Review of cumulative impact assessments on North Sea basin level

Literature study and analysis

Greater North Sea Basin Initiative - Rijkswaterstaat Zee en Delta

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GLOSSARY

Abrasion: the physical interaction of human activities with seafloor habitats and with benthic fauna/flora, causing physical damage and/or mortality.

Driver: the social, demographic, and economic developments which influence the human activities that have a direct impact on the environment. Primary driving forces refer to technological and societal actors that motivate human activities and secondary driving forces refer to human activities.

Ecosystem component: an ecosystem component can be a living component (e.g. marine mammals) or a non-living component (e.g. benthic habitat) and together they can form an ecosystem.

Effect: the direct or indirect consequence or outcome of an intervention on the environment (see impact for example).

Extraction: extraction (and subsequent mortality) of any aquatic fauna (vertebrate or invertebrate) and/or flora (plants and algae) from their natural habitat, including incidental non-target catch.

Human activities: Human activities are the various actions for recreation, living, or necessity done by people. For instance, it includes leisure, manufacturing, recreation and fishing.

Impact: the influence of the intervention, human activity, pressure or changes in state on the ecosystem/population/individual. For example, the effects of pile-driving are, among others, disturbance of the sediment. This effect of pile-driving impacts benthic life.

Impact chain: the linear interaction between a sector, pressure, and ecological component.

Pressure: the mechanism through which an activity has an effect on any ecosystem component.

Response: actions taken to correct the problems of the previous stages (driver, pressure, state and impact), by adjusting the drivers, reducing the pressure on the system, bringing the system back to its initial state, and mitigating the impacts.

Sensitivity: the likelihood of change when a pressure is applied to an environmental component and is a function of the ability of the environmental component to adapt, tolerate or resist change and its ability to recover from the impact.

Species group: a group of closely related organisms that have similar features and / or ecological functionality. For example, demersal fish.

State: describes the physical, chemical and biological condition and dynamics of the environment or observable temporal changes in the system.

SUMMARY

Introduction and study objective

In the North Sea, anthropogenic activities – including wind energy development, fishing activities, coastal protection (i.e. sand suppletion), and maritime transport - are leading to an increasing use of space within the region. All human activities taking place in and around the North Sea contribute to pressures which, individually or cumulatively, have the potential to affect the state of species, habitats and associated ecosystem services. While knowledge about cumulative impacts is increasing, and in the last couple of decades multiple scientific studies have been conducted to this topic, methodology as well as outcomes of these studies vary. A comprehensive understanding of cumulative effects in the North Sea Basin is still lacking.

The aim of this study is to review existing Cumulative Impact Assessments (CIAs), to identify topics which require (urgent) attention on a Greater North Sea Basin level. The analysis in this study uses the DAPSIR (Drivers-Activities-Pressures-State-Impacts-Responses) framework to identify which ecosystem components are under the highest pressure in the Greater North Sea, and which human activities have the highest impact risk. In total six different CIA studies were identified to meet the selection criteria (I. describes a cumulative impact assessment, II. covers Greater North Sea Basin, III. recently published, and IV. publicly available in English). The CIAs within these studies differed in their level of detail. Therefore, not all studies could be included in the analysis of all DAPSIR framework components. The results of this review will serve as information (expert advice) for policymakers at a ministerial conference in November 2024.

Ecosystem components

The cumulative pressures from human activities affect marine ecosystems and biodiversity in the Greater North Sea Basin in significant and measurable ways. Hence, all ecosystem components (fish, marine mammals, birds, benthic habitats and pelagic habitats) are in a poor environmental state. Nonetheless, the majority of studies conclude that fish (and cephalopods) experience the highest pressure. Benthic habitats, specifically the deep-sea bed and sublittoral sediment were identified to be under the second highest pressure, followed by marine mammals, birds, and finally, the pelagic habitat.

Identified human activities

All studies that have included fishing activities in their cumulative impact assessment, found that fishing has the highest impact risk on almost all ecosystem components. The second and third most impactful activities were distinctly different between studies, so no clear top three of activities could be distinguished. Other important activities that were mentioned in studies were residential and commercial developments, agriculture and forestry, shipping, oil and gas industry, renewable energy generation, non-renewable energy generation, tourism, aquaculture and industrial developments. Moreover, climate change is considered as major threat, but one that cannot be derived from a single activity. Instead, it can be seen as a top-down pressure, whereas human activities are related to bottom-up pressures.

Identified pressures

Pressures from human activities are widespread across the European Sea and there is barely any area that is not affected by these pressures. Generally, coastal areas and the continental shelf are under higher pressure in comparison to offshore areas due to the influence of activities on land and at sea. Main pressures identified were extraction of flora and/ or fauna and abrasion/ damage, both strongly related to the human activity with the highest impact risk (i.e. fishing, specifically benthic trawling). Also, hazardous substances were found to exert a high pressure on the marine ecosystem.

Overall, the six CIAs reviewed in this study indicate that the ecosystem component under the highest pressure is fish, and that fishing is the human activity that causes the highest pressure; also, on most of the other ecosystem components.

1

INTRODUCTION

1.1 Context and objective

In the North Sea, spatial pressures are increasing due to developments in anthropogenic activities - including wind energy development, fishing activities, coastal protection (i.e. sand suppletion), maritime transport. These activities, driven by various interests and involving many different stakeholders and countries, are intertwined: actions taken within one sector can have both negative and positive impacts on other sectors, and on the overall ecological status of the North Sea. To optimise the use of the North Sea while protecting and improving the status of the marine ecosystem of the Greater North Sea Basin (GNSB), the Greater North Sea Basin Initiative (GNSBI) has been established (see text box).

Greater North Sea Basin Initiative
The North Sea countries (Belgium, France, Germany, Denmark, Norway, Ireland, Sweden, the United Kingdom, and the Netherlands) are working together for comprehensive and international alignment in the North Sea. The Greater North Sea Basin Initiative (GNSBI) has been established to optimise the use of the North Sea and meanwhile protect and improve the marine ecosystem of the Greater North Sea Basin (GNSB). This is achieved through proposing international alignment of marine spatial planning, implementing effective management processes, and coordinating sectoral interests across borders.

All human activities taking place in and around the North Sea contribute to pressures which, individually or cumulatively, have the potential to affect the state of species, habitats and associated ecosystem services (OSPAR, 2023a). While it is relatively straightforward to study the potential ecological impacts of a single activity within a local region, understanding the cumulative impacts of all these anthropogenic activities (combined with effects of climate change) on a sea basin level is more challenging.

In the recent decade, our understanding of cumulative impacts has been increasing and multiple scientific studies have been conducted on this topic. However, the methodology as well as the outcome of these studies vary. A comprehensive understanding of cumulative effects in the GNSB is still lacking. Questions that still remain are:
- Is there a consensus among different cumulative impact studies on which activities have the greatest impacts on the North Sea environment?
- Is there a consensus about which ecosystem components are under highest pressure?

This consensus can contribute to collaboration in the (spatial) management of the GNSB. This contributes to the goal of the GNSBI - optimise the use of the North Sea while protecting the marine environment.

1.2 Study objectives

The aim of this study is to review existing Cumulative Impact Assessments (CIAs) on a regional sea level, to identify topics which require (urgent) attention on a GNSB level. In this analysis we will explore which findings differ or overlap between CIAs. The analysis will serve as input to define which ecosystem components are under the highest risks of pressures in the North Sea and also which activity causes the highest impact risks.

The preliminary results have been presented in a GNSBI technical session (Hamburg, the 22nd of May 2024). The concept report has been presented representatives of the GNSBI countries. The discussion and written feedback has been integrated in this report. The final result will be used as input for the ministerial conference in November 2024.

Selected papers

For this project, cumulative impact studies were selected based on expert opinion by the GNSBI working track *Cumulative Impact Assessment*, with the aid of dr. R. Jongbloed from Wageningen Marine Research. This resulted in a list of 10 papers. All papers were required to meet the following criteria:

- It describes a cumulative impact assessment.
- Covers the entire GNSB or a larger area that includes the Greater North Sea (OSPAR area II) (including Irish Sea).
- Are recently published (last 4-6 years), and
- Are publicly available in English.

As a result, Witteveen+Bos in consultation with the GNSBI, selected a total of six papers:

- Kenny et al. (2018). Assessing cumulative human activities, pressures, and impacts on North Sea benthic habitats using a biological traits approach.
- Piet et al. (2023). A Cumulative Impact Assessment on the North Sea Capacity to Supply Ecosystem Services.
- Piet et al. (2021). Cumulative impacts of wind farms on the North Sea ecosystem (No. C081/21). Wageningen Marine Research.
- Jongbloed et al. (2023). Quick scan of cumulative impacts on the North Sea biodiversity: with a focus on selected species in relation to future developments in offshore wind energy.
- OSPAR, Quality Status Report (2023a). Including the thematic Assessments for Benthic Habitats, Fish, Pelagic Habitats, Marine Birds, Marine Mammals.
- European Environment Agency (2020). Multiple pressures and their combined effects in Europe's seas. Including the underlying technical report.

This study provides an overview of the above-mentioned papers, rather than a full review of all available knowledge on cumulative effects in the Greater North Sea Basin.

Reading guide

The report contains the following chapters:

- Chapter 2 contains the main results of the review:
    - Section 2.1 provides insight in the methodology of the analysis of each of the reviewed papers, including their scope and input data.
    - Section 2.2 contains a general overview of the main findings of all studies.
    - Section 2.3 details the overlap and difference of the outcome of the studies based on identified activities, identified pressures, identified state, identified impacts, and ecosystem components.
- Chapter 3 details the conclusions of the reviewed studies.
- Chapter 4 provides the full list of references.

2

LITERATURE STUDY

In this literature study, the cumulative impact studies have been assessed based on eight aspects, defined beforehand in collaboration with the GNSBI working track *Cumulative Impact Assessment*:

- Methodology components:
  - Specific geographic area.
  - Time horizon.
  - Assumption of the models.
- DAPSIR components (see paragraph 2.1):
  - Identified ecosystem components.
  - Identified activities (and associated drivers).
  - Identified pressures.
  - Identified state.
  - Identified impacts.

Below the selected studies are discussed and compared in more detail in line with these criteria.

2.1 Methodology analysis

Differences between the input and method of the CIAs can explain differences in their outcomes. A distinction is made between geographic area, for which the OSPAR regions were taken as basic premise, time horizon, applied models and analysis, and included activities in the analysis.

2.1.1 Geographic area

The study area of the CIAs differ. Where some of the studies focus on only the GNSB (OSPAR region II), other studies have also included the Celtic Sea (OSPAR region III) or studied the whole North-East Atlantic (OSPAR region I - V) (see Figure 2.1 for the location of the different regions). In Table 2.1 an overview of the study areas of the included studies is given.

Table 2.1 Study areas of cumulative impact studies

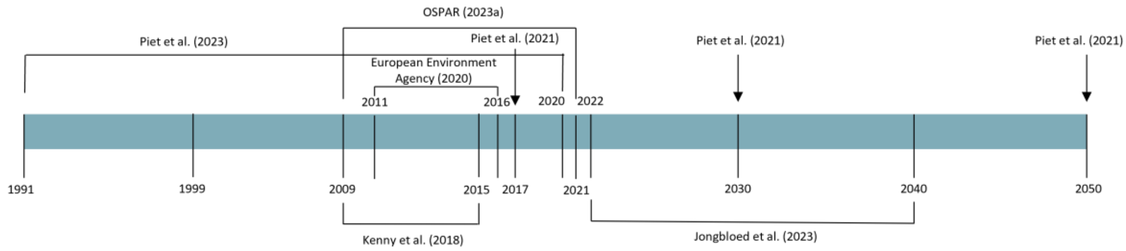
Paper	OSPAR region
Kenny et al. (2018)	II and part of III (Irish Sea, and parts of the Celtic Sea)
Piet et al. (2021)	II, excluding the most northern part (part of EEZ of Great Britain and Norway) and the Kattegat
Piet et al. (2023)	II
Jongbloed et al. (2023)	II
OSPAR (2023a)	North-East Atlantic (OSPAR regions I - V)
European Environment Agency (2020)	North-East Atlantic (OSPAR regions II, II, IV and part of I and V); Baltic Sea; Mediterranean Sea and Black Sea

Figure 2.1 The different OSPAR Regions (OSPAR, 2023a)

2.1.2 Time Horizon

The time component of the CIAs ranges between 1991 and future scenarios until 2050. Some studies included data from a time series, while others compared a baseline situation with future scenarios. In Figure 2.2, a timeline is given with the time periods that were considered in the selected studies.

Figure 2.2 Study timelines CIA's. Note that Piet et al. (2021) covers 3 moments in time, rather than a continuous time period



2.1.3 Applied models and analysis

In the table below, an overview is given of the applied models/methods and input data of the different studies. For a more detailed description of the models/methods applied in the selected paper we refer to Appendix I.

