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

Author(s): R.H. Jongbloed, J.E. Tamis, J.T. van der Wal, P. de Vries, A. Grundlehner, G.J. Piet

Wageningen University & Research report C074/23

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

Authors: R.H. Jongbloed, J.E. Tamis, J.T. van der Wal, P. de Vries, A. Grundlehner, G.J. Piet

Wageningen Marine Research
Den Helder, 21 November 2023

Wageningen Marine Research report C074/23

Keywords: Cumulative effects assessment, offshore wind farm, energy transition, future scenarios marine spatial planning

Client: Rijkswaterstaat
Attn.: Aylin Erkman & Rob Gerits
PO Box 2232
3500 GE, Utrecht
Netherlands

This report can be downloaded for free from https://doi.org/10.18174/642357
Wageningen Marine Research provides no printed copies of reports

Wageningen Marine Research is ISO 9001:2015 certified.

© Wageningen Marine Research

Wageningen Marine Research, an institute within the legal entity Stichting Wageningen Research (a foundation under Dutch private law) represented by
Drs.ir. M.T. van Manen, Director Operations

Wageningen Marine Research accepts no liability for consequential damage, nor for damage resulting from applications of the results of work or other data obtained from Wageningen Marine Research. Client indemnifies Wageningen Marine Research from claims of third parties in connection with this application.
All rights reserved. No part of this publication may be reproduced and / or published, photocopied or used in any other way without the written permission of the publisher or author.

KvK nr. 09098104,
WMR BTW nr. NL 8113.83.696.B16.
Code BIC/SWIFT address: RABONL2U
IBAN code: NL 73 RABO 0373599285

A_4_3_2 V32 (2021)

Contents

Summary

The energy transition requires a fast upscaling of offshore wind energy. This, however, needs to be considered in the context of all the other human activities taking place as these together impact biodiversity. Furthermore, besides offshore wind developments several other activities are expected to change in the future. This report describes an analysis (quick scan) of the consequences of these developments in terms of the potential impacts of offshore wind as well as those other human activities in the North Sea.
A Cumulative Impact Assessment (CIA) was applied to evaluate the consequences of these developments on biodiversity and thus the achievement of GES as the MSFD requires. CIAs are considered one of the key tools to apply in the context of an "Ecosystem Based Approach (EBA)". For the use of these results, it should be noted that only impacts on biota and only direct effects were included (the abiotic/physical environment and effects via food web relations and other cascading effects were disregarded). This assessment was applied at the scale of the Greater North Sea and within this area spatial variation can be expected. This, however, was beyond the scope of this study. Besides an increase of offshore wind farm (OWF) developments, future scenarios include a decrease of several other activities taking place in the North Sea (e.g. fisheries, oil & gas industry). The results of this quick scan show that the cumulative Impact Risk for the whole North Sea for the majority of the ecological components considered in this study is likely to decrease in future scenarios of all human activities. This was observed to be most pronounced for fish and deep seabed. On the other hand, for some ecological components an increase of the cumulative Impact Risk is predicted, especially for birds, primarily caused by OWF. Mostly affected are the bird species with sensitivity to specific OWF pressures overlapping with their distribution area. These include Black-legged kittiwake, Great black-backed gull, Northern gannet, Great skua and Northern fulmar. Among the bird species that are expected to receive a high threat from OWF in the future there are several species that currently have an unfavourable status and trend. These are Black-legged kittiwake, Great black-backed gull, Northern fulmar and Herring gull. These species should receive special attention in the planning of OWF and mitigation of OWF impacts but might also be protected through measures directed at pressures from other activities than OWF.

1 Introduction

1.1 Background

The countries cooperating in North Seas Energy Cooperation (NSEC) have worked out their offshore wind energy plans up to at least 2030 and laid them down spatially for the seas of the countries involved (North Sea and Celtic Seas). NSEC members are Belgium, Denmark, France, Germany, Ireland, Luxembourg, the Netherlands, Norway, Sweden and the European Commission. The United Kingdom of Great Britain and Northern Ireland and the participants of NSEC have a memorandum of understanding on their collaboration since 18 December 2022. These plans are expected to lead to a quadrupling by 2030 of the offshore wind farm capacity already installed in 2022 (approximately 25 GW) in the seas of these countries. National and EU ambitions for 2050 are even moving towards and beyond a tenfold increase in installed capacity in 2050 compared to the situation in 2022.

In the vision of NSEC this ambition necessitates an assessment of the effects of their wind energy plans on a regional sea scale, because nature in these seas is protected and due to EU ambitions to restore biodiversity. The plans can have major consequences for biodiversity at a regional sea level, but there may also be possibilities to mitigate potential impacts through careful management, including a careful choice of locations where offshore wind is planned.

