. Correspondence table of the IUCN Global Ecosystem typology and EUNIS 2019 classification for the relevant Ecosystem types of the Dutch North Sea

IUCN Global Ecosystem typology	EUNIS (2019)
M1.1 Seagrass meadows	MA522 Seagrass beds on Atlantic littoral sand MA623 Seagrass beds on Atlantic littoral mud MB522 Seagrass beds on Atlantic infralittoral sand
M1.4 Shellfish beds and reefs	MB2222 Ostrea edulis beds on Atlantic infralittoral muddy mixed sediment
M1.7 Subtidal sand beds	MD52 Atlantic offshore circalittoral sand MC52 Atlantic circalittoral sand MB52 Atlantic infralittoral sand MC42 Atlantic circalittoral mixed sediment MD42 Atlantic offshore circalittoral mixed sediment MB32 Atlantic infralittoral coarse sediment MC32 Atlantic circalittoral coarse sediment MD32 Atlantic offshore circalittoral coarse sediment
M1.8 Subtidal mud plains	MB62 Atlantic infralittoral mud MD62 Atlantic offshore circalittoral mud MC62 Atlantic circalittoral mud

3.8.2 Seascapes

The seascapes that are distinguished by van der Reijden et al. (2018) are based on detailed bathymetry analysis and span a larger area than our ecosystem accounting area (EAA). Our EAA intersects with five seascapes. Seascape 8 is characterized by high relief at the small scale caused by tidal ridges. Seascape 6 is characterized by low relief and a deeper sea floor (40-50m), it coincides with the Central Oyster Grounds and the Frisian Front. Seascape 5 is strongly elevated compared to its surroundings, only a small part of it, including the Dogger Bank, intersects with the EEA. Seascape 7, including the Cleaver Bank, is characterized by some very low areas. Seascape 9 is characterized by locally elevated areas and situated close to the coast.

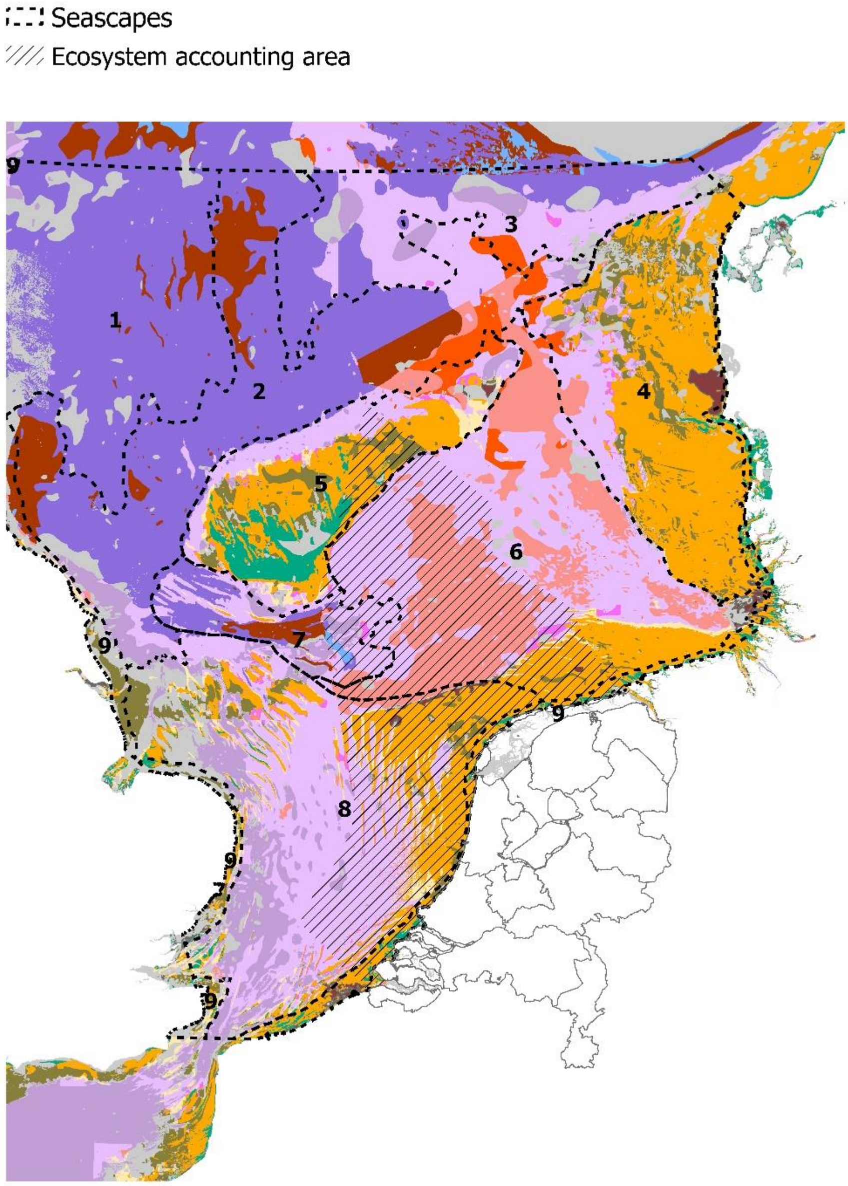


Figure 10. Ecosystem type map showing the nine distinct seascapes that are based on bathymetric data. See the main text and van der Reijden et al. (2018) for more information on the individual seacapes.

3.8.3 Natura 2000 areas

There are seven Natura 2000 sites situated within the EAA. Three of these are situated in the coastal area and four in the remaining of the Dutch part of the North Sea. Figure 11 and Table 15 to Table 21 show the composition of the sites. The coastal sites are mainly composed of circalittoral sand (MC52), while the Friese Front is made up of mainly offshore circalittoral mud (MD62) and the Bruine Bank of mainly offshore circalittoral sand (MD52). The Doggersbank and Klaverbank have a relatively mixed composition: while the Doggersbank is largely made up of several types of circalittoral sand (MCC52 and MD52), the Klaverbank has a fair share of offshore circalittoral coarse sediment (MD32).

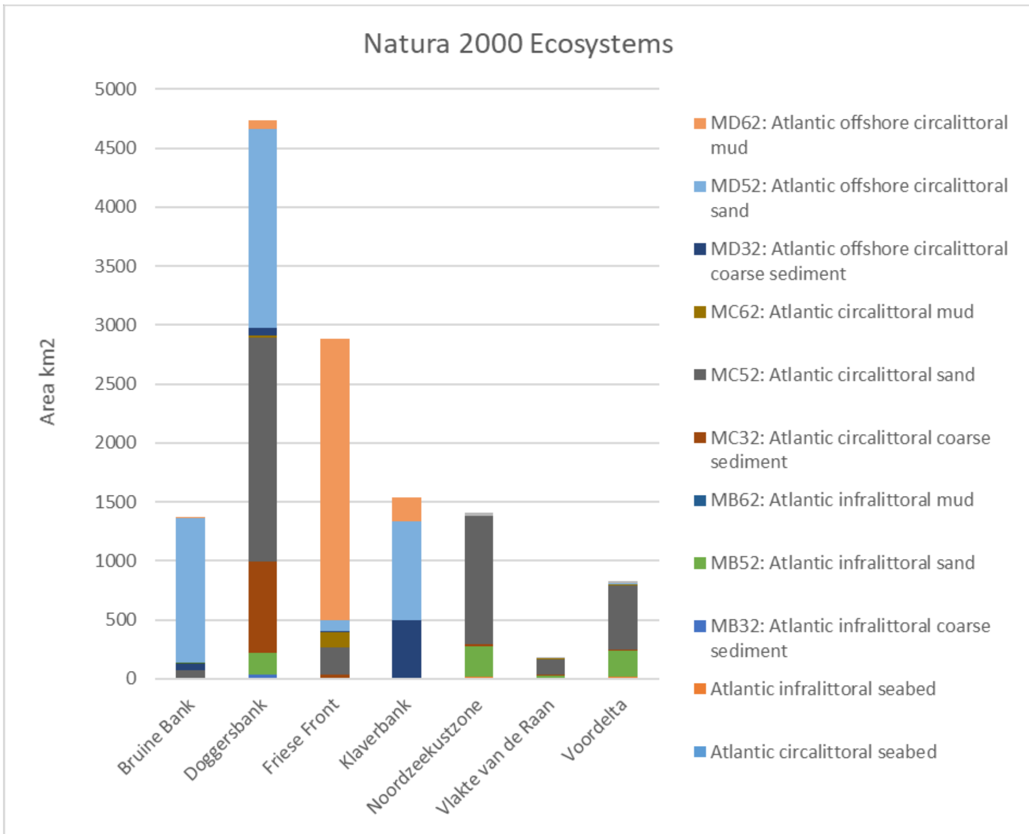


Figure 11. Composition of the Natura 2000 sites in terms of ecosystem types.

Table 15. Composition of the Doggersbank in terms of ecosystem types (major contributions only)

Energy	Biozone	Substrate	EUNIS 2019	km2
High energy	Shallow circalittoral	Sand	MC52: Atlantic circalittoral sand	1884
Moderate energy	Deep circalittoral	Sand	MD52: Atlantic offshore circalittoral sand	1648
High energy	Shallow circalittoral	Coarse substrate	MC32: Atlantic circalittoral coarse sediment	770
High energy	Infralittoral	Sand	MB52: Atlantic infralittoral sand	185
Moderate energy	Deep circalittoral	Muddy sand	MD62: Atlantic offshore circalittoral mud	71
Other combinations				176

Table 16. Composition of the Klaverbank in terms of ecosystem types (major contributions only)

Energy	Biozone	Substrate	EUNIS 2019	km2
Moderate energy	Deep circalittoral	Sand	MD52: Atlantic offshore circalittoral sand	692
Moderate energy	Deep circalittoral	Coarse substrate	MD32: Atlantic offshore circalittoral coarse sediment	452
Low energy	Deep circalittoral	Sandy mud	MD62: Atlantic offshore circalittoral mud	156
Low energy	Deep circalittoral	Sand	MD52: Atlantic offshore circalittoral sand	109
High energy	Deep circalittoral	Sand	MD52: Atlantic offshore circalittoral sand	38
Other combinations				91

Table 17. Composition of the Friese Front in terms of ecosystem types (major contributions only)

Energy	Biozone	Substrate	EUNIS 2019	km2
Moderate energy	Deep circalittoral	Muddy sand	MD62: Atlantic offshore circalittoral mud	2379
High energy	Shallow circalittoral	Sand	MC52: Atlantic circalittoral sand	231
High energy	Shallow circalittoral	Muddy sand	MC62: Atlantic circalittoral mud	97
Moderate energy	Deep circalittoral	Sand	MD52: Atlantic offshore circalittoral sand	96
High energy	Shallow circalittoral	Coarse substrate	MC32: Atlantic circalittoral coarse sediment	38
Other combinations				40

Table 18. Composition of the Noordzeekustzone in terms of ecosystem types (major contributions only)

Energy	Biozone	Substrate	EUNIS 2019	km2
High energy	Shallow circalittoral	Sand	MC52: Atlantic circalittoral sand	1083
High energy	Infralittoral	Sand	MB52: Atlantic infralittoral sand	231
High energy	Littoral	Sand	MB52: Atlantic infralittoral sand	21
No energy informatic	Littoral	Seabed		21
High energy	Shallow circalittoral	Coarse substrate	MC32: Atlantic circalittoral coarse sediment	15
Other combinations				35

Table 19. Composition of the Voordelta in terms of ecosystem types (major contributions only)

Energy	Biozone	Substrate	EUNIS 2019	km2
High energy	Shallow circalittoral	Sand	MC52: Atlantic circalittoral sand	525
High energy	Infralittoral	Sand	MB52: Atlantic infralittoral sand	193
Moderate energy	Shallow circalittoral	Sand	MC52: Atlantic circalittoral sand	21
No energy informatic	Littoral	Seabed		17
High energy	Littoral	Sand	MB52: Atlantic infralittoral sand	16
Other combinations				55

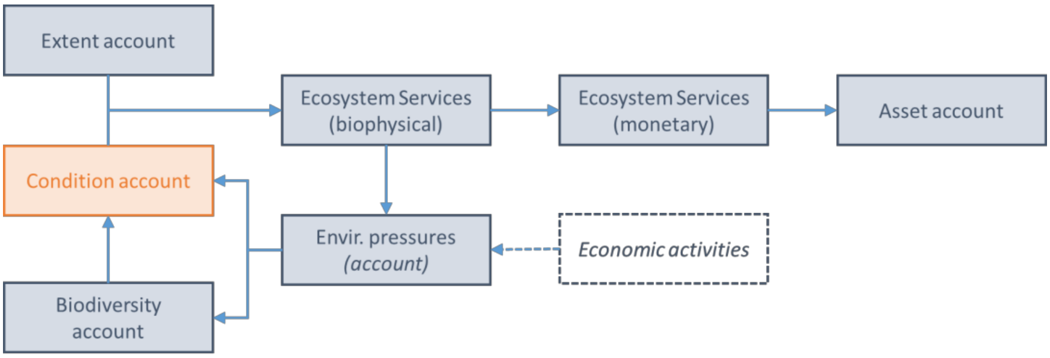
Table 20. Composition of the Vlakte van de Raan in terms of ecosystem types (major contributions only)

Energy	Biozone	Substrate	EUNIS 2019	km2
High energy	Shallow circalittoral	Sand	MC52: Atlantic circalittoral sand	129
High energy	Infralittoral	Sand	MB52: Atlantic infralittoral sand	26
High energy	Shallow circalittoral	Muddy sand	MC62: Atlantic circalittoral mud	8
High energy	Shallow circalittoral	Coarse substrate	MC32: Atlantic circalittoral coarse sediment	6
Moderate energy	Shallow circalittoral	Muddy sand	MC62: Atlantic circalittoral mud	2
Other combinations				4

Table 21. Composition of the Bruine bank in terms of ecosystem types (major contributions only)

Energy	Biozone	Substrate	EUNIS 2019	km2
Moderate energy	Deep circalittoral	Sand	MD52: Atlantic offshore circalittoral sand	1191
Moderate energy	Deep circalittoral	Coarse substrate	MD32: Atlantic offshore circalittoral coarse sediment	58
High energy	Shallow circalittoral	Sand	MC52: Atlantic circalittoral sand	44
High energy	Deep circalittoral	Sand	MD52: Atlantic offshore circalittoral sand	37
Moderate energy	Shallow circalittoral	Sand	MC52: Atlantic circalittoral sand	27
Other combinations				8

4. Ecosystem Condition



Ecosystem condition accounts describe the quality of the North Sea and their ecosystems. In this chapter first the SEEA framework for ecosystem accounts is presented, followed by a discussion of existing alternative quality framework, mainly MSFD and OSPAR. Finally, available information on ecosystem quality is organized and presented. Throughout this chapter, the distinction between ecosystem state and (human) pressures are discussed. Pressure will be the main topic of the next chapter.

4.1 Introduction

The ecosystem condition account is one of the core accounts of the SEEA-EA. Ecosystem condition is the quality of an ecosystem measured in terms of its abiotic and biotic characteristics (UN, 2021, ¶2.13, ¶5.2). The ecosystem condition account organizes data on selected ecosystem characteristics and, preferably, the distance to a reference condition to provide insight into the ecological integrity of ecosystems. It also organizes data relevant to the measurement of the capacity of an ecosystem to supply different ecosystem services. Biodiversity (discussed separately in Chapter 0) is an integral part of the measurement of ecosystem condition, contributing to the composition, structure and functioning of ecosystems.

Within the EU, the data collected as part of the requirements by the EU MSFD, and in support of that, the OSPAR monitoring reports, are de-facto data sources for monitoring and assessment of status of, and pressures on, the marine environment. Given this context, the purpose of the SEEA ecosystem condition account as presented here is not per se to add new additional data, but rather reorganize existing data and indicators in such a way that it fits the SEEA-EA framework (as much as possible) and can provide an overview of the condition of the different ecosystem types and how this changes over time, and that it can be related to the other accounts, e.g. the supply of ecosystem services, or the environmental pressures.

Instrumental context: the connection to ecosystem services

Ecosystem condition has a clear instrumental context in the sense that it describes how the quality of ecosystems relates to the capacity to provide certain ecosystem services. Ecosystems in better condition often support a greater quantity and quality of ecosystem services, for example good sea water quality supports more beach recreation. This capacity is thus a function of ecosystem condition, but the function varies between different services, and is often non-linear.

Intrinsic context: the connection to biodiversity and sustainability

Ecosystem condition also has a clear intrinsic context in the sense that it measures also the ecological integrity of the ecosystems, which is subject to overexploitation and other forms of environmental pressures.

Condition 'state' versus 'pressure' indicators

There is a difference between ecosystem condition characteristics, for example fish species diversity, and pressures exerted on ecosystems such as overfishing. Ecosystem condition variables measure directly the state of the ecosystem; pressures can affect the state of the ecosystem but are not a direct rendition of it. Measurements of environmental pressures are sometimes used as a proxy for measuring ecosystem condition. They can be a useful alternative when there are no direct measurements available on the state of the ecosystem, or when there is a considerable time lag between a pressure and evidence of a resultant change in state. The relationship between the environmental pressure and the state of the ecosystem should be well established in these cases. Chapter 5 goes into more detail about pressures exerted on the marine ecosystems.

A tiered approach to ecosystem condition accounting.

The SEEA-EA framework uses a tiered approach for compiling the ecosystem condition account. The first step is the selection of appropriate condition variables. These variables are quantitative metrics that describe individual characteristics of an ecosystem asset, such as for example turbidity, pH and fish species richness. When these condition variables are set against reference levels, e.g. related to a specific ecological state (e.g. historical, undisturbed, or as defined by the MSFD Good Environmental Status, or as resulting from expert elicitation), they can be rescaled to derive condition indicators. Rescaling the variables this way produces indicators that are easier to interpret, compare or potentially aggregate. Aggregating condition indicators into indices and sub-indices is optional and can be done across thematic or spatial aspects such as the ECT classes or ecosystem types. In this study, only the first step is carried out (but see Section 9.2 for further discussion).

Ecosystem condition typology.

Variables and indicators can be classified using the SEEA Ecosystem Condition Typology (SEEA ECT, Table 22). The ECT is a hierarchical typology for organizing data on ecosystem condition characteristics. By describing a meaningful ordering and coverage of characteristics, it can be used as a template for variable and indicator selection and provide a structure for aggregation. The ECT also establishes a common language to support increased comparability among different ecosystem condition studies (UN, 2021, section 5.2.3).

Table 22. The SEEA Ecosystem Condition Typology (ECT). (UN, 2021, p.90)

ECT groups and classes
Group A: Abiotic ecosystem characteristics
Class A1. Physical state characteristics: physical descriptors of the abiotic components of the ecosystem (e.g., soil structure, water availability)
Class A2. Chemical state characteristics: chemical composition of abiotic ecosystem compartments (e.g., soil nutrient levels, water quality, air pollutant concentrations)
Group B: Biotic ecosystem characteristics
Class B1. Compositional state characteristics: composition / diversity of ecological communities at a given location and time (e.g., presence / abundance of key species, diversity of relevant species groups)
Class B2. Structural state characteristics: aggregate properties (e.g., mass, density) of the whole ecosystem or its main biotic components (e.g., total biomass, canopy coverage, annual maximum normalized difference vegetation index (NDVI))
Class B3. Functional state characteristics: summary statistics (e.g., frequency, intensity) of the biological, chemical, and physical interactions between the main ecosystem compartments (e.g., primary productivity, community age, disturbance frequency)
Group C: Landscape level characteristics
Class C1. Landscape and seascape characteristics: metrics describing mosaics of ecosystem types at coarse (landscape, seascape) spatial scales (e.g., landscape diversity, connectivity, fragmentation)

The SEEA-EA (UN, 2021), proposes an example set of condition variables to be used in ocean accounting. This (rather small) list, which should be seen as the starting point for the discussion on SEEA Ocean Accounting, rather than a definitive typology, distinguishes between intrinsic characteristics, and instrumental ones (Table 23).

Table 23. Example condition indicators for ocean accounting. Adapted from: (UN, 2021, Annex 13.3).

SEEA
For marine and coastal ecosystems
Acidification (pH)
Eutrophication (BOD, COD, Chlorophyll-A concentrations)
Temperature (°C)
Plastics density (g/m3)
Biodiversity (Shannon index)
Health (index)
For individual environmental assets
Minerals (quality, accessibility)
Energy (quality, accessibility)
Fish (quality in terms of size, age, health)
Timber (e.g., mangrove) (quality, accessibility)
Other flora available for harvesting (e.g., seaweed) (quality, health)

Spatially explicit

The level of spatial aggregation in the accounting approach used for the condition account builds further upon the level of ecosystem assets, as defined in the ecosystem extent account. Condition indicators are aggregated across ecosystem assets of the same ecosystem type, usually using area-weighted sums or means. In order to do this, the condition variables have to be spatially explicit so they can be related to the corresponding ecosystem assets. Currently, the lack of spatial resolution of the various monitoring programs prevents this approach.

4.1.1 EU Marine Strategy (MSFD)

The main goal of the EU Marine Strategy Framework Directive (MSFD) is to achieve Good Environmental Status (GES) of European marine waters (originally 2020). GES means that the different uses of the marine resources are conducted at a sustainable level, ensuring their continuity for future generations. In addition, GES means that:

- Ecosystems, including their hydro-morphological (i.e. the structure and evolution of the water resources), physical and chemical conditions, are fully functioning and resilient to human-induced environmental change.
- The decline of biodiversity caused by human activities is prevented and biodiversity is protected.
- Human activities introducing substances and energy into the marine environment do not cause pollution effects. Noise from human activities is compatible with the marine environment and its ecosystems.

Annex 1 of the Directive sets out eleven qualitative *descriptors* that describe what the environment will look like when GES has been achieved[46].

D1. Biodiversity is maintained
D2. Non-indigenous species do not adversely alter the ecosystem
D3. The population of commercial fish species is healthy
D4. Elements of food webs ensure long-term abundance and reproduction
D5. Eutrophication is minimized
D6. The sea floor integrity ensures functioning of the ecosystem
F7. Permanent alteration of hydrographical conditions does not adversely affect the ecosystem
D8. Concentrations of contaminants give no effects
D9. Contaminants in seafood are below safe levels
D10. Marine litter does not cause harm
D11. Introduction of energy (including underwater noise) does not adversely affect the ecosystem

These descriptors all pertain to elements of ecosystem condition as described in the SEEA-EA condition framework, though most descriptors concern environmental pressures more than ecosystem state. The three descriptors on biological diversity (D1), food webs (D4) and seafloor integrity (D6) are crucial from the point of view of the ecosystem approach. These are the so-called 'status descriptors’. The other descriptors relate to disruptions of the marine ecosystem as a result of human activities. GES could be considered to be a reference condition, though it is a desired ecosystem state from the human perspective more than a natural state dominated by natural ecological and evolutionary processes, as is recommended by the SEEA-EA framework.

For each of the 11 descriptors a series of *criteria* has been developed, each of which is implemented through one or more *indicators* (Table 24). It should be noted that not all status criteria that represent the ecosystem status are considered condition state variables from the SEEA-EA perspectives. For instance, mortality rate (D1D1 and D3C1) represent state changes, and hence pressures, rather than stock state.

[46] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32008L0056

Table 24. Status descriptors and criteria of the European Marine Strategy[47]. Highlighted cells indicate criteria that are considered pressure factors rather than state variables in the SEEA-EA context.

Descriptor		Criterion		State/Pressure MSFD	SEEA
D1	Biodiversity	D1C1	Mortality rate per species from incidental bycatch	S	P
		D1C2	Population abundance	S	S
		D1C3	Population demographic characteristics	S	S
		D1C4	Species distributional range	S	S
		D1C5	Size and condition of the habitat	S	S
		D1C6	Condition of the habitat type	S	S
D3	Commercial Fish stocks	D3C1	Fishing mortality rate of commercially exploited species	S	P
		D3C2	Spawning stock biomass of commercially exploited species	S	S
		D3C3	Age and size distribution of commercially exploited species	S	S
D4	Food webs	D4C1	The diversity of the trophic guild	S	S
		D4C2	The balance of the total abundance between the trophic guilds	S	S
		D4C3	The size distribution of individuals in the trophic guild	S	S
		D4C4	The productivity of the trophic guild	S	S
D6	Sea Floor Integrity	D6C1	Spatial extent and distribution of physical loss (permanent change) of the natural seabed	S	S
		D6C2	Spatial extent and distribution of physical disturbance pressures on the seabed	S	P
		D6C3	Spatial extent of each habitat type which is adversely affected by physical disturbance	S	P
		D6C4	Extent of loss of the habitat type, resulting from anthropogenic pressures	S	S
		D6C5	The extent of adverse effects from anthropogenic pressures on the condition of the habitat type	S	S

Vice versa, the MSFD pressure descriptors are often state variables from the SEEA-EA point of view (Table 25). Therefore, these are mostly discussed in this chapter as well. Pressure factors are further discussed in Chapter 5.

Table 25. 'Pressure' descriptors and criteria of the European Marine Strategy[47]. Highlighted cells indicate criteria that are considered system states rather than pressure factors in the SEEA-EA context.

Descriptor		Criterion		State/Pressure MSFD	SEEA
D2	Non-indigenous species (NIS)	D2C1	Number of newly introduced NIS	P	P
		D2C2	Abundance and spatial distribution of established NIS	P	P
		D2C3	Proportion of the species group or spatial extent of the broad habitat type which is adversely altered due to NIS	P	S
D5	Eutrophication	D5C1	Nutrient concentrations	P	S
		D5C2	Chlorophyll-a concentrations	P	S
		D5C3	The number, spatial extent and duration of harmful algal bloom events	P	S
		D5C4	The photic limit (transparency) of the water column	P	S
		D5C5	Concentration of dissolved oxygen	P	S
		D5C6	Abundance of opportunistic microalgae	P	S
		D5C7	Species composition and relative abundance or depth distribution of macrophyte communities	P	S
		D5C8	Species composition and relative abundance of macrofaunal communities	P	S
D7	Hydrography	D7C1	Spatial extent and distribution of permanent alteration of hydrographical conditions	P	S
		D7C2	Spatial extent of each benthic habitat type adversely affected due to permanent alteration of hydrographical conditions	P	S
D8	Contaminants	D8C1	Concentrations of contaminants	P	S
		D8C2	Health of species and the condition of habitats adversely affected due to contaminants	P	S
		D8C3	Spatial extent and duration of significant acute pollution events	P	P
		D8C4	Effects of significant acute pollution events on the health of species and on the condition of habitats	P	S
D9	Contaminants (Seafood)	D9C1	Level of contaminants in edible tissues of seafood	P	S
D10	Litter	D10C1	Composition, amount and spatial distribution of litter	P	S
		D10C2	Composition, amount and spatial distribution of micro litter	P	S
		D10C3	Amount of litter and micro litter ingested by marine animals	P	S
		D10C4	Number of individuals of each species which are adversely affected due to litter	P	S
D11	Energy and Noise	D11C1	Spatial distribution, temporal extent and levels of anthropogenic impulsive sound sources	P	P
		D11C2	Spatial distribution, temporal extent and levels of anthropogenic continuous low-frequency sound	P	P

In Table 26 these are linked to the SEEA ECT classes and groups.

Implementation in the Netherlands

The Dutch Marine Strategy consists of three parts. Part 1 describes the current environmental status, good environmental status and the environmental targets, together with associated indicators, for the Dutch part of the North Sea (better known as the Dutch Continental Shelf, DCS). Parts 2 and 3 of the Marine Strategy contain the related monitoring programme and programme of measures[48].

[47] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32017D0848
[48] See https://www.noordzeeloket.nl/en/policy/marine-strategy/

The environmental status is evaluated using the descriptors and underlying criteria described in the MSFD[49]. In order to determine whether GES is achieved, indicators are evaluated for each of the criteria wherever possible.

Both the assessment and the monitoring program build heavily upon the activities and assessments by OSPAR, described in the next section.

Data considerations

The Marine Strategy is updated every six years. This means that GES is evaluated over a time period of multiple years, consequently the indicators that are used often aggregate data from consecutive years into one value for the entire reporting period. In some cases only the trend value is used to estimate GES. Spatial distribution of the corresponding measurement points differ widely between indicators. For some indicators there is only one value for the entire ecosystem accounting area, other indicators make use of ICES or OSPAR subdivisions or a specific rectangle grid for spatial aggregations.

4.1.2 GOAP

The Global Ocean Accounts Partnership (GOAP), in their draft Technical Guidance[50], while mirroring globally the SEEA-EA in structure, presents an example condition account with only a few marine condition variables. These are included in Table 26.

[49] Marine Strategy part 1, Appendix IV
[50] https://oceanaccounts.atlassian.net/wiki/spaces/DTGOOA/pages/47743101/2.+Structure+of+Ocean+Accounts

Table 26. Crosswalk between SEEA -ECT and MSFD criteria and GOAP condition indicators

SEEA ECT Group class	MSFD criterion	GOAP Indicator
A: Abiotic ecosystem characteristics		
A1. Physical state	D1C5. Size and condition of the habitat	
	D5C4. The photic limit (transparency) of the water column	
	D6C1. Spatial extent and distribution of physical loss (permanent change) of the natural seabed	
	D6C3. Spatial extent of each habitat type which is adversely affected by physical disturbance	
	D6C4. Extent of loss of the habitat type, resulting from anthropogenic pressures	
	D6C5. The extent of adverse effects from anthropogenic pressures on the condition of the habitat type	
	D7C1. Spatial extent and distribution of permanent alteration of hydrographical conditions	
	D7C2. Spatial extent of each benthic habitat type adversely affected due to permanent alteration of hydrographical conditions.	
	D10C1. Composition, amount and spatial distribution of litter	Plastics
	D10C2. Composition, amount and spatial distribution of micro litter	
	D6C2. Spatial extent and distribution of physical disturbance pressures on the seabed	
	D11C1. Spatial distribution, temporal extent and levels of anthropogenic impulsive sound sources	
	D11C2. Spatial distribution, temporal extent and levels of anthropogenic continuous low-frequency sound	
A2. Chemical state	D5C1. Nutrient concentrations	Eutrophication
	D5C2. Chlorophyll-a concentrations	Chlorophyll-A
	D5C5. Concentration of dissolved oxygen	BOD, COD
	D8C1. Concentrations of contaminants	Acidification Temperature
	D8C3. Spatial extent and duration of significant acute pollution events	
B: Biotic ecosystem characteristics		
B1. Compositional state	D1C2. Population abundance	Biodiversity
	D1C3. Population demographic characteristics	
	D1C4. Species distributional range	
	D2C2. Abundance and spatial distribution of established non-indigenous species	
	D5C8. Species composition and relative abundance of macrofaunal communities	
	D8C2. Health of species and the condition of habitats adversely affected due to contaminants.	
	D10C3. Amount of litter and micro litter ingested by marine animals	
	D10C4. Number of individuals of each species which are adversely affected due to litter	
	D1C1. Mortality rate per species from incidental bycatch	
	D2C1. Number of newly introduced non-indigenous species	
B2. Structural state	D1C6. Condition of the habitat type	
	D2C3. Proportion of the species group or spatial extent of the broad habitat type which is adversely altered due to non-indigenous species	
	D5C3. The number, spatial extent and duration of harmful algal bloom events	
	D5C6. Abundance of opportunistic microalgae	
	D5C7. Species composition and relative abundance or depth distribution of macrophyte communities	
	D8C4. Effects of significant acute pollution events on the health of species and on the condition of habitats	
B3. Functional state	D4C1. The diversity of the trophic guild	
	D4C2. The balance of the total abundance between the trophic guilds	
	D4C3. The size distribution of individuals in the trophic guild	
	D4C4. The productivity of the trophic guild	
	D3C1. Fishing mortality rate of commercially exploited species	
	D3C2. Spawning stock biomass of commercially exploited species	
	D3C3. Age and size distribution of commercially exploited species	
	D9C1. Level of contaminants in edible tissues of seafood.	
C: Landscape level characteristics		
C1. Landscape and seascape	(none)	
Non-SEEA-ECT		
	(none)	Quality Accessibility Health

4.1.3 OSPAR

As introduced in Section 2.1.3, the OSPAR vision of "a clean, healthy and biologically diverse North-East Atlantic Ocean, which is productive, used sustainably and resilient to climate change and ocean acidification" is delivered by a set of 12 strategic objectives (Table 1). One additional and implicit objective of OSPAR is to align the efforts of Contracting Parties that are EU Member States concerning the governance of the North-East Atlantic, and the implementation of the MSFD. Therefore, the efforts of OSPAR to monitor and assess the status of the marine environment of the OSPAR maritime area is not only focused on tracking the effects of pressures from human activities on the marine environment, and assessment of progress towards the objectives set out in the OSPAR strategy, but are also focused on providing information for Member States relating to their MSFD obligations.

In order to measure progress towards these strategic objectives, OSPAR has set up an extensive and evolving system of indicators and associated monitoring programme, focusing on biodiversity and pressures that result from human activities. The results of these monitoring activities are presented in the 'OSPAR Quality Status Reports' (QSRs), e.g. QSR 2000, QSR 2010, and most recently the QSR 2023, which was published only a couple of weeks before the finalisation of this report. Therefore, unfortunately, we could not use all information from the most recent report, but have largely relied on the previous versions.

According to OSPAR, "A key starting point for developing methodologies to assess ecosystem health is an assessment of the overall status of biodiversity of the OSPAR area. Species and habitats that occur in the marine environment interact in complex and dynamic spatial and temporal patterns. Assessment methodologies need to link knowledge of the biology, chemistry and physics of the ecosystem. The basic challenge comprises three main steps: (1) to assess the status of species and habitats; (2) to assess the pressures from human activities; (3) to link the status and the impacts from pressures and take into account cumulative effects arising from multiple pressures and the interactions among species and habitats in the ecosystem".[51]

The corresponding OSPAR indicator typology (OSPAR, 2013) is structured in a similar way as the MSFD descriptor and criterion system (Table 27), although marked differences occur. In Table 28 a crosswalk between the two typologies is presented (for *state* descriptors only, see the corresponding tables in Chapter 5 for pressures).

[51] https://qsr2010.ospar.org/en/ch11.html

Table 27. Indicator typology of OSPAR (2013; state indicators only). Highlighted cells mark indicators that are not implemented yet.

Descriptor	Crieterion		Indicator	
1 Biological Diversity	1.1	Species distribution	1.1.1	Species distibutional range
			1.1.2	Species distribution pattern
			1.1.3	Area covered by species
	1.2	Population size	1.2.1	Population abundance / biomass
	1.3	Population condition	1.3.1	Population demographics
			1.3.2	Population Genetic structure
	1.4	Habitat Distribution	1.4.1	Hab. Distributional range
			1.4.2	Hab. Distributional pattern
	1.5	Habitat extent	1.5.1	Habitat Area
			1.5.2	Habitat Volume
	1.6	Habitat condition	1.6.1	Condition of typical species/communities
			1.6.2	Relative abundance/biomass of spp.
			1.6.3	Physical, hydrological & chemical conditions
	1.7	Ecosystem Structure	1.7.1	Composition and relative proportions of ecosystem components
4 Marine Food Webs	4.1	Productivity of key species / groups	4.1.1	Performance of key predators (productivity)
	4.2	Proportion of selected species at the top of food webs	4.2.1	Large fish
	4.3	Abundance/distribution of key trophic groups/species	4.3.1	Abundance and trends of selected groups/species
6 Seafloor Integrity	6.1	Physical damage, having regard to substrate characteristics	6.1.1	Biogenic substrate
			6.1.2	Extent of seabed significantly affected for the different substrate types
	6.2	Condition of benthic community	6.2.1	Presence of sensitive species
			6.2.2	Multimetric indices
			6.2.3	Biomass / nr of individuals above specified length /size
			6.2.4	Size spectrum of benthic community

Table 28. Crosswalk between MSFD and OSPAR condition state typologies. Gray cells indicate groups that are not implemented (yet).

MSFD Descriptor		Criterion		OSPAR Indicator group			
D1	Biodiversity	D1C1	Mortality rate per species from incidental bycatch	NA			
		D1C2	Population abundance	1.2	Population size	1.2.1	Pop. abundance / biomass
		D1C3	Population demographic characteristics	1.3	Population condition	1.3.1	Pop. demographics
						1.3.2	*Pop. Genetic structure*
				4.2	*Proportion of selected species at the top of food webs*	*4.2.1*	*Large fish*
		D1C4	Species distributional range	1.1	Species distribution	1.1.1	Sp. distibutional range
						1.1.2	Sp. distributiona pattern
						1.1.3	Area covered by species
		D1C5	Size and condition of the habitat	1.6	Habitat condition	1.6.1	Condition of typical species/communities
						1.6.2	Relative abundance/biomass of spp.
						1.6.3	Physical, hydrological & chemical conditions
		D1C6	Condition of the habitat type	1.5	Habitat extent	1.5.1	Habitat Area
						1.5.2	Habitat Volume
		Other		1.4	Habitat Distribution	1.4.1	Hab. Distributional range
						1.4.2	Hab. Distributional pattern
				1.7	Ecosystem Structure	1.7.1	Composition and relative proportions of ecosystem components
D3	Commercial Fish stocks	D3C1	Fishing mortality rate of commercially exploited species	NA			
		D3C2	Spawning stock biomass of commercially exploited species	NA			
		D3C3	Age and size distribution of commercially exploited species	NA			
D4	Food webs	D4C1	The diversity of the trophic guild	NA			
		D4C2	The balance of the total abundance between the trophic guilds	4.3	Abundance/distribution of key trophic groups/species	4.3.1	Abundance and trends of selected groups/species
		D4C3	The size distribution of individuals in the trophic guild	4.2	Proportion of selected species at the top of food webs	4.2.1	Large fish
		D4C4	The productivity of the trophic guild	4.1	Productivity of key species / groups	4.1.1	Performance of key predators (productivity)
D6	Sea Floor Integrity	D6C1	Spatial extent and distribution of physical loss (permanent change) of the natural seabed	6.1	Physical damage, having regard to substrate characteristics	6.1.1	Biogenic substrate
		D6C2	Spatial extent and distribution of physical disturbance pressures on the seabed				
		D6C3	Spatial extent of each habitat type which is adversely affected by physical disturbance				
		D6C4	Extent of loss of the habitat type, resulting from anthropogenic pressures			6.1.2	Extent of seabed significantly affected for the different substrate types
		D6C5	The extent of adverse effects from anthropogenic pressures on the condition of the habitat type				
		Other		6.2	Condition of benthic community	6.2.1	Presence of sensitive species
						6.2.2	Multimetric indices
						6.2.3	Biomass / nr of individuals above specified length /size
						6.2.4	Size spectrum of benthic community

OSPAR Common Biodiversity Indicators

The relatively abstract OSPAR typology has been implemented by means of an elaborated system of more specific indicators, most notably the set of Common Biodiversity Indicators (CBIs), where the term 'common' refers to the fact that these indicators are to be developed in a coordinated fashion between countries (OSPAR, 2013). These Indicators are classified as either '*core'*, expected to be operational soon after publication, while '*candidate'* indicators require(d) more development (Table 29).

Table 29. OSPAR biodiversity indicator framework (OSPAR, 2013). Indicators labeled "Common" are included in the OSPAR Common Indicators, as currently used for the QSR23.

		Indicator	Category	Common
Mammals				
	M1	Distributional range and pattern of grey and harbour seal haul-outs and breeding colonies	Core	
	M2	Distributional range and pattern of cetaceans species regularly present	Core	
	M3	Seal abundance and distribution	Core	*
	M4	Abundance and Distribution of marine mammals	Core	*
	M5	Grey seal pup production	Core	*
	M6	Marine mammal bycatch	Core	*
Birds				
	B1	Marine bird abundance	Core	*
	B2	Annual breeding success of kittiwake	Core	
	B3	Marine Bird Breeding Success / Failure	Core	*
	B4	Non-native/invasive mammal presence on island seabird colonies	Core	
	B5	Mortality of marine birds from fishing (bycatch) and aquaculture	Candidate	
	B6	Distributional pattern of breeding and non-breeding marine birds	Core	
Fish and Cephalopods				
	FC1	Recovery in the population abundance of sensitive fish species	Core	*
	FC2	Proportion of large fish (Large Fish Index)	Core	*
	FC3	Mean maximum length of demersal fish and elasmobranchs	Core	
	FC4	By-catch rates of Chondrichthyes	Candidate	
	FC5	Conservation status of elasmobranch and demersal bony-fish species (IUCN)	Candidate	
	FC6	Proportion of mature fish in the populations of all species sampled adequately in international and national fish surveys	Candidate	
	FC7	Distributional range of a suite of selected species	Candidate	
	FC8	Distributional pattern within range of a suite of selected species	Candidate	
Benthic habitats				
	BH1	Sentinels of the Seabed	Core	
	BH2	Condition of Benthic Habitat Communities	Core	*
	BH3	Extent of Physical Damage to Predominant and Special Habitats	Candidate	*
	BH4	Area of habitat loss	Candidate	
	BH5	Size-frequency distribution of bivalve or other sensitive/indicator species	Candidate	
Pelagic habitats				
	PH1	Changes in plankton functional types (life form) index Ratio	Core	*
	PH2	Plankton biomass and/or abundance	Core	*
	PH3	Changes in biodiversity index (s)	Core	*
Food webs				
	FW1	Reproductive success of marine birds in relation to food availability	Core	
	FW2	Production of phytoplankton	Core	
	FW3	Size composition in fish communities	Core	*
	FW4	Changes in average trophic level of marine predators (cf MTI)	Core	*
	FW5	Changes in plankton functional types (life form) index Ratio	Core	*
	FW6	Biomass, species composition and spatial distribution of zooplankton	Candidate	
	FW7	Fish biomass and abundance of dietary functional groups	Candidate	
	FW8	Changes in average faunal biomass per trophic level (Biomass Trophic Spectrum)	Candidate	
	FW9	Ecological Network Analysis indicator (e.g. trophic efficiency, flow diversity)	Candidate	
Non-Inidigenous species				
	NIS1	Pathways management measures	Candidate	
	NIS2	Rate of new introductions of NIS (per defined period)	Candidate	

Current OSPAR indicators

The OSPAR indicator framework is continuously evolving and expanding. For the 2017 intermediate assessment and the 2023 Quality Status Report many new common biodiversity status or pressure indicators have been developed (in some cases as *candidate* or *pilote* indicators). Many of these indicators are explicitly linked to MSFD Descriptors and Criteria. (Table 30).

Table 30. OSPAR state indicators as currently in use. 'CBI' refers to the Common Biodiversity Indicator framework (Table 29), **'Common'** marks if this indicator is part of the current list of Common indicators[52]; orange cells highlight indicators that are not part of this set. **'IA17'** marks if the indicator was used in the 2017 Intermediate Assessment ('p' if it was a pilot assessment). **'QSR23'** marks if the indicator is part of the 2023 Quality Status Report. Asterisks * are put between parentheses to indicate the corresponding QSRs are not yet completed (as of August 2023). **'OCT'** refers to the OSPAR Condition typology (Table 27) while **'MSFD'** refers to the MSFD descriptor typology (Table 24). Grey lines indicate indicators that are not relevant for the Dutch part of the North Sea.

OSPAR Indicators		CBI	Comm.	IA17	QSR23	OCT	MSFD
Marine Mammals	Seal abundance and distribution	M3	*	*	*	D1.1, D1.2	D1C2
	Abundance and Distribution of marine mammals	M4	*	*	*	D1.1, D1.2, D4.3	D1C2
	Grey seal pup production	M5	*	*	*	D1.3	D1C3
	Marine mammal bycatch	M6	*	*	*	D1.3	D1C1
	— *Killer whales (pilot)*					D1.1, D1.2, D4.3	D1C2
	— *in Arctic waters (pilot)*				(*)		
Seabirds	Marine bird abundance	B1	*	*	*	D1.2	D1C2
	— *Non-breeding offshore birds (pilot)*				(*)		
	Marine Bird Breeding Success / Failure	B3	*	*	*	D1.3	D1C3
	Marine Bird Bycatch (pilot)	B5			(*)		
	Marine Bird Habitat Quality (pilot)				(*)		
Fish Community	Recovery in the population abundance of sensitive fish species	FC1	*	*	*	D1.2	D1C2
	Mean Maximum Length of Fish (pilot)			p	(p)	D1.7	
Benthic Habitat	Sentinels of the seabed	BH1	*		*		
	Condition of Benthic Habitat Communities): The Common Conceptual Approach	BH2	*	*	*	D1.6, D5.3, D6.2	D6C5
	— Assessment of Coastal Habitats in relation to Nutrient and/or Organic Enrichment	BH2	*	*	*	D1.6, D5.3	
	— Subtidal Habitats of the Southern North Sea	BH2	*	*	*	D1.6, D6.2	
	Extent of Physical Damage to Predominant and Special Habitat:	BH3	*	*		D1.6, D6.1	
	— Aggregate extraction				*		
	— Fisheries with mobile bottom-contacting gears				*		
	Area of Habitat Loss (pilot)	BH4			*		
Pelagic Habitat	Changes in Phytoplankton and Zooplankton Communities	PH1; FW5	*	*	*	D1.4, D1.6, D4.3	D1C6
	Changes in Phytoplankton Biomass and Zooplankton Abundance	PH2	*	*	*	D1.6, D1.7, D4.1	D1C6, D4C4
	Plankton diversity index (PH3)	PH3	*	p	*	D1.6, D.17	
Food Web	Size composition in fish communities	FW3	*	*	*	D4.2	D4C3
	Changes in average tropihic level of marine predators in the Bay of Biscay	FW4	*	*		D4.2, D4.3	
	Proportion of large fish (Large Fish Index)	FC2	*	*	*	D1.7	D1C3
	Production of Phytoplankton (pilot)			p		D4.1	
	Ecological Network Analysis Indices (pilot)				(*)	*D4.?*	
	Feeding Guilds (pilot)				(*)	*D4.?*	
	Primary Productivity (pilot)				(*)	*D4.?*	

[52] https://www.ospar.org/work-areas/cross-cutting-issues/ospar-common-indicators

In the first ecosystem account for the Northeast Atlantic, Alarcon Blazquez (2021) cross walked the OSPAR (IA 2017) quality status and pressure indicators to the SEEA ECT.

For the QSR 2023 16 different thematic assessments were carried out (OSPAR, 2023): Marine Birds; Marine Mammals; Fish; Food Webs; Benthic Habitats / Sea Bed Disturbance; Pelagic Habitats ; Non Indigenous Species ; Marine Litter ; Underwater Noise; Impact of Human Activities; Integrated eutrophication assessment; Atmospheric and riverine inputs; Hazardous substances; Offshore Industries; Radioactive Substances; Climate Change.

4.1.4 Previous work

Netherlands

In the 2019 pilot account for the Dutch part of the North Sea (Schenau et al., 2019), 11 condition indicators were used, covering 4 out of 11 MSFD Descriptors (Table 31). Notable gaps were fish population, food web structure and litter.

For some of these indicators (salinity; nitrogen; chlorophyll) maps were used or developed, in order to intersect them with the ecosystem type map and arrive at condition indicators per ecosystem type. This, however was severely hindered by the coarse spatial resolution of available data (e.g. salinity, inorganic N, chlorophyll).

Table 31. Ecosystem condition indicators used in the 2019 pilot marine ecosystem account (Adapter after Schenau et al, 2019))

Descriptor Marine Directive	Indicator	Source	Year
1. Biodiversity	Benthos	RWS	2015-2016
2. Non-indigenous species	(none)		
3. Fish populations	(none)		
4. Foodwebs	(none)		
5. Eutrophication	Inorganic nitrogen concentration surface water	RWS	2016
	Dissolved O2 concentration	Emodnet	2016
	Phosphorus concentration surface water	Emodnet	2016
	Chlorophyl a	RWS	2016
	Phytoplankton	RWS	2016
6. Seafloor integrity	Benthic fishing intensity	RWS	
7. hydrographical conditions	Salinity	RWS	2016
8. Contaminents	Tributyltin concentration surface water	RWS	2015-2106
	Lead concentration surface water	Emodnet	2016
	PCB concentration surface water	RWS	2015-2016
9. Contaminants in seafood	(none)		
10. Marine litter	(none)		
11. Energy/underwater sound	(none)		

United Kingdom

The United Kingdom, in their initial natural capital account for the marine and coastal environments (Thornton et al., 2019), took a purely instrumental perspective on condition. For a limited set of ecosystem services, they first identified the ecosystem types which are involved in contributing to the delivery of these ecosystem services, and, in a next step, identified the characteristics of these habitats that enable them to deliver these ecosystem services on a sustainable basis.

Table 32 lists the key “enabling characteristics” identified by (Thornton et al., 2019), and organized according to the SEEA Ecosystem Condition Typology (ECT, Table 22). As can be seen, there is a fairly good coverage of all ECT classes, with a relatively large number of physical characteristics, and relatively few representing biotic structure. Overall, there is relatively little overlap in characteristics between ecosystem services. Sediment particle size is a key characteristic for three services, while vegetation coverage and primary production are key characteristics for two services. Extent is listed as relevant for all ecosystem services because the areal size of ecosystem assets (obviously) defines the potential total volume of ecosystem services supplied.

Table 32. Enabling characteristics for seven ecosystem services, as used in the UK marine accounts. Double stars indicate the most imported ones. Based on information provided by (Thornton et al., 2019).

SEEA ECT		Characteristic	Ecosystem Service						
			Fish provisioning	Waste remediation	Natural hazard protection	Climate regulation	Recreation	Wind	Aggregates
Abiotic	A1 Physical	Spatial extent	**	**	**	**	**	**	**
		Sediment particle size		**		**			**
		Distance from land			**				
		Distance to terr. infra.						*	*
		Height			**				
		Sedimentation rate				*			
		Temperature				*			
		Distance from sea					*		
		Substrate solidity					*		
		Aspect						**	
		Depth						*	*
	A2 Chemical	Nutrient availability	*						
		Water quality	*						
		Soil organic content		*					
		Salinity				*			
		Particulate org. Matter				*			
		Sediment organic content				*			
Biotic	B1 Compositional	Plant community		**					
		Invertebrate community		*					
		Plant species			*				
		Species community				*			
		Species diversity					*		
	B2 Structural	Vegetation coverage		**	**				
		Above/belowground biomass		*	*				
	B3 Functional	Marine food web	**						
		Primary production		**	*	**	*		
		Flushing time		*					
		Species age				*			
		Bioturbation				*			
		Biodeposition				*			
		Nutrient cycling					*		
C1 Land en seascape		Habitat fragmentation			**				
		Form of seascape					*		
		Habitat heteogeneity					*		

4.2 Data sources

Quantitative information on the (condition of the) marine environment is available through a number of organizations. In this section we give a brief overview of the most important ones.

Netherlands

In the Netherlands extensive monitoring programs have been implemented to support reporting obligations linked to the EU (MSFD, WFD, Habitat Directive, Bird Directive), OSPAR and ICES. Data sets on biology; habitats, hydrography and chemistry are mainly accessed through the Marine Information and Data Centre (Dutch: *Informatiehuis Marien*, IHM)[53] This is a collaborative venture between several Dutch ministries and serves as a platform for finding and sharing data about the North Sea. Data from national monitoring programmes, including data used for the MSFD assessment, is available through the open data viewer.

Important to mention here is that there is a large variety in monitoring density, both in time and in space, depending on the indicator. Table 33 gives an overview of some of the most important monitoring schemes run directly by Rijkswaterstaat and Wageningen Marine Research (WMR):

[53] https://www.informatiehuismarien.nl/uk/

- Most chemical parameters (and phytoplankton) are measured on 13 to (mostly) 20 sites along a number of transects (northwest of Vlissingen; Noordwijk; Terschelling; some intermediate).
- Benthos are counted with a gridded approach, intermediate dense (240 sites on the North Sea; dense grid in the Coastal Zone)
- Porpoises and seals are counted in 4 areas (North Sea)
- Temporal resolution varies between once every 3 years (North Sea benthos) to annually or seasonally (chemistry; litter).

Table 33. Overview of selected monitoring programs run by Rijkswaterstaat (RWS) and Wageningen Marine research (WMR) to support the MSFD (source: compiled using data published on rws.nl and wmr.wur.nl)

Who	What		Where			When	How
RWS	Litter		Beaches		4 sites	4/year	
	Biology	Sea grass	Wadden Sea		11 sites	1/3 year	Species comp.; Extent
			SW Delta		9 sites	1/3 year	Species comp.; Extent
		Benthos					
			North Sea	sublit.	240 sites	1/3 year	Abundence; sediment
			Wadden Sea	lit.	235 sites	1/3 year	Abundence; sediment
				sublit.	45 sites	1/3 year	Abundence; sediment
			Scheldes	lit.	215 sites	1/year	Abundence; sediment
				sublit.	110 sites	1/year	Abundence; sediment
		Phytoplankton	all		*As with Chemistry*		
		Sediment characteristics			*As with Benthos*		
	Chemistry	all	North Sea		20 sites	3-19/year	Concentration
			Wadden Sea		?	4-19/year	Concentration
			SW Delta		?	4-19/year	Concentration
WMR	Benthos		Coastal zone		dense grid	1/year	Density; Biomass
	Porpoises		North Sea		4 areas	1/year	Counts
	Seals		Wadden Sea		11 areas	1/year	Counts

OSPAR

OSPAR data are available through the OSPAR Data Information Management System (ODIMS)[54]. and differ widely in scope and spatio-temporal coverage, depending on the indicator. Most current (QSR23) data submissions are on “Biological diversity and ecosystems” (n=384), followed by “Hazardous Substances and Eutrophication” (n=95) and “Environmental Impacts of Human Activity (n=87)”

WISE

Information and data on the state of Europe’s seas and related pressures and policy actions, as reported for the MSFD and other relevant legislation and initiatives, such as the related Water Framework Directive (WFD), is available through the Web-based Information Service for the Environment (WISE)-Marine digital portal[55]. WISE-Marine contains information on the various articles on the MSFD for each Member State, such as the results of the Initial Assessment (Article 8) and the determination of GES (Article 9) as well as interactive tables and visualizations to explore all aspects of the MSFD.

[54] https://odims.ospar.org/en/

[55] https://water.europa.eu/marine

EMODNet

The European Marine Observation and Data Network (EMODnet) [56] is a collaborative initiative, supported by the EU's integrated maritime policy that gathers, harmonizes, and makes marine data publicly accessible. EMODnet provides access to European marine data across seven discipline-based themes: bathymetry; biology; chemistry; geology; human activities and physics, to support marine research, policy-making, and sustainable ocean management across European waters. These data are processed according to international standards and made freely available as interoperable data layers and data products.

ICES

ICES, or the International Council for the Exploration of the Sea, is an intergovernmental organization that focuses on marine science and research. ICES plays a crucial role in advising on sustainable fisheries management and conservation of marine ecosystems in the North Atlantic Ocean and adjacent seas. Its work involves data collection, scientific analysis, and collaboration among Member countries to promote responsible and informed decision-making for the protection of marine resources. The ICES data portal holds information on core parameters related to biodiversity, the marine environment, and especially fish and fisheries, but also seafloor litter.

Earth observation

Earth observation is increasingly being used to collect high-resolution information on the state of marine ecosystems. The Copernicus Marine Service is the marine element of Copernicus, the Earth observation component of the European Union's Space programme. It provides free, regular and systematic authoritative information on the state of the Blue (physical), White (sea ice) and Green (biogeochemical) ocean, on a global and regional scale[57]. Data sets are based on in-situ or remote observations (including the EU Sentinel missions), and in many cases integrated in numerical models (e.g. the) and interpolation schemes.

Data sets provided by Copernicus Marine Services are organized as follows:

- 'Blue': Physical, e.g. sea surface temperature, salinity, pH, wave statistics,
- 'White': Sea ice, and
- 'Green': Biogeochemical, e.g. nutrient concentration, net primary productivity.

In addition, there are many research projects, often aiming at proving data sets for reporting obligations related to the MSFD. One example with a large Dutch involvement is the (JMP EUNOSAT project[58], focusing on the monitoring of Chlorophyll-a concentrations in the surface layer of the water column, in the context of the assessment of eutrophication of the North Sea. Other examples include research to map net primary production (NPP), using a combination of earth observation and in-situ measurements (Loveday et al., (2022), Turbidity (Vanhellemont, 2019) and (Large) plastic litter (Themistocleous et al., 2020)

4.3 Methodology

As evident from above overviews of especially MSFD and OSPAR there is no lack of measurements and indicators related to the status of and pressures on the marine environment. The purpose of the SEEA ecosystem condition account as presented in this report

[56] https://emodnet.ec.europa.eu/en
[57] https://www.copernicus.eu/en/copernicus-services/marine
[58] https://www.informatiehuismarien.nl/projecten/projecten-archief/algae-evaluated-from-space/

is not to add additional data, but rather reorganize existing data and indicators in such a way that it can provide an overview of the condition of the different ecosystem types and how this changes over time, and fits within the SEEA-EA framework, so that it can be related to the other accounts.

4.3.1 Crosswalks to connect classifications

As outlined above in Section 4.1, SEEA, the MSFD and, to a lesser extent OSPAR, each use their own typologies and classification schemes. Therefore, an important step is to reorganize the indicators as used by MSFD and OSPAR according to the SEEA-EA condition typology. The results are described in Section 4.4.

4.3.2 Distinction between state and pressure

Both the SEEA ECT and OSPAR make an explicit distinction between ecosystem state and the pressure factors acting on these systems. However, there appears to be a difference in interpretation of these terms. In the SEEA ECT the 'ecosystem' is the central concept. Following the CBD definition, this involves both the biotic and the abiotic components, and their interaction. 'State' variables can thus relate to abiotics as well. The main difference between 'state' and 'pressure' is that state often refers to a *stock*, and pressure to a *flow*. For example, within the SEEA-EA nutrient concentration is a *state*, not a *pressure*. Within the OSPAR framework *state* mainly refers to biodiversity and nutrient concentration is considered to be a pressure, because of its link to eutrophication.

In this study, we review the designation of OSPAR indicators as either *state* or *pressure* in order to be able to have a correct translation from the OSPAR framework to the SEEA-ECT. See Table 34 to Table 37 in Section 4.4.

4.3.3 Spatial resolution

Both MSFD and OSPAR do not necessarily report on the ecosystem type level, as required for the SEEA condition account. Usually reporting is for larger areas, such as OSPAR regions (Figure 4); the Dutch NCP, or the Natura 2000 sites, as required by legislation.

In the ideal case, locally representative values for all SEEA-ECT condition variables are assigned to each individual ecosystem asset. To what extent that is possible within useful uncertainty ranges will depend on the spatial coverage of data, which is highly variable and ranges from a few sites for the entire North Sea area to fine grids in the coastal zone.

Obviously, as a baseline approach, even a few measurement sites could be used as input into a geostatistical model that generates spatially explicit maps, that could be intersected with the ecosystem type map. But this approach would not necessarily result in locally representative estimates.

A related question is to what extent pressure factors resulting from human activities spatially "radiate" from their origin. For example, beam trawling has a significant but largely local impact on soil integrity, whereas stormy weather can have significant impacts at a much larger spatial scale. Some pressure factors such as underwater noise, which decays with distance from the source, form an intermediate class. In order to link pressures in one location with status/condition and the delivery of ecosystem services in another location these spatial processes have to be taken into account.

By analysing how different pressure factors relate to ecosystem types and/or ecosystem services of interest, it can be deduced to what extent data coverage is sufficient to develop meaningful condition estimates, or to arrive at a meaningful assessment of the capacity of the ecosystem to supply ecosystem services. We also note that this analysis would require substantial efforts.

4.4 Condition indicators crosswalk

Existing and proposed indicators from the MSFD and OSPAR were classified according to the SEEA-EA ecosystem condition typology (ECT, Table 22). Each indicator was additionally classified as either a state or a pressure indicator. Information on the reporting scale, parameters and threshold values were included as much as possible. Where available, the assessment status and reporting years from the June 2018 MSFD report were added.

Physical state characteristics (ECT class A1)

Even though there is a substantial list of indicators for the physical state characteristics of the North Sea, there are still gaps with respect to the assessment status (Table 34). Indicators that pertain to the physical loss of natural seabed and permanent alterations to hydrographical conditions have the assessment status ‘good’. However, this status is applicable to the period 2012–2018 and does not account for major changes before this time. Effects of anthropogenic pressures, including sound[59] and physical disturbances are not well-known. Indicators for beach litter and floating litter have the status ‘good’ for the Netherlands, but ‘not good’ for the OSPAR Greater North Sea region. Not enough is known about the sea bed litter to already have an assessment in place[60]. There are few to no indicators that directly reflect hydrographical conditions such as temperature, salinity, waves, currents and water transparency.

Chemical state characteristics (ECT class A2)

Chemical state characteristics that have the assessment status ‘good’ include Chlorophyll concentrations and dissolved oxygen concentrations. Nutrient concentrations (DIN and DIP) are considered good in the offshore waters but not in the coastal areas. Not enough is known on the concentrations of contaminants in biota and sediment. There is currently no indicator for acidification of the North Sea (Table 35).

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[59] Now available in SQR23: https://oap.ospar.org/en/ospar-assessments/quality-status-reports/qsr-2023/indicator-assessments/distribution-reported-impulsive-sounds-sea/ and https://oap.ospar.org/en/ospar-assessments/quality-status-reports/qsr-2023/indicator-assessments/risk-impact-anthropogenic-sound/.

[60] Now available in QSR23: https://oap.ospar.org/en/ospar-assessments/quality-status-reports/qsr-2023/indicator-assessments/seafloor-litter/

Table 34. SEEA Ecosystem condition indicators crosswalked from MSFD. ECT class A1: Abiotic physical state characteristics. Empty cells in the 'Assessment' column represent indicators for which is no assessment is published. Highlighted cells indicate indicators that are pressures rather than stats variables.

MSFD Descriptor		Framework	Indicator	State/Pressure	Reporting Scale	Parameter	Assessment	Period
D1 Biodiversity	D1C5. Size and condition of the habitat	HD	Preservation of the size and quality of habitat of: Harbour porpoise (Phocoena phocoena)	State	DCS		Favourable	2013-2018
		—	— Grey seal (Halichorus grypus)	State	DCS		Favourable	2013-2018
		—	— Harbour seal (Phoca vitulina)	State	DCS		Favourable	2013-2018
		WFD	Reduction of barriers in migratory routes (WFD IN15)	Pressure	National	Number of barriers	not assessed	
D5 Eutrophication	D5C4. The photic limit (transparency) of the water column			State			not assessed	
D6 Sea floor integrity	D6C1. Spatial extent and distribution of physical loss (permanent change) of the natural seabed	NL	Spatial extent of physical loss (natural seabed)	State	DCS	Surface area	good	2012-2017
	D6C2. Spatial extent and distribution of physical disturbance pressures on the seabed	ICES	... including any habitat type that has been damaged by changes to its biotic and abiotic structure and their functions	Pressure	ICES Greater North Sea	Pressure from fishing and impact on the seabed	unknown	2009-2015
	D6C3. Spatial extent of each habitat type which is adversely affected by physical disturbance	ICES						
		BISI	Quality of benthic habitats	State	DCS	trend	not good / unknown	2015
	D6C4. Extent of loss of the habitat type, resulting from anthropogenic pressures	NL	Spatial extent of physical loss (habitat type)	State	DCS	Surface Area	unknown	
			Conservation targets for habitat types	State	Natura 2000 areas in the	Surface area and quality (largely		
	D6C5. The extent of adverse effects from anthropogenic pressures on the condition of the habitat type	OSPAR BH2	Condition of Benthic Habitat Communities: Subtidal Habitats of the Southern North Sea	State	OSPAR Southern North Sea	Margalef Index (species rich-ness corrected for total abun-dance)	unknown	2010-2015
			—Assessment of Coastal Habitats in relation to Nutrient and/or Organic enrichment	State	Coastal habitats (data from WFD)			
			Extent of Physical Damage to Predominant and Special Habitats	Pressure	OSPAR Southern North Sea	% Area Disturbance categories 0-4 and 5-9		
D7 Hydrography	D7C1. Spatial extent and distribution of permanent alteration of hydrographical conditions D7C2. Spatial extent of each benthic habitat type adversely affected due to permanent alteration of hydrographical conditions.		*No indicators anticipated. Reliance on environmental impact assessments.*				good	2012-2018
D10 Litter	D10C1. Composition, amount and spatial distribution of litter	OSPAR	Beach litter - Volume, composition and trends	State	OSPAR Greater North Sea	Macro litter (items/m)	not good	2009-2015
			Plastic particles in the stomachs of Northern fulmars in the North Sea as a proxy for floating litter	State	OSPAR Greater North Sea	Plastic particles - Mass (g/Northern fulmar)	not good	2005-2014
			Seabed litter	State	OSPAR Greater North Sea	Macro litter (items/km2)	unknown	2013-2016
		NL	Beach litter - Volume, composition and trends	State	DCS	Macro litter (items/m)	good	2009-2015
			Plastic particles in stomachs of Northern fulmars in the North Sea as a proxy for floating litter	State	DCS	Plastic particles - Mass (g/Northern fulmar)	good	2005-2015
			Seabed litter	State	DCS	Macro litter (items/km2)	unknown	2015-2017
	D10C2. Composition, amount and spatial distribution of micro litter		*Indicator(s) in development.*					
D11 Energy and Noise	D11C1. Spatial distribution, temporal extent and levels of anthropogenic impulsive sound sources	OSPAR	Distribution of Reported Impulsive Sounds	Pressure	OSPAR Greater North Sea	Pulse block days	unknown	2015
		NL	— Supplementary Dutch assessment	Pressure	DCS	Pulse block days	unknown	2015
	D11C2. Spatial distribution, temporal extent and levels of anthropogenic continuous low-frequency sound		In development. Joint Monitoring Programme of Ambient Noise North Sea (JOMOPANS)					

Table 35. SEEA Ecosystem condition indicators crosswalked from MSFD. ECT class A2 Abiotic chemical state characteristics**.**

MSFD Descriptor		Framework	Indicator	State/Pressure	Reporting Scale	Parameter	Assessment	Period
D5 Eutrophication	D5C1. Nutrient concentrations	WFD	Nutrient concentrations in Dutch coastal waters	State	Dutch coastal waters (up to 1 n	DIN Concentration	not good	2009-2015
		OSPAR	— International North Sea, Kattegat and Skagerrak (offshore areas)	State	OSPAR Greater North Sea (offsh	DIN and DIP Concentration	good	2006-2014
		OSPAR	—(coastal areas)	State	OSPAR Greater North Sea (coast	DIN and DIP Concentration	not good	2006-2014
			Nutrient inputs to the Greater North Sea and the the Bay of Biscay and Iberian Coast	Pressure	OSPAR Greater North Sea	kt / y		
	D5C2. Chlorophyll-a concentrations	WFD	Chlorophyll a concentrations in Dutch coastal waters	State	Dutch coastal waters (up to 1 n	Concentration in water	good	2009-2015
		OSPAR	— in the Greater North Sea and Celtic Sea (offshore areas) (OSPAR)	State	OSPAR Greater North Sea (offsh	Concentration in water	good	2006-2014
		OSPAR	— (coastal areas)	State	OSPAR Greater North Sea (coast	Concentration in water	good	2006-2014
	D5C5. Concentration of dissolved oxygen	WFD	Dissolved oxygen concentrations near the seafloor	State	Dutch coastal wa-ters (up to 1 r	Concentration in water	good	2009-2015
		OSPAR	— (offshore areas)	State	OSPAR Greater North Sea (offsh	Concentration in water	good	2006-2014
		OSPAR	— (coastal areas)	State	OSPAR Greater North Sea (coast	Concentration in water	good	2006-2014
D8 Contaminants	D8C1. Concentrations of contaminants	OSPAR	Metals in biota	State	OSPAR Southern North Sea	Concentration in biota; µg/kg wet wei	unknown	1995-2015
			Metals in sediment	State	OSPAR Southern North Sea	Concentration in sediment; µg/kg	unknown	1995-2015
			Organotin in sediment	State	OSPAR Southern North Sea	Concentration in sediment; µg/kg	unknown	2000-2015
			PAHs in biota	State	OSPAR Southern North Sea	Concentration in biota; µg/kg wet wei	unknown	2000-2015
			PAHs in sediment	State	OSPAR Southern North Sea	Concentration in sediment; µg/kg	unknown	1995-2015
			PBDEs in biota	State	OSPAR Southern North Sea	Concentration in biota; µg/kg wet wei	unknown	2009-2015
			PBDEs in sediment	State	OSPAR Southern North Sea	Concentration in sediment; µg/kg	unknown	2010-2015
			PCBs in biota	State	OSPAR Southern North Sea	Concentration in biota; µg/kg wet wei	unknown	1995-2015
			PCBs in sediment	State	OSPAR Southern North Sea	Concentration in sediment; µg/kg	unknown	1995-2015
		WFD	The status of the concentrations of the WFD's priority substances and specific pollutants in water	State	For the WFD spe-cific pollutant	Concentration in water	unknown	2012-2014
		OSPAR	Inputs of Mercury, Cadmium and Lead via Water and Air to the Greater North Sea	Pressure	OSPAR Greater North Sea	Tonnes		
	D8C3. Spatial extent and duration of significant acute pollution events		Contamination with oil and other oily substances (Bonn Agreement)	Pressure	Area of Bonn Agreement	Ratio: Count/Flight hours	not good	2010-2015

Compositional state characteristics (ECT class B1)

The indicators on the compositional state of the ecosystem are largely related to population abundance and distribution (Table 36). Cetaceans and seals mostly have a positive assessment status, while marine birds and fish populations are doing less well. Indicators for incidental bycatch of marine birds, fish and cephalopods are still under development. The number of newly introduced non-indigenous species is low enough for a 'good' assessment, however there is no indicator on the abundance and spatial distribution of established non-indigenous species.