Table 2.2 Overview of the applied methods. Note that for OSPAR (2023a) all five regions have been studied, but results are in some cases also given per region. For this literature review, results of Regions II and III were considered. The same applies to the European Environmental Agency (2020) - when results were given per region only those of the North East Atlantic were included in this review

Studies	Method / model	Aim	Input data	Type of analysis	Including direct/indirect effects
Kenny et al. (2018)	- Integration of the pressure and corresponding habitat sensitivity data layers - Based on expert judgement	Provide a better understanding of the spatial extent of selected human activities and their impacts on seabed habitats using a biological trait-based sensitivity analysis.	ICES (2016); EMODnet; SEAPOP program; Waggit et al. (2020); ICES North Sea International Bottom Trawl Survey	- Biological trait-based sensitivity analysis - expert judgement	Not specified
Piet et al. (2021)	Based on peer-reviewed studies conducted in international collaborations, mainly Borgwardt et al. (2019) and Knights et al. (2015)	Evaluate for the North Sea marine ecosystem the knowledge base to assess the cumulative impacts of all the main human activities under various planning scenarios	EMODnet seabirds and habitats; WRM/ WindSpeed; KEC2; SCANS3 and AquaMaps; WWF representatives	Semi-quantitative	Only direct
Piet et al. (2023)	Linkage framework, Ecopath with Ecosim model and SCAIRM	Identifying the main threats acting on the natural environment and how these may impact the capacity to supply ecosystem services by conducting a CIA	North Sea CIA linkage framework, ICED 5.1, North Sea EwE model	Semi-quantitative	Only direct
Jongbloed et al. (2023)	SCAIRM	Perform a quick scan of the consequences of the future development of offshore wind energy in the North Sea in terms of the magnitude of the expected effects of offshore wind in itself as well as in relation to other human activities	CIA database Greater North Sea, RWS GIS data on OWF, KEC 4.0, OSPAR ORED list, EMODnet, SCANS-III, AquaMaps, species specific information from literature	Semi-quantitative	Only direct
OSPAR (2023a)	Adaptation of ODEMM pressure assessment	Assess the environmental status of the North East Atlantic against the objectives of the North East Atlantic Environmental Strategy 2010-2020; evaluate any updated or additional objectives from NEAES 2020-2030, and identify the priority elements for actions to achieve OSPAR's 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*	Guantitative OSPAR monitoring data and data and assessment products from 'third party' organisations managed through ODIMS	Modified bow-tie analysis	Both
European Environment Agency (2020)	Spatial assessment based on two types of spatial input layers: pressures and ecosystem components which are linked with sensitivity scores	(1) Mapping human activities, (2) describing their pressures in a spatial context, (3) mapping ecological elements, i.e. species and habitats, (4) describing their sensitivity to the set of pressures, and (5) combining the information to establish the connections needed to inform management	- Spatial data derived from European data sources such as the EEA, Eurostat, ICES, EU Joing Research Centre, RSCs, regional EU projects and EMODnet; - Sensitivity scores are based on the surveys that were filled in by 54 experts.	Analysis of the spatial distribution of human activities on land and at sea and of the pressures they cause	Both

2.1.4 Included activities

Each study included a different set of activities (see paragraph 2.2). Table 2.3 provides an overview of the included activities per study.

Table 2.3 Included activity input per study.

CIA	Activity input for CIA
Kenny et al. (2018)	Bottom fishing, dredging, sediment disposal, renewable energy, oil and gas
Piet et al. (2021)	In-situ aquaculture, telecom and electricity cables (what is included activity; laying or also the presence of cables)), fishing: benthic trawling, fishing: nets, fishing: pelagic trawls, mining, oil and gas (activity), sand extraction, shipping, wind farm development
Piet et al (2023)	106 human activities as described in the SCAIRM model CIA database
Jongbloed et al. (2023)	Fishing: benthic trawling, fishing: nets, fishing: pelagic trawls, aquaculture, mining, oil and gas, shipping, telecoms and electricity, wind farms, agriculture, angling and sport fishing, artificial reefs, beach replenishment, boating/yachting/water sports without engine, boating/yachting/water sports with engine, collecting, commercial cruise, culverting lagoons, dredging, ex-situ aquaculture, flood and coastal defence, forestry, hunting, land claim and conversion, manufacturing, marinas and dock/port facilities, military, non-renewable power stations, research, shore recreational activities, tidal sluices and barrages, tourist resort, transport (on land), urban dwellings and commercial developments, waste management, wave energy
OSPAR (2023a)	Fish and shellfish harvesting, fisheries, extraction of minerals, agriculture, aquaculture, oil and gas, renewable energy, shipping, tourism and leisure, aggregates extraction, hunting and collecting, military operations, water management, waste treatment and disposal
European Environment Agency (2020)	Extraction of minerals, extraction of salts, extraction of oil and gas, extraction of water, fish and shellfish harvesting, fish and shellfish processing, marine plant harvesting, hunting and collecting for other purposes, aquaculture, renewable energy generation, transmission of electricity and communications, transport infrastructure, restructuring of seabed morphology, transport - shipping, tourism and leisure infrastructure, tourism and leisure activities, military operations, research, survey and educational activities, land claim, canalisation and other watercourse modifications, coastal defence and flood, offshore structures and waste management

2.2 Study overview

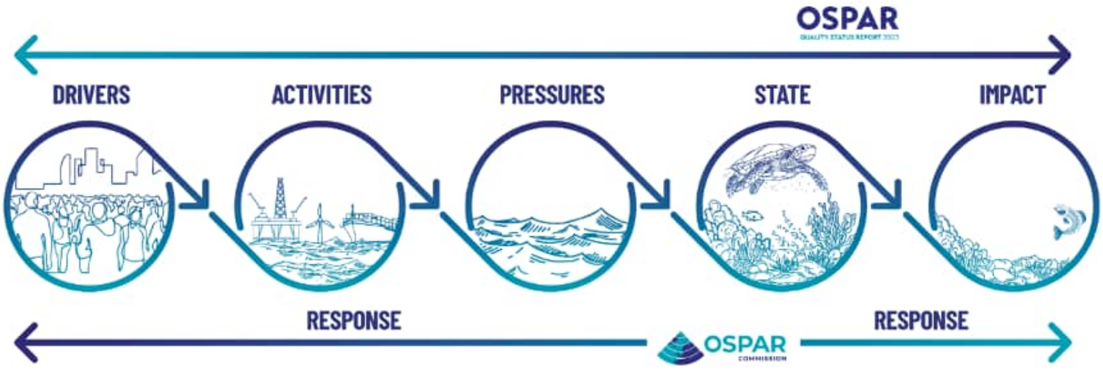
The selected papers are reviewed and compared using the DAPSIR framework (figure 2.3). This follows the methodology of OSPAR, as used for the 2023 Quality Assessment Report and the OSPAR Thematic Assessments. DAPSIR is a well-established framework used for ecosystem assessments. The framework requires an understanding and integration of the following components, as defined by OSPAR (2023a) (adapted from Patrício et al., 2017):

- **Drivers** of basic human needs (e.g. demand for food or energy), which require.
- Human **Activities** (e.g. fishing or oil extraction), which exert.
- **Pressures** (e.g. extraction of biomass or changes to the seabed), which have the potential to affect changes in **State** affecting ecosystem health, integrity and dynamics (e.g. unfavourable state of fish or bird populations), which can.
- **Impact** ecosystem goods and services (e.g. harvestable fish stock or conservation value), requiring
- Integrated management measures (**Response**) (e.g. lowering of fish quotas).

For more information on the DAPSIR framework, we refer to OSPAR (2023b).

The human activities exert pressures on the marine environment, which may lead to an altered state of the environment. This altered state results in various impacts on the marine ecosystem; and society may then implement responses to mitigate (or adapt to) these impacts or take measures to prevent adverse impacts. As part of the state, certain specific, affected, ecosystem components may be identified (species as well as habitats). For instance, fishing (activity) to provide food for society (driver) can lead to overfishing (pressure), resulting in depleted fish stocks (state), which impacts overall ecosystem health, but also fishery-dependent communities.

Figure 2.3 Example overview of DAPSIR framework used in the OSPAR QSR (2023)



From each paper, the most impactful activities and pressures, most affected ecosystem components or species groups, most affected states, and strongest impacts were identified. An overview can be found in Table 2.4. A more detailed description of these results is discussed in section 2.3.

Climate change

A complex aspect in the CIAs is climate change, as this often cannot be linked to one or more activities in the study area, exceeds a range of different pressures and the impact on the ecosystem is to a certain extend unknown. In OSPAR (2023a) climate change pressures have been identified as most important for pelagic habitats and marine birds. Similarly, the European Environment Agency (2020) recognises the threat of climate change and mentions that climate change-related impacts can further reduce the resilience of the marine ecosystem and increase the sensitivity to other pressures. They conclude that the most wide-spread pressures are related to climate change, but current knowledge is too scarce to conclude on the magnitude of climate change effects on the marine environment (European Environment Agency, 2020).

Climate change is multidimensional, and its effects stem from a wide range of human activities that cause an increase in greenhouse gas emissions on a global scale. Hence, addressing the issue of climate change is even more complex than addressing pressures from one activity, and the capacity of the GNSBI to make recommendations on how to deal with risks due to climate change is therefore limited. In this report, whenever climate change pressures were identified in an article as most important, we have listed the activity with the second highest impact instead. This approach allows us to identify the main threats other than climate change and to make conclusions on the GNSBI level.

Table 2.4 Overview of the drivers, human activities, pressures, ecosystem component, state and impacts identified as most impactful/ impacted/ relevant in the cumulative impact studies

Paper	Drivers	Activities	Pressures	Ecosystem component		State	Impacts
				Species group	Habitat		
Kenny et al. (2018)	Not specified	Bottom fishing	Physical (abrasion)	Benthic species	Benthic habitat	Biological traits	Not specified
Piet et al. (2021)	Not specified	Bottom trawl fisheries	Biological (extraction) and physical (abrasion/damage)	Fish and cephalopods	Seafloor habitat with its benthic community	Biological diversity	Not specified
Piet et al. (2023)	Not specified	Fishing	Biological (extraction)	Fish and cephalopods	Deep-sea bed **	Species abundance	Cultural ecosystem services
Jongbloed et al. (2023)	Not specified	Benthic trawling	Biological (extraction) and physical (abrasion/damage)	Fish and cephalopods	Deep-sea bed	Not specified	Not specified
OSPAR (2023a)	Society's need for food, materials, energy, global communications and trade	Fishing	physical (abrasion)	Fish and shellfish	Benthic habitats	Species abundance	Wildfish and other natural aquatic biomass and raw materials
	Society's need for food, energy, appreciation of nature and biodiversity, to mitigate effects of climate change, stable economies, trade and movement of goods, health and wellbeing	Fishing	Biological (extraction) and physical (abrasion)	Fish	N/a	Species abundance	Wildfish and other natural aquatic biomass and raw materials
	Growing global population and the demand this generates for food production, waste disposal, coastal development and energy systems	Agriculture	Biological (input of organic matter, change in nutrients)	Plankton	Pelagic habitats	Species abundance	Wildfish and other natural aquatic biomass and raw materials
	Society's need for stable economies, energy, materials, national security, industrial processes, trade and movement of goods, food and health and wellbeing	Fishing *	Biological (disturbance of species)	Marine birds	N/a	Foraging opportunities	Wildfish and other natural aquatic biomass and raw materials
	Society's need for stable economies, energy, materials,	Fishing	Biological (extraction)	Marine mammals	N/a	Foraging opportunities	Wildfish and other natural aquatic

Paper	Drivers	Activities	Pressures	Ecosystem component		State	Impacts
				Species group	Habitat		
	National security, industrial processes, trade and movement of goods, food and health and wellbeing						Biomass and raw materials
European Environmental Agency (2020) ***	Not specified	Demersal fishing	Hazardous substances, extraction of species and bycatch	Cetaceans, fish and seals	Benthic habitat (offshore circalittoral sand and bathyal seabed)	Biodiversity	Ecosystem resilience and sensitivity

* Climate change pressures was in the CIAs as most impactful, but due to the scope of this project only activities with a direct impact were taken into account and therefore mentioned here.

** This habitat can be found in the deeper waters like in the more northern regions of the North Sea and Celtic Sea.

*** Only the North-east Atlantic ocean were considered, not the other three regions that were also included in the analysis.

2.3 DAPSIR analysis

The DAPSIR analysis describes which ecosystem components are under most pressure and which human activities are related to this, for each of the studies. From there, the related pressures, states and impacts were identified. The level of detail differs between studies, and the scope of some studies is limited to certain activities. Therefore, in some parts of the analysis, certain studies could not be included. In Table 2.5 an overview is given of the included studies per component of the DAPSIR analysis.

Table 2.5 Studies included in the different DAPSIR components for this analysis. Blue (O) = on a generic level, green (✓) = on species, habitat type or ecosystem component level, and grey (X) = not included

	Ecosystem components	Drivers	Activities	Pressures	State	Impacts
Kenny et al. (2018)	Only related to benthic habitats	X	Only related to benthic habitats	Only related to benthic habitats	O	X
Piet et al. (2021)	O	X	O	X	O	X
Piet et al. (2023)	✓	X	✓	X	O	O
Jongbloed et al. (2023)	✓	X	✓	✓	X	X
OSPAR (2023a)	✓	✓	✓	✓	O	O
European Environmental Agency (2020)	Marine mammals and benthic habitats on species/ habitat type level. All other ecosystem component at group level	X	O	O	O	O

2.3.1 Ecosystem components

Ecosystem components
An ecosystem component can be a living component (e.g. marine mammals) or a non-living component (e.g. benthic habitat) and together they can form an ecosystem.

Per species group and habitat, where possible a top five was made of the species most affected by the cumulative activities in the GNSB, using results from all six studies included in this review.

OSPAR (2023a) found that the cumulative pressures from human activities affect marine ecosystems and biodiversity in the Greater North Sea in significant and measurable ways. Hence, all ecosystem components are in a poor environmental state and therefore require further attention (OSPAR, 2023a). Nonetheless, based on our review we found that there are differences in cumulative impact risk between ecosystem components. The ecosystem components, in order of highest perceived pressure, are:
- Fish and cephalopods.
- Benthic habitats.
- Marine mammals.
- Birds, and
- Pelagic habitats.