1.2 Cumulative impacts

A Cumulative Impact Assessment should always be comprehensive and include all impacts on the marine ecosystem of all human activities. The link between human activities and impact on the ecosystem can be captured in a linkage framework (Knights et al., 2013). To illustrate this an example of a subset of such linkages is given in Figure 1: activities can cause a range of pressures (e.g., gillnet fishing causes bycatch and litter (ghost nets). etc.), and these pressures can affect a range of ecosystem components (e.g., bycatch affects marine mammals and birds). This linear interaction between an activity, pressure, and ecological component is referred to as an “impact chain” (Knights et al., 2015).

For the quick scan of all human activities in the Greater North Sea, we applied the CIA method, which originated from the method and results of the EU-funded projects ODEMM (www.liverpool.ac.uk/odemm) and Aquacross (www.aquacross.eu) with an extensive track record of peer-reviewed papers: e.g., Knights et al.(2015), Piet et al. (2015, 2017, 2019) and Borgwardt et al. (2019). The database of Borgwardt et al. (2019) contains 7771 impact chains for the Greater North Sea, all of which have been estimated semi-quantitatively using (scientific) knowledge from literature supplemented with expert judgment by a large team of international experts. The CIA method has been further developed in the ongoing EU-funded GES4SEAS (www.ges4seas.eu) and ICES WGCEAM (Working Group On Cumulative Effects Assessments for Management) resulting in more peer-reviewed papers including Piet et al., 2021a, 2021b; 2023 and the SCAIRM (Spatial Cumulative Assessment of Impact Risk for Management) method now being considered for further application in other EU waters and ICES ecoregions.

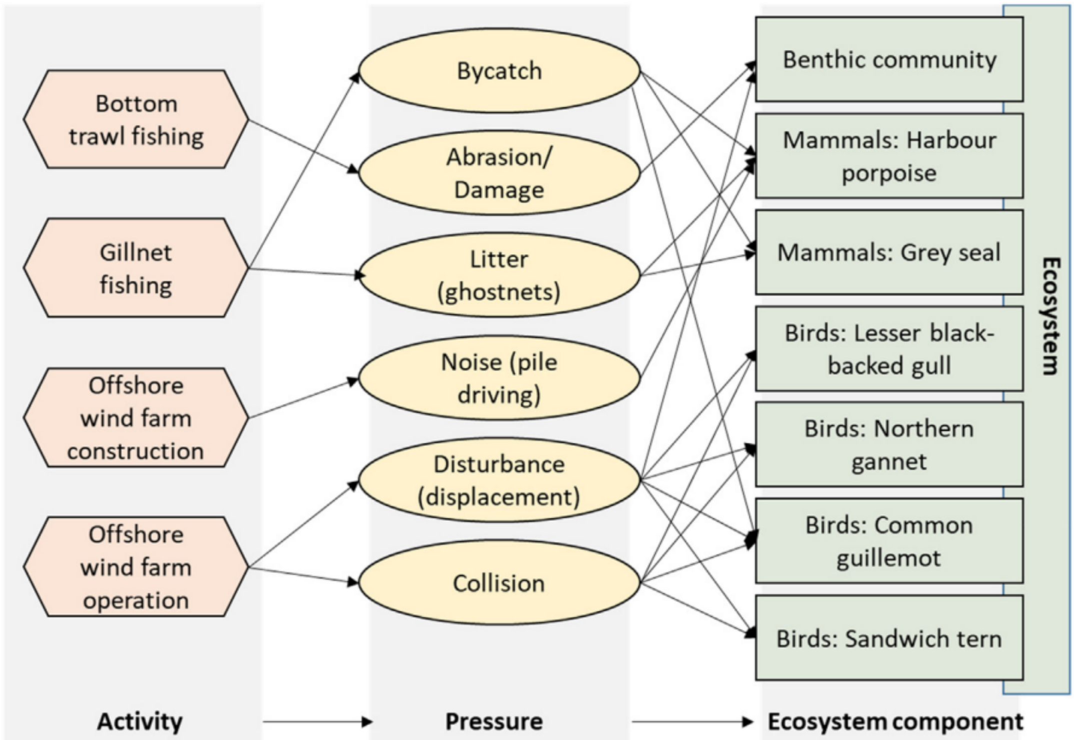


Figure 1 Linkage framework indicating a subset of elements (activities, pressures and ecosystem components) and their relations selected to conduct a fully quantitative CIA (Piet et al., 2021a).

1.3 Description of the assignment

On behalf of the Spatial and environmental NSEC support group (Support Group 2), Rijkswaterstaat (RWS) requested Wageningen Marine Research (WMR) to carry out a quick scan of the ecological effects of the realization of offshore wind farms (OWF) together with and in relation to other human activities, using an existing Cumulative Impact Assessment (CIA) method as can be applied in the context of ecosystem-oriented management, i.e. the "Ecosystem Based Approach (EBA)" method. The project is being carried out in the context of the international NSEC SG2/CEAF 2023 workplan1.