Structural state characteristics (ECT class B2)

Indicators on the structural state are mostly related to plankton and microbe communities involved in the ecosystem primary production (Table 37). While there are two indicators derived from OSPAR (D1C6 and D5C3), there is currently not enough information to have an assessment of the criteria. Trends in harmful algae (*Phaeocystis*) blooms are used by OSPAR as an indicator for eutrophication. However, it was decided in the MSFD not to use this indicator since it is not considered a good measure for eutrophication in the Dutch part of the North Sea. It is included here as an information source for the structural state of the ecosystem.

Functional state characteristics (ECT class B3

Functional state characteristics relate to processes that are important for ecosystem functioning such as the composition of trophic guilds and food web functionality (Table 37). There are no good indicators available yet on the diversity and balance of the trophic guilds. Most available indicators relate to the functioning of fish communities. Populations of commercially exploited fish and shellfish species have a 'not good' assessment, based on the mortality rate and spawning stock biomass. Not enough is known about the size structure of the fish community to have an assessment. The concentrations of contaminants in edible tissues of seafood are below the specified threshold values and are therefore considered 'good'.

Landscape and seascape characteristics (ECT class C)

There are currently no indicators that capture specific seascape characteristics, such as sea water level, large-scale currents and aspects related to connectivity.

Table 36. SEEA Ecosystem condition indicators crosswalked from MSFD. ECT class B1 Biotic compositional state characteristics**.**

MSFD Descriptor		Framework	Indicator	State/Pressure	Reporting Scale	Parameter	Assessment	Period	Source
D1 Biodiversity	D1C1. Mortality rate per species from incidental bycatch		Harbour porpoises	Pressure	OSPAR North Sea	Mortality rate of harbour porpoises as	good	2013	MSFD 2018
			— Marine birds	Pressure			*in developmen t*		
			— Fish and cephalopods	Pressure			*in developmen t*		
	D1C2. Population abundance	OSPAR	Seal Abundance and Distribution	State	OSPAR Greater North Sea	Abundance	good	1992/2009-2014	MSFD 2018
			Abundance and Distribution of Cetaceans	State	OSPAR Greater North Sea	Population trend	good	1994-2016	MSFD 2018
			Restoration of populations of vulnerable fish species	State	OSPAR Greater North Sea	Species – individuals	not good	2010-2016	MSFD 2018
			Marine bird abundance	State	Southern North Sea	Wading feeders; Surface feeders; Wate	not good	1992-2014	MSFD 2018
			Abundance and distribution of killer whales (pilot assessment, OSPAR)	State					
		HD	**Favourable Reference Population (FRP): Harbour porpoise (Phocoena phocoena)**				good	2013-2018	HD Art 17
			— Grey seal (Halichorus grypus)				good	2013-2018	HD Art 17
			— Harbour seal (Phoca vitulina)				good	2013-2018	HD Art 17
			Favourable reference value for population abundance (FRP) - migratory fish: River lamprey (Lampetra fluviatilis)	State	National	Population abundance	not good	2013-2018	HD Art 17
			— Allis shad (Alosa alosa)				unknown	2013-2018	HD Art 17
			— Twait shad (Alosa fallax)				not good	2013-2018	HD Art 17
		BD	BD: numbers, trends, distribution, share in BD areas	State	National	Marine bird species			
		other	Populations of all commercially-ex-ploited fish and shellfish species. (See D3C1 and D3C2)						
			no indicator yet: population abundance of sharks and rays						
	D1C3. Population demographic characteristics	OSPAR	Breeding success or breeding failure among marine birds	State	OSPAR Greater North Sea	Dutch species: Cor-morant, Herring gu	not good	2010-2015	MSFD 2018
			Grey seal: pup production	State	Wadden Sea	Percentage development of the numb	good	1992/2009-2014	MSFD 2018
			Large Fish Indicator (LFI)	State	OSPAR Greater North Sea	Large Fish Indicator (LFI)	not good	1983-2016	MSFD 2018
		?	Harbour seal: pup production	State	Wadden Sea and Southwestern	Percentage development of the number of harbour seals born.			
	D1C4. Species distributional range	HD	**Favourable reference value for population range (FRR) - seals and harbour porpoise**	State	National	Population range	**HD: Good; MSFD: not good**		
			— Harbour seal (Phoca vitulina)				**good**	2013-2018	HD Art 17
			— Grey seal (Halichorus grypus)				**good**	2013-2018	HD Art 17
			— Harbour Porpoise (Phocoena phocoena)				**good**	2013-2018	HD Art 17
			— migratory fish	State	National	Population range			
D2 Non-indigenous species (NIS)	D2C1. Number of newly introduced non-indigenous species	OSPAR; NL	Introductions of non-indigenous species	Pressure	The Dutch section of the North	Presence	good	2012-2017	MSFD 2018
	D2C2. Abundance and spatial distribution of established non-indigenous species								
D5 Eutrophication	D5C8. Species composition and relative abundance of macrofaunal communities								
D8 Contaminants	D8C2. Health of species and the condition of habitats adversely affected due to contaminants.		Imposex (OSPAR)	State	OSPAR Southern North Sea	Vas deferens index	unknown	2010-2015	MSFD 2018
D10 Litter	D10C3. Amount of litter and micro litter ingested by marine animals D10C4. Number of individuals of each species which are adversely affected due to litter								

Table 37. SEEA Ecosystem condition indicators crosswalked from MSFD. ECT classes B2 Biotic structural state characteristic and B3 Biotic functional state characteristics

MSFD Descriptor		Framework	Indicator	State/Pressure	Reporting Scale	Parameter	Assessment	Period
B2 Biotic structural state								
D1 Biodiversity	D1C6. Condition of the habitat type	OSPAR	Pelagic habitats biomass and abundance	State	OSPAR Greater North Sea	Biomass of phyto-plankton and abu	unknown	1958-2012
			Changes in phytoplankton and zooplankton communities	State	OSPAR Greater North Sea	Holoplankton ver-sus meroplankton	unknown	2004-2014
D2 Non-indigenous species (NIS	D2C3. Proportion of the species group or spatial extent of the broad habitat type which is adversely altered due to non-indigenous species							
D5 Eutrophication	D5C3. The number, spatial extent and duration of harmful algal bloom events	OSPAR	Trends in blooms of the nuisiance Phytoplankton species Phaeocystis in Belgian, Dutch and German Waters	State	Belgium, Netherlands, Germa	maximum Phaocystis concentration	not used	
	D5C6. Abundance of opportunistic microalgae							
	D5C7. Species composition and relative abundance or depth distribution of macrophyte communities							
D8 Contaminants	D8C4. Effects of significant acute pollution events on the health of species and on the condition of habitats							
B2 Biotic functional state								
D3 Commercial Fish Stocks	D3C1. Fishing mortality rate of commercially exploited species D3C2. Spawning stock biomass of commercially exploited species		Populations of all commercially exploited fish and shellfish species	State	MSFD Greater North Sea	Number of commercially exploited s	not good (one out, all out)	2014
	D3C3. Age and size distribution of commercially exploited species		Size structure in fish communities (OSPAR)	State	OSPAR Greater North Sea	Typical Length (TyL)	Under development; not implemented	
D4 Food webs	D4C1. The diversity of the trophic guild		*no indicators yet*					
	D4C2. The balance of the total abundance between the trophic guilds		*no indicators yet*					
	D4C3. The size distribution of individuals in the trophic guild		Size structure (length) of the fish community	State	OSPAR (South East) Greater I	Typical Length (TyL)	unknown	1983-2016
	D4C4. The productivity of the trophic guild	OSPAR	Changes in phytoplankton biomass and zooplankton abundance	State	OSPAR Greater North Sea	annual anomalies	unknown	2004-2014
D9 Contaminants (seafood)	D9C1. Level of contaminants in edible tissues of seafood.		Contaminants in edible tissue	State	Greater North Sea	Concentration of contaminants in fi	good	2016

4.5 Selected condition variables: pH, Temperature and Salinity

4.5.1 Introduction

As shown in Section 4.4, the MSFD reports provide a wealth of information that can be used to fill the condition accounts. However, there is a number of indicators suggested by SEEA-EA for which the MSFD reports do not provide information. This Section will provide information on those additional indicators. These include acidification (decrease in pH), temperature and salinity (Table 23). Eutrophication and plastics density are also important ocean condition variables, but these are already measured in some way within the Marine Strategy Framework Directive. Acidification can negatively impact certain biota and pH is therefore an important factor for the type of biota that can survive in a marine ecosystem. A decrease in pH can have multiple causes, one of which is the increase of atmospheric carbon dioxide that is currently taking place globally. The temperature of the oceans is also influenced by atmospheric warming and can impact the living conditions of biota. Additionally, ocean temperature and salinity are important drivers for ocean circulation.

Data Sources

To investigate the acidification, temperature and salinity of the North Sea, data has been used from the Netherlands Marine Information and Data Centre (IHM), ICES and EMODnet, i.e. the North Sea - Eutrophication and Acidity aggregated datasets (Aarhus University, 2021). See Section 4.2 for more information on these data platforms.

Methodology

For each parameter, an initial data search was carried out to analyse the number of measurements, as well as spatial and temporal resolution. The EMODnet dataset has high spatial coverage, but measurements were not collected consistently over time. This dataset is therefore unsuitable to investigate long-term trends. Data from IHM and ICES contains measurements from long-term monitoring programs and were used for further analysis. For this purpose, the data from IHM and ICES were merged into one dataset and duplicate measurements were filtered out. See Figure 12 for an indication of the spatial and temporal resolution of the three datasets with respect to pH.

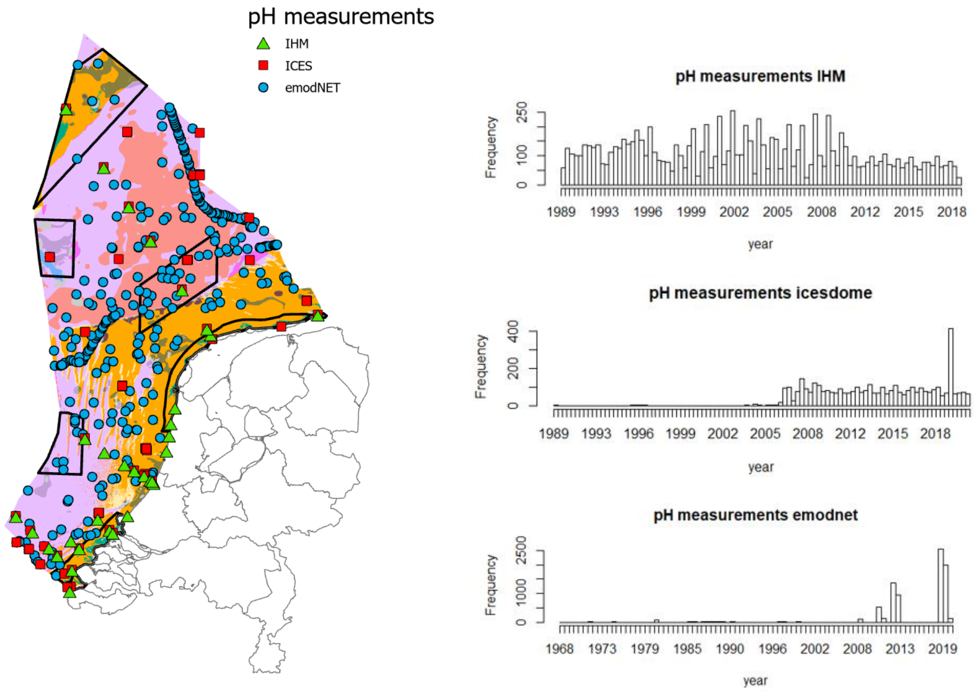


Figure 12. Illustration of data coverage in time and space for pH.

4.5.2 Acidification

Figure 13 shows the location for each measurement station that has data for at least five consecutive years. The longest time series span about thirty years and are part of the monitoring programme of Rijkswaterstaat. An example of such a time series is given for the measurement station 50 km from the coast of Terschelling (TERSLG50). Local polynomial regression (loess) was used to show a trend line (Figure 14). In general, the pH measurements fluctuate between roughly 7.5 and 8.5. Looking at the evolution of pH between 1990 and 2020, there appears to be a decrease at first (1990-2010), followed by an increase (2011-2020). Trend analysis with a Kalman filter (Visser, 2004) showed that there were indeed significant changes during this time for some of the locations. During the period 2001-2010 there was a significant decrease of pH at 14 of the 33 measurement locations. During the period 2011-2020 there was a significant increase of pH at four measurement locations (See also Appendix A1).

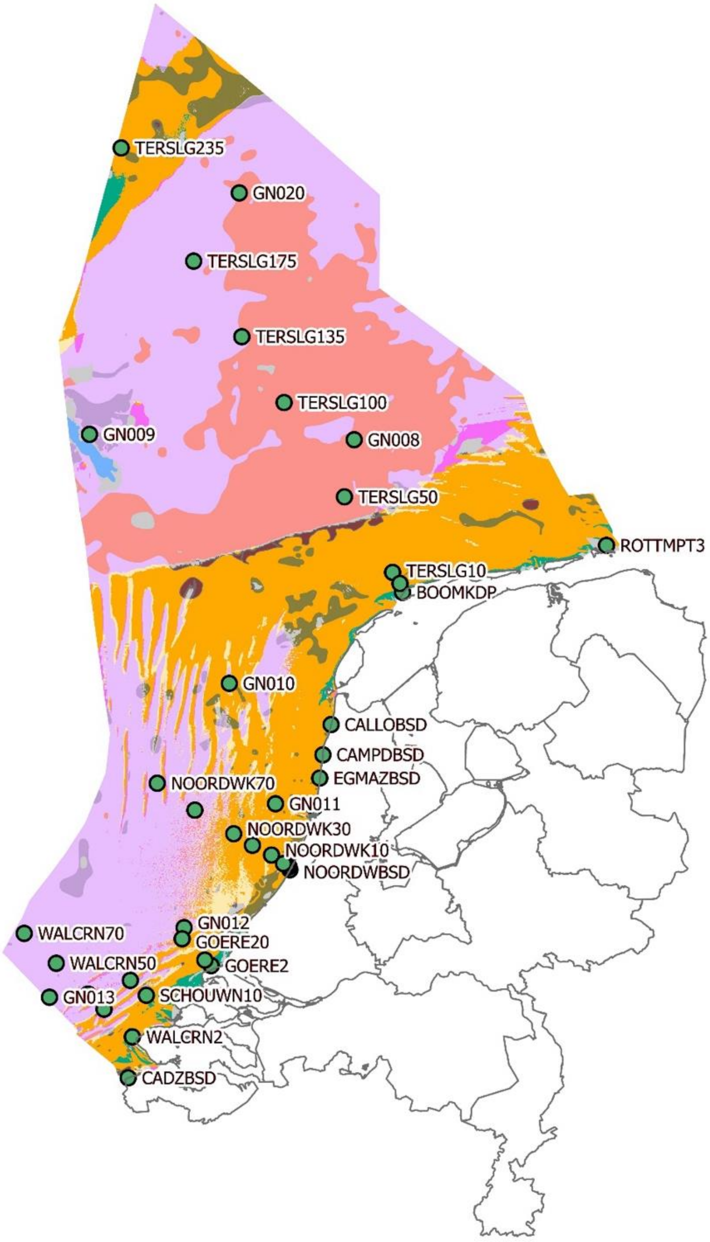


Figure 13. Locations of sites that have at least five consecutive years of pH measurements.

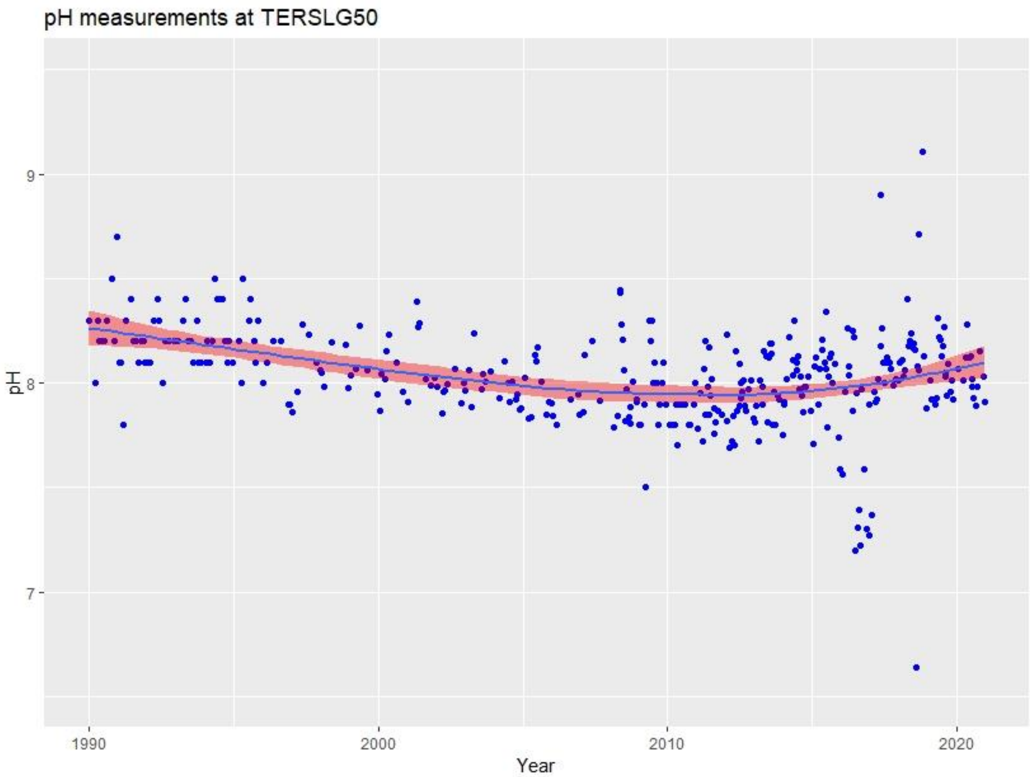


Figure 14. pH measurements at site TERSLG50.

spatial variability

To investigate the spatial variability of pH in the North Sea we looked at the transect of measurement stations from the coast of Terschelling. There are measurement stations situated at 10km, 50km, 100km, 135km, 175km and 235km from the coast that have long time series of pH measurements. Most of these measurements were taken at a depth of 1m from the water surface, and only this depth was selected to ensure comparability. Because there is a natural fluctuation in pH between summer and winter we looked at the average pH in summer and winter months separately. In summer, the pH seems to be higher closer to the coast then further seaward. In winter, there doesn't appear to be much difference. Overall, pH is higher in summer than in winter (Figure 15).

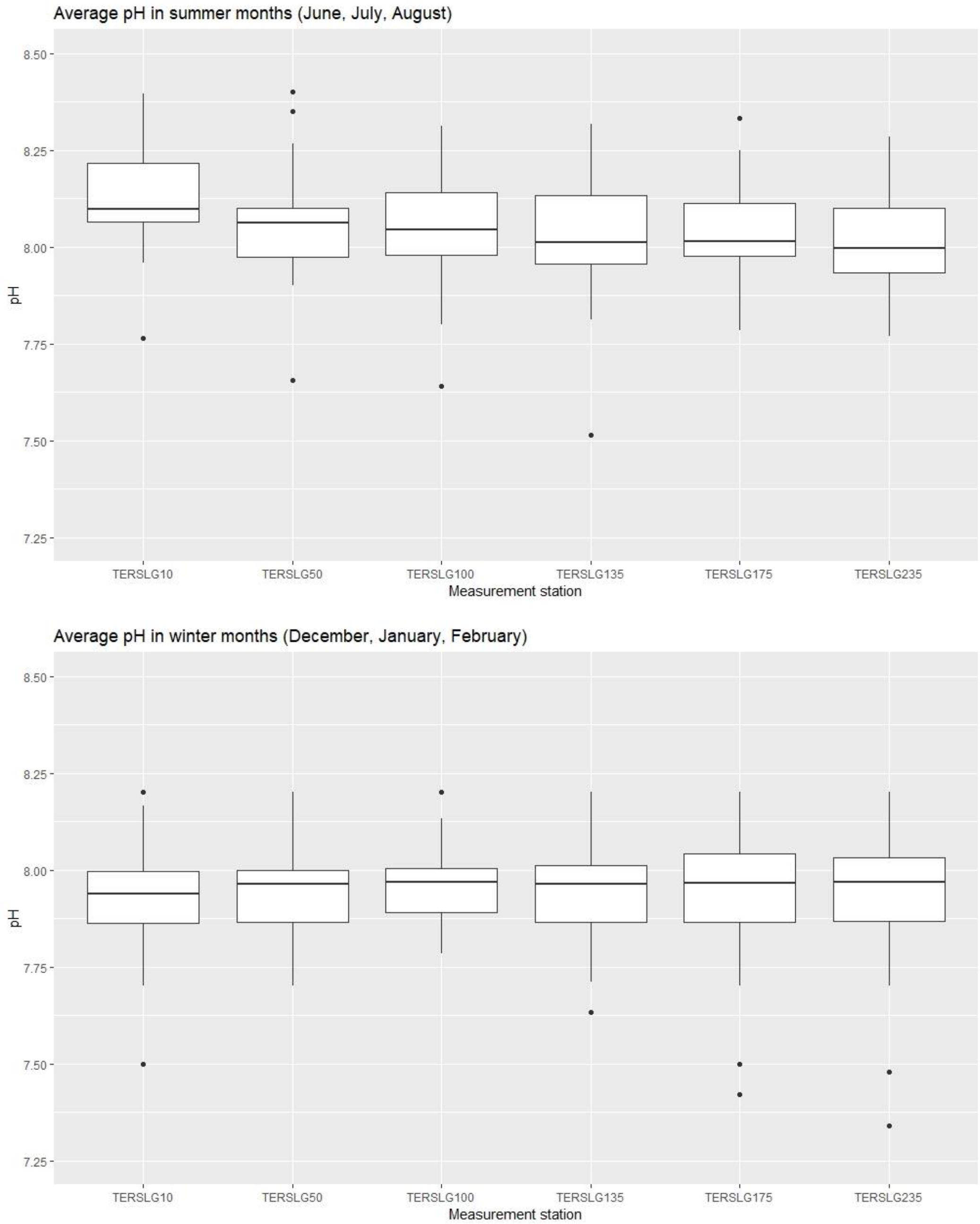


Figure 15. Offshore gradient in sea water pH, for a transect off the coast near Terschelling, for summer (top) and winter (bottom).

Depth variability

At some of the measurement locations pH was measured at different depths, which gives an insight into the influence of stratification. In summer months, the top layer of water becomes warmer and less dense, and can form a stable layer above deeper waters. This can limit the mixing between these different layers and lead to stratification effects. At measurement station 'GN008' the pH was measured down to 37m depth in August 2019, with a sample taken at each 1m interval. Figure 16 shows that pH decreases with depth, although the effect is much smaller than the overall temporal and seasonal variability. There is a sharp drop between 10m and 18m depth, which can be indicative of the different layers of stratification at this location.

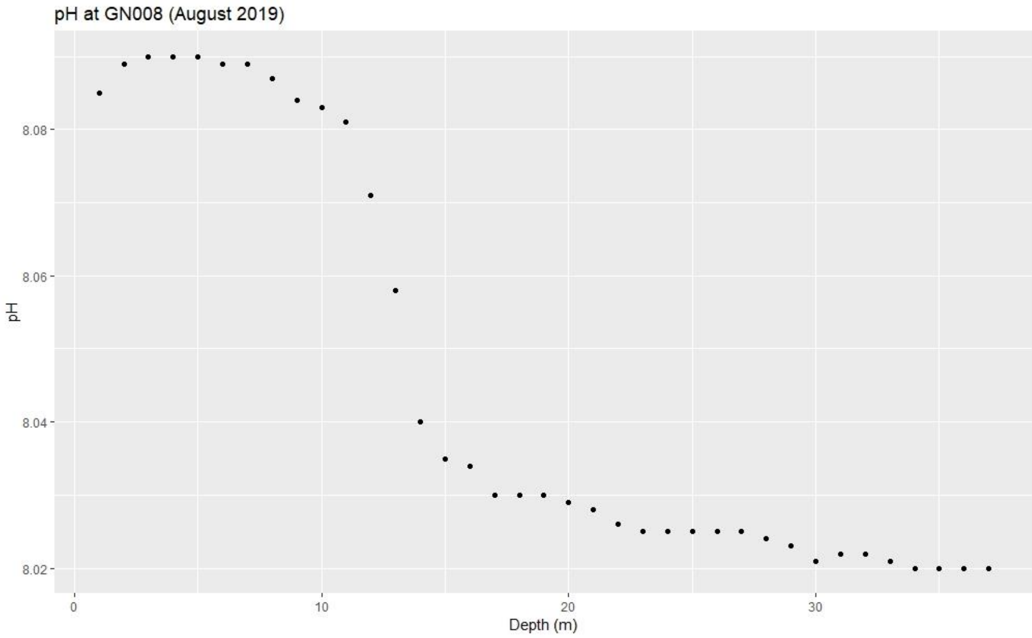


Figure 16. pH as a function of depth, for measurement station GN008.

Looking at the depth profiles of pH at other locations, we can see that this decline in pH with depth is not always present (see Figure 72 in Appendix A1). For example, no such effect is observed at locations GN010, GN012 and GN013, which seem to have a stable pH throughout the water column. At other locations, a decline in pH is visible, but the depth at which a strong decrease takes place differs depending on the location.

Discussion

Long-term temporal trends in the pH of the North Sea have been the focus of research due to concerns about ocean acidification resulting from increasing CO2 concentrations in the atmosphere. Indeed, we have seen a decreasing trend in pH from 1990 to 2010. However, after this period the pH seems to be increasing again, suggesting other biogeochemical processes are involved. Provoost et al. (2010) already established that pH changes greatly exceed those expected from enhanced CO2 uptake, when they looked at pH trends from 1975-2006. The observed seasonal variability is congruent with earlier results and reflects the interaction of pH with primary production.

The OSPAR 2023 Quality Status Report has a first in-depth assessment of ocean acidification within the OSPAR maritime area. They report that acidification takes place in all OSPAR regions, but the rate and dynamics differ per region. On the continental shelf the acidification rate is highest, though this is also the region with the most variability, making interpretation difficult. There is also a need to sustain long-term observations and further expand the observation network (McGovern et al., 2023).

Since 2018 there is an improved monitoring program in place by the Ministry of Infrastructure and Water Management in collaboration with NIOZ to measure acidification in the North Sea. This monitoring program focusses on the parameters dissolved inorganic carbon (DIC), total alkalinity (TA) and pH (Humphreys et al. 2021). Since 2018, seasonal pH variability can be accurately reproduced using the quantitative contribution of seasonal DIC, temperature, TA and other pH sensitivity factors (Hilgen, 2022). However, the observed long-term changes in pH are larger than those predicted from TA and DIC. It seems the Dutch coastal zone has experienced major changes in their biogeochemical functioning that cannot be fully explained yet.

4.5.3 Temperature

The temperature of the North Sea is highly variable throughout the year, with temperatures between 5-10 degrees in winter and between 15-20 degrees in summer. There is also a high variability between years due to natural climate variability and atmospheric and oceanic circulation patterns. Because of this high variability it is necessary to have a very consistent series of measurements in order to say something about a general trend.

Figure 17 shows an example of the temperature measurements taken at one location (TERSLG50). The seasonal trend is very apparent, but there is no clear distinction between separate years or even between decades. It is not possible to aggregate to a reliable mean annual temperature because of insufficient data coverage. This is because temperature measurements were not always taken consistently over time, with some months having multiple measurements and some months lacking data points all together. Note however, that the long-term warming of the North Sea since approx. 1980–1990 is undisputed (Figure 18)

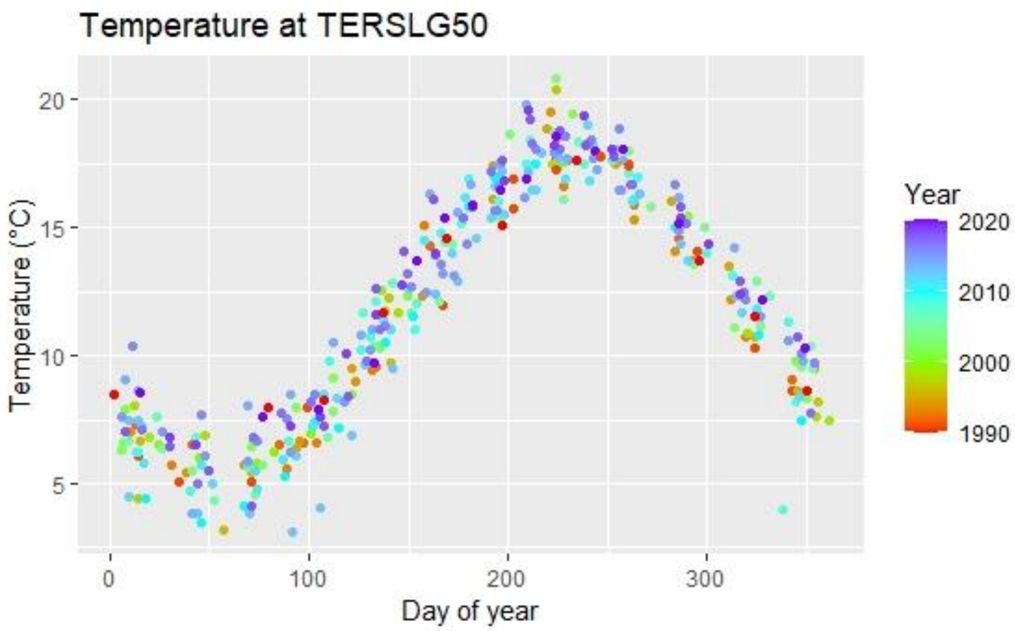


Figure 17. Annual temperature cycle for measurement station TERSLG50.

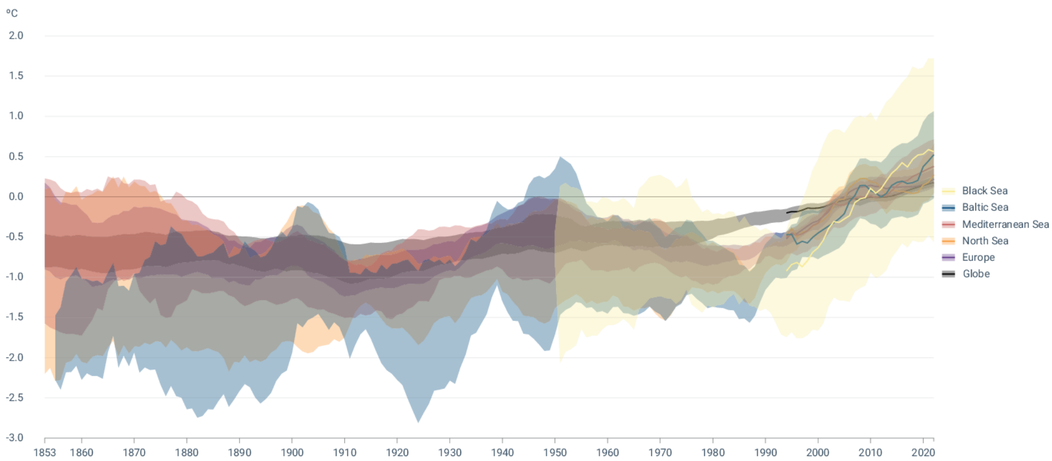


Figure 18. Decadal average sea surface temperature anomaly in different European seas. Source: EEA.

Spatial variability

Looking at the transect of measurement stations from the coast of Terschelling, there is good coverage for the year 2009 (see Figure 19). In summer, sea water temperature closer to the coast is warmer than further away from the coast. Adversely in winter, the seawater closest to the coast is a few degrees colder. It is likely that shallow waters have a lower buffer capacity and are therefore more variable in temperature.

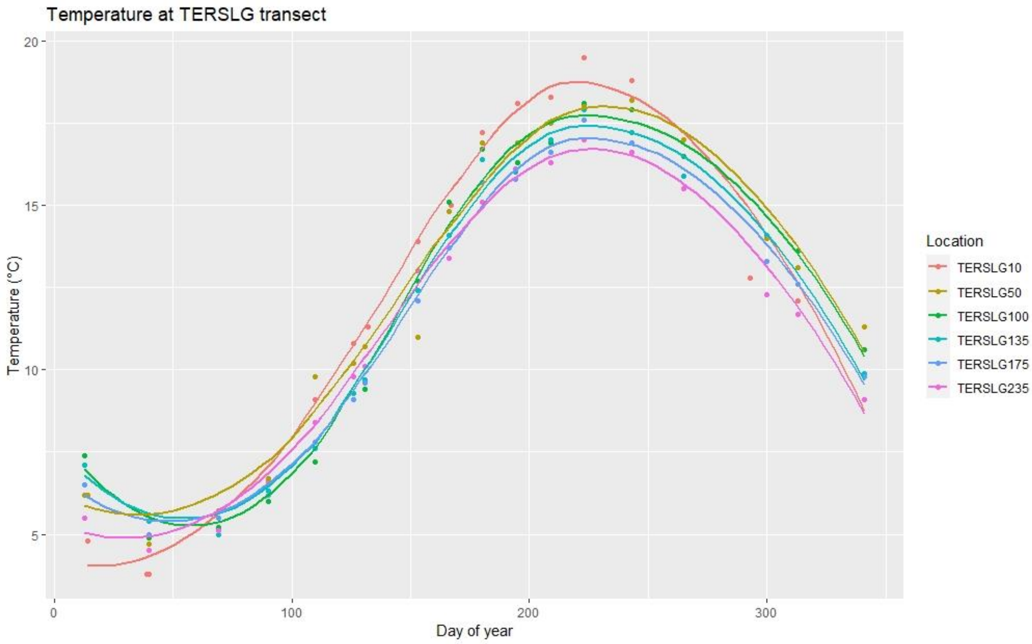


Figure 19. Temperature variability along am offshore transect near Terschelling.

Depth variability

As is the case with pH, temperature is also related to depth and can be subject to stratification effects. Figure 20 shows the temperature at different depths measured on the same location (GN008) and day in August 2019. There is a decline in temperature of roughly 3.5 degrees between 7m and 15m depth.

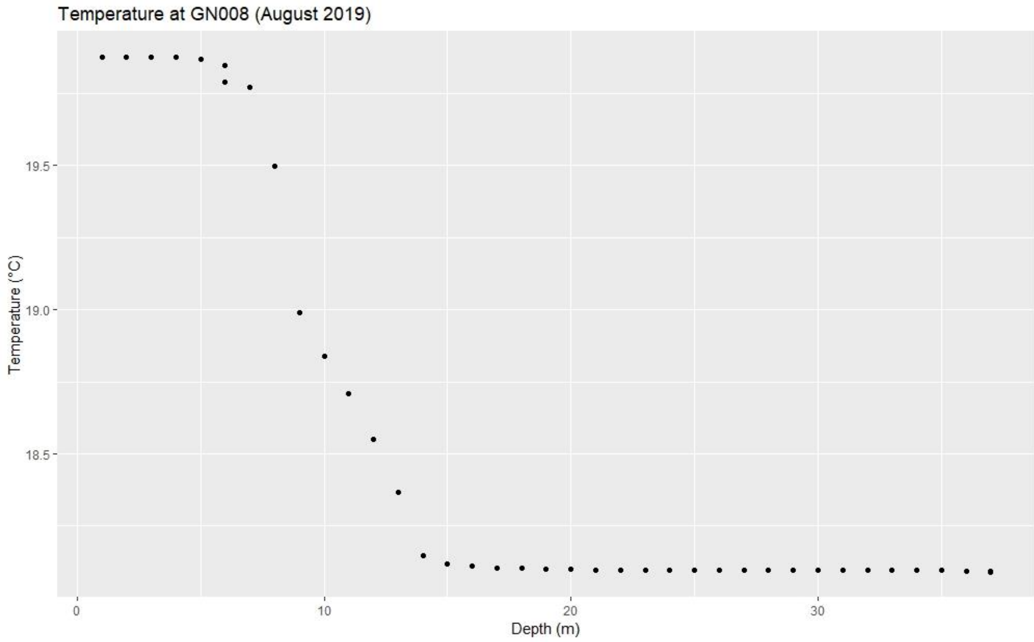


Figure 20. Temperature variability with depth, for measurement station GN008

The depth profiles for temperature at other locations look to be consistent with those for pH, with no decline in temperature at locations GN010,GN012 and GN013 (Appendix A2). It is likely that at those locations, the seabed is simply not deep enough and the water is mixed sufficiently. The most pronounced stratification can be seen at location GN020, which is the furthest away from the coast and has a seabed depth of over 40 meters. At this location, the sea water temperature drops more than 5 degrees between 27m and 30m depth.

4.5.4 Salinity

Salinity of the North Sea depends on various factors. Freshwater inputs from rivers can decrease salinity, while evaporation and mixing of water masses can increase salinity. Salinity does not have a very strong seasonal component such as temperature. Figure 21 shows the salinity time series for one location. The average salinity lies around 34.5 Practical Salinity Units (PSU), and it fluctuates mostly between 33 and 35 PSU. No clear overall trend is visible when looking at all measurement stations (Annex VII).

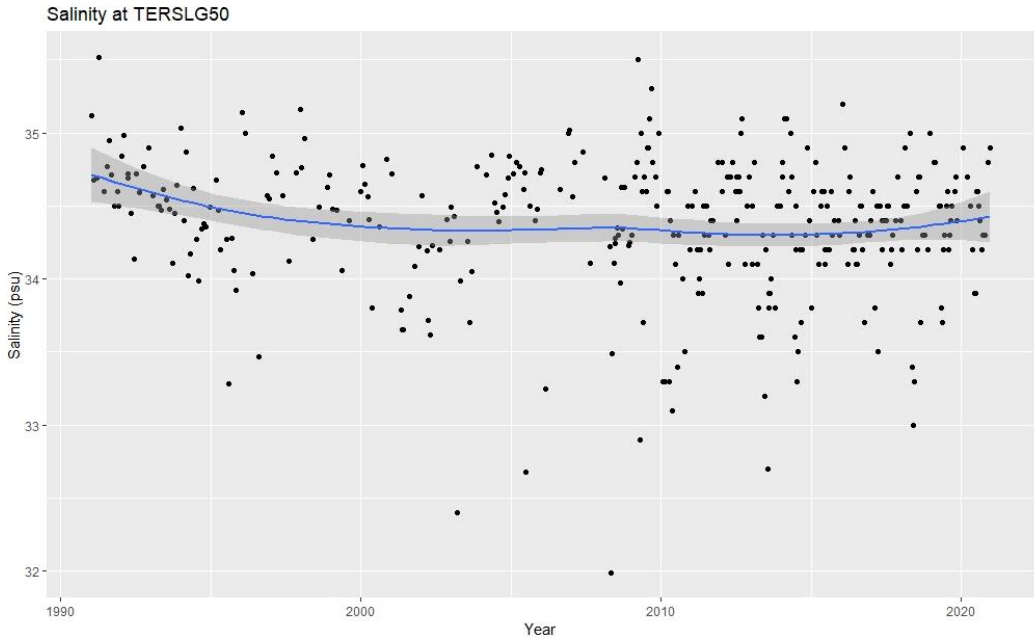


Figure 21. Trend in salinity, for measurement station TERSLGN50.

Spatial variability

Salinity appears to be quite stable (around 35 ppt) for measurement locations located far away from the coast. Closer to the coast the mean salinity is lower and it fluctuates more (between 30 and 35 ppt), likely because of the influx of fresh water from rivers (Figure 22).

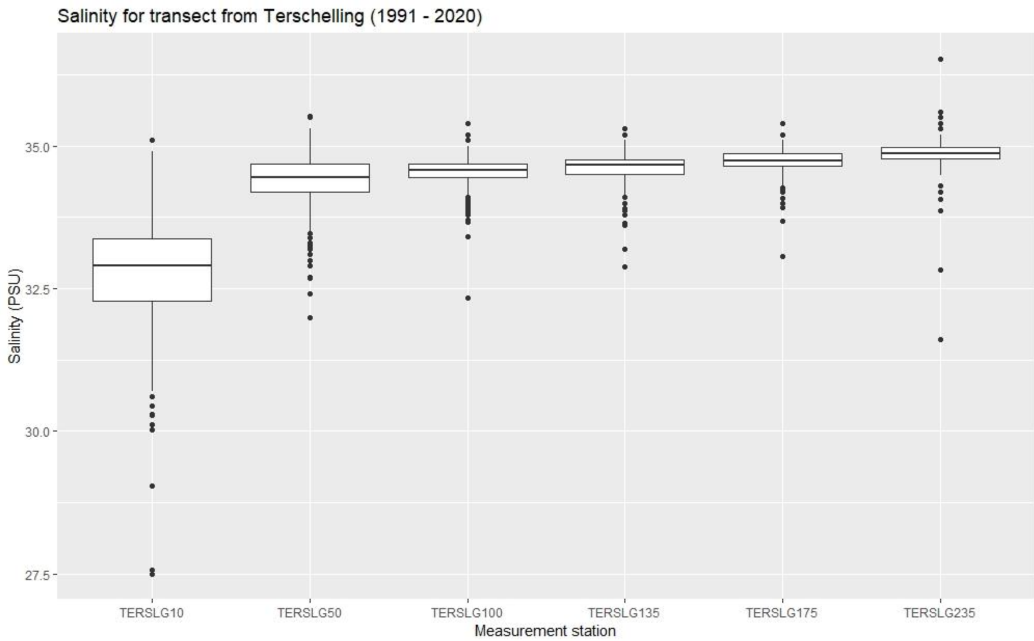


Figure 22. Salinity variability along an offshore gradient near Terschelling

Depth variability

Salinity doesn't show high variability at different depths in most cases (Annex VI). In Figure 23 it can be seen that the fluctuation at GN008 with increasing depth is only about 0.02 PSU. Salinity at this location is slightly higher at lower depths. Looking at other locations we can see a more pronounced increase in salinity with depth at location GN011. This location lies closer to the coast and is more shallow, and therefore likely to be more influenced by freshwater input. Adversely, at location GN020, we can see a slight decrease of salinity with depth.

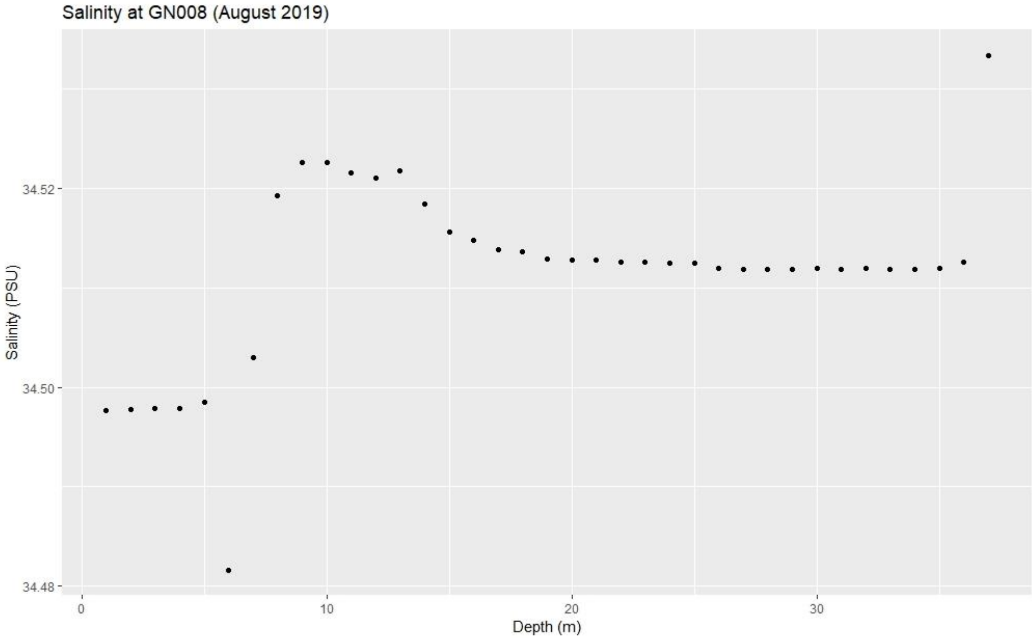


Figure 23. Salinity variability with depth, for measurement station GN009.

4.6 Selected instrumental values

4.6.1 Introduction

Instrumental values are the values attributed to something as a means to achieve a particular end. With regard to ecosystem condition variables, instrumental values describe how the quality of ecosystems relates to the capacity to provide certain ecosystem services. Here we will not provide an complete overview of relevant instrumental condition variables for all ecosystem services, but provide two examples; fish stocks and marine aggregates.

4.6.2 Fish stocks

There are several condition variables that directly link to fish provisioning services, but the most direct obviously are the marine fish stocks. The stocks for various species are shown in Figure 24, below.

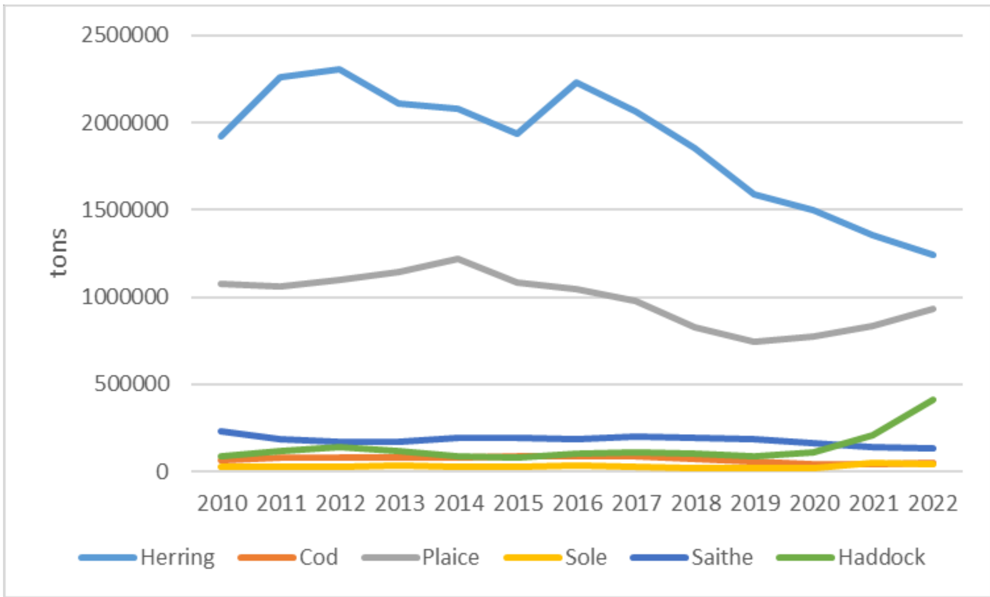


Figure 24. Fish stocks of various species, 2010-2022 (data source: ICES)

4.6.3 Marine aggregates

To determine the provision of the ecosystem service 'sand extraction' from the DCS, several condition factors need to be considered, with the most important being the supply of potentially extractable sand. The Dutch government has reserved an area for sand extraction between the 12-mile limit and the continuous NAP -20m isobath. In this area of 5,134 km2, sand extraction is a priority. In order to steer sand extraction in the right direction, a sand extraction strategy has been drawn up that is based on a balanced consideration of all relevant interests. Figure 25 shows locations of nearby wind farms, shipping routes and pipelines/cables. It provides some insights into the trade-offs between the different uses of space in the North Sea area (Noordzeeloket, 2023).

To determine the actual sand supply, Deltares and TNO have developed a mineral information system (DIS) for the Department of Sea and Delta of Rijkswaterstaat, that provide extractable sand quantities at different water depths (up to 12 m) with varying sand quality requirements. Multiple scenarios have been developed to identify litho- and silt classes that are considered as disturbance layers (non-extractable layer), with four scenarios created to specify the composition of the disturbance layer. The most realistic extractability criteria belong to scenario "B2" and is shown in Figure 26. It was concluded that that there is enough sea sand available for the sand demand at national level, both in the short and in the long term (Deltares, 2018).

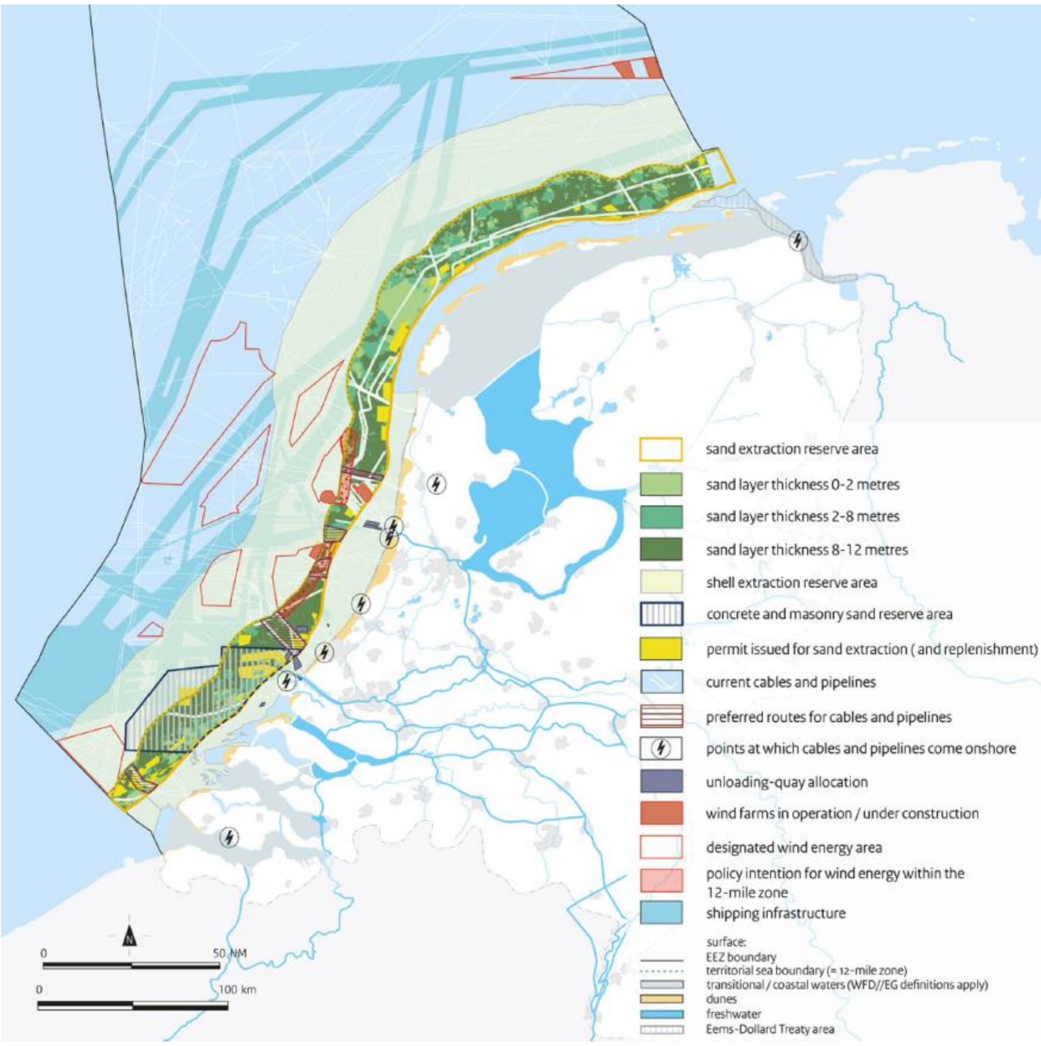


Figure 25. Dutch sand extraction strategy (Noordzeeloket, 2023)

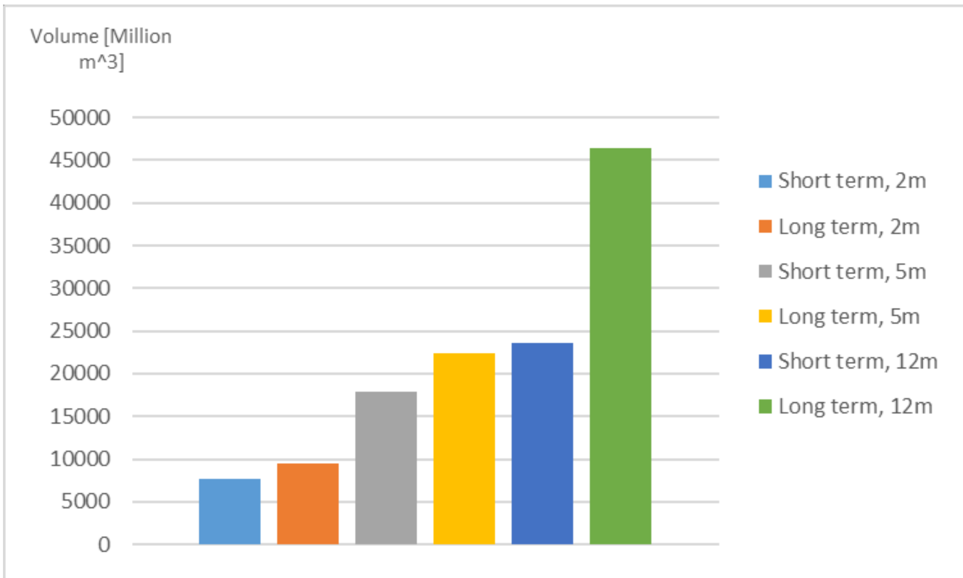
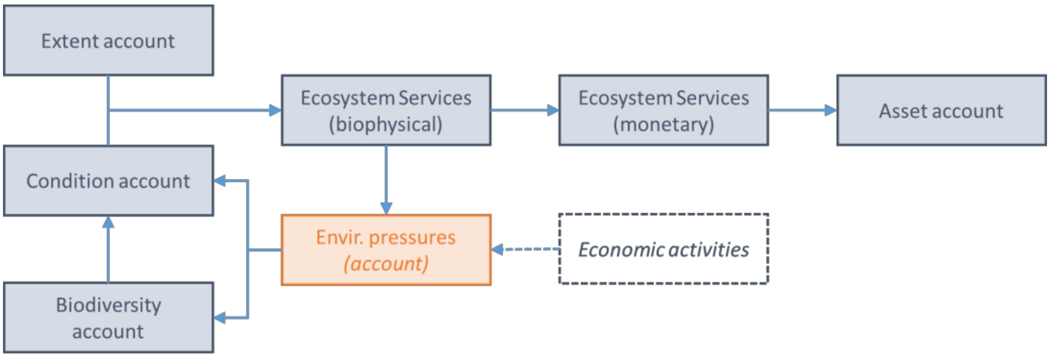


Figure 26. Sand supply of the DSC short and long term, specific depth levels (Deltares, 2018)

5. Environmental pressures



5.1 Introduction

According to SEEA -EA, an environmental pressure is "*a human induced process that alters the condition of ecosystems*"[61]. Thus, although environmental pressures can have a strong impact on ecosystem condition, but they are not the same. In the SEEA ecosystem condition typology (ECT) framework there is a strong distinction between *state* variables, that mainly refer to stock variables, and *pressures*, that mainly refer to flows, or states external to the system under consideration. For example, pollutant influx would be a "pressure", whereas pollutant concentrations are a "state".

The MSFD and OSPAR frameworks use a slightly different approach. For example, in the "Biodiversity and ecosystems" work area of OSPAR "status" indicators are related to biodiversity only, and anything related to pressures due to human activities is referred to as a "pressure", even when it concerns abiotic stocks, such as pollutant concentration which is considered to be a pressure within OSPAR. Chapter 3.7.6 lists ecosystem condition indicators that are being used within the MSFD and OSPAR frameworks. Many of these are related to environmental pressures.

A common theme in reporting on environmental pressures is the link with economic activities that drive these pressures. These linkages are often described through the lens of the influential conceptual framework DAPSIR, which is an abbreviation for Driver–Activity–Pressure–State–Impact–Response. This DAPSIR framework (presented in Figure 27), describes a causal chain starting with the *drivers* of basic human needs, which require human *activities* to achieve these needs, which lead to *pressures*, which are the mechanisms of change in the *state* of the natural system which then leads to *impacts* on human welfare (including ecosystem services, goods and benefits). These state changes and associated impacts require human *responses* (e.g. as measures). These responses are usually targeted at activities and their pressures, but can also focus on the drivers, the system state directly, or the impact. These policy feedbacks then close the loop between human activities and ecosystem dynamics (Atkins et al, 2011; Elliott et al, 2017; Judd and Lonsdale, 2021).

[61] SEEA EA, ¶ 5.105

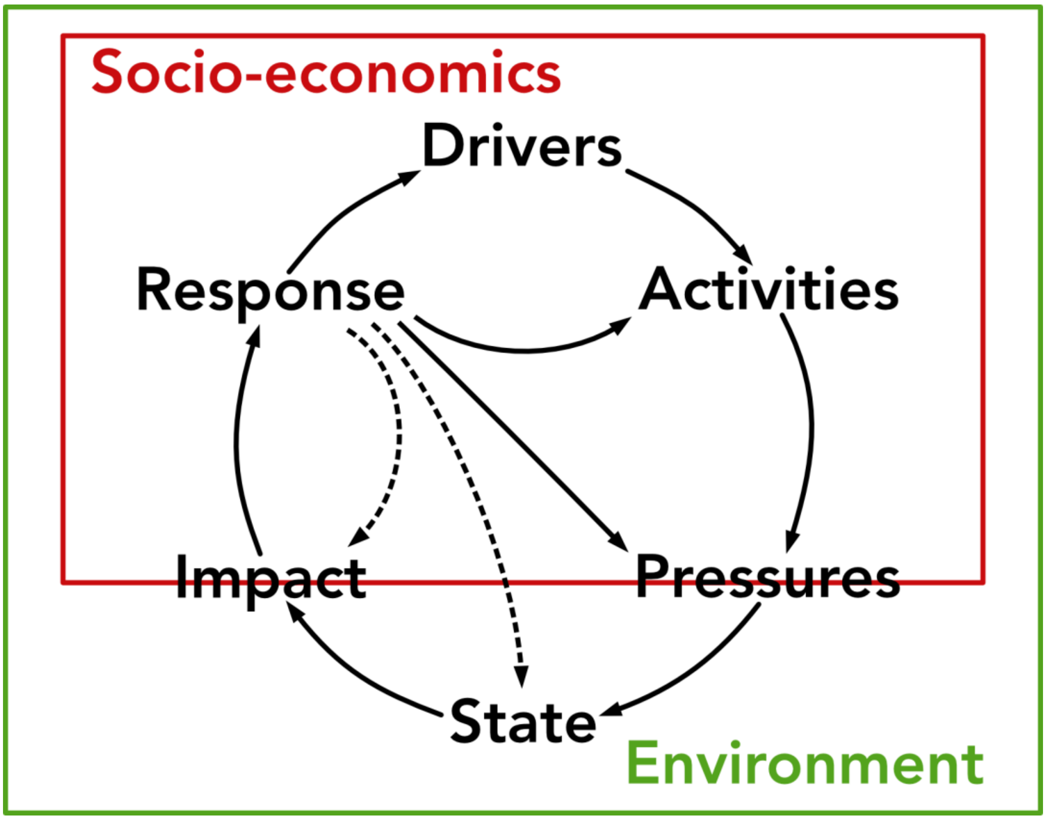


Figure 27. Visualization of the conceptual structure of the DAPSIR framework.

Environmental pressure accounts

There is a strong interest in linking environmental pressures with economic or societal drivers, for example through the DAPSIR lens. Although many of these linkages are included in the SEEA Central Framework, environmental accounts, e.g. air and water emissions, the established SEEA EA does not yet include a "pressure account" where pressures are explicitly linked to economic units (including government and households). Currently, SEEA, in collaboration with GOAP, is developing a separate framework, SEEA-Ocean, that extents the SEEA-EA with several components, including pressure accounts. The current report aims at compiling such an (experimental) environmental pressure account, using data from relevant environmental accounts and statistics (e.g. emissions to water and air), both from the Netherlands and from other countries around the North Sea, using data from various sources, including those from Statistics Netherlands.

As an add-on to the SEEA accounting structure, information on environmental pressures can be organized in tables using the same accounting structure as ecosystem services, but reversed, in so-called 'pressure accounts'. Where ecosystem services are supplied by ecosystem assets, and used by economic sectors, environmental pressures are caused ("supplied") by economic activities and affect ("used by") ecosystem assets. Table 38 presents a (hypothetical and abstract) example of such an account, where, following standard accounting principles, total pressures emissions originating by from economic activities (supply, organized by sectors) and imported from abroad, are equal to the total pressure on ecosystem types. We note, though, that a full quantification of the pressure accounts will not yet be possible in most cases.

Table 38. Example pressure account. Environmental pressured are "supplied" by economic sectors (or imported) and "used" by ecosystem types (or exported)

		Economic Sectors					Ecosystem Types				
		S1	S2	S3	import	total	ET 1	ET 2	ET 3	export	total
Pressure factors	PF 1	20	10	5	10	45	15	5	10	15	45
	PF 2										
	PF 3										

Where applicable, the economic sectors as distinguished by NACE (international) or SBI (Statistics Netherlands) will be used.

Contents of the chapter

In the remainder of this chapter, we will look at information on pressures from both the EU MSFD and OSPAR (which both were also extensively covered by the previous chapter on Condition, followed by a qualitative analysis of the pressures as reported under the EU Bird- and Habitat directives. The last section deals with a more in-depth analysis of several specific pressure factors associated with wind energy, fishing, eutrophication and pollution.

In the remainder of this chapter, we will look at information on pressures as presented in the monitoring reports for both the EU MSFD and OSPAR (which both were also extensively covered by the previous chapter on Condition), followed by a qualitative analysis of the pressures as reported under the EU Bird- and Habitat directives. The last section deals with a more in-depth analysis of several specific pressure factors associated with offshore wind energy, fishing, eutrophication and pollution, as examples of how these pressure accounts can be used to provide policy relevant information. These specific pressure factors were chosen because of their policy relevance (fishing and energy) and the link with 'traditional' environmental accounts (water emissions)

5.2 Previous work: the Nature lookout 2011 & 2020

In addition to the reporting within MSFD, OSPAR and Natura 2000, the Netherlands "Nature lookout" (Natuurverkenningen) studies by the PBL Netherlands Environmental Assessment Agency are of special interest for national policy development, especially on biodiversity.

Nature lookout 2011

In their background study to support the Nature Lookout 2011, van Hal et al (2011) distinguish between *autonomous* and *manageable* pressures related to human activities.

- Autonomous developments and pressures include *population dynamics*; *bioengineers* (reef builders); *invasive species*; and *climate change* (i.e., warming; acidification; regime shifts).
- Manageable activities that put pressures on the ecosystems within the Dutch North Sea include: *Fishery* (beam trawling; shrimping); *Aquaculture*; *Oil and Gas exploration and exploitation*; *Shipping* (including spillage of oil, ballast water, waste); *construction* (e.g. wind parks); *dredging*; *emissions* (urban; industrial; agricultural); *atmospheric deposition* (e.g. nitrogen from agriculture, traffic); *mineral extraction* (sand & gravel); *coastal recreation* and *military training*.

However, this distinction only hold to a certain limit. Both invasive species and climate change, are strongly related to human activities, and are therefore in principle manageable, although not directly, and only to a certain extent. The same holds for atmospheric deposition, which is although eventually linked to anthropogenic emissions, only partly manageable. If only because a major share of the deposition is due to emissions abroad (see also Sections 5.6.3 and 5.6.4)

Nature lookout 2020

For the Nature Lookout 2020, Jongbloed et al (2019) performed a risk assessment to identify the most relevant pressure factors related to policies related to the energy transition, food provisioning, and sand mining. This assessment was based on a much wider risk assessment on European scale (Borgwardt et al, 2019). Table 39 lists for each policy the five most relevant pressure factors. Jongbloed et al (2019) further link each pressure factor to (a set of) economic activities, that can further be coupled to economic sectors as distinguished in the System of National Accounts (SNA), see Table 40 for a preliminary analysis of the top 5 overall pressure factors.

Table 39. Most relevant pressure factors per policy. Based on Jongbloed et al. (2019)

Policy goal	Pressure factor
Energy transition	Introduction of Non-synthetic compounds
	Introduction of Synthetic compounds
	Introduction of Radionuclides
	Barrier to species movement
	Noise (Underwater and Other)
Food provisioning	Extraction of flora and/or fauna
	Litter
	Change of habitat structure/morphology
	Introduction of Microbial pathogens
	Changes in input of organic matter
Sand mining and suppletion	Introduction of Radionuclides
	Introduction of Non-synthetic compounds
	Introduction of Synthetic compounds
	Noise (Underwater and Other)
	Changes in Siltation
Overall	Extraction of flora and/or fauna
	Litter
	Change of habitat structure/morphology
	Introduction of microbial pathogens
	Introduction of Non-synthetic compounds

Table 40. (preliminary) crosswalk between top-5 pressure factors (Jongbloed et al, 2019), economic activities, and economic sectors as recognized in the SNA.

Pressure factor	Activity	SNA sector
Extraction of flora and/or fauna	Fishing	Fishing
Litter	Manufacturing	Manufacturing
	Shipping [1)]	*Transport*
	Fishery related [1)]	*Fishing*
	Tourism [1)] */ Take-away* [2)]	*Households*
Change of habitat structure/morphology	Beach replenishment	Government
	Benthic trawling	*Fishing*
	Wind park	*Energy*
Introduction of microbial pathogens	Flood and coastal defence	Government
Introduction of Non-synthetic compounds	*Hunting* [3)]	

[1)] Boonstra and Hougee (2020)

[2)] Morales-Caselles et al (2021)

[3)] Greater North Sea only; not in Dutch EEZ

5.3 Pressures within the EU Marine Strategy (MSFD)

As introduced in Section 3.7.6, the EU MSFD distinguishes between *status* and *pressure* descriptors to assess whether the main goal of a Good Environmental Status has been reached. It was also shown that some of the status indicators (D1 biodiversity; D3 Fish Stocks; D4 Food webs; D6 Sea floor integrity) can be interpreted as pressure factors from the SEEA-EA perspective as well. (Table 24). Vice versa, many of the individual criteria of the pressure categories of descriptors can be interpreted as state variables in terms from the SEEA-EA perspective (Table 25).

Table 41. ‘Pressure’ descriptors and criteria of the European Marine Strategy[62]. Highlighted cells indicate criteria that are considered system states rather than pressure factors in the SEEA-EA context.