Piet et al. (2023) made a quantitative ranking, we can refer to for cumulative impact risks. This impact risk is defined as a 'relative change in equilibrium of each ecosystem component compared to an undisturbed situation' (caused by 106 human activities, through 28 pressures). Piet et al. (2023) determined this to be 98 % for fish, 68 % for marine mammals and 58 % for birds. The most threatened habitat is the deep sea with an impact risk of 88 %, followed by the sublittoral sediment (42 %) (Piet et al., 2023). Additionally, a distinction between species within a species group and habitat per habitat type can be made. An overview can be found in Table 2.6.

Table 2.6 Most affected species per species group and habitat per habitat type, based on OSPAR (2023a), Piet et al. (2021; 2023), Jongbloed et al. (2023) and European Environmental Agency (2020). *For marine mammals, no order has been established due to a lack of population data

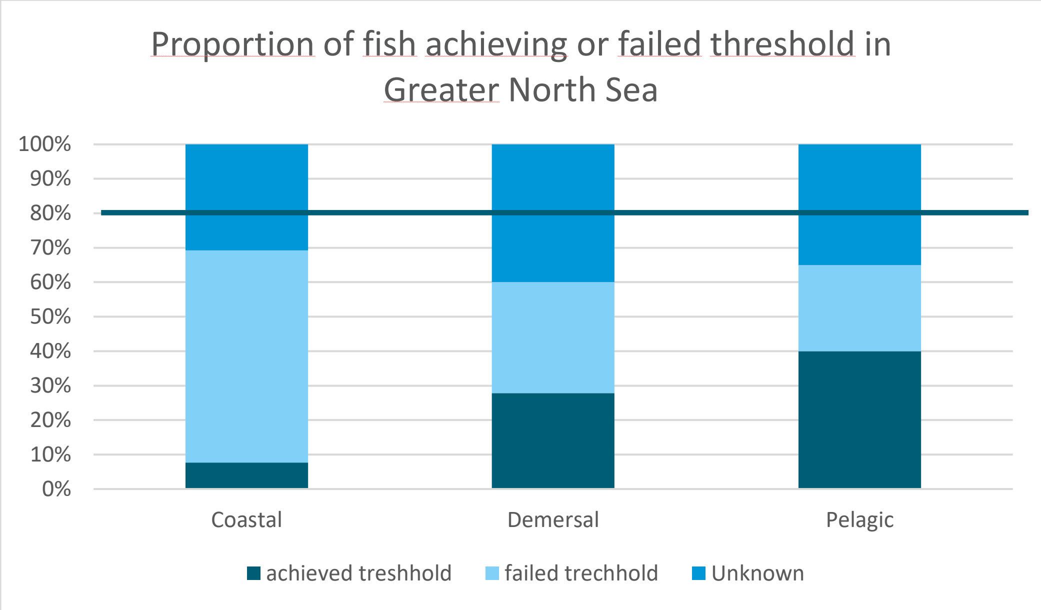
Fish (and cephalopods)[7]	Marine Mammals	Birds	Benthic habitats	Pelagic habitats
1. Coastal fish	* Harbour porpoise	1. Black-throated diver	1. Deep-sea bed	Not defined
2. Demersal fish	* Grey seal	2. Red-throated diver	2. Sublittoral sediment	
3. Pelagic fish	* Harbour seal	3. Common scoter	3. Infralittoral rock	
	* Common dolphin	4. Razorbill	4. Circalittoral rock	
	* Other cetaceans	5. Common guillemot	5. Littoral sediment	

Fish (and cephalopods)[1]

Three out of five studies, which included multiple ecosystem components, concluded that the species group of fish (and cephalopods) is currently under the highest pressure (Piet et al., 2023; Jongbloed et al., 2023; OSPAR 2023a). In the other two studies fish (and cephalopods) ranked second (Piet et al., 2021; European Environmental Agency, 2020). For example, OSPAR (2023a) analysed a total of 119 different fish species in the Greater North Sea Basin which have been grouped into coastal fish, demersal fish and pelagic fish. None of these groups have achieved the threshold for Good Environmental Status (defined as 80 % of populations being in good status), as can be seen in Figure 2.4 (see Appendix II for details). The European Environment Agency (2020) also recognizes that many flatfish and cod stocks are under heavy pressure, especially in the Southern North Sea, English Channel and Celtic Sea. Moreover, ~35 % of shark, ray and skate species are being threatened in the North-east Atlantic Ocean. However, they do mention that pelagic fish stocks are mainly in a healthy state, which contradicts with the findings of OSPAR (2023a) who found that only 40 % of the pelagic fish have a good environmental status. This is possible due to a difference in definition of a *healthy state* and a *good environmental status*. Where a *healthy state* indicates a reproductive capacity of >1.0 (European Environment Agency, 2020) and a *good environmental status* indicates that recovery is taking place or that harvesting takes place at levels of mortality which can produce maximum sustainable yield and at biomass levels capable of producing maximum sustainable yield (OSPAR, 2023a).

[1] There is a mismatch between OSPAR (2023a) and the other papers; in OSPAR the ecosystem component exist of only fish, while in the other papers also cephalopods are included.

Figure 2.4 Proportion of fish having achieved or failed the threshold for good environmental status (adapted form OSPAR, 2023a)



Marine mammals

One out of five studies found marine mammals to experience the highest cumulative impact risk (European Environmental Agency, 2020). In the other studies marine mammals were identified to be under higher pressure than birds but were often ranked after a specific habitat type (Piet et al., 2021, 2023; Jongbloed et al., 2023; European Environmental Agency, 2020). There are some nuanced differences between studies about which species within this group is under the greatest threat. According to Jongbloed et al. (2023) the grey seal and harbour porpoise receive a comparable impact risk, and both show an increase in impact risk for future scenarios. OSPAR (2023a) denotes the grey seal to be of slightly lower concern based on the current estimated population size of grey seals. The status of other marine mammal species is overall not good (harbour seal, common dolphin) or unknown for most dolphin species for OSPAR region II (OSPAR, 2023a). In contrast, the European Environmental Agency (2020) concludes that deep diving toothed cetaceans, closely followed by small, toothed cetaceans and baleen whales are under highest pressure in the North-east Atlantic Ocean. Possibly the broader study area causes this difference. Given the aforementioned uncertainties, we do not differentiate or rank which marine mammal species are most affected by human activities in the GNSB.

Birds

Birds were by all five studies identified to be under lesser pressure than fish (and cephalopods) and marine mammals (Piet et al. 2021, 2023; Jongbloed et al., 2023; OSPAR, 2023a; European Environmental Agency, 2020). According to OSPAR (2023a) the majority of surface feeders, water column feeders, benthic feeders and wading feeders are in poor status - meaning that less than 75 % of their populations were assessed as being in good status. Only grazing birds were identified to be in good status (OSPAR, 2023a). This group of birds typically forage on salt marshes adjacent to the shoreline. The dependency of grazing birds on offshore environments is therefore somewhat limited compared to other marine/ seabirds. Jongbloed et al. (2023) studied birds on a species level and identified the black-throated diver, red-throated diver, common scoter, razorbill and common guillemot as the top five most affected bird species in relation to all human activities in both 2022 and 2040 (Table 2.6). The five aforementioned species are also part of four species groups that were identified by OSPAR (2023a) to be in poor status.

Benthic habitats

The habitat of primary concern is the benthic habitat, which is overall in poor status (OSPAR, 2023a). According to the European Environmental Agency (2020) this is mostly in relation to habitat loss, as this also influences long-living marine mammals and seabirds (European Environment Agency, 2020), who rely on these habitats to feed, hide, rest or reproduce (OSPAR, 2023a).

Kenny et al. (2018), Jongbloed et al. (2023) and Piet et al. (2021; 2023) differentiated between different benthic habitat types. In Figure 2.2 a map with the different benthic habitat types is given as defined by Piet et al. (2021). Kenny et al., (2018), Jongbloed et al. (2023) and Piet et al. (2023) concluded that the deep-sea bed is under the highest pressure, more precisely deep-water coarse sediments (Kenny et al., 2018). Piet et al. (2021) concluded, however, that the sublittoral sediment the main seabed in the North Sea is under the highest pressure (Table 2.7). The sublittoral sediment was identified as second most affected benthic habitat by Jongbloed et al. (2023) and Piet et al. (2023). Kenny et al. (2018) found that the shallow-water coarse sediment is the second most affected habitat, which could be considered as a specific type of sublittoral sediment.

Figure 2.5 Seabed habitats in the North Sea, based on data from EMODnet (Piet et al., 2021)

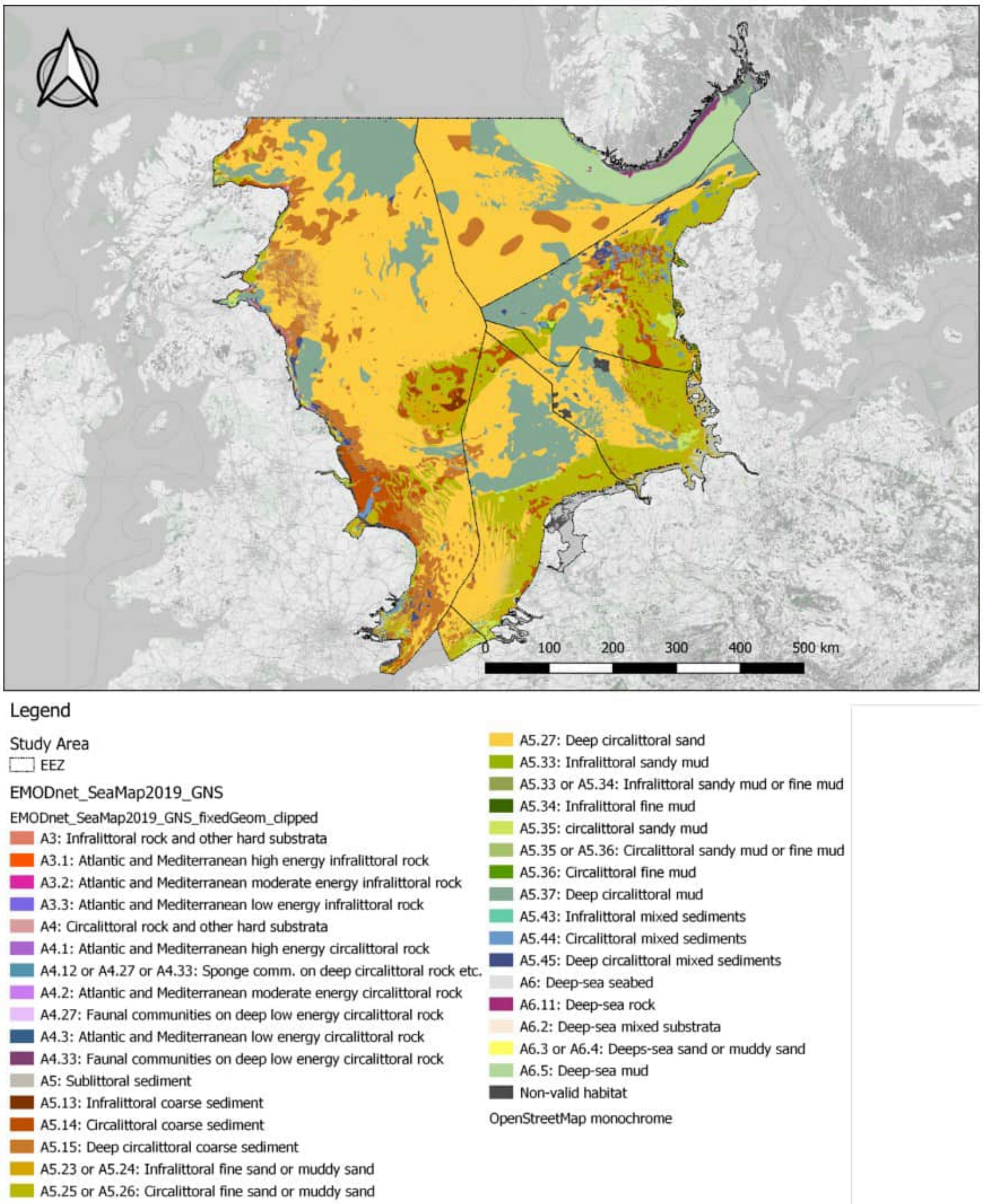


Table 2.7 Weighing and extent of benthic habitat types in the North Sea. Rock also included other hard substrata (Piet et al., 2023).

Benthic habitat	Weight (%)	Extent (km^2)
Deep-sea rock	0.1	427
Deep-sea sediment	5	23,021
Sublittoral sediment	93	406,202
Circalittoral rock	0.5	1,979
Infralittoral rock	0.07	298
Littoral rock	0.4	1,540
Littoral sediment	0.4	1,540

Pelagic habitats
Finally, the cumulative impact risk on pelagic habitats is relatively small compared to the other ecosystem components. Nonetheless, pelagic habitats (coastal and shelf) are in a poor environmental state in OSPAR region II and III (OSPAR, 2023a). It has not been defined which part of the pelagic system experiences the highest pressure.

2.3.2 Identified drivers

Driver
The social, demographic, and economic developments which influence the human activities that have a direct impact on the environment. Primary driving forces refer to technological and societal actors that motivate human activities and secondary driving forces refer to human activities.

According to OSPAR (2023a), all social and economic drivers (see standardised list of terms and definitions of DAPSIR elements in QSR (2023) for an overview) have the potential to influence the quality status of fish, marine mammals, birds, benthic habitats and pelagic habitats.