Human activities influence the marine ecosystem and its components (birds, marine mammals, fish, benthos, etc.) in different ways and through different impact chains. In order to determine whether the potential impacts are unacceptably high and whether unacceptable impacts can be prevented or mitigated, an overall picture must be obtained of the magnitude of these effects and where and how they come about. That overall picture has beenassessed in a quick scan carried out by WMR, but it will be the responsibility of the policy/decision-makers to decide whether effects of future developments of OWF, with or without combination of other human activities, on the North Seas will be acceptable or not.

Study area

The requested study area is the NSEC area which includes the Greater North Sea (OSPAR area II) and the Celtic Sea (OSPAR area III). In this quick scan the EEZ of the UK in the Greater North Sea will also be considered. The CIA applied for this quick scan (SCAIRM: Spatial Cumulative Assessment of Impact Risk for Management (Piet et al., 2023)) includes all the relevant impact chains for the Greater North Sea but not for the Celtic Sea. WMR is asked to indicate in the report which steps are necessary to be able to do this and what is already being done at this point. This is important for possible follow-up studies.

[1] https://energy.ec.europa.eu/system/files/2020-02/work-programme2020-2023_0.pdf

Selected species

The request included a focus on bird species and marine mammal species. The CIA applied for this study is based on ecosystem components consisting of habitat types and species groups of the North Sea at an aggregated level. It was not possible to study all species occurring in this area in the limited time available for this quick scan. A representative choice of different species groups and species was made in a pragmatic way:

- Birds were determined in consultation with the client: the species treated in the Dutch Kader Ecologie en Cumulatie (KEC) and a selection of species drawn up by the OSPAR ICG-ORED group (expert meeting January 2023).
- Marine mammals were determined in consultation with the client: Harbour porpoise and Grey seal.
- Fish were included at a group level only as information about species of fish is sporadically available.
- Benthos was contained in different habitat types instead of on species level.

The resulting list of species group and species, together with habitat types can be found in section 2.6.

1.4 Aim and process

The aim is to 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.

Process: The approach and the preliminary results have been presented in May 2023 for the NSEC support group 2 together with the sub-working group CEAF.

Subsequently a second quick scan was performed incorporating recent changes in OWF GIS data provided by RWS and evaluating the results against the conservation status and trends of the bird species.

2 Method

This section describes the working method of the quick scan, including the method components and assumptions, human activities in the North Sea, selections of ecosystem components.

2.1 Study area

The study area is the Greater North Sea (OSPAR area II) (Figure 2). The Celtic Sea (OSPAR area III) is not yet part of the SCAIRM method (Spatial Cumulative Assessment of Impact Risk for Management) and therefor it is no part of this quick scan. Although a quick scan is not performed in this quick scan, there are possibilities to develop a quick scan with SCAIRM for the Celtic Sea in the future and these are described in Annex 4).