Descriptor		Criterion		State/Pressure MSFD	SEEA
D2	Non-indigenous species (NIS)	D2C1	Number of newly introduced NIS	P	P
		D2C2	Abundance and spatial distribution of established NIS	P	P
		D2C3	Proportion of the species group or spatial extent of the broad habitat type which is adversely altered due to NIS	P	S
D5	Eutrophication	D5C1	Nutrient concentrations	P	S
		D5C2	Chlorophyll-a concentrations	P	S
		D5C3	The number, spatial extent and duration of harmful algal bloom events	P	S
		D5C4	The photic limit (transparency) of the water column	P	S
		D5C5	Concentration of dissolved oxygen	P	S
		D5C6	Abundance of opportunistic microalgae	P	S
		D5C7	Species composition and relative abundance or depth distribution of macrophyte communities	P	S
		D5C8	Species composition and relative abundance of macrofaunal communities	P	S
D7	Hydrography	D7C1	Spatial extent and distribution of permanent alteration of hydrographical conditions	P	S
		D7C2	Spatial extent of each benthic habitat type adversely affected due to permanent alteration of hydrographical conditions	P	S
D8	Contaminants	D8C1	Concentrations of contaminants	P	S
		D8C2	Health of species and the condition of habitats adversely affected due to contaminants	P	S
		D8C3	Spatial extent and duration of significant acute pollution events	P	P
		D8C4	Effects of significant acute pollution events on the health of species and on the condition of habitats	P	S
D9	Contaminants (Seafood)	D9C1	Level of contaminants in edible tissues of seafood	P	S
D10	Litter	D10C1	Composition, amount and spatial distribution of litter	P	S
		D10C2	Composition, amount and spatial distribution of micro litter	P	S
		D10C3	Amount of litter and micro litter ingested by marine animals	P	S
		D10C4	Number of individuals of each species which are adversely affected due to litter	P	S
D11	Energy and Noise	D11C1	Spatial distribution, temporal extent and levels of anthropogenic impulsive sound sources	P	P
		D11C2	Spatial distribution, temporal extent and levels of anthropogenic continuous low-frequency sound	P	P

Section 3.7.6 presented an extensive evaluation of the most recent assessment of the individual criteria.

Note that some descriptors can be directly related to the provision of ecosystem services, for example descriptor 3 on commercial fish species concerns the extraction of fish by marine fisheries. Other ecosystem services that put pressure on ecosystems are also reflected in the descriptors, such as sand and gravel extraction which affects sea floor integrity (D6).

5.4 Pressures within OSPAR

As introduced in Section 3.7.6, OSPAR developed their own typology of indicators, largely, but not completely, matching the MSFD typology (Table 42 and Table 43). Also, not all OSPAR indicators are implemented yet.

OSPAR pressure are partly taken into account in the overview of MSFD condition variables, where in many cases they are they are used as input.

OSPAR ‘pressures’ are partly taken into account in the crosswalk of (MSFD) condition variables (Section 4.4).

[62] E.g.: https://mcc.jrc.ec.europa.eu/main/dev.py?N=19&O=118&titre_page=&titre_chap=D1%20Biological%20diversity

Table 42. Pressure typology of OSPAR. Grey entries are not yet implemented. See also Table 27.

Descriptor	Criterion		Indicator	
2 Non-Indigenous Species	2.1	Abundance and state of NIS, in particular invasives	2.1.1	Trends in abundance, occurrence and distribution of NIS
	2.2	Impact of invasives	2.2.1	Ratio: invasives to native species
			2.2.2	Impacts of invasive species
5 Eutrophication	5.1	Nutrients levels		
	5.2	Direct effects of nutrient enrichment		
	5.3	Indirect effects of nutrient enrichment		
8 Contaminants	8.1	Concentration of contaminants		
	8.2	Effects of contaminants		
10 Marine Litter	10.1	Characteristics of litter in the marine and coastal environment		
	10.2	Impacts of litter on marine life		
11 Introduction of Energy	11.1	Distribution in time and place of loud, low and mid frequency impulsive sounds		

Table 43. Crosswalk between MSFD and OSPAR pressure typologies. Grey entries indicate groups that are not implemented (yet),

MSFD Descriptor		Criterion		OSPAR Indicator group	
D2	Non-indigenous species (NIS)	D2C1	Number of newly introduced NIS	NA?	
		D2C2	Abundance and spatial distribution of established NIS	2.1	Abundance and state of NIS, in particular invasives
		D2C3	Proportion of the species group or spatial extent of the broad habitat type which is adversely altered due to NIS	2.2	Impact of invasives
D5	D5 Eutrophication	D5C1	Nutrient concentrations	5.1	Nutrients levels
		D5C2	Chlorophyll-a concentrations	5.2	Direct effects of nutrient enrichment
		D5C3	The number, spatial extent and duration of harmful algal bloom events		
		D5C4	The photic limit (transparency) of the water column	5.3	Indirect effects of nutrient enrichment
		D5C5	Concentration of dissolved oxygen		
		D5C6	Abundance of opportunistic microalgae		
		D5C7	Species composition and relative abundance or depth distribution of macrophyte communities		
		D5C8	Species composition and relative abundance of macrofaunal communities		
D7	Hydrography	D7C1	Spatial extent and distribution of permanent alteration of hydrographical conditions	NA	
		D7C2	Spatial extent of each benthic habitat type adversely affected due to permanent alteration of hydrographical conditions	NA	
D8	Contaminants	D8C1	Concentrations of contaminants	8.1	Concentration of contaminants
		D8C2	Health of species and the condition of habitats adversely affected due to contaminants	8.2	Effects of contaminants
		D8C3	Spatial extent and duration of significant acute pollution events		
		D8C4	Effects of significant acute pollution events on the health of species and on the condition of habitats		
D9	Seafood	D9C1	Level of contaminants in edible tissues of seafood		
D10	Litter	D10C1	Composition, amount and spatial distribution of litter	10.1	Characteristics of litter in the marine and coastal environment
		D10C2	Composition, amount and spatial distribution of micro litter		
		D10C3	Amount of litter and micro litter ingested by marine animals	10.2	Impacts of litter on marine life
		D10C4	Number of individuals of each species which are adversely affected due to litter		
D11	Energy and Noise	D11C1	Spatial distribution, temporal extent and levels of anthropogenic impulsive sound sources	11.1	Distribution in time and place of loud, low and mid frequency impulsive sounds
		D11C2	Spatial distribution, temporal extent and levels of anthropogenic continuous low-frequency sound	NA	

Table 44. OSPAR pressure indicators as currently in use. 'Common' marks that this indicator is part of the current list of Common indicators. 'IA'17' marks that the indicator was used in the 2017 Intermediate Assessment ('p' if it was a pilot assessment); 'QSR23' marks that the indicator is part of the 2023 Quality Status Report. Asterisks are put between parentheses to indicate that the corresponding assessments were not yet published in August 2023. OCT refers to the OSPAR Condition Typology (Table 42) while MSFD refers to the MSFD descriptor typology (Table 24 and Table 25,). Grey lines indicate indicators that are not relevant for the Dutch North Sea[63].

OSPAR Indicators		Com.	IA'17	QSR23	OCT	MSFD
Non-Indigenous Species	Trends in New Records of Non-Indigenous Species (NIS) Introduced by Human Activities (NIS)	*	*	*	D2.1	D2C1
Marine Litter	Beach Litter — Abundance, Composition and Trends	*		*	D10.1	D10C1
	Composition and Spatial Distribution of Litter on the Seafloor	*		*	D10.1	D10C1
	Plastic Particles in Fulmar Stomachs in the North Sea	*		*	D10.1, D10.2	D10C1, D10C3
	Litter ingested by sea turtles	*		*		
Underwater Noise	Distribution of Reported Impulsive Sounds	*	*	*	D11.1	D11C1
	Ambient Noise (pilot)			(*)		
Eutrophication	Nutrient Inputs to the Greater North Sea and the Bay of Biscay and Iberian Coast	*	*	*	D5.1	
	Winter Nutrient Concentrations in the Greater North Sea, Kattegat and Skagerrak	*	*	*	D5.1	D5C1
	Concentrations of Chlorophyll-a in the Greater North Sea and Celtic Seas	*	*	*	D5.2	D5C2
	Trends in Blooms of the Nuisance Phytoplankton Species Phaeocystis in Belgian, Dutch and German Waters	*	*		D5.2	D5C3
	Concentrations of Dissolved Oxygen Near the Seafloor	*	*	*	D5.3	D5C5
Hazardous substances	Inputs of Mercury, Cadmium and Lead via Water and Air to the Greater North Sea	*	*	*	D8.1	D8C1
	Status and Trend for Heavy Metals (Hg, Cd, Pb) in Fish and Shellfish	*	*	*	D8.1	D8C1
	Status and Trend for Heavy Metals (Cd, Hg, Pb) in Sediment	*	*	*	D8.1	D8C1
	Trends of Organotin in Sediments in the Southern North Sea	*	*	*	D8.1	D8C1
	Status and Trends in the Levels of Imposex in Marine Gastropods (TBT in	*	*	*	D8.2	D8C2
	Status and Trends in the Concentrations of Polycyclic Aromatic	*	*		D8.1	D8C1
	—in sediment	*	*		D8.1	D8C1
	Status and Trends of Polychlorinated Biphenyls (PCB) in Fish and Shellfish	*	*		D8.1	D8C1
	—in marine mammals (pilot)			(*)		
	—in sediment	*	*		D8.1	D8C1
	Trends in Concentrations of Polybrominated Diphenyl Ethers (PBDEs) in	*	*		D8.1	D8C1
	—in sediment	*	*		D8.1	D8C1

5.5 Pressures within the Bird and Habitat Directives

The EU Bird and Habitats Directive requires Member States to monitor the habitats and species listed in the annexes. Every 6 years an assessment of the conservation status of these habitats and species is reported. The assessment is made based on information on status and trends of species populations and habitats, and on information on main pressures and threats. In the EU Bird and Habitats Directive, 'Pressures' are past and present impacts that have an effect on the long-term viability of the species or its habitat(s), while 'threats' are future/foreseeable impacts that can affect the long-term viability of the species and/or its habitat(s).

Table 45 lists for all 7 Natura 2000 sites in the Dutch part of the North Sea the qualifying habitats and species, either under the Habitat Directive or the Bird Directive. This list includes 12 habitats, 39 birds, 4 species of fish, 3 species of mammals and one vascular plant.

[63] Recently the OSPAR Quality Status Report has been updated (QSR2023). New information from this assessment has not been included in the current ecosystem account.

Table 45. Qualifying habitats and species for the 7 Natura 2000 sites within the Dutch North Sea. For birds, the column ‘Season’ distinguishes between Breeding (B), Passage (P) and Winter (W). Letters In the Site column specify the relative importance of the habitat or species with reference to the area or population at national scale (C: <2%; B1: 2–6%; B2:6–15%; A1:15–30%; A2: 30–50% A3: 50–75%; A4: >75%). Grey Cells marked with an ‘?’ indicate species/site combinations for which no importance was listed[64].

					Site						
					Bruine Bank	Friese Front	Kustzone	Voordelta	Doggersbank	Klaverbank	Vlakte vd Raa
Directive											
	Bird Directive				☐	☐	☐	☐			
	Habitat Directive						☐	☐	☐	☐	☐
Habitat				**Variant**							
Coastal and Halophytic habitats											
	Open sea and tidal areas										
H1110	Sandbanks which are slightly covered by sea water all the time			A				C			
				B			A1	B2			B1
				C					A4		
H1130	Estuaries										
H1140	Mudflats and sandflats not covered by seawater at low tide			A				C			
				B			A3	A1			
H1160	Large shallow inlets and bays										
H1170	Reefs									A4	
	Atlantic and continental salt marshes and salt meadows										
H1310	Salicornia and other annuals colonizing mud and sand			A			B1	C			
				B			A1	C			
H1320	Spartina swards (Spartinion maritimae)							C			
H1330	Atlantic salt meadows (Glauco-Puccinellietalia maritimae)			A			C	C			
Coastal sand dunes and inland dunes											
	Sea dunes of the Atlantic, North Sea and Baltic coasts										
H2110	Embryonic shifting dunes						A2	B1			
H2120	Shifting dunes along the shoreline with Ammophila arenaria ('white							C			
H2130	Fixed coastal dunes with herbaceous vegetation ('grey dunes')										
H2190	Humid dune slacks			A			B				
				B			B1				
Species				**Season**							
	Birds										
A001	Gavia stellata	Red-throated loon	Roodkeelduiker	W			?	A1			
A002	Gavia arctica	Black-throated loon	Parelduiker	W			A2				
A005	Podiceps cristatus	Great crested grebe	Fuut	W				C			
A007	Podiceps auritus	Horned grebe	Kuifduiker	W				B2			
A016	Morus bassanus	Northern gannet	Jan van Gent	P/W?	C						
A017	Phalacrocorax carbo	Great cormorant	Aalscholver	W			B2	B1			
A034	Platalea leucorodia	Eurasian spoonbill	Lepelaar	P				C			
A043	Anser anser	Greylag goose	Grauwe gans	W				C			
A048	Tadorna tadorna	Common shelduck	Bergeend	W			C	C			
A050	Mareca penelope	Eurasian wigeon	Smient	W				C			
A051	Mareca strepera	Gadwall	Krakeend	W				B1			
A052	Anas crecca	Eurasian Teal	Wintertaling	W				B1			
A054	Anas acuta	Northern Pintail	Pijlstaart	W				B1			
A056	Spatula clypeata	Northern Shoveler	Slobeend	P/W				B1			
				W				B1			
A062	Aythya marila	Greater Scaup	Toppereend	W			B1-B2	?			
A063	Somateria mollissima	Common Eider	Eider	W			A1	?			
A065	Melanitta nigra	Black Scoter	Zwarte-zee-eend	W			?	C			
A067	Bucephala clangula	Common Goldeneye	Brilduiker	W				B2			
A069	Mergus serrator	Red-breasted Merganser	Middelste zaagbek	W				B1			
A130	Haematopus ostralegus	Eurasian Oystercatcher	Scholekster	W			C	?			
A132	Recurvirostra avosetta	Pied Avocet	Kluut	W			C	C			
A137	Charadrius hiaticula	Common ringed plover	Bontbekplevier	B			B1				
				P				B1			
				W				B1			
A138	Charadrius alexandrinus	Kentish Plover	Strandplevier	B			B1				
A141	Pluvialis squatarola	Grey Plover	Zilverplevier	P			B2	C			
				W			B	C			
A143	Calidris canutus	Red Knot	Kanoetstrandloper	P			C				
				W			C				
A144	Calidris alba	Sanderling	Drieteenstrandloper	W			A2	B1			
A149	Calidris alpina	Dunlin	Bonte strandloper	P				C			
				W			B1-B2	C			
A157	Limosa lapponica	Bar-tailed Godwit	Rosse grutto	W			B1-B2	B1			
A160	Numenius arquata	Eurasian Curlew	Wulp	W			C	C			
A162	Tringa totanus	Common Redshank	Tureluur	W				B1			
A169	Arenaria interpres	Ruddy Turnstone	Steenloper	W			B1				
A175	Stercoratius skua	Great Skua	Grote Jager	P/W?	C						
A177	Hydrocoloeus minutus	Little Gull	Dwergmeeuw	P	C		?	B2			
A191	Thalasseus sandvicensis	Sandwich Tern	Grote stern	B				(A2)			
A193	Sterna hirundo	Common Tern	Visdief	B				(A2)			
A195	Sterna albifrons	Little Tern	Dwergstern	B			C				
A187	Larus marinus	Great Black-backed Gull	Grote Mantelmeeuw	B	(C)						
A199	Uria aalge	Common Guillemot	Zeekoet	P	C	?					
A200	Alca torda	Razorbill	Alk	P/W?	C						
	Fish										
H1095	Petromyzon marinus	Sea lamprey	Zeeprik				B1	A			C
H1099	Lampetra fluviatilis	River lamprey	Rivierprik				B1	B			C
H1102	Alosa alosa	Allis shad	Elft					A			
H1103	Alosa fallax	Twait shad	Fint				B1	A			C
	Mammals										
H1351	Phocoena phocoena	Harbour porpoise	Bruinvis				C	C	B1	B	C
H1364	Halichoerus grypus	Grey seal	Grijze zeehond				B1-B2	B1	C	C	C
H1365	Phoca vitulina	Harbour seal	Gewone zeehond				B1-B2	C	C	C	C
	Vascular plants										
H1903	Liparis loeselii	Fen orchid	Groenknolorchis				C				

[64] On the official Natura-2000 website: https://www.natura2000.nl/gebieden/noordzee-nederlandse-exclusieve-economische-zone

In this section we analyse which pressures (and, to a lesser extent, threats) are reported for habitats (Article 17) and species (Articles 12 and 17), and how these pressures can be associated with specific economic sectors in the sense of SEEA and SNA.

5.5.1 Pressure Typology

The EU Habitat Directive recognizes 216 different pressures and threats (including 'unknown'), organized in 15 different categories (Table 46). In some cases, e.g. 'A Agriculture' (36 individual pressures) and 'D Energy' (14 individual pressures), these correspond with clearly defined economic sectors as defined in the NACE classification system for economic activities. In other cases, e.g. 'I Alien and problematic species' (5 pressures) or 'N Climate change', this is much less the case. Note that for the next reporting period 2018–2024 a new top-level classification scheme and additional pressures are to be used. While being outside the scope of the current study, this classification is given for future reference.

Table 46. Classification of pressures and threats, as defined for the reporting under Article 12 and Article 17 of the Habitat Directive. In grey, for reference, the new classes for the upcoming 2018–2024 assessments. Source: European Environmental Agency[65].

Class		Description	2024 Class	
A	Agriculture		PA	Agriculture related practices
B	Forestry		PB	Forestry related practices
C	Extraction of resources (minerals, peat, non-renewable energy resources)		PC	Extraction of resources (minerals, peat, non-renewable energy resources)
D	Energy production processes and related infrastructure development		PD	Energy production processes and related infrastructure development
E	Development and operation of transport systems	Includes transportation corridors outside of human settlements and industrial developments. These corridors create specific stresses to biodiversity, especially the fragmentation of habitats, and lead to other threats including farms, invasive species, and poachers.	PE	Development and operation of transport systems
F	Development, construction and use of residential, commercial, industrial and recreational infrastructure and areas		PF	Development, construction and use of residential, commercial, industrial and recreational infrastructure and areas
G	Extraction and cultivation of biological living resources (other than agriculture and forestry)		PG	Extraction and cultivation of biological living resources (other than agriculture and forestry)
H	Military action, public safety measures, and other human intrusions		PH	Military action, public safety measures, and other human intrusions
I	Alien and problematic species		PI	Alien and problematic species
J	Mixed source pollution	Threats from the introduction of exotic and/or excess materials or energy from point and diffuse sources for which no clear driver(s) (level 1 category) can be identified. Where (one or several) key sectoral driver(s) can be identified, the pressure/threat should be reported under the corresponding sectoral categories. In some cases, the source of the pollution may be either unknown or from a historical source (e.g., heavy metals buried in sediments).	PK	Mixed source pollution
K	Human-induced changes in water regimes	Human-induced changes in hydraulic conditions should only be reported under this category when key sectoral driver(s) of the change is/are unclear. When (one or several) key sectoral driver(s) can be identified, the pressure/threat should be reported under the corresponding sectoral categories.	PL	Human-induced changes in water regimes
L	Natural processes (excluding catastrophes and processes induced by human activity or climate change)	Does not include pressures linked to natural catastrophes (M), climate change (N) or human activity. Where the natural processes to be reported are clearly linked to human induced land use change the pressure should be reported under this alternate category.	PM	Geological events, natural processes and catastrophes
M	Geological events, natural catastrophes		PM	Geological events, natural processes and catastrophes
N	Climate change		PJ	Climate change
X	Unknown pressures, no pressures and pressures from outside the Member State		PX	Unknown pressures, no pressures and pressures from outside the Member State

5.5.2 Protected Habitats

The most recent completed period for the assessment of habitat quality under article 17 of the Habitat Directive is for 2013–2018. Table 47 summarizes the pressures and threats that are

[65] https://cdr.eionet.europa.eu/help/habitats_art17

reported by the Netherlands as the “major pressures and threats” for three groups of habitats that are part of the designation of the marine and coastal Natura-2000 areas in the Netherlands. Five true marine habitats (sand banks, mudflats, transitional waters and reefs), three subtidal coastal habitats (salt marshes and *Salicornia* or *Spartina* dominated habitats) and four types of coastal dune habitats (Embryonic dunes, grey and white dunes, dune slacks).

The pressures and threats listed in the Article 17 reporting are not uniformly distributed among all pressure classes. The most prominent classes, based on the number of medium and high-importance pressures reported, are F (Development, construction and use of residential, commercial, industrial and recreational infrastructure and areas, or ‘built-up’ for short), K (human-induced changes in water regime, or ‘hydrography’ for short), L (Natural processes). Notably absent classes are B (Forestry[66]), H (human intrusions) and M (geological events).

Table 47. Main pressures as listed for the Dutch marine and coastal habitats protected by the Habitat Directive. `H’ refers to pressures of high importance/impact, while ‘M’ refers to pressures of medium importance/impact. Non-highlighted symbols in parentheses indicate a *threat*, rather than a *pressure.* Source: EEA[67]. See Most of **the pressures in this section can be linked to SBI sector A: Agriculture, Forestry and Fishing. An interesting exception might be pressure A06 (abandonment of grassland). Since this concerns areas that are no longer used for agricultural purposes, but instead have become part of nature areas, one might associate this pressure with sector O (Public administration, Government, etc.).**

Table 50 and further for the meaning of the individual pressure codes (‘A06’ etc.)

Habitat type	A06	A10	C01	C02	C03	D01	E03	F06	F08	F21	F24	G01	G03	G17	G19	I02	I04	J02	J03	K01	K04	K05	L01	L02	L03	L04	L07	N01	N04	N08
	Agriculture		Mining			Energy	Transport	Built-up				Fishing				NIS+		Pollution		Hydrography			Natural					Climage change		
Coastal and Halophytic habitats																														
Open sea and tidal areas																														
H1110 Sandbanks which are slightly covered by sea water all the time					(M)			M					H			(M)		H										(M)		
H1130 Estuaries							H		M	M								M			H	H							M	M
H1140 Mudflats and sandflats not covered by seawater at low tide				M	M			M					M			M												(M)	(H)	
H1160 Large shallow inlets and bays												M		M	M	H		M			H	H								M
H1170 Reefs			M			(M)							H					M												
Atlantic and continental salt marshes and salt meadows																														
H1310 Salicornia and other annuals colonizing mud and sand																					H		M						H	
H1320 Spartina swards (Spartinion maritimae)																	H													
H1330 Atlantic salt meadows (Glauco-Puccinellietalia maritimae)		M																			M		M	H	M				M	
Coastal sand dunes and inland dunes																														
Sea dunes of the Atlantic, North Sea and Baltic coasts																														
H2110 Embryonic shifting dunes											H												M						M	
H2120 Shifting dunes along the shoreline with Ammophila arenaria ('white dunes')											H								M											
H2130 Fixed coastal dunes with herbaceous vegetation ('grey dunes')	H								H							M			H					M	M	M	H			
H2190 Humid dune slacks																M				H				H						

5.5.3 Protected Species

The Natura 2000 network is area based. That it is made up of Special Areas of Conservation (SACs, under the Habitat Directive) and Special Protection Areas (SPA, under the Bird Directive). Each SAC or SPA is designated for not only the presence of specific habitats (listed in Annex I), but also specific birds and other species groups (Annex II to V). For birds, a distinction is made between breeding and non-breeding birds.

[66] Because some of the coastal dunes are forested, and ara managed with timber production as a secondary goal, we would have expected forestry to be included as well.
[67] https://nature-art17.eionet.europa.eu/article17/

Table 48 summarizes the pressures and threats for all species that are protected either under the Bird Directive or the Habitat directive. The most important groups of pressures (in terms of number of medium and high-impact pressures reported) are changes in water regime (H), fishing (F) and development of built-up areas (34).

Table 48. Main pressures as listed for the species protected by the Bird and Habitat Directives

Species			Pressure category																						
			Agriculture									Mining		Energy		Transport				Development					
			A02	A08	A13	A16	A19	A20	A21	A26	A27	C02	C03	D01	D06	E01	E02	E03	E06	F03	F05	F06	F07	F08	F12
Birds																									
Gavia stellata	Red-throated loon	Roodkeelduiker												(M)			M						M		
Gavia arctica	Black-throated loon	Parelduiker												(M)			M						M		
Podiceps cristatus	Great crested grebe	Fuut												(M)							M		M		
Podiceps auritus	Horned grebe	Kuifduiker																							
Morus bassanus	Northern gannet	Jan van Gent																							
Phalacrocorax carbo	Great cormorant	Aalscholver												M(H)											
Platalea leucorodia	Eurasian spoonbill	Lepelaar												(M)											
Anser anser	Greylag goose	Grauwe gans												(M)	(M)										
Tadorna tadorna	Common shelduck	Bergeend										(M)	(M)										M		
Mareca penelope	Eurasian wigeon	Smient	M																						
Mareca strepera	Gadwall	Krakeend																							
Anas crecca	Eurasian Teal	Wintertaling																							
Anas acuta	Northern Pintail	Pijlstaart																							
Spatula clypeata	Northern Shoveler	Slobeend																							
Aythya marila	Greater Scaup	Toppereend												M(H)											
Somateria mollissima	Common Eider	Eider												(M)									M		
Melanitta nigra	Black Scoter	Zwarte-zee-eend												M(H)			M								
Bucephala clangula	Common Goldeneye	Brilduiker																							
Mergus serrator	Red-breasted Merganser	Middelste zaagbek																							
Haematopus ostralegus	Eurasian Oystercatcher	Scholekster		H	M		M	M	M			(M)	(M)					M					M		
Recurvirostra avosetta	Pied Avocet	Kluut																					M		
Charadrius hiaticula	Common ringed plover	Bontbekplevier				M						(M)	(M)	(M)	(M)			M							
Charadrius alexandrinus	Kentish Plover	Strandplevier												(M)	(M)								H		
Pluvialis squatarola	Grey Plover	Zilverplevier										(M)	(M)	(M)	(M)			M					M		
Calidris canutus	Red Knot	Kanoetstrandloper										(M)	(M)		(M)			M					M		
Calidris alba	Sanderling	Drieteenstrandloper													(M)			M					M		
Calidris alpina	Dunlin	Bonte strandloper										(M)	(M)		(M)			M					M		
Limosa lapponica	Bar-tailed Godwit	Rosse grutto										(M)	(M)		(M)			M					(M)		
Numenius arquata	Eurasian Curlew	Wulp										(M)	(M)	M	(M)	M		M					M		
Tringa totanus	Common Redshank	Tureluur										(M)	(M)		(M)								M		
Arenaria interpres	Ruddy Turnstone	Steenloper										(M)	(M)		(M)			M					M		
Stercoratius skua	Great Skua	Grote Jager																							
Hydrocoloeus minutus	Little Gull	Dwergmeeuw												(M)											
Thalasseus sandvicensis	Sandwich Tern	Grote stern												(M)									M		
Sterna hirundo	Common Tern	Visdief												M				M		M					
Sterna albifrons	Little Tern	Dwergstern												(M)									M		
Larus marinus	Great Black-backed Gull	Grote Mantelmeeuw																							
Uria aalge	Common Guillemot	Zeekoet															M								
Alca torda	Razorbill	Alk																							
Fish																									
Petromyzon marinus	Sea lamprey	Zeeprik																							
Lampetra fluviatilis	River lamprey	Rivierprik																							
Alosa alosa	Allis shad	Elft																							
Alosa fallax	Twait shad	Fint																							
Mammals																									
Phocoena phocoena	Harbour porpoise	Bruinvis											M	M									M		
Halichoerus grypus	Grey seal	Grijze zeehond											M	H			H					H	(M)	H	(M)
Phoca vitulina	Harbour seal	Gewone zeehond											M	H			H					H	(M)	H	(M)
Vascular plants																									
Liparis loeselii	Fen orchid	Groenknolorchis								M	H								H						

Table 48 (continued)

Species			Pressure category Fishing				Intrusions		Pollution		Hydro			Geophysical					Climate change								Other	
			G01	G03	G05	G12	H06	H08	J01	J02	K03	K04	K05	L02	L03	L04	L06	L07	N01	N02	N04	N05	N06	N07	N08	N09	Xe	Xo
Birds																												
Gavia stellata	Red-throated loon	Roodkeelduiker																										
Gavia arctica	Black-throated loon	Parelduiker																										
Podiceps cristatus	Great crested grebe	Fuut			H				M			M	M										(M)					
Podiceps auritus	Horned grebe	Kuifduiker																										
Morus bassanus	Northern gannet	Jan van Gent																										
Phalacrocorax carbo	Great cormorant	Aalscholver																										
Platalea leucorodia	Eurasian spoonbill	Lepelaar	(M)														M				(M)			(M)				
Anser anser	Greylag goose	Grauwe gans																										
Tadorna tadorna	Common shelduck	Bergeend									(M)		(M)								(M)							
Mareca penelope	Eurasian wigeon	Smient																							M		M	
Mareca strepera	Gadwall	Krakeend																										
Anas crecca	Eurasian Teal	Wintertaling																										
Anas acuta	Northern Pintail	Pijlstaart																										
Spatula clypeata	Northern Shoveler	Slobeend																										
Aythya marila	Greater Scaup	Toppereend	M									M																
Somateria mollissima	Common Eider	Eider	H(M)																		(M)			(M)				
Melanitta nigra	Black Scoter	Zwarte-zee-eend	M																						M			
Bucephala clangula	Common Goldeneye	Brilduiker										M		M											M			
Mergus serrator	Red-breasted Merganser	Middelste zaagbek																										
Haematopus ostralegus	Eurasian Oystercatcher	Scholekster	H								H										(M)							
Recurvirostra avosetta	Pied Avocet	Kluut									H	H	H	H			H	M			(M)						M	
Charadrius hiaticula	Common ringed plover	Bontbekplevier									M										(M)							
Charadrius alexandrinus	Kentish Plover	Strandplevier									H	H	H	H			M				(M)							
Pluvialis squatarola	Grey Plover	Zilverplevier									M										(M)							
Calidris canutus	Red Knot	Kanoetstrandloper	M								M								M		(M)							
Calidris alba	Sanderling	Drieteenstrandloper																			(M)							
Calidris alpina	Dunlin	Bonte strandloper									M										(M)							
Limosa lapponica	Bar-tailed Godwit	Rosse grutto									(M)										(M)							
Numenius arquata	Eurasian Curlew	Wulp									M										(M)							
Tringa totanus	Common Redshank	Tureluur																			(M)							
Arenaria interpres	Ruddy Turnstone	Steenloper	H																		(M)							
Stercoratius skua	Great Skua	Grote Jager																										
Hydrocoloeus minutus	Little Gull	Dwergmeeuw			M												M						(M)					
Thalasseus sandvicensis	Sandwich Tern	Grote stern	H								M	M		M			M				(M)			(M)				
Sterna hirundo	Common Tern	Visdief	H		H						M	H		M							M		M					
Sterna albifrons	Little Tern	Dwergstern									M	M	M	M			M				M							
Larus marinus	Great Black-backed Gull	Grote Mantelmeeuw																										
Uria aalge	Common Guillemot	Zeekoet	M																									x
Alca torda	Razorbill	Alk																										
Fish																												
Petromyzon marinus	Sea lamprey	Zeeprik					H																					
Lampetra fluviatilis	River lamprey	Rivierprik					H	M																				
Alosa alosa	Allis shad	Elft																										
Alosa fallax	Twait shad	Fint				M	H						H															
Mammals																												
Phocoena phocoena	Harbour porpoise	Bruinvis	H	H				M		M												H	H			M		
Halichoerus grypus	Grey seal	Grijze zeehond	M	M		H																						
Phoca vitulina	Harbour seal	Gewone zeehond	M	M		H																						
Vascular plants																												
Liparis loeselii	Fen orchid	Groenknolorchis												H	M	M				(M)								

5.5.4 Detailed analysis and links with economic sectors

The next few sections summarize for each of the major categories of the Bird and Habitat Directive (BHD) pressures the most relevant ones ("medium" and "high" relevance/impact), as reported by the Netherlands under Articles 12 and 17, supplemented by additional pressures that are potentially relevant from an ecosystem accounting perspective. A (preliminary) link with economic sectors that exert these pressures is made. The economic sectors are classified by the international NACE standard, which is used within macro-economic statistics, such as the System of National Accounts (SNA) and SEEA (Table 49).

Table 49. NACE classification for economic activities (main level only)

Section	Title
A	Agriculture, forestry and fishing
B	Mining and quarrying
C	Manufacturing
D	Electricity, gas, steam and air conditioning supply
E	Water supply; sewerage, waste management and remediation activities
F	Construction
G	Wholesale and retail trade; repair of motor vehicles and motorcycles
H	Transportation and storage
I	Accommodation and food service activities
J	Information and communication
K	Financial and insurance activities
L	Real estate activities
M	Professional, scientific and technical activities
N	Administrative and support service activities
O	Public administration and defence; compulsory social security
P	Education
Q	Human health and social work activities
R	Arts, entertainment and recreation
S	Other service activities
T	Activities of households as employers; undifferentiated goods- and services; producing activities of households for own use
U	Activities of extraterritorial organisations and bodies

A: Agriculture

There are three “high impact” pressures reported for the Agriculture sector and linked to coastal and marine habitats and species: The abandonment of grassland management (mentioned for grey dunes, H2130), the moving and cutting of grassland (mentioned for Oystercatcher / Scholekster) and the generation of point-source air pollution related to agricultural activities (mentioned for Liparis loeselii / Fen orchid / Groenknolorchis).

Most of the pressures in this section can be linked to SBI sector A: Agriculture, Forestry and Fishing. An interesting exception might be pressure A06 (abandonment of grassland). Since this concerns areas that are no longer used for agricultural purposes, but instead have become part of nature areas, one might associate this pressure with sector O (Public administration, Government, etc.).

Table 50. Summary of pressures reported for three groups of ecosystems and four groups of species, under Article 12 and Article 17 of the Bird and Habitat Directives, respectively. For each combination of pressure and habitat/groups, only the highest level of pressure is indicated (M for Medium; H for high). Pressures in grey font are not mentioned in the Art 12 or 17 reports, but are considered to be potentially relevant.

Pressure/threat (2013-2018)		Marine	Coastal	Dunes	Birds	Fish	Mammals	Plants
Agriculture related practices								
A02	Conversion from one type of agricultural land use to another (excluding drainage and burning),				M			
A06	Abandonment of grassland management (e.g. cessation of grazing or mowing)			H				
A07	— of management/use of other agricultural and agroforestry systems							
A08	Mowing or cutting of grasslands				H			
A10	Extensive grazing or undergrazing by livestock		M					
A13	Reseeding of grasslands and other semi-natural				M			
A16	Other soil management practices in agriculture				M			
A19	Application of natural fertilisers on agricultural land				M			
A20	Application of synthetic (mineral) fertilisers on agricultural land				M			
A21	Use of plant protection chemicals in agriculture				M			
A25	Agricultural activities generating point source pollution to surface or ground waters							
A26	— generating diffuse pollution to surface or ground waters							M
A27	— generating air pollution							H
A28	— generating marine pollution							
A31	Drainage for use as agricultural land							
A32	Development and operation of dams for agriculture							
A33	Modification of hydrological flow or physical alteration of water bodies for agriculture (excluding development and operation of dams)							

Some additional pressures are included (marked grey). For example, pressures A31–33 represent water management that might impact coastal dunes (desiccation).

B: Forestry

There are no formal pressures reported for this group. Some potentially relevant pressures included refer to the plantations of exotic tree species (notably *Pinus nigra*) that are considered to be preventing the required conditions for coastal dune habitats, which favour a more open type of landscape.

Depending on the actual use of the forest (products), these pressures should be mainly associated with sectors A (Agriculture, Forestry and Fishing) and O (Public Administration / Government, for nature management).

Most of the pressures in this section can be linked to SBI sector A: Agriculture, Forestry and Fishing. An interesting exception might be pressure A06 (abandonment of grassland). Since this concerns areas that are no longer used for agricultural purposes, but instead have become part of nature areas, one might associate this pressure with sector O (Public administration etc.).

Most of the pressures in this section can be linked to SBI sector A: Agriculture, Forestry and Fishing. An interesting exception might be pressure A06 (abandonment of grassland). Since this concerns areas that are no longer used for agricultural purposes, but instead have become part of nature areas, one might associate this pressure with sector O (Public administration, Government, etc.).

Table 50 (continued).

Pressure/threat (2013-2018)		Marine	Coastal	Dunes	Birds	Fish	Mammals	Plants
Forestry related practices								
B01	Conversion to forest from other land uses, or afforestation (excluding drainage)							
B02	— to other types of forests including monocultures							
B03	Replanting with or introducing non-native or non-typical species (including new species and GMOs)							
B27	Modification of hydrological conditions, or physical alteration of water bodies and drainage for forestry (including dams)							

C: Extraction of resources (minerals, peat, non-renewable energy resources)

This group only represents some medium pressures, notably the extraction of minerals, which is a pressure on *Reefs* (H1170), and the extraction of subsoil resources (salt and fossil fuels), which are a pressure to mudflats (due to soil subsidence) and mammals (due to underwater noise).

All resource extraction activities, including support activities, are associated with NACE sector B (Mining and Quarrying). Preparation activities, e.g. seismic surveys, are associated with sector M (Professional, scientific and technical activities).

Most of the pressures in this section can be linked to SBI sector A: Agriculture, Forestry and Fishing. An interesting exception might be pressure A06 (abandonment of grassland). Since this concerns areas that are no longer used for agricultural purposes, but instead have become part of nature areas, one might associate this pressure with sector O (Public administration, Government, etc.).

Table 50 (continued). Non-highlighted entries between brackets indicate threats, rather than pressures.

Pressure/threat (2013-2018)		Marine	Coastal	Dunes	Birds	Fish	Mammals	Plants
Extraction of resources (minerals, peat, non-renewable energy resources)								
C01	Extraction of minerals (e.g. rock, metal ores, gravel, sand, shell)	M						
C02	Extraction of salt	M			(M)			
C03	Extraction of oil and gas, including infrastructure	M			(M)		M	
C07	Dumping/depositing of dredged materials from marine extraction							

D: Energy production processes and related infrastructure development

The main pressures in this group are related to wind energy. It is marked as medium-impact for several (5) article 12 birds and for two out of three article 17 mammals (Seals; for porpoises this pressure is labelled *Medium*).

The generation of wind energy, including the operation of the corresponding infrastructure is associated with NACE sector D (Electricity, Gas, Steam and Air Conditioning Supply), while the preparation (e.g. drilling) and construction are associated with sector F (Construction) and possibly (e.g. seismic surveys) sector M (Professional, scientific and technical activities).

Most of the pressures in this section can be linked to SBI sector A: Agriculture, Forestry and Fishing. An interesting exception might be pressure A06 (abandonment of grassland). Since this concerns areas that are no longer used for agricultural purposes, but instead have become part of nature areas, one might associate this pressure with sector O (Public administration, Government, etc.).

Table 50. (continued).

Pressure/threat (2013-2018)		Marine	Coastal	Dunes	Birds	Fish	Mammals	Plants
Energy production processes and related infrastructure development								
D01	Wind, wave and tidal power, including infrastructure	(M)			M		H	
D05	Development and operation of energy production plants (including bioenergy plants, fossil and nuclear energy plants)							
D06	Transmission of electricity and communications (cables)				(M)			
D07	Oil and gas pipelines							
D08	Energy production and transmission activities generating pollution to surface or ground waters							
D09	— generating air pollution							
D10	— generating marine pollution							
D11	— generating noise pollution							
D12	— light, heat or other forms pollution							

E: Development and operation of transport systems

The main pressures of high-importance in this category include shipping operations (impacting both protected species of seals) and infrastructure (impacting *Estuaries*, H1130). Air pollution from transport is impacting *Liparis loeselii* (Fen orchid / Groenknolorchis).

The operation of all modes of transport is associated with NACE sector H (Transportation and storage). Maintenance of infrastructure (e.g. dredging) is associated with sector F (Construction)

Most of the pressures in this section can be linked to SBI sector A: Agriculture, Forestry and Fishing. An interesting exception might be pressure A06 (abandonment of grassland). Since this concerns areas that are no longer used for agricultural purposes, but instead have become part of nature areas, one might associate this pressure with sector O (Public administration, Government, etc.).

Table 50. (continued).

Pressure/threat (2013-2018)		Marine	Coastal	Dunes	Birds	Fish	Mammals	Plants
Development and operation of transport systems								
E01	Roads, paths, railroads and related infrastructure (e.g. bridges, viaducts, tunnels)				M			
E02	Shipping lanes and ferry lanes transport operations				M		H	
E03	Shipping lanes, ferry lanes and anchorage infrastructure (e.g. canalisation, dredging)	H			M			
E04	Flight paths of planes, helicopter and other non-leisure aircrafts							
E05	Land, water and air transport activities generating pollution to surface or ground waters							
E06	— generating air pollution							H
E07	— generating marine pollution							
E08	— generating noise, light and other forms of pollution							

F: Development, construction and use of residential, commercial, industrial and recreational infrastructure and areas

This is a very large category, clustering together all kinds of activities associated with built-up areas. The main pressures labelled to be high-importance are associated with coastal recreation and tourism (F06 and F07; impacting Seals and beach-dwelling birds species); coastal defence (F08; impacting Grey dunes and Seals); and physical (noise and light) pollution (impacting near-shore Embryonic and White coastal dunes.

In terms of economic sectors, recreational activities themselves are associated with individual persons, represented by NACE sector T (households). Supporting and enabling activities are mainly associated with sectors I (Accommodation and food service) and L (Real estate). Beach maintenance is associated with sectors F (Construction) and O (Government). Noise and light pollution is mainly associated with sectors T (Households) and O (Government)

Most of the pressures in this section can be linked to SBI sector A: Agriculture, Forestry and Fishing. An interesting exception might be pressure A06 (abandonment of grassland). Since this concerns areas that are no longer used for agricultural purposes, but instead have become part of nature areas, one might associate this pressure with sector O (Public administration, Government, etc.).

Table 50. (continued).

Pressure/threat (2013-2018)		Marine	Coastal	Dunes	Birds	Fish	Mammals	Plants
Development, construction and use of residential, commercial, industrial and recreational infrastructure and areas								
F01	Conversion from other land uses to housing, settlement or recreational areas (excluding drainage and modification of coastline, estuary and coastal conditions)							
F02	Construction or modification (e.g. of housing and settlements) in existing urban or recreational areas							
F03	Conversion from other land uses to commercial / industrial areas (excluding drainage and modification of coastline, estuary and coastal conditions)				M			
F05	Creation or development of sports, tourism and leisure infrastructure (outside the urban or recreational areas)				M			
F06	Development and maintenance of beach areas for tourism and recreation incl. beach nourishment and beach cleaning	M					H	
F07	Sports, tourism and leisure activities				H		M	
F08	Modification of coastline, estuary and coastal conditions for development, use and protection of residential, commercial, industrial and recreational infrastructure and areas (including sea defences or coastal protection works and infrastructures)	M		H			H	
F12	Discharge of urban waste water (excluding storm overflows and/or urban run-offs) generating pollution to surface or ground water						(M)	
F18	Residential and recreational activities and structures generating air pollution							
F19	Industrial and commercial activities and structures generating air pollution							
F20	Residential or recreational activities and structures generating marine pollution (excl. marine macro- and micro-particular pollution)							
F21	Industrial or commercial activities and structures generating marine pollution (excluding marine macro- and micro-particular pollution)	M						
F23	— generating marine macro- and micro- particulate pollution (e.g. plastic bags, Styrofoam)							
F24	Residential or recreational activities and structures generating noise, light, heat or other forms of pollution			H				
F25	Industrial or commercial activities and structures generating noise, light, heat or other forms of pollution							
F26	Drainage, land reclamation and conversion of wetlands, marshes, bogs, etc. to settlement or recreational areas							
F27	— to industrial/commercial areas							
F28	Modification of flooding regimes, flood protection for residential or recreational development							
F29	Construction or development of reservoirs and dams for residential or recreational development							
F30	— for industrial or commercial development							
F33	Abstraction of ground and surface waters (including marine) for public water supply and recreational use							
F34	— for commercial/industrial use (excluding energy)							

G: Extraction and cultivation of biological living resources (other than agriculture and forestry)

This category is mainly associated with fishing and aquaculture. Main pressures listed as *High importance* are related to reduction of prey populations (G01; impacting 6 bird species and Porpoises) and habitat loss (G03; impacting *Sandbanks* (H1110), *Reefs* (H1170) and Porpoises). Bycatch (G12) has the highest impact on Seals.

Fishing is associated with NACE sector A (Agriculture, forestry and fishing). Most of the pressures in this section can be linked to SBI sector A: Agriculture, Forestry and Fishing. An interesting exception might be pressure A06 (abandonment of grassland). Since this concerns areas that are no longer used for agricultural purposes, but instead have become part of nature areas, one might associate this pressure with sector O (Public administration, Government, etc.).

Most of the pressures in this section can be linked to SBI sector A: Agriculture, Forestry and Fishing. An interesting exception might be pressure A06 (abandonment of grassland). Since this concerns areas that are no longer used for agricultural purposes, but instead have become part of nature areas, one might associate this pressure with sector O (Public administration, Government, etc.).

Table 50. (continued).

Pressure/threat (2013-2018)		Marine	Coastal	Dunes	Birds	Fish	Mammals	Plants
Extraction and cultivation of biological living resources (other than agriculture and forestry)								
G01	Marine fish and shellfish harvesting (professional, recreational) causing reduction of species/prey populations and disturbance of species	M			H		H	
G02	Marine fish and shellfish processing							
G03	Marine fish and shellfish harvesting (professional, recreational) activities causing physical loss and disturbance of seafloor habitats	H					H	
G04	Marine plant harvesting							
G05	Freshwater fish and shellfish harvesting (professional)				H			
G08	Management of fishing stocks and game							
G09	Harvesting or collecting of other wild plants and animals (excluding hunting and leisure fishing)							
G12	Bycatch and incidental killing (due to fishing and hunting activities)					M	H	
G13	Poisoning of animals (excluding lead poisoning)							
G14	Use of lead ammunition or fishing weights							
G15	Modification of coastal conditions for marine aquaculture							
G16	Marine aquaculture generating marine pollution							
G17	Introduction and spread of species (including GMOs) in marine aquaculture	M						
G18	Abandonment of marine aquaculture							
G19	Other impacts from marine aquaculture, including infrastructure	M						
PG02	*Marine fish and shellfish harvesting causing reduction of species/prey populations and disturbance of species (recreational)*							

H: Military action, public safety measures, and other human intrusions

The main pressure of High importance in this category is H06, restricted access, which is listed for three of the four species of protected fish: Sea and river lamprey (zee- en rivierprik) and Twait shad (Fint), which is related to the blocking of migration pathways between salt and fresh water. This blocking is mainly associated with the water management infrastructure, represented by Sector O (Government).

Most of the pressures in this section can be linked to SBI sector A: Agriculture, Forestry and Fishing. An interesting exception might be pressure A06 (abandonment of grassland). Since this concerns areas that are no longer used for agricultural purposes, but instead have become part of nature areas, one might associate this pressure with sector O (Public administration, Government, etc.).

Table 50. (continued).

Pressure/threat (2013-2018)		Marine	Coastal	Dunes		Fish	Mammals	Plants
Military action, public safety measures, and other human intrusions								
H01	Military, paramilitary or police exercises and operations on land							
H02	— in the freshwater and marine environment							
H03	Abandonment of terrestrial military or similar exercises (loss of open habitats)							
H04	Vandalism or arson							
H06	Closure or restricted access to site/habitat					H		
H08	Other human intrusions and disturbance not mentioned above					M	M	

I: Alien and problematic species

The intrusion of invasive species is seen as a pressure of high relevance for marine habitat Large shallow inlets (H1160. For example, the Scheldt estuary[68] (partly H1160) is experiencing pests of e.g. *Eriocheir sinensis* (Chinese mitten crab / wolhandkrab) and *Mnemiopsis leidyi* (Warty comb jelly / Amerikaanse ribkwal).

Problematic native species are seen as a pressure of high importance for *Spartina swards* (HH1320). The Article 17 report mentions that >90% of the habitat is dominated by *Spartina anglica* (Common cordgrass / Engels slijkgras), a young species developed through hybridization of *Spartina maritima* (Small cordgrass; Klein slijkgras) and the non-native *Spartina alterniflora (smooth cordgrass)*.

Both examples of alien species are introduced through ballast water, which suggest an association with NACE Sector H (Transportation).

Interestingly enough, the impact of invasive species on protected native species, either directly, or indirectly, through the food web, was not reported as a major pressure.

Most of the pressures in this section can be linked to SBI sector A: Agriculture, Forestry and Fishing. An interesting exception might be pressure A06 (abandonment of grassland). Since this concerns areas that are no longer used for agricultural purposes, but instead have become part of nature areas, one might associate this pressure with sector O (Public administration, Government, etc.).

Table 50. (continued).

Pressure/threat (2013-2018)		Marine	Coastal	Dunes	Birds	Fish	Mammals	Plants
Alien and problematic species								
I01	Invasive alien species of Union concern							
I02	Other invasive alien species (other then species of Union concern)	H		M				
I04	Problematic native species		H					
I05	Plant and animal diseases, pathogens and pests							

[68] The Scheldt Estuary is formally outside of the scope of the current study. The reporting under Articles 12 and 17 is, however, on the level of habitats and species, and does not distinguish between North Sea, Wadden Sea and the estuaries.

J: Mixed source pollution

This category includes different types of pollution of various origins. It is listed as a main pressure of high importance for habitats Sandbanks (H1110) and Grey Dunes (H2130).

Per definition, pollution should only be reported under this category when the key driver of the pollution is unclear or where pollution is related to several causes. As a result, this pressure cannot be associated with a single economic sector (although a list of sectors could be identified that emit the relevant pollutants).

Most of the pressures in this section can be linked to SBI sector A: Agriculture, Forestry and Fishing. An interesting exception might be pressure A06 (abandonment of grassland). Since this concerns areas that are no longer used for agricultural purposes, but instead have become part of nature areas, one might associate this pressure with sector O (Public administration, Government, etc.).

Table 50. (continued).

Pressure/threat (2013-2018)		Marine	Coastal	Dunes	Birds	Fish	Mammals	Plants
Mixed source pollution								
J01	Mixed source pollution to surface and ground waters (limnic and terrestrial)				M			
J02	Mixed source marine water pollution (marine and coastal)	H					M	
J03	Mixed source air pollution, air-borne pollutants			H				
PK04	*Atmospheric N-deposition*							

K: Human-induced changes in water regimes

This is one of the more important categories, with pressures affecting all habitat groups and both fish and birds. Most individual pressure mechanisms relate to drinking water production (K01) water management (K03–3) and large-scale land use change (K05).

In most cases, the main direct causes of changes in water regime can be associated with Sector O (Government), either on a national scale (marine spatial planning), or on the regional scale (provincial government and regional water authorities). One notable exception is the abstraction of drinking water, causing desiccation of humid dune slacks (H2190), which is associated with Sector E (Water Supply).

Most of the pressures in this section can be linked to SBI sector A: Agriculture, Forestry and Fishing. An interesting exception might be pressure A06 (abandonment of grassland). Since this concerns areas that are no longer used for agricultural purposes, but instead have become part of nature areas, one might associate this pressure with sector O (Public administration, Government, etc.).

Table 50. (continued).

Pressure/threat (2013-2018)		Marine	Coastal	Dunes	Birds	Fish	Mammals	Plants
Human-induced changes in water regimes								
K01	Abstraction from groundwater, surface water or mixed water			H				
K02	Drainage							
K03	Development and operation of dams				H			
K04	Modification of hydrological flow	H	H		H			
K05	Physical alteration of water bodies	H			H	H		
PL03	*Old barriers or other obsolete infrastructures*							

L: Natural processes (excluding catastrophes and processes induced by human activity or climate change) Taken together[69] with: M: Geological events, natural catastrophes

This category includes various ecological processes, such as succession and competition. Due to the absence of human impact, no association with economic sectors can be made. However, it is possible to use a special pseudo-sector "Environment".

Most of the pressures in this section can be linked to SBI sector A: Agriculture, Forestry and Fishing. An interesting exception might be pressure A06 (abandonment of grassland). Since this concerns areas that are no longer used for agricultural purposes, but instead have become part of nature areas, one might associate this pressure with sector O (Public administration, Government, etc.).

Table 50. (continued).

Pressure/threat (2013-2018)		Marine	Coastal	Dunes	Birds	Fish	Mammals	Plants
Geological events, natural processes and catastrophes								
L01	Abiotic natural processes (e.g. erosion, silting up, drying out, submersion, salinization)		M	M				
L02	Natural succession resulting in species composition change (other than by direct changes of agricultural or forestry practices)		H	H	H			H
L03	Accumulation of organic material		M	M				M
L04	Natural processes of eutrophication or acidification			M				M
L06	Interspecific relations (competition, predation, parasitism, pathogens)				H			
L07	Absence or reduction of interspecific faunal and floral relations (e.g. pollinators)			H	M			
M02	Tidal waves, tsunamis							
M07	Storm, cyclone							
M08	Flooding (natural processes)							
M09	Fire (natural)							

N: Climate change

This category includes various mechanisms by which climate change affects habitats and species. The most relevant individual pressures are sea level change, impacting especially the pioneering stage of salt marshes (H1310, Salicornia and other annuals colonizing mud and sand), change in habitat extent (size), condition (quality) and location (impacting especially Porpoises), and desynchronization of ecological processes (e.g., food supply), also impacting Porpoises.

Although climate can be, and has been in the past, a natural phenomenon, the current climate change of unprecedented magnitude and speed is almost entirely man-made. As with Mixed source pollution, not a single economic sector can be held responsible.

Most of the pressures in this section can be linked to SBI sector A: Agriculture, Forestry and Fishing. An interesting exception might be pressure A06 (abandonment of grassland). Since this concerns areas that

[69] Because of the clustering in the new 2024 classification, see Table 46.

are no longer used for agricultural purposes, but instead have become part of nature areas, one might associate this pressure with sector O (Public administration, Government, etc.).

Table 50. (continued).

Pressure/threat (2013-2018)		Marine	Coastal	Dunes	Birds	Fish	Mammals	Plants
Climate change								
N01	Temperature changes (e.g. rise of temperature & extremes) due to climate change	(M)			M			
N02	Droughts and decreases in precipitation due to climate change							(M)
N04	Sea-level and wave exposure changes due to climate change	M	H	M	M			
N05	Change of habitat location, size, and / or quality due to climate change						H	
N06	Desynchronisation of biological / ecological processes due to climate change				M		H	
N07	Decline or extinction of related species (e.g. food source / prey, predator / parasite, symbiote, etc.) due to climate change				(M)			
N08	Change of species distribution (natural newcomers) due to climate change	M			M			
N09	Other climate related changes in abiotic conditions						M	

X Unknown pressures, no pressures and pressures from outside the Member State

This last category includes mainly “imported” pressures. For example, for *Mareca penelope* (Eurasian wigeon / Smient) the decline of breeding effort in Northern-Europe is listed as a medium impact pressure. For *Recurvirostra avosetta* (Pied Avocet / Kluut) pressures from outside EU, such as habitat loss, pollution and hunting outside of the EU, are listed as main pressure (*medium impact*). For *Uria aalge* (Common Guillemot / Zeekoet) the breeding effort, affected by changes in food availability due to climate change and overfishing, is listed as a foreign pressure.

In terms of economic sectors, and in accordance with the accounting principles of both SNA and SEEA, these pressures can be recorded under the pseudo-sector “Import”.

Most of the pressures in this section can be linked to SBI sector A: Agriculture, Forestry and Fishing. An interesting exception might be pressure A06 (abandonment of grassland). Since this concerns areas that are no longer used for agricultural purposes, but instead have become part of nature areas, one might associate this pressure with sector O (Public administration, Government, etc.).

Table 50. (continued).

Pressure/threat (2013-2018)		Marine	Coastal	Dunes	Birds	Fish	Mammals	Plants
Unknown pressures, no pressures and pressures from outside the Member State								
Xe	Threats and pressures from outside the EU territory				M			
Xo	Threats and pressures from outside the Member State				M			

5.5.5 Synthesis

An initial effort is made to integrate the results of above sections (Table 51). For each pressure factor the total number of habitats and species are counted, where high-impact pressures count double. A weighted total impact is obtained by relating the counts to the number of habitats (12) and species (47) involved, and averaging[70]. Each pressure is associated with one or more economic sectors. In the case of mixed-source pollution and climate change no clear link with individual sectors can be established (but see the discussion, Section, 9.4).

[70] Note that this step ignores the double counting of high-impact pressures. This is subject for future research

When combining the (weighted) impacts of pressures with the distribution across sectors, one sector that stands out is the government (O), which is strongly associated with high-impact pressures such as land use change planning and water management.

Table 51. Synthesis of pressure factors, impacted habitats and species, and associated economic sectors. Percentages in bold ('weighted'') are the average of the fraction of habitats and species impacted.

Pressure/threat		Impacted Habitats		Impacted Species		Weighted	Sector: Agriculture A	Fishing A	Mining B	Manufacturing C	Energy supply D	Water, waste E	Construction F	Transport H	Accommodation, food I	Real estate services L	Specialist services M	Government O	Sports & Recreation R	Households T	Import	Environment
Agriculture related practices																						
A02	Conversion of agricultural land use			1	2%	**1%**	x															
A06	Abandonment of grassland management	2	17%			**8%**												x				
A08	Mowing or cutting of grasslands			2	4%	**2%**	x															
A10	Extensive grazing or undergrazing	1	8%			**4%**	x															
A13	Reseeding of grasslands			1	2%	**1%**	x															
A16	Other soil management practices			1	2%	**1%**	x															
A19	Application of natural fertilisers			1	2%	**1%**	x															
A20	Application of synthetic fertilisers			1	2%	**1%**	x															
A21	Use of plant protection chemicals			1	2%	**1%**	x															
A26	— generating diffuse pollution to water			1	2%	**1%**	x															
A27	— generating air pollution		0%	2	4%	**2%**	x															
Forestry related practices																						
Extraction of resources (minerals, peat, non-renewable energy resources)																						
C01	Extraction of minerals	1	8%			**4%**			x								(x)					
C02	Extraction of salt	1	8%			**4%**			x								(x)					
C03	Extraction of oil and gas, including infra	1	8%	3	6%	**7%**			x								(x)					
Energy production processes and related infrastructure development																						
D01	Wind, wave and tidal power, including infra			11	23%	**12%**					x		(x)				(x)					
Development and operation of transport systems																						
E01	Roads, paths, railroads and related infra			1	2%	**1%**												x				
E02	Shipping lanes and ferry lanes transport operations			8	17%	**9%**								x								
E03	Shipping lanes, ferry lanes and anchorage infra	2	17%	12	26%	**21%**							x									
E06	— generating air pollution			2	4%	**2%**							x									
Development, construction and use of residential, commercial, industrial and recreational infrastructure and areas																						
F03	Land use conversion to commercial / industrial			1	2%	**1%**							(x)					x				
F05	Development of sports, tourism and leisure infra			1	2%	**1%**							(x)		x	x		x	x			
F06	Maintenance of beach areas for leisure	2	17%	4	9%	**13%**												x	x			
F07	Sports, tourism and leisure activities			24	51%	**26%**								x					x	x		
F08	Coastal protection etc	3	25%	4	9%	**17%**												x	x			
F21	Ind. or com. activities generating marine pollution	1	8%			**4%**			?	?	?	?	?	?	?	?	?					
F24	Res. or rec. activities generating physical pollution	4	33%			**17%**														x		
Extraction and cultivation of biological living resources (other than agriculture and forestry)																						
G01	Fishing causing reduction / disturbance of pecies	1	8%	20	43%	**25%**		x														
G03	Fishing causing loss and disturbance of habitats	5	42%	4	9%	**25%**		x														
G05	Freshwater fish and shellfish harvesting			6	13%	**6%**		x														
G12	Bycatch and incidental killing			5	11%	**5%**		x														
G17	Introduction and spread of species in m. aquaculture	1	8%			**4%**		x														
G19	Other impacts from marine aquaculture	1	8%			**4%**		x														
Military action, public safety measures, and other human intrusions																						
H06	Closure or restricted access to site/habitat			6	13%	**6%**												x				
H08	Other human intrusions and disturbance			2	4%	**2%**												x				
Alien and problematic species																						
I02	Other invasive alien species	5	42%			**21%**								x								
I04	Problematic native species	2	17%			**8%**								(x)								x
Mixed source pollution																						
J01	Mixed source pollution to water			1	2%	**1%**	?	?	?	?	?	?	?									
J02	Mixed source marine water pollution	4	33%	1	2%	**18%**	?	?	?	?	?	?	?									
J03	Mixed source air pollution, air-borne pollutants	3	25%			**13%**	?	?	?	?	?	?	?									
Human-induced changes in water regimes																						
K01	Abstraction from ground. surface or mixed water	2	17%			**8%**						x						x				
K03	Development and operation of dams			20	43%	**21%**												x				
K04	Modification of hydrological flow	7	58%	13	28%	**43%**												x				
K05	Physical alteration of water bodies	4	33%	11	23%	**28%**												x				
Geological events, natural processes and catastrophes																						
L01	Abiotic natural processes	3	25%			**13%**																x
L02	Natural succession	5	42%	10	21%	**31%**																x
L03	Accumulation of organic material	2	17%	1	2%	**9%**																x
L04	Natural eutrophication or acidification	1	8%	1	2%	**5%**																x
L06	Interspecific relations			7	15%	**7%**																x
L07	Reduction of interspecific faunal and floral relations	2	17%	1	2%	**9%**																x
Climate change																						
N01	Temperature changes			1	2%	**1%**	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?
N02	Droughts etc						?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?
N04	Sea-level and wave exposure changes	5	42%	2	4%	**23%**	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?
N05	Change of habitat location, size, and / or quality			2	4%	**2%**	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?
N06	Desynchronisation of ecological processes			2	4%	**2%**	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?
N07	Decline or extinction of related species						?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?
N08	Change of species distribution	2	17%	3	6%	**12%**	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?
N09	Other climate related changes in abiotic conditions			1	2%	**1%**	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?
Unknown pressures, no pressures and pressures from outside the Member State																						
Xe	Threats and pressures from outside the EU			2	4%	**2%**															x	
Xo	Threats and pressures from outside the MS			1	2%	**1%**															x	

5.6 Detailed analysis of individual pressure factors

In this section we look more in detail to several specific pressures factors, related to wind energy, bottom trawling fishing, eutrophication and pollution, as examples of how these pressure accounts can be used to provide policy relevant information. Wind energy and fishing are choses because they play a dominant role in the current societal debate on the North Sea, which focuses one three major transitions: nature, food (fishing) and energy (offshore wind farms)[71]. Eutrophication and pollution are chosen because they reflect 'classical' environmental pressures as recognised in the SEEA Central Framework, and are well embedded in the environmental accounts developed by Statistics Netherlands.

5.6.1 Wind energy

Offshore wind energy production produces basically two types of pressures. One type occurs above the water surface, as the ever-larger scale of the wind turbines poses a risk to migrating birds. A second type of pressure occurs under water, and is related to the alteration of the sea bed through the foundational structures for the wind turbines. This creates a different artificial habitat, and it potentially also influences currents and wave patterns. In addition to these, another possible pressure source is the noise created by the wind turbines, both above and under the water surface.

Offshore wind energy production produces basically two types of pressures. One type occurs above the water surface, as the ever-larger scale of the wind turbines poses a risk to migrating birds. A second type of pressure occurs under water, and is related to the alteration of the sea bed through the foundational structures for the wind turbines. This creates a different artificial habitat, and it also influences currents and wave patterns. In addition to these, another possible pressure source is the noise created by the wind turbines, both above and under the water surface, and both during the construction phase (pile driving) and the operational phase (ambient noise).

Introduction

Offshore wind energy is regarded to be the major source of sustainable and affordable energy for the Netherlands to meet the climate targets as set out in the Paris Climate agreement. The generation of wind energy itself can be regarded an (abiotic) ecosystem service, see Section 7.5.3.

The generation of wind energy is however not without cost to the environment. Construction and operation of OWFs lead to several types of environmental pressures. Boon et al. (2018) provides an overview of potential effects:

- **Wind and waves.** Wind farms interact with the wind in three different ways:
  - They harvest wind energy and thereby slow down the wind velocity;
  - they mix the atmosphere and increase the turbulence intensity;
  - they are obstacles deflecting the wind around them, which causes the wind to slow down upstream of the turbine and to speed up around the turbine.

  Subsequently, these processes affects wave propagation and dissipation.

[71] https://www.noordzeeoverleg.nl/noordzeeakkoord/default.aspx

- **Tides and currents.** Wind farms obstruct water flow which changes local flow velocities and can lead to an increase in vertical mixing, while the associated production of turbulence may also lead to an increase in the dissipation of tidal energy.
- **Suspended matter and morphodynamics.** Offshore wind farms affect the vertical distribution and lateral transport of suspended particulate matter (SPM) as a result of the effect of OWFs on bed shear stress, turbulence, currents, vertical mixing and erosion/deposition processes. A second effect is on bed forms and sedimentology.
- **Ecology.** The impacts of the large-scale development of OWFs on the ecology of the North Sea can theoretically be extensive and significant. Priority risks are expected to be:
    - Destratification may lead to significant changes in the timing and spatial distribution of primary production, which may propagate into secondary production (zooplankton and benthos).
    - Feeding activities from epistructural fauna (e.g. mussels) on the offshore wind farm foundations may significantly decrease phytoplankton densities affecting in turn zooplankton densities.
    - Changes in wave height leeward of OWFs extend over tens of kilometres and may also affect the upper water layer mixing. In shallow coastal areas, such changes in wave heights may impact density driven transport of suspended matter and influence the mixing of fresh (riverine) water mixes with salt (marine) water, with impacts on primary production and shellfish production.
    - The stepping-stone effects from the OWFs may lead to genetic homogenisation and to the spread of species beyond their natural boundaries. This specifically holds for non-endemic species that are found in the intertidal zone of OWF foundations.

  However, Boon et al. (2018) warn that, the uncertainties about the net effect are large because various effects may counteract each other.

Additional pressures associated with OWFs include:

- **Underwater Noise and Vibration.** Construction and operation of wind farms can produce underwater noise and vibration, which may affect some marine species' behavior and migration patterns. Especially porpoises, seals and fish larvae are affected.
- **Collision Risks for Birds and Bats.** Offshore wind turbines can pose collision risks for migrating birds and bats, potentially leading to fatalities.
- **Other:** Including habitats loss of seabirds and effects of electromagnetic fields on benthos and fish (van Duren et al., 2021).

However, there are also some ecological advantages due to the construction and operation of wind farms. For example, because fishing is generally prohibited in offshore wind parks, these areas may contain more and larger fish, and therefore may become an attractive foraging and resting location for birds. Also, because (due to fishing activities in the past) there is virtually no hard substrate found in many parts of the DCS, the foundations of OWFs provide an opportunity for species that favour hard substrate.

While the full breadth of these effects on marine ecosystems of the North Sea is currently the scope of the WOZEP (*Wind op zee ecologisch programma*) research programme, this Ecosystem Account focuses on relevant data on the existing OWF installations, that is, wind farm area, and the number and size of the turbines within them.

Available data

As (Figure 28) shows, the last 20 years have seen a rapid increase in the number of offshore wind farms (OWFs) on the DCS, with the development of wind farms Egmond (2006), Amalia (2008), Luchterduinen (2015), Gemini (2017) and most recently, Borssele (2021).