Fish
The growing needs of society in times of global change are impacting marine fish on many levels. As the global population expands, so does the demand for food. This has a direct impact on marine fish populations, which are targeted and exploited as a source of protein that has a lower carbon footprint than many terrestrial counterparts. Alongside these, the need for materials (for example, to support the demand for housing and utilities) directly impacts the marine habitats that many marine fish rely upon. The increasing demand for energy drives the use of the fossil fuels that contribute to climate change, or the development of infrastructure to exploit renewable energy (OSPAR, 2023a).

Marine mammals and birds
Society’s need for stable economies, energy and materials has been one of the main drivers for the extraction of materials and oil and gas production impacting marine mammals and birds. These activities have been linked to increases of impulsive noise, visual disturbance, barriers in water and air and releases of chemicals directly into marine habitats. Other important drivers impacting marine mammals and birds are society’s responses to mitigate and adapt to the effects of climate change (introduction of associated infrastructure; sea defences; levees and dikes), society’s needs for industrial processes and for trade and movements of goods (increases in underwater noise levels; input or remobilisation of contaminants; disturbance), food (input of contaminant and increased nutrient levels), health and wellbeing (OSPAR, 2023a).

Benthic habitats
Society's need for food (fish), materials, energy, global communications and trade drives human activities which, in turn, may exert physical and biological pressures on the seabed and its benthic habitat. The need for energy, health and wellbeing, materials and trade also drive various human activities which can input or spread chemical pollutants, non-indigenous species, heat, litter, and other pressures (OSPAR, 2023a).

Pelagic habitats
The growing global population and the demand this generates for food production, waste disposal, coastal development and energy systems are according to OSPAR (2023a) probably the most important drivers affecting pelagic habitats.

2.3.3 Identified human activities

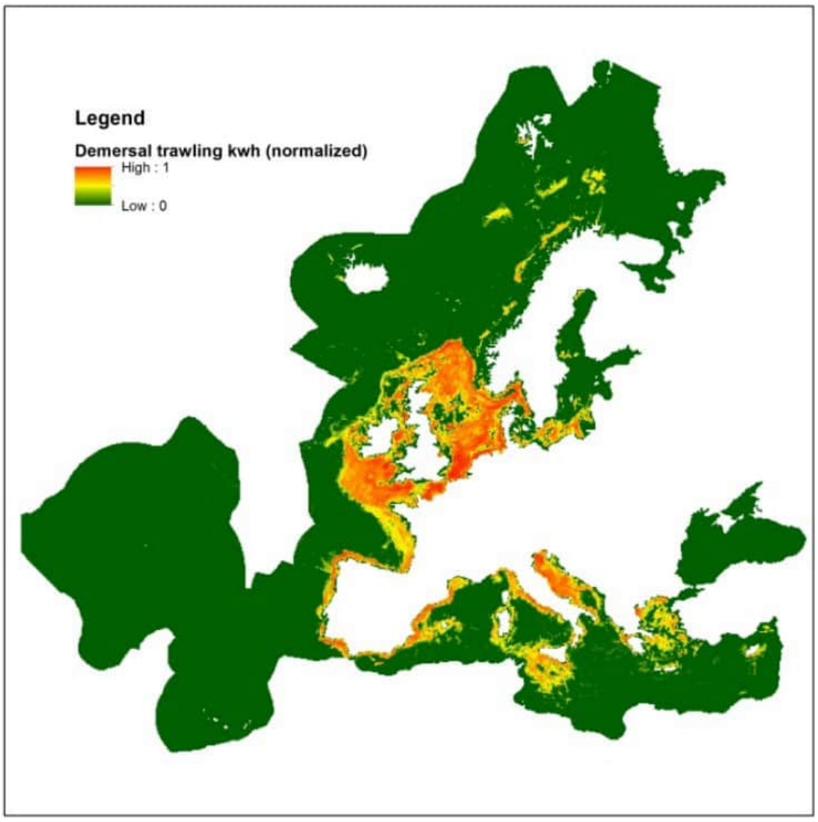
Human activity
Human activities are the various actions for recreation, living, or necessity done by people. For instance, it includes leisure, manufacturing, recreation and fishing.

In section 2.3.1, it was established which ecosystem components are under the highest pressure and which causes relate to those pressures. Here, we provide an overview of the human activities with the highest impact risk and associated drivers. This is followed by a list of key human activities per ecosystem component, based on the studies of Piet et al. (2023), Jongbloed et al. (2023) and OSPAR (2023a).

Human activity with highest impact risk
Fishing, specifically bottom trawling, was identified as the activity with the highest impact risk on ecosystem components (Piet et al., 2021; 2023; Jongbloed et al., 2023; OSPAR, 2023a; Kenny et al., 2018; European Environmental Agency, 2020). For example, bottom-trawling fisheries have reduced the stocks of large fish species by 90 - 96 % (European Environmental Agency, 2020), indicating the large impact of this activity on its target species. Additionally, fishing (1) can lead to seabed damage, (2) produces underwater noise and (3) causes bycatch and therefore also has an effect on non-target species, may this be other fish species or other species making use of the marine environment (e.g. marine mammals and seabirds) (European Environmental Agency, 2020).

In the quality status report of OSPAR (2023a) it is mentioned that bottom trawls are deployed over 73 % of the ICES ecoregion (OSPAR Region II except the English Channel) in 2018, making bottom trawling the spatially widest disturbance activity (f) (European Environmental Agency, 2020). Moreover, fishing has increased since QSR 2010 (OSPAR, 2023a). Areas of highest effort in the North Sea are Skagerrak, Shetland and the southern North Sea (European Environmental Agency, 2020). According to Jongbloed et al. (2023) and Piet et al. (2021) the impact risk of benthic fisheries is expected to decrease in the future. However, it is expected to remain the main cause of impact risk.

Figure 2.6 Bottom trawling areas in European seas (European Environmental Agency, 2020)



Aside from fishing, main activities with a negative impact on the North Sea ecosystem are aquaculture, shipping, oil- and gas production, mining, coastal infrastructure, various land-based activities (mostly agriculture), renewable energy (mostly offshore wind developments) and tourism/recreation (Piet et al., 2021; 2023; OSPAR, 2023a; Jongbloed et al., 2023). Moreover, as mentioned in section 2.1, climate change is in multiple studies considered as a major negative impact.

Studies that included multiple human activities, found that compared to other activities, the potential negative impact of offshore wind is relatively small (Piet et al., 2021; Jongbloed et al., 2023; OSPAR, 2023a). More specifically, Jongbloed et al. (2023) found that compared to other activities, effects of offshore wind farms contributes ~1 % to the total impact risk (unweighted average for all ecosystem components), which increases marginally in future scenarios. However, it should be noted that offshore wind may have significant local impacts that do not show up at a North Sea scale CIA (Piet et al., 2021) - other activities, such as fishing, take place on a much broader scale and therefore impacts are possibly more notable.

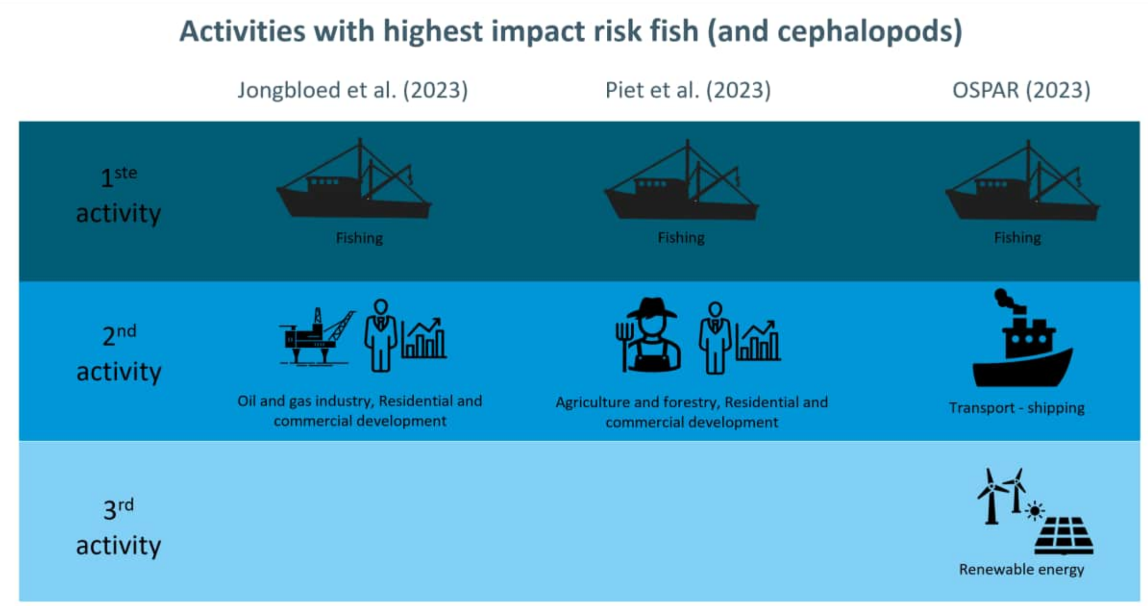
Fish (and cephalopods)

Piet et al. (2023), Jongbloed et al. (2023) and OSPAR (2023a) all identified fishing to be the most impactful activity for fish and cephalopods (figure 2.7). In all three assessments, fishing contributed at least 25 % to the total cumulative impact risk and was thereby clearly the activity with highest impact risk. While regulations from the EU Common Fisheries Policy and the North-east Atlantic Fisheries Commission have limited the harvesting of commercial fish stocks to sustainable levels, many stocks are still being harvested unsustainably, threatening fish populations (OSPAR, 2023a).

The second most impactful activity differed between studies. Piet et al. (2023) found that agriculture and forestry and residential and commercial development had a more or less even impact risk. The impact risk of both activities, however, was quite small compared to fishing (factor ~10 smaller). Jongbloed et al. (2023) identified oil and gas industry and residential and commercial development as both the second most impactful activities. From there, a multitude of activities represent the remaining ~70 % of the impact on fish, where each activity represents less than 2 % of the impact. Impact risk of each of these activities is relatively marginal, compared to the 25 % impact risk of the fishing industry. As for Jongbloed et al. (2023) and Piet et al. (2023) already two activities were identified as second most impactful, no activity was considered ranking third. OSPAR (2023a), in contrast found shipping to be the activity with the second highest impact risk closely followed by renewable energy generation as a third activity. Most likely, these differences are caused by different activities categorisation and selections that were considered in the different studies (see section 2.1.4). For example, Piet et al. (2023) did not include shipping.

The impact risk on fish is predicted to decrease in the future, with 1.7 % in 2030 and 3.7 % in 2040 compared to 2022. This is mainly related to a decrease in benthic trawling expected for future scenarios (Jongbloed et al., 2023). This is in line with the findings of Piet et al. (2021), who also found that the impact risk for fish is expected to decrease in future scenario's (in 2030 and 2050). However, according to Jongbloed et al. (2023) fish (and cephalopods) still remains under the highest pressure by fishing in the future.

Figure 2.7 Current top activities with highest impact risk on fish (and cephalopods)

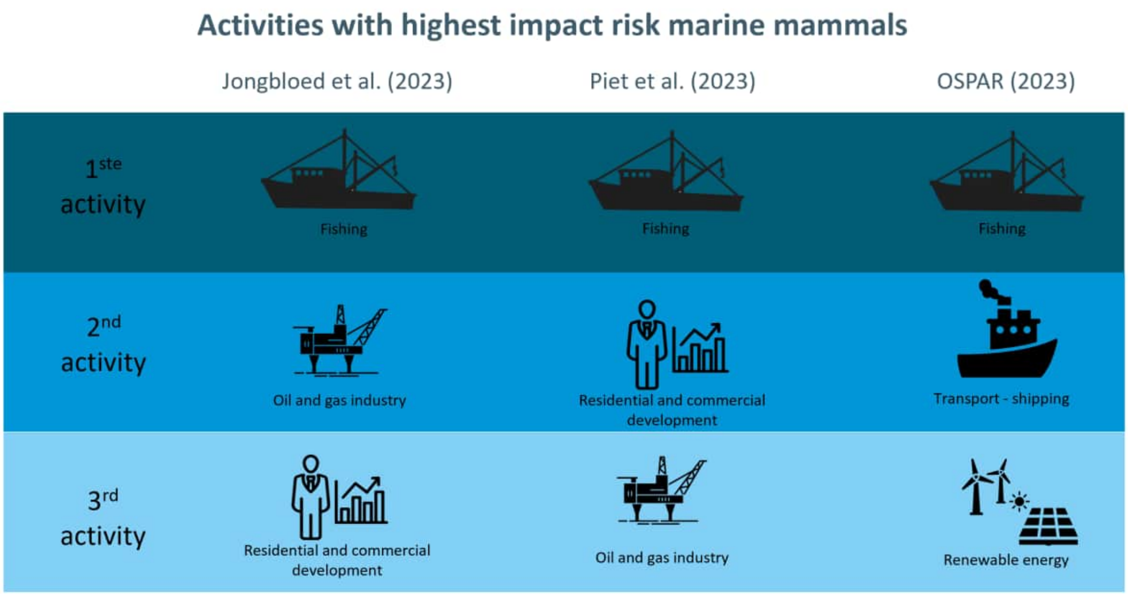


Marine mammals

Similarly, for marine mammals, fishing was by all three papers identified as activity with the highest impact risk (Figure 2.8). The impact risk of fishing is 1.5 - 2 times as high (ranging from ~ 10-20 %) compared to the second most impactful activities, depending on the selected study. There was no consensus on the second and third activity. Piet et al. (2023) identified residential and commercial development as second most impactful activity (~ 7-8 % of cumulative impact risk), closely followed by oil and gas industry (i.e. non- renewable energy) (~ 6 %). Moreover, agriculture and forestry and tourism/recreation and non- commercial harvesting (both ~ 5 %) were the fourth and fifth activity with highest impact, respectively (Piet et al. 2023). In contrast, Jongbloed et al. (2023) identified oil and gas industry as second activity (~ 6 % of cumulative impact risk) and residential and commercial development as activity with the third highest impact risk (~ 4 %). OSPAR (2023a) found shipping to be the second most impactful activity followed by renewable energy generation.