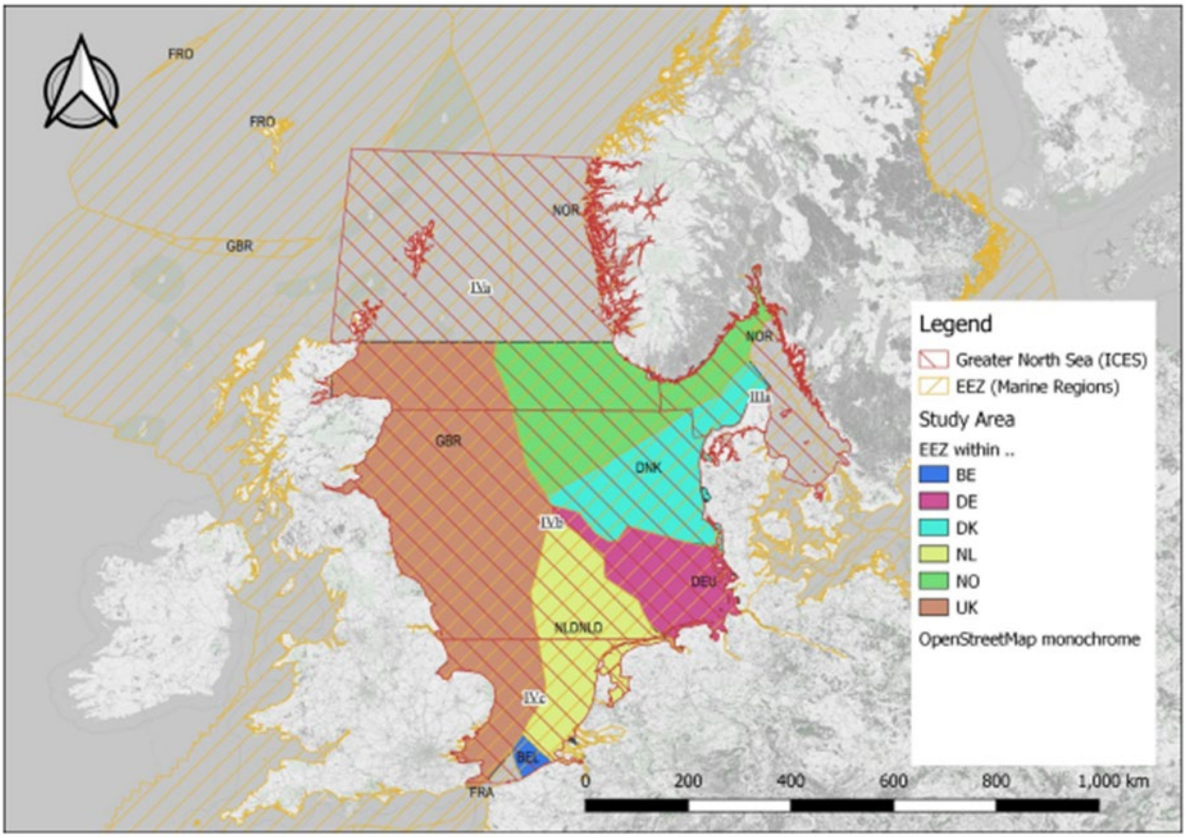


Figure 2 Study area of the quick scan of cumulative impacts on the North Sea comprising EEZ of Belgium (BE), Netherlands (NL), Germany (DE), Denmark (DK), Norway (NO) and UK. Note that spatial OWF information is available and applied for this study area, but the North Seas Offshore Grids (NSOG) sea-basin for which future OWF targets are proposed only comprises the EEZ of BE, NL, DE and DK (see Table 10).

2.2 Study period

Three scenarios were calculated in this quick scan: the baseline scenario (2022), a scenario for 2030 and a scenario for 2040.

2.3 Spatial data

Data for the spatial distribution of a number of activities, habitat types and species were obtained from EMODnet data, AquaMaps, SCANS III and KEC 4.0. However, there are some limitations in spatial coverage of the distribution with GIS data considering ecological components and human activities for the Greater North Sea. For example, for the selected bird species, which are also KEC 4.0 species (Potiek et al, 2022; Soudijn et al., 2022), the spatial distribution is only available for the Central and Southern North Sea. The analysis for the quick scan therefore makes it clear whether the results relate to the Greater North Sea or the Central and Southern North Sea.

2.4 Cumulative Impact Assessment Method

2.4.1 SCAIRM method

To guide the development of offshore wind parks as part of an ecosystem approach (Long et al., 2015) to Maritime Spatial Planning a tool to assess the cumulative impacts of all human activities was required. We use (and further develop) the CIA state-of-the art model: SCAIRM. SCAIRM stands for Spatial Cumulative Assessment of Impact Risk for Management (Piet et al., 2023). CIA (and thus SCAIRM) were identified by the ICES WGCEAM as one of the key tools to inform ecosystem-based management as well as an ecosystem approach to Maritime (or marine) Spatial Planning (EA-MSP). It should specifically provide strategic cross-sectoral scientific advice to guide the implementation of more operational sector-specific management measures.

In SCAIRM, Impact Risk (IR) is the key output that allows cumulation across different pressures and is defined as the change in equilibrium state (i.e. biomass or abundance) of the receptor caused by a stressor (Piet et al., 2021a; 2023). IR can be estimated per impact chain as Exposure*Effect Potential (Figure 3) and can be assessed using the spatial distributions of the stressor (i.e. activities-pressure), the spatial distributions of the receptor (i.e. ecosystem component) and several population dynamics parameters. More information on SCAIRM can be found in Annex 1.