For the measurement of the environmental pressures related to wind energy, there are two rough statistics available. These are the rotor surface (m^2) and the ground surface (km^2) of OWFs (Figure 29). Compared to the overall surface area of the Dutch North Sea, the total ground surface of the OWFS is relatively small, with 471 km^2 for 2021 (approx. 0.8% of the DCS). However, on the one hand the sea floor area that is physically affected (i.e. the turbine fundaments) is much smaller, while on the other hand the area in which (water) conditions are affected. e.g. wake effects, might be much larger,

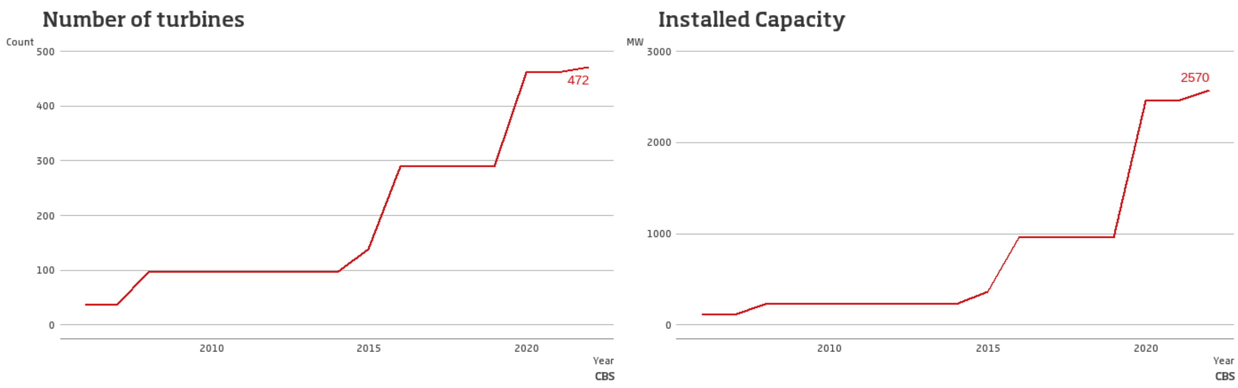


Figure 28. Number of wind turbines installed on the DCF, and their total nominal capacity. Data: CBS

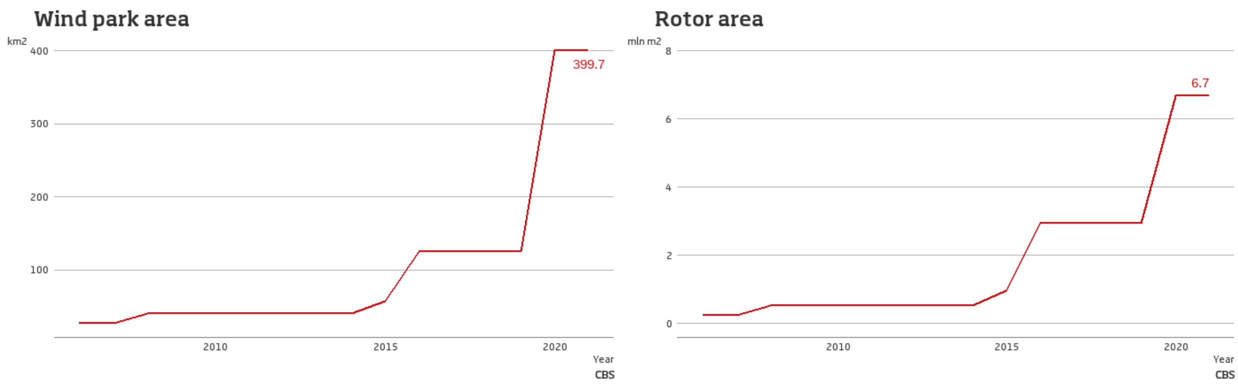


Figure 29. Wind park area and total rotor area for wind turbines installed on the DCS. Data: CBS

Future prospects

However, these numbers dwarf in the context of planned wind parks. The current policy is to develop an additional[72] 2.1 GW until 2023 (+850% of current installed capacity), resulting in 3–4 times the current number of turbines (depending on capacity, assuming 11–14MW), 8–10 times the current rotor area (assuming 0.3–0.4 MW/1000m^2) and total area of 5.5–9 times the

[72] The older existing OWFs will be decommissions, though.

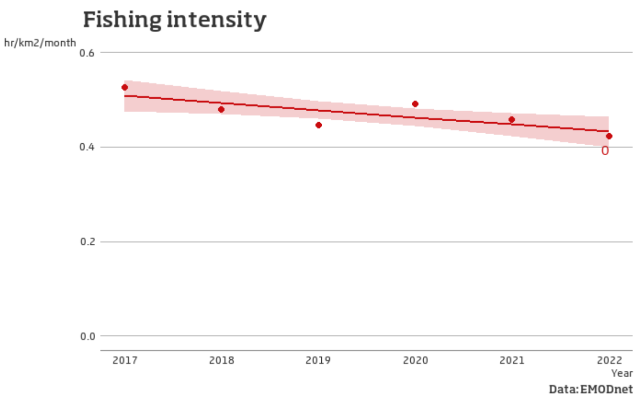
current total footprint area (assuming a turbine density of 5–8 MW/km^2), resulting in a total spatial claim of 4.5–7.3% of the DCS. In the more distant future, 60 GW installed capacity is assumed, which may require up to 15–20% of the DCS.

The impact of these developments on the biodiversity of the Dutch North Sea will depend on the precise implementation and the choice of mitigating measures. Currently, offshore wind farms are reported as major pressure for three species of protected mammals and five species of protected birds. For the future, wind energy is reported as a threat for another twelve species of birds.

5.6.2 Bottom Trawling

Fishing exerts significant pressure on marine ecosystems, if only because, by definition, it removes part of the biomass stock. In the Dutch part of the North Sea, bottom trawling is the dominant type of fishery, targeting mainly sole and plaice (see Section 7.2.1), but also shrimp. While from an ecosystem services perspective the volumes of fish caught is of interest, from a pressure point of view the fishing *intensity* is more relevant, because of the impact on sea bottom habitat, which is the type pressure we focus on in this section.

Automatic Identification Systems (AIS) provide a means to gather information on marine traffic. In Section 7.6.1 this data source is used to quantify marine shipping (see there for more background information).Because "Fishing" is of one of the 12 vessel types recognized, and because the actual fishing activity dominates the hours spend on sea, this data set is used as a proxy for fishing intensity. The results suggest that shipping showed a steady decrease of about 20% during the period 2017–2022 (Figure 30). The broader (transport services) analyses suggested that during that same period Fishing represented 10–14% of all marine shipping.



Year	Intensity hr/km^2/month	Index
2017	0,526	100%
2018	0,480	91%
2019	0,447	85%
2020	0,492	93%
2021	0,458	87%
2022	0,422	80%

Figure 30. Average fishing intensity on the DSC, expressed as hours per km^2 per month. Data: EMODnet.

EMODnet provides separate maps for fishing intensity, again based on AIS data, and expressed in 'mW fishing hours' for several types of fishing gears. These data are only available for a few years, i.e. 2020 to 2022. The maps for beam trawling (the type of gears used for sole and plaice, and damaging the sea bottom), show a large spatial variability in fishing intensity, with high intensities located near the coast (associated with shrimp fishing) and in the south west, and low intensities off the coast of the Wadden islands (the so-called "Plaice Box", where beam trawling above 300hp is prohibited) and in the deep water of the central oyster grounds (Figure 31).

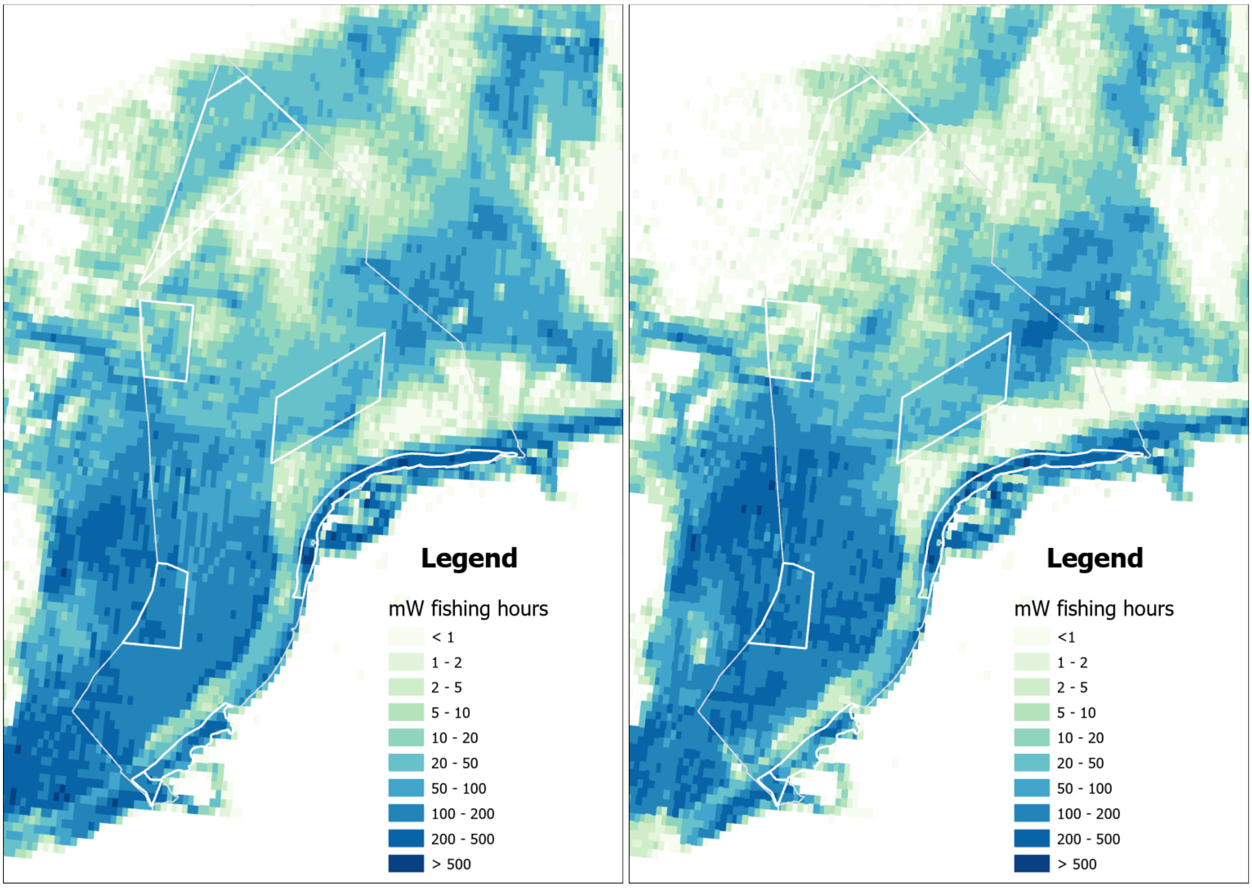


Figure 31. Fishing intensity (beam trawling only) for 2020 (left) and 2022 (right). Data: EMODnet.

The maps also suggest marked changes between these two years. An additional GIS analysis revealed that this is the case. While total (DCS –scale) beam trawling intensity has increased with 10%, intensities in some of the N2000 has been strongly decreasing, notably the *Voordelta*, *Klaverbank* and *Doggersbank*. Also note that some N2000 sites are among the most intensely fished areas, especially the *Noordzeekustzone*. Interestingly enough, the *Bruine bank* and *Friese Front* sites have experienced an increase of almost twice the DCS average.

Table 52. Mean fishing intensities within the Dutch Continental Shelf (DCS) as a whole, and within the individual N2000 sites. Data: EMODnet

Site	**Fishing intensity (mW hours)**		
	2020	2022	change
Noordzeekustzone	298,7	262,2	-12%
Bruine Bank	155,9	184,7	18%
Vlakte van de Raan	166,9	153,2	-8%
Voordelta	138,1	85,8	-38%
DCS	**69,3**	**76,1**	**10%**
Friese Front	45,9	53,9	17%
Klaverbank	28,5	13,0	-54%
Doggersbank	22,8	8,1	-64%

5.6.3 Eutrophication

Eutrophication is regarded to be a pressure factor for the North Sea, resulting in for example harmful algae blooms. The Dutch emission registration (ER) compiles basic statistics on emissions of several pollutants to both air and water, including information on the economic sector and the production process responsible for the emissions. Data are available for a suite of spatial units, and reported annually, up to 2021. In addition, the ER compiles statistics on influxes from the main rivers (Rhine, Meuse, Scheldt). These data are available every 5 years.

In this section we analyse the emissions of nitrogen (total N) and phosphorous (total P) to the surface water. It is assumed that all surface water will flow towards the North Sea eventually.

Nitrogen

In the Netherlands, the main (recent, 2021) source of total nitrogen (N) emissions to the North Sea is the influx from abroad by the main rivers (240 kton; 64% of total emissions), followed by atmospheric deposition (60 kton; 16%), agriculture (40 kton; 11%), sewage (5%) and leaching from nature areas (4%). All other sources contribute less than 1%. Total load of Nitrogen has been declining with 38% since 1990, or with 48% since the peak load in 1995.

Direct emissions to the North Sea are 10% of the total load, consisting of atmospheric depositions (37 kton) only.

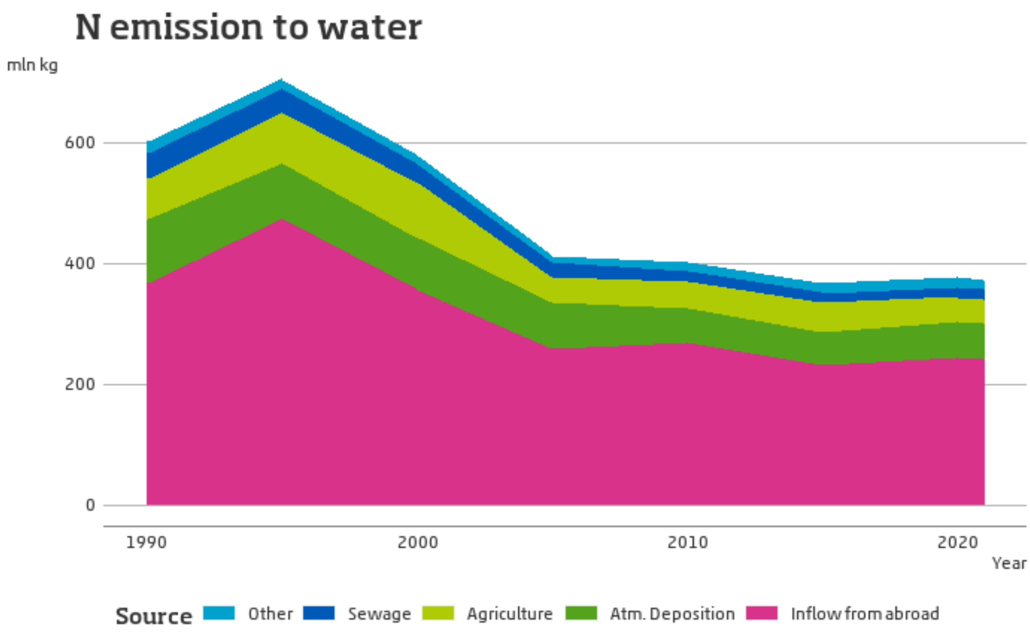


Figure 32. Emissions of total nitrogen to water (including riverine influxes from abroad). Data source: Emission Registration

Most of the individual sources of nitrogen have been declining since 1990, but this decline has largely halted since approximately the year 2005.

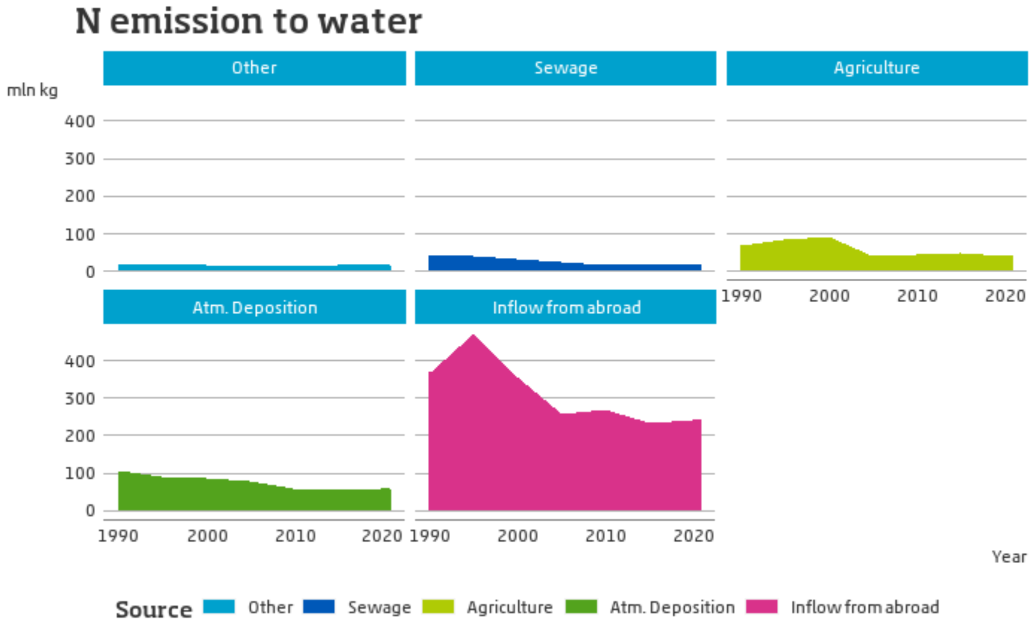


Figure 33. Emissions of total nitrogen to water per main sector. Data source: Emission Registration

Phosphorus

In the Netherlands, the main (recent, 2021) source of total phosphorus (P) emissions to the North Sea is the influx from abroad by the main rivers (10 kton; 58% of total emissions, which is less than for N), followed by agriculture (3.4 kton; 20%), sewage (13%) and leaching from nature areas (8%). All other sources contribute less than 1%. Direct emissions to the North Sea are negligibly small. The total load of phosphorous has been declining with 60% since 1990.

In the recent past, the chemical industry used to be a major emitter of phosphorous, contributing 24% of the total load in 1990.

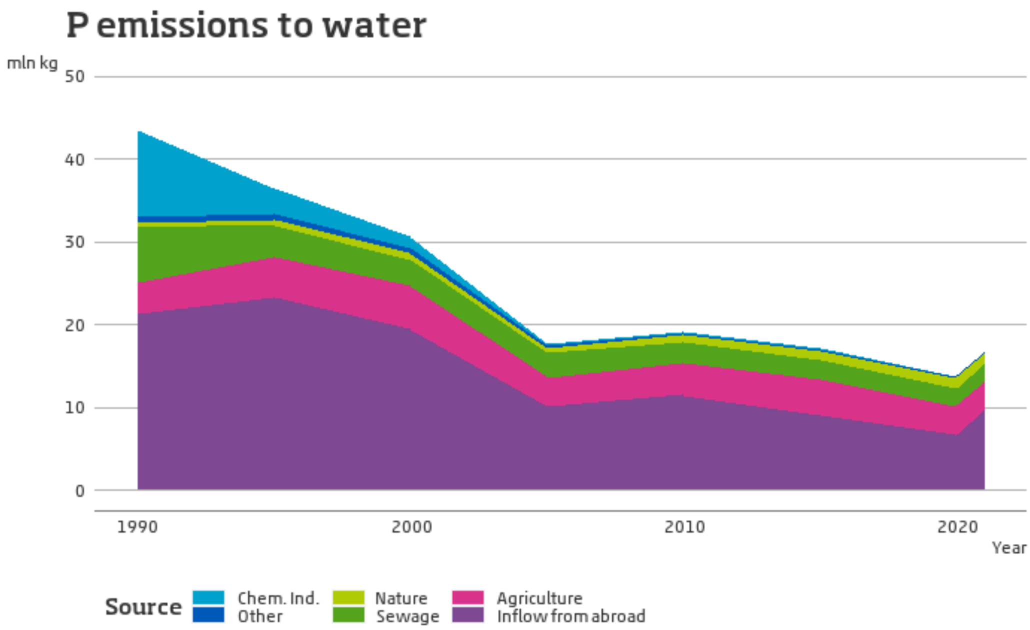


Figure 34. Emissions of total phosphorus to water (including riverine influxes from abroad). Data source: Emission Registration

Since 1990, the emissions from the chemical industry have effectively disappeared. And the influx from abroad has more than halved (but stabilized after approximately the year 2005. The (small) leakage from nature areas has been slightly increasing, and the (larger) emissions by agriculture have been stable.

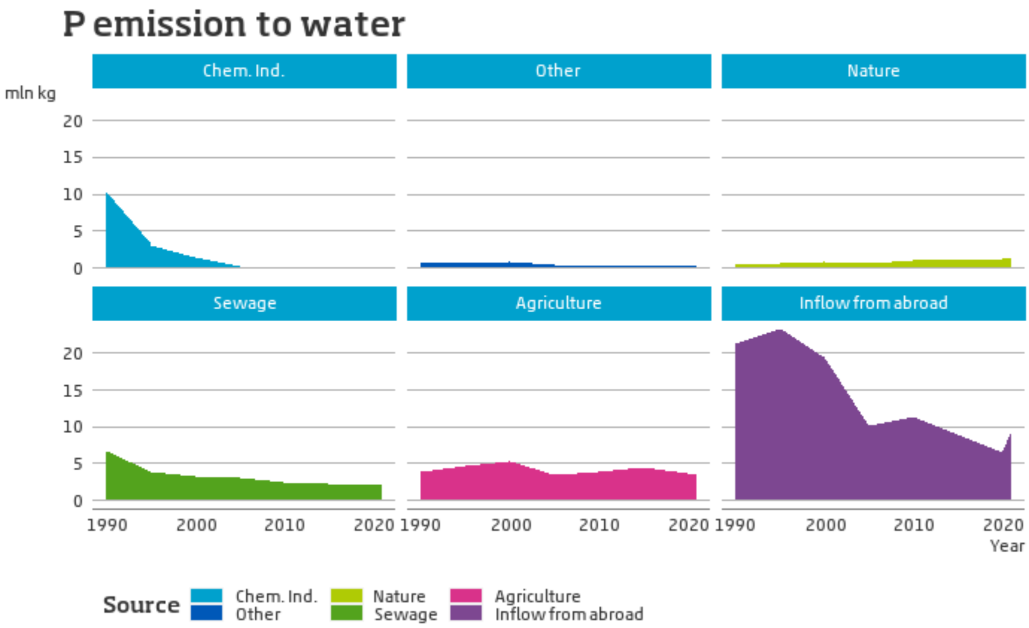


Figure 35. Emissions of total phosphorus to water per main sector. Data source: Emission Registration

5.6.4 Pollution

A major concern for the North Sea, and the wider marine realm, is the pollution by harmful substances. Although the emissions are to a small part due to direct input by coastal or marine sources (e.g. shipping), the majority of the input is from the rivers. OSPAR developed a comprehensive "riverine inputs and direct discharges" (RID) program. Here, we analyzed the reported influx from the rivers and other discharge locations. Note that the RID reports are incomplete: not all substances and not all locations are reported for every year. The year 2020 is not available at all.

Since for many measuring stations no data were reported for 2012 and 2017, and because the resulting low loads of substances severely impacted the analysis, all trend estimates are carried out without these years.

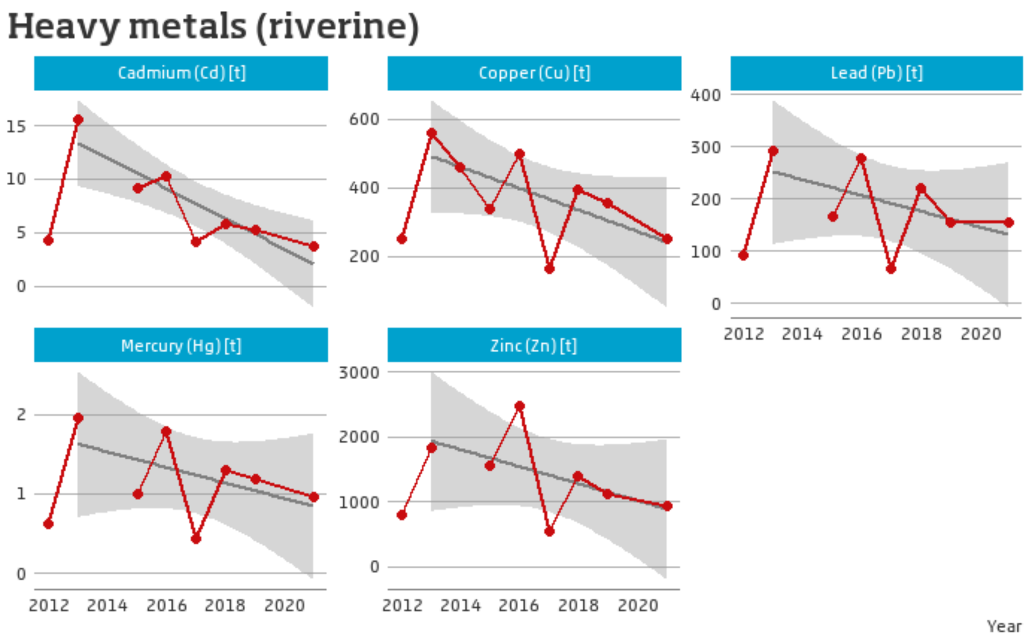


Figure 36. Influx of heavy metals to the North Sea. Data: OSPAR RID

During the period 2012–2021 the influx of heavy metals to the North Sea from rivers and discharge locations within the Netherlands appear to have been declining for all substances. Based on a linear trend analysis the changes vary between −80% (p=0.004) for Cadmium to −46% (p=0.028) for Copper. Note that the inter-annual variability is large and not all trends are significant at even the modest p=0.1 level (e.g. Lead, Mercury, Zinc).

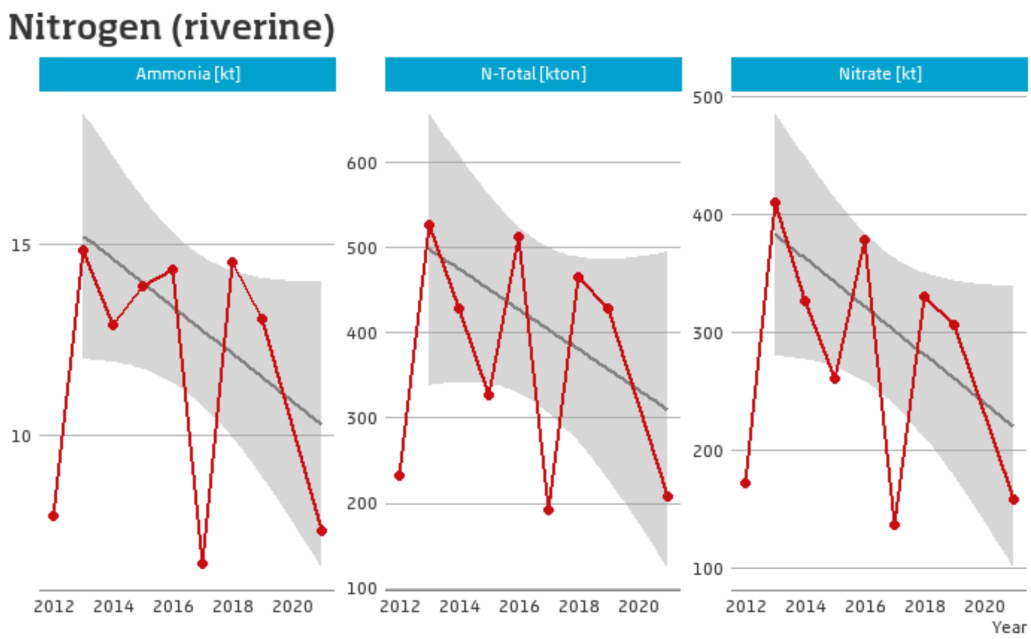


Figure 37. Influx of nitrogen to the North Sea. Data: OSPAR RID

For nitrogen input the picture is the same as for heavy metals, with the time series suggesting a (non-significant) decline of N total (−40%; p=0.15). Nitrate (NO_3) appears to be declining faster (−43%; p=0.07) than ammonium (NH_4) (−32%; p=0.08). But again, the variability is probably too large to distinguish these trends.

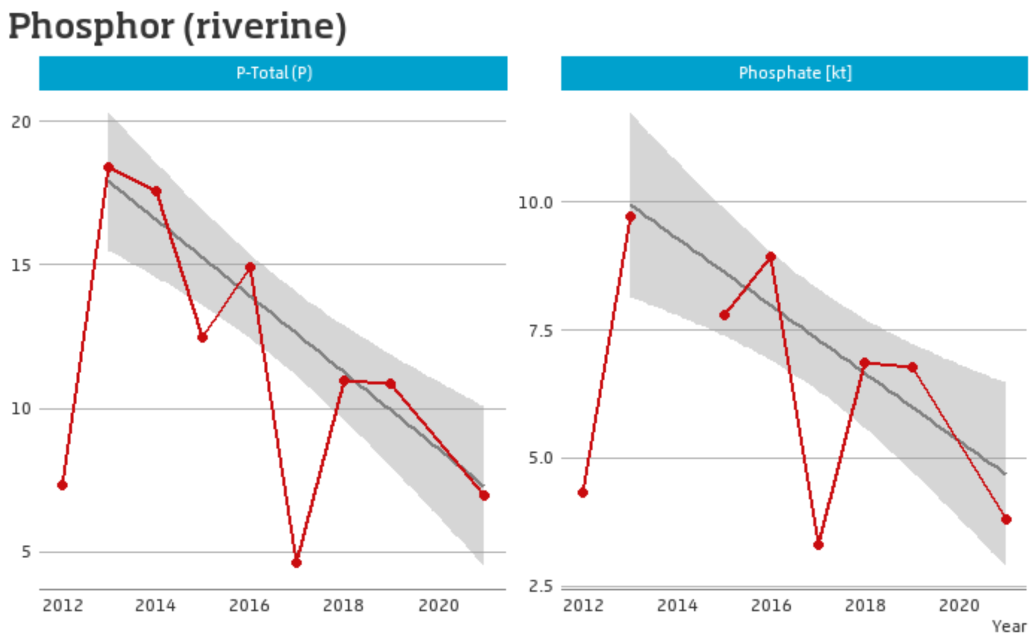


Figure 38. Influx of phosphor to the North Sea. Data: OSPAR RID

Also phosphor shows a declining trend, both in P-Total (−59%; p=0.001) and phosphate (PO_4) (−53%; p=0.08).

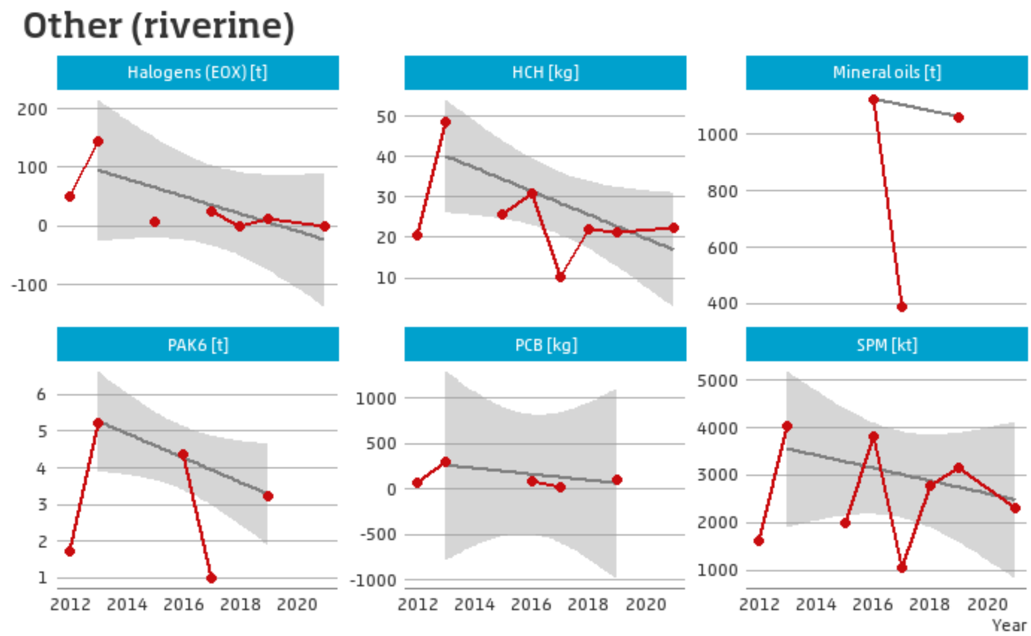
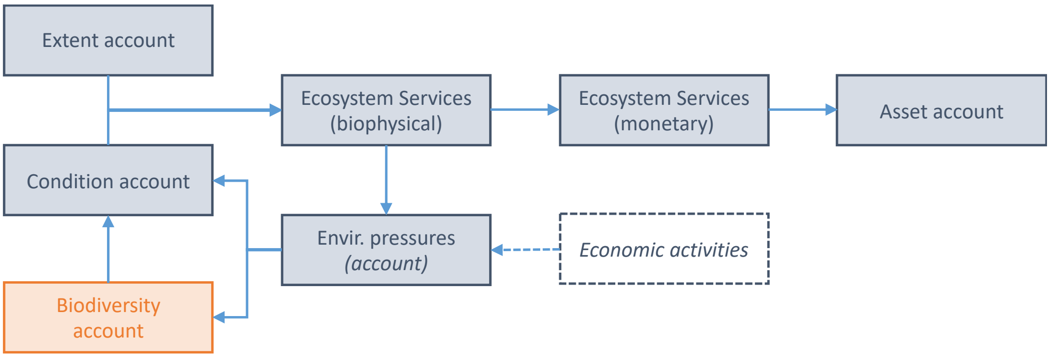


Figure 39. Influx of other substances to the North Sea. Data: OSPAR RID

The trends in other harmful substances vary, with the largest decline (≈−100%; p=0.14) for halogens, followed by HCH (−58%; p=0.052) and PAKs (−38%; p=0.054). All other trends are insignificant at the p=0.1 level.

6. Biodiversity



6.1 Introduction

. Biodiversity indicators are increasingly used to monitor trends in biodiversity at various habitats and scales, the most popular being the combined population trends of individual species (Gregory et al., 2005). Such multi-species indicators (MSI) have the advantage of being relatively insensitive to the fluctuations of individual species, thus helping scientists, conservationists and decision makers to better understand the dominant factors influencing biodiversity in a region, country, continent or the entire biosphere. Until now the development of MSIs has mainly focused on methods to calculate the mean index of species, of which the geometric mean of species indices appears one of the most appropriate to use (van Strien et al., 2012). Popular examples of MSIs include the global Living Planet Index, the European Grassland Butterfly Indicator, and the European Wild Bird Indicators.

The MSI's presented in this report have the same objective as the Living Planet Index (LPI) published by WWF (WWF 2022) in that report they describe the mean population development in the selected species. There are some technical differences, that don't affect the essence of the indicator. The most essential aspect affecting the usefulness of MSIs (including the LPIs) is the selection of species. The most useful indicators consist of species that are typical for a specific ecosystem or habitat, or species that may be expected to have common drivers for population development, for instance species that are sensitive to climate change, to protection measures, or to pollution.

The MSI's in this report concern species found in geographical areas that represent different ecosystems (e.g. coastal zone, offshore) and species groups representing different trophic levels within the ecosystem (benthos, fish, birds, harbour porpoises), making them highly indicative of any changes or disturbances in the marine environment. Species selection is data-driven: all species of the species group for which a time series is available are included. For bird indicators time series with uncertain trend classification (caused by large standard errors in relation to the trend value) were not included. For benthos indicators also genera with time series with an uncertain trend were included, in order to let the indicator represent this large species group better. Many benthos species have uncertain trends because their presence is irregular due to population dynamics.

Fish is the species group which is under the direct influence of human activity as they are actively caught for economic purposes. The marine food web is thus directly influenced by fishing. The indicator on sea fish contains most species that are caught commercially. In addition the indicator on northern and southern fish species is included in this report as it links climate change as pressure factor to the North Sea biodiversity.

Birds are a very convenient species group for monitoring the state of nature in an area. Although changes in nesting opportunities on land may affect their populations, sea birds by definition depend on food availability at sea. In addition, most species are at the top of the food web, so disturbances or other changes in the food web are likely to be reflected in bird populations. There are also political reasons that make birds a relevant group to take into account: the European Birds Directive and, especially for seabirds, the MSFD. In the context of these regulations EU Member States have to report every six years on the population status and trend of regularly occurring birds. As a consequence, the data collection for birds is well organized with standardized monitoring methods.

Benthic macrofauna regulate important biogeochemical properties and ecosystem functions in benthic environments, especially at the sediment-water interface (e.g. distribution of organic matter, mineralization of organic matter; Norling et al., 2007). They are also an important player in the marine food web, as they form the link between primary producers and detritus and higher trophic levels. Consequently, any alterations in organic waste (such as eutrophication) and chemical waste directly affect the nutritional quality and quantity of organic matter fluxes, rendering benthic macrofauna susceptible to these changes (Campanyà-Llovet et al., 2017).

Additionally, human activities, either direct, such as bottom trawling fisheries and mineral extraction / suppletion, or indirect, such as climate change, leave their mark on the abundances of benthic macrofauna. Offshore benthic communities, in particular, are highly vulnerable, since they experience minimal natural disturbances (Van Denderen, 2015).

The Biodiversity Account for the North Sea will be based on the same multi-species indicators (MSI) as used for the Living Planet report on marine fauna. Besides the overall index (Section 6.4.4) indices are developed for fish, benthic macrofauna, sea birds and harbour porpoises, both in- and outside the coastal zone.

6.2 Data sources

6.2.1 Benthic macrofauna

Offshore

Data related to offshore benthic macrofauna is acquired through the MWTL (*Monitoring Waterstaatkundige Toestand des Lands*) monitoring program of Rijkswaterstaat that samples different stations spread across the DCS area. Monitoring intensity varied through the years with around 20 stations being sampled between 1991–1994, which increased to around 88 stations between 1995–2015, and since 2015 around 140 stations are being sampled each time. Even though more stations are being sampled through the years, the sampling frequency has decreased. In 2011, 2013, 2014, 2016, 2017, and 2020 no sampling took place.

Sampling stations can be located inside or outside the coastal zone (here defined as max. 10m from the shore). A total of 10 stations from 1991-1994, 70 around 1995-2015, and 100 stations from 2015 onwards are located outside the coastal zone, and are included in the offshore MSI.

For the MWTL monitoring, a box-corer was used, , which had a sampling surface of 0.068 m^2 (later increased to 0.078 m^2), a sample was collected once during the first half of each year (before June) at each designated site. The macrofaunal specimens present in each sample were counted to determine their abundance. It is important to note that species determinations were not consistently conducted by the same researchers throughout the monitoring period. To mitigate potential biases arising from changes in the researchers performing the determinations, macrofaunal species were grouped together at the genus level (see Appendix B).

Coastal zone

For the MSI of benthic macrofauna in the coastal zone, data is acquired through three different monitoring programs, MWTL, the WOt-shellfish survey (*Wettelijke Onderzoekstaken*), and the SMP (*strandaanspoel monitoring*) project from the Anemoon Foundation.

As part of the MWTL program around 7 stations were sampled from 1991–1994, which increased to around 17 from 1995–2015, and to around 45 stations from 2015 onwards. Sampling was done in the same way as described for the offshore benthic macrofauna.

The WOt inventory of shellfish has been conducted annually since 1995 at hundreds of locations along dozens of transects crossing and running parallel to the entire Dutch coast. In addition to shellfish, other species are also included. A bottom dredge is used in this process, which samples approximately 15 m^2 of the seabed surface. Sampling was done once during the first half of each year.

The SMP project from the Anemoon Foundation is executed by volunteers since 1994. Fixed transects along the coast are inspected at low tide once every week or two weeks, and species or remains of species are registered. The monitored benthic macrofaunal species mainly reside just off the coast.

Trends based on the WOT-program take precedence over those based on the MWTL box-corer data, since a much larger surface area is sampled with a dredge. SMP data are used for species that are either absent or barely present in the dredge and box-corer data or when the standard error of the trend based on dredge and box-corer data is large (standard error of the trend > 0.15).

Similar to the offshore benthic macrofauna, to prevent species from appearing to decline or improve due to changes in identifications, species that are suspected to be frequently confused are aggregated at the genus level. For example, all species of the *Spisula* genus are counted as a single combined species. This has reduced the total number of distinct taxa in the entire benthic fauna dataset from over 1000 to approximately 360 species and species groups. Nearly 80% of these are distinct species.

6.2.2 Fish

Offshore

Data is collected in the International Bottom Trawl Survey (IBTS) and the Beam Trawl Survey (BTS). Both programs are coordinated by the International Council for the Exploration of the Sea (ICES, Copenhagen) and both programs follow a protocol designed by ICES. The data was downloaded from the DATRAS database of ICES in the autumn of 2022. Not all fish species can be caught with IBTS and BTS; rare species, coastal species, species that live near wrecks and fast swimming species are underrepresented.

Data from the BTS and IBTS surveys is also used for the indicator on the effect of climate change on cold and warm water fish. The indicator suggests a link between the environmental pressure, climate change and sea fish.

The IBTS-program samples the entire North Sea annually using research vessels. The sampling units are ICES rectangles of approximately 56 by 56 km. In principle, in each rectangle the bottom five meters of the water column is fished twice (each time by a different country) a year over a width of 70-90 meters. A standard net (otter trawl) is used. The measurement provides the number of individuals per length class per species per 60 minutes of fishing. Only data collected in rectangles with a depth of less than 200 meters and north of the Channel were used in the analysis. For most fish species, data from the first quarter of 1990 were used. Data from the third quarter was used for mackerel, horse mackerel and mullet, because they are caught more often that time of year. IBTS data from the third quarter are available since 1991.

In the BTS-program, only the southern part of the North Sea is fished by research vessels with beam trawls. This gear catches flatfish and a number of other species that live on or in the bottom. The width of the beam trawl and the sailing speed vary. Data from the third quarter from rectangles north of the Channel were used.

Some sampling locations outside the DCS are used, since data for many species would otherwise be too scarce to produce population trends. Sampling points corresponding to ICES area 4.b and 4.c were included.

Coastal zone

Data is derived from the Demersal Fish Survey (DFS) conducted by Wageningen Marine Research (WMR), which fishes annually in the autumn at 80–180 sampling locations. Fishing is done using a shrimp trawl (6 meter wide for the North Sea surveys), either 3 or 6 meters wide.

6.2.3 Birds

Offshore

Seabirds are counted from a small aircraft in the MWTL-monitoring program. The aircraft follows the same trajectory every year, but the counting method changed since season 2013/2014: since then, bulb windows were used instead of flat windows, the flying altitude changed from 150 m to 75 m, the flying pattern in the coastal zone changed from parallel transects to a zigzag pattern and counting frequency offshore changed from six to four times a year. The impact of these changes on the number of counted birds could be successfully corrected for by transforming all raw counts before and after 2013/2014 to bird numbers per counted surface.

Migrating birds in the coastal zone are counted frequently, but irregularly, at 18 counting posts along the North Sea coast. These observations cover seabirds up to about 3 km from the shore. In this process, seabirds are counted in a standardized manner using telescopes (www.trektellen.nl) on an almost weekly basis. Additional data are collected on the duration of the count, time since sunrise, flight direction, wind speed, wind direction, cloud cover and sight condition. Trends in bird numbers are calculated with statistical correction for these ‘noise’ factors.

Coastal zone

A part of the bird data (Northern gannet, cormorant, black-headed gull, common gull, lesser black-backed gull, European herring gull, great black-backed gull, and black-legged kittiwake) is derived from the MWTL seabird monitoring program in the North Sea (see description for Offshore).

For a few rare species (great crested grebe, pomarine skua, Arctic skua, little gull, and little tern), data from offshore bird counts have been utilized. Trends for red-throated diver/black-throated diver, sandwich tern, common tern/Arctic tern , auk/guillemot are based on a combination of aircraft and offshore bird counts.

Furthermore, a separate aircraft monitoring program is in place for sea ducks (common scoter and velvet scoter). Data have also been incorporated from the integral counting program of Sovon Bird Research Netherlands for species such as sanderling, ruddy turnstone, long-tailed duck, and purple sandpiper, supplemented by individual observations (via platforms such as waarneming.nl).

6.2.4 Marine fauna (overall)

Offshore

In the overall offshore index, abundances of porpoises and some free swimming pelagic species, such as jellyfish and cuttlefish are also included next to abundances of benthic macrofauna, fish and birds (sea Appendix B).

Data on porpoises was acquired concomitantly with the MWTL airplane counts that are performed for birds. Systematic transects are flown with a survey plane throughout the Dutch NCP area six times a year, and observations outside the coastal zone are included here.

Data on four jellyfish species (bluefire jellyfish, barrel jellyfish, compass jellyfish, and common jellyfish), the sea gooseberry, and cuttlefish was acquired through the SMP project from the Anemoon Foundation, which is executed by volunteers. Fixed transects along the coast are inspected at low tide once every week or two weeks, and species or remains of species are registered. Even though this survey is performed along the coast washed up remains of these particular species are largely derived from offshore regions.

Coastal zone

In the overall coastal zone indicator, abundances of three different marine mammals (porpoises, grey seal, harbour seal) are also included next to abundances of benthic macrofauna, fish and birds.

Data on porpoises was acquired in the same fashion as offshore birds. Only observations inside the coastal zone are included here.

Data on seals is acquired through WMR, which produces yearly counts on the number of seals on sandbanks in the Wadden Sea and in the Dutch delta area[73]. Only data from the Dutch delta area was used here.

6.3 Methodology

6.3.1 Data selection and cleaning

Benthic macrofauna

As mentioned in Section 6.2.1, benthic macrofauna is grouped together at the genus level, unlike the other species groups, to mitigate biases. Despite this approach, the number of measured genera over the years is extensive, resulting in the inclusion of 100 different genera in the offshore indicator and 57 different genera in the coastal indicator (see Table 75 in Appendix B). However, data availability for some of these genera may still be limited, leading to

[73] https://www.clo.nl/indicatoren/nl1231-gewone-en-grijze-zeehond-in-waddenzee-en-deltagebied

statistically uncertain trends. These uncertain trends may still be included in the indicators as two separate tests showed the overall trends to be robust.

Another factor taken into consideration, based on expert advice, is the correction for spawning events of benthic species. During the early summer, a substantial number of juveniles are often released simultaneously, which can lead to inflated abundance estimates if included in the analysis. To address this issue, a correction method was implemented. When sampling occurred in June for a specific year, only abundances below the 95% confidence interval were considered per genera, filtering out extreme values.

Fish

The selection of fish species for the offshore and coastal indicators was informed by expert guidance. Different fishing gear is employed in the three monitoring programs (BTS, IBTS, and DFS), and as a result, some species may not be adequately captured in certain surveys due to gear limitations. Great sand eel, herring, smelts, and European sprat were therefore left out of the coastal indicator. The species selection for the offshore indicator omitted turbot, great sandeel, sea bass and brill, because caught numbers of these species are not considered to be representative for the actual species populations Heessen et al. (2015). Consequently, the number of species included in each indicator may vary. Specifically, the offshore indicator includes a total of 30 fish species, while the coastal indicator encompasses 26 fish species (see Table 76 in Appendix B). Data on sea fish in the online database from ICES, DATRAS[74], has to pass an extensive quality check before entering DATRAS. Additionally CBS has checked all downloaded data and shared findings with ICES. Checks were focused on data selection to guarantee an objective analysis. Only records collected during day time, from the North Sea, at a maximum depth of 200m have been used.

For species selection in the indicator on cold- and warm-favouring fish species, Engelhard et al., (2011) was followed. . Which means that the species Engelhard et al., considered as cold-favouring species are designated by us to the group of cold favouring species in the analysis. The same goes for the warm-favouring species.

Additionally, a distinct indicator was established for "nursery" fish species, which are fish that settle and grow in shallow coastal waters for the first period of their lives and inhabit deeper waters later on. This indicator included species that are jointly represented in the BTS/IBTS and DFS surveys. A subsequent MSI was then calculated for both offshore and coastal regions, which included a total of 9 species.

Birds

Some seabird species are indistinguishable during the counts and are combined for trend analyses, these include auk/guillemot, red-throated loon/black-throated loon, common tern/Arctic tern.

A total of 18 different seabird species are included in the offshore bird indicator, while the coastal bird indicator comprises 23 species, with some consisting of combined species (see Table 77 in Appendix B) . These species make up the majority of all birds in the DCS. For details on the selection of bird species, see Van Roomen et al. (2017).

[74] https://www.ices.dk/data/data-portals/Pages/DATRAS.aspx

6.3.2 Trend estimation

Annual indices on population numbers have been calculated for each species using Poisson regression implemented in the R-package rtrim (Bogaart et al., 2020).

6.3.3 Multi-species indicators

The calculation of an MSI starts with a data set with time series of indices and standard errors (SE) of individual species (Soldaat et al., 2017). In a Monte-Carlo approach this data set is reproduced 1000 times. In each data set an index for each species is sampled from a normal distribution based on the logarithms of the original index and SE. Missing values are replaced by a chain method. Then the time series for all species are rescaled to index 100 in the same base year. The MSI in a specific year is defined as the geometric mean of all species indices that year. By calculating a geometric mean, increases and decreases are equivalent. For instance, a species that doubles in numbers (from index 100 to 200) is exactly counterbalanced by a species that halves in numbers (from index 100 to 50). In each simulated data set an overall trend in MSI is calculated, as well as a trend for the last 12 years. The uncertainty of the mean trends is derived from the variation between the 1000 trends. The advantage of indexing is that rare and common species get the same weight in the MSI. A weaker point is that appearing or disappearing species can dominate the MSI, because indices for such species can become very high or very low (Korner-Nievergelt et al. 2022). In the MSI's in this report this impact is reduced by first setting the index in the year with the maximum numbers of a species to 100, and then truncate all indices below 1 to index=1.

6.3.4 Trend evaluation

The Monte-Carlo approach described in the previous paragraph produces overall trends and SE's. The SE and the length of the time series determine the confidence interval of the trend. The upper and lower confidence limits (CL) are the base for a classification in increasing, stable, declining or uncertain trends (Table 53).

Table 53. Classification of trends based on the 95% confidence interval (CI) of the trend (Upper CL = upper limit of CI, Lower CL = lower limit of CI)

Trend class	Criteria	Description
Strong increase	Lower CL > 1.05	> 5% increase/year (≈ doubling in 15 years)
Moderate increase	1.00 < lower CL ≤ 1.05	Increase, but unsure whether > 5%/year
Stable	Confidence interval contains 1.00 *and* lower CL ≥ 0.95 and upper CL ≤ 1.05	Population changes less than 5%/year
Moderate decrease	0.95 ≤ upper CL < 1.00	Decrease, but unsure whether > 5%/year
Strong decrease	Upper CL < 0.95	> 5% decrease/year (≈halving in 15 years)
Uncertain	Confidence interval contains 1.00 *and* *(* lower CL < 0.95 or upper CL > 1.05)	CI too large for reliable trend classification

6.4 Results

6.4.1 Benthic macrofauna

Offshore

The abundance of offshore benthic macrofauna genera exhibited a moderate decline, averaging around 40%, from 1991 to 2010 (Figure 40). However, starting from 2010, there has been a noticeable recovery. Among the 100 genera included in this analysis, 18 experienced an increase in abundance, 9 saw a decrease, 18 remained relatively stable, while 55 genera displayed uncertain trends due to substantial uncertainty in the data. Despite the prevalence of uncertain trends among many genera, two separate tests confirmed the robustness of the overall trend. More specifically, excluding the 10% most significant decliners and risers and a leave-one-out test revealed similar trends.

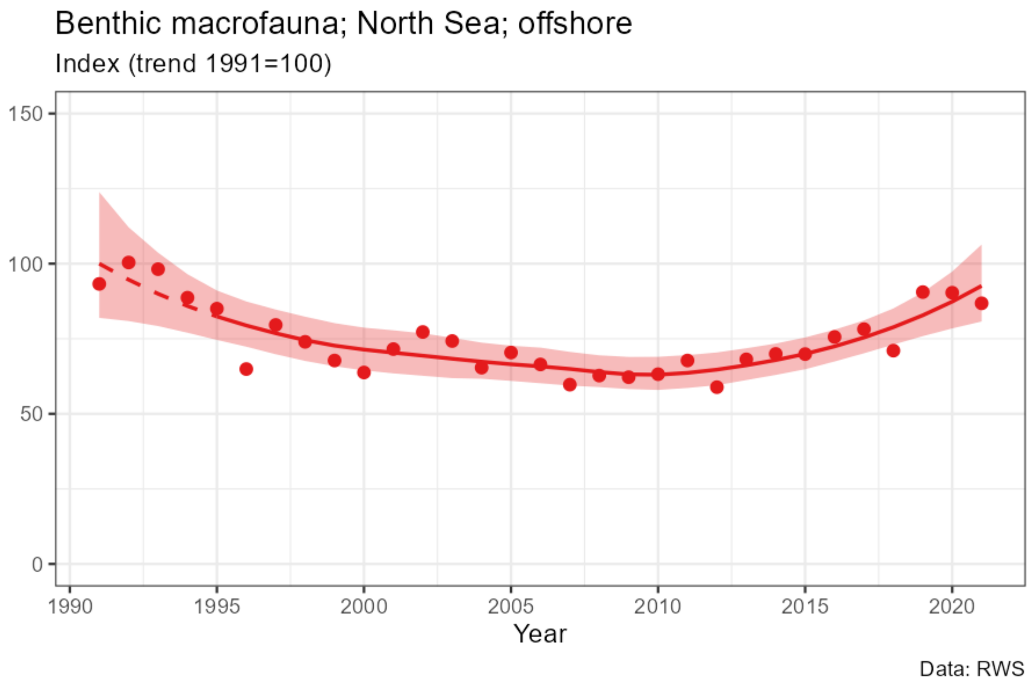


Figure 40. MSI of all benthic macrofauna genera in the North Sea offshore area since 1991.

The decline of benthic macrofauna in the past (before 1991) is most likely attributed to beam trawling in the DCS. In this fishing method, trawlers drag heavy chains across the seabed to disturb flatfish and drive them into nets (beam trawl), resulting in the upheaval of the seabed and the death of many bottom-dwelling organisms (Polet and Depestele, 2010). This fishing practice is particularly harmful in deep waters where natural disturbances are scarce (Van Denderen, 2015). Long-lived species such as the great scallop and common whelk have been declining due to this fishing method, well before 1991 (Bruyne et al., 2013). The decline until 2010 is likely to have other causes than fishing, as the fishing intensity did not increase beyond the levels seen before 1991. For instance, the decline of the common whelk can also be attributed to the use of tributyltin (TBT)-containing paints that inhibit the growth of barnacles and other organisms on ship hulls. Furthermore, the effects of climate change are already noticeable in the DCS, with the seabed temperature increasing by 1.6°C between 1980 and 2004 (Dulvy et al., 2008). This could have contributed to the less favorable conditions for some species of soil fauna (Hiddink et al., 2015).

Since 2000, demersal fishing has decreased in the Netherlands. The use of the beam trawl has diminished, primarily due to policies, especially with the advent of less seabed-disturbing fishing techniques like pulse trawling around 2010. In pulse trawling, bottom-dwelling fish are not caught using drag chains but are instead startled by electric impulses. However, the ban on pulse trawling by the EU led to a small resurgence in beam trawling around 2019. Nonetheless, a slight recovery in benthic fauna beyond the coastal zone is visible around 2013, with a modest increase over the past twelve years, even among sensitive species. In the coming years, further recovery may be possible, as fishing has continued to decline since 2020 due to rising fuel costs, fleet rationalization, and growing societal pressures on trawling activities. Still, even a low fishing pressure can be harmful for benthic macrofauna (Van Denderen, 2015).

Coastal zone

Benthic macrofauna living in the soft substrate of the North Sea's coastal zone showed a declining population trend until 2003, after which a moderate increase is apparent (with 19 species increasing, 7 decreasing, 7 remaining stable, and 24 uncertain over the entire monitoring period; Figure 41). Also in the North Sea offshore regions, benthic macrofauna have seen improvements over the past twelve years, partly due to reduced bottom-disturbing fishing practices. The impact of such fishing is however less pronounced near the coast, where natural disturbances like wind, currents, and wave action are more influential, naturally resulting in fewer disturbance-sensitive benthic animals.

However, the overall decline in benthic animal populations until around 2008 can be attributed to the introduction of invasive species, such as the American razor clam (not included in the indicator). Since 2010, the American razor clam's population seems to have stabilized. The recent recovery in the indicator may be attributed to species that have been expanding in response to climate change, such as the common otter shell, small hermit crab, and velvet crab.

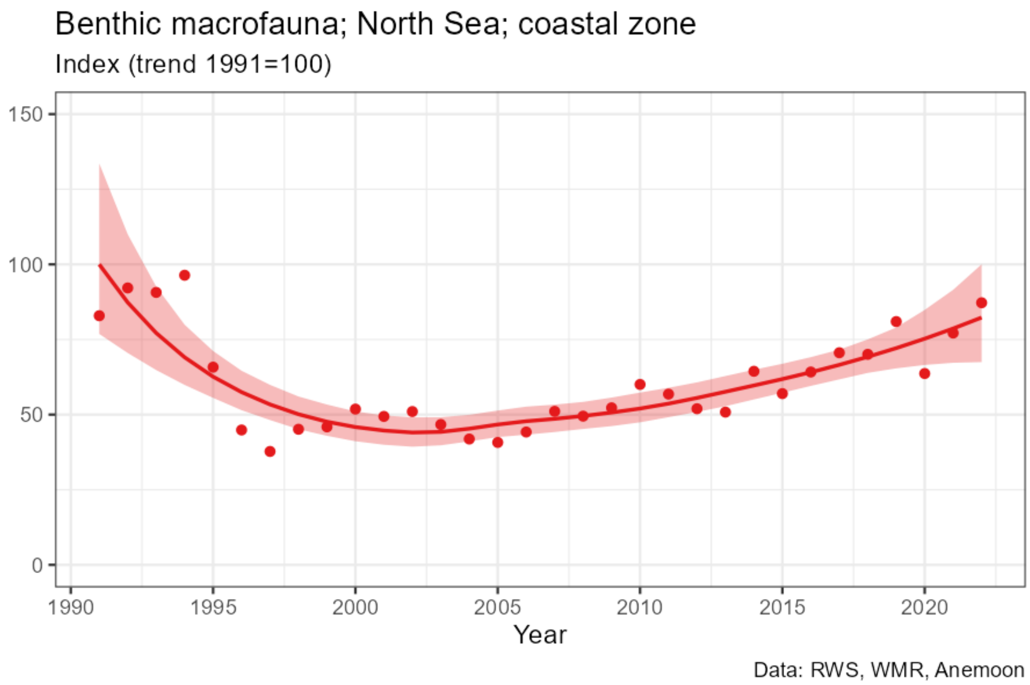


Figure 41. MSI of all benthic macrofauna genera in the North Sea offshore area since 1991.

6.4.2 Fish

Offshore

Since 1990 sea fish increase steadily in the North Sea. From the 30 species, 14 increase, 8 decrease and 8 have stable populations. The 30 species are listed in Table 76 (Appendix B). The main drivers for the population changes are most likely the decrease in fishing intensity and climate change. Species that have increased since 1990 are small-spotted catshark, lemon sole and solenette. Also thornback ray and spotted ray have increased. On the other hand thorny skate has decreased. From the North Sea species that are of importance for commercial fishery, herring, cod and European plaice still decrease. Common sole is stable in population numbers over the whole period and the last twelve years.

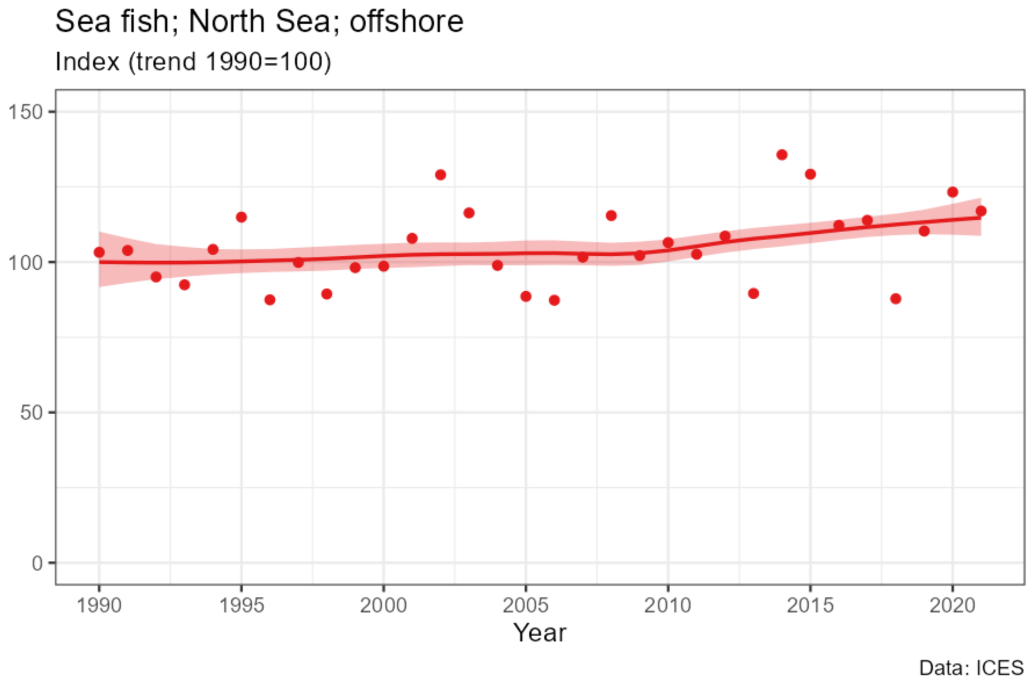


Figure 42. Mean population development for 30 sea fish on the offshore part of the North Sea from 1990–2021.

Cold- and warm-favouring sea fish

Cold-favouring fish species in the North Sea on average remain stable in population numbers, but warm-favouring fish species are increasing (Figure 43). This development possibly is the result of climate change.

Cold-favouring marine fish species are species with a northern distribution in the North Sea. Species with a preference for warmer water have a southern distribution. As a group, southern species show a moderate increase in population numbers, as well over the period 1990–2021 as over the last twelve years (2010–2021). Population numbers of northern species are, on average, stable from 1990 to 2021. The last twelve years however, the northern species show a moderate decline. Species richness of North Sea fish has increased, this increase was mainly due to warm-favouring species, and temperature seems the most likely driver of the increase in species richness (Jones et al., 2023).

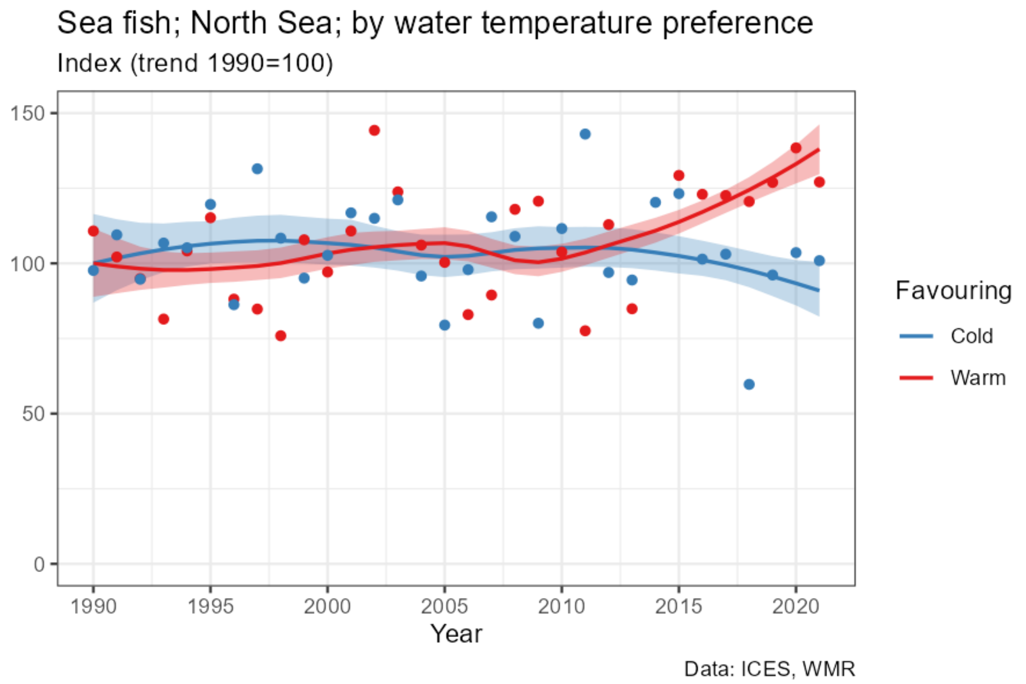


Figure 43. Trend in cold- and warm water favouring fish species. See Table 76 in Appendix B for the warm- and col-favouring species.

Causes of fish stock changes

The increase in southern species is related to the warming of the North Sea, although commercial fishing and other factors also play a role in the trends of individual species (Jones et al., 2023). The water of the North Sea is becoming warmer as a result of climate change, making conditions more favourable for warm-favouring species. Climate change will affect fisheries altering opportunities for fishing in the North Sea (Peck et al., 2020).

Coastal zone

The abundance of coastal fish species has exhibited a declining trend since 1990, with the most pronounced decrease observed between 1990 and 2006, followed by a period of stability (Figure 44) Throughout this entire timeframe, three species demonstrated an increase, nine experienced a decrease, five remained stable, while the trends for eight species remain uncertain.

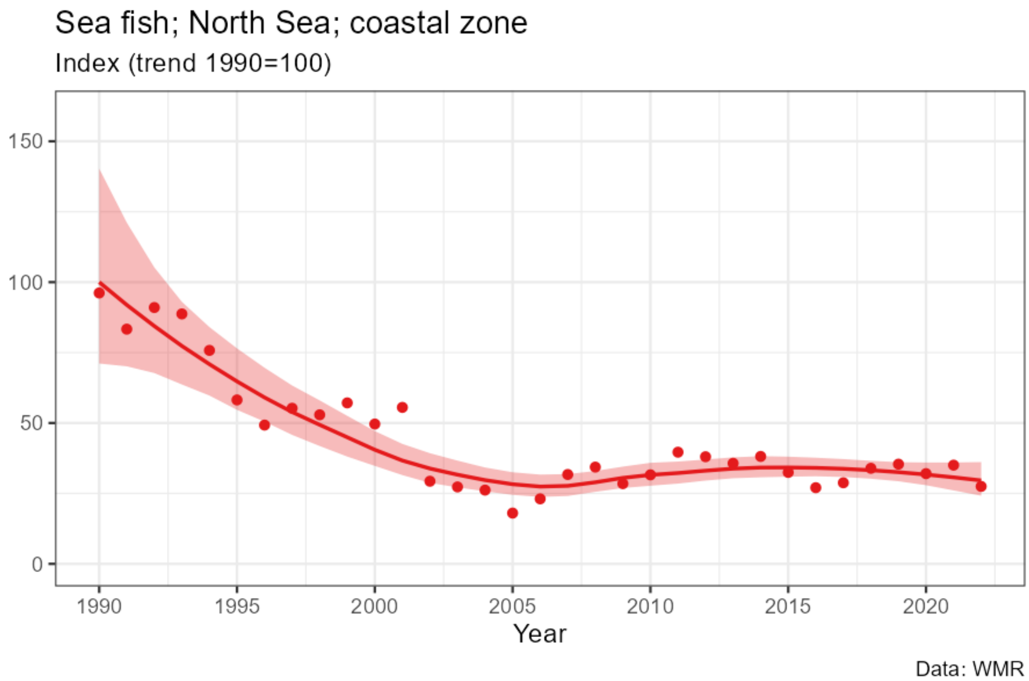


Figure 44. MSI of selected fish species in the North Sea coastal area since 1990. A loess-smoothed trend line is drawn through the geometric mean index numbers with a 95% confidence interval.

The decline in fish abundance at the onset of the monitoring program can be attributed in part to (human-induced) habitat disturbances, although these practices had already been in existence before 1990. Notably, the most substantial changes can be ascribed to the influence of climate change, in particular the rise in sea surface temperatures. With the evident warming of the seas, especially in the shallower coastal waters, numerous fish species have migrated to greater depths, resulting in fewer fish being sampled in proximity to the shore (Dulvy et al., 2008). The decline in fish abundance already started in 1980, and presented here is the final phase of the decline. It is worth mentioning that juvenile fish also tend to inhabit areas closer to the shore, and there is evidence indicating an earlier departure of juveniles from these inshore areas (van Keeken et al., 2007; Tulp et al., 2009; Teal et al., 2008, 2012; further details are available in the following section on Nursery species).

Nursery species

The species covered in this indicator encompass whiting, cod, tub gurnard, common dab, plaice, pouting, turbot, lemon sole, and common sole. Since 1990, there has been a decline in the populations of fish nursery species in both offshore (Figure 45) and coastal areas (Figure 46) of the North Sea. Notably, the decline in the coastal zone has been more pronounced. The trend starts to stabilize around 2005, with no significant declines observed since that time. In the offshore area, 4 species have shown an increase, 3 have exhibited a decrease, and one has remained stable. In the coastal zone, 5 species have experienced a decrease, 2 have remained stable, and 2 species exhibit uncertain trends.