Jongbloed et al. (2023) predict that the cumulative impact risk on marine mammals will slightly decrease in the future, with 0.3 % in 2030 and 0.4 % in 2040 compared to 2022. This is mainly caused by the decrease in fishing as well as oil and gas winning expected for the future scenarios (Jongbloed et al., 2023). In contrast, Piet et al. (2021) predict that the impact risk on marine mammals will slightly increase by 2050. This is mostly in relation to offshore wind energy developments (Piet et al., 2021). However, the order of activities causing the highest impact risk on marine mammals will not change in the future.

Figure 2.8 Current top activities with highest impact risk on marine mammals

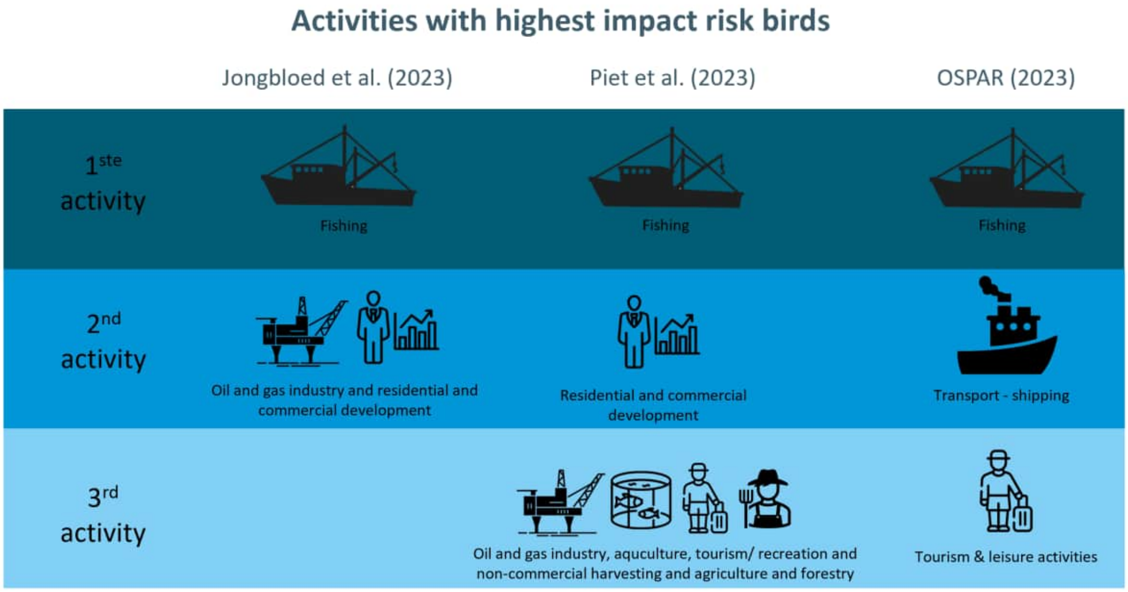


Birds

Fishing is again by all three papers identified as activity with the highest cumulative impact risk. Also, for birds the impact risk of fishing is about 1.5-3.5 times as high (ranging from ~ 12-15 %) compared to the second most impactful activities, depending on the selected study. Jongbloed et al. (2023) found that oil and gas industry and residential and commercial development have more or less an even impact potential on birds, of ~ 4-5 %. Piet et al. (2023) identified commercial development to be the second most impactful activity, also with a cumulative impact risk of ~ 4-5 %. The cumulative impact risk of (1) oil and gas industry, (2) aquaculture, (3) tourism/ recreation and non-commercial harvesting and (4) agriculture and forestry are more or less even and therefore no distinction was made between these activities. Hence, all four activities are considered to be the third activity with highest impact. OSPAR (2023a) clearly found that transport (shipping) to be the activity with the second highest impact risk and tourism and leisure activities the activity with the third highest impact risk.

However, Jongbloed et al. (2023) predicts a change in the impact risk of the main human activities for birds. In the period of 2023-2030, the activities with the highest impact risk are (1) fishing, (2) residential and commercial development, and (3) oil and gas industry. This changes in the future scenario of 2031-2040. While fishing remains the activity with the highest impact risk, it is now followed by offshore wind as the activity with the second strongest impact risk, while residential and commercial development is the third. The oil and gas industry is in this period no longer in the top three. Moreover, the cumulative impact risk for birds is expected to increase with 0.4 % in 2030 and 2.9 % in 2040, both compared to the scenario in 2022 (Jongbloed et al., 2023). Hence, for future scenario's the impact risk on birds is increasing.

Figure 2.9 Current top activities with highest impact risk on birds

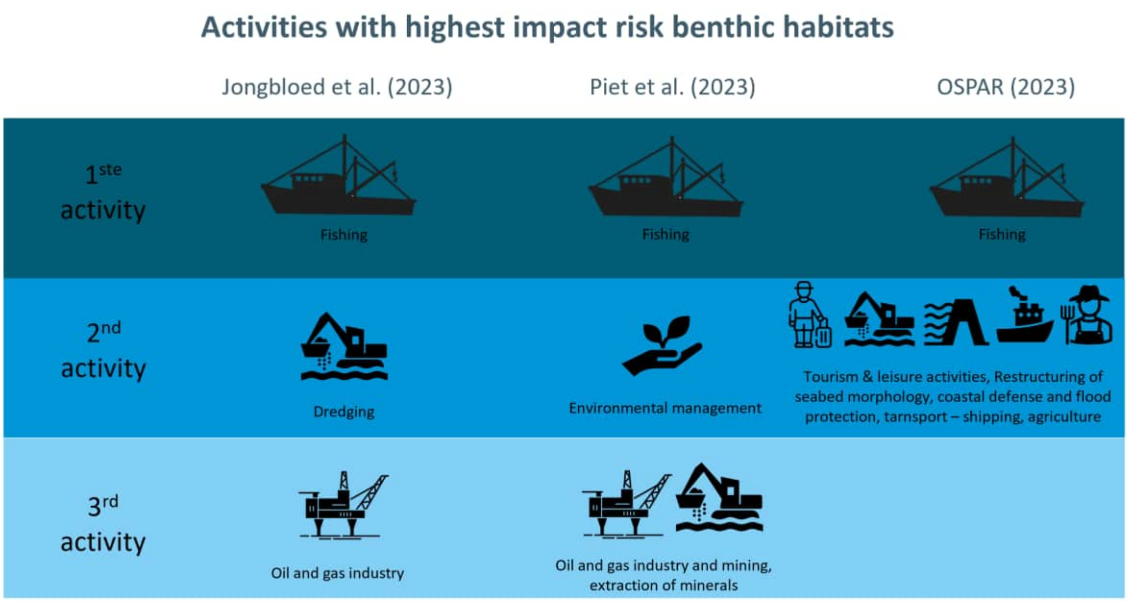


Benthic habitats

Fishing was identified as the activity with the highest impact risk on the benthic habitat by all three studies (Figure 2.10). For the deep-sea bed and sublittoral sediment, fishing made up more than or almost half of the cumulative impact risk. For the other types of benthic habitats (littoral sediment, littoral rock, circalittoral rock and infralittoral rock) the impact risk of fishing was lower (Jongbloed et al., 2023; Piet et al., 2023). OSPAR (2023a) did not make a distinction between different benthic habitat types. Still the impact potential of fishing was considerable for benthic habitats in general (~ 30 - 40 %). There was no consensus on the second and third activity. Jongbloed et al. (2023) found dredging to be the second most impactful activity and oil and gas industry the third. Piet et al. (2023) found the same, although the cumulative impact risk of activities differed. Piet et al. (2023) identified environmental management (not further defined) to be the second most impactful activity and oil and gas industry and mining extraction of minerals are considered to be of more or less even impact and are therefore both considered as the third activities with highest impact risk. OSPAR (2023a) didn't identify one activity with the second highest impact risk, but five: (1) tourism and leisure activities, (2) restructuring of seabed morphology, (3) coastal defence and flood protection, (4) transport - shipping and (5) agriculture. Restructuring of seabed morphology also includes dredging and therefore overlaps with one of the activities identified as second highest impact risk by Jongbloed et al. (2023).

It is expected that the cumulative impact risk on most benthic habitats will decrease in the future. Only for the littoral sediment and littoral rock and other hard substrata the impact risk is expected to increase with 0.2 % in 2040 compared to 2022 (Jongbloed et al., 2023).

Figure 2.10 Current top activities with highest impact risk on benthic habitats

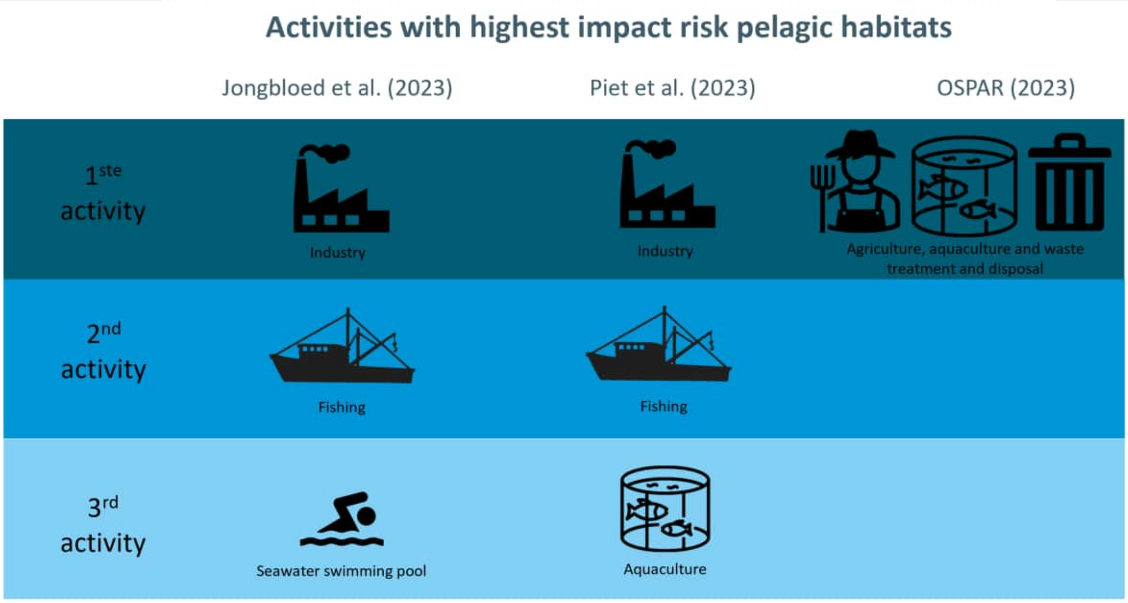


Pelagic habitats

For pelagic habitats Piet et al. (2023) and Jongbloed et al. (2023) identified industrial activities, with discharges into coastal waters as the highest impact risk (Figure 2.11). In both papers the contribution of these activities is two to three times higher (ranging from ~ 4 to 5 %) than the activity with the second highest impact risk. OSPAR (2023a) found that agriculture, aquaculture and waste treatment and disposal all have an even impact potential on pelagic habitats. Fishing was identified as the activity with the second highest impact risk by both Piet et al. (2023) and Jongbloed et al. (2023), followed by aquaculture and seawater swimming pool effects, respectively.

The impact risk on the pelagic habitat is expected to decrease in the future (Piet et al., 2021; Jongbloed et al., 2023), With 0.8 in 2030 and 1.7 % in 2040 (both compared to 2022) (Jongbloed et al., 2023).

Figure 2.11 Current top three activities with highest impact risk pelagic habitats



2.3.4 Identified pressures

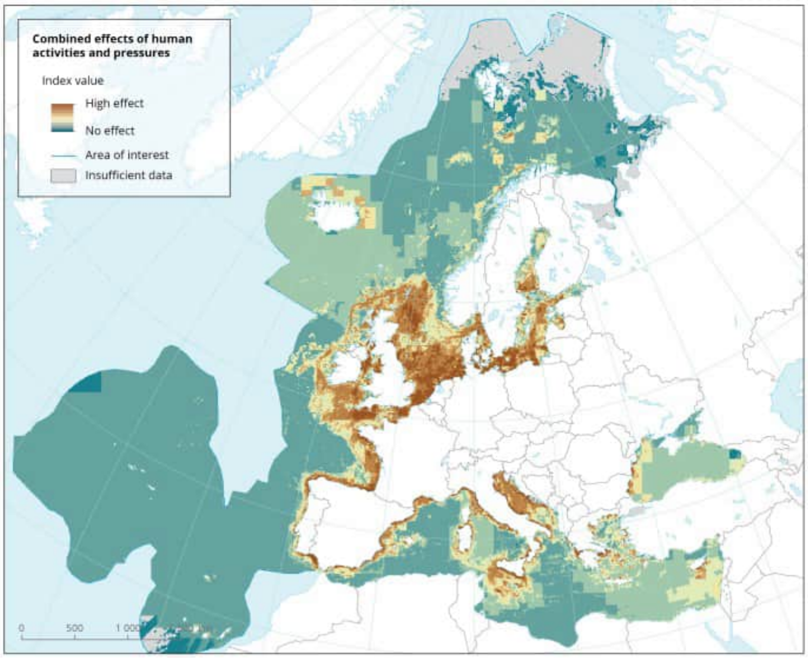
Pressure
The mechanism through which an activity has an effect on any ecosystem component.