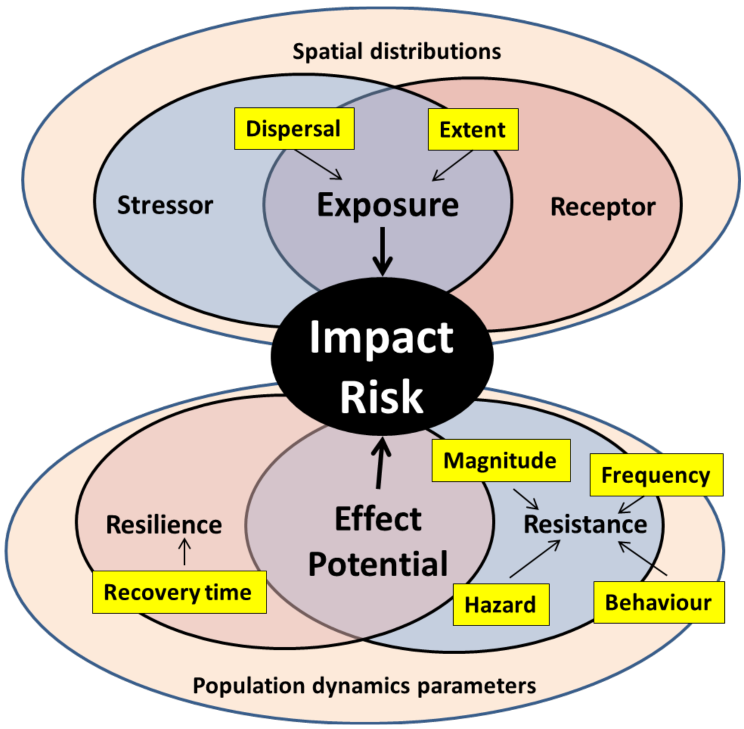


Figure 3 Calculation of Impact Risk from Exposure and Effect Potential which, in turn, can be estimated from respectively the spatial distributions of the stressor (i.e. activities-pressure) and receptor (i.e. ecosystem component) and population dynamics parameters resilience and resistance if quantitative information is available. If lacking, these can be estimated from the boxed terms using categorical scores based on expert judgement. (Piet et al., 2023).

2.4.2 Assumptions and limitations

The main assumptions of SCAIRM are:

- It only considers impacts on the biota, not the abiotic/physical environment. Also, when impact on habitats is considered, this only involves its associated biotic component (e.g. the benthos, not the sediment).
- It only includes direct effects, i.e., effects via food web relations and other cascading effects are not included. This also means that potential "positive effects" such as the artificial reef effect and provision of a sanctuary for fish are not taken into account.
- Because knowledge on the interaction mechanisms of multiple stressors (additivity, synergy, antagonism) is lacking, first assumption is that they will act in an additive fashion (following e.g. Halpern & Fujita, 2013; Judd et al., 2015).
- Impact Risk is the main output of the model and reflects the potential risk from the cumulative anthropogenic pressures. It can be used to provide an integrated perspective on the (change in) vulnerability of the ecosystem as a whole (in a specific study area like the Greater North Sea) as well as each of the different ecosystem components.
- Note that Impact Risk is a risk estimate of the potential change in state of the various ecosystem components. It does not represent an actual (change in) abundance as can be observed from monitoring programmes. As such it cannot be used to predict the actual values for specific indicators (e.g. MSFD). It is best used to assess some (future) alternative situations relative to a baseline/reference situation.
- Impact Risk can be used to indicate the main threats to the ecosystem or specific ecosystem components. It provides ranking orders of main contributors to the overall threat caused by human activities.
- The distribution of ecological component groups is assumed to be homogenous over the study area of the pilots. Therefore, the output of the CIA has currently only limited value in providing spatially explicit advice, but the development of a spatially-explicit and quantitative CIA method was started by Piet et al. (2021a) allowing for some activity-ecological component combinations to be included. In this quick scan that will be done for a selection of offshore wind-bird species combinations.
- The assessment focusses on cumulative impacts from all marine uses in the North Sea. Due to the different distribution of habitats and species, as well as varying intensities of human activities, the sub-regions of the North Sea differ in the contribution to the cumulative impact for the North Sea.

These assumptions of the SCAIRM method together with proposed calculation options (paragraph 2.4.3) and selections concerning human activities (paragraph 2.5) and ecological components (paragraph 2.6) for the quick scan, were discussed with RWS and the CEAF group in the preparatory phase of this project.

Other issues that need to be considered when using the results of this study:

- The applied future OWF development plan for UK until 2030 may not be entirely up to date and is not available for the period beyond 2030. This also means that 2040 estimates are low.
- The French OWF in Greater North Sea is not included in the CIA of this quick scan due to lack of available bird and mammal density data.
- OWF specific corrections (utilization factors were derived and applied in the assessment of the Impact Risk. This improves the accuracy of the predictions for the future scenarios. However, for an important part of the future OWF there remains considerable uncertainty, mostly due to spatial planning. Shoreward choices inside a development zone will generally lead to higher impacts for coastal birds, and less for more marine species and vice versa in case of a seaward preference. In information about type and capacity of wind turbines will become a requirement when collision risk for sea birds is to be assessed.
- 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.

2.4.3 Data input options

Three options were applied in the quick scan, depending on the quality of the data for the two key aspects of risk, i.e. likelihood of interaction between a stressor (human activity and its pressures) (Exposure) and the consequence of that interaction (Effect Potential) on a receptor (ecosystem component/species):

Data input option	Data input applied for
1) CIA method (SCAIRM) as in Piet et al. (2023) and the associated CIA database for the Greater North Sea.	Impact Risk of all human activities for 7 habitat types and 3 species groups
2) CIA method (SCAIRM) and database as in option 1, including a more accurate spatial overlap estimation for a selection of impact chains (i.e. replacement of the Exposure value for the impact chains by a more accurate spatial overlap estimation, namely based on density maps.	Impact Risk of offshore wind energy for 16 bird species and 2 marine mammal species
3) CIA method (SCAIRM) and database as in option 1, with replacement of Exposure value as in option 2 and Effect Potential value. Applied to a selection of impact chains.	Impact Risk of offshore wind energy for 16 bird species

These main options are described in more detail, i.e. considering activities and ecological components, below.