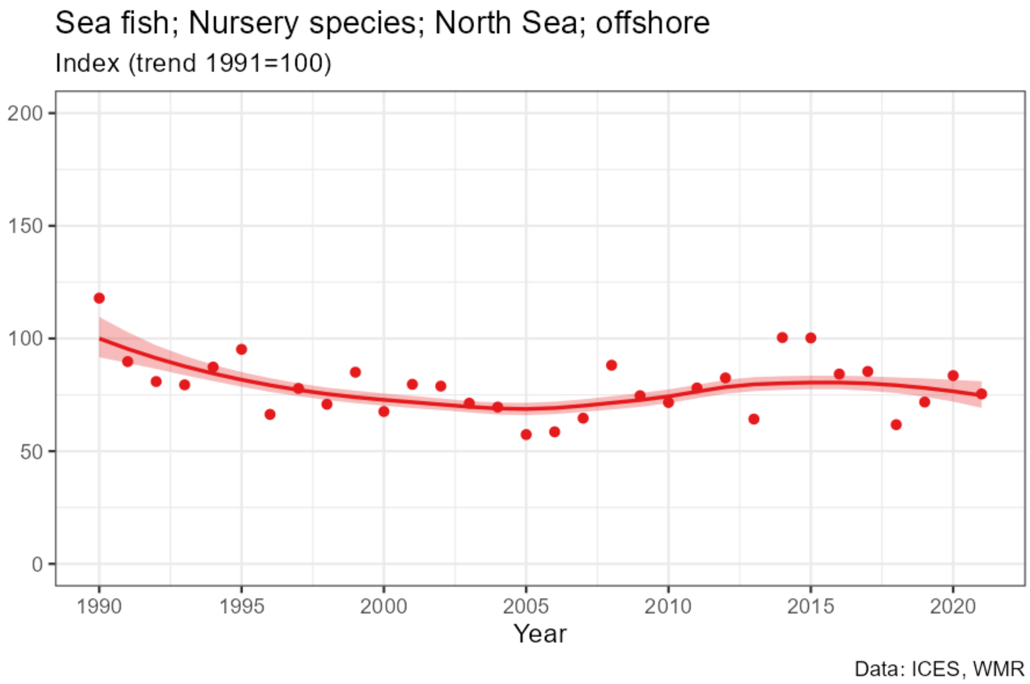


Figure 45. MSI of selected fish nursery species in the North Sea offshore area since 1990.

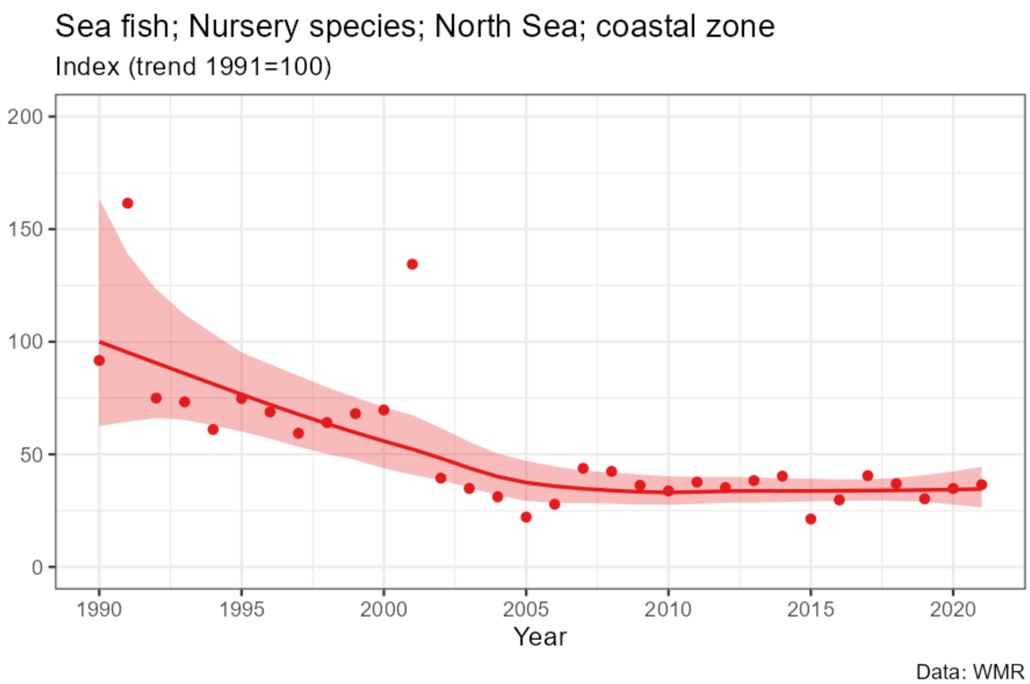


Figure 46. MSI of selected fish nursery species in the North Sea coastal area since 1990.

The stronger decline in the coastal areas is due to juvenile fish leaving these regions earlier and maturing farther out at sea. The situation is well-studied in the case of plaice, particularly in the Wadden Sea (van Keeken et al., 2007; Tulp et al., 2009; Teal et al., 2008, 2012). Plaice spawn in open waters and then migrate to the coast. However, nowadays, juvenile plaice that migrate to the North Sea do not return to the Wadden Sea. This change is attributed to rising water temperatures caused by climate change, which increase the fish's energy demands and can lead to a shortage of food in the Wadden Sea during the summer. Other factors that prevent them from coming back are fisheries, and the increasing presence of predators, such as seals and piscivorous birds.

Note that the coastal nursery fish species trend (Figure 46) differs from the one presented on the Environmental Data Compendium[75] (CLO 1602[76]) as only North Sea coastal regions are considered here.

6.4.3 Birds

Offshore

Seabirds show a steady increase in the offshore part of the DCS since 1991 (Figure 47). Ten of the 18 species increase, five show a decrease and three species have stable populations. Species are selected because they are regularly seen during monitoring and reliable trends can be estimated. The 18 species are listed in Table 77 (Appendix B). The drivers for the population changes probably differ between species. Several species have profited from protection measures such as nest protection and the banning of hunting and egg collecting. For the sandwich tern large new breeding populations arose in new nature reserves along the Dutch coast. Northern fulmars fall victim to plastic waste they confuse with fish, but plastic concentrations are decreased since the beginning of this century while fulmar numbers keep decreasing. Several species have profited from discards accompanying increased fishing intensity in the second half of the 20th century, but the introduction of the landing obligation since 2015 seems not to have affected their populations until now. The causes for the changes in population numbers will lay partly outside the Dutch part of the North Sea. The recent outbreak of bird flu has decimated populations of northern gannet, sandwich tern and greater skua, but this impact has taken place after the period covered by the MSI.

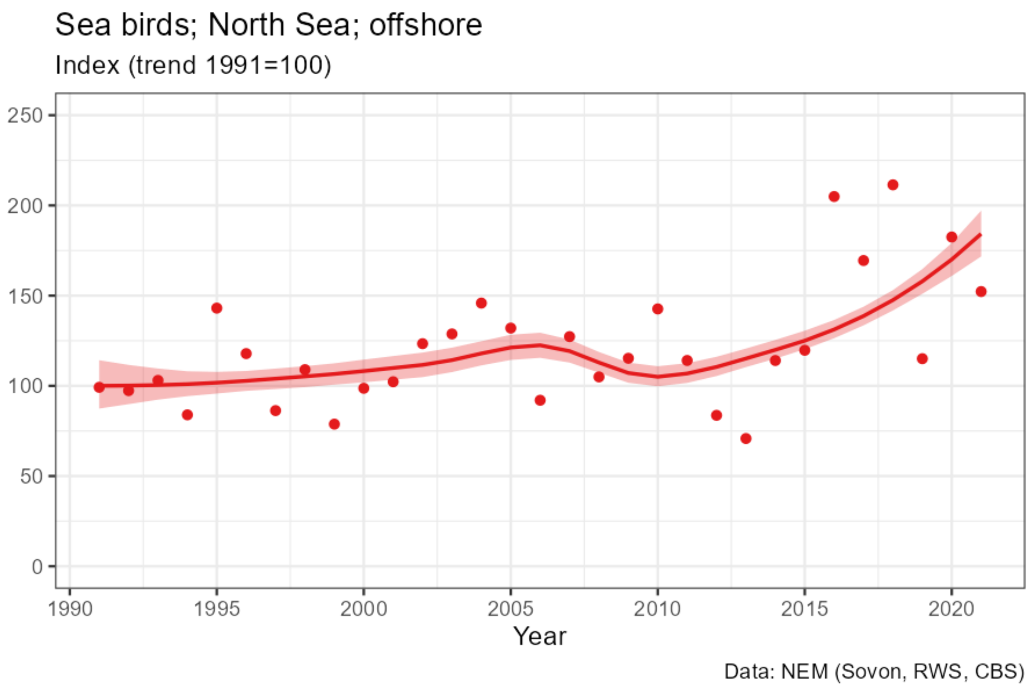


Figure 47. Mean population development for seabirds in the offshore DCS from 1991 to 2021.

[75] https://www.clo.nl/en
[76] https://www.clo.nl/indicatoren/nl1602-zoutwatervissen--kinderkamersoorten (Dutch only)

Coastal zone

Coastal seabird populations have exhibited a noteworthy increase since 1991, particularly after 2010. Among these avian species, 10 have experienced growth, while 6 have shown declining numbers, and 4 remained stable, with 2 species demonstrating an uncertain trend (Figure 48). This recent surge in seabird populations is quite remarkable, given the ongoing decline of these species in the OSPAR maritime regions since 1996 (OSPAR QSR, 2023), which relates to heightened disturbances in the North Sea stemming from factors such as climate change and human activities, which are expected to adversely affect seabird abundance.

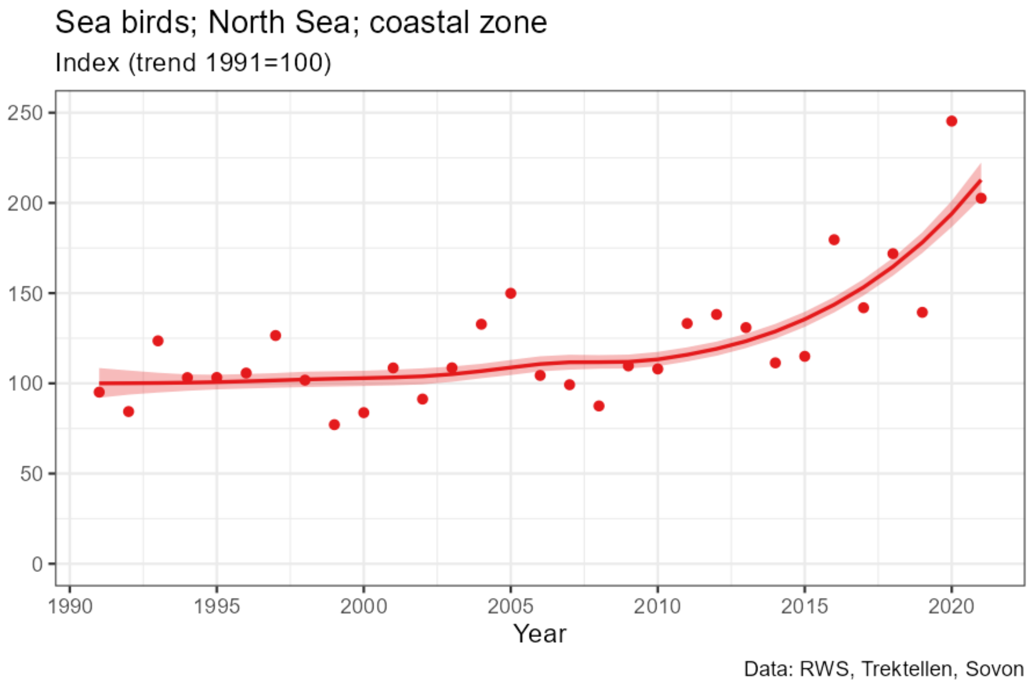


Figure 48. Mean population development for seabirds in the coastal zone from 1991 to 2021.

It is worth noting that these increases may be regionally constrained and can significantly depend on selected species.[77]

Several factors may have contributed to the increase in the abundance of select bird species. Notably, a reduction in fishing-related impacts can have a positive influence on the availability of food resources and foraging conditions for seabirds, as well as diminished disturbances to fish behaviour. It is crucial to acknowledge that the extent of these impacts varies markedly among different species (Searle et al., 2023). Furthermore, established offshore wind parks have the potential to enhance food availability for specific seabird species (Dierschke et al., 2016).

Seabirds are known to be highly susceptible to oil contamination in the North Sea. Fortunately, there has been a significant decrease in the proportion of oil-contaminated carcasses among stranded seabirds along the coast, which signifies a reduction in certain pollution pressures (CLO 1254)[78].

[77] Additionally, a status report on Ireland's breeding seabirds, also confirmed population abundance increases for certain species (Cummins et al., 2019).
[78] https://www.clo.nl/indicatoren/nl1254-zeevogels-en-olieverontreiniging

6.4.4 Marine fauna

Offshore

Between 1990 and 2010, the trend of marine organisms in the North Sea has experienced a decline of just under 20% (Figure 49). Notably, over the last 12 years, there has been a visible trend of recovery. Of the total 156 species included in this indicator, 22 have exhibited a significant decrease in population, while 46 have shown an increase, and 32 remained stable. Particularly, benthic fauna species, constituting the largest group with 100 genera in this indicator, have experienced a decline in numbers, but show some recovery in recent years. In contrast, marine fish (30 species) have moderately increased over the entire period but remained stable since 2010. Conversely, seabirds (18 species) have shown a recent increase over the past twelve years. Jellyfish (4 species) and the sea gooseberry have also seen moderate population increases, along with cuttlefish. The harbor porpoise, the sole marine mammal in this indicator, has shown a significant increase in population throughout the entire period.

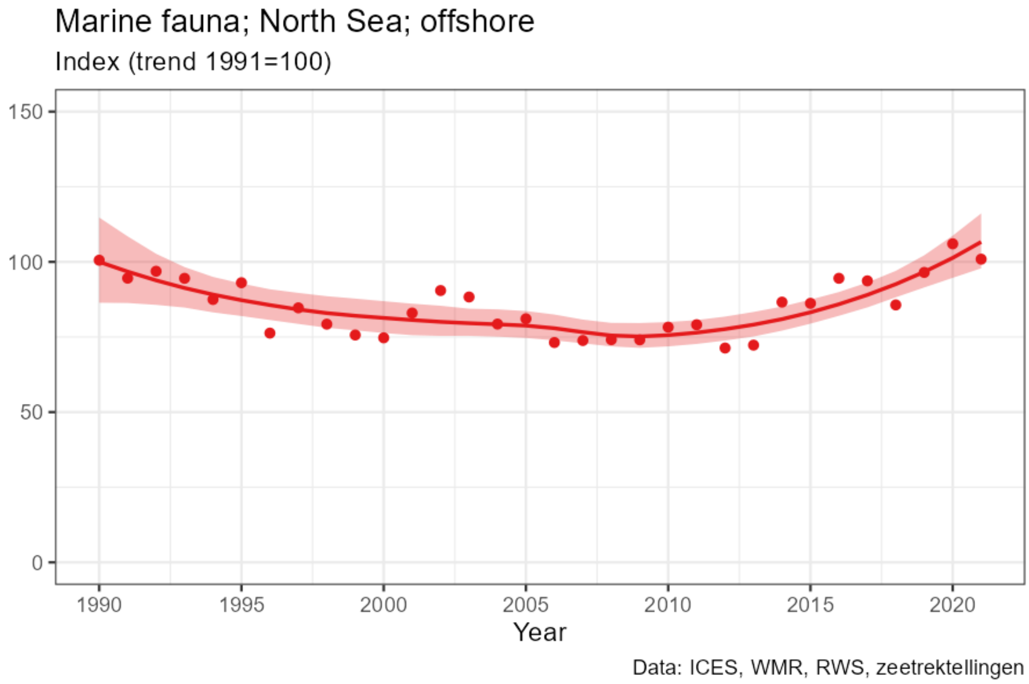


Figure 49. MSI of all offshore marine species/genera since 1990.

Coastal zone

The trend in marine species within the coastal zone showed a moderate decline overall, with a subsequent moderate increase around 2010 (Figure 50). Out of the 116 species in total in the indicator, 35 species increased, 22 species declined, 16 species remained stable, while 34 species trends are uncertain. This indicator represents the combined average trend of marine fish (25 species), benthic macrofauna (57 genera), seabirds (23 species), and marine mammals (3 species). Fish populations decreased, while benthic macrofauna remained stable, and seabirds and marine mammals experienced an increase.

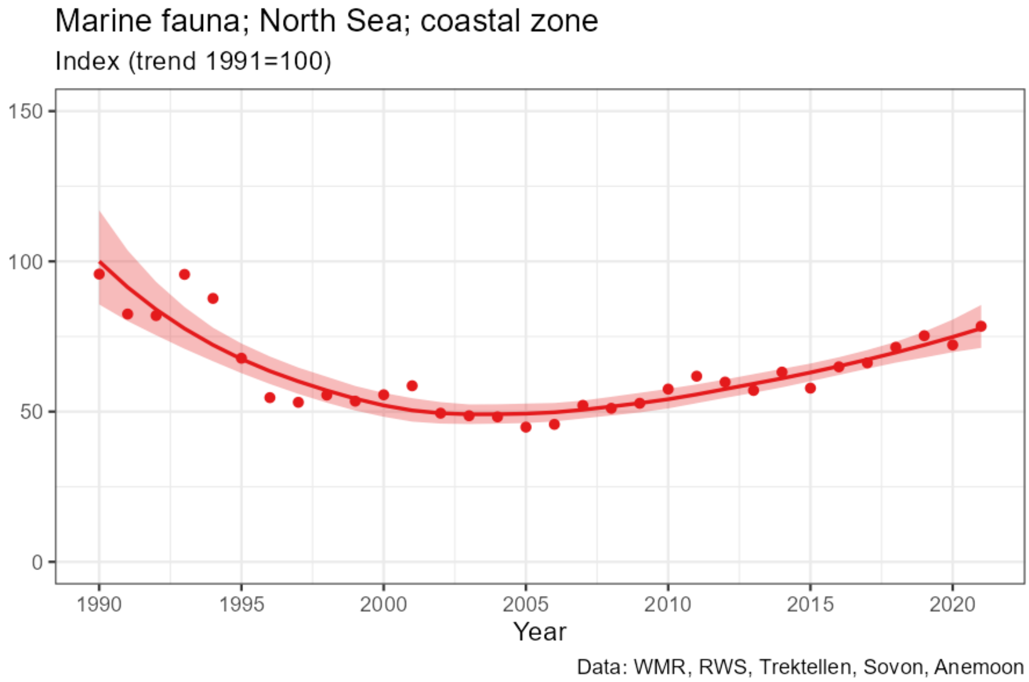


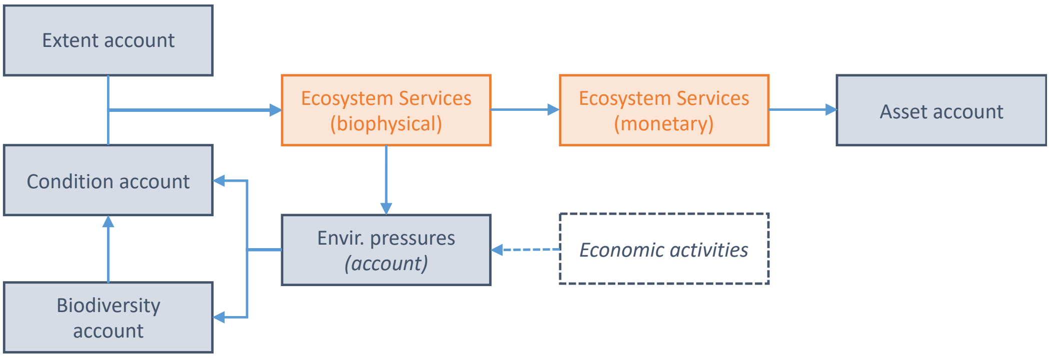
Figure 50. MSI of all coastal marine species/genera since 1990.

The various marine species groups have experienced increases in abundance for a range of reasons, as detailed in preceding sections.

In addition, jellyfish populations may be benefitting from climate change and elevated sea surface temperatures. Moreover, changes in fishing practices, especially in demersal fisheries over the past two decades, have also altered the community composition of pelagic fish species, potentially creating favorable conditions for the proliferation of jellyfish species (Lynam et al., 2011; Kennerley et al., 2021).

Higher abundances of marine mammals (common seal, grey seal, and harbour porpoise) are due to varied reasons: for the common seal, improvement of water quality and measures against distubances play a significant role; for the grey seal, the increase in numbers may be attributed to seals migrating from British Isles (Brasseur et al., 2015); and for the harbour porpoise, the primary factor is a shift in their feeding areas in the North Sea.

7. Ecosystem Services



7.1 Introduction

Ecosystem services are the contributions of ecosystems to the benefits that are used in economic and other human activities[79]. The SEEA ecosystem accounting framework recognizes three main types of ecosystem services:

Provisioning services are those ecosystem services representing the contributions to benefits that are extracted or harvested from ecosystems.

Regulating and **maintenance** services are those ecosystem services resulting from the ability of ecosystems to regulate biological processes and to influence climate, hydrological and biochemical cycles, and thereby maintain environmental conditions beneficial to individuals and society.

Cultural services are the experiential and intangible services related to the perceived or actual qualities of ecosystems.

In addition, the SEEA EA framework uses intermediate and abiotic services, and spatial functions. These are defined later on in this chapter.

Ecosystem services can be quantified in *biophysical* units (e.g. kg fish caught) and in *monetary* units (e.g. economic value in €). In this chapter we will discuss these in parallel. Therefore, for clarity, we will first give an overview of the most relevant monetary valuation methods. We then continue with an overview of individual relevant ecosystem services, grouped by the above-mentioned categories.

Table 54 presents an overview of ecosystem services that are potentially relevant for the Dutch NCP. The list is based on crosswalks between the SEEA-EA lists of ecosystem services, and the (older, more general) CICES list (v 5.1). The table also indicates which ecosystem services were included in the previous 2019 study.

[79] SEEA-EA, ¶ 6.9

Table 54. Overview of marine ecosystem services, based on crosswalks between the SEEA-EA recommended list of ecosystem services, and the CICES v5.1 inventory

SEEA		CICES		2019 Study Relevance	ES	This report Section
Provisional services						
1.4	Aquaculture	1.1.2	Cultivated aquatic plants for nutrition, materials or energy	low		7.2.2
		1.1.4.x	Reared aquatic animals for nutrition, materials or energy	medium		
1.5	Wood	1.1.5.2	Fibres and other materials from wild plants for direct use or processing	-		
1.6	Wild fish and other natural aquatic products	1.1.5	Wild plants (terrestrial and aquatic) for nutrition, materials or energy	low		
		1.1.6	Wild animals (terrestrial and aquatic) for nutrition, materials or energy	high	Marine fishing	7.2.1
1.8	Genetic material services	1.2.1	Genetic material from plants, algae or fungi	low		7.2.3
		1.2.2	Genetic material from animals	low		
1.10	Other provisioning	1.1.4.3	Animals reared by in-situ aquaculture as an energy source	-		
Regulating services						
2.1	Global climate regulation	2.2.6.1	Regulation of chemical composition of atmosphere and oceans	high		7.3.1
2.2	Rainfall pattern regulation	2.2.1.3	Hydrological cycle regulation	-		P.M.
2.4	Air filtration	2.1.1.2	Filtration/sequestration/storage/accumulation by micro-organisms, algae, plants, and animals	-		(coastal)
		2.1.2.1	Smell reduction	medium?		P.M.
2.6	Soil erosion control	2.2.1.1	Control of erosion rates	High		P.M,
2.7	Landslide mitigation	2.2.1.2	Buffering and attenuation of mass movement	-	low	no
2.8	Solid waste remediation	2.1.1.1	Bio-remediation by micro-organisms, algae, plants, and animals	high		7.3.2
		5.1.1.3	Mediation by other chemical or physical means (e.g. via Filtration, sequestration, storage or accumulation)			P.M.
		5.1.2.1	Mediation of nuisances by abiotic structures or processes	-		P.M.
2.13	Coastal protection	2.2.1.3	Hydrological cycle and water flow regulation (Including flood control, and coastal protection)	-		7.3.3
2.17	Pollination services	2.2.2.1	Pollination (or 'gamete' dispersal in a marine context)	High		P.M.
2.18	Pest control	2.2.3.1	Pest control	?		P.M.
2.19	Disease control	2.2.3.2	Disease control	?		P.M.
2.20	Nursery population and habitat maintenance	2.2.2.3	Maintaining nursery populations and habitats (Including gene pool protection)	-		P.M.
2.21	Other regulating an maintenance services	2.1.2.3	Visual screening			P.M.
		2.2.2.1	Seed dispersal			P.M.
		2.2.5.2	Regulation of the chemical condition of salt waters by living processes	High		P.M.
Cultural services						
3.1	Recreation related ESD	3.1.1.1	Characteristics of living systems that that enable activities promoting health, recuperation or enjoyment through active or immersive interactions	High	Nature related recreation idem, tourism	7.4.1 7.4.2
3.2	Visual amenity services	3.1.1.2	Characteristics of living systems that that enable activities promoting health, recuperation or enjoyment through active or immersive interactions	-		7.4.3
3.3	Education, scientific and research	3.1.2.1	Characteristics of living systems that enable scientific investigation or the creation of traditional ecological knowledge	medium		7.4.4
		3.1.2.2	Characteristics of living systems that enable education and training	-		
3.4	Spiritual, artistic and symbolic services	3.1.2.4	Characteristics of living systems that enable aesthetic experiences			7.4.5
		3.2.1.3	Elements of living systems used for entertainment or representation	-		
		3.1.2.3	Characteristics of living systems that are resonant in terms of culture or heritage	-		
		3.2.1.1	Elements of living systems that have symbolic meaning	medium		
		3.2.1.2	- sacred or religious meaning			
4.1	Ecosystem and species appreciation services	3.2.2.1	Characteristics or features of living systems that have an existence value	low?		7.4.6
		3.2.2.2	Characteristics or features of living systems that have an option or bequest value	low?		
Abiotic flows						
	Geophysical: water, wind, etc.	4.2.1	Surface water used for nutrition, materials or energy	medium		7.5.4
		4.3.2	Non-mineral substances or ecosystem properties used for nutrition, materials or energy	high	Wind energy	7.5.3
	geological: fossil fuels, minerals	4.3.1	Mineral substances used for nutrition, materials or energy	High	Extraction of sand & gravel	7.5.2
				High	Extraction of oil & gas	7.5.1
Spatial functions						
	Location: transport; structures			High		7.6.1
	Sink: pollutants and waste			Low		

7.1.1 Monetary valuation

The SEEA EA, adopted by the UN Statistical Commission in March 2021, provides internationally recognized statistical principles and recommendations for the valuation of ecosystem services and assets in a context that is coherent with the concepts of the System of National Accounts (UN, 2021a). A key purpose of valuing ecosystem services in monetary terms in SEEA is the integration of information on ecosystem condition and ecosystem services with information in the standard national accounts. Therefore, in SEEA, the focus is on so-called exchange values. Exchange values are the values at which goods, services, labour or assets are in fact exchanged or else could be exchanged for cash. (2008 SNA, para. 3.118). In an ecosystem accounting context, exchange values are those values that reflect the price at which ecosystem services and ecosystem assets are exchanged or would be exchanged between willing buyers and sellers if a market existed (UN, 2021a). Since the ecosystem assets (the providers of ecosystem services) themselves are not actual market participants, the challenge in valuation lies in establishing the assumptions about the institutional arrangements that would apply if there was an actual market involving ecosystem assets.

In this section, we describe the most relevant methods for the valuation of ecosystem services. There are five main categories of valuation methods that are relevant for SEEA :

- Methods based on directly observable values;
- Methods where the price for the ecosystem service is obtained from markets for similar goods and services;
- Methods where the price for the ecosystem service is embodied in a market transaction;
- Methods where the price for the ecosystem services is based on revealed expenditures (costs) for related goods and service;
- Methods where the price for the ecosystem service is based on expected or simulated expenditures for related goods and services.

In addition, we briefly discuss stated preference methods.

Methods based on directly observable values.

Directly observed values or market prices are the most direct method for measuring prices and estimating values for the accounts. A key example are **rental prices** which can be used as a proxy for the value of ecosystem services. Rent is the income receivable by the owner of a natural resource (the lessor or landlord) for putting the natural resource at the disposal of another institutional unit (a lessee or tenant) for use of the natural resource in production (SNA, 2018). In some cases, rent payments (or imputed rent payments) can be directly related to the provision of certain ecosystem services. Rent payments take place when the user of the asset and the legal owner are not the same. When the user owns the asset there is no rent payment. When we apply the rent prices, we assume that this price is also valid for the assets where no actual rent payment occurs. An example is the rent that farmers pay for the land for crop production or for livestock farming. As yet these methods are not applied in this study.

Methods where the price for the ecosystem service is obtained from markets for similar goods and services.

When market prices for a specific ES are not observable, valuation according to market price equivalents, or proxy markets, may provide an approximation of market prices. For example, when non-wood forest products (e.g. mushrooms) from one forest are marketed but those from a similar forest are not, the prices observed in the former can be used to value the non-wood forest products from the latter, adjusting for differences in products and other factors. In applying this method, the price from the similar market will need to be adjusted for any costs incurred to supply the good or service to ensure the price used refers to the ecosystem service (UN et al., 2021; ¶ 9.35).

Methods where the price for the ecosystem service is embodied in a market transaction.

Market price methods use the prices of goods and services that are bought and sold in commercial markets to determine the value of an ecosystem service. One example is the resource rent method, which can be interpreted as the annual return stemming directly from the natural capital asset itself. The resource rent can be derived from the national accounts by deducting costs of labour, produced assets and intermediate inputs from the market price of outputs (benefits). The resource rent is not equal to the value added, because this still includes wages and normal profits. The use of the resource rent method to pricing is commonly associated with provisioning services such as those related to the outputs of agriculture, forestry, and the fishing industry, in particular where there are limited or no possibilities for using land leases and prices as an indicator of the price of ecosystem services.

The **production function** method – also known as the productivity method, the net factor income method, or the derived value method – is applied to estimate the economic value of ecosystems that contribute goods and services to the production of marketed products (King, Mazzotta & Markowitz, 2004). The production function method can be used to estimate direct use values for provisioning services, such as crop production, and indirect use values for regulating services, such as pollination and flood protection services. However, it is often difficult to map the entire value chain and understand the relationships between ecosystem services on the one hand and man-made inputs and produced assets on the other.

The **hedonic pricing** method is used to determine the value consumers attach to one particular attribute of a (marketed) product in relation to all the product's other attributes. The most common application is the analysis of variations in housing prices in relation to physical attributes, properties of the neighbourhood, and the proximity to and quality of the natural environment (King, Mazzotta & Markowitz, 2004)

Methods where the price for the ecosystem services is based on revealed expenditures (costs) for related goods and services

The revealed-preferences method involves determining the value that consumers hold for an environmental good by observing their purchase of goods in the market that directly (or indirectly) relate to environmental quality. An example of a revealed preference method is the **Travel Cost Method**, which is used to calculate the monetary value of recreational ecosystem services. Recreation in nature requires physical access, which may require travel. The amount of money consumers spend to visit a recreational site (e.g. transport, fuel, parking fees, bike rentals) are a proxy for their willingness-to-pay for recreational ecosystem services. Travel time and visiting time can be valued as well, although this value is usually seen as a welfare value (SEEA EEA, 5.103; ONS, 2014). Note that there are two interpretations of the Travel Cost Method. In the first, the Travel Cost Method uses *actual travel costs* as an indicator of the value of the service, e.g. total value of a day trip. In the second, a demand curve for visiting a specific site is constructed based on travel costs and relative annual visitation rates – this method leads to an estimate of the *consumer surplus* generated through recreational visits to a site. These demand curves can be used to say something about the value of recreating in e.g. a more natural surroundings. Given that we possess data on the actual travel costs, we will apply the first method to estimate the value of marine recreation and tourism services.

Methods where the price for the ecosystem service is based on expected or simulated expenditures for related goods and services.

Cost-based methods do not provide strict measures of economic values. Instead, they assume that the costs of avoiding damage or replacing ecosystems or their services provide useful estimates of the value of these ecosystems or services. The **replacement cost** method estimates the value of an ecosystem service based on the costs that would be associated with mitigating actions if the ecosystem service would be lost (SEEA-EA, 9.50). Replacement costs are often used to value regulating services, such as natural coastal protection. The core assumption of the replacement cost method is that a service can be replaced, i.e., that a man-made alternative can be developed.

The **avoided damage** method estimates the value of ecosystem services based on the costs of the damages that would occur due to the loss of these services (Farber, Costanza, Wilson, 2002; De Groot et al., 2002). Similar to replacement costs, the focus will generally be on services provided by ecosystems that are lost due to human activities that impact on environmental condition, particularly through pollution. This method is also often used to value regulating services such as erosion prevention, flood control, sedimentation control, air filtration, and carbon sequestration.

Stated preference methods

Methods such as **contingent valuation** and **choice experiments** are applied to measure the stated preferences of a population. They can be used to identify the willingness to pay (WTP) for an ecosystem service or willingness to accept (WTA) payment for its loss. These methods result in welfare values. Stated preference methods usually rely on detailed and comprehensive surveys. However, the results are not compatible with the SNA exchange value concept. Stated preference methods do not produce exchange values. They only relate to consumer surplus and not to producer surplus or production costs, and that’s why stated preference methods are not preferred in the SEEA-EA framework and thus also not in this study.

Non-use values

The treatment of non-use values in an accounting setting requires additional considerations. In the context of the environment, non-use values are those values that people assign to ecosystems (including the associated biodiversity), irrespective of whether they use (directly or indirectly), or intend to use, the ecosystems (SEEA EA 6.70). Unlike flows of ecosystem services, there is no direct or indirect interaction with the environment associated with non-use values. Consequently, while non-use values require that ecosystems exist and may be associated with flows of environmental knowledge or information, it is not considered, from an accounting perspective, that a transaction has taken place consistent with the framing used for recording ecosystem services in the SEEA EA (SEEA EA 6.72). The results in this project are therefore not a measure of the total value of nature, it only concerns the economic value of the benefits for people. Welfare values and 'non-human' benefits are not included.

7.2 Provisioning services

Provisioning services are those ecosystem services representing the contributions to benefits that are extracted or harvested from ecosystems (UN, 2021). The next three provisioning services will be discussed: the capture of wild fish; aquaculture and the collection of genetic material.

7.2.1 Wild fish and other natural aquatic products provisioning services

According to the SEEA-EA definition: *"Wild fish and other natural aquatic biomass provisioning services are the ecosystem contributions to the growth of fish and other aquatic biomass that are caught in uncultivated production contexts by economic units for various uses, primarily food production. This is a final ecosystem service."* (UN, 2021)

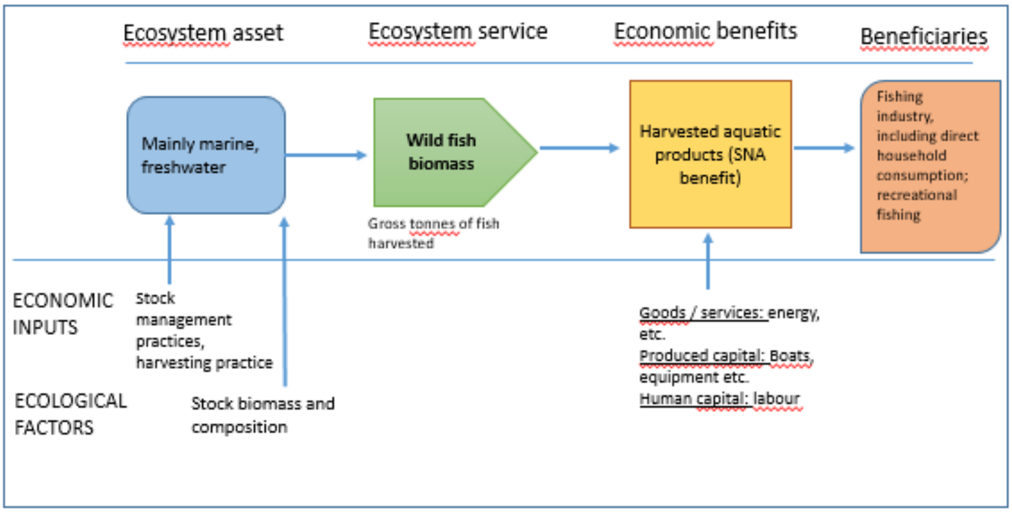


Figure 51. Logic chain for Wild fish and other natural aquatic products

Wild fish and other natural aquatic products provisioning service is supplied by marine and freshwater ecosystems, the ecosystem service is expressed in gross tonnes of fish harvested. The economic benefits for these services are the catch of aquatic products. These benefits are the result of a joint production process, where the role of the ecosystem in supplying the biomass intersects with the activity (and associated human inputs, e.g., labour and produced assets) of people and economic units. The beneficiaries are the fishing industry and possibly recreational fishermen. In the North Sea several kinds of fish (e.g. sprat, sole, herring) and other aquatic species (e.g. shrimp, cockles) are caught, both by Dutch vessels as non-Dutch vessels.

Physical supply

A variety of data sources and approaches are available to quantify the physical stocks and flows associated with the provisioning service of fisheries biomass. These include the use of catch statistics to quantify flows as well as the use of survey trawls, modelling approaches, satellites, and novel genetic techniques to estimate the size and distribution of the biomass stock (Dvarkas et al., 2019). Each approach has its own embedded uncertainties and different costs associated with the collection and support of the data collection. Our first entry here is using catch statistics that are available for the North Sea area. Data were available for a) total amount of different fish species caught, b) the location where the fish is landed, c) the nationality (flag) of the operating ships, and d) the area where the fish is harvested (ICES fishing areas). Figure 53 shows total fish landed in the Netherlands from the North Sea according to the three ICES regions. Note that the Northern North Sea Region (IVa) is not visible in the figure, as it lies to the north of IVb and does not overlap with the DCS. IVd lies outside and to the south of the DCS (dark green colour).

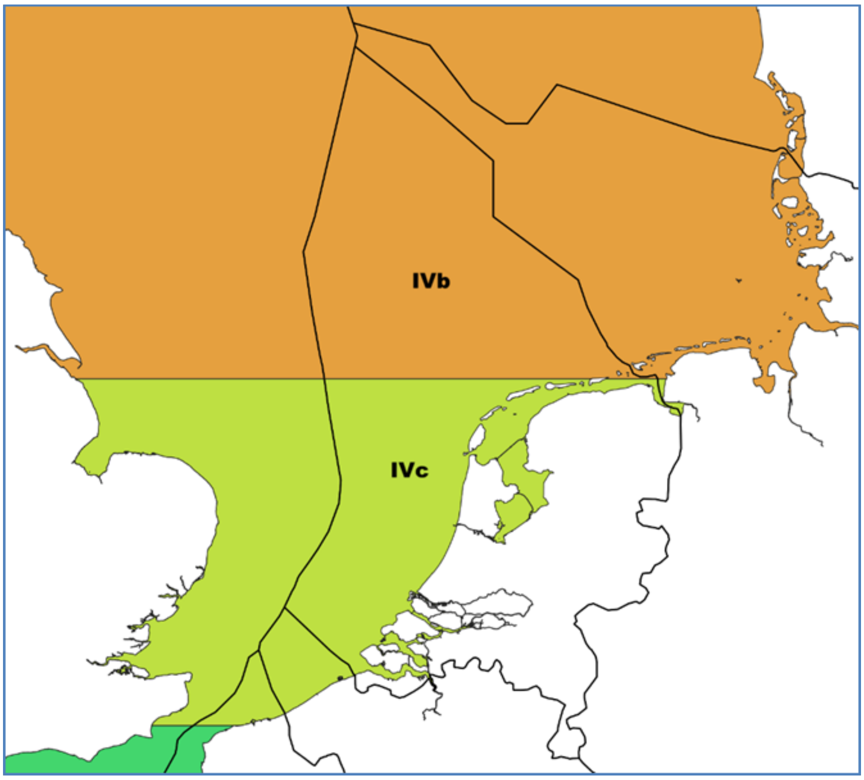


Figure 52. ICES fishing areas that overlap with the Dutch Continental Shelf.

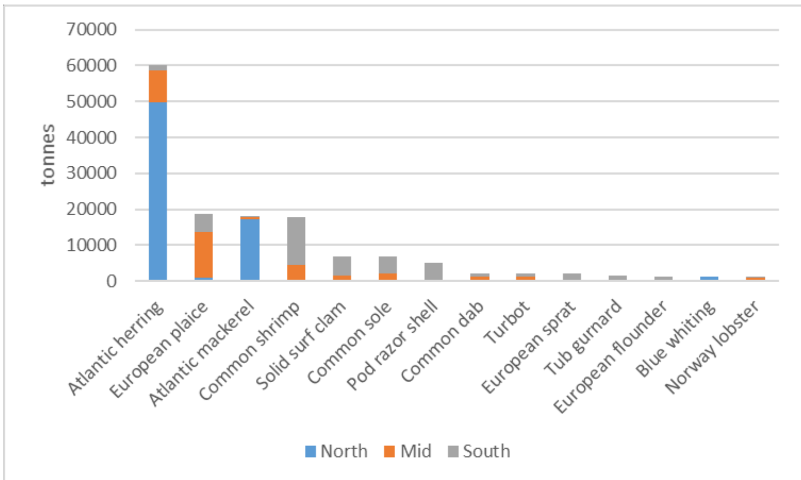


Figure 53. Fish from the North Sea landed in the Netherlands according to the three ICES regions (2020). Source: CICES Official Nominal Catches 2006-2020. Version 13-10-2022.

In the Dutch part of the North Sea several kinds of fish (e.g. sprat, sole, herring) and other aquatic species (e.g. shrimp, cockles) are caught, both by Dutch vessels as non-Dutch vessels. The national catch statistics do not determine the total fish caught on the DCS, but include all fish caught in the North Sea that was landed in the Netherlands. As can be seen in Figure 51, the DCS constitutes only a small part of ICES areas IVb and IVc of the North Sea. In addition, available data do not include fish caught in the DCS that was landed outside the Netherlands. The required data, however, has been calculated by 'The Sea Around Us', a research initiative at the University of British Columbia (located at the Institute for the Oceans and Fisheries, formerly Fisheries Centre) that assesses the impact of fisheries on the marine ecosystems of the world[80]. Data were calculated for individual countries EEZs based on a combination of official reported data (mainly extracted from the Food and Agriculture Organization of the United Nations (FAO) Fisheries) and reconstructed estimates of unreported data (including major discards). Data are also provided by taxon (fish species) and fishing country. This data provides the best measure for the total supply of fish biomass from the DCS.

The fishing industry in the Netherlands consists of trawler fisheries, large-scale high sea fisheries (taking place outside the DSC), mussel farming and aquaculture. The Dutch fleet in the Greater North Sea consists of about 500 vessels. The largest part of the demersal fleet is the beam trawl fleet (275 vessels, of which 85 are >24 m and 190 are < 24 m) that operates in the southern and central North Sea, targeting sole (*Solea solea*; dominant in value) and plaice (*Pleuronectes platessa*; dominant in volume) as well as other flatfish species(ICES, 2017). From the Dutch system of national accounts we know that fisheries in the Netherlands contribute ca. 320 million euro to GDP, which is 0,04 %.[81] Over the past years the number of self-employed in the fishing industry has declined and the profitability of the industry is under pressure.[82]

Table 55. Total fish catch in the Dutch EEZ in tonnes

Species	Catch, tonnes									
	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Anchovies	-	2	21	2	4	956	16	1.947	2	2
Cod-likes	9.479	7.443	7.586	6.966	7.838	6.620	7.173	6.456	6.750	5.830
Crustaceans	15.074	10.642	11.507	13.932	15.955	12.609	13.596	12.572	18.741	13.340
Flatfishes	42.407	37.906	37.437	40.797	38.313	36.256	39.886	32.843	34.194	27.731
Herring-likes	39.479	31.221	24.802	28.278	28.105	52.596	41.909	20.539	29.456	22.168
Molluscs	3.870	4.873	4.399	3.735	5.707	5.946	9.028	5.814	6.023	8.778
Other fishes & inverts	49.344	66.549	13.047	44.040	29.713	38.971	7.169	69.530	31.567	18.793
Perch-likes	6.926	1.567	1.089	1.136	1.176	1.509	1.355	1.359	1.428	1.678
Salmon, smelts, etc	169	48	93	73	31	8	41	121	53	10
Scorpionfishes	1.276	1.638	1.639	1.859	1.935	2.358	2.712	2.379	2.089	1.630
Sharks & rays	671	805	832	785	813	881	822	736	1.068	965
Tuna & billfishes	88	83	40	101	85	6	88	43	227	14
Total	**168.783**	**162.775**	**102.491**	**141.703**	**129.675**	**158.717**	**123.795**	**154.339**	**131.598**	**100.940**

Monetary valuation

The data used for valuing wild fish provisioning services are obtained from the Dutch System of National Accounts. This has the advantage that the data are reliable from year to year and the disadvantage is that there is a lower level of detail due to industrial sector aggregation, compared to financial statements from relevant private companies. Data on the output value, operating costs, intermediate consumption, compensation of employees, consumption of fixed capital, return on fixed assets, taxes and subsidies is directly obtained from the Dutch supply and use tables (Statistics Netherlands, 2022). Additionally, data on the compensation for the self-employed is obtained from the Dutch statistics on the self-employed (Statistics Netherlands, 2022).

Not all Dutch fisheries activities occur within the Dutch Continental Shelf (DCS). To distribute a portion of the Dutch fisheries to the DCS, division keys are essential. Wageningen Economic Research (WEcR) has computed these division keys using data from the Vessel Monitoring System (VMS). VMS data, obtained through satellite monitoring of fishing vessels, reveal the time and location of fishing activities. The allocation of the fishing sector to the DCS is determined by comparing the value of the catch from the DCS to the overall catch value in all waters. While not all vessels contribute data to the VMS, the excluded vessels account for only

[80] http://www.seaaroundus.org/

[81] https://opendata.cbs.nl/statline/#/CBS/nl/dataset/84088NED/table?ts=1700658001336

[82] https://agrimatie.nl/?subpubid=2526

about 1% or 2% of the total catch value, making their omission inconsequential to the results. The WEcR data used in this process originates from the NAMWA north sea economy project conducted by Statistics Netherlands in 2020. The division keys cover the period from 2010 to 2017. For 2018 and onwards, the division keys remain constant, based on the latest available data from 2017. Throughout the period from 2010 to 2017, the share of fisheries in the DCS consistently ranged between 27% and 31% (CBS, 2020).

The theory suggests that when fish are scarce, meeting the entire market demand becomes challenging. Consequently, the heightened demand leads to an increase in prices, yielding higher profits. Additionally, the European Union (EU) protects fish stocks by implementing fishing quotas based on the total allowable catch (TAC). These quotas, specifying the maximum quantity of each species that can be caught in a designated area, act as a barrier for current fishermen to expand production and dissuade new entrants to the industry. The resulting surplus in profits and demand generates economic rents tied to the ecosystem service provided by fish stocks. In such situations, applying the resource rent method could be valuable for analysis and management.

To calculate the resource rent, one can derive it from national accounts by subtracting the costs of labour, produced assets, and intermediate inputs from the market price of outputs (such as revenue from fish sales). The resource rent is calculated for the whole Dutch “fisheries and aquaculture” sector (ISIC 03 or NACE A3).

Table 56 shows the calculation of the resource rent for marine fisheries for 2020. The total estimated resource rent of marine fisheries was 10 million euros in 2020.

Table 56. Resource rent calculation for the DCS marine fisheries, (2020)

Output		**127**	**mln euro**
	Intermediate consumption	52	mln euro
	Ccompensation of employees	26	mln euro
	Other taxes on production	0	mln euro
	Other subsidies on production	-3	mln euro
Equals Gross operating surplus		**52**	**mln euro**
	Consumption of fixed capital (depreciation)	19	mln euro
	Less return to produced assets	8	mln euro
	less labour of self-emlpoyed persons	15	mln euro
Equals Resource rent		**10**	**mln euro**

The total output value of the marine fisheries in the DCS has decreased from 164 million euro in 2016 to 127 million euro in 2020. This decrease is also reflected in the resulting lower values of the resource rents. Overall, the value of the resource rent is low and has a high variability over the years, even showing negative values in 2013 and 2014 (Table 57). In cases where the economic rent is negative, it means that the costs of exploiting the resource are greater than the total revenue generated by it. This can occur for a variety of reasons, including low demand, high supply, or high costs of exploitation. A negative resource rent may also result from external factors such as regulatory changes, technological developments, or changes in consumer preferences.

Table 57. Resource rent estimates of the DCS marine fisheries, million euro (current prices)

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
	million euro										
Resource rent	14	9	8	-10	-3	8	24	24	21	17	10

Furthermore, we note that these values represent the value that can be attributed to the total catch of the Dutch fisheries worldwide, and not specific to the North Sea area.

It is also important to note that while increased fishing can yield more ecosystem services in the short term, it may lead to deterioration in the long run. Capturing a larger quantity of fish now can result in a high monetary value attached to the ecosystem service. However, the sustainability of this approach comes into question. If all fish are harvested today, the future value of the ecosystem service could plummet more often to zero or negative. Therefore, sustainable management of the stocks is required to ensure the continued provision of valuable ecosystem services over time.

7.2.2 Aquaculture provisioning services

According to the SEEA-EA definition: *"Aquaculture provisioning services are the ecosystem contributions to the growth of animals and plants (e.g. fish, shellfish, seaweed) in aquaculture facilities that are harvested by economic units for various uses. This is a final ecosystem service."* (UN, 2021)

Aquaculture (provision of biomass by reared animals such as mussels and oysters), i.e. shellfish culture and finfish culture, is mostly located in the Scheldes area and plays a less important role in the Dutch North Sea economy (Statistics Netherlands, 2017c), but may become more important in the future, especially if aquaculture pilots within offshore windfarms are going to be expanded in the future. Additionally, the Scheldes are outside the geographical scope of the current account. Therefore, in the current account aquaculture is included only in P.M. form.

7.2.3 Genetic material services

According to the SEEA-EA definition: *"Genetic material services are the ecosystem contributions from all biota (including seed, spore or gamete production) that are used by economic units, for example (i) to develop new animal and plant breeds; (ii) in gene synthesis; or (iii) in product development directly using genetic material"* (UN, 2021)

This ecosystem service is most commonly recorded as an intermediate service to biomass provisioning. Currently, harvesting of genetic material is linked to aquaculture in the Schelde area and other estuaries, which are outside the geographical scope of the current account. Also, it is difficult to quantify and measure this ecosystem service. Therefore, it is included as a P.M. term.

7.3 Regulating services

Regulating and maintenance services are those ecosystem services resulting from the ability of ecosystems to regulate biological processes and to influence climate, hydrological and biochemical cycles, and thereby maintain environmental conditions beneficial to individuals and society (UN, 2021). The next three regulating services will be discussed: global climate regulation, waste remediation, and coastal protection.

7.3.1 Global climate regulation services

According to the SEEA-EA definition: *"Global climate regulation services are the ecosystem contributions to the regulation of the chemical composition of the atmosphere and oceans that affect global climate through the accumulation and retention of carbon and other GHG (e.g., methane) in ecosystems and the ability of ecosystems to remove (sequester) carbon from the atmosphere. This is a final ecosystem service."* (UN, 2021)

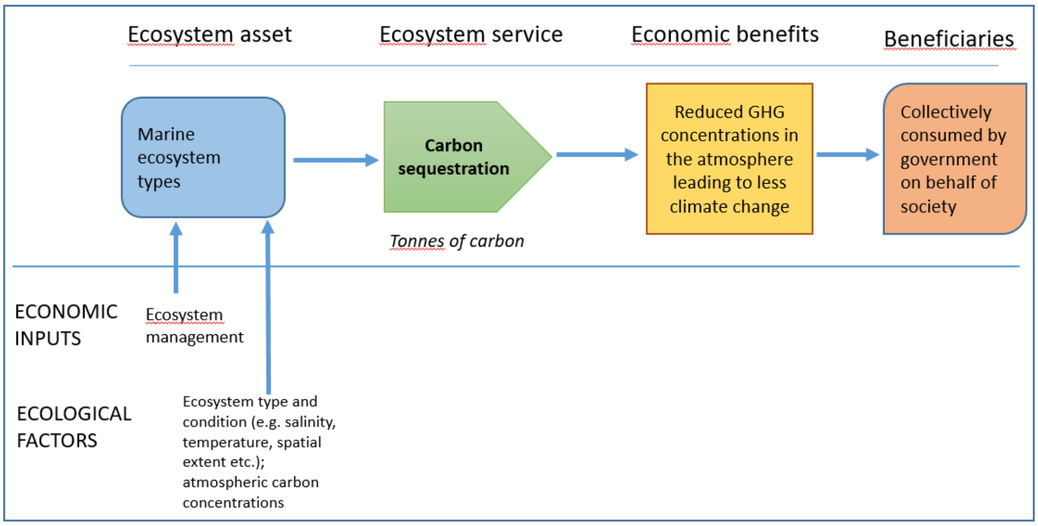


Figure 54. Logic chain for marine climate regulation (carbon sequestration)

The semi-permanent removal of CO_2 from the atmosphere by natural biotic and abiotic processes results in a decrease in atmospheric CO_2 concentration and subsequently assists in mitigating global anthropogenic climate change, which is generally accepted to be a threat to human welfare and wellbeing. The measurement approach recommended in the SEEA EA is to consider global climate regulation services (in case of carbon) as a single service consisting of two components: a carbon retention and a sequestration component, reflecting the importance of ecosystems both in terms of removing carbon from the atmosphere as well as storing carbon over longer periods of time, avoiding its release (UN, 2022). The global population can be seen as the beneficiary here, in accounting terms the government acts as the final consumer of this ecosystem (on behalf of society as a whole).

Defining Carbon sequestration and retention in marine ecosystems

In terrestrial ecosystems carbon sequestration and retention is relatively well understood. The carbon retention component of the service is quantified by recording the stock of carbon retained in ecosystems at the beginning of the accounting period (i.e., the opening stock). Carbon is stored both in living biomass and in dead biomass (including organic carbon in soils). This is a proxy indicator for the flow of the service, analogous to the quantification of the services supplied by a storage company in terms of the volume of goods stored (SEEA EA ¶6.111). In terrestrial ecosystems, forests but also organic rich soils (including peat lands) play a key role in the retention or carbon[83]. The carbon sequestration component of the service reflects the ability of ecosystems to remove carbon from the atmosphere by photosynthesis. In measuring this component, it is assumed that carbon sequestration concerns only carbon that is expected to be stored for long periods of time (SEEA EA ¶6.114). In view of mitigation options,

[83] Conversely, peat oxidation may release carbon, resulting in a negative sequestration. Within the North Sea, the disturbance of the sea floor by bottom trawling may be a similar mechanism.

carbon sequestration is measured on relatively short time scales, i.e. as the net annual removal of carbon from the atmosphere by vegetation, primarily forests. An increase in the quantity of terrestrial organic carbon driven by a temporary excess in organic carbon sequestration relative to its oxidation thus lowers atmospheric CO_2.

In marine environments carbon sequestration and carbon retention is a more complex process which is still less well understood, and, maybe even more important, acts on different timescales. In the ocean, there are no aggregations of biomass comparable to the forests on land. Yet biological productivity in the ocean plays a central role in the sequestration of carbon away from the atmosphere, overshadowing the effects of terrestrial biospheric carbon storage on timescales longer than a few centuries (Hain et al., 2014). Contrary to the terrestrial realm, national assessments for greenhouse gas reporting do not account for marine stocks such as organic carbon stored in shelf sediments, although the can be an important sink (see below).

The ocean naturally sequesters carbon through three different processes (e.g. Hain et al., 2014). First, the so-called solubility pump takes up carbon dioxide from the atmosphere into the surface ocean where it reacts with water molecules to form carbonic acid. The solubility of carbon dioxide increases with decreasing water temperatures. In the Polar Regions, more dense water flows towards the Deep Sea dragging down dissolved carbon. Actually, in high latitudes water stores CO_2 more easily because low temperatures facilitate atmospheric CO_2 dissolution. The ocean holds roughly fifty times as much carbon as does the atmosphere and almost twenty times as much as the terrestrial biosphere (Bopp et al, 2019).

Second, the biological pump moves dissolved carbon dioxide from the surface ocean to the ocean’s interior through the conversion of inorganic carbon to organic carbon by photosynthesis. The cycle with the shortest timescale, which operates within the surface waters of the ocean, is composed of net primary production by phytoplankton (their photosynthesis less their respiration) and heterotrophic respiration by zooplankton and bacteria that oxidize most of the primary production back to CO_2. Organic matter that survives respiration and remineralisation can be transported through sinking particles to the seafloor. Furthermore, after burial, a large portion of the organic matter is demineralized in the sediment as a result of diagenetic processes. Eventually, only a tiny fraction of the organic matter exported from the surface ocean survives its passage through the water column and sediment/water interface and is buried in the accumulating sediments, thereby removing carbon from the ocean/atmosphere system. This part of the biological pump operates on a 100 to 10000 year time scales (or even longer). The biological pump relies on ecosystems’ good health. In the high seas for instance, the planktonic ecosystem is a major player.

Third, many marine organisms also extract carbon from surface waters to produce inorganic carbon compounds, mainly calcium carbonate ($CaCO_3$). Contrary to organic matter, a greater fraction of the $CaCO_3$ that precipitates to the seafloor is preserved and buried, so that $CaCO_3$ production by organisms in the surface is a major contributor sedimentation, and this burial flux constitutes the largest sink of carbon from the ocean/atmosphere system. Carbonate formation, however, not only removes carbon from seawater, but also produces CO_2.[84] The formation and sinking of $CaCO_3$ therefore results in a raise of the pH of surface waters, shifting the speciation of dissolved carbon to raise the partial pressure of dissolved CO_2 in surface waters, which actually raises CO_2 atmospheric levels. The burial of $CaCO_3$ in sediments serves to lower overall oceanic alkalinity, tending to raise pH and thereby atmospheric CO_2 levels if not counterbalanced by the new input of alkalinity from weathering.

[84] 2 HCO_3- + Ca_2+ → $CaCO_3$+ CO_2 + H_2O

The notion of time is crucial with respect to carbon storage in the oceans. The biological pump can act on short timescales and is sensitive to disturbances. Consequently, it can be destabilized and re-emit carbon into the atmosphere. The solubility pump on the other hand acts on another timescale. It is less sensitive to disturbances but it is affected on a long-term basis. The carbon transferred to the deep sea due to ocean circulation, is temporarily removed from the surface cycle but will resurface after 500 to 1500 years.

Summarizing, carbon cycling in the marine environment consists of several sub-cycles that act on different timescales and also in different parts of the marine realms (shallow marine versus deep marine; surface water, water column, sediment). This makes it difficult to define and measure carbon sequestration and carbon retention in terms of ecosystem services, as ecosystem services are usually measured on short timescales (i.e. annually) and, in ecosystem accounting, have to be attributed to certain ecosystem types. Carbon uptake by the solubility pump is an abiotic process and stems from the imbalance between the atmospheric and surface water CO_2 concentrations which is not considered an ecosystem service as such. Carbonate formation and burial removes carbon from the oceans, but at the same time produces CO_2, and on the short timescale is thus not considered as an ecosystem service. With respect to carbon sequestration and retention in the oceans, the focus is thus on organic carbon formation and storage. This is in line with the IPCC definition for Blue carbon: "Biologically driven carbon fluxes and storage in marine systems that are amendable to management." (IPCC, 2021). The focus for blue carbon has been on rooted vegetation in the coastal zone, such as tidal marshes, mangroves and seagrasses, but can be extended to organic carbon buried in subtidal ecosystems (Hilmi et al., 2021).

In subtidal marine environments annual net primary productivity of the surface water is not a good measure for *carbon sequestration* as a significant part of this carbon will be demineralized in the water column, the sea bottom and upon burial in the sediment. A better measure are the annual carbon burial rates, although there are also problems with this measure, not only because it is hard to measure, but also because diagenetic processes and decomposition of the organic matter will continue long after burial. This would also imply that the carbon sequestration service is allocated to the place where carbon burial is taking place, and not where the carbon uptake by primary production occurs.

Similarly as for the terrestrial environment, *carbon retention* as an ecosystem service for the marine environment can best be defined as the stock of carbon in a) benthic and pelagic living biomass and b) the (upper part of the) sediments. Similar as to soils, the question is how to define the scope of the stock of carbon with regard to the sediment depth. The most commonly applied solution here is to take a depth where the sediment may be prone to human induced disturbances, such as bottom trawling, which usually is ca. 10 cm. Demersal fishing-induced sediment disturbance stimulates mineralization of organic carbon (OC) in sediments, likely due to the enhanced decomposition of previously buried refractory OC (van de Velde et al., 2018). In the long-term, the result of repeated and vigorous sediment mixing due to demersal fishing is a general impoverishment in OC (Martín et al., 2014a). Establishment of Marine protected areas protecting against demersal fishing could therefore not only facilitate the recovery of benthic species, but also promote carbon uptake by seabed ecosystems, as well as prevent further loss of OC stored in sediments (Roberts et al., 2017).

Carbon burial in the North Sea

Continental shelf sediments are estimated to hold 16% of the global OC stock (Atwood et al., 2020) and annually account for 86% of all OC buried in marine subtidal sediments (Berner, 1982; Hedges and Keil, 1995). Shelf seas, like the North Sea, thus could potentially act as an important sink for organic carbon. Continental shelf sediments are also places of rapid organic carbon turnover, while at the same time increasingly subjected to human-induced disturbances.

There are several recent studies on carbon sedimentation and burial in the North Sea. Haas et al. (1997) found that in large parts of the shallow North Sea recent sedimentation is (nearly) absent and that the majority of the organic matter is exported from the shelf over the shelf edge into the Norwegian Sea and into inner shelf deeps (Skagerrak and Norwegian Channel). Diesing et al. (2020) reported similar results for the North Sea: carbon stocks and accumulation rates are high in the Norwegian Trough (Northern part of the North Sea), while large parts of the North Sea are characterized by low stocks and zero net-accumulation. The seafloor in the Southern Bight, on Dogger and Fisher Banks is characterized by shallow water depths, high tidal current speeds, and wave orbital velocities. The supply of oxygen to the sedimentary microbial community facilitates the effective degradation of OC. Consequently, oxygen penetrates deep into these sediments and OC density is low. The potential for longer-term accumulation of OC is very low, as these environments are characterized by repeated erosion-redeposition cycles.

Smeaton et al. (2021) studied the marine sedimentary carbon stocks of the United Kingdom's Exclusive Economic Zone. They found that the muddy sediments of coastal and inshore waters hold higher amounts of OC. These coastal and inshore zones encompasses estuaries and coastal mud belts which receive significant quantities of additional OC from terrestrial sources. However, these areas tend to be well oxygenated and characterized by sediment mobility, factors which increase the rates of OC degradation and lead to reduced quantities of OC held within the individual sediment types. The continental shelf sediments differ from coastal sediments in that the OC contents show little variation, with mean OC values ranging between 0.32% for the gravelly sand and 1.10% for mud. The similarity of the OC values across sediment classes may partly be driven by the lateral transport of OC across the continental shelf, which enhances oxidation and significantly increases OC degradation in all these sediment types.

Carbon retention in the Dutch EEZ

As discussed above, carbon *retention* as an ecosystem service should be expressed as the stock of carbon. In the North Sea ecosystems, blue carbon is mostly concentrated in seabed sediments, while carbon stored in living biomass like kelp and seagrasses play a minor role (Burrows, 2021). It is common to asses carbon stocks only in the top 10 cm of the sediment, as these parts are prone to (human induced) disturbances and loss of carbon (e.g. Burrows, Diesing et al. 2020). Diesing (2017) found that carbon concentrations in top sediment are primarily correlated with sediment type (grain size), and to a lesser extend to bottom water temperature and distances to the shoreline. Here we have applied the data reported by Diesing (carbon concentrations and bulk dry sediment densities in relation to sediment type) to estimate the carbon stocks for the Dutch EEZ (Table 58). Accordingly, we calculated that the carbon stock is ca. 26 Mton of carbon, with most carbon stored in sandy sediment (due to the size of sandy surface within the EEZ). We acknowledge that this calculation holds a high degree of uncertainly, However, it provides a reasonable estimate order of magnitude and is in line with other studies for the North Sea. When we compare this with the terrestrial carbon stock reported for the Dutch terrestrial ecosystems (370 Mton) in the Natural capital accounts, blue carbon is more than a factor 10 smaller. These finding are consistent with similar results reported for other countries (Burrows et al; Diesing et al., 2021). The apparent contrast with the earlier remark that the oceans store "*twenty times as much carbon as does the terrestrial biosphere*" can be explained by the fact that globally most carbon sequestration will occur in deep oceans, not in the shallow North Sea. Still, the North Sea stores significant amounts of carbon, currently not taken into account in IPCC reporting. In addition, we note that for terrestrial ecosystem 30 cm of soil organic carbon is taken into account. Taking a larger sediment depth would result in a higher carbon retention figure, although carbon concentration usually decrease with sediment depth as a result of diagenetic degradation of organic matter.

Table 58. Carbon stock in the Dutch North Sea

	Extent km2	POC (%)	Dry bulk density kg/m3	Carbon stock top 10 cm Mton
Sandy mud	289,7	0,78	828	0,2
Coarse substrate	2992,5	0,23	1515	1,0
Muddy sand	13990,3	0,54	1323	10,0
Sand	41750,2	0,24	1511	15,1
Total				26,4

Carbon sequestration in the Dutch EEZ

Carbon sequestration, or carbon accumulation rates for the North Sea are even more uncertain than the carbon stocks. De Haas (1997) provides an average estimate of 0.2 gC m^{-2} yr^{-1}, but also reports that for many sites the accumulation is actually zero or negative. When we apply this average carbon accumulation rate to the area of the Dutch EEZ, this would result in a total annual carbon sequestration rate of 0.01 Mton. This low figure reflects that the Dutch EEZ is currently not acting as a significant ecosystem removing carbon from the atmosphere.

Monetary valuation

There are two approaches to estimate the economic value of carbon sequestration, both of which represent a measure of avoided damage. The first approach involves the EU ETS (Emissions Trading System) price, which is a market instrument used by the EU to reduce greenhouse gas emissions in a cost-effective manner to achieve its targets and those of the Kyoto Protocol. Purchasers and suppliers trade in emission allowances, the right to emit certain volumes of greenhouse gases, which results in a market price for CO_2.

The second approach is to calculate the costs of achieving a policy-defined target of reduction in CO_2 emissions (i.e., *replacement cost*). This calculation produces a carbon price. By valuing carbon sequestration in biomass at this carbon price, we estimate in monetary terms the contribution of ecosystems to achieving the policy target. The Netherlands Environmental Assessment Agency (PBL) and the Netherlands Bureau for Economic Policy Analysis (CPB) have calculated a carbon price – the *efficient carbon price* - for the Netherlands. The efficient carbon price is the price at which the necessary cumulative reduction in CO_2 emissions is achieved at the lowest costs (PBL, 2018)[85]. A number of different scenarios have been developed: a high-reduction scenario, a low-reduction scenario, and a two-degree temperature increase scenario.

According to PBL (2016), by 2050 the efficient price is equal to the ETS price of a ton of CO2 emissions, as all economic actors fall under the ETS. In the high-reduction scenario, the efficient price is 160 euros per ton of CO2 in 2050; in the low-reduction scenario it is 40 euros per ton; and in the two-degree policy target scenario it ranges from 200 to 1000 euros per ton. The

[85] PBL and CPB are currently working on an update of the scenario study Welfare, Prosperity and the Human Environment (WLO), which include new efficient carbon prices. This new calculation will take into account, among other things, the current and more ambitious targets for reducing CO_2. The new efficient prices will therefore in all likelihood be higher than the ones used in this study.

discounted net present value is calculated using a discount rate of 3.5%, which is the European standard discount rate. CE Delft takes the high-reduction scenario as the central scenario (between the low-reduction and the 2°- scenario).

In this report we follow previous publications of Statistics Netherlands and apply the high-reduction scenario (Statistics Netherland and WUR, 2022). For the year 2020, the corresponding figures are then 57 euros per ton of CO_2.[86] For the annual carbon sequestration, we concluded in this chapter that the Dutch EEZ is currently not acting as an ecosystem removing carbon from the atmosphere, which would imply a monetary value of zero.

7.3.2 Solid waste remediation and water purification services (water quality amelioration)

According to the SEEA-EA definition: "*Solid waste remediation services are the ecosystem contributions to the transformation of organic or inorganic substances, through the action of micro-organisms, algae, plants and animals that mitigates their harmful effects. This is may be recorded as a final or intermediate service."* (UN, 2021).