Main overall pressure

Activities can cause a range of pressures (Jongbloed et al., 2023). The combined distribution of human activities and pressures in European Seas exerts potential effects that cumulate over the ecosystem. Pressures from human activities are widespread across European Seas and there is barely any area that is not affected by these pressures (Figure 2.12). Generally, coastal areas and the continental shelf are under higher pressure in comparison to offshore areas due to the influence of activities on land and at sea. This is also highly the case for the North Sea (European Environmental Agency, 2020).

Jongbloed et al. (2023) found that the main pressure on the ecosystem is extraction of flora and/or fauna and abrasion/damage, both strongly related to the human activity with the highest impact risk (i.e. fishing, specifically benthic trawling). In contrast, the European Environmental Agency (2020) found that hazardous substances rank as the top pressure for the North-east Atlantic Ocean, but closely followed by extraction of species and bycatch. Due to their chosen method, widely occurring pressures are emphasized over local pressures, which may cause a bias in their results.

Figure 2.12 Combined effects of human activities and pressures in European seas (European Environmental Agency, 2020)



Main pressure per ecosystem component

Only two studies identified specific pressures per ecosystem component in their cumulative analysis; OSPAR (2023a) and Jongbloed et al. (2023). Additionally, Kenny et al. (2018) studied pressure on specifically the benthic habitat.

For fish and the benthic habitat, the same pressures with highest cumulative impact risk were identified by OSPAR (2023a) and Jongbloed et al. (2023) (Table 2.8). For fish, extraction of or mortality/injury to, wild species was identified as strongest pressure and for the benthic habitat physical disturbance of the seabed (i.e. abrasion, damage and smothering). Both of these pressures reflect the high contribution of fishing (specifically benthic trawling) to the cumulative impact risk of both ecosystem components. In contrast, Kenny et al. (2018) found that sediment removal in relation to dredging is the strongest pressure on the benthic habitat.

This difference could possibly be related to the pressure types that were assessed by Kenny et al. (2018) - they only considered four of which one was related to fishing: sediment surface abrasion. This one specific pressure could impact the seabed less compared to when all pressures related to fishing are considered.

For the other ecosystem components results differed between the reviewed studies. While OSPAR (2023a) identified extraction of, or mortality/injury to wild species to be the strongest pressure on marine mammals, Jongbloed et al. (2023) identified both impulsive noise as well as microplastics and other litter that may be ingested to be the strongest pressures. For birds both studies found that disturbance of species (e.g. where they breed, rest and feed) to be the strongest pressure, but Jongbloed et al. (2023) identified that microplastics and other litter that may be ingested has the same cumulative impact risk. Lastly, OSPAR (2023a) identified changes in nutrients to be the strongest driver for pelagic habitats, while Jongbloed et al. (2023) found that selective extraction of non-living resources has the highest cumulative impact risk. Note that pressures from climate change were not included in this list. When we consider climate change, the strongest pressure on birds would be depletion, extraction of, or mortality/injury to wild species and disturbance of species (OSPAR, 2023a). For all other ecosystem component, the strongest pressures do not differ when climate change is considered (OSPAR, 2023a).

Furthermore, Jongbloed et al. (2023) studied pressures for future scenarios. Comparing those scenarios to the current pressures does not yield substantially different results. A single difference is that in the future, disturbance of birds increases, making it the single strongest pressure (tTable 2.8).

Table 2.8 Strongest pressure per ecosystem component (OSPAR 2023a, Jongbloed et al. 2023), excluding climate change pressures

Ecosystem component	Present			Future (period 2031 - 2040)
	OSPAR (2023a)	Jongbloed et al. (2023)	Kenny et al. (2018)	Jongbloed et al. (2023)
Fish (and cephalopods)	Extraction of, or mortality/ injury to, wild species	Extraction of flora and/or fauna	Not specified	Extraction of flora and/or fauna
Marine mammals	Extraction of, or mortality/ injury to, wild species	Impulsive noise; microplastics and other litter that may be ingested	Not specified	Impulsive noise; microplastics and other litter that may be ingested
Birds	Disturbance of species	Disturbance of species; microplastics and other litter that may be ingested	Not specified	Disturbance of species
Pelagic habitats	Changes in nutrients	Selective extraction of non-living resources (substrate e.g. gravel)	Not specified	Selective extraction of non-living resources (substrate e.g. gravel)
Benthic habitats	Physical disturbance to seabed	Sbrasion/damage; smothering	Sediment removal	Abrasion/damage; smothering

2.3.5 Identified state

State
Describes the physical, chemical and biological condition and dynamics of the environment or observable temporal changes in the system.

The reports included in our analysis applied different definitions and categorisations for the impacted state. However, it is clear that the most impacted state is the species abundance (Piet et al., 2023, OSPAR 2023a), or impacts closely related to abundance (biological diversity (Piet et al., 2021; European Environmental Agency, 2020), biological traits (Kenny et al., 2018)). As biological diversity decreases with decreasing number of species, and changes in biological traits (such as size, longevity, mobility and reproductive strategy), it can indicate a change in species composition and abundance. For instance, changes in habitat can create an environment that is more beneficial for species with biological traits that differ from the species originally present in this habitat (Kenny et al., 2018).

2.3.6 Identified impacts

Impact
The influence of the intervention, human activity, pressure or changes in state on the ecosystem/population/individual. For example, the effects of pile-driving are, among others, noise disturbances. This effect of pile-driving impacts for example marine mammals.

Lastly, no strongest impact on the ecosystem services due to changes in the state of the environment could be identified, since not all papers explored the impacts to this level of detail. In order to give some description, the papers that did include impacts are discussed below.

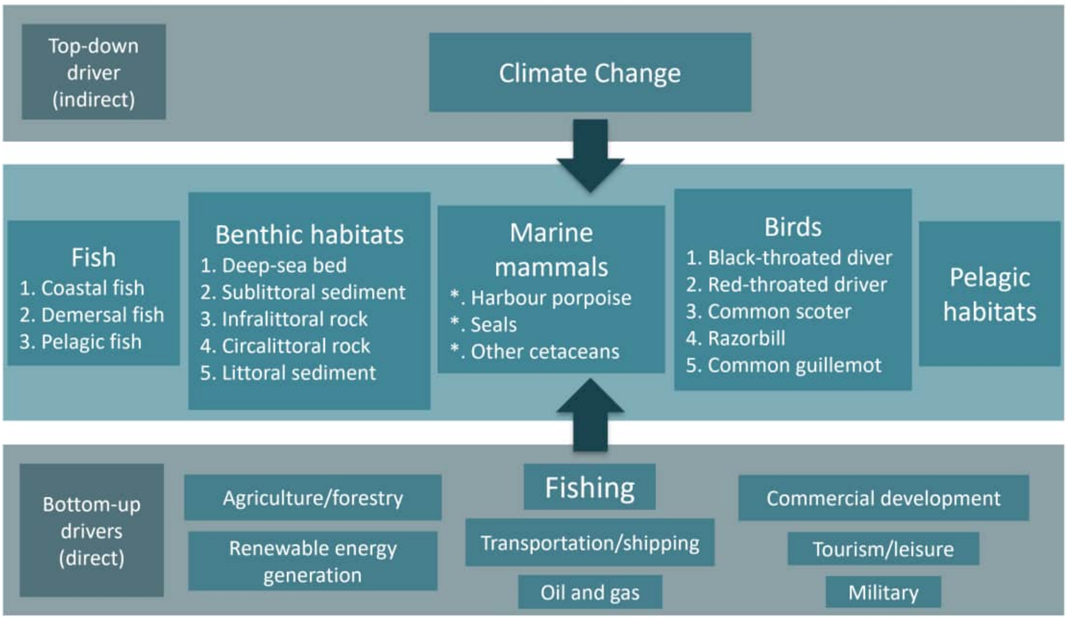
Piet et al. (2023) found that cultural ecosystem services and the food web were impacted most. OSPAR (2023a) also mentioned impacts and found that the ecosystem service of ‘wild fish and other natural aquatic biomass and raw species’ was the most affected, for all thematic assessments (benthic habitats, fish, marine birds, marine mammals, pelagic habitats). The European Environmental Agency (2020) is mainly concerned about the impact on the resilience and sensitivity of the ecosystem. They further indicate what is at stake for the human population due to the degradation and depletion of the marine ecosystem, being (1) the fulfilment of our basic needs, (2) our well-being, and (3) our livelihoods and economy.

3

CONCLUSION AND DISCUSSION

The conclusion of this study is summarized in Figure 3.1. In this chapter, we first discuss the underlying pressures and activities for each ecosystem component and try to explain what factors could likely explain the difference in findings between the CIA's. Second, the activities with highest impact risk affecting the ecosystem are described. Finally, the concluding remarks include study limitations and the main take-away from this review.

Figure 3.1 Summary: Activities with the highest impact risk on the Greater North Sea Basin and the most-affected ecosystem components



Of the six studies included in this review, five papers studied the effect of multiple human activities on multiple ecosystem components: Piet et al. (2021; 2023), Jongbloed et al. (2023), OSPAR (2023a) and European Environmental Agency (2020). Therefore, only these papers are considered below when conclusion are given on cumulative impacts. Additionally, regarding benthic habitats, Kenny et al. (2018) is included as they studied the impact of multiple human activities on this specific habitat.

3.1 Ecosystem components under pressure

Fish (and cephalopods)

Three out of five studies found that the species group of fish (and cephalopods) is currently under the highest human pressure (Piet et al., 2023; Jongbloed et al., 2023; OSPAR 2023a) and the other two studies identified fish to be the second ecosystem component under highest pressure (Piet et al., 2021; European Environmental Agency, 2020).

This difference in findings is likely related to the selected method. In the study of the European Environmental Agency (2020) surveys among European experts were considered while defining the ecosystem component under highest pressure. In the other studies expert judgement was combined with quantitative data while defining impact risks. This could possibly explain the difference in findings between the European Environmental Agency (2020) and the other papers. For Piet et al. (2021) the difference can likely be explained by the number of human activities that were considered in the CIA - they only included nine activities, while in all other studies significantly more activities were considered.

The poor status of fish populations has an impact on higher trophic levels within the food chain such as seabirds. All studies that investigated pressures on fish found that the strongest pressure is the extraction of fish and abrasion, both primarily caused by fishing activities (Jongbloed et al., 2023; OSPAR, 2023a). Between the CIAs, there is no consensus on secondary or tertiary activities with the highest impact risk. These activities of lesser concern are residential and commercial developments, agriculture and forestry, transport (shipping), oil and gas industry, and renewable energy. In future scenario's the impact risk on fish will likely decrease. However, fish remains the ecosystem component with the highest cumulative impact risk.

Marine mammals

One out of five studies found marine mammals to experience the highest cumulative impact risk (European Environmental Agency, 2020). In the other studies marine mammals were identified to be under higher pressure than birds, but were often ranked as under less pressure than a specific benthic habitat (e.g. deep- sea bed or sublittoral sediment) and in the study by Piet et al. (2021), marine mammals were even ranked as under less pressure than the pelagic habitat (for more detail refer to paragraph 2.3.1). Within this group, there is no consensus of which species are under the highest pressure, due to a lack of population data.

There is no consensus of the strongest pressure - OSPAR (2023a) found extraction of, or mortality/injury to, wild species to be most important, while Jongbloed et al. (2023) identified both impulsive noise and, microplastics and other litter which may be ingested, to be the strongest pressures. Still, fishing was considered to have the highest cumulative impact risk on marine mammals (Piet et al., 2023; Jongbloed et al., 2023; OSPAR, 2023a). There is no consensus on secondar and tertiary - either oil and gas industry, residential and commercial development, transport (shipping) or renewable energy is mentioned as activity with the highest impact risk. These discrepancies are likely to be explained by differences in the included human activities (and their categorisation) and the applied method of the different studies. For future scenarios the impact risk on marine mammals is expected to decrease.

Birds

Many birds have a poor conservation status. However, none of the studies identified birds as the ecosystem component under highest pressure. All studies agreed that birds are under lower pressure than fish (and cephalopods) as well as marine mammals and some types of habitats (Piet et al., 2021; 2023; Jongbloed et al., 2023; European Environmental Agency, 2020). Still four out of five bird groups are in poor environmental status (OSPAR, 2023a), with the black-throated diver being the most affected species (Jongbloed et al., 2023). As such, birds are currently under pressure, but to a lesser extent than the aforementioned ecosystem components.

Again, fishing was identified as the most impactful human activity by all concerned studies, but there was no consensus on the second and third activity with highest cumulative impact risk. These activities of lesser concern are residential and commercial developments, transport (shipping), oil and gas industry, agriculture and forestry, aquaculture and tourism and leisure activities. The same reasoning applies as for marine mammals as why these findings differ per study. The most important pressures on birds are disturbance of species (Jongbloed et al., 2023; OSPAR, 2023a) and microplastic and other litter that may be ingested (Jongbloed et al., 2023). Notable is, when future scenarios were simulated, offshore wind became the second most impactful human activity in 2040. As such, the pressure on birds is expected to increase in the future.

Benthic habitats

The benthic habitat, specifically the sublittoral sediment, was by Piet et al. (2021) identified as the ecosystem component with the highest impact risk, while Piet et al. (2023) and Jongbloed et al. (2023) identified the deep-sea bed to be the second most impacted ecosystem component and the sublittoral sediment the fifth. In the assessment performed by the European Environmental Agency (2020), benthic habitats ranked third. It is likely that the applied model explains part of these differences as both Piet et al. (2023) and Jongbloed et al. (2023) used the SCRAIM model, while Piet et al. (2021) and the European Environmental Agency (2020) did not. Findings of Piet et al. (2021) are mainly based on peer-reviewed studies conducted in international collaborations and the European Environmental Agency (2020) conducted a spatial assessment based on two types of spatial input layers: (1) pressures and (2) ecosystem components which are linked with sensitivity scores derived from surveys (expert judgement). Additionally, the included human activities may be of influence.