2.5 Human activities in the North Sea

There are many human activities taking place in the North Sea or its surroundings (e.g. land-based activities) that may be impacting the North Sea. The CIA database distinguishes 36 activities. These includes activities that are relatively extensive and/or intensive, and that may have a greater impact on natural values in the North Sea. It is therefore useful to have a quantitative and spatial picture of the exposure of these activities as much as possible. Spatial data was not available for all activities. For 9 activities (referred to as the top 9 activities) data was available and a real Exposure was calculated from GIS analyses. GIS data has been provided by RWS for the current offshore wind farms and future plans for offshore wind farms (until at least 2030). This data needed to be analysed before it could be used in the CIA. For the remaining 27 activities the spatial extent is based on estimated exposures as in the CIA method of Piet et al. (2023), These two categories of activities are further described below.

Human activities with spatial (and for some) density distribution for the Greater North Sea (most obtained from EMODnet). The so-called **Top 9 activities** in this quick scan CIA:

- Fishing: Benthic trawling
- Fishing: Nets (explanation, is this static gear?
- Fishing: Pelagic trawls
- Aquaculture
- Mining: extraction of materials
- Oil and Gas
- Shipping
- Telecoms and Electricity
- Wind farms

Moreover, there are **27 other human activities** on the North Sea also included in this quick scan CIA:

- Agriculture (crops and livestock)
- Angling and sport fishing
- Artificial reefs
- Beach replenishment
- Boating/Yachting/Watersports (without engine)
- Boating/Yachting/Watersports, including tourist boats (with engine)
- Collecting (bird eggs, individuals, curios, bait)
- Commercial Cruise
- Culverting lagoons
- Dredging
- Ex-situ aquaculture
- Flood and coastal defence
- Forestry
- Hunting
- Land claim and conversion
- Manufacturing: Industry with discharges
- 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

Data input

Main (top 9) human activities (and their different phases, e.g. construction versus operations) are included in the CIA using the scenario values presented in Table 1. The values 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 the scenarios were taken from Piet et al. (2021b). For wind farms, baseline and future scenarios have been reassessed by WMR in April and October 2023 using data provided by RWS (see Annex 2 for more information on the wind farm scenarios and underlying data). In addition WMR assessed how much of future OWF development areas will be required for installation of the OWF capacity at that location. This can be regarded as a utilization factor representing the ratio: *required OWF area/OWF development area*. The utilization factor varies considerably among the individual future OWF development areas. Using the recent RWS data and utilisation factors, a map of the status of offshore wind farm areas with different stages of development was composed (*Figure* ***4***, Figure 5). Two main phases can be distinguished:

1. Development zones, which are areas designated for wind energy development (the shaded areas in *Figure* ***4***). Developments zones often have a OWF development area that is much larger than the required OWF area, resulting in a small utilisation factor;
2. Wind farm areas, which indicate the sites where wind farms are being developed in stages ranging from early planning to fully commissioned (the coloured areas indicating the fraction utilised in Figure 5). During the stages the surface area of the development zone (i.e. the OWF development area from bullet 1) decreases as decisions are made and therefore the utilisation factor increases.

For the other 27 human activities (see list above) there were no scenarios available. These were therefore assumed not to change in future scenarios, i.e. the baseline as used in Piet et al. (2023) was also used for the future scenarios.

Table 1 Scenario values (% of study area) for the main human activities in the North Sea study area (Piet et al., 2021b)

Activity	Phase	Baseline (2022)	Scenario for 2030	Scenario for 2040
Aquaculture: fish	Operation	0.00356	0.00625	0.10861
Aquaculture: fish	Set-up	0.00036	0.00027	0.00512
Aquaculture: macro-algae	Operation	0.00105	0.00184	0.03194
Aquaculture: macro-algae	Set-up	0.00105	0.00184	0.03194
Aquaculture: shellfish	Operation	0.00545	0.00956	0.16611
Aquaculture: shellfish	Set-up	0.00054	0.00041	0.00783
Fishing: benthic trawling	Mooring/anchoring	0.89099	0.83975	0.78081
Fishing: benthic trawling	Operation	89.09860	83.97510	78.08124
Fishing: Nets	Operation	6.86605	6.47122	6.01704
Fishing: Nets	Set-up	6.86605	6.47122	6.01704
Fishing: Pelagic trawls	Mooring/anchoring	0.17532	0.16524	0.15364
Fishing: Pelagic trawls	Operation	17.53183	16.52368	15.36396
Oil and Gas	Construction	0.00538	0.00538	0.00000
Oil and Gas	Operation	0.10760	0.10760	0.00230
Sand/gravel mining	Operation	2.55918	3.37578	4.09468
Sand/gravel mining	Disposal	2.55918	3.37578	4.09468
Shipping	Mooring/anchoring	0.07972	0.07972	0.11081
Shipping	Operation	20.86627	20.86627	29.00411
Telecoms and Electricity	Operation	0.04168	0.05602	0.07762
Telecoms and Electricity	Laying cables	0.00104	0.00143	0.00108
Wind farms	Construction	0.06144	0.17251	0.27723
Wind farms	Operation	0.73154	2.11163	4.88391