And: "*Water purification services are the ecosystem contributions to the restoration and maintenance of the chemical condition of surface water and groundwater bodies through the breakdown or removal of nutrients [2.9]and other pollutants [2.10] by ecosystem components that mitigate the harmful effects of the pollutants on human use or health. This may be recorded as a final or intermediate ecosystem service*."

Watson et al (2016) provide an extensive framework for waste remediation /water purification as an ecosystem service. They distinguish between 3 types of waste: Nutrients and organic matter, biological waste or contaminants, and persistent contaminants. Waste remediation includes different mechanisms: cycling/detoxification; sequestration; export. Watson et al (2016) further include an overview of underlying ecosystem processes that are involved and possible indicators to provide quantification.

Data sources

Monitoring data collected for MSFD or OSPAR reporting could be linked to the indicators mentioned by Watson et al (2016) but spatial coverage is an issue, and possible point data must be incorporated in a larger scale mass balance involving in- and outfluxes as well.

A first starting point is to consider the total offshore discharges of pollutants into the North Sea from the Netherlands. Section 5.6.3 discusses the discharges into the North Sea from the Netherlands based on OSPAR data. Here we will focus on nutrients and organic matter which are remediated by marine ecosystems in contrasts to persistent contaminants such as heavy metals for which ecosystems can only provide a sink function (which is not considered an ecosystem service).

Monetary valuation

The replacement cost method is the best available valuation method for waste remediation. This method was also used by the UK account for example. A key assumption here is that all pollution is "taken care of" somehow by the North Sea. Under this assumption, waste remediation would be equal to the influx of pollutants into the North Sea. The replacement for the water purification service would be water purification operated by urban waste water treatment plants. For these we know both the operating costs and the amount of pollutants

[86] For comparison, the current (2022) ETS price is €41,75. Source: emissieautoriteit.nl

removed. Based on this we can calculate the costs per pollutant (euro /kg). As only the total costs for waste water treatment is known, this results in different costs per pollutant. Here we take nitrogen as a benchmark, being the key nutrient governing eutrophication in the North Sea. Multiplying the costs for nitrogen purification with the total nitrogen load into the North Sea (from the Netherlands) results in a value of 2802 million euro for 2015 and 3014 million euro for 2019 (Table 59). We note that alternatively, another benchmark pollutant could be chosen (for example phosphorus), which would lead to different values.

Table 59. Calculation of the monetary valuation for waste remediation.

Cost component		Year	
		2015	2019
Operating costs water purification	million euro	995	1.114
Amount of pollutants removed	1000 kg	74.481	79.818
Costs per pollutant	euro/kg	€ 13,36	€ 12,93
total nitrogen load into the North Sea	kton / a	209,7	214,7
Value purification service	**million euro**	**2.802**	**3.014**

7.3.3 Coastal protection services

According to the SEEA-EA definition: SEEA EA: "*Coastal protection services are the ecosystem contributions of linear elements in the seascape, for instance coral reefs, sand banks, dunes or mangrove ecosystems along the shore, in protecting the shore and thus mitigating the impacts of tidal surges or storms on local communities. This is a final ecosystem service.*" (UN, 2021)

In the Netherlands, coastal dunes, salt marshes and sand banks and perhaps the entire coastal zone sea floor can be expected to contribute to coastal protection, either due to the physical barrier (coastal dunes) or by absorption of wave energy (other ecosystem types). A complicating factor, though, is that, especially in the case of coastal dunes, the most protective areas, i.e., the first row of dunes, are for the most part highly managed, and thus not services that are provided by the marine ecosystem.

Method

The protection against flooding as provided by coastal dunes is not to be ignored or underestimated. In fact, without the existence of these dunes the lower part of the Netherlands would not exist at all (i.e. would not have formed during the Holocene). In the most recent 2015–2020 ecosystem account for the terrestrial part of the Netherlands protection against flooding by coastal dunes is included as an ecosystem service. The results in this report are directly obtained from this previous work.

The monetary value is calculated based on replacement costs. Dunes could either be replaced by new dikes or by new dunes. The height of these dikes depend on the tide but also on the set norm for flooding. However, the Netherlands has a very long history of using dikes as coastal protection, therefore there are mainly examples of costs for increasing the height of the dikes, and not so much for placing a new coastal dike. The costs for elevation of dikes are in the order of 10 million euro per 1m elevation of 1 km dike. The Delta norm for dikes at the North Sea coast is about 11.5 meter. It is not likely that there are constant costs per meter elevation for this height.

In 2015, the *Hondsbossche en Pettemer zeewering* (a coastal dike of 5.5 km) was replaced by a completely man-made system of dunes and a beach. These dunes and beach completely took over the function of primary coastal defence. This project costed 140 million euro (excl. VAT). Taking the total costs of 140 million euro to replace 5.5 km dike for the *Hondsbossche en Pettemer zeewering*, assuming a resource rent of 2% (Statistics Netherlands and WUR, 2022) and a total period of 100 years, the monetary value would be 0.59 million euro per km coastal dune. In total, 264.1 km of the coast is protected by dunes. This results in 158 million euro in 2015. The monetary value per km has been adjusted with the annual inflation data from Statistics Netherlands[87] to estimate the value of this ecosystem service in 2020 and other years (assuming the total number of km of coastal dunes remains constant).

Results

The replacement cost method based on the Hondsbossche en Pettemer zeewering gives an estimate for the total value of the coastal defence service of 158 million euro for 2015. Correcting for inflation, this was 168 million euro in 2020. These are flow values and indicate the value for that specific year. The asset value of the entire coastal protection by dunes is found in Chapter 8.

7.4 Cultural ecosystem services

Cultural services 68 are the experiential and intangible services related to the perceived or actual qualities of ecosystems whose existence and functioning contributes to a range of cultural benefits (UN. 2021). The following three cultural ecosystem services will be discussed in detail: nature related recreation and tourism, and visual amenity. Three additional cultural services will be discussed in concept only.

A distinction is made between nature-related *recreation* without overnight stays, and by definition almost only supplied to national residents, and nature-related *tourism*, with at least one overnight stay. Nature-related tourism includes overnight stays of residents and non-residents.

7.4.1 Nature related recreation

According to the SEEA-EA definition: *“Recreation-related services are the ecosystem contributions, in particular through the biophysical characteristics and qualities of ecosystems, that enable people to use and enjoy the environment through direct, in-situ, physical and experiential interactions with the environment. This includes services to both locals and non-locals (i.e. visitors, including tourists). Recreation-related services may also be supplied to those undertaking recreational fishing and hunting. This is a final ecosystem service.”* (UN, 201)

The ecosystem service nature recreation may be supplied by many ecosystem types, including natural and semi natural ecosystem types. The benefits provided by this ecosystem service are better physical and mental health conditions, enjoyment, but also (extra) final consumption of products and services associated with recreation, which is a direct benefit for the economy. The beneficiaries are (national) households or non-residents (visitors from abroad).

[87] https://opendata.cbs.nl/statline/#/CBS/nl/dataset/70936NED/table?dl=91024

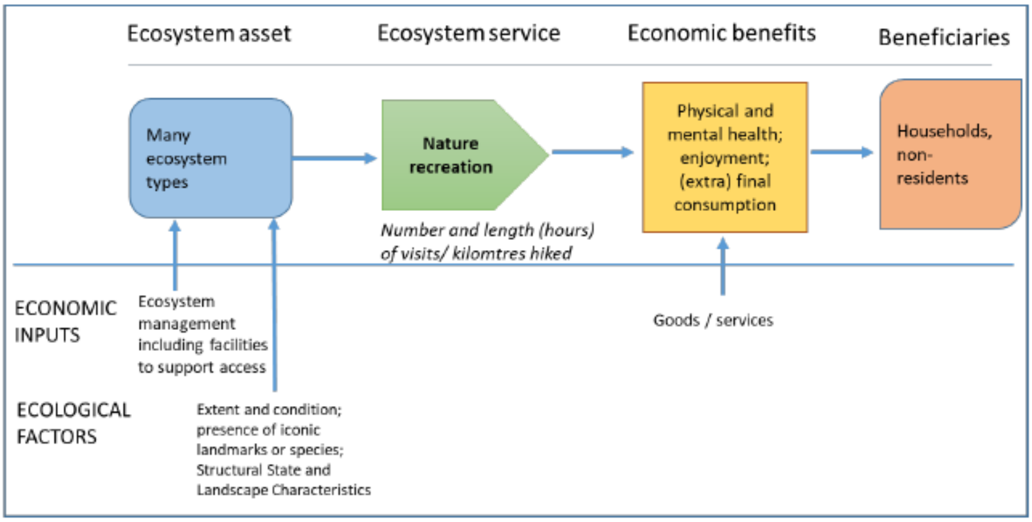


Figure 55. Logic chain for nature-oriented recreation.

It is not straightforward to define nature related recreation and tourism for marine ecosystems. Many of the activities where the North Sea plays a significant role, do not actually take place in the marine environment, but rather on its adjacent land area (i.e. beaches, coastal dunes). Activities that are associated with true marine ecosystems include recreational fishing and water sports (sailing, boating, surfing, kiting, diving/snorkeling, etc.), while while activities that are associated with the marine coastal zone include beach and coastal dune recreation (hiking, biking, sunbathing, picnics, beach sports) and beach festivals (e.g. Scheveningen kite festival). Other activities are associated with both, e.g. wildlife/nature watching (birds, seals, etc.).

Depending on which recreational activities to include in the account, the physical metric for this ecosystem service can be the number of visits, trips or, in the case of hiking, total kilometers hiked.

Current treatment in ocean accounts:

This study continues the approach to nature related recreation as developed as part of the previous Dutch North Sea account (CBS, 2019), using results from the more recent terrestrial NCA studies, based on data from CVTO (ContinuVrijeTijdsOnderzoek) surveys (CBS, 2022). Hiking is the most popular recreational activity, representing 46 percent of outdoor recreational activities (NBTC-NIPO 2018), and therefore previous Dutch NCA studies focused on this activity. To select the hiking activities related to the North Sea, only hikes taking place in the ecosystem types 'dunes' and 'beaches' were selected.

The UK, in its report 'Marine accounts, natural capital, UK: 2021' (ONS, 2021), also reports on recreational activities around the marine ecosystem. Two physical metrics are used, time spent at and total visits to beaches and the marine environment for recreation and nature watching. Monetary valuation was done with the travel cost method to consider expenditures (travel, parking and admission costs) associated with traveling to the coastal and marine environment.

Data sources

Data on recreational activities and expenditures were obtained from the CVTO (ContinuVrijeTijdsOnderzoek) surveys held by NBTC-NIPO. These statistics provide information on the a wide range of types of recreational activities. It includes variables such as: number of activities, length of the activity, travel distance towards the activity, regional data such as the natural environment in which the activity took place, and the specific province. It also contains data on different kinds of expenditures. These reports are available for the years 2015 and 2018. The remaining years have been estimated with the support of additional statistics from the Statistics Netherlands on the mobility of persons, which are based on survey data (Statistics Netherlands, 2022).

There are two issues with the NBTC-NIPO survey data that need to be mentioned:

1. In the near future there will be no update of the surveys. This means we currently only have data for 2015 and 2018 available. NBTC is currently working on a pilot study with data from the “Nederlands Verplaatsingspanel (NVP)”, which might provide data on recreational activities in the Netherlands in the future.
2. Data on activities that are less frequently conducted are of lower quality.

Methodology

Recreational activities include all marine and coastal leisure related activities for which one is away from home for one hour or longer, but that do not include an overnight stay. In order to delineate nature related recreation, we selected the following types of recreational activities, which take place outdoors and to a large extent depend on the outdoor environment:

- Outdoor recreation, which includes hiking for pleasure, cycling for pleasure, general outdoor recreation (including beach recreation), touring around in the (coastal) countryside by car or motor, and trips by tour boats.
- Water sports, which include kayaking, rowing, surfing, fishing, sailing, and boat trips (excluding indoor water sports).
- Outdoor sports (excluding water sports), which include jogging/running, mountain biking, horse riding, hiking (as a sport), and cycling

To determine the activities that take place in the marine environment, we use the variable in the NBTC-NIPO survey data that indicates the natural environment in which the recreational activity took place. Two of these types of natural environments were selected: “At and on sea” and “coastal dunes”. These data are available per type of activity and per province.

Results

The results consist of a time series with data on marine recreational activities for the years 2013-2020. A regional distinction can be made on a province level as is shown in Figure 56. The densely populated province of Zuid-Holland and the province Noord-Holland with relatively large coastal areas provided the most marine recreational activities.

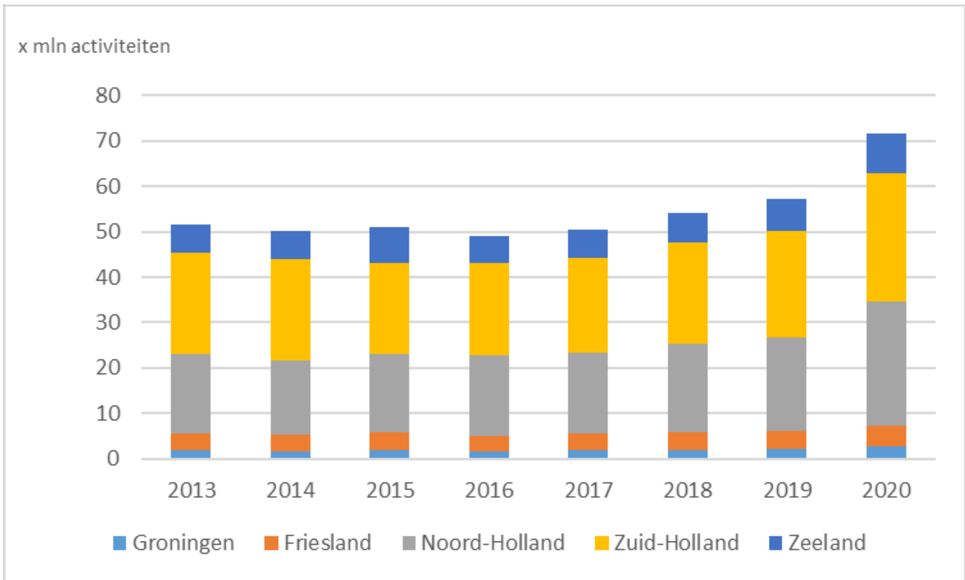


Figure 56. Number of marine recreational activities per province, time series (Source: Statistics Netherlands)

It is also possible to make a distinction between different recreational activities. As shown in Figure 57, the most frequently undertaken coastal activity is 'outdoor recreation', which includes hiking, cycling, and general outdoor recreation (sunbathing, lounging, barbecuing, picnicking, etc.).

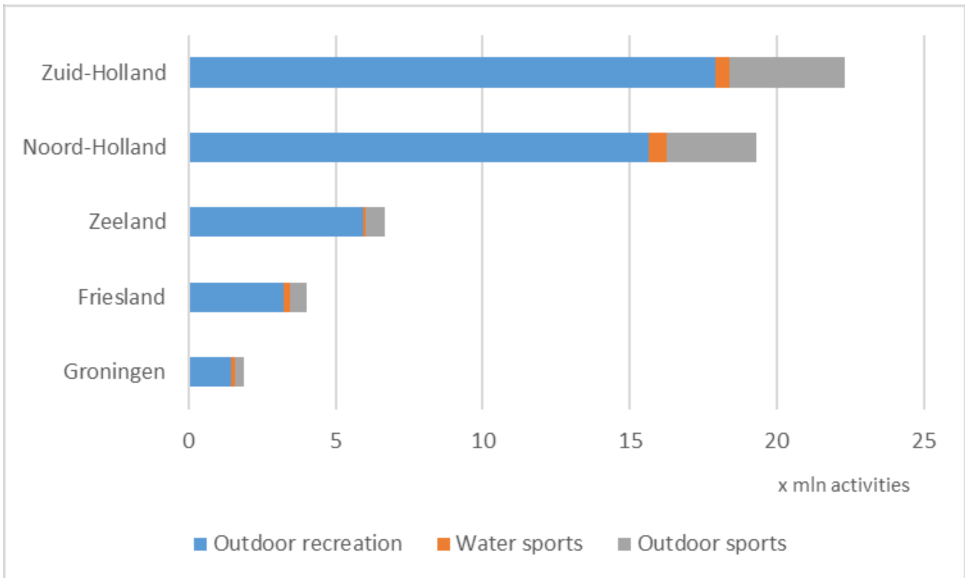


Figure 57. Number of marine recreational activities per province and type of activity in 2018 (Source: Statistics Netherlands)

Monetary valuation

As explained above, data on recreational expenditures were obtained from CVTO (ContinuVrijeTijdsOnderzoek) surveys held by NBTC-NIPO, with data for 2015 and 2018 (NBTC-NIPO 2015, 2018). The remaining years have been estimated with the support of additional statistics from the Statistics Netherlands, such as mobility statistics, consumer price indices and data on fuel prices (Statistics Netherlands, 2022).

The travel cost method is often used to value recreational services (e.g. Barton et al., 2019). This method assumes that travel costs of tourists and recreationists can be taken as an indication for their willingness to pay for the services of nature. However, the consumer expenditure approach is applied in this study and uses the same principles as the travel cost method approach. The consumer expenditure approach as presented here is very similar to the 'simple' travel cost method applied in the United Kingdom to value these ecosystem services (ONS, 2016). Expenditures by households are also key examples of market transactions and consequently represent exchange values, which is a requirement to be aligned with the SNA. With respect to expenditure categories we thus included admission fees, travel costs and other related costs. Expenditures on foods and drinks and purchases in shops are excluded since they are not primarily related to the marine ecosystem services.

The monetary value of marine recreational activities has increased from 166 million euro in 2013 to 242 million euro in 2020 (Figure 58). The recreational activities at and on sea account for about 72% of this value.

Table 60. Value of marine recreation, in million euros (current prices) (Data: Statistics Netherlands)

Area	**Year**							
	2013	2014	2015	2016	2017	2018	2019	2020
On and at sea	122	122	113	133	141	155	163	174
Coastal dunes	45	45	42	51	54	59	63	68
Total	**166**	**166**	**155**	**184**	**195**	**214**	**226**	**242**

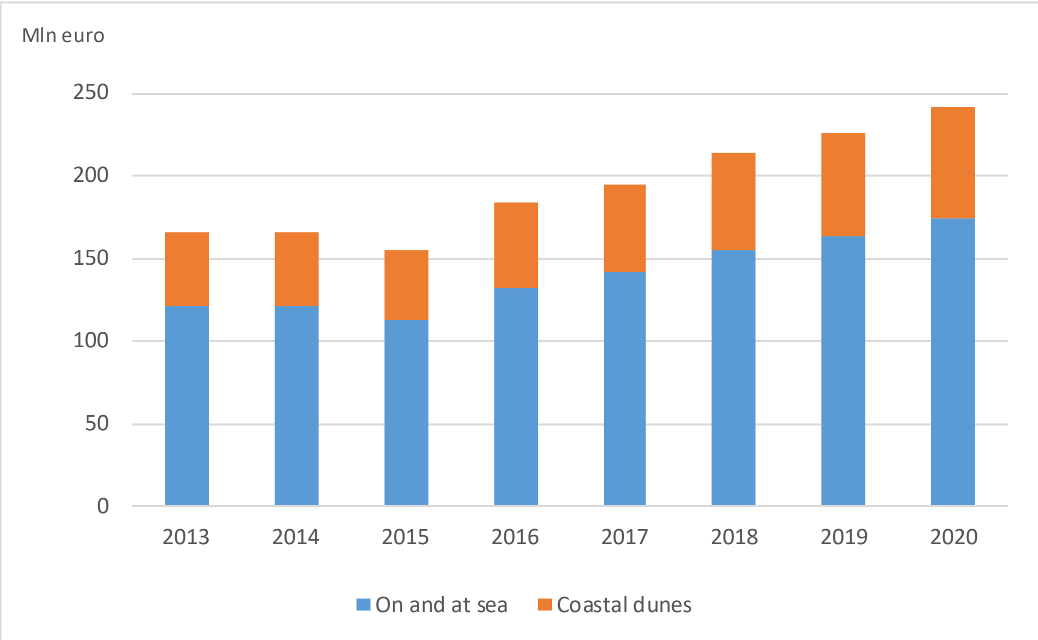


Figure 58. Value of marine recreation, in million euros (current prices) (Data: Statistics Netherlands)

7.4.2 Nature related tourism

Nature-related tourism is strongly related to nature-related recreation (the topic of the previous paragraph), and falls within the same SEEA-EA definition. The distinction is that tourism by definition involves overnight stays, while recreation does not.

Nature related tourism includes tourists (residents and non-residents) with a primary focus on nature. In the case of the North Sea, this includes beach tourism and water tourism. Water tourism includes activities that take place on the sea, such as sailing and surfing.

The ecosystem service nature tourism may be supplied by many ecosystem types, including natural and semi natural ecosystem types. The benefits provided by this ecosystem service are better physical and mental health conditions, enjoyment, but also (extra) final consumption of products and services associated with tourism, which is a direct benefit for the economy. The beneficiaries are (national) households or non-residents (visitors from abroad).

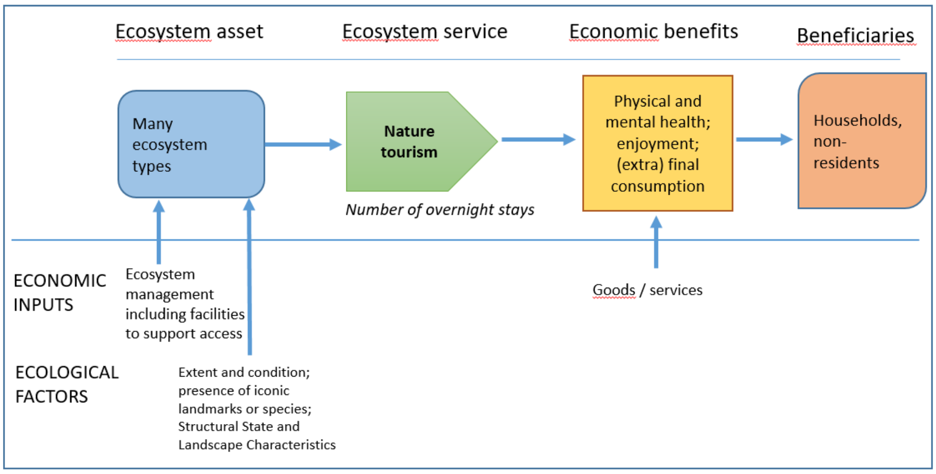


Figure 59. Logic chain for nature-oriented tourism.

Data and methods

The ecosystem service was modelled based on Dutch tourism statistics, namely the quantity of overnight stays by tourism type, available at the aggregated scale of provinces (NBTC-NIPO, 2013, 2015, 2018 & 2020) and statistics on the number of overnight stays of domestic and international tourists (Statistics Netherlands, 2022).

From the Dutch tourism statistics we are able to extract beach tourism by residents for the Netherlands. We can also extract the number of overnight stays for foreign tourist that stay in the coastal regions.

From the source data it is possible to extract "beach tourism". For Dutch residents, this data is available per province. To distribute the overnight stays of foreign coastal tourists, we applied the same distribution that was found for the Dutch residents: We assume that the distribution per province is the same for Dutch residents as for non-residents.

For each province, the number of overnight stays were distributed evenly across the ecosystem types that are considered to be the main targets of the tourism type. For nature and active tourism these include forests, wetlands, coastal dunes and open nature such as heathland and natural grasslands. For beach tourism only the ecosystem type beach was used. Agricultural land was also excluded; even though some agricultural areas may be the target of active tourism (cycling, walking) this is not considered to be the main attractor of active tourism in the marine environment.

To allocate the overnight stays related to water sports within the provinces, the number and size of marinas were used as a proxy. Marinas were selected from the topographic map (Top10NL) and converted to point data. The surface area of each marina was used in a kernel density analysis using a 10km search radius. The kernel density map was used to distribute the overnight stays proportionally over all water ecosystems and determine the number of overnight stays per ha.

Results

The results are shown in Figure 60 and Figure 61. Coastal tourism was increasing between 2013 and 2018 from 12,6 million overnight stays to 16,7 million overnight stays. The sharp decline in 2020 was due to the COVID regulations that made it more difficult for foreign tourists to go on holidays in the Netherlands. Overall, the natural environments in Noord-Holland and Zeeland facilitate the most coastal tourists (Table 61).

Table 61. Nature tourism in the Dutch coastal region per province, in million overnight stays (Statistics Netherlands)

Province	Year 2013	2015	2018	2020
Friesland	1,2	1,0	1,5	1,2
Groningen	0,0	0,0	0,0	0,0
Noord-Holland	5,0	6,7	8,1	4,8
Zeeland	4,4	4,3	4,5	3,9
Zuid-Holland	2,1	1,4	2,5	1,3
Total	**12,6**	**13,4**	**16,7**	**11,3**

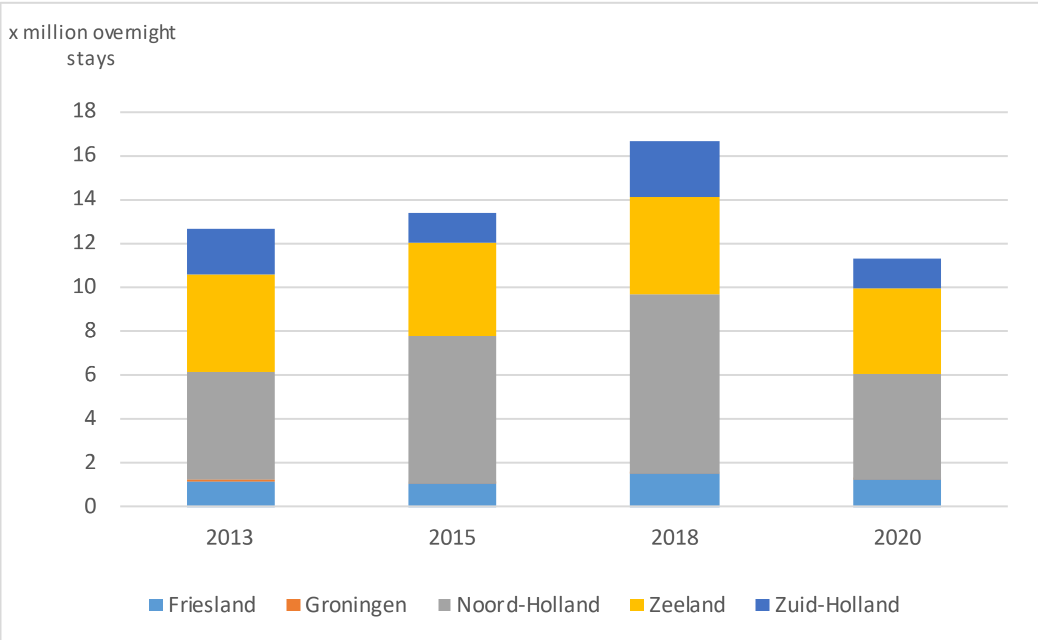


Figure 60. Nature tourism in the Dutch coastal region per province, in million overnight stays (Statistics Netherlands)

Table 62. Number of coastal holidays by residents and non-residents, time series (Statistics Netherlands)

Residency	Year			
	2013	2015	2018	2020
Residents	8,1	7,6	8,8	8,1
Non-residents	4,5	5,9	7,8	3,2
Total	**12,6**	**13,4**	**16,7**	**11,3**

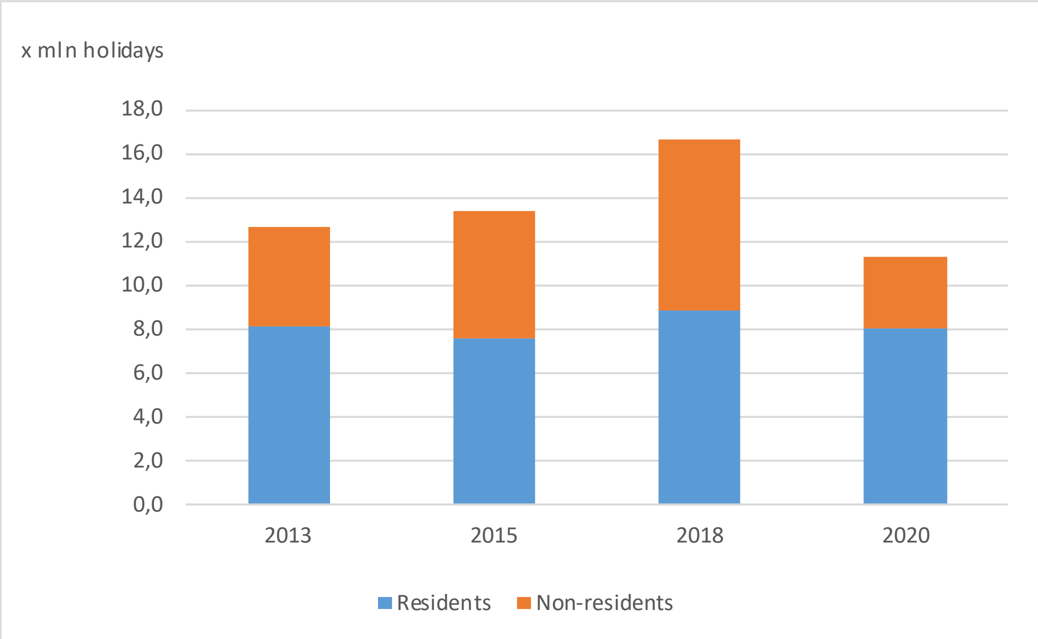


Figure 61. Number of coastal holidays by residents and non-residents, time series (Statistics Netherlands)

Monetary valuation

Data and methodology

Similar to the physical data, data on expenditures by residents were obtained from the Dutch tourism statistics, which in turn are based on survey results (the 'continuous holiday survey'). These statistics provide information on the different kinds of expenditures by residents, the types of holidays and the different regions (provinces) where the holidays take place. In order to delineate nature related tourism, we selected beach holidays.

Data for tourism expenditures by non-residents (inbound tourism) were directly obtained from the Dutch tourism satellite accounts within Statistics Netherlands. Most inbound tourism in the Netherlands takes place in the large urban areas (i.e. Amsterdam, The Hague, etc.). No information is available on the main motive of the inbound tourists. Therefore, as an approximation, we took the location where these tourists stay overnight to delineate nature related tourism by non-residents. The selected location "coastal areas" was chosen to represent the overnight stays of non-residents (Statistics Netherlands, 2022).

The valuation method is similar to that for nature recreation, namely the consumer expenditure approach. Data are available for different kinds of expenditures, the types of holidays and the different regions (provinces) where the holidays take place. We selected beach holidays to represent tourism that is related to the coastal area. Expenditures include costs for accommodation., travel costs and other costs (entry fees, etcetera). Expenditures related to shopping and on foods and drinks are excluded, in line with the approach used for nature recreation.

Results

The monetary estimates show very similar patterns as the physical results discussed earlier. Between 2013 and 2018 the monetary value of nature tourism increased from 896 million euro to 1,412 million euro. This can be attributed to an increase in holidays as well as an increase in expenses per holiday. In 2020 the COVID regulations caused a sharp decline in the beach holidays booked by non-residents. Expenditures during beach holidays were the highest in Zeeland and Noord-Holland for all years (Table 63).

Table 63. Monetary estimates coastal tourism per province,2013– 2020 (Data: Statistics Netherlands)

Province	Year			
	2013	2015	2018	2020
Zeeland	342	422	562	264
Noord-Holland	257	305	403	183
Friesland	154	163	217	97
Zuid-Holland	142	173	230	58
Groningen	1	1	1	0
Total	**896**	**1065**	**1412**	**603**

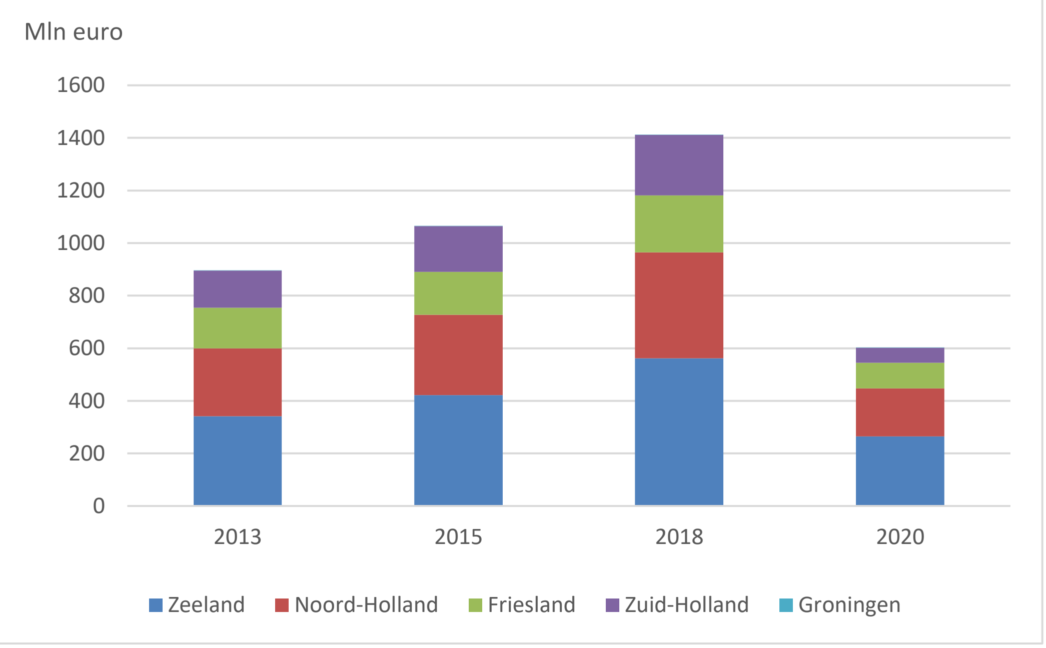


Figure 62. Monetary estimates coastal tourism per province,2013– 2020 (Data: Statistics Netherlands)

7.4.3 (Visual) amenity services

According to the SEEA-EA definition: *"Visual amenity services are the ecosystem contributions to local living conditions, in particular through the biophysical characteristics and qualities of ecosystems that provide sensory benefits, especially visual. This service combines with other ecosystem services, including recreation-related services and noise attenuation services to underpin amenity values. This is a final ecosystem service."* (UN, 2021)

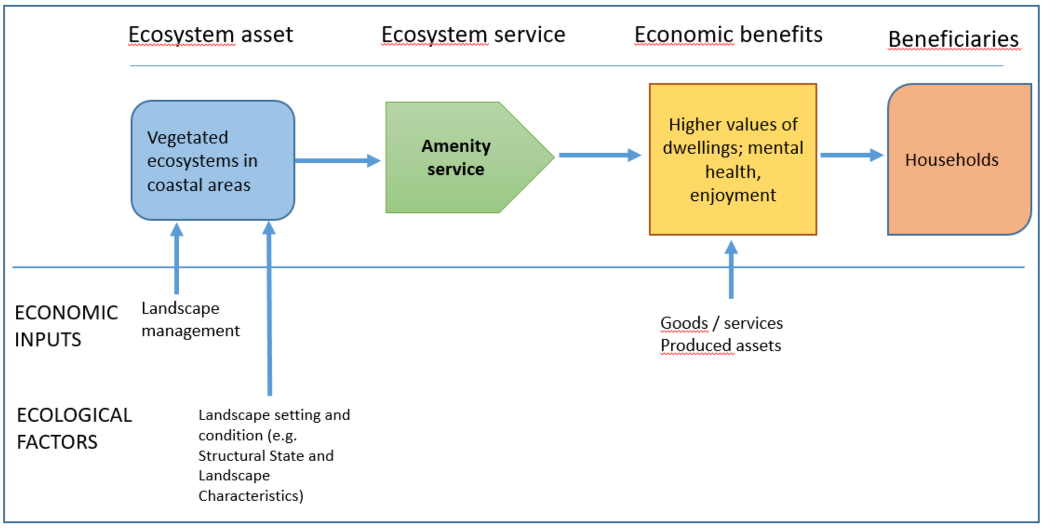


Figure 63. Logic chain for the amenity service.

The amenity service is a monetary ecosystem service (no physical metric available) and estimated through the effect nearby nature has on housing values. It is assumed that if people prefer living close to nature, this will be reflected in housing values. This is also particularly relevant for the marine environment as living close to the coast, especially with a sea side view, provides sensory benefits.

Data and methodology

The basis for estimating this ecosystem service is a hedonic pricing model (Rosen 1974). The hedonic pricing model offers a clear and powerful means for assessment of the economic value of nature and may do so beyond the scope of other methods, such as the replacement cost and travel cost methods (De Groot et al., 2002). The hedonic method is firmly established in the environmental valuation literature that considers nature (a.o. McConnell and Walls, 2005).

A spatial approach was taken in order to locate nearby nature areas to each house, calculate its Euclidean distance to be able to use this as the independent variable in a regression analysis along with other relevant variables to estimate the marginal effect of nearby nature on real estate values. These values were then aggregated and distributed using a spatial approach to the natural environment providing the ecosystem service.

Data sources are the housing stock registry (including real estate values) of all houses in the Netherlands (Statistics Netherlands) and the Building and Addresses registry (BAG; Cadastre) for spatial representation of location of the houses and their surrounded nature areas

Options considered

In the previous North Sea NCA report (Schenau et al., 2019), amenity service was not yet included. As it is a very relevant ecosystem service, also for the marine ecosystem, it will be included in the current study. There are several options which could be considered, based on the methodology already developed in the terrestrial account (Statistics Netherlands and WUR, 2022):

1. A similar approach as taken with nature recreation: selection of the part of the ecosystem services provided by ecosystem assets beaches and dunes, i.e., clipping from the terrestrial account
2. Using similar methods and data as the amenity service for the terrestrial account, however re-estimate the hedonic price model with solely 'distance to marine

ecosystems' (including or excluding dunes and beaches, depending on the accounting area approach taken in the study). This would give a model that solely estimates the effect of living close to the marine environment.

3. In the current approach of the terrestrial account, aspects on viewsheds are not taken into account. This might be of extra relevance for the marine environment. The hedonic pricing model could be extended with variables on 'view on sea', for which a methodology has already been pioneered (Havinga et al, 2020).

Due to time constraints the results presented here are developed according to option one. Figure 64 shows the monetary estimates for the amenity services in the coastal area. It has been clipped from the results of the terrestrial accounts. The total value of the coastal area is approximately 260 million euros, which is about 16% of the total value for the Netherlands.

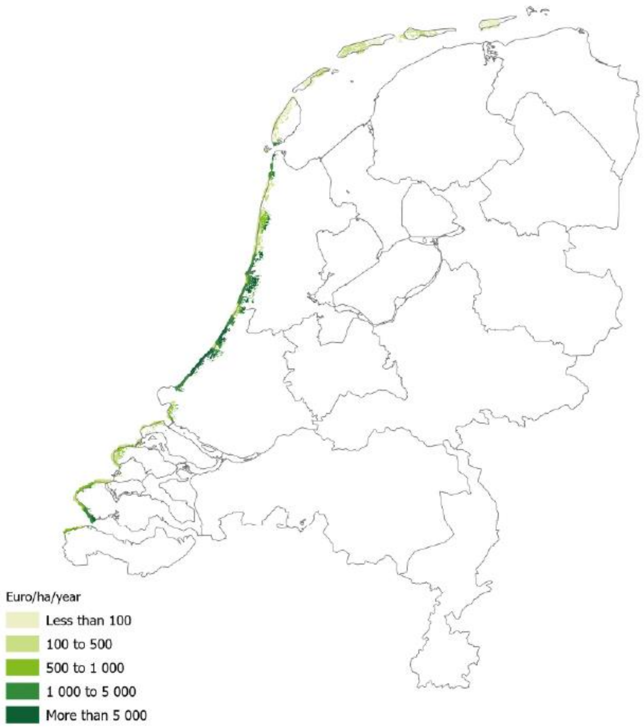


Figure 64. Result of the amenity service estimation for the coastal area (Source: Statistics Netherlands[88])

7.4.4 Education, scientific and research services

According to the SEEA-EA definition: *"Education, scientific and research services are the ecosystem contributions, in particular through the biophysical characteristics and qualities of ecosystems, that enable people to use the environment through intellectual interactions with the environment. This is a final ecosystem service."* (UN, 2021)

The Netherlands is closely connected with the North Sea. This is also the case with education, science and research. There are institutes undertaking (scientific) research in or around the North Sea. Additionally, education by (young) children, in terms of school trips to the North Sea or (cultural) places related to the North Sea is part of this ecosystem service.

[88] https://www.cbs.nl/nl-nl/over-ons/onderzoek-en-innovatie/project/hoeveel-draagt-de-natuur-bij-aan-de-economie-en-ons-welzijn-

It is difficult to biophysically and monetary quantify this ecosystem service. A recent study estimated on how many FTE's from the Dutch government are directly involved in policy work, management, monitoring of the North Sea environment and economic activities, and the improvement of the knowledge about- and further understanding of the North Sea environment. It was estimated that in 2015 around 354 FTE's were involved, which corresponds to a monetary value of 35 million euro, assuming that 1 FTE cost €100,000 per year, including salary and other costs such as overhead, housing, etc. (WEcR, 2018). Since this number is only an estimate, and not based on ecosystem service valuation methods, we do not include it in our further overviews.

7.4.5 Spiritual, artistic and symbolic services

According to the SEEA-EA definition: *"Spiritual artistic and symbolic services are the ecosystem contributions, in particular through the biophysical characteristics and qualities of ecosystems, that are recognized by people for their cultural, historical, aesthetic, sacred or religious significance. These services may underpin people's cultural identity and may inspire people to express themselves through various artistic media. This is a final ecosystem service."* (UN, 2021)

The North Sea has a cultural and historical significance in Dutch society. With a long coast line the North Sea plays a significant role in the history of the Netherlands. Many wars have been fought on the North Sea (for example in the English-Dutch wars). Additionally, being situated next to the North Sea gave the Netherlands advantages compared to other countries in for example trade during the Golden Age (e.g. establishment of the Dutch East India Company). Nowadays, spiritual, artistic and symbolic services are still delivered: e.g. literature and movies on the historical significance of the North Sea (for example, the movie "Slag om de Schelde".

Since this ecosystem service is currently difficult to quantify and value, it will be included only as p.m. in the current account

7.4.6 Ecosystem and species appreciation services

According to the SEEA-EA definition: SEEA EA: *"Ecosystem and species appreciation concerns the wellbeing that people derive from the existence and preservation of the environment for current and future generations, irrespective of any direct or indirect use."* (UN, 2021)

This ecosystem service is not straightforward to define as it is not about the (in)direct flow of services, but rather on wellbeing that people derive on the existence and preservation of the environment. The North Sea provides wellbeing to people by its mere existence, irrespectively of the direct benefits to people and therefore this ecosystem service is relevant. At the same time, this makes it very hard to measure.

Approach

Wellbeing associated with ecosystem and species appreciation services could be captured by (the membership of) the many (volunteer) associations related to the North Sea, such as seal sanctuaries, bird protection associations, Stichting De Noordzee, Waddenvereniging, etc. A physical metric for this ecosystem service could therefore be the number of volunteers, members or donators to these associations.

An alternative approach is to harness the "citizen science" data collected by e.g. birders and stored in the NDFF data base. These recorded sightings can be taken as a proxy for cultural appreciation of biodiversity. Another example is to analyse the metadata of photo's uploaded to Flickr (Wienhoven et al., 2021; Havinga et al., 2021; 2023)

Monetary estimates of the ecosystem and species appreciation services are elicited using stated preference methods. These values are considered welfare values and are generally excluded from the SEEA EA framework. Though, for some other purposes these valuation methods can be very useful. In a recent study, a survey (N=396) was held among the Dutch public about their knowledge of, commitment to, and financial willingness to contribute to achieving good environmental status (GES) in the North Sea. It focused on biodiversity, underwater noise and litter. When looking at the financial willingness to contribute to achieving GES in the North Sea, respondents were willing to contribute between 30 and 40 euros per household per year. However, a significant share of the participants did not want to contribute at all. Important reasons for this are that they believe that the main polluters of the North Sea should pay for the costs (the polluter pays principle), and that funding should come from the government and not from individual contributions (Schendel, 2022).

7.5 Abiotic flows

Abiotic flows are contributions to benefits from the environment that are not underpinned by or reliant on ecological characteristics and processes (SEEA EA). Abiotic flows arise through the abstraction/extraction of resources where a distinction is made between those flows related to geophysical sources, i.e., sources related to climate and the atmosphere; and those related to geological resources. Depending on the location of the resources and the point of abstraction/extraction, geological resources may be attributed as flows from ecosystem assets (e.g., sand and gravel) or from deep geological resources (e.g. oil and gas).

Ecosystem services are thus distinct from abiotic flows even though both reflect contributions from the environment to human wellbeing. Abiotic flows can be monitored and valued using the SEEA EA framework, and their values can be presented and compared to the ecosystem services: "*Compilers are encouraged to record abiotic flows from geophysical sources and from geological resources extracted from ecosystem assets together with ecosystem services since analysis of environmental trends for spatial areas may be enhanced greatly from joint consideration of these flows*"[89]

This section will describe the following abiotic flows: Oil and gas extraction, Mineral extraction, Wind energy, and Water supply.

7.5.1 Oil and gas extraction

Extraction of natural gas and oil contributes significantly to the Dutch GDP. Over the last twenty years, the benefits arising from oil and gas extraction, contributed on average 3 percent to total revenue of the Dutch government.

Oil and gas are extracted from the deep subsoil. The deep subsoil does not belong to the marine ecosystem assets, i.e., the biotic and abiotic components interacting as a functional unit. This is also in line with the recent findings for defining ecosystem assets for the SEEA EA revision (Schenau et al., 2019; UN et al., 2021)

As a result, the extraction of gas and oil will not be included *as an ecosystem service* in the ecosystem services supply tables. However, given the important role oil and gas extraction plays in the North Sea spatial policy and planning, and the strong interaction with ecosystem services and environmental pressures, it does make sense to include it *as a natural resource* in an extended *ocean account*, placed in a separate location, to denote their special status.

[89] SEEA-EA, ¶ 6.37

Results

As of January 1st, 2022, The Netherlands has 290 natural gas fields and 31 oil fields located in the Dutch part of the North Sea (see Table 64 below).[90] More than 120 of the natural gas fields are in production, and within 5 years there will be another 17 fields added. For oil, the figures are 7 and 4 respectively.

Table 64. Discovered fields of natural gas and oil in the sea (The Netherlands), as of January 1, 2022. Source: TNO[91]

	Natural gas	Oil
In production	123	7
Not developed		
Will be in production within 5 years	17	4
Will not be in production within 5 years	51	15
Production ceased		
Temporarily	16	0
Permanent	83	5
Total	290	31

The natural gas stock in the Dutch part of the North Sea amounts to 78.2 bln Nm^3 (*Normal cubic metre*[92]) as of January 1st 2022 (see Table 65). Part of this (54.2 bln Nm^3) is the commercially viable extractable reserve. The remainder of 24 bln Nm^3 is pending development for commercial purposes. This conditional stock is partly in the fields that are already in production, but mostly in fields that are not yet developed.

Table 65. Reserves and production of natural gas and oil in the sea (The Netherlands), 2015-2022. Source: TNO Annual Reports 2014 - 2021 "Delfstoffen en aardwarmte Nederland" (Natural resources and geothermal energy Netherlands), Tables 1.2, 2.2, 3.3, 3.4 and 3.5 (https://www.nlog.nl/jaarverslagen).

	2015	2016	2017	2018	2019	2020	2021	2022
Natural gas reserves as of January 1st (mld Nm3)								
Reserves	94	92	86,5	75,1	70,8	66,3	57,4	54,2
Conditional stocks a)	24	25	20,6	23,9	32,0	18,5	12,9	24,0
Total	118,0	117,0	107,1	99,0	102,8	84,8	70,3	78,2
Natural gas production (mld Nm3)	14,0	13,3	12,2	11,0	9,8	9,3	8,9	
Oil reserves as of January 1st (mln Sm3)								
Reserves	4,1	9,1	3,7	3,6	10,3	13,6	2,5	1,9
Conditional stocks a)	2,8	2,0	9,3	7,9	1,5	1,7	13,0	20,7
Total	6,9	11,1	13,0	11,5	11,8	15,3	15,5	22,6
Oil production (1000 Sm3)	1307	957	705	556	487,2	467,6	436,5	
Condensate production (1000 Sm3)	192	164	169	145	85,0	72,1	61,1	

a) Conditional stocks: pending development for commercial production

The known natural gas stock was recently adjusted upwards, from 70.3 bln Nm^3 as of January 1, 2021, with 16,8 bln Nm^3. With a production of 8.9 bln Nm^3 in 2021, this resulted in the higher stock of 78.2 Nm^3. This adjustment was because of the periodic revaluation of the fields, such as

[90] In total (including fields on land), The Netherlands has nearly 500 discovered natural gas fields and more than 50 oil fields (as of January 1, 2022).

[91] Annual Report 2021 "Delfstoffen en aardwarmte Nederland" (Mineral rersources and geothermal energy Netherlands), Tables 1.1 and 2.1 (https://www.nlog.nl/jaarverslagen)

[92] Volumes of natural gas are expressed in *Normal* cubic metre, Nm^3, measured at reference temperature (0°C) and pressure (101.325 kPa). Similarly, stocks of oil are measured in *Standard* cubic metre, Sm^3, using a reference temperature (15°C) and pressure (101.325 kPa)

technical changes leading to a longer production life span and drilling of new wells, and increased economic viability resulting from the current higher energy prices.

In the past years, the gas production in the sea has been decreasing. By now, with the Ukraine war and the strong decrease of production on land in the Groningen gas field, the Dutch Government explicitly aims to slow down the decrease of production in the North Sea, in order to reduce dependency on import for security of supply, and CO_2 footprint.

The oil stocks in the sea are smaller. But the developments are similar to those of the gas stocks, with a decreasing production but a recent upward adjustment of the reserves. As of January 2019 and 2020, the reserves have increased significantly, whereas the conditional stock increased as of January 2021 and 2022. In total, the jump is clear between January 2021 and 2022 (from 15.5 to 22.6 bln Sm^3).

Monetary value

To determine the monetary value of oil and gas as abiotic flows, the resource rent method is commonly used. This approach measures the annual return generated directly from the natural capital asset itself. To calculate the resource rent, costs of labour, produced assets, and intermediate inputs are deducted from the market price of outputs, which are the benefits of oil and gas extraction.

In the Netherlands, the calculated resource rent for oil and gas extraction are presented in the national accounts on an annual basis. Unfortunately, specific monetary data on the DCS are not available. However, the physical extraction data were used to allocate a certain portion of the resource rent to the North Sea region. While there may be differences in the cost structures between onshore and offshore oil and gas extraction, for the purposes of this analysis, they were assumed to be equal.

The results of the analysis, shown in Table 66, indicate that the resource rent fluctuates from year to year. However, there was a decrease observed between 2015 and 2020, with a significant low value in 2020, likely due to low prices and high costs, and an increase in 2021 due to the price increase of fossil fuels. It's worth noting that these estimates are based on assumptions and should be interpreted with caution.

Table 66. Resource rent oil and gas extraction on the DCS.

	2015	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**
	Million euro						
Resource rent	2.339	996	1.021	1.173	690	54	1.298

Overall, the resource rent approach provides useful insights into the development of the value of oil and gas extraction extraction as abiotic flow in the marine region. However, further research is necessary to refine the estimates and account for any differences in cost structures between onshore and offshore oil and gas extraction.

7.5.2 Mineral extraction

Mineral extraction is a provisional abiotic service. Several natural environments in the coastal region can provide different minerals for extraction. Minerals, such as sand and gravel, are not only collected from the mainland, but also from the North Sea. Sand is used for land reclamation, for the protection of the coast, for maintaining shipping channels on the DCS and as fill sand for (infrastructural) projects. Due to roundness, sand from the marine environment is not used to produce concrete. This abiotic flow can be defined as the total amount of sand

and gravel extracted from the marine environment. The minerals are generally harvested by mineral extraction companies, who are the direct beneficiaries.

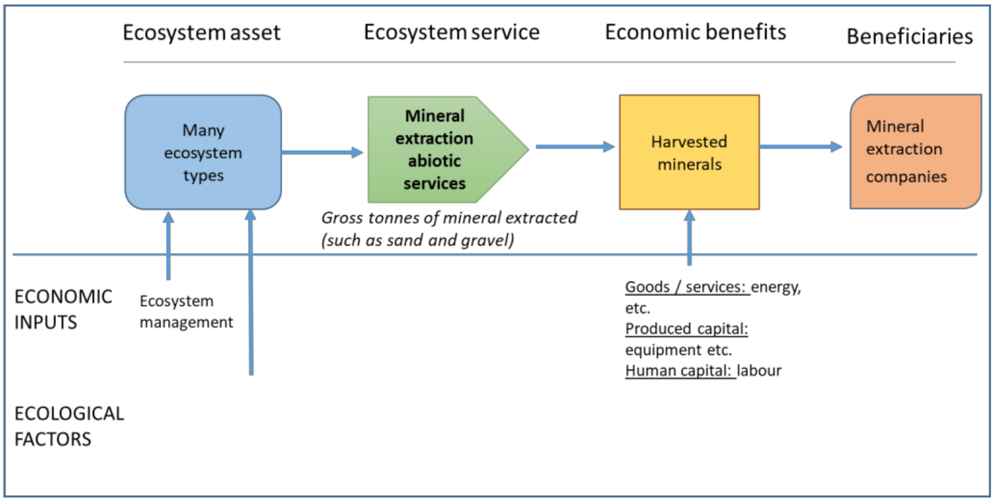


Figure 65. Logic chain for Mineral extraction

Data on the monitoring of building materials were derived from annual reports by the company H2H Advies in cooperation with industry association Cascade[93]. In these reports, data on the annual extraction, consumption, import and export of primary construction raw materials can be found. This concerns the following building materials: coarse aggregates (gravel, crushed gravel/crushed stone), fine aggregates (concrete and masonry sand), fill sand and other building materials (lime sandstone sand, silver sand, clay and marl). Data after 2018 were not available, because the annual reports were no longer produced and published online. In cooperation with H2H and Cascade, Statistics Netherlands has started to collect this data from all provinces in the Netherlands on an annual basis. The provinces issue permits to extraction companies, including maximum allowed quantities. These extraction companies report their extraction amounts to the provinces, which in return submit this information to Statistics Netherlands through annual questionnaires. These data are needed to compile the Material Flow Accounts (MFA), which are an obligatory statistic required by Eurostat. The data also suit the needs of this marine ecosystem report, as the data distinguishes between extraction from the North Sea and inland. Additionally, the Central Government Real Estate Company (Dutch: RVB) and Rijkswaterstaat (RWS) provide additional extraction data for specific regions in the Netherlands.

Extraction data for sand and gravel from the North Sea area are specified in annual questionnaires. There are three categories that can be distinguished: regular extraction, coastal defense and land reclamation. From the data it is not possible to make further regional distributions within the North Sea area. The physical amounts are collected from the survey data. In the North Sea area, fill sand is the only relevant mineral that is extracted.

Results

The results are presented in Figure 66. In the Netherlands there is no extraction of gravel from the North Sea area. The regular extraction of fill sand varies between 11 and 19 million tonnes annually. The size of irregular extraction can vary strongly from year to year. In some years large quantities of fill sand are being extracted from the North Sea for coastal defence and land

[93] https://www.cascade-zandgrind.nl/

reclamation (such as the construction of the second Maasvlakte in the period 2008-2015[94], the sand engine in 2011[95]). And the construction of Hondsbossche duinen in 2014[96]. In the period 2009-2010 the irregular extraction was 4 to 5 times the regular fill sand production. This non-regular extraction came on top of the regular fill sand production.

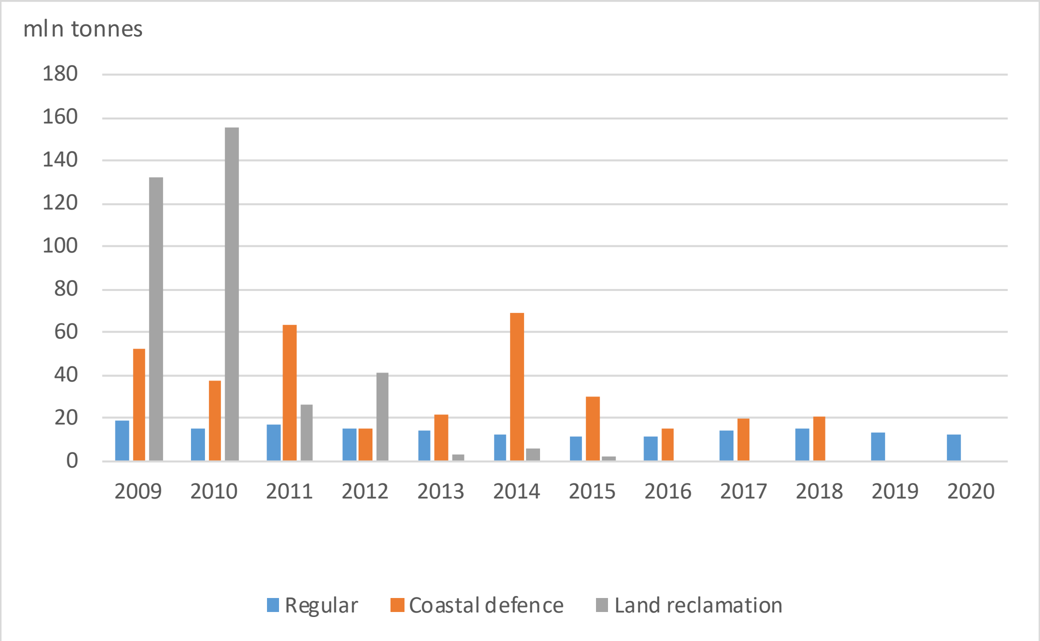


Figure 66. Extraction of fill sand, time series.

Monetary valuation

The common valuation approach for the extraction of minerals such as sand and gravel is the resource rent method. This method requires a large amount of data on the specific market. The Dutch sand and gravel extraction is a small and opaque market, for which the available data are scarce. Therefore, the resource rent calculations in this chapter involve a set of assumptions.

Within the Dutch supply and use tables from the SNA, data is available for the sector "other mineral extraction". Sand extraction is a part of this economic sector. Additionally, data on the compensation for the self-employed is obtained from the Dutch statistics on the self-employed (Statistics Netherlands, 2022). Data on the average profit and risk shares are obtained from the literature (Rijkswaterstaat, 2009).

The first step is to derive a resource rent calculation for the entire "other mineral extraction" sector. This is done in a similar way as the resource rent calculations for the fishing sector discussed earlier in this report. For the output in basic prices, it is possible to obtain data specifically for the goods category "sand". Data on the operating costs, intermediate consumption, compensation of employees, consumption of fixed capital, return on fixed assets, taxes and subsidies are only available for the entire mineral extraction sector. Sand covers about 33% of the entire output for this economic sector. The assumption is that this share can be transferred and used to calculate the cost components, such as intermediate costs and wages. The return to produced assets is calculated as an percentage of the total costs. From a

[94] https://waterinfo-extra.rws.nl/projecten/@207615/aanleg-2e-maasvlakte/
[95] https://dezandmotor.nl/over-de-zandmotor/
[96] https://www.ecoshape.org/nl/pilots/hondsbossche-en-pettemer-zeewering/

study by Rijkswaterstaat on the economic and environmental effects of the Dutch sand extraction strategy, a profit and risk percentage of 15% was obtained and applied.

The last step is to determine the part of the resource rent that accrues from marine sand extraction. We assume that the economic structure for marine sand extraction is equal to the economic cost structure of the total sand extraction sector, including the terrestrial part. From the physical data we know that about 51% of the sand extraction takes place in the North Sea. We have applied this share to all of the components of the resource rent.

Results

The resource rents for marine fill sand extraction in the North Sea area are shown in Figure 67. We were unable to make a time series before 2015 due to the revision of the national accounts data from Statistics Netherlands. Including data from before 2015 would cause a trend break in the time series. Similar to marine fisheries, the value obtained by the resource rent method is low compared to the value other ecosystem services and volatile. A breakdown for 2021 can be seen in Table 67.

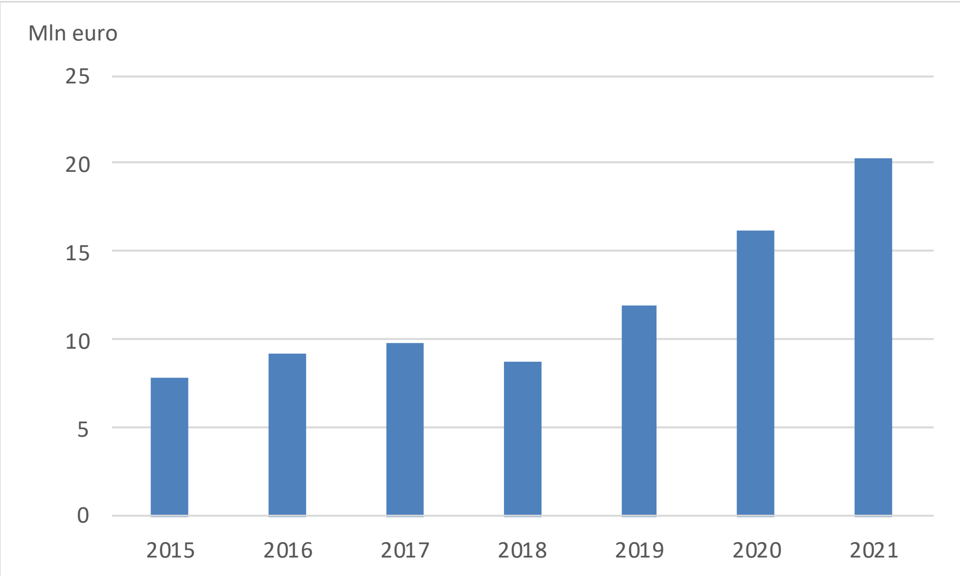


Figure 67. Resource rent of marine sand extraction, time series.

Table 67. Breakdown of resource rent calculation marine aggregates for 2021 in million euro.

	mln euro	**2021**
Output		**213**
	Intermediate consumption	131
	Compensation of employees	27
	Other taxes on production	0
	Other subsidies on production	-1
Equals Gross operating surplus		**56**
	Less consumption of fixed capital (depreciation)	10
	Less return to produced assets	25
	less labour of self-employed persons	0
Equals Resource rent		**20**

7.5.3 Wind energy

Flows related to geophysical processes include the abstraction of water (included here as abiotic provisioning service, see section 7.5.4), and the capture of wind, solar, tidal, geothermal and similar sources of energy. For the Dutch North Sea area, the production of wind energy is the most important. In the Netherlands, wind energy is harvested on the DCS since 2006. The abiotic flow wind generation can be defined as the total electricity generated by offshore wind farms.

In the SNA, fossil energy resources are recorded as non-produced assets on the national balance sheet. So far, renewable natural energy resources are not recorded as assets on the national balance sheet. This seems to be a serious omission since their share in the total energy production is increasing. When only including non-renewable energy sources, there is a risk to undervalue a countries' energy resources. Wind is provided to us by nature and each country has the potential to exploit wind within their borders.

In the CICES classification, the generation of electricity from wind is classified as "*Non-mineral substances or ecosystem properties used for nutrition, materials or energy*". For simplicity, the ecosystem service will be referred to as the provision of wind energy, which is a provisioning service (Haines-Young and Potschin, 2018).

The production of wind energy is published by Statistics Netherlands[97]. The physical unit is kWh per year. The data make a distinction between production of wind energy on land and by offshore windfarms.

Results

The generation of offshore wind energy has increased from 68 million kWh in 2006 to 7.952 million kWh in 2021 (see Figure 68).

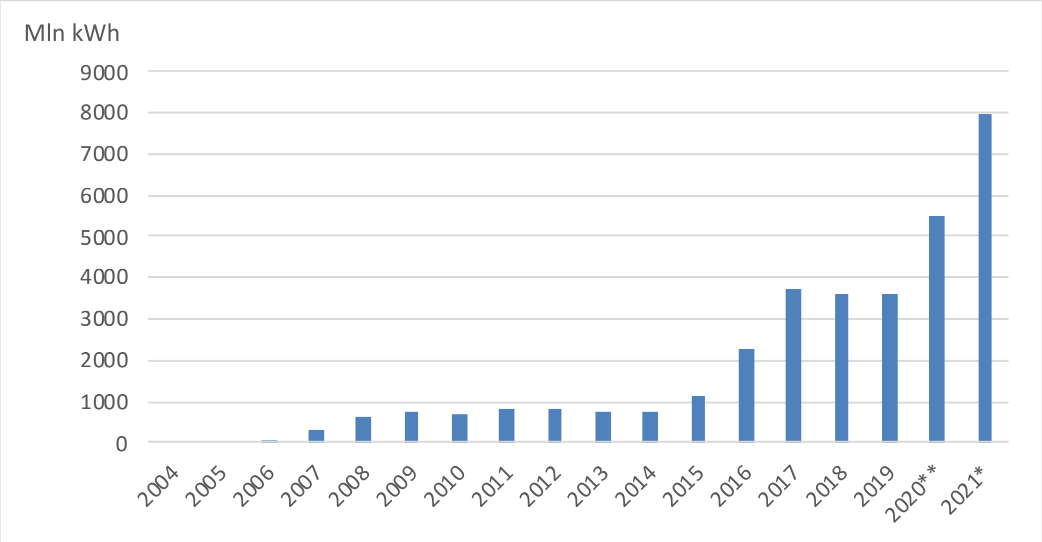


Figure 68. Offshore energy production from wind energy in million kWh. Data: Statistics Netherlands.

Monetary valuation

Economic data on offshore wind energy that are available on a structural level are scarce. Annual ECN reports (ECN, 2022) provide some data on all kinds of costs, including investment, depreciation, maintenance and network costs. They distinguish between several types of wind

[97] https://opendata.cbs.nl/statline/#/CBS/nl/dataset/82610NED/table?dl=3BFA4

energy, such as 'wind on land' and 'wind in lake'. However, they do not include offshore wind energy, which is needed for the calculation of the resource rent for offshore wind energy. Statistics Netherlands is currently looking for alternative data sources to compile a time series for the resource rent calculations. This would require specific economic data on the offshore wind market.

Reports have assessed the cost levels of wind farms and their grid connections in new or existing offshore wind energy areas in the Netherlands. A recent study focused on the Levelized Cost of Energy (LCoE) for selected potential wind farm zones after Roadmap 2030, with IJmuiden Ver as the reference zone. The study found significant LCoE variations among wind farm zones and sites. Consequently, prioritizing attractive sites or optimizing site allocation can lead to lower average LCoE for these zones. Generally, all zones exhibit a lower LCoE compared to IJmuiden Ver. While this report offers insights into some cost trends and wind farm location optimization, using this data to create a resource rent time series is more complex (Blix consultancy et al., 2020).

Another monetary method concerns the avoided damage costs. By producing electricity from wind energy, society potentially avoids the emissions of CO_2 that would arise by traditional production of fossil fuels. Pricing the emissions could give an estimation that would reflect the value of wind from an avoided damage perspective. This is the method currently applied. The data, available from Statistics Netherlands[98], shows the avoided CO_2 per renewable source of electricity, distinguishing between offshore and onshore wind energy.

To be consistent with previous work on natural capital accounting, we use the policy-oriented carbon price for the Netherlands. The Netherlands Environmental Assessment agency (PBL) and the Netherlands Bureau for Policy analysis (CPB) calculated an 'efficient' carbon price for the Netherlands. The efficient price implies the introduction of efficient policies to reach a certain scenario, which comes with the lowest social cost. This is done with different scenarios, high-reduction, low-reduction and a two-degree temperature increase scenario. They have used a discount rate of 3.5%, which is the average value used for Europe. This price is calculated specifically for the Netherlands and it is, among others, applied by research agency CE Delft in their analyses (Aalbers et al., 2016). The avoided emissions are multiplied with this efficient carbon price.

The second method that could be applied is the resource rent method, which was discussed in previous sections. The first step is to determine the monetary value of annual electricity production from wind energy resources. This involves multiplying the physical production in kWh with the basic prices for electricity plus subsidies (SDE++ and MEP). We also need to make a correction for the profile and imbalance costs of wind energy, which refer to the difference between the average electricity price received by the wind producer and the average electricity price on the wholesale market. After subtracting intermediate costs, which include operation and management costs (O&M), such as fixed costs (e.g., insurances) and variable costs (e.g., warranty and maintenance contracts for turbines), we arrive at the value added.