Benthic habitats are mostly threatened by physical disturbance of the seabed (abrasion/damage) and smothering, which is primarily caused by fishing (Jongbloed et al., 2023; OSPAR, 2023a), but also by dredging (Kenny et al., 2018). Additionally, other human activities (e.g. environmental management, oil and gas industry, tourism and leisure activities, mining, restructuring of seabed morphology, coastal defence and flood protection, transport (shipping) and agriculture) contribute towards the poor status of the benthic habitats, but those are considered of lesser importance. It is expected that the cumulative impact risk on most benthic habitats will decrease in the future.

Pelagic habitats

None of the studies consider the pelagic habitat to be under the highest impact risk. In Piet et al. (2021) the pelagic habitat was considered to be third ecosystem component under highest pressure, while in all other studies it was ranked even lower (Piet et al., 2023; Jongbloed et al., 2023; European Environmental Agency, 2020). Nonetheless, pelagic habitats have a poor environmental status (OSPAR, 2023a). They are under pressure due to changes in nutrients (OSPAR, 2023a) and selective extraction of non-living resources (substrate e.g. gravel) (Jongbloed et al., 2023). This is also the only ecosystem component where fishing does not propose the highest impact risk, but rather the secondary (Piet et al., 2023; Jongbloed et al., 2023; OSPAR, 2023a). Key pressure activities differ per study, but generally include industries which dispose waste into the marine environment. This includes agriculture, aquaculture, waste treatment and (manufacturing) industries onshore. It is expected that the cumulative impact risk on pelagic habitats will decrease in the future.

3.2 Key pressure activities

Fishing activities as direct impact

All studies that have included fishing activities in their CIA, found that fishing has the highest impact risk on almost all ecosystem components. The only exception to this is the pelagic habitat. The second and third most impactful activities were distinctly different between studies. This variation can be explained by the variety in study areas and differences in methodologies and input data. For example, OSPAR (2023a) uses relatively more quantitative data compared to the other studies, who more often rely on expert-judgment or future scenarios.

One could also argue that the chosen time period is of influence as the year of reference used is not the same across all studies, nor is the extend of the future scenarios (up to 2030 or 2050). The included time period, however, seems of lesser influence compared to the chosen model and input data. The time difference between the baseline scenario and future scenarios was decades as given in Jongbloed et al. (2023), while changes in the outcome were marginal. The time period for the baseline scenario (i.e. current scenario) were less then decades, at most a few years. Hence, the differences in outcomes between Piet et al. (2023), Jongbloed et al. (2023) and OSPAR (2023a) cannot be attributed to differences in applied time horizon.

Climate change as indirect impact

The combined effect of multiple pressures on marine species and habitats reduces the overall resilience of the marine ecosystem. This is aggravated by climate change-related changes. Moreover, climate change increases the sensitivity to other pressures (European Environment Agency, 2020). Hence, the impact of climate change was identified as important, but one that cannot be derived from a single activity. Instead, it can be regarded as a top-down pressure, whereas human activities (other than climate change) are related to bottom-up pressures (Figure 3.1). Both affect the ecosystem components of the GNSB.

Climate change has an interaction with some of the human activities, for example offshore wind. Climate change mitigation increases the need for renewable energy generation, which in turn also has an impact on ecosystem components. Alternatively, climate change mitigation may lead to a reduction in oil and gas production. Therefore, climate change must be taken into account when considering the pressures on species of the GNSB, even though the reduction of risks to ecosystem components from climate change cannot be addressed by looking at the GNSB alone. Nonetheless, the GNSBI can make recommendations to policymakers on how the succession of climate change could be reduced.

Other human activities

Although fishing has been identified by most studies as the most impactful human activity, it is the cumulation of all activities that exert a pressure on the ecosystem components. Other important activities that were mentioned in the reviewed studies were residential and commercial developments, agriculture and forestry, shipping, oil and gas industry, non-renewable energy generation, tourism, aquaculture and industrial developments. These activities mostly exert pressure due to disturbance of species, extraction of, or mortality/injury to, wild species, input of anthropogenic sound, input of microplastics and other litter that may be ingested, changes in nutrients, selective extraction of non-living resources and physical disturbance of the seabed. Nonetheless, the contributions of these activities to the overall cumulative effect is much lower in comparison to fishing activities.

Renewable energy as notable exception

To reduce CO2 emissions, offshore wind developments have gained momentum in recent years, putting it often at the centre of many effect studies. The studies that investigated several human activities (including renewable energies) do not conclude that offshore wind farms are of primary concern for the marine environment now or in upcoming decades, if one considers cumulation. It should be noted that the impact of this industry may be underestimated, as little is known about long term effects and large-scale effects. Importantly, the current status of the ecosystem of the GNSB is poor (OSPAR, 2023a). Offshore wind farms will increase tremendously in the GNSB region within the next decades thereby forming a new and additional pressure on the ecosystem including on most of the ecosystem components that are on a poor state already., which should already be considered for future decision making (e.g. spatial planning). However, at the moment, it would be most beneficial to reduce impacts of the fishing industry to alleviate pressures on the ecosystem.

3.3 Limitations of this study

The number of studies that have performed a CIA on or beyond the scale of the GNSB, is low. Although the number of studies may be limited, all of these studies are based on substantial databases, sub-studies and underlying reports. Furthermore, OSPAR's QSR is a highly extensive report that has assessed the status of the GNSB through a wide range of themes, including different activities, species groups and habitats. On top of that the QSR is politically endorsed. Combined with the other studies, this provides a relatively high level of scientific certainty.

There is also overlap between the authors who wrote or co-wrote, as well as in authors cited. For example, Jongbloed et al. cites the earlier studies by Piet et al., but they have also both co-written each other's articles. This may have created some biases for this analysis.

While all articles focus on multiple activities, often the data available for most activities is relatively little in comparison to the data available on offshore wind. Therefore, the impact risk of offshore wind is mostly based on qualitative data, while for the estimation of the impact risk for the other activities is for a large part based on expert judgement. While this may be the case, our conclusion is that the current and future impact of offshore wind is relatively low compared to the cumulation of other impacts. This is supported by the OSPAR (2023a), which included the widest range of human activities out of all selected articles.

3.4 Conclusion

The cumulative impact studies included in this analysis have a clear consensus on their primary conclusion: fish are under the most pressure and fishing extends the most pressure on the ecosystem. Within the relative contribution of impact risk, fishing is dominant for multiple ecosystem components although not all. When the cumulative impact risk is considered, then there is not one human activity that is dominant, now or in the coming decades. On secondary ecosystem components or human activities, there is no clear consensus between the studies. This can best be explained by differences in the applied model, type of analysis (i.e. quantitative or qualitative) and included activities. Additionally, climate change is an indirect pressure but key driver of change on the North Sea ecosystem.

4

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Appendices

APPENDIX: METHODS OF SELECTED STUDIES

Kenny et al. (2018)

Pressure types

Kenny et al. (2018) compiled four human activity benthic pressure layers covering a significant area of the Northeast Atlantic region, utilising spatial data from multiple sources. The pressure layers are:

- Surface sediment abrasion caused by bottom fishing activities. This layer has been generated by ICES (2016).
- Sediment removal by aggregate dredging activities. Data were obtained from EMODnet. For the UK, licensed polygon areas were obtained from the Crown Estate.
- Smothering caused by sediment disposal activities. Data on licensed sea disposal sites were obtained from EMODnet.
- Deposition of hard (concrete and steel) structures by renewable energy and oil and gas activities. Obtained from EMODnet and the Crown Estate UK.

Habitat mapping and biological traits

Habitat spatial data was obtained from the European EMODnet seabed habitats project EUSeaMap and divided into four categorical habitat classes (coarse deep, coarse shallow, fine deep and fine shallow) based on water depth and grain size. Data on the dominant biological traits associated with the four categorical habitat classes were derived from data presented in Bolam et al., (2017).

Habitat sensitivity score

The sensitivity of each habitat category was then evaluated by a group of five experts to evaluate the sensitivity (as high, moderate, or low sensitivities) of benthic habitat biological traits to the four pressure types under consideration. The expert group evaluated each biological trait associated with each habitat attribute (course, fine, deep, shallow), and assigned it a categorical value from 0 (least affected), 0.5 (moderately affected) to 1 (highly affected) in response to the different pressure categories, comparable to the approach adopted by Bolam et al. (2014).

Estimating cumulative impact

Estimating the pressure specific impacts involved integrating the pressure and corresponding habitat sensitivity data layers:

Pressure (0-1) * Sensitivity (0-1) = Impacts (0-1).

This was repeated for each pressure and corresponding habitat sensitivity layer before summing the pressure specific impact scores together to generate a single cumulative impact layer.

Piet et al. (2021)

In Piet et al. (2021) a baseline situation (around 2017) was compared with two future scenarios (2030 and 2050). Information requirements for the baseline situation were covered by WMR and for the future scenario's information is collected for each country separately and compiled by the WWF representatives from various WWF offices. At the time of the final assessment information from three countries (i.e. Germany, Denmark and the Netherlands) was available.

Human activities
The human activities of interest in Piet et al. (2021) are: Wind farms; Oil & Gas; Cables & Pipelines; Protected nature areas; Fishery; Aquaculture; Sand extraction; and Shipping (shipping routes). These sectoral activities may involve multiple sub-activities which are based on the North Sea activities according to (Borgwardt et al., 2019). All other activities on the North Sea were disregarded. This selection was based on the findings in publications about the relative contribution of a broad range of many human activities to the cumulative impacts on nature values of the North Sea (Knights et al., 2015; Borgwardt et al., 2019).

Ecosystem components
Spatial data on the different ecosystems components was gathered from EMODnet seabirds and habitats; WRM/ WindSpeed; KEC2; SCANS3 and AquaMaps. Spatial coverage and quality of spatial distribution maps often differs highly among species and species groups.

Impact assessment
The method used by Piet et al. (2021) is based on peer-reviewed studies conducted in international collaborations. The study of Borgwardt et al. (2019), including the accompanying database, was derived from the EU-funded project AQUACROSS, which built on previous work from the EU-funded project ODEMM.

The database of Borgwardt et al. (2019) contains 7771 causal impact chains for the North Sea, which were all semi-quantitatively assessed using (scientific) knowledge from literature supplemented by expert judgement by a large team of international experts. The assessment of Piet et al. (2021) was based on five AQUACROSS criteria: (i) extent, (ii) dispersal, (iii) frequency, (iv) persistence, and (v) severity (Borgwardt et al., 2019) and two additional criteria: (vi) resilience (Knights et al., 2015) and (vii) pressure load developed as part of the ICES WGCEAM.

Impact risk
Impact Risk is calculated through a risk assessment of the potential impact on nature as the combination of two aspects of risk, i.e. exposure and potential effect. Because this study does not include a full quantitative assessment, the exposure is semi-quantitative. The potential effect is completely based on categoric scores as included in the Aquacross database.

Pressures
A total of 45 human activities were linked through 31 pressures to 82 ecosystem components, resulting in a linkage framework of >22,000 activity-pressure-ecosystem component interactions across seven European case studies, of which one involves the North Sea (Borgwardt et al., 2019). Piet et al. (2021) only considered direct effects of sector–pressures on ecological components. The identified pressures are categorised in broad pressure types: (1) biological; (2) chemical; (3) physical; (4) energy.

Each cell in the impact-chain matrix is a qualitative and deterministic assessment of the presence or absence of a link, which was assessed using a combination of published literature and expert judgment (Borgwardt et al., 2019).

Piet et al. (2023)
Piet et al. (2023) adopted the linkage framework that is at the basis of previous North Sea CIA (Knights et al., 2015; Borgwardt et al., 2019) and extended this by incorporating ecosystem services. The linkage framework used as part of the CIA consists out of impact chains that link the activities, pressures and ecosystem components to assess the main threats to biodiversity caused by human activities and their pressures. The ecosystem components were selected by adopting biotic groups proposed by Culhane et al. (2018, 2019), but without further distinctions between the groups based on predominant habitats. Instead, ecosystem components are represented through the biotic groups or through the main predominant habitats in which the group is known to occur. Ecosystem services and their typology were adopted from ICED 5.1 (Haines- Young, 2013; Potschin-Young et al., 2018).

Ecosystem service supply potential

This linkage framework implies that all ecosystem components contribute equally to the capacity to supply specific ecosystem services, which is not the case. Therefore Piet et al. adopted methods from Teixera et al. (2019) and Culhane et al. (2019) to determine the ecosystem service supply potential (ES SSP) for each ecosystem component. To estimate the SPP, Piet et al. developed an approach consisting out of two parts: (1) quantitative information based on selected metrics; (2) expert-judgement-based likelihood of contribution.

Piet et al. then used the structured indicator pool as developed by von Thenen et al. (2021) to operationalize ES assessments and to identify a sufficient proxy metric using three criteria:

- The metric adequately captures how the functioning of the EC contributed to the SPP of a specific ES.
- The metric can be estimated from information that is readily available.
- The metric is sufficiently consistent among all the EC that contribute to that ES.