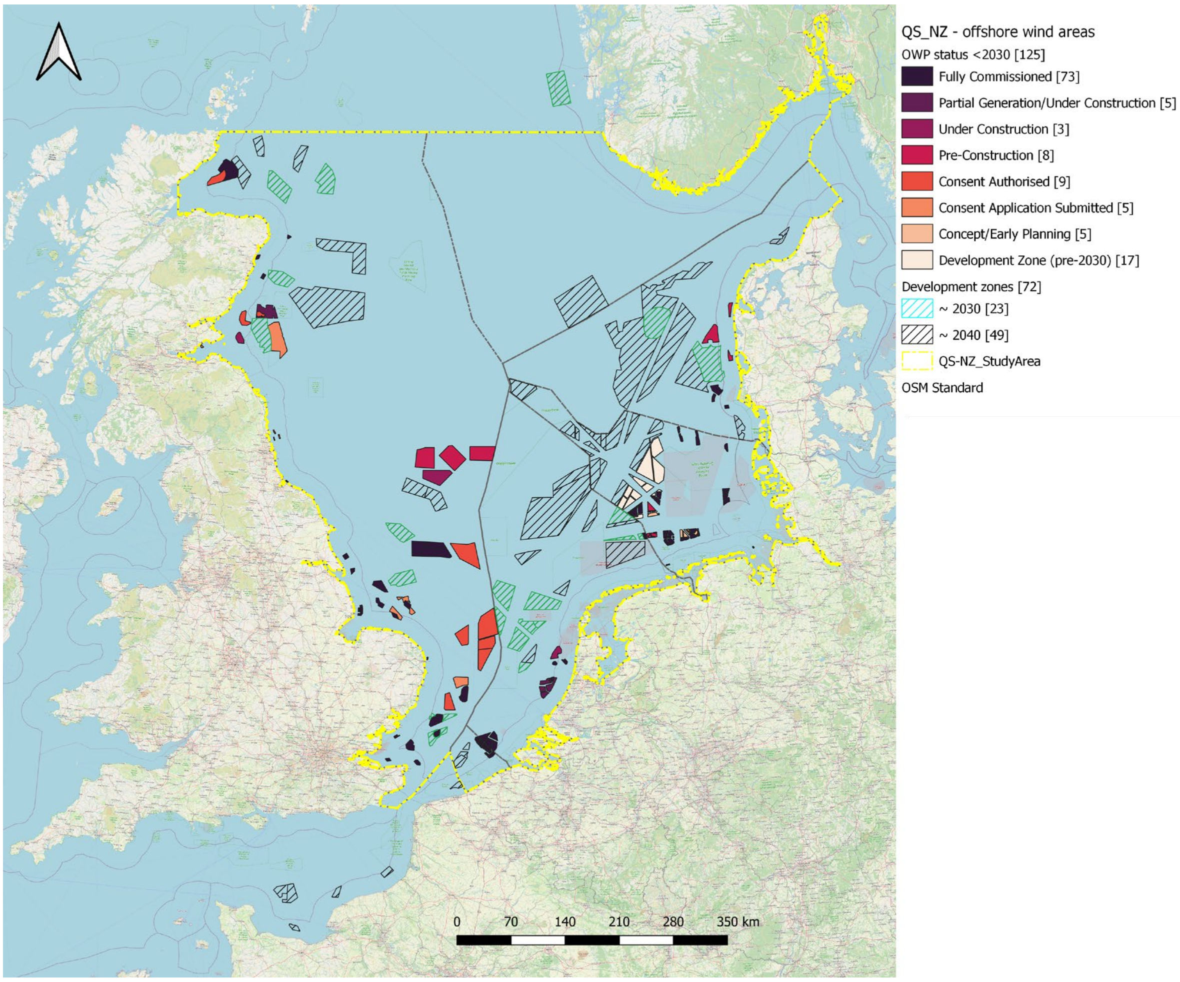


Figure 4 Map of the status of offshore wind farm areas with indication of different stages of development. Based on the information provided by RWS and elaborated by WMR in October 2023.