To calculate the capital services, we compile the capital stock by analysing annual investments in newly placed windmill capacity (in MW) and multiplying it by the investment costs per MW of that particular year. These costs include expenditures on foundations, turbines, electric infrastructure, mains connection, construction interest, land acquisition costs and civil engineering. Since investments take place some years before the completion, the investments are spread over multiple years. We then construct the fixed capital stock using the perpetual

[98] https://opendata.cbs.nl/statline/#/CBS/nl/dataset/84918NED/table?dl=71493

inventory method and assume a linear depreciation of 20 years. This fixed capital stock is necessary to calculate the return to capital and the depreciation, which together form the capital services rendered by an asset. The return on capital can be measured using the weighted average cost of capital (WACC), which PBL publishes for wind energy in general (PBL, 2022). Subtracting the output (including subsidies), intermediate costs, and capital services results in the resource rent estimates.

It is important to note that the resource rent method values the actual production of electricity generated from wind energy resources, not their potential. This is in accordance with the System of National Accounts (SNA), which measures actual market transactions and not potential gains from a particular resource or market. Only renewable energy resources that are inputs in the energy transformation process are valued.

Results

The results of the avoided damage cost calculations is shown in Figure 69. The trends in the value are similar to those of the physical production data (Figure 68). The more wind energy is generated, the more CO_2 emissions are avoided, which is reflected in these monetary estimates.

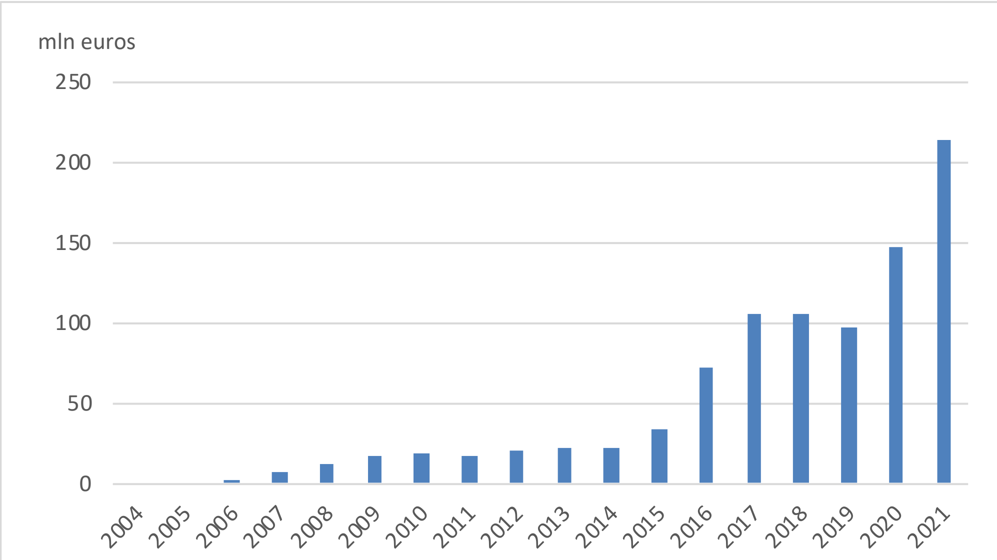


Figure 69. Monetary estimates offshore wind energy using avoided damage cost method, time series

The results using the resource rent method are shown in Table 68. It becomes immediately clear that they are very volatile and, in many cases, negative. Between 2019 and 2021 the production (in KWh) of offshore wind energy increased sharply, but this also leads to an increase in intermediate consumption, which is based on the physical production and capacity as described in the methodology. However, the phasing out of SDE++ subsidies[99] has caused the resource rent to decline and become negative in 2021. In the case that we would calculate the

[99] It is important to note that underlying data regarding the SDE++ subsidies for 2021 are provisional and will be revised in the second half of 2023.

resource rent without subsidies, the resource rent estimates would be negative for all reported years.

Table 68. Monetary estimates offshore wind energy using resource rent method, time series

	2013	2014	2015	2016	2017	2018	2019	2020	2021
	million euro								
Resource Rent	-41	-144	-148	-85	206	120	110	4	-124

When a natural resource has a negative resource rent, it may be a sign that it is being overexploited or that its economic value is declining. Negative resource rent can lead to unsustainable management practices and environmental degradation, as resource users may continue to exploit the resource even if it is no longer economically viable.

7.5.4 Water supply

According to the SEEA-EA definition: *“Water supply services reflect the combined ecosystem contributions of water flow regulation, water purification, and other ecosystem services to the supply of water of appropriate quality to users for various uses including household consumption. This is a final ecosystem service.”* (UN, 2021)

In the Netherlands, seawater is extracted solely for cooling purposes in industry and energy supply. As such, it can also be regarded as an abiotic flow. A point to be considered, however, is that especially power plants are located along the coast because of the continuous availability of sea water. Alternative locations along rivers would have a higher risk that cooling water is temporarily unavailable (either because of low flows, or high temperatures of the water taken in, which makes the surface water less suitable for cooling purposes). If that risk could be quantified, then “avoided damage” could be used as an alternative valuation method.

Physical data is collected from the SEEA water accounts. The physical supply and use tables provide insight into the volumes of water exchanged between economy and environment, and between economic units. There are three main flows. First, water flows from the environment to the economy: abstractions. Second, water flows within the economy: own use, distribution of water from one sector to another or to households, exchanges with the rest of the world and wastewater flows. Third, water flows from the economy back to environment. Data on the extraction from the North Sea is available on company level.

Results

The results of the water extractions for cooling water purposes from the North Sea area and the adjacent saline harbour areas are shown in Figure 70. The trend is mainly determined by fluctuations in the intake of cooling water at the power stations, in recent years, among other things, due to production restrictions at the coal-fired power stations.

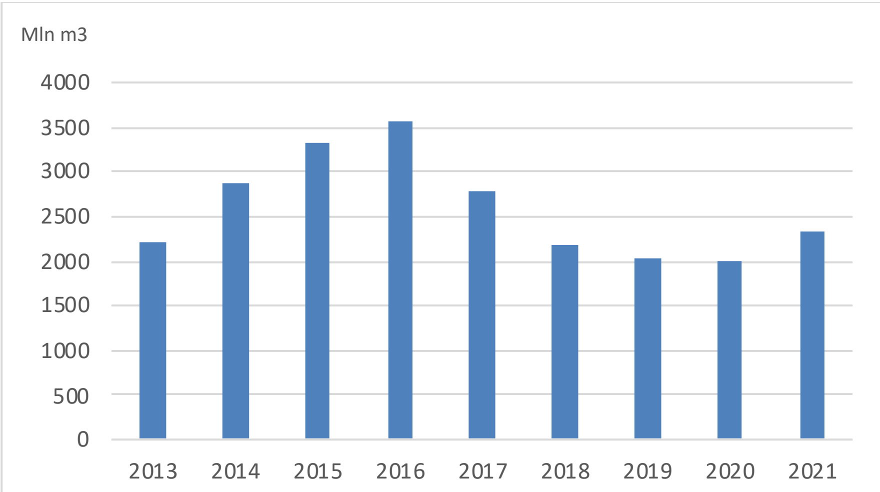


Figure 70. Time series of extraction of sea water.

7.6 Spatial functions

According to the SEEA-EA, spatial functions are defined as "*flows related to the use of the environment for undertaking economic and other activities. These flows relate primarily to the fact that all activities take place in a location. Flows related to the use of environment for these activities are treated as spatial functions within the broader framing of abiotic flows. While ecosystems will, by definition, be present in those locations, there are no ecological processes providing a contribution to those activities that should be recorded as ecosystem services. This implies that the benefits derived from land in supporting buildings, houses, roads, railways and other structures and the associated values related to location are not considered to incorporate ecosystem services. Further, there is no abstraction or extraction from the ecosystem that would require recording abiotic flows.*"[100]

Thus, spatial functions are not treated as either ecosystem services or abiotic flows. In SEEA EA three main types are identified (i) the use of the environment for transportation and movement on land, water or through the air; (ii) as the base for buildings and structures; and (iii) the use of the environment as a location in which pollutants and waste are deposited, i.e., use of the environment as a sink (beyond the mediation or capture of such residuals by ecosystems which is treated as an ecosystem service). "*There is no expectation that compilers of ecosystem accounts will record […] flows relating to spatial functions*"[101].

Furthermore, "*Flows related to the use of the environment as the location for transportation and movement, and for buildings and structures are not recorded explicitly in the SEEA Central Framework or SEEA EA. Relevant information may be recorded in the SEEA Central Framework land use accounts*".[102] Translated to the marine realm, this can be interpreted as suggestion to develop a "sea surface use" account as part of the North Sea marine account.

Nevertheless, given the importance of shipping in the North Sea, and the interaction with the marine ecosystems, it was decided to include transport in the current account.

[100] SEEA EA, ¶ 6.136
[101] SEEA EA, ¶ 6.37
[102] SEEA EA, ¶ 6.39

7.6.1 Transport

The inclusion of transport in the North Sea account as a spatial function could be beneficial because of the relevance for policy, the impact on other ecosystem services (esp. wind energy) and the various environmental pressures associated with shipping.

In the case of the North Sea marine account the use of the North Sea for transportation is especially relevant. Two main forms of transport can be distinguished: transport to and from Dutch harbours (cargo and passenger transport, i.e. ferries), and international transport crossing the North Sea, using the established corridors.

Since 2005 the International Maritime Organisation (IMO) requires all larger cargo ships and all passenger ships to carry Automatic Identification Systems (AISs) on board, to provide information on the ship to other ships and coastal authorities[103]. The data provided by AIS contains among other information about the ship's identity, type, position, course and speed.

Using an extensive data set of AIS data, spanning the period 2013–2017, Robbins et al. (2022) analysed the marine traffic density within the north-east Atlantic. Averaged across the period, they found that the Dutch EEZ was the second most densely used areas (1.55 ship/hour/10km^2); only Belgium had a higher density (2.59 ship/hour/10km^2). While the German EEZ is also quite dense (0.8), all other country's EEZs have densities lower than 0.5.

Furthermore, it was found that across the NE-Atlantic shipping intensities increased by approximately 33% during the period 2013–2017. In the greater North Sea, this increase was higher (37%), especially for smaller ships, fishing and passenger vessels (Robbins et al, 2022).

Since 2019 vessel density maps for all European marine waters are published by the European Marine Observation and Data Network (EMODnet), as part of the larger set of indicators related to human activities. The maps are based on AIS data and processed into monthly and annual 1x1km gridded raster data sets. Vessel density is expressed as hours per square kilometre per month. 11 types of ships are presented with additional categories for *other* and *unknown* type of ship (Figure 71).

Table 69. Shipping density per ship type an overall, 2017–2022. Data from EMODnet.

Ship type	Year											
	2017		2018		2019		2020		2021		2022	
Cargo	1,41	38%	1,41	36%	1,35	35%	1,28	33%	1,29	33%	1,58	37%
Tanker	0,93	25%	1,05	27%	1,11	29%	1,17	31%	1,20	31%	1,20	28%
Fishing	0,53	14%	0,48	12%	0,45	12%	0,49	13%	0,46	12%	0,42	10%
Service	0,14	4%	0,14	4%	0,16	4%	0,13	4%	0,15	4%	0,19	4%
Sailing	0,09	2%	0,11	3%	0,11	3%	0,10	3%	0,11	3%	0,16	4%
Dredging	0,10	3%	0,11	3%	0,11	3%	0,10	3%	0,12	3%	0,12	3%
Pleasure	0,04	1%	0,06	2%	0,07	2%	0,06	2%	0,06	2%	0,09	2%
Tug	0,05	1%	0,07	2%	0,08	2%	0,06	1%	0,07	2%	0,08	2%
High speed	0,02	1%	0,03	1%	0,02	1%	0,05	1%	0,04	1%	0,06	1%
Military	0,02	1%	0,02	0%	0,02	0%	0,02	0%	0,03	1%	0,03	1%
Passenger	0,03	1%	0,03	1%	0,03	1%	0,04	1%	0,03	1%	0,03	1%
Unknown	0,07	2%	0,05	1%	0,04	1%	0,02	1%	0,00	0%	0,00	0%
Other	0,28	8%	0,31	8%	0,32	8%	0,29	8%	0,29	8%	0,38	9%
All	**3,71**		**3,88**		**3,88**		**3,82**		**3,87**		**4,34**	

[103] https://www.imo.org/en/OurWork/Safety/Pages/AIS.aspx

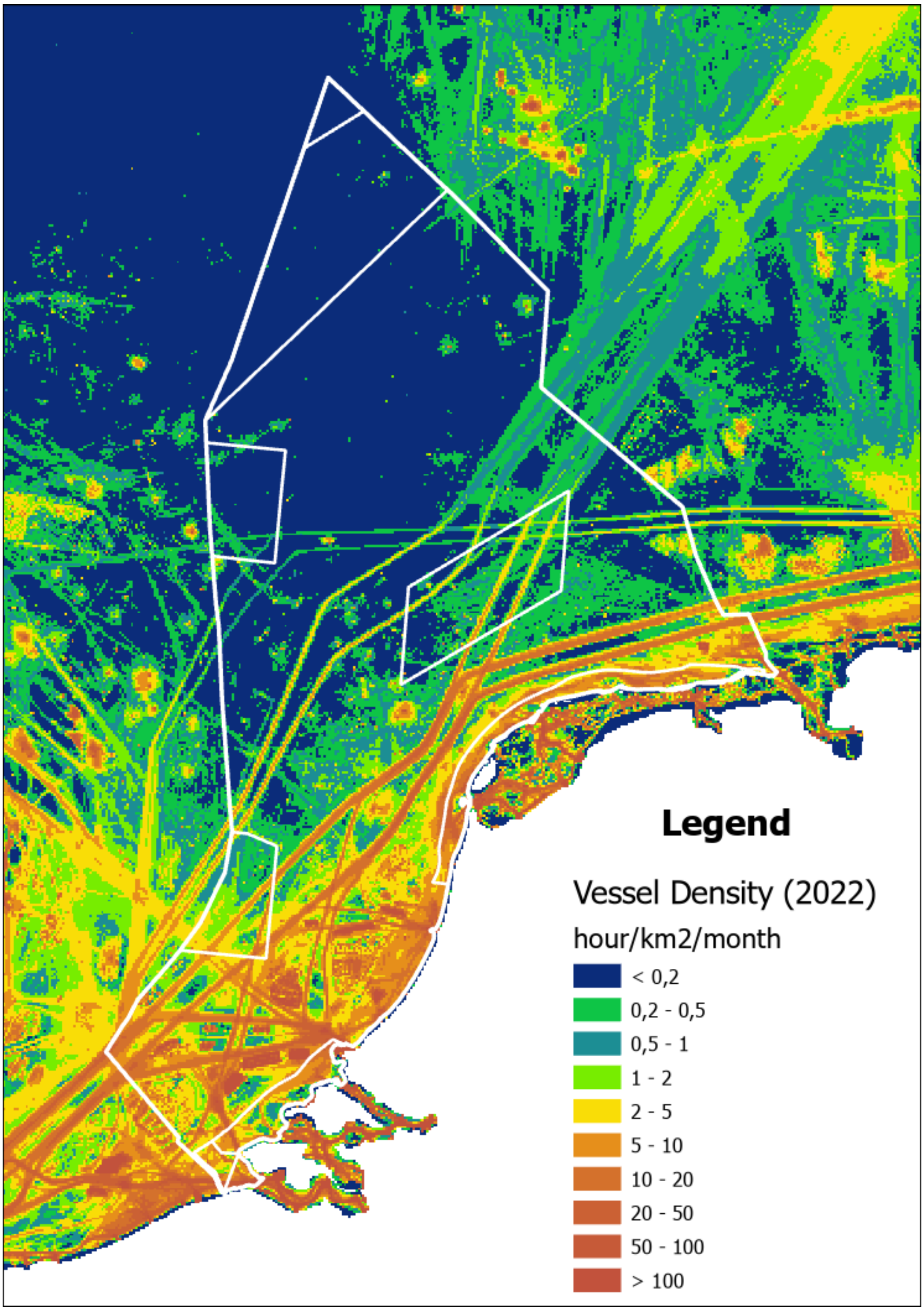


Figure 71. Average vessel density for 2022 (all types oif ships). Data source: EMODnet.

Analysis of this data set revealed that shipping is dominated by Cargo vessels (37%) Tankers (28%) and Fishing (10%). Densities were not stable during the period 2017–2022: Cargo shipping density slowly decreased from 2017–2020 but then rose sharply to a record density in 2022. Tanker density increased slowly throughout the period (+20%) while Fishing slowly decreased (−20%). Overall vessel density has increased from 3.71 hour/km^2/month in 2017 to 4.34 in 2022, with a small dip in (COVID year) 2020 (Table 69).

Obviously, shipping is most dense in shipping lanes and near the shore. Consequently, shipping density is high in the Natura 2000 areas *Vlakte van de Raan*, *Voordelta* and *Noordzeekustzone*. In the latter area, shipping density just within the Natura-2000 site is clearly higher than just outside, mainly due to Fishing, and to a lesser extent, Sailing and Pleasure.

In terms of volumes transported, there is a clear increase in total volume incoming (approx.. +7% since 2011) and outgoing (approx. +12–20%) across all economic sectors and product types[104]. Since the outgoing transport is less than incoming; total volume transport to and from has been increasing with approx. +8–10% (Table 70). Most of the transport volumes is for international trade, though[105].

Table 70. Total volume to and from Dutch sea harbours. Data: Statistics Netherlands[106].

Volume	**Year**												**Trend**
mln tonne	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	
In	387	386	387	397	407	398	401	408	412	365	393	414	
Out	164	171	171	175	188	190	194	197	196	192	197	183	
Total	**551**	**557**	**559**	**572**	**594**	**589**	**596**	**605**	**608**	**558**	**590**	**596**	

Monetary valuation

According to SEEA EA (¶ 6.40): "*The monetary value of […] spatial functions will generally be captured in current SNA based values*". The question, though, is how it should be monetarized in marine environments and obviously there are no land prices available. One option is to apply a resource rent approach, using the global cost structure of marine shipping and perhaps a comparison between different modes of transport (sea; land; air) to quantify the relative benefits of sea transport that can be attributed to the marine realm. This approach was however not feasible to explore fully within the scope of the current study.

In their analysis of the economy of the Dutch North Sea, Walker et al., (2023) list production and gross value added (GVA) for the *national* maritime transport sector (thus: excluding foreign shipping in Dutch waters). They note an increase in nominal GVA (≈+25% since 2015; but following a decrease of ≈−20% until 2019), but taking inflation into account, a consistent decrease (−22%) when expressed in 2015 prices (Table 71).

Table 71. Marco-economic indicators for the sea shipping sector (residents only). After Walker et al., (2023).

Year	**Employment**	**Compensation**	**Production**	**Intermediate consumption**	**GVA (current prices)**	**GVA (2015 prices)**
	1000 FTE	*mln euro*				
2015	9,5	542	6,601	4,694	1,907	1,907
2017	9,2	543	6,059	4,372	1,687	1,848
2019	8,7	547	6,31	4,758	1,552	1,565
2021	9,2	587	7,352	4,954	2,398	1,479

In their analysis of the economic impact of future development scenarios for the North Sea, Strietman et al., (2019) assumed that 10% of all Dutch marine activities are located on the DCS. . If we apply this percentage to the GVA of the Sea shipping sector, we may get a first rough

[104] Increases are mainly due to Chemistry and Fertilizers, where export volumes doubled since 2007, and which are the largest product group (35–45% of all outgoing volume). Source: https://opendata.cbs.nl/statline/#/CBS/nl/dataset/84668NED

[105] https://www.cbs.nl/nl-nl/longread/diversen/2023/internationale-goederenstromen-2021/1-omvang-en-kenmerken-goederenstromen

[106] https://opendata.cbs.nl/#/CBS/nl/dataset/82850NED

estimate for the value if this spatial function, but we acknowledge this is an imprecise method and additional research is needed to come to a better estimate.

7.7 Intermediate ecosystem services[107]

The primary focus of ecosystem accounting is on the measurement of final ecosystem services, i.e., those ecosystem services in which the user of the service is an economic unit.[108]

However, when digging deeper in the ecological mechanisms underlying these final ecosystem services, one finds many "indirect" ecosystem services that contribute to benefits. Common terrestrial examples include pollination and pest control. Marine examples include e.g., the nursery service provided by seagrass meadows. In these cases, the user of the ecosystem service is not an economic unit (as for final ecosystem services), but an ecosystem asset.

Although intermediate ecosystem services could be seen as part of the final services, as one out of many underlying processes, it is important to note that they are not always being provided by the same ecosystem type. For example, populations of wild fish may be caught at sea while the associated nurseries are located in seagrass meadows closer to shore. Thus, while the overall contribution of ecosystems to human wellbeing will be embodied in the catch of wild fish (a final ecosystem service), this recording will not reveal the indirect contribution of the seagrass meadows.

Focus on connections with final ecosystem services.

For ecosystem accounting purposes, the measurement of intermediate services should generally focus on cases where there are observable connections between ecosystem assets that are of high analytical or policy interest, for example concerning connections among trophic layers for fish species, and links between pelagic and benthic habitats.

Potentially, quite complex interlinkages between different ecosystems, and between ecosystem services, can be recorded within a supply and use accounting structure. However, the focus of ecosystem accounting should remain on recording final ecosystem services and entries for intermediate services should concern only those flows that can be clearly connected to a final ecosystem service and that are of particular relevance for ecosystem management.

Connection with the condition account

The wide array of biophysical flows within and between ecosystems that reflect ongoing ecological processes are fundamental to the supply of ecosystem services, but a complete mapping of intra- and inter- ecosystem flows is beyond the scope of ecosystem accounting. Nonetheless, there will be interest in understanding the extent to which the various ecological processes are well-functioning, for example in understanding the ability of an ecosystem to provide ecosystem services into the future. In ecosystem accounting, the maintenance of well-functioning ecosystems is considered in the measurement of ecosystem condition and ecosystem capacity.

Valuation of intermediate services[109]

In some cases, flows of ecosystem services are inputs to the production of goods and services within the production boundary of the SNA, i.e., SNA benefits. In these cases, the values of

[107] Based largerly on SEEA EA, ¶ 6.24–29
[108] SEEA EA, ¶ 6.24
[109] Based on SEEA EA ¶ 8.28

ecosystem services are implicitly embodied within values of goods and services recorded in the national accounts. Examples for the marine realm include biomass provisioning services such as fishery and abiotic flows such as wind. Monetary valuation therefore involves partitioning the values of the goods and services recorded in the national accounts to reveal the ecosystem contribution.

The contribution of ecosystem services to human welfare may encompass both final ecosystem services and intermediate services recognizing that the values of intermediate services will themselves be embodied in the value of the associated final ecosystem service.

For non-SNA benefits, e.g. waste remediation, different valuation methods are being used, but the underlying logic regarding the embodiment of the value of intermediate services within final services remains the same.

However, "Where intermediate services are recorded, the same valuation methods can be applied since there remains the intent to measure the contribution of the ecosystem to economic and human activity. For example, where flows of pollination services are recorded as inputs to biomass provisioning services, both of these services can be valued in terms of their contribution to the associated agricultural output"[110], but care must be taken to prevent double counting, e.g., by using the value of the intermediate service only to put context to that of the final service.

7.8 Overview of ecosystem services

In this section, we provide a comprehensive overview of the monetary estimates of the various ecosystem services discussed in this report. The results are shown in Table 72. It can help to evaluate the relative importance of these services from an ecosystem perspective.

The value wind energy in this overview is calculated with the avoided cost method, which provides more reliable and positive outcomes than the resource rent method discussed earlier. We have also decided to exclude oil and gas extraction from this overview, as it does not qualify as an ecosystem service.

Drawing from previous research on terrestrial ecosystem accounts, our analysis reveals that tourism is the most valuable service in monetary terms, followed by amenity services. On the other hand, the monetary value of the ecosystem contribution to mineral extraction and fisheries is relatively low across all reported years.

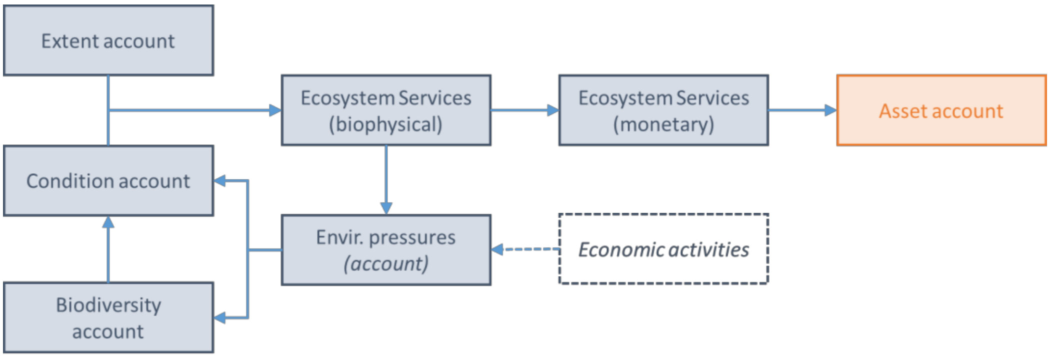
[110] SEEA EA, ¶ 9.26

Table 72. Overview of monetary value of marine ecosystem services, abiotic flow and spatial functions, in current prices. Values in grey are estimates based on the preceding (or following) years for which values are available.

Ecosystem Service		2013	2014	2015	2016	2017	2018	2019	2020	2021
		million euro								
High certainty	Fisheries	-10	-3	8	24	24	21	17	10	10
	Global climate regulation	0	0	0	0	0	0	0	0	0
	Recreation	166	166	155	184	195	214	226	242	242
	Tourism	896	981	1065	1181	1296	1412	840	603	603
	Amenity	188	188	**188**	188	188	188	188	**259**	**259**
	Wind energy	21	22	34	72	106	106	97	148	213
	Mineral extraction	8	8	8	9	10	9	12	16	20
	Subtotal	1270	1362	1456	1657	1820	1950	1379	1278	1348
Low certainty	Coastal protection	158	158	158	158	158	158	158	168	168
	Waste remediation	2802	2802	2802	2802	2802	2802	3014	3014	3014
	Education, R&D	35	35	35	35	35	35	35	35	35
	Oil and Gas	2339	2339	2339	996	1021	1173	690	54	1298
	Transport (GVA)	191	191	191	191	185	185	155	155	240
Total		**6795**	**6887**	**6982**	**5839**	**6021**	**6303**	**5432**	**4704**	**6103**

The monetary valuation of ecosystem services is just one aspect of the total value of nature. Therefore, the results should not be seen as a measure of the value of nature itself. Instead, it only reflects the economic value of the contribution of the marine environment to the benefits to humans. Non-economic values, such as the beauty of the landscape, and non-human benefits, such as animal welfare, are not included in this analysis. The intrinsic value of nature cannot be expressed in monetary terms. It is also important to note that the monetary value has not yet been calculated for all marine ecosystem services. As a result, the total figures presented in this publication underestimate the economic contribution of ecosystems.

8. Asset account



An estimate of the overall value of an ecosystem asset can be derived from aggregate values of future flows of ecosystem services, following the standard approaches to capital accounting, using the net present value approach (UN, 2021). Such an approach requires several assumptions about the future flows of income, as well as about the discount rate used to convert the future income to current values and the corresponding time horizon:

The SEEA EA considers environmental assets from a different perspective than that of the SEEA CF. The focus of the SEEA EA is on the biophysical environment as viewed through the lens of ecosystems in which the various biophysical components (including individual resources) are seen to operate together as a functional unit. Ecosystem assets are environmental assets viewed from a systems perspective. Furthermore, in the SEEA EA the extended asset boundary as defined in SEEA CF is used, which means that all ecosystems (regardless of ownership) are within the scope of the accounts.

In this chapter, we describe how the value of ecosystem assets has been derived from the estimated value of ecosystem service flows. We have used a net present value (NPV) approach, using assumptions on the future flow of ecosystem services, the discount rate, and the economic lifespan of ecosystem assets.

Assumption 1: *The future flow of income for each ecosystem service is constant, and equal to the flow observed most recently.*

This implies a number of further assumptions. We assume that no (future) degradation takes place. This assumption is not necessarily realistic, since it implies that e.g. there is no overharvesting (where offtake exceeds mean annual increment) of fish in the DCS. We anticipate that declining effects are, for now, modest for most services (given that there are no clear indications that ecosystems are reaching a point where they are close to collapse in the Netherlands, and given ongoing efforts to rehabilitate ecosystems).

Assumption 2: *The discount rate equals 3 percent, unless the ecosystem asset is thought to become scarcer and there are limited substitution possibilities.*

The discount rate reflects the time preference of money: it captures the trade-off between consumption today and consumption in the future. It takes into account a risk-free return on investment and a risk-premium. The value that is chosen for this discount rate is an important determinant of the asset value.

Following earlier work of Statistics Netherlands on natural capital accounting, and the guidelines provided by PBL Netherlands Environmental Assessment Agency,[111] the discount rate of 3 percent is applied for provisioning and cultural services. For regulating services, which are scarcer and harder to substitute, we use a discount rate of 2 percent.

Assumption 3: *The asset life is 100 years (or infinite) for all ecosystem assets.*

The asset life is the expected period of time over which the ecosystem services are to be delivered and determines the time-horizon over which the net present value is calculated. The longest asset life that is used in the estimation of the value of produced assets is 75 years for dwellings (see Statistics Netherlands, 2019). For nature, which in principle renews itself, it makes sense to set an asset life substantially longer than 75 years. In their experimental estimates for ecosystem assets, the British Office of National Statistics (ONS, 2018) sets the asset life to 100 years. One can also argue that ecosystem services benefits are provided indefinitely. We have therefore applied both assumptions to analyse the effects on the resulting asset values.

Results

The value of an ecosystem asset can be determined by calculating the net present value of the future flows of income associated with the different ecosystem services. The asset value K_0 is calculated using the NPV formula:

$$K_0 = \sum_{t=1}^{T} \frac{d_t}{(1+r)^t}$$

Assuming a flow of income d_t in year t, a discount rate r, and an asset life T.

The ecosystem services and abiotic flows that are included here are fisheries, wind energy (based on the avoided damage method), mineral extraction, nature recreation, nature tourism and amenity services, i.e. the ‘high certainty’ services and flows presented in Table 72.

Table 73. Total asset value based on different life spans, and the monetary value of the ecosystem services as determined for the years 2015 and 2020.

Life span	2015	2020
	Million euro	
100 years	54.044	44.266
infinite	57.701	52.565

Beyond a certain value, the asset life (T) has less impact on the ultimate asset value, for a sufficiently high value of the discount rate. As shown in Table 73, the asset value in 2020 with a life span of 100 years is around 85% of the value of an infinite life span. It should be noted that the discount rate[112]and the time horizon may differ across asset types and each ecosystem asset may provide a basket of ecosystem services, it is necessary to calculate asset values for the different ecosystem service separately before aggregating to an overall value.

[111] https://www.pbl.nl/publicaties/de-discontovoet-voor-natuur-de-relatieve-prijsstijging-voor-ecosysteemdiensten
[112] See assumption 2

9. Discussion and recommendations

This chapter discusses some of the results obtained in the current study, some topics that were not addressed properly yet, and gives recommendations for future research.

9.1 Extent account

Ecosystem Accounting Area

Ecosystem accounting requires a strict delineation of the scope, both in terms of "the economy" and "the environment". To this end, a well-defined ecosystem accounting area (Section 3.2) is required. We found that current delineations of the DCS fall short of the requirements: the available delineations of the EEZ are typically defined only beyond the 12 mile zone. This leaves room for interpretation with respect to both the transition to land, the Wadden Sea or river inlets, and the location of the border with Germany (the boundary dispute within the Eems-Dollard). In this study, we took a pragmatic approach, based on the delineations as used in the Top10NL topographic map, but we would recommend to properly define the full extent of the Dutch part of the North Sea.

Habitats

The EU Habitat Directive is one of the leading ecological frameworks as used in the Dutch North Sea. Ideally, the habitats that are protected under the Habitat Directive would be explicitly recognizable within the extent account. Unfortunately, the exact location of these habitats is not publically available, which prevented this approach. It is recommended to combine forces between Statistics Netherland with the agencies responsible for the mapping and reporting of these habitats.

EUNIS

The ecosystem extent account as developed in the current study was based on the EUSeaMap that implements part of the EUNIS ecosystem typology in use throughout the EU. Unfortunately, this map only implements the upper levels of the EUNIS classification, which are abiotic, essentially ignoring the biodiversity component of the EUNIS typology, rendering the ecosystem extent account rather a *geosystem* account. It is recommended that future mapping efforts also encompasses the lower, biotic, levels of EUNIS as well.

The EUSeaMap is currently being updated every 2 years (2019, 2021, 2023). We note that this interval is not ideal given the intended interval of formal (Eurostat) ecosystem accounts as being currently proposed (every three years). We recommend that all EU mapping and reporting intervals be aligned.

Pelagic habitats

As explained in Section 3.7.4, there is a lack of data pertaining to pelagic habitats, forcing the ecosystem extent account to mainly represent benthic ecosystems. One possible approach could be to include information on pelagic habitats, *where available*, in the condition account. This is also the approach recommended by SEEA-EA (§ 3.12).

Once data sources on pelagic habitats are on the same level as for benthic habitats, this information can be used for either a separate — pelagic —extent account (in recognition of the

3D character of the marine realm) or as an intersection, i.e. define assets based on benthic and pelagic characteristics.

Immobile biotia

An important aspect of available habitat mapping products is that they are almost entirely *abiotic* in nature, combining information on sediment, water, wave energy etc. One particular example is the EUSeaMap map product that includes the abiotic levels 1 and 2 of EUNIS, but excludes the biotic community information that defines the EUNIS levels 4 and higher. The main reason for this omission is the absence of a good spatial coverage of data pertaining to these species and communities to allow mapping of the corresponding EUNIS habitats. However, there is an extensive and growing literature on immobile biota and their mapping. For example, van der Reijden et al. (2019) report on the discovery of *Sabellaria spinulosa* reefs in the deeper troughs of the Brown Bank.

The location (spatial patterns) of immobile biota is of high relevance, both from a local habitat quality / ecosystem functioning point of view, and/or from an ecosystem services point of view. For example, sea grass plays an important role as a habitat (supporting ecosystem services), but also contributes to final ecosystem services such as carbon sequestration. Tracking the fate of sea grass meadows is thus of importance. In a recent study, it was found that between 1869 and 2016 around one third of the European extent in sea grass was lost, mainly due to "*disease, deteriorated water quality, and coastal development*" (De los Santos et al., 2019). Since around the year 2000 this decline has been halted and "*density metrics improved or remained stable in most sites*".

Currently, data of sufficient quality on immobile biota, such as biogenic reefs or sea grass is lacking, which makes it impossible to represent them in the extent account with an adequate level of certainty. But ignoring the body of data that is available seems to be undesirable as well.

Hence, it is advisable to systematically incorporate existing data concerning immobile biota within ecosystem accounting. When dealing with minor occurrences that align with the prevalent ecosystem type in their respective locations, these instances can be documented within the condition account. Conversely, for more substantial areas necessitating the establishment of distinct ecosystem types, supplementary ecosystem assets can be defined. To facilitate the continuous integration of newly available data, one can leverage the revision mechanisms inherent in the accounting structure.

Lost and artificial habitats

In preparation of the designation of Natura 2000 sites in the Dutch part of the North Sea (see section 3.5), Lindeboom (2008) presented an overview of the natural and anthropogenic habitats in the North Sea. Besides the natural habitats (fronts, sandy silty and gravel sea floors, and sand banks) Lindeboom (2008) also emphasized a number of "lost" and artificial habitats.

Examples of the 'lost' habitats are the former *Oyster banks* and the *Texelse Stenen* gravel area Although from the "modern" perspective there appears to be no direct need to include these in the ecosystem extent account, it seems important to explicitly take notice of these habitats, for example because they carry information on what the natural reference state of the system could be. One option could be to extend the ecosystem extent account back in time far enough to include these habitats. Problem with this approach is that both area and extent are not precisely known, making it difficult to combine with the modern data.

One practical approach to tackle this problem would be to do this: First, strictly for informative purposes, to include a separate "soft data" description of these habitats and relate them more informally to the ecosystems that have replaced them (i.e., as in Lindeboom (2008)). Second, the former presence of these habitats could be recorded in the Condition account to indicate the degraded state of some ecosystem types, where it is assessed to be relevant for current policy development, e.g. the EU Nature Restoration Law.

Examples of anthropogenic (artificial) habitats with relevance for (local) biodiversity include (Lindeboom, 2008):

- Strongly disturbed "ploughed" sea bottom, caused by repeated beam trawling;
- Lightly disturbed "raked" sea bottom, caused by other forms of mechanical fishing;
- Wind parks and mining platforms, resulting in artificial hard substrate, and relevant because of the limitations upon fishing;
- Mineral extraction sites, resulting in entrapment of organic matter (in deeper sites only);
- Ship wrecks, due to the presence of hard substrate, and the absence of fishing in the direct vicinity;

and, in addition, it should be noted that since 2008 a new and important anthropogenic habitat has been introduced: the "sand engine" near Ter Heijde.

Some of these habitats are the result of continuous disturbance due to human activities (e.g. fishing), which can be regarded as a pressure factor. So the question is whether or not these artificial habitats should be in the extent account (i.e. be a separate ecosystem type) or in the condition account, as a degraded form of a natural ecosystem type.

It seems logical to follow the same line of reasoning that underlies the structure of the IUCN Global Ecosystem Typology: ecosystem types are being recognized on the basis of distinct ecological functioning: different types of resources, different guilds present etc.

When applied to artificial habitats, one possible way forward is to 1) group artificial habitats together based on ecological functioning (e.g. hard substrate), and 2) distinguish between mild' disturbance of ecosystems (e.g. the 'raking' type of bottom disturbance and shallow mineral extraction), which can be included in the condition account and related to a pressure factor, and 'intensive' disturbance which semi-permanently affect the functioning of the local ecosystem types, which will give rise to novel (anthropogenic) ecosystem types.

One possible approach would be to identify a critical beam trawling intensity above which there is a permanent change in the ecological functioning of benthic habitats. With this definition it would be able to define the following anthropogenic ecosystem types:

- Strongly and semi-permanently disturbed sea bottom (subtypes: abiotic EUSeaMap habitats);
- Artificial reefs (subtypes: wind parks; mining platforms; wrecks);
- Deep mineral extraction sites;

and to include artificial habitats such as lightly disturbed sea bottom and shallow extraction sites in the Condition account.

Possible limitations of this approach are i) insufficient availability of spatio-temporal data and ii) how this links to indicators of benthic intactness.

One possible risk of this approach could be that only the 'mild' type of disturbance will be recognized as ecosystem degradation, and the impact of the 'intensive' type of disturbance will be overlooked, because it is recorded in the extent account, rather than in the condition account. Thus, in order to make this approach useful for policy applications, evaluations of total ecosystem degradation must consider both the extent and the condition accounts.

9.2 Ecosystem condition

.Within the SEEA-EA framework, the condition account aims to quantitatively describe ecosystem health using condition variables that can be determined for each ecosystem type separately. Since the spatial distribution of measurements, especially those with long times series, are rather coarsely distributed this poses a challenge. To develop an indicator per ecosystem type would require spatial extrapolation, which brings more uncertainty into the interpretation of what is already a complex and dynamic biogeochemical system. Indeed it might be more fruitful to develop indicators at a broader level that reflect the underlying distribution of these properties. For example, one set of indicators for the more shallow coastal marine waters and one set of indicators for the deeper waters situated further away from the coast. In this way, though there is limited spatial resolution, the amount of measurements will make the indicators themselves and the significant changes in them more robust. Another option would be to use the gradients in bathymetry, possibly current- and wave induced energy and the distance to known measurements to develop a full coverage map. This would provide more insight into the specific properties and allow an estimate for each ecosystem type. However, special care would have to be taken to draw conclusions for ecosystem types that are far away or characteristically different from ecosystem types that have actual measurements.

Spatial scale

The current ecosystem condition account is mainly a re-organization of indicators reported for the MSFD, and the Habitat Directive. Especially the MSFD indicators are in most cases reported on the scale of the DCS as a lumped unit. As a result, the underlying data is collection is to a large extent not of sufficient detail to allow for a fully spatial approach to condition accounting as is the SEEA-EA ideal. We do recognize, though that increasingly spatially distributed data sets are becoming available (e.g. through EMODnet), allowing a more spatial approach to ecosystem accounting in the future.

A related issue is the large variability in spatial scale across reporting for the Habitat Directive, and for MSFD and OSPAR. We recommend attention to the alignment of these spatial scales, to allow meaningful comparison between indicators from different origin.

Also, earth observation is an emerging source of relevant data for the marine realm. Unfortunately, within the scope of the current study we were not able to fully explore the potential of this data source.

Incompleteness and instrumental condition

We note that not all indicators proposed by OSPAR and/or MSFD are available yet, and that not all relevant ecosystem properties are captured by the MSFD indicators (e.g. climate change; acidification). We recommend completion of the current set of indicators proposed, and assessment of the need to broaden the set of indicators

One example of a category that may require broadening is that of instrumental condition. We recognize that the MSFD descriptors are focused on the assessment of Good Environmental

Status (GES), including the relevant pressures, and therefore are less suitable to be used in the context of the assessment of the capacity of the ecosystems to supply ecosystem services. Although we made some steps in that direction in the current report, we note that there are additional initiatives working in this field as well, for example the ICES Workshop on Assessing Capacity to supply Ecosystem Services (WKASCAPES) and the assessments of impact of state change on ecosystem service capacity as developed for OSPAR (Cornacchio, 2022). It is recommended that the results of these initiative are to be followed up and combined with the SEEA-EA framework in order to maximize synergy and efficiency.

One other example is the lack of landscape / seascape scale indicators in the MSFD typology. In order to comply with the SEEA-EA requirements for condition indicators on this scale, it is recommended to explore options, e.g. linking to the seascapes already defined (Section 3.8.2). In order to make these indicators useful for policy applications, the links between seascape characteristics, spatial variability on micro-scale habitats (i.e., variability within a seascape), and conservation targets (or similar policy goals) should be identified.

SEEA-EA vs MSFD vs OSPAR

We found that the various frameworks for ecosystem condition are not optimally aligned. Even the OSPAR indicator typology, while designed to support and align MSFD reporting activities by EU Member States, is not *fully* compatible with MSFD (Section 4.1.3). The SEEA-EA ecosystem typology takes a fundamental different approach. In many cases we could find one or more MSFD criteria or indicators to develop a SEEA-EA style condition account, but not in all cases (e.g. the before mentioned climate variables). However, the question arises what would be a more policy-relevant structure of ecosystem accounts: one that uses the SEEA-EA as the “golden standard”, but deviates from the existing legislation, or a “modified” structure that is better aligned with these existing frameworks.

We also found that SEEA-EA and OSPAR/MSFD take a different approach to the distinction between ecosystem *state* and environmental *pressure*. Again, we do recognize the logic of the OSPAR/MSFD approach, and would not recommend to define the SEEA-EA as “golden standard”.

We recommend to raise these issues in the appropriate international platforms (OSPAR, GOAP, Eurostat and the SEEA-Ocean working group).

The tiered SEEA-EA approach.

As explained in the introduction of Chapter 4, the SEEA-EA recommends a three-step approach to ecosystem condition:

1. Collection of raw *variables*, each having their own units
2. Normalization of the variables against reference levels, resulting in *indicators* with non-dimensional relative values, e.g. 0…1
3. Aggregation of these indicators into (eventually) a single overall *index*, describing overall quality of the ecosystem.

In this report, only step 1 has been carried out. It would be interesting to see whether in the future steps 2 and 3 could be carried out, but that would require agreement on the definition of meaningful reference levels. Given the context of the MSFD, it would seem logical to use the Good Ecological Status (GES) values as reference levels. This however requires quantitative thresholds for all GES indicators, which are not available yet.

However, In the typology of reference conditions, this approach would classify as ‘prescribed levels’, which are most suitable for policy applications and anthropogenic ecosystems, but not necessarily the best method if (the distance to) undisturbed or even least disturbed conditions are sought (Table 74). In addition, not all relevant condition indicators are included in the MSFD framework, limiting the scope of this approach. Either way, this topic would require further exploration and discussion with policy makers, stakeholders, statisticians, scientists and all other people involved.

In that respect, it would be interesting to follow the developments in the Dutch Wadden Sea, where the full three-stage approach for condition will be explored during the next few years in the ”State of the Wadden Sea” project carried out by Statistics Netherlands and the Wadden Academy, and commissioned by the Ministry of Agriculture, Nature, and Food quality.

Table 74. Summary of methods for estimating possible reference condition for natural and managed ecosystems. After UN (2021), table 5.9

		Natural ecosystems				
		Anthropogenic ecosystems				
	Possible reference condition	Undisturbed or minimally-disturbed condition	Historical condition	Least-disturbed condition	Comtemporary condition	Best-attainable condition
Methods for estimating the reference condition	1. Reference sites	•	•	•	•	
	2. Modelled reference conditions	•	•	•		•
	3. Statistical approaches based on ambient distributions			•		•
	4. Historical observations and paleo- environmental data		•			
	5. Contemporary data				•	
	6. Prescribed levels					•
	7. Expert opinion	•		•		•

9.3 Biodiversity

Multi-species indicators (MSI’s) per species group can provide a holistic view of population abundance trends, as demonstrated by the compilation of all accessible data within these taxonomic categories. Nonetheless, it is essential to recognize that alterations in the overall abundance of species do not consistently offer a complete depiction of the ecosystem's status, particularly in regard to ecosystem functions. The specific traits exhibited by certain species can hold significant ecological functions within diverse environments, and their presence or absence may consequently serve as a reflection of the environmental quality within a given habitat. These nuanced ecological signals may not be adequately captured by a generalist MSI approach, even though distinctions between coastal and offshore regions are made. For fish, we already made separate MSI’s based on preferred habitat and spawning behaviour, and such MSI’s can provide a better ecological understanding of the potential drivers behind some of the changes we see.

For instance, for benthic macrofauna in the North Sea, the Benthic Indicator Species Index (BISI) was developed in 2017 for assessing the habitat quality, sediment integrity, and the ecological functioning of benthic fauna for the Dutch MSFD reporting. Several key species have been identified for distinct benthic habitats, and their occurrence and population levels can be linked to good abiotic conditions, good biotic structure, or a combination of both, in addition to characteristic and exclusive species for each habitat.

The recently released OSPAR quality status report[113] features a whole section addressing indicator assessments. Certain indicators include similar species groups to those discussed here. These indicators aim to achieve greater granularity by considering specific species traits and ecosystem functions. In the context of benthic species, they also incorporate metrics such as species richness and diversity indices, alongside sensitivity/tolerance species classification systems, to assess the qualitative state of benthic habitat communities.

ICES (International Council for the Exploration of the Sea) also introduced a similar measure and identified Vulnerable Marine Ecosystems (VMEs) [114] and organisms considered to be indicators of VMEs, which relate to benthic species in more deep-sea environments. This approach also looks at particular species instead of the abundances of the species assemblage.

For a complete overview of the dynamics of marine species over time in the Netherlands, it can make sense to include other coastal areas as well, such as the Wadden Sea, Eastern Scheldt and Western Scheldt. Specifically for nursery fish species, but also for birds, as these regions also make up part of their habitat with potential feeding and breeding grounds.

Moreover, for fish species even more distinctions can be made in the indicators to better evaluate the causes for changes. For instance, a distinction between juvenile and adult fish using the size of the fish.

There is no unambiguous explanation for the recent increase in the seabird MSI. Interestingly, comparable increases are found for benthos (Section 6.4.1) and fish (Section 6.4.2). It is tempting to make a causal link to some major recent changes in the North Sea landscape: the decrease in fishing intensity mentioned in this report (Section 5.6.2), the increase in sea water temperature (Section 4.5.3) and the establishment of large offshore wind farms (Section 5.6.1). For each of these factors it is not hard to think of how it positively affects animal populations. Evidence of actual causal relations is sparse, however, but would be interesting to further explore.

Not all aspects of the marine food web are covered by the species groups mentioned above. The most notable missing components are the lower part of the food web, including primary producers, such as phytoplankton, and important secondary consumers, such as zooplankton. Plankton species stands at the base of the marine food web, and environmental changes will be most directly visible in these components. Incorporating the dynamics within these food web constituents may help to elucidate environmental impacts and drivers as we would have a more complete picture of the marine ecosystem and possible food web cascades. Some of these components are covered in the Condition chapter (4) of this report.

Changes in for instance nutrient loadings in the North Sea may be more directly reflected in plankton species, because of their higher generation times. Moreover, not only total amounts of plankton are important, but higher sea surface temperatures can also result in smaller zooplankton body size, which, in turn, negatively effects the size of planktivorous fish (Ljungström et al., 2020).

Limitations of including plankton lay within the availability of high resolution monitoring data. However, Rijkswaterstaat started the '*Monitoring-Onderzoek-Natuurversterking-Soortbescherming*' (MONS) program this year, which will collect high resolution plankton data along the North Sea coast. So this can be taken into account in the near future.

[113] https://oap.ospar.org/en/ospar-assessments/quality-status-reports/qsr-2023/indicator-assessments/
[114] https://www.ices.dk/data/data-portals/Pages/vulnerable-marine-ecosystems.aspx

As a final note, it should be emphasized that the multispecies indicators developed in the current report are independent of the state of biodiversity indicators as used for MSFD (Section 4.1.1). It is recommended that in the future these two sets of indicators are compared more closely, and – if possible – be aligned.

9.3.1 Monetary valuation of biodiversity

One of the key questions from a policy perspective is how measures related to economic activities, such as fishing and offshore wind energy, relate to changes in biodiversity, either positive (pay offs; synergy) or negative (trade-offs). One simple approach is to compare "oranges" (economics) with "apples" (biodiversity), respecting the fundamental differences between these two.

A second approach is to try to express biodiversity (changes) in monetary terms in order to arrive at similar units (euro) that allow for direct comparison. The risk of this approach is that "valuing nature" on a fundamental level cannot take into account the intrinsic value of nature.

However, several less ambitious methods may be worth exploring, for example focusing on the financial risk and societal cost of biodiversity decline (DNB and PBL, 2020; Dasgupta et al, 2021) or restoration (Schweppe-Kraft and Ekinci, 2021). This latter approach would be consistent with the "replacement cost" valuation method.

Spraos Romain (2022), in their evaluation of valuation methods for biodiversity of the Dutch North Sea, note that at least the instrumental value of biodiversity could in principle be established by analysing the contribution of biodiversity to the (monetary value of) the ecosystem services provided. They identified three approaches to value biodiversity monetarily:

1. Measuring the value of final ecosystem services as a means of valuing biodiversity. This method essentially corresponds to the sum of the monetary ecosystem asset values identified
2. Revealing ecosystem services that are heavily linked to biodiversity. This could either take the form of quantifying and valuing the role of specific biological resources for the provision of ecosystem services, or
3. It could take the form of quantifying only certain ecosystem functions and services that are linked to biodiversity in the strict definition of the word, e.g., the approach taken by Schweppe-Kraft and Ekinci (2021), or by considering species appreciation as an ecosystem service.

It should be noted that approached 1 and 2 focus on the instrumental value of biodiversity (i.e., the human use of nature), where approach 3 captures (to some extent) the intrinsic value (i.e., nature for nature's sake).

The second approach is based on the contribution of biodiversity, via intermediate ecosystem services, to final ecosystem services and their monetary value. One way to determine this contribution could be to use the so-called 'emergy' method that converts all contributions in the final ecosystem service to a common unit, allowing the attribution of the value to these contributions (Odum, 1996; Berrios et al., 2017; Nadalini et al., 2021). We recommend investigation of the applicability of this method to assess the contribution of biodiversity and ecosystem processes to the monetary value of final ecosystem services.

9.4 Environmental pressures

Connections between ecosystem services and environmental pressures

While developing the environmental pressure accounts presented in Chapter 5, we found that although some environmental pressures are related to drivers and activities outside of the marine realm (e.g. pollution from terrestrial sources such as industry and agriculture), many of the pressures on the marine ecosystems are caused by the ecosystem services provided by the North Sea: Fishing; Wind energy; Shipping, etc. We do interpret this as a sign that pressure accounts have a large added value in the ecosystem accounting framework, and recommend further conceptual development of these accounts under the umbrella of the upcoming SEEA-Oceans framework, and the associated SEEA-GOAP working group.

Quantification

The environmental pressure account as developed in the current study is to a large extent a qualitative one, based on the qualitative assessments of pressure factors as reported under Articles 12 and 17 of the Bird and Habitat directives. For future follow-ups, it is recommended to develop quantitative metrics for these pressures.

Spatial footprint

Some pressures will act mainly locally, such as mineral extraction or bottom trawling For other pressures, such as pollution, the effect will literally disperse from the (point) sources. For wind offshore farms the effect is mixed: turbine impact on birds will be locally, but wake effects in the water may stretch out for many miles. These spatial effects should be taken into account in future analysis of the links between economic activities (as pressure sources), and condition.

The role of national statistics

Not all pressures exerted upon the North sea have their origin in activities of Dutch economic actors, or even within the territory of the Netherlands. This is especially the case for either mobile activities, such as shipping or fishing, or pollution due to inflow from the major rivers, whose catchments are all international. The use of national data on the associated economic activities and pressures is therefore limited, and a harmonized approach across Europe and the NE Atlantic should be sought. It is therefore recommended to build upon the work pioneered within OSPAR and the EU to develop Ocean Accounts.

Eutrophication and pollution

The sections on eutrophication (5.6.3) and pollution (5.6.4) of the Dutch North Sea are currently based on data from the Dutch Emissions Authority (the Emissions Registration), which contain data on direct emissions, influx from rivers abroad and deposition from the atmosphere. Because of a lack of time (and readily available data), we did not use any information on the in- or outflux of pollutants through ocean currents. For future research, it is recommended to combine emission data with ocean flow and pollutant concentration data to obtain the full picture.

The main source of pollutants addressed in this study is the flux from the main rivers towards the Dutch North Sea. Although a major share of this load comes from abroad, a significant share is still due to emissions by the Netherlands' economy. In principle these emissions can be linked to the specific economic sectors using data available in the Emission Registration, and using the concepts of the SEEA water emissions accounts (United Nations, 2014), as compiled by

Statistics Netherlands until 2014.[115] It is recommended to review the potential added value of renewing the compilation of these statistics. The identification of how much each sectors contributes to pollution is expected to help the development of effective policies.

One of the products that could be developed with those data sets could be full mass balances of pollutants for the terrestrial, freshwater and marine parts of the Netherlands.

Many pollutants will eventually and up in sediment or biota. It is recommend to link the available data sets on pollutants influx and concentrations in water, sediment and biota. Data sources available from ICES and Wageningen Marine Research could be considered.

Attribution of climate change to economic sectors

In the (qualitative) environmental pressure account (Section 5.5.5) climate change emerged as a major pressure or threat. Unlike other pressures, climate change was not associated with specific economic sectors. The main reason for this is that the major part of climate change is due to anthropogenic greenhouse gas emissions on the global scale, where the Dutch contribution is small (0.38%, but still relevant). In principle, this national share could be attributed to individual economic sectors by using the data published in the air emissions accounts[116], but still the sector "import" would then account for 99.6%.

State versus pressure

One result of the current study is that we found that the distinction within the SEEA-EA framework between condition state and environmental pressures is not the same as a similar distinction within the MSFD and OSPAR frameworks. The main difference is that SEEA-EA regards all stock variables as states, while within MSFD and OSPAR state refers to biodiversity status. For future uptake of environmental pressures in the SEEA-Ocean Accounts framework it is advised to carefully consider the scope of pressures.

9.4.1 Monetary valuation of environmental pressures

A topic related to environmental pressures is that of externalities. '*Externalities are impacts that "arise when the actions of an individual, firm or community affect the welfare of other individuals, firms or communities [and the] agent responsible for the action does not take full account of the effect*" (Markandya et al., 2001)'[117]. Translated to ecosystem accounting, examples include water pollution by an oil tanker affecting local fisheries and tourism, and inflicting extra costs. Similarly, beam trawling fishery (addressed in Section 5.6.2) may, through bottom disturbance and directly, be a source of CO_2 emissions.

According to the SEEA standard, "*Accounting approaches explicitly do not [directly] account for externalities*"[118]. The main reason for this is that externalities are not exchanges (between economic units and the environment), but rather "*outcomes that arise as a consequence of other activities."*[119]

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[115] https://www.cbs.nl/nl-nl/onze-diensten/methoden/onderzoeksomschrijvingen/korte-onderzoeksomschrijvingen/milieurekeningen-emissies-naar-water-herkomst-en-bestemming (beschrijving) en https://opendata.cbs.nl/statline/#/CBS/nl/dataset/83605NED/table?ts=1698911101076 (data)
[116] https://www.cbs.nl/nl-nl/dossier/dossier-broeikasgassen/welke-sectoren-stoten-broeikasgassen-uit-
[117] SEEA-EA, ¶12.14
[118] SEEA-EA, ¶12.15
[119] Ibid.

In effect, ecosystem accounts describe the world as it is, including externalities. The recorded trends in stocks and flows "*will reveal any actual costs or changes in income that may be associated with externalities, such as increased costs incurred with respect to pollution*"[120].

Thus, "*While the accounts do not directly adjust or measure negative externalities as a distinct concept, the data in any set of accounts will track the effects of externalities over time, to the extent that the effects are within the prescribed accounting boundaries*", "*In addition, in the related economic accounts, additional costs incurred by affected economic units will be recorded and changed patterns of income of affected economic units will be able to be assessed.*"[121]

While we do recognize the usefulness to measure and value externalities that directly result from economic activities on the North Sea, and are related to ecosystem services, we also note the conceptual difficulties of including these in the accounting framework, especially where actual (restoration) costs or damage estimates are difficult to assess. Since the topic of externalities is currently outside of the scope of both SEEA-EA and SEEA-Ocean, it will not be further discussed here in a quantitative sense.

Ecosystem degradation

The standard SEEA EA approach to ecosystem degradation is "involves measuring the value of degradation in terms of the loss in the future value of ecosystem services due to a decline in ecosystem condition and deducting this cost of capital from the relevant aggregate measure of income (e.g., GDP)"[122]. However, alternative approaches to account for the effects of degradation can be (and have been) developed. In general, cost and damage-based valuation approaches can be distinguished. Of these, cost-based approaches better reflect the focus on actual transactions in both the SEEA and the SNA and are therefore the preferred method.[123] E.g., the costs associated with restoration of degraded ecosystems towards a previous or desired state.[124]

We recommend discussing the topic of valuation of ecosystem degradation and other forms of externalities (e.g. related to emissions) in the appropriate fora (SEEA; GOAP). Treating externalities as monetary equivalents of environmental pressures could be part of this discussion.

9.5 Ecosystem services

Scope of marine ecosystem services

This section delves into some of the remaining discussion points concerning marine ecosystem services, and where feasible, offers recommendations for future work.

While we've identified a range of marine ecosystem services in the Dutch part of the North Sea, we acknowledge that our assessment isn't exhaustive. Our focus was primarily on services that are strongly interlinked with both ecosystems and the economy, taking into account time and data constraints. However, certain marine services, such as waste remediation and coastal protection, require more comprehensive investigation. Waste remediation remains inadequately understood due to data limitations, and coastal protection, especially in the context of climate change, needs further methodological development. In Table 54 (page 137),

[120] Ibid.
[121] SEEA-EA, ¶12.20
[122] SEEA-EA, ¶12.30
[123] SEEA-EA ¶12.6, 12.32
[124] SEEA-EA ¶12.37

we identified and prioritized ecosystem services relevant for the marine environment. Although we have now included most relevant ecosystem services for the North sea area the scope of ecosystem services certainly could be further extended. To attain a comprehensive understanding of the Dutch North Sea's contributions to our social welfare and economic development, we propose expanding research endeavours to encompass these ecosystem services.

In addition, in this report we have described several abiotic services and spatial functions that are relevant for the marine environment. As discussed in sections 7.5 and 7.6, these are important aspects to describe in the marine environment in addition to the ecosystem services in the strict sense

Spatial distribution

In addition to the quantity of ecosystem services, there is room for improvement in exploring the spatial distribution within the Dutch part of the North Sea. Vital marine services such as fisheries, marine aggregates extraction, and wind energy, which hold significant roles in the region's economic and environmental dynamics, frequently show distinct regional patterns. More research in this area will help us better connect ecosystem services to different ecosystem types, improving our understanding of the complex interlinkages between ecological and economic systems.

Monetary valuation

In this report, most of the marine ecosystem services have been quantified both in physical and monetary terms. While monetary valuation methods are crucial for ecosystem accounting, the selection of these methods can notably influence the results. Additionally, methods such as the resource rent method have faced criticism for yielding low values and displaying significant variability, including negative values on occasion. These issues have been found in this study for the estimates for marine fisheries and marine aggregates extraction for example. This highlights the ongoing need for fine-tuning in the field of ecosystem accounting. Furthermore, more research is essential to identify the most appropriate valuation methods for specific marine ecosystem services, and the continued development of international standards, such as SEEA EA, is vital to ensure uniformity and comparability in assessments.

When assessing the monetary ecosystem accounts of the Dutch North Sea, we have focused on exchange values to measure the economic benefits of services such as fisheries production, tourism revenue, and carbon sequestration. Although this is in line with the international guidelines of the SEEA EA, it is important to understand that the monetary valuation in this report provides a limited perspective, focusing solely on the socio-economic importance of these services to our society. Notably, we intentionally exclude welfare values, which include non-market values such as intrinsic values and the well-being of non-human entities. This omission highlights the need to recognize the limitations of monetary valuation in fully representing the entire value of the marine ecosystem, emphasizing that the ecosystem's total or true worth extends beyond what is quantified and monetised in this report. However, it's worth noting that for specific purposes or policy interests, it could be valuable to consider the intrinsic and non-market values.

Marine recreation and tourism

In addition to general improvements, there are specific ecosystem service issues that need improvement and additional research in the future. Regarding nature recreation and tourism, we looked at the coastal zone, however these services are also included in the terrestrial natural capital accounts, posing a risk of double counting. Other issues are often related to limited data availability, such as for marine recreation. We rely on CVTO surveys (2015 and 2018), but concerns include a lack of future survey updates and a lower quality for survey data on less frequent recreational activities.

Coastal protection

An emerging ecosystem service is the coastal protection service provided by natural ecosystems such as sand banks, which dissipate wave energy (Hanley et al, 2014), sea grass (Ondiviela et al, 2014), salt marshes (Zhu et al., 2020) and oyster reefs (Fivash et al., 2021). One famous semi-natural example in the Netherlands is the so called 'sand engine' (zandmotor[125]), where natural processes move sediment from an artificially supplemented patch along the coast line.

From a policy evaluation commissioned by the Department of Waterways and Public Works (Gerdes et al, 2021), we know that the sand engine has led to an extra strengthening of the coast and extending the lifespan of the coastal reinforcement. There has been a gradual growth of the dunes / sea strip of sand of the sand engine. It concerns a considerable volume (700,000 m^3 landward of the sand engine). Due to the design of the sand engine with a lagoon and a dune lake is the additional dune growth as a result of the sand engine over the past 10 years has been smaller than anticipated. The formation of vegetation and embryonic dunes have increased since 2016, but are not yet making a significant contribution to the further strengthening of long-term coastal security. In the first five years, one hectare of new dune was created. The dune growth in recent years is more positive: development has accelerated since 2016. In 2018 there were approx. 6 ha of embryonic dunes created, in 2020 this has increased to approximately 13 ha. (Gerdes et al., 2021).

The sand engine not only provides a cost-effective alternative to traditional suppletion, it also contributes to biodiversity goals and creates opportunities for recreation (Huisman et al., 2021). A recent value of the socio-economic added value of the sand engine concluded that the monetary value of the ecosystem services generated is fairly small, but the added value for biodiversity was large (Wienhoven et al., 2021).

Intermediate ecosystem services.

Intermediate, or supporting ecosystem services, are among the most important ecosystem services, because they form the ecosystem functions that connect the biodiversity state of the marine ecosystems with the final ecosystem services that are used by economic actors.

These ecosystem functions and intermediate services are not explicitly covered by the chapter on ecosystem services, because the focus of SEEA Ecosystem accounts is on the final ecosystem services. The intermediate services are contributing to these final services, their benefits, and the monetary value.

To some extent, the ecosystem functions are covered by the ecosystem conditions account, although it is acknowledged that this coverage is limited. It is therefore recommended to compile a wider overview of relevant marine ecosystem functions, in order to fully grasp the logic chain from biodiversity to final ecosystem services. Ideally, this overview should be made within the wider community (SEEA; GOAP; OSPAR).

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[125] https://dezandmotor.nl/

The monetary value of an intermediate ecosystem services is assumed to be part of the value of the final ecosystem services to which they contribute. It is thus not advised to value the intermediate services *in addition to* final services, since that would lead to double counting. However, one relevant question would be whether the value of the final services can be distributed across all underlying components. It is recommend to further explore the methods that have been proposed to this end, such as the *emergy* method (see Section 9.3.1).

9.6 Asset account

To calculate values for the asset account and to apply the net present value (NPV) approach important assumptions had to be made with regard to the future flow of benefits, the discount rate, and the life length of the assets. There is room for further improving and testing these assumptions, for example by making assumption on the future flow of income for each of the ecosystem services based on scenario analysis.

In principle, the asset account can be used to derive a monetary estimate for environmental degradation, using a decomposition approach. It needs to be further investigated whether this is also feasible for the marine environment.

9.7 Further remarks

Communicating and interpreting the results

A key challenge for the SEEA EA accounts is determining how to present the results to users and how to interpret them. This is particularly relevant for the monetary data on ecosystem services and ecosystem assets. For users, there may be misconceptions on how to use and interpret these data. This is a key issue that is currently faced by statistical institutes who are starting to work in this area. Valuation of ecosystem services and assets represent a kind of special data, which requires careful consideration with regard to its dissemination. Additional new analyses, like a decomposition analysis, may help to better understand what the data is actually telling us.

Potential policy applications

A recent study investigated the potential applications of natural capital accounting in marine policies for the North Sea and North East Atlantic (van Veghel, 2023). The following general policy applications were identified:

- Issue identification and monitoring the state of the marine environment.
- Establish insights on trade-offs and interactions between marine ecosystems and economy and provide quantitative spatial information for maritime spatial planning.
- Provide a communication tool for policy makers to raise awareness with respect to the importance of the marine environment and blue economy.
- Serve as a data input or baseline for other types of analysis (including scenario analysis).
- Support multidisciplinary communication and cooperation between stakeholders.
- Measure the development of the marine environment and look beyond GDP.
- Transparency in natural resource extractions from ecosystems.
- Reducing transaction costs when communicating and sharing information across different institutions from various disciplines.

In addition the following specific (potential) policy applications of NCA for the Dutch part of the North Sea and the OSPAR area were identified:

- NCA can support the program of measures for the MSFD by providing a more comprehensive economic insight into the assessment of measures.
- NCA can provide various indicators for sustainability of the marine environment and support monitoring on the development of sustainability of the European Blue Economy.
- The quantitative economic-environmental information provided by marine natural capital accounts can improve insights in the trade-offs for various stakeholders and support Maritime Spatial Planning.
- The information from the Dutch NCA can be used to support a better description of ecosystem services for the North Sea Programme 2022-2027
- OSPAR is facing challenges in multiple areas such as biodiversity loss, pollution, and climate change. NCA can support monitoring and decision making in those areas by providing relevant and robust information in a consistent way.
- One of the assessment tools for the state of the marine environment used by OSPAR is the Drivers-Activities-Pressures-State Impacts-Response (DAPSIR) framework. The focus on synergies between the NCA framework and the DAPSIR framework can promote a common approach for stakeholders and improve communication, data collection and usage.