This method resulted in 6 generic proxy metrics that cover the essence of most of the indicators and indicator themes, but excluding the specificity that prevents access to available data and consistency in the estimation among all the ecosystem components. Selection of the proxy metrics was based on previous work by Maes (2013) and Burdon et al. (2022). This resulted in the choice of *production* (of biomass) as the preferred flow-type proxy metric to represent the SSP for most of the EC-ES linkages.

Additionally, Piet et al. proposes several asset-type proxy metrics as a fallback option in cases where *production* is not available: *biomass, abundance* of species*, extent* of habitats or *presence* (in order of informativity). They also included a complementary metric that captures the *composition* of the asset (in terms of size- or age-class, traits, species richness or biodiversity indices).

For the expert-judgement-based likelihood of contribution to the SPP, Piet et a. assumed that for the biomass division of the provisioning ES, all biotic groups not commonly extracted are assumed to contribute much less (0.1 %) compared to regular groups. For cultural ES they assumed all biotic groups that are not directly visible are also assumed to contribute much less (0.1 %) compared to regular groups. For all regulation and maintenance ES the default 100 % contribution was applied.

Ecopath and Ecosim to calculate key proxy metrics

To estimate the SPP for EC-ES linkages for which production or biomass was assumed an appropriate proxy, Piet et al. used estimates of the functional groups as they occur in the North Sea EwE model. They then matched the output for the biotic groups used in the ES context, merging them with the EC from the CIA. The North Sea EwE model was built in 2007 by Mackinson, and subsequently used as an ICES advice product. For studies like this one the model was updated, bringing simulations to 2020 by updating the underlying time series data. The model includes 69 functional groups.

Piet et al. used the mass-balanced (Ecopath) and time-dynamic (Ecosim) components of the model to extract estimates of production and biomass for each functional group from 1991 to 2020. These production rates are driven by fishery catch rate, predation mortality, other mortality, migration and biomass. Annual estimates of biomass and production were used to create a range of 'observed' or 'plausible' metrics for each functional group based on retrospective dynamics and changes in fisheries exploitation.

CIA on capacity to supply ecosystem services

For the CIA on the ecosystem and its components, Piet et al. applied the Spatial Cumulative Assessment of Impact Risk for Management (SCAIRM) model, that Piet et al. developed for the North Sea. The model consists out of 23,744 impact chains that link 106 human activities through 28 pressures to a limited set of 8 ecosystem components. By combining the SCAIRM ecosystem components, with the supply potential of the ecosystem components, the study assessed the cumulative impacts on the capacity to supply ecosystem services.

Jongbloed et al. (2023)

Jongbloed et al. performed a quick scan in which they applied a Cumulative Impact Assessment (CIA) to evaluate the consequences of developments on the North Sea on biodiversity. They did so use the Spatial Cumulative Impact Assessment of Impact Risk for Management (SCAIRM) method as in Piet et al., 2023. The SCAIRM method was then combined with either 1) the associated CIA database for the Greater North Sea, 2) the same CIA database but including a more accurate spatial overlap estimation for a selection of impact chains, i.e. replacement of the Exposure value; or 3) the same CIA database but with replacement of the Exposure value AND the Effect Potential value.

The CIA database distinguishes 36 unique activities. For 9 activities spatial data was available, which was used to calculate the real Exposure from GIS analyses. The GIS data for current and future OWFs was provided by Rijkswaterstaat. For the remaining 27 activities, the spatial extent was based on estimated exposures as in the CIA method of Piet et al. (2023).

Scenarios

In the quick scan, Jongbloed et al. calculated different scenarios: a baseline scenario for 2022, a 2030 scenario and a 2040 scenario. The 9 main human activities are included in the CIA using scenario values which represent the extent of the activity expressed as the percentage of the North Sea study area. The baseline and future scenario values for aquaculture, fishing, oil and gas, sand/gravel mining, shipping and telecoms, and electricity were taken from Piet et al. (2021b). Data for windfarms was provided by Rijkswaterstaat and reassessed by WMR. For the other 27 human activities, no scenarios were available and therefore these were assumed not to change in future scenarios, using only data from the baseline scenario from Piet et al. (2023).

SCAIRM model

In the SCAIRM method, Impact Risk (IR) is the key output that allows cumulation across different pressures. It can be estimated per impact chain as Exposure* Effect Potential and can be assessed using the spatial distributions of the stressor. Jongbloed et al. identifies the following main assumptions of the SCAIRM model:

- Only impacts on biota are considered, not the abiotic/physical environment.
- Only direct effects are included.
- It first assumes that stressors will act in an additive fashion.
- Impact Risk is a risk estimate of the potential change in state of the various ecosystem components.
- Impact Risk can be used to indicate the main threats to the ecosystem or specific ecosystem components.
- The distribution of ecological component groups is assumed to be homogenous over the study area of the pilots.
- The assessment focusses on cumulative impacts from all marine uses in the North Sea, for which sub-regions of the North Sea differ in contribution to the cumulative impact.

Ecological components

As for the ecological components that were included, Jongbloed et al. selected relevant ecological components (habitat types, species groups and species). These are as follows:

- Selection of ecosystem components is identical to the CIA method from Piet et al. (2023) and the corresponding CIA database.
- A selection of 16 bird species that fall under the KEC and OSPAR ORED list and a selection of 2 additional marine mammal species was made.

Data input

Spatially specific data for species density distribution was available for the habitat types (EMODnet) and selected bird and mammal species (SCANS-III, AquaMaps), but not for the species groups fish, birds and mammals. These species groups are assumed to be homogenously distributed over the study area.

To account for species sensitivity, for example for the sensitivity of selected bird species to collision and displacement, species specific information was used from literature by Bowgen & Cook (2018), Cook et al. (2018), Leopold et al. (2014), Potiek et al. (2022) and Soudijn et al. (2022).

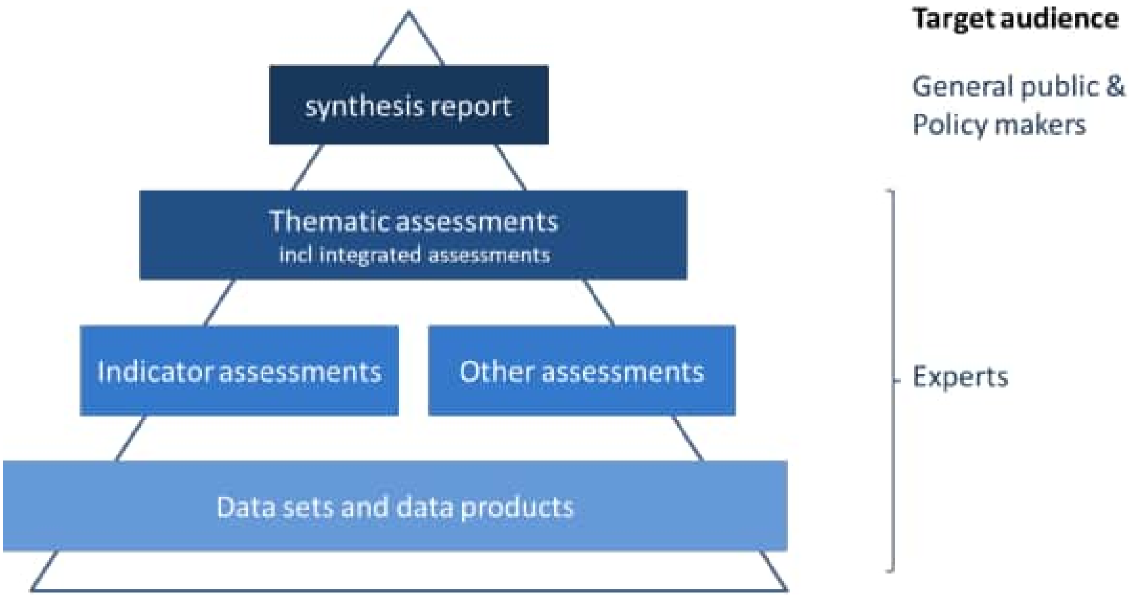
Avoidance rates were used to calculate the collision risk. Relative displacement risk scores (RDRS) were used to account for sensitivity to displacement. These scores were derived by Leopold et al. (2014) and also used by Soudijn et al. (2022).

Considerations
When using results of the study, the following issues should be considered:
- The applied future OWF development plan for the UK until 2030 may not be entirely up to date and is not available for the period beyond 2030.
- The French OWF in the Greater North Sea is not included in the CIA.
- OWF specific corrections were derived and applied in the assessment of the Impact Risk.
- It is difficult to establish future scenarios for other main human activities on the North Sea. The proposed and applied scenarios are based on large assumptions.

OSPAR (2023a)
The QSR 2023 is made up of several components that bring together a large amount of information through a structure of increased integration in each level resulting in more concise and less technical language at the Synthesis Report stage (Figure I.1). The QSR 2023 is ideally based on quantitative OSPAR monitoring data, but when monitoring data is not available or scarce also data and assessment products from 'third party' organisations and thus qualitative information was used. This was mostly the case for the Arctic Waters and Wider Atlantic and less for the Greater North Sea region.

Only geospatial information (e.g. coordinates specifying a monitoring station providing a measurement value) accessible through ODIMS are included in the QSR 2023 as OSPAR maps.

Figure I.1 QSR 2023 structure



Thematic assessments
The QSR brings together information from the thematic assessments. The thematic assessments are comprehensive reports that integrate information from several indicators and other sources to underpin the conclusions on specific topics/themes. Each thematic assessment will be supported by several indicator assessments, reports on implementation and effectiveness of OSPAR measures and as relevant other data products such as spatial information on human activities. There will be differences in the scope and technical implementation of the thematic assessments. Some topics were based on quantitative data, whereas for other topics, a more qualitative approach based on expert judgement was applied. Each thematic assessment covers all elements of the DAPSIR framework, however, the amount of information to be presented for each element differs between thematic assessments.

Methodology

A modified bow-tie analysis (Cormier *et al*., 2018, Cormier *et al*., 2019) was developed to identify and connect all the DAPSIR components, integrating these into either a pressure- or a biodiversity receptor- focused analysis of the causes and consequences of change. For the biodiversity assessments, the APS connections are weighted to determine which are the most important, using an adaptation of the Options for Delivering Ecosystem-Based Marine Management (ODEMM) pressure assessment (Robinson *et al*., 2013 and Knights *et al*., 2015) focusing on:

- Exposure module: spatial extent and frequency for all activity pressure combinations on state to generate exposure weightings.
- Impact potential module: spatial extent, frequency of occurrence and impact potential for all activity pressure combinations on state to generate impact potential weightings.
- Risk module: spatial extent, frequency of occurrence, impact potential for all activity pressure combinations on state combined with pressure persistence and ecosystem resilience to generate risk weightings.

The ecosystem services connections are weighted to determine which are the most important (Cornaccia, 2022).

European Environment Agency (2020)

Data input

For the assessment the European Environment Agency has used different European data sources such as the EEA, Eurostat, ICES, EU joint Research Centre, RSCs, Regional EU projects and EMODNET. All pressures were assessed as spatial layers (10 km x 10 km grid cells, using the EEA reference grid). For many pressures the data layers were prepared by identifying human activities causing a pressure, mapping the activity data and then aggregating that into a pressure proxy layer. Some layers were prepared on basis of in-situ observations at sea. The data for analysis were collected from the period 2011-2016. For some pressures the magnitudes were assessed, but in many only occurrences were counted for the assessment period. The pressure distributions were further divided to coastal strip, continental shelf and offshore areas.

Applied method

The method used by the European Environment Agency (2020) was selected upon a review and it follows the same methodology as already in use in many of the Europe's seas and other parts of the world's ocean (Halpern et al., 2008; Coll et al., 2012; Korpinen et al., 2012; Andersen & Stock, 2013; Micheli et al., 2013; de Vries et al., 2011; van der Wal and Tamis, 2014). The cumulative effect assessment builds on spatial layers of pressures and ecosystem components and an estimate of ecosystem sensitivity through an expert questionnaire. The questionnaire asked for estimated of sensitivity of each species group or habitat for a specific pressure. In total 54 experts form the four marine regions replied to a survey which asked about the regional sensitivity of 23 habitats and 7 species groups for 14 pressures. The pressures were the same in all four regions, but habitats and species groups differed partly if a certain habitat or species group does not occur in a region.

II

APPENDIX: FISH SPECIES THAT HAVE FAILED THE INDICATOR THRESHOLD ACCORDING TO OSPAR (2023A)

OSPAR (2023a) analysed a total of 119 different fish species in the Greater North Sea Basin which have been grouped into coastal fish, demersal fish and pelagic fish. None of these groups have achieved the threshold for Good Environmental Status (defined as 80 % of populations being in good status). Out of these species' groups, coastal fish are the most affected, followed by demersal fish and lastly pelagic fish. Within these groups, OSPAR does not differentiate between which species are most or least affected but does give an overview of the exact species that can be found within a group.

Tabel II.1 Species or stocks in the Greater North Sea Basin that have failed the indicator threshold, per group (OSPAR, 2023a)

Coastal fish	Demersal fish	Pelagic fish
European seabass	Atlantic cod (2 stocks)	Sand eels (2 stocks)
Shads	Witch flounder	Atlantic herring
European eel	Megrim (2 stocks)	Blue whiting
Lumpfish	Haddock (2 stocks)	Atlantic horse mackerel
River lamprey	Whiting	
Sea lamprey	European plaice (2 stocks)	
Pollack	Saithe (pollock)	
Viviparous eelpout	Common sole (3 stocks)	
	Spur dog	
	Starry ray	
	Atlantic wolffish	
	Common stingray	
	Tope	
	Atlantic halibut	
	Sandy ray	
	Shagreen ray	
	Small eyed ray	
	Brill	
	Nurse hound	
	Norway redfish	