Cumulative impact assessments

Recently (September 2023), The ICES Workshop on ASsessing CAPacity to supply Ecosystem Services (WKASCAPES) met to evaluate the functions and processes of ecosystem components in terms of their potential to contribute to the capacity to supply ecosystem services (ES). The outcomes of this workshop were further developed as part of the HorizonEurope GES4SEAS project resulting in a study entitled “A Cumulative Impact Assessment on the North Sea capacity to supply Ecosystem Services” by Piet et al. (recently submitted to Ecosystem Services). The focus was exclusively on the ecological system and, specifically, the ecological functional units, i.e. biotic groups, that produce the ES (the assets in an accounting context) and did not consider the societal goods and benefits that are part of the social system. To identify the threats that may compromise an ecosystems capacity to supply ecosystem services, they apply

- a Cumulative Impact Assessment (CIA) methodology (Piet et al., 2021; 2023) which estimates how the cumulative pressures of all human activities impact the (condition of) ecosystem components that make up marine biodiversity (i.e. assets), with
- an estimate of the Service Supply Potential (SSP) (Culhane et al. 2019) representing the relative contributions of the biodiversity components in terms of their functioning. This SSP was then quantified using a foodweb model (i.e. Ecopath with Ecosim) estimating biomass and productivity thus covering respectively 'assets' and 'flows' as used in ecosystem capital accounting (Maes, 2012).

As such the method allows an estimation of the potential impact (=change in condition) on the ecosystem assets and how this then compromises the ecosystem capacity to supply services. Results showed that, overall, the capacity of the North Sea to supply Cultural ecosystem services was most threatened, with an average Impact Risk of 70%. This was followed by the Provisioning ecosystem services with an impact risk of 62% and the Regulation & Maintenance ecosystem services with an impact risk of 38%.

We recommend to explicitly link the SEEA and SCAIRM approaches to leverage the synergies that may result from combining the two frameworks,.

SEEA-Ocean

A recent development is the establishment of a working group within SEEA to develop a SEEA-OCEAN which builds upon the SEEA Central Framework (UN et al, 2014) and the SEEA ecosystem accounting (UN et al, 2021) frameworks, but also on the activities by the Global Ocean Accounting Partnership (GOAP).

One characteristic of the proposed SEEA-Ocean accounting structure is the attention to environmental pressures, economic activities and information regarding governance of the marine system. In the Netherlands, we already have extensive experience with the ocean economy (the 'NAMWA' projects, Walker et al., 2023) and the current study provides first, experimental, steps towards pressure accounts. We therefore look forward to share these experiences within the SEEA-Ocean working group, and contributing to the further development of the framework.

References

AAC-europe (2022). Recommendation on carbon sequestration by molluscs. AAC 2022-16.

Aarhus University, Department of Bioscience, Marine Ecology Roskilde (2021). North Sea - Eutrophication and Acidity aggregated datasets 1902/2020 v2021. Aggregated data products are generated by EMODnet Chemistry under the support of DG MARE Call for Tenders EASME/EMFF/2016/006-lot4, EASME/2019/OP/0003-lot4.

Aalbers, R., Renes, G., & Romijn, G. (2016). WLO-klimaatscenario's en de waardering van CO_2-uitstoot in MKBA's. CPB/PBL Achtergronddocument, 18pp.

Alarcon Blazquez, M. (2021). Natural capital accounting for the North-East Atlantic area. https://www.noordzeeloket.nl/publish/pages/193624/natural-capital-accounting-for-the-nort-east-atlantic-area.pdf

Alarcon Blazquez, M. G., R. van der Veeren, J. Gacutan, P. A. S. James (2023) Compiling preliminary SEEA Ecosystem Accounts for the OSPAR regional sea: experimental findings and lessons learned. *One Ecosystem, 8*: e108030. https://doi.org/10.3897/oneeco.8.e108030

Atkins, J. P., Burdon, D., Elliott, M., & Gregory, A. J. (2011). Management of the marine environment: integrating ecosystem services and societal benefits with the DPSIR framework in a systems approach. *Marine pollution bulletin*, *62*(2), 215-226.

Barton D.N., Obst C., Day B., Caparrós A., Dadvand P., Fenichel E., Havinga I., Hein L., McPhearson T., Randrup T., Zulian G. (2019). Discussion paper 10: Recreation services from ecosystems. Paper submitted to the Expert Meeting on Advancing the Measurement of Ecosystem Services for Ecosystem Accounting, New York, 22-24 January 2019 and subsequently revised. Version of 25 March 2019. Available at: https://seea.un.org/events/expert-meeting-advancing-measurement-ecosystemservices-ecosystem-accounting

Bellingen, M., S. Felgendreher, J. Oehrlein, S. Schürz and S. Arnold (2021), Ecosystem accounts – ecosystem extent accounts. *Wista*, *6*, p. 31. https://www.destatis.de/EN/Methods/WISTAScientificJournal/_publikationen-articles-en.html#620618

Bennema, F. P., Engelhard, G. H., and Lindeboom, H. 2020. Ostrea edulis beds in the central North Sea: delineation, ecology, and restoration. ICES Journal of Marine Science, 77: 2694–2705.

Berrios, F., Campbell, D. E., & Ortiz, M. (2017). Emergy evaluation of benthic ecosystems influenced by upwelling in northern Chile: Contributions of the ecosystems to the regional economy. *Ecological Modelling*, *359*, 146–164. https://doi.org/10.1016/j.ecolmodel.2017.05.005

Blix Consultancy. van den Brink, I. M., Olijve, N., & Pustjens, W. (2020). Determination of the cost levels of wind farms (and their grid connections) in new offshore wind energy search areas. In *Technical Report*..

Bogaart P, van der Loo M, Pannekoek J (2020). rtrim: Trends and Indices for Monitoring Data_. R package version 2.1.1, https://CRAN.R-project.org/package=rtrim .

Boon, A. R., S. Caires, I. L. Wijnant. R. Verzijlbergh, F. Zijl, J. J. Schouten, S. Muis, T. van Kessel, L. van Duren, T. van Kooten (2018), *Assessment of system effects of large-scale implementation of offshore wind in the southern North Sea*. Technical Report, 11202792-002-ZKS-0006, Deltares, Delft, 61pp.

Boonstra, M., Hougee, M. 2020. OSPAR Beach Litter Monitoring in the Netherlands Update 2019 2019. Annual Report. North Sea Foundation, Utrecht.

Bonn Agreement, Bonn Agreement Aerial Surveillance Programme, Annual report on aerial surveillance for 2016 (2016) https://www.bonnagreement.org/site/assets/files/3949/2016_report_on_aerial_surveillance.pdf

Borgwardt F., L. Robinson, D. Trauner, H. Teixeira, A.J.A. Nogueira, A.I. Lillebø, G. Piet, M. Kuemmerlen, T. O'Higgins, H. McDonald, J. Arevalo-Torres, A. Luisa Barbosa, A. Iglesias-Campos, T. Hein, F. Culhane (2019). Exploring variability in environmental impact risk from human activities across aquatic ecosystems. *Science of The Total Environment* , *652*, 1396–1408, https://doi.org/10.1016/j.scitotenv.2018.10.339

Bopp, L., C. Bowler, L. Guidi, E. Karsenti and C. De Vargas (2019), The Ocean, a carbon pump. Ocean and Climate Platform, Scientific Sheet, https://ocean-climate.org/en/presentation-of-the-ocean-and-climate-scientific-items/the-ocean-carbon-pump/

Brasseur, S.M.J.M, T.D. van Polanen Petel, T. Gerrodette, E.H.W.G. Meesters, P.J.H. Reijnders & G.M. Aarts (2015). Rapid recovery of Dutch gray seal colonies fueled by immigration. Marine Mammal Science 31:405-426.

Bruyne, R. de, S. van Leeuwen, A. Gmelig Meyling en R. Daan (2013). Schelpdieren van het Nederlandse Noordzeegebied. Ecologische atlas van de marine weekdieren (Mollusca). Stichting Anemoon Bennebroek en Tirion Natuur, Utrecht.

Burrows, M.T., Moore, P., Sugden, H., Fitzsimmons, C., Smeaton, C., Austin, W., Parker, R., Kröger, S., Powell, C., Gregory, L., Procter, W., Brook, T. (2021) Assessment of Carbon Capture and Storage in Natural Systems within the English North Sea (Including within Marine Protected Areas). A North Sea Wildlife Trusts, Blue Marine Foundation, WWF and RSPB commissioned report.

Neus Campanyà-Llovet, Paul V.R. Snelgrove, Christopher C. Parrish (2017), Rethinking the importance of food quality in marine benthic food webs, Progress in Oceanography, 156: 240-251. https://doi.org/10.1016/j.pocean.2017.07.006

CBS (2020) Economic description of the Dutch North Sea and coast: 2010, 2015, 2017. Den Haag/Heerlen. www.cbs.nl/en-gb/custom/2020/19/economic-description-of-the-dutch-north-sea-and-coast

CBS (2022). *Natuurlijk kapitaal en brede welvaart in Nederland*. https://www.cbs.nl/nl-nl/publicatie/2022/20/natuurlijk-kapitaal-en-brede-welvaart-in-nederland

Cornacchia, F. (2022), *Impacts on ecosystem services due to changes in the state of the environment in the North-East Atlantic Ocean*. Rijkswaterstaat, 97pp. https://open.rijkswaterstaat.nl/open-overheid/onderzoeksrapporten/@142922/impacts-on-ecosystem-services-due-to/ .

Culhane F, Teixeira H, Nogueira AJA, Borgwardt F, Trauner D, Lillebø A, et al. (2019) Risk to the supply of ecosystem services across aquatic ecosystems. Science of the Total Environment 660; ISSN: 0048-9697.

Cummins, S., Lauder, C., Lauder, A., and Tierney, D. (2019). The status of Ireland's breeding seabirds: Birds Directive article 12 reporting 2013-2018. Irish Wildlife Manuals 114.

Dammers, E., A. van Hinsberg, W. Wiersinga, P. van Egmond, J. Vader, D. Melman, W. van der Bilt & R. van Oostenbrugge (2013). *Natuurverkenning 2010–2040. Achtergrondrapport*. Den Haag: Planbureau voor de Leefomgeving, 500414010. ISBN : 978-94-91506-29-1, 188pp.

Dasgupta, P. (2021), The Economics of Biodiversity: The Dasgupta Review. (London: HM Treasury)

Deltares, 2018. Update Delfstoffen Informatie Systeem, DIS 2.1.

Denderen, P.D. van (2015). Ecosystem effects of bottom trawl fishing. Proefschrift Wageningen Universiteit, Wageningen.

Dierschke, V., R. W. Furness, S. Garthe (2016), Seabirds and offshore wind farms in European waters: Avoidance and attraction, *Biological Conservation, 202*, 59-68, https://doi.org/10.1016/j.biocon.2016.08.016.

Diesing, M., Kröger, S., Parker, R. et al. Predicting the standing stock of organic carbon in surface sediments of the North–West European continental shelf. Biogeochemistry 135, 183–200 (2017). https://doi.org/10.1007/s10533-017-0310-4 [*pdf available*]

DNB (De Nederlandsche Bank) and PBL (Environmental Assessment Agency) (2021). Biodiversiteit en de financiële sector: een kruisbestuiving?. https://www.pbl.nl/publicaties/financiele-sector-en-natuur-een-kruisbestuiving

Dulvy, N.K., Rogers, S.I., Jennings, S., Stelzenmüller, V., Dye, S.R. and Skjoldal, H.R. (2008), Climate change and deepening of the North Sea fish assemblage: a biotic indicator of warming seas. Journal of Applied Ecology, 45: 1029-1039. https://doi.org/10.1111/j.1365-2664.2008.01488.x

Duineveld, G., M. Bergman en M. Lavaleye (2007). Effects of an area closed to fisheries on the composition of the benthic fauna in the southern North Sea. ICES Journal of Marine Science 64: 899–908.

van Duren, L. A., F. Zijl, T. van Kessel, V. T. M. van Zeist, L. M. Vilmin, J. van der Meer, G. M. Aarts, J. van der Molen, K. Soetaert, A. W. Minns (2021), Ecosystem effects of large upscaling of offshore wind on the North Sea — Synthesis report. Technical report 11203731-004-ZKS-0010, Deltares, delft, 42pp.

Elliott, M., Burdon, D., Atkins, J. P., Borja, A., Cormier, R., De Jonge, V. N., & Turner, R. K. (2017). "And DPSIR begat DAPSI (W) R (M)!"—a unifying framework for marine environmental management. *Marine Pollution Bulletin*, *118*(1–2), 27-40.

Engelhard, G.H., J.R. Ellis, M.R. Payne, R. ter Hofstede en J.K. Pinnegar (2011). Ecotypes as a concept for exploring responses to climate change in fish assemblages. ICES Journal of Marine Science 68: 580-591.

Fivash, G. S., Stüben, D., Bachmann, M., Walles, B., van Belzen, J., Didderen, K., ... & Bouma, T. J. (2021). Can we enhance ecosystem-based coastal defense by connecting oysters to marsh edges? Analyzing the limits of oyster reef establishment. Ecological Engineering, 165, 106221.

Gerdes, E., R. R. Koning M. Kort, H. Soomers (2021), Beleidsevaluatie Zandmotor 2021. Rebel Economics and transactions, 38pp.

https://www.rijksoverheid.nl/documenten/rapporten/2021/07/19/bijlage-1-beleidsevaluatie-zandmotor-2021

Gregory, R.D., Van Strien, A., Vorisek, P., Meyling, A.W.G., Noble, D.G., Foppen, R.P., Gibbons, D.W., 2005. Developing indicators for European birds. Phil. Trans. R. Soc. B: Biol. Sci. 360, 269–288.

Groenewold, S. en M. Fonds (2000). Effects on benthic scavengers of discards and damaged benthos produced by the beam-trawl fishery in the southern North Sea. ICES Journal of Marine Science 57: 1395–1406.

de Groot, R. S., Wilson, M. A., and Boumans, R. M. (2002). A typology for the classification, description and valuation of ecosystem functions, goods and services. Ecological Economics, 41(3), 393-408.

de Haas, H., Boer, W., and van Weering, T.C.E., 1997. Recent sedimentation and organic carbon burial in a shelf sea: The North Sea. Marine Geology 144, 131–146. https://doi.org/10.1016/S0025-3227(97)00082-0 [*pdf available*]

Haines-Young, R., & Potschin, M. B. (2018). Common International Classification of Ecosystem Services (CICES) V5. 1 and guidance on the application of the revised structure. European Environment Agency (EEA).

van Hal, R., O. G. Bos & R. G. Jak (2011). *Noordzee: systeemdynamiek, klimaatverandering, natuurtypen en benthos; Achtergronddocument bij Natuurverkenning 2011*. Wageningen, Wettelijke Onderzoekstaken Natuur & Milieu, WOt-werkdocument 255. 108 pp.

Hanley, M. E., Hoggart, S. P. G., Simmonds, D. J., Bichot, A., Colangelo, M. A., Bozzeda, F., ... & Thompson, R. C. (2014). Shifting sands? Coastal protection by sand banks, beaches and dunes. Coastal Engineering, 87, 136-146.

Havinga, I., Bogaart, P. W., Hein, L., & Tuia, D. (2020). Defining and spatially modelling cultural ecosystem services using crowdsourced data. *Ecosystem Services*, 43, 101091. https://doi.org/10.1016/j.ecoser.2020.101091

Havinga, I., Marcos, D., Bogaart, P. W., Hein, L., & Tuia, D. (2021). Social media and deep learning capture the aesthetic quality of the landscape. Scientific reports, 11(1), 20000.

Havinga, I., Marcos, D., Bogaart, P., Massimino, D., Hein, L., & Tuia, D. (2023). Social media and deep learning reveal specific cultural preferences for biodiversity. People and Nature, 5(3), 981-998.

Heessen, H.J.L., Daan, N. en J.R. Ellis (2015). Fish atlas of the Celtic Sea, North Sea, and Baltic Sea. Wageningen Academic Publishers, Wageningen en KNNV Publishing, Zeist

Hiddink, J.G., S. Jennings en M.J. Kaiser (2006). Indicators of the Ecological Impact of Bottom-trawl Disturbance on Seabed Communities. Ecosystems 9: 1190-1199.

Hilgen, C. S. (2022). *The carbonate system on the long-term in the Dutch coastal zone: ocean acidification in reverse?* Utrecht University and NIOZ Koninklijk Nederlands Instituut voor Zeeonderzoek. Guided research paper.

Ter Hofstede, R., J.G. Hiddink en A.D. Rijnsdorp (2010). Regional warming changes fish species richness in the eastern North Atlantic Ocean. Marine Ecology Progress Series 414: 1-9.

Humphreys, M. P., L.J. de Nooijer, K.Bakker, S. Ossebaar, G.J. Reichart, 2021. Rapportage Monitoring Verzuring Noordzee 2021. NIOZ Koninklijk Nederlands Instituut voor Zeeonderzoek.

Huisman, B.J.A., J.W.M. Wijsman, S.M. Arens, C.T.M. Vertegaal, L. van der Valk, S.C. van Donk, H.S.I. Vreugdenhil and M.D. Taa (2021), Evaluatie van 10 jaar Zandmotor. Bevindingen uit het Monitoring- en Evaluatie Programma (MEP) voor de periode 2011 tot 2021.

ICES, 2017. ICES Special Request Advice sr.2017.13. https://www.ices.dk/sites/pub/Publication%20Reports/Advice/2017/Special_requests/eu.2017.13.pdf

D. Ieuan Jones, Tanja Miethe, Elizabeth D. Clarke, C. Tara Marshall (2023). Disentangling the effects of fishing and temperature to explain increasing fish species richness in the North Sea. Biodiversity and Conservation, 32:3133–3155.

Jones, D.I., Miethe, T., Clarke, E.D. et al. (2023), Disentangling the effects of fishing and temperature to explain increasing fish species richness in the North Sea, *Biodivers Conserv*, *32*, 3133–3155. https://doi.org/10.1007/s10531-023-02643-6

Jongbloed, R.H., J.E. Tamis, P. de Vries and G.J. Piet (2019). *NatuurVerkenning voor de Noordzee: Voorbeeld uitwerking van een Noordzee bijdrage aan de Natuurverkenningen*. WUR report rapport C055/19. Den Helder: Wageningen Marine Research, 84pp.

Judd, A., & Lonsdale, J. A. (2021). Applying systems thinking: The Ecosystem Approach and Natural Capital Approach–Convergent or divergent concepts in marine management?. Marine Policy, 129, 104517.

Kaiser, M.J., K. Ramsay, C.A. Richardson, F.E. Spence en A.R. Brand (2000). Chronic fishing disturbance has changed shelf sea benthic community structure. Journal of Animal Ecology 69: 494-503.

van Keeken O. A., M. van Hoppe, R. E. Grift and A. D. Rijnsdorp (2007) Changes in the spatial distribution of North Sea plaice (*Pleuronectes platessa*) and implications for fisheries. *Journal of Sea Research*, *57*, 187–197.

Kennerley, A., Lorenzoni, I., Luisetti, T. et al. (2021) Mapping habitats for the suitability of jellyfish blooms around the UK and Ireland. Hydrobiologia 848, 1535–1552. https://doi.org/10.1007/s10750-021-04539-4

Keith, D.A., Ferrer-Paris, J.R., Nicholson, E. et al. A function-based typology for Earth's ecosystems. *Nature, 610*, 513–518 (2022). https://doi.org/10.1038/s41586-022-05318-4

Korner-Nievergelt, F., N. Strebel, S. T. Buckland, R. Freeman, R. D. Gregory, J. Guélat, N. J. B, Isaac, L. Mc Rae, T. Roth, S. Schirner, L. L. Soldaat, P. Voříšek, T. Sattler (2022). Multi-species population indices for sets of species including rare, disappearing or newly occurring species. Ecological Indicators, 140, 109005.

Loveday, B. R., Smyth, T., Akpinar, A., Hull, T., Inall, M. E., Kaiser, J., Queste, B. Y., Tobermann, M., Williams, C. A. J., and Palmer, M. R.: Application of a new net primary production methodology: a daily to annual-scale data set for the North Sea, derived from autonomous underwater gliders and satellite Earth observation, Earth Syst. Sci. Data, 14, 3997–4016, https://doi.org/10.5194/essd-14-3997-2022, 2022.

Lindeboom, H., A. D. Rijnsdorp, R. Witbaard, D. Slijkerman, M. Kraan (2015). *Het ecologisch belang van het Friese Front. Wageningen*, IMARES Wageningen UR (University & Research centre), IMARES rapport C137/15A. 24 pp.

Ljungström G, Claireaux M, Fiksen Ø, Jørgensen C (2020) Body size adaptions under climate change: zooplankton community more important than temperature or food abundance in model of a zooplanktivorous fish. Mar Ecol Prog Ser 636:1-18. https://doi.org/10.3354/meps13241

Luisetti, T., Turner, R.K., Andrews, J.E., Jickells, T.D., Kröger, S., Diesing, M., Paltriguera, L., Johnson, M.T., Parker, E.R., Bakker, D.C.E. and Weston, K., 2019. Quantifying and valuing carbon flows and stores in coastal and shelf ecosystems in the UK. Ecosystem Services. 35, 67–76. https://doi.org/10.1016/j.ecoser.2018.10.013 [*pdf available*]

Lynam, C. P., Lilley, M. K. S., Bastian, T., Doyle, T. K., Beggs, S. E., & Hays, G. C. (2010). Have jellyfish in the irish sea benefited from climate change and overfishing?. Global Change Biology, 17(2), 767-782. https://doi.org/10.1111/j.1365-2486.2010.02352.x

Maes J, Egoh B, Willemen L, Liquete C, Vihervaara P, Schagner JP, et al. (2012) Mapping ecosystem services for policy support and decision making in the European Union. Ecosystem Services 2012; 1: 31-39.

Markandya, A., Mason, P., Perelet, R., & Taylor, T. (2001). A dictionary of environmental economics. Earthscan.

McConnell, V., and Walls, M. (2005). The Value of Open Space: Evidence from Studies of Non-market Benefits. Washington, DC: Resources for the Future.

McGovern, E., Schilder, J., Artioli, et al., (2022). *Ocean Acidification.* In: OSPAR, 2023: The 2023 Quality Status Report for the North-East Atlantic. OSPAR Commission, London. Available at: https://oap.ospar.org/en/ospar-assessments/quality-status-reports/qsr-2023/other-assessments/ocean-acidification

Morales-Caselles, C., Viejo, J., Martí, E. et al. An inshore–offshore sorting system revealed from global classification of ocean litter. *Nat Sustain 4*, 484–493 (2021). https://doi.org/10.1038/s41893-021-00720-8

Nadalini, A. C. V., Kalid, R. de A., & Torres, E. A. (2021). Emergy as a Tool to Evaluate Ecosystem Services: A Systematic Review of the Literature. *Sustainability*, *13*(13), 7102. https://doi.org/10.3390/su13137102

Noordzee loket, 2023. Surface mineral extraction https://www.noordzeeloket.nl/en/functions-and-use/artikel-baseline/

Norling, K., R. Rosenberg, S. Hulth, A. Grémare, E. Bonsdorff (2007), Importance of functional biodiversity and species-specific traits of benthic fauna for ecosystem functions in marine sediment. MEPS 332:11-23. doi:10.3354/meps332011

Odum, H. T. (1996). *Environmental accounting: emergy and environmental decision making*.

Ondiviela, B., Losada, I. J., Lara, J. L., Maza, M., Galván, C., Bouma, T. J., & van Belzen, J. (2014). The role of seagrasses in coastal protection in a changing climate. Coastal Engineering, 87, 158-168.

ONS (2016). UK natural capital: monetary estimates, 2016. Office of National Statistics.

ONS (2021). Marine accounts, natural capital, UK: 2021. Office of National Statistics.

van Oostenbrugge, R., P. van Egmond, E. Dammers, A. van Hinsberg, D. Melman, J. Vader, W. Wiersinga (2011), *Nature Outlook 2010–2040. Nature and landscape in 2040: Development visions*, The Hague: PBL Netherlands Environmental Assessment Agency

van Oostenbrugge, R., P. van Egmond, E. Dammers, A. van Hinsberg, D. Melman, J. Vader, W. Wiersinga (2012), *Natuurverkenning 2010-2040. Visies op de ontwikkeling van natuur en landschap*. Den Haag: Planbureau voor de Leefomgeving, 500414008, ISBN 978-90-78645-88-7, 140pp.

OSPAR (2013). *Development of a OSPAR common set biodiversity indicators.* 213pp.

OSPAR (2021). *Strategy of the OSPAR Commission for the Protection of the Marine Environment of the North-East Atlantic 2030 (Agreement 2021-01: North-East Atlantic Environment Strategy)*. OSPAR, 14pp. https://www.ospar.org/convention/strategy

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

Peck MA, Catalán IA, Damalas D, Elliott M, Ferreira JG, Hamon KG, Kamermans P, Kay S, Kreiß CM, Pinnegar JK, Sailley SF, Taylor NGH (2020) Climate Change and European Fisheries and Aquaculture: 'CERES' Project Synthesis Report. Hamburg. DOI: 10.25592/uhhfdm.804

PBL and CPB(2016). WLO-klimaatscenario's en de waardering van CO_2-uitstoot in MKBA's. CPB/PBL Achtergronddocument, 18pp.

PBL (2022). Eindadvies basisbedragen SDE++ 2022.

Piet GJ, Tamis JE, Volwater J, de Vries P, van der Wal JT, Jongbloed RH. (2021) A roadmap towards quantitative cumulative impact assessments: Every step of the way. The Science of the total environment 2021; 784: 146847.

Piet, G.J. Grundlehner, A., Jongbloed, R., Tamis,J. de Vries, P. (2023). SCAIRM: A spatial cumulative assessment of impact risk for management. Ecological Indicators 157. https://doi.org/10.1016/j.ecolind.2023.111157

Polet, H. en J. Depestele (2010). Impact assessment of the effects of a selected range of fishing gears in the North Sea. ILVO Technisch Visserij-onderzoek, Oostende.

Populus, J., Vasquez, M., Albrecht, J. et al. (2017). *EUSeaMap. A European broad-scale seabed habitat map*. https://doi.org/10.13155/49975

Provoost,P., S. van Heuven , K. Soetaert , R. W. P. M. Laane , and J. J. Middelburg. (2010). Seasonal and long-term changes in pH in the Dutch coastal zone. Biogeosciences, 7, 3869–3878.

van der Reijden KJ, Hintzen NT, Govers LL, Rijnsdorp AD, Olff H (2018) North Sea demersal fisheries prefer specific benthic habitats. PLoS ONE 13(12): e0208338. https://doi.org/10.1371/journal.pone.0208338

van der Reijden KJ, Koop L, O'Flynn S, Garcia S, Bos O, van Sluis C, Maaholm DJ, Herman PMJ, Simons DG, Olff H, Ysebaert T, Snellen M, Govers LL, Rijnsdorp AD, Aguilar R (2019): Discovery of *Sabellaria spinulosa* reefs in an intensively fished area of the Dutch Continental Shelf, North Sea. *Journal of Sea Research*, https://doi.org/10.1109/JOE.2018.2791878

Rijkswaterstaat (2009). Economische en milieukundige effecten van de zandwinstrategie. *Rapport Blueconomy,9014*.

Robins, J. R., , Ph. J. Bouchet, D. L. Miller, P. G.H. Evans, J. Waggitt, A. T. Ford, S. A. Marley (2022), Shipping in the north-east Atlantic: Identifying spatial and temporal patterns of change, *Marine Pollution Bulletin*, *179*, 113681. DOI: 10.1016/j.marpolbul.2022.113681 .

Roomen M. van, E.A.J. van Winden en C. A. M. van Turnhout (2017). Selectie van water- en zeevogelsoorten voor de Nederlandse Living Planet Index Zoute- en Zoete wateren. Sovon rapport 2017/35, Nijmegen

Rosen, S. (1974). Hedonic Prices and Implicit Markets: Product Differentiation in Pure Competition. Journal of Political Economy, 82 (1): 34–55.

de los Santos, C.B., Krause-Jensen, D., Alcoverro, T. et al. Recent trend reversal for declining European seagrass meadows. *Nat Commun* **10**, 3356 (2019). https://doi.org/10.1038/s41467-019-11340-4

Schenau, S., H. Rietveld and D. Bosch (2019). *Natural capital accounts for the North Sea: The physical SEEA EEA accounts. Final report.* Statistics Netherlands, 51pp,

Schweppe-Kraft, B. and B. Ekinci (2021) Ecosystem and Species Appreciation – Service Flow, Biodiversity Wealth and Biodiversity Debt. Discussion paper prepared for the 27th meeting of the London Group on Environmental Accounting. https://seea.un.org/events/london-group-environmental-accounting-27th-meeting

Searle, K. R., C. E. Regan, M. R. Perrow, A. Butler, A. Rindorf, M. P. Harris, M. A. Newell, S. Wanless, F. Daunt (2023), Effects of a fishery closure and prey abundance on seabird diet and breeding success: Implications for strategic fisheries management and seabird conservation, *Biological Conservation, 281*, 109990, https://doi.org/10.1016/j.biocon.2023.109990.

Soldaat, L. L., Pannekoek, J., Verweij, R. J., van Turnhout, C. A., & van Strien, A. J. (2017). A Monte Carlo method to account for sampling error in multi-species indicators. Ecological Indicators, 81, 340–347.

Spraos Romain, C. (2022), *Monetary valuation of biodiversity in the Dutch Part of the North Sea*, Unpublished MScThesis, Vrije Universieit Amsterdam, 66 pp.

Statistics Netherlands and WUR (2022), *Natural Capital Accounting in the Netherlands – Technical report.* Statistics Netherlands (CBS) and Wageningen University and Research (WUR)

van Strien, A.J., Soldaat, L.L., Gregory, R.D., 2012. Desirable mathematical properties of indicators for biodiversity change. Ecol. Indic. 14, 202–208.

Strietman, W.J., K.G. Hamon, A. Mol, 2019. *De economische effecten van twee toekomstscenario's voor de Noordzee; Een economische verkenning van de effecten van twee ruimtelijke scenario's voor de Noordzee, opgesteld door het Planbureau voor de Leefomgeving, op de Noordzee gebruiksfuncties tot en met 2050*. Wageningen, Wageningen Economic Research, Rapport 2019-080. 66 blz.

Teal, L.R., R. van Hal, T. van Kooten, P. Ruardij en A.D. Rijnsdorp (2012). Bio-energetics underpins the spatial response of North Sea plaice (*Pleuronectes platessa* L.) and sole (*Solea solea* L.) to climate change. *Global Change Biology 18*: 3291-3305.

Teal, L.R., J.J. de Leeuw, H.W. van der Veer en A.D. Rijnsdorp (2008). Effects of climate change on growth of 0-group sole and plaice. Marine Ecology Progress Series 358: 219-230.

Themistocleous, K., Papoutsa, C., Michaelides, S., & Hadjimitsis, D. (2020). Investigating detection of floating plastic litter from space using sentinel-2 imagery. Remote Sensing, 12(16), 2648

Thornton, A., Luisetti, T., Grilli, G., Donovan, D., Phillips, R. and Hawker, J., 2019. *Initial natural capital accounts for the UK marine and coastal environment. Final Report.* Report prepared for the Department for Environment Food and Rural Affairs

Tulp, I., R. van Hal, R. ter Hofstede en A. Rijnsdorp (2009). Klimaatverandering in de Noordzee: gevolgen voor vis. De Levende Natuur 110: 273-276.

United Nations, European Commission, International Monetary Fund, Organisation for Economic Co-operation and Development, & World Bank (2014). *System of Environmental-Economic Accounting 2012 — Central Framework.* New York: United Nations. https://seea.un.org/content/seea-central-framework

United Nations et al. (2021). *System of Environmental-Economic Accounting— Ecosystem Accounting (SEEA EA).* White cover publication, pre-edited text subject to official editing. Available at: https://seea.un.org/ecosystem-accounting.

Vanhellemont, Q. (2019). Adaptation of the dark spectrum fitting atmospheric correction for aquatic applications of the Landsat and Sentinel-2 archives. Remote Sensing of Environment, 225, 175-192.

Vasquez M., Manca E., Inghilesi R. et al. (2019). *EUSeaMap 2019, A European broad-scale seabed habitat map*, Technical Report, 77p.

van Veghel, W (2023), Potential applications of natural capital accounting in marine policies for the North Sea and North East Atlantic. Rijkswaterstaat Water Verkeer en Leefomgeving, 92pp.

Visser, H. (2004). Estimation and detection of flexible trends. *Atmospheric Environment*, *38*(25), 4135-4145.

Walker A. N., F. Prins, R. Mosterd, L. Linderhof, K. de Groot, A. J. Provoost, I. Bijlsma, 2023. *Economic description of the Dutch North Sea and coast: 2015, 2017, 2019 and 2021.* Statistics Netherlands, 60pp. https://www.cbs.nl/nl-nl/achtergrond/2023/26/de-economie-van-de-nederlandse-noordzee-en-kust

Watson, S. C., Paterson, D. M., Queirós, A. M., Rees, A. P., Stephens, N., Widdicombe, S., & Beaumont, N. J. (2016). A conceptual framework for assessing the ecosystem service of waste remediation: in the marine environment. *Ecosystem services*, *20*, 69–81. https://doi.org/10.1016/j.ecoser.2016.06.011 [*pdf available*]

WEcR (2018). The cost of degradation of the Dutch North Sea environment. A study into the costs of avoiding degradation and the applicability of the Ecosystem Services approach.

Wienhoven, M., H. Schutte, A. van Langevelde, E. van Ossenbruggen, S. Schep, M. Grutters (2021), Onderzoek naar de economische en sociale meerwaarde van de Zandmotor – Eindrapport. Ecorys, 75pp.

Wijnhoven, S. en O. Bos (2017). Benthische Indicator Soorten Index (BISI). Ontwikkelingsproces en beschrijving van de Nationale Benthos Indicator Noordzee inclusief protocol voor toepassing. Ecoauthor Report Series 2017 - 02, Heinkenszand & WMR, Wageningen

WWF (2022) Living Planet Report 2022 – Building a naturepositive society. Almond, R.E.A., Grooten, M., Juffe Bignoli, D. & Petersen, T. (Eds). WWF, Gland, Switzerland.

Zhu, Z., Vuik, V., Visser, P.J. et al. (2020), Historic storms and the hidden value of coastal wetlands for nature-based flood defence. Nat Sustain 3, 853–862. https://doi.org/10.1038/s41893-020-0556-z

Appendices

Additional figures and tables supplementing Chapters 4 (Condition) and 0 (Biodiversity).

Appendix A1. Acidification

Material in this section supplements Section 4.5.2

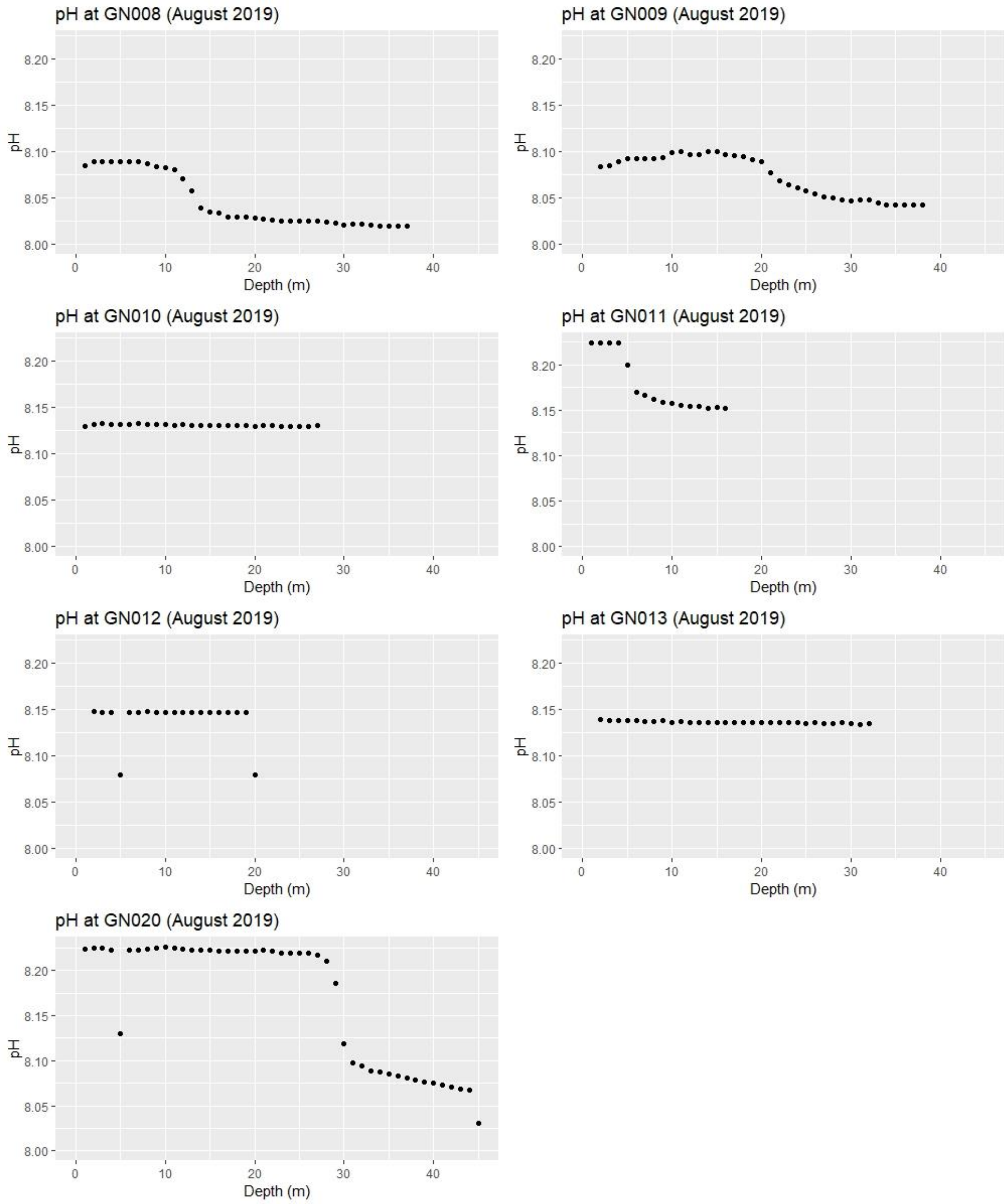

Figure 72. Depth profiles of pH for selected locations.

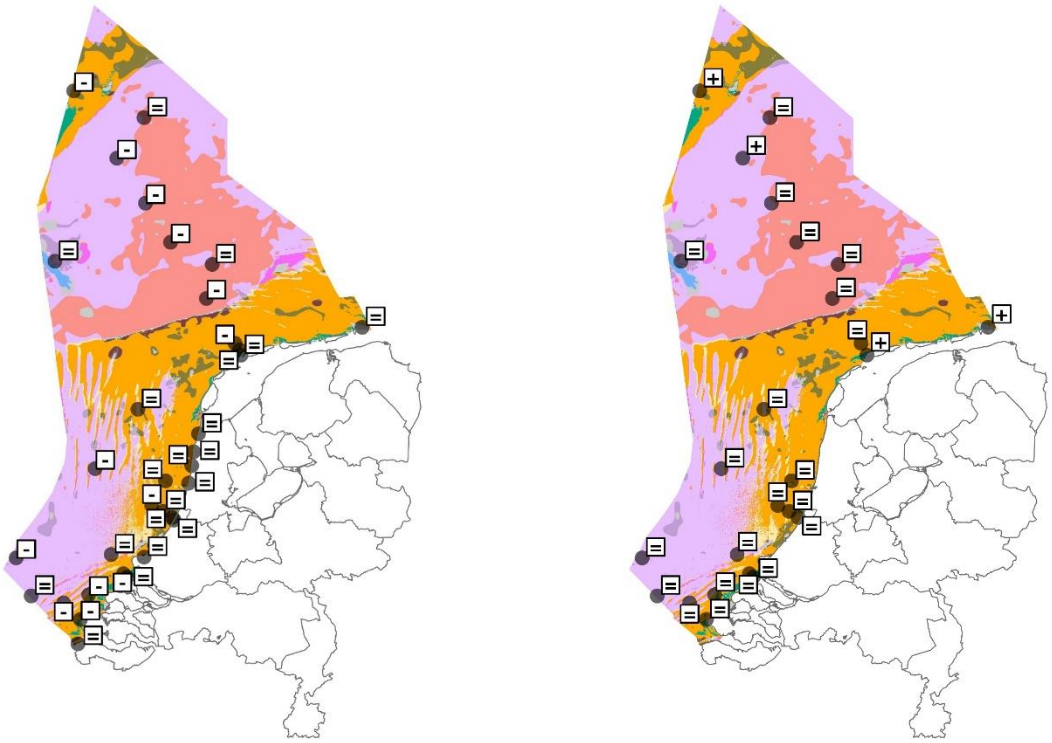

Figure 73. Significant changes in pH during the ten-year periods 2001–2010 (left) and 2001–2010 (right).

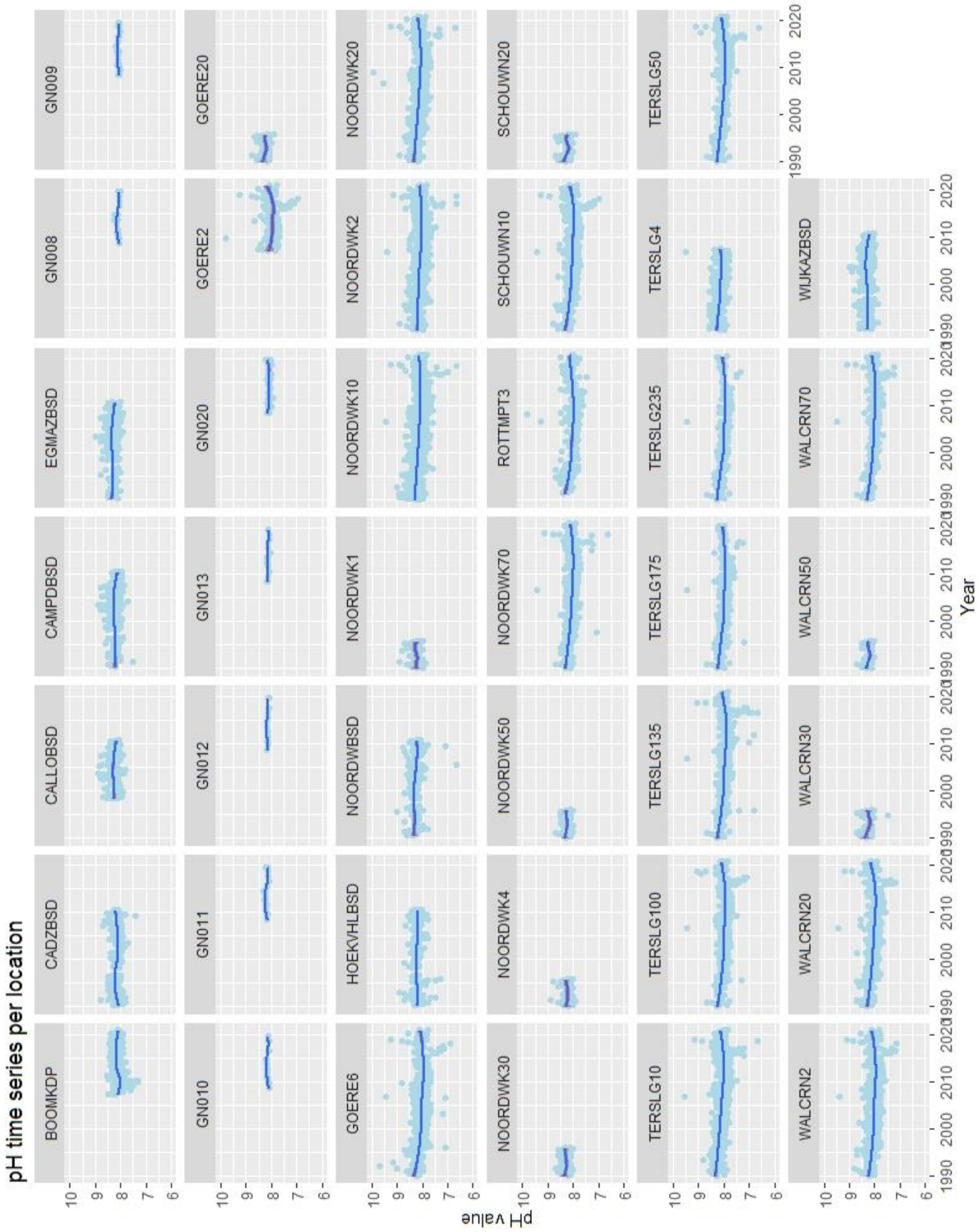

Figure 74. Time series of pH for all measurement locations that have at least 5 years of consecutive data.

Appendix A2. Sea water temperature

Material in this section supplements Section 4.5.3.

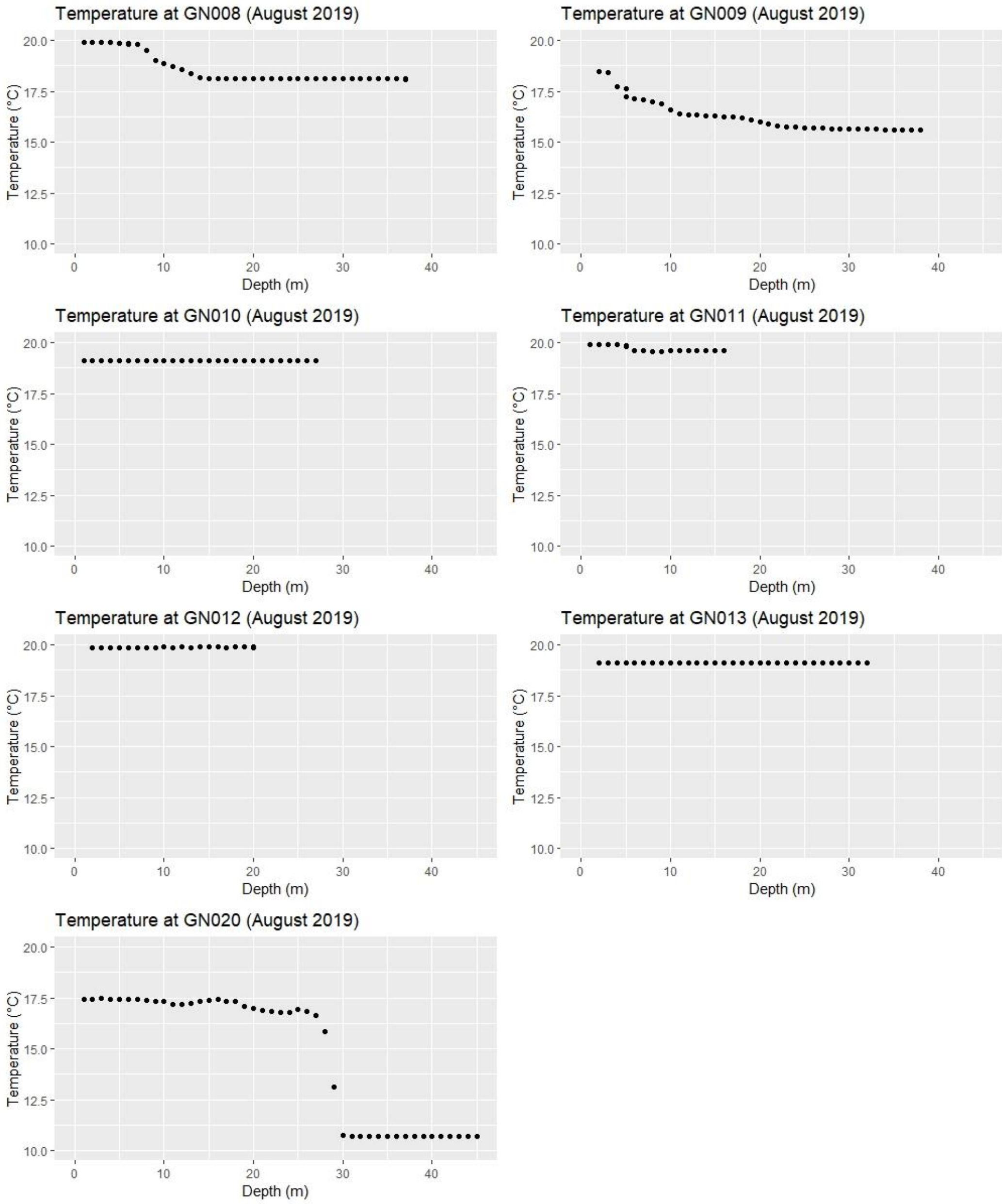

Figure 75. Depth profiles of sea water temperature.

Appendix A3. Salinity

Material in this section supplements Section 4.5.4.

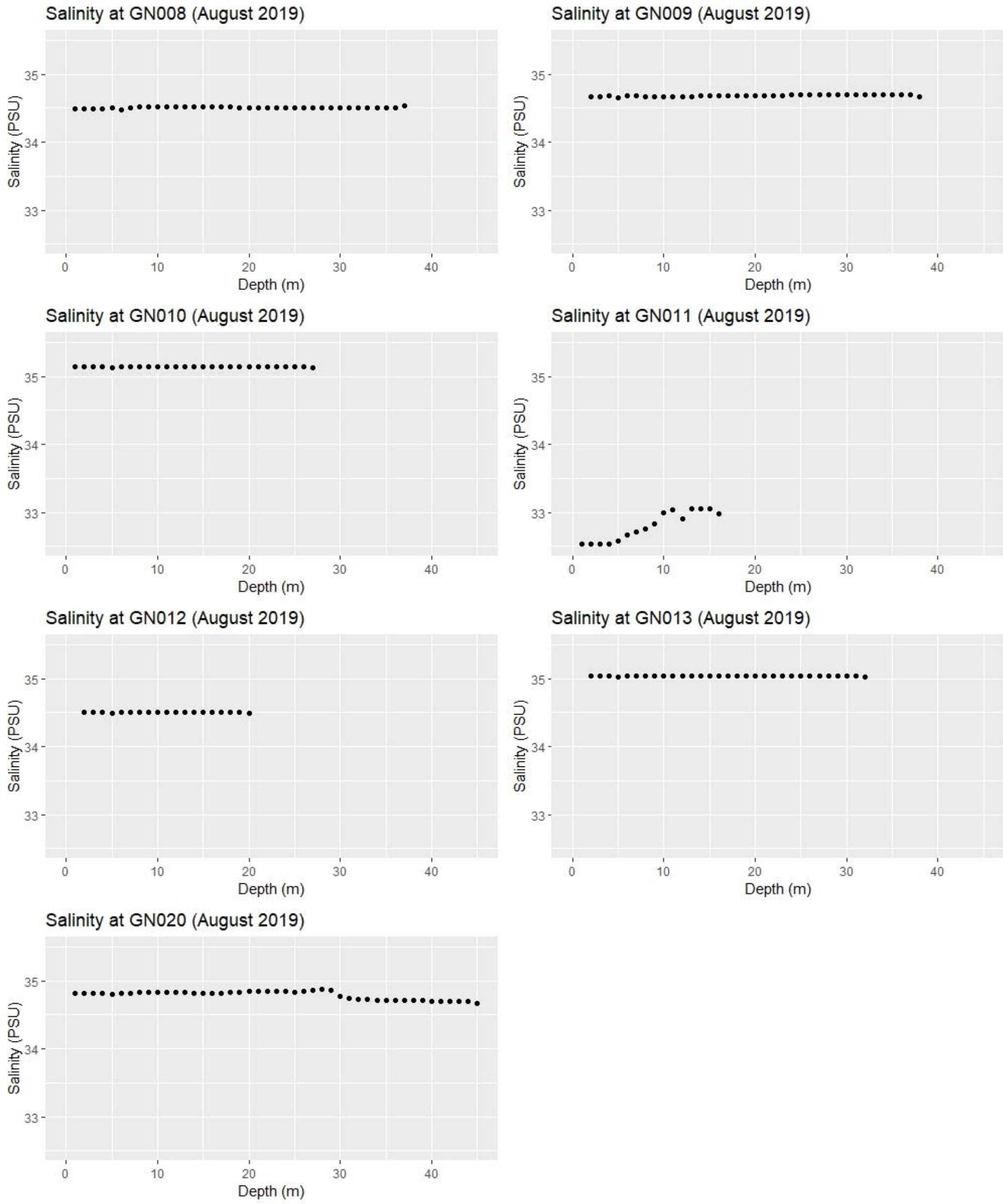

Figure 76. Depth profiles of sea water salinity.

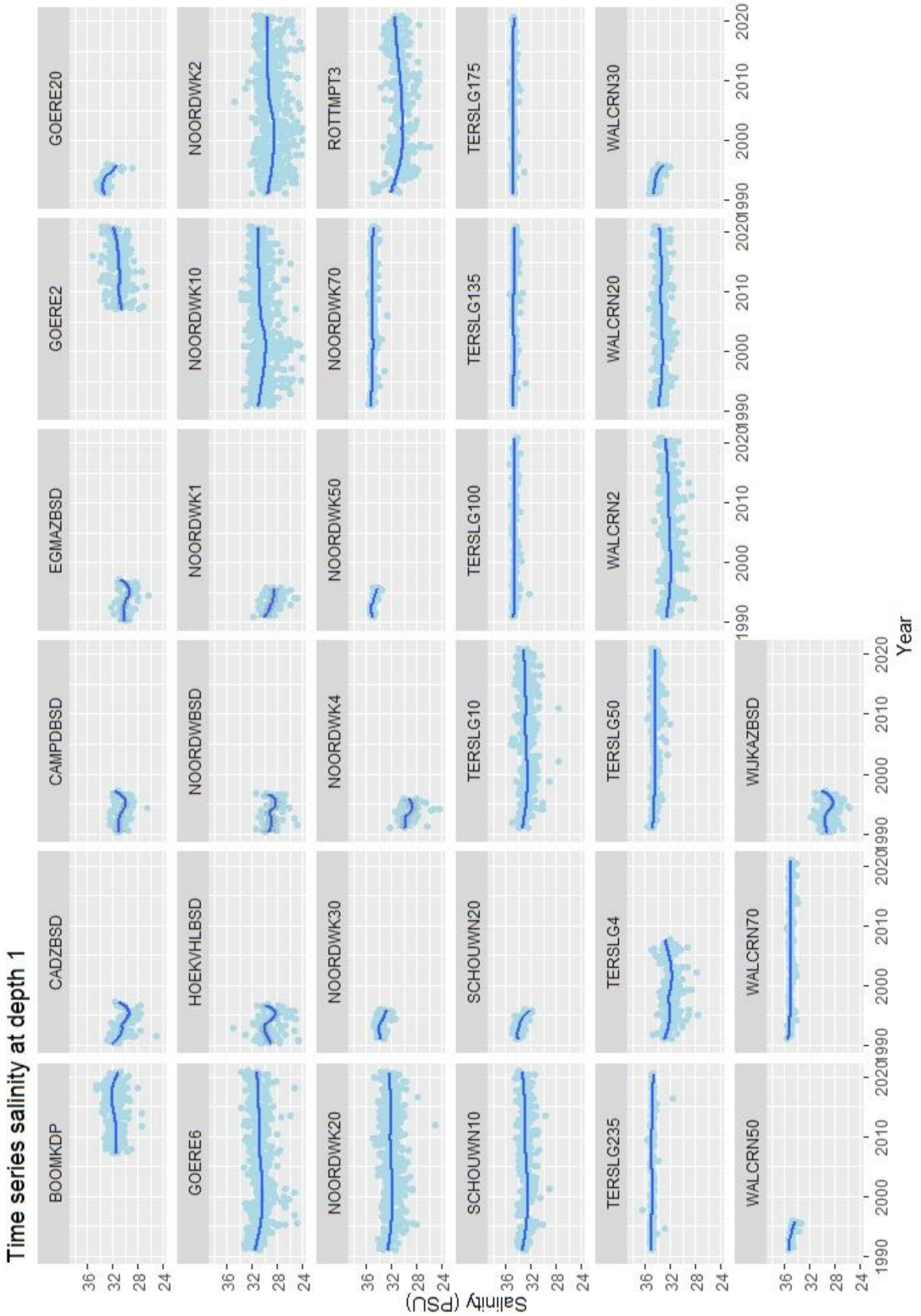

Figure 77. Salinity for all measurement stations with time series at depth 1.

Appendix B. Species selection

This appendix lists the species included in the various multi-species biodiversity indicators presented in Chapter 0.

Table 75. Benthic macrofauna species included in the multi-species biodiversity indicators.

Taxonomy (Phylum / Class / Order)	**Genus** (or group)	**Dutch name**	**Environment** Offshore	Coastal
Arthropoda		**Geleedpotigen**		
Crustacea		*Kreeftachtigen*		
	Callianassa	Molkreeft	x	
	Ione	Pissebedden	x	
	Pseudione	Pissebedden	x	
	Thia	Nagelkrab		x
	Upogebia		x	
	Cancer	Noordzeekrab		x
	Carcinus	Strandkrab		x
	Corystes	Helmkrab		x
	Diogenes	Kleine heremietkreeft		x
	Gastrosaccus	Aasgarnalen	x	
	Liocarcinus	Gewone - / Blauwpoot- / Gewimperde zwemkrab		x
	Macropodia	Hooiwagenkrab		x
	Necora	Fluwelen zwemkrab		x
	Pagarus	Gewone heremietkreeft		x
	Portumnus	Breedpootkrab		x
Amphipoda		*Vlokreeftjes*		
	Ampelisca		x	
	Argissa		x	
	Bathyporeia		x	x
	Caprellidae		x	
	Harpinia		x	
	Hippomedon		x	
	Leucothoe		x	
	Megaluropus			x
	Nototropis		x	x
	Perioculodes		x	
	Pontocrates		x	x
	Siphonoecetes		x	
	Synchelidium		x	
	Urothoe		x	x
Cumacea		*Zeekomma's*		
	Diastylis		x	x
	Eudorella		x	
	Eudorellopsis		x	
	Iphinoe		x	
	Pseudocuma		x	
Echinodermata		**Stekelhuidigen**		
	Acrocnida	Ingegraven slangster	x	
	Amphiuridae	Slangster	x	x
	Asterias	Gewone zeester		x
	Astropecten	Kamster		x
	Brissopsis	Zeeëgel	x	
	Echinocardium	Zeeklitten	x	x
	Echinocyamus	Zeeboontje	x	
	Leptosynapta	Zeekomkommer	x	
	Ophiothrix	Brokkelster		x
	Ophiura	Kleine / Gewone slangster	x	x

Table 75 (Continued)

Taxonomy (Phylum / Class / Order)	**Genus** (or group)	**Dutch name**	**Environment** Offshore	Coastal
Mollusca		**Weekdieren**		
Bivalvia		*Tweekleppigen*		
	Abra	Witte / Prismatische dunschaal	x	x
	Acanthocardia	Gedoornde hartschelp		x
	Altenaeum	Scheefbultschelpje	x	
	Barnea	Witte boormossel		x
	Cerastoderma	Kokkel		x
	Chamelea	Venusschelp	x	x
	Corbula	Korfschelp	x	
	Donax	Gewoon zaagje	x	x
	Dosinia	(Dichtgestreepte) artemisschelp	x	
	Ensis	Zwaardscheden	x	x
	Gari	Geplooide zonneschelp	x	
	Kurtiella	Tweetandschelp	x	x
	Lepton	Stippelschelp	x	
	Lucinoma	Noordse cirkelschelp	x	
	Lutraria	Gewone otterschelp		x
	Macoma	Gewoon nonnetje		x
	Macomangulus	Tere platschelp		x
	Mactra	Grote strandschelp		x
	Mya	Grote / Afgeknotte gaper		x
	Mysia	Zandschelp	x	
	Nucula	Ovale parelmoerneut	x	
	Phaxas	Sabelschede	x	
	Spisula	Halfgeknotte / Stevige / Elliptische / strandschelp	x	x
	Tellimya	Ovaal / dunschalig zeeklitschelpje	x	x
	Tellina	Rechtsgestreepte platschelp	x	x
	Thracia	Papierschelpen	x	
	Thyasira	Golfschelpje	x	
Gastropoda		*Slakken*		
	Cylichna	Valse oubliehoren	x	
	Eulima		x	
	Euspira	Gewone / Glanzende tepelhoren	x	x
	Hyala	Doorschijnend spiraalhoorntje	x	
	Nassarius	Grofgeribde / Gevlochten fuikhoorn		x
	Turritella	Penhoren	x	
Solenogastres		*Wormmollusken*		
	Solenogastres		x	
Cnidaria		**Neteldieren**		
Anthozoa		*Bloemdieren*		
	Anthozoa	Zeeanemonen	x	x
	Sagartia	Slibanemoon		x

Table 75 (Continued)

Taxonomy (Phylum / Class / Order)	Genus (or group)	Dutch name	Environment Offshore	 Coastal
Annelida (Segmented worms)		**Ringwormen**		
Polychaeta (Bristle worms)		*Borstelwormen*		
	Abyssoninoe		x	
	Amphictene		x	
	Aonides		x	
	Aricidea		x	
	Atherospio		x	
	Capitella			x
	Chaetopterus		x	
	Chaetozone		x	x
	Diplocirrus		x	
	Eteone			x
	Eunereis	Zeeduizendpoot	x	
	Gattyana		x	
	Glycera		x	
	Glycinde		x	
	Glyphohesione		x	
	Goniada		x	
	Harmothoe		x	x
	Hesionura		x	
	Lanice	Schelpkokerworm	x	x
	Levinsenia		x	
	Lumbrineris		x	
	Magelona	Zandkokerworm	x	x
	Malmgrenia		x	
	Nephtys	Gewone zandzager	x	x
	Notomastus		x	x
	Ophelia		x	
	Owenia		x	
	Oxydromus		x	
	Paraonis			x
	Pholoe		x	x
	Phoronida		x	x
	Phyllodoce	Gestippelde dieseltreinworm	x	
	Pisione		x	
	Podarkeopsis		x	
	Poecilochaetus		x	
	Prionospio		x	
	Scolelepis		x	x
	Scoloplos	Wapenworm	x	x
	Sigalion		x	x
	Sphaerosyllis		x	
	Spio	Oranje zandkokerworm	x	x
	Spiophanes	Noordelijke zandkokerworm	x	x
	Sthenelais		x	
	Streptodonta		x	
	Streptosyllis		x	
	Terebellides		x	
Sipuncula		*Pindawormen*		
	Golfingia	Pindawormen	x	
Oligochaeta				
	Oligochaeta			x
Hemichordata		**Kraagdragers**		
	Enteropneusta	Eikelwormen	x	
Platyhelminthes (Flatworms)		**Platwormen**		
	Platyhelminthes		x	

Table 76. Fish species included in the multi-species biodiversity indicators.

Species name			**Environment**		**Climate**
Scientific	English	Dutch	Offshore	Coastal	preference
Agonus cataphractus	Hooknose	Harnasmannetje	x	x	Cold
Amblyraja radiata	Thorny skate	Sterrog	x		Cold
Arnoglossus laterna	Scaldfish	Schurftvis	x	x	Warm
Buglossidium luteum	Solenette	Dwergtong	x	x	Warm
Callionymus lyra	Common dragonet	Pitvis	x		Warm
Callionymus sp	Dragonets	Pitvissen		x	
Chelidonichthys lucerna	Tub gurnard	Rode poon	x	x	Warm
Ciliata mustela	Five-bearded rockling	Vijfdradige meun		x	
Clupea harengus	Herring	Haring	x		Cold
Echiichthys vipera	Lesser weever	Kleine pieterman	x	x	Warm
Enchelyopus cimbrius	Four-bearded rockling	Vierdradige meun	x		Cold
Eutrigla gurnardus	Grey gurnard	Grauwe poon	x		Warm
Gadus morhua	Cod	Kabeljauw	x	x	Cold
Hippoglossoides platessoides	American plaice	Lange schar	x		Cold
Limanda limanda	Dab	Schar	x	x	Cold
Liparis liparis liparis	Sea-snail	Slakdolf		x	
Melanogrammus aeglefinus	Haddock	Schelvis	x		Cold
Merlangius merlangus	Whiting	Wijting	x	x	Warm
Microstomus kitt	Lemon sole	Tongschar	x	x	Cold
Mullus surmuletus	Striped red mullet	Mul	x	x	Warm
Myoxocephalus scorpius	Bull-rout	Zeedonderpad	x	x	Cold
Osmerus eperlanus	Smelt	Spiering		x	
Pholis gunnellus	Butterfish	Botervis		x	
Platichthys flesus	Flounder	Bot	x	x	Warm
Pleuronectes platessa	Plaice	Schol	x	x	Cold
Pomatoschistus sp	Gobies	Grondels		x	
Raja clavata	Thornback ray	Stekelrog	x		Warm
Raja montagui	Spotted ray	Gevlekte rog	x		Warm
Scomber scombrus	Mackerel	Makreel	x		
Scophthalmus maximus	Turbot	Tarbot		x	
Scophthalmus rhombus	Brill	Griet		x	
Scyliorhinus canicula	Lesser spotted dogfish	Hondshaai	x		Warm
Solea solea	Sole	Tong	x	x	Warm
Sprattus sprattus	Sprat	Sprot	x		Warm
Squalus acanthias	Spurdog	Doornhaai	x		Cold
Syngnathus sp	Pipefishes	Zeenaalden		x	
Trachurus trachurus	Horse mackerel	Horsmakreel	x	x	Warm
Trisopterus luscus	Pouting	Steenbolk	x	x	Warm
Trisopterus minutus	Poor cod	Dwergbolk	x	x	Warm

Table 77. Bird species included in the multi-species biodiversity indicators.

Species name			**Environment**	
Scientific	English	Dutch	Offshore	Coastal
Alle alle	Little auk	Kleine alk	x	
Ardenna grisea	Sooty shearwater	Grauwe pijlstormvogel	x	
Arenaria interpres	Ruddy turnstone	Steenloper		x
Calidris alba	Sanderling	Drieteenstrandloper		x
Charadriiformes	Auk / Guilemot	Alk/zeekoet	x	x
Chroicocephalus ridibundus	Black-headed gull	Kokmeeuw	x	x
Clangula hyemalis	Long-tailed duck	IJseend		x
Fratercula arctica	Atlantic puffin	Papegaaiduiker	x	
Fulmarus glacialis	Northern fulmar	Noordse stormvogel	x	
Gavia stellata / arctica	Red-throated / Black-throated loon	Ongedetermineerde duiker	x	x
Hydrobates leucorhous	Leach's storm-petrel	Vaal stormvogeltje	x	
Hydrocoloeus minutus	Little gull	Dwergmeeuw	x	x
Larus argentatus	European herring gull	Zilvermeeuw	x	x
Larus canus	Common gull	Stormmeeuw	x	x
Larus fuscus	Lesser black-backed gull	Kleine mantelmeeuw	x	x
Larus marinus	Great black-backed gull	Grote mantelmeeuw	x	x
Melanitta fusca	Velvet scoter	Grote zee-eend		x
Melanitta nigra	Common scoter	Zwarte zee-eend		x
Morus bassanus	Northern gannet	Jan-van-gent	x	x
Phalacrocorax carbo	Great cormorant	Aalscholver		x
Podiceps cristatus	Great crested grebe	Fuut		x
Puffinus puffinus	Manx shearwater	Noordse pijlstormvogel	x	
Rissa tridactyla	Black-legged kittiwake	Drieteenmeeuw	x	x
Stercorarius parasiticus	Arctic skua	Kleine jager		x
Stercorarius pomarinus	Pomarine skua	Middelste jager		x
Stercorarius skua	Great skua	Grote jager	x	
Sterna hirundo / paradisaea	Common / Arctic tern	Visdief/Noordse stern	x	x
Sternula albifrons	Little tern	Dwergstern		x
Thalasseus sandvicensis	Sandwich tern	Grote stern	x	x

Table 78. Mammal species included in the multi-species biodiversity indicators.

Species name			**Environment**	
Scientific	English	Dutch	Offshore	Coastal
Halichoerus grypus	Grey seal	Grijze zeehond		x
Phoca vitulina	Harbor seal	Gewone zeehond		x
Phocoena	Harbor porpoise	Bruinvis	x	x

Table 79. Jellyfish species included in the multi-species biodiversity indicators.

Species name			**Environment**	
Scientific	English	Dutch	Offshore	Coastal
Chrysaora hysoscella	Compass jellyfish	Kompaskwal	x	
Cyanea lamarckii	Bluefire jellyfish	Blauwe haarkwal	x	
Pleurobrachia pileus	Sea gooseberry	Zeedruif	x	
Rhizostoma pulmo	Barrel jellyfish	Zeepaddestoel	x	
Sepiida	Cuttlefish	Zeekat	x	