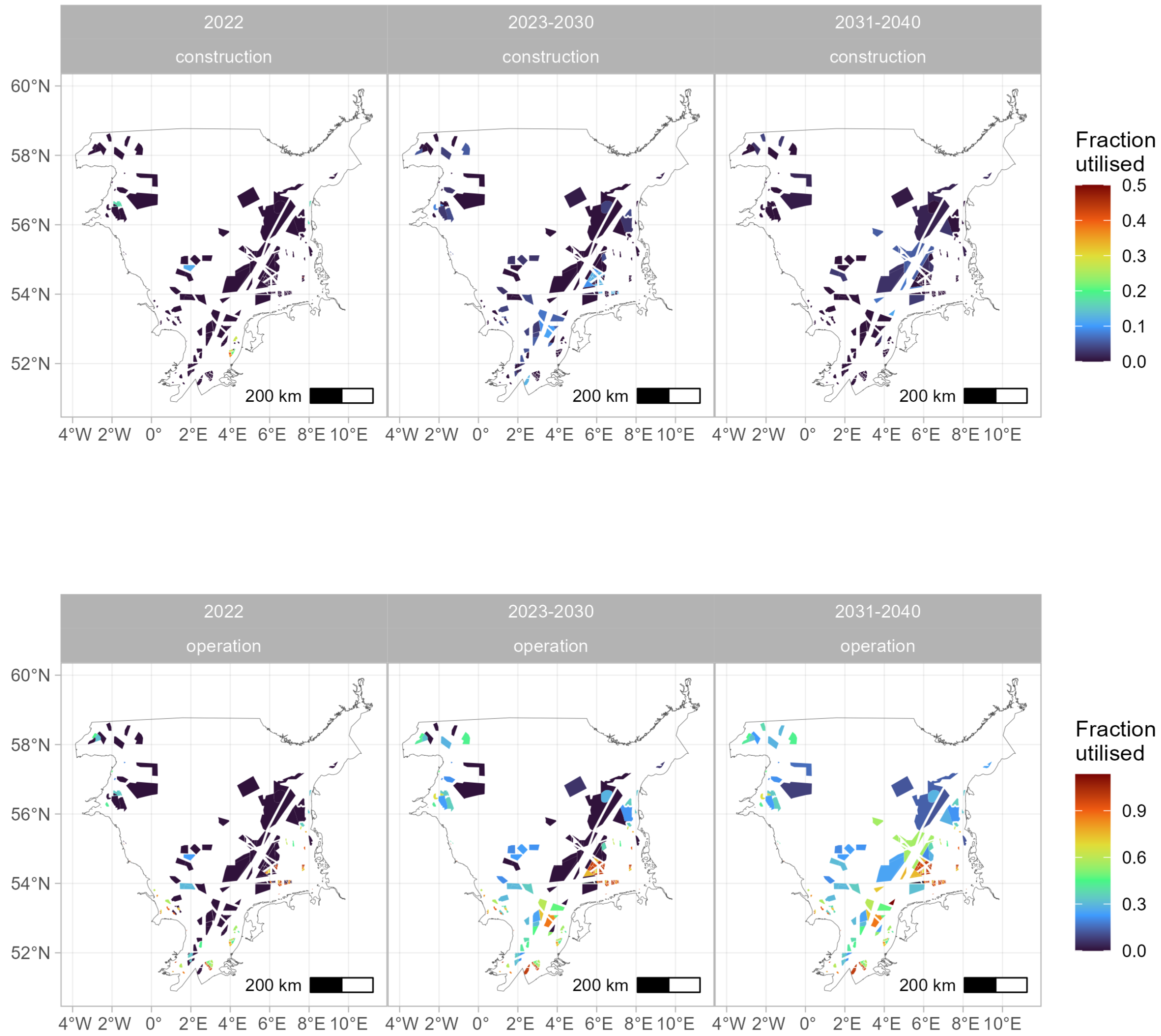


Figure 5 Map of offshore wind farm areas showing fractions of the area utilised by OWF (per year in case of construction) in the different periods (scenarios). Based on the information provided by RWS and elaborated by WMR in October 2023. Note that surface area for each area differs, therefore the fraction utilised applies to varying surface areas. In the construction phase (upper panel) black indicated that the area is not under construction or already in operation. In the operation phase (lower panel) black indicates that the area is not in operation.

2.6 Ecological components: habitat types, species groups and species

A selection is made of relevant ecological components of the North Sea. The selection of habitat types, species groups and species is as follows:

- All ecosystem components (as represented by species groups) identical to the CIA method in the version of Piet et al. (2023) and the corresponding CIA database (included in Table 2).
- In consultation with RWS and CEAF group, WMR has made a selection for 16 bird species, all so-called KEC species (used in Dutch impact studies for offshore renewable energy development) that are also on the OSPAR ORED list. In addition, 2 marine mammal species (Harbour porpoise, Grey seal) have been selected. The chosen bird species and mammal species are listed in Table 2.

Table 2 Ecosystem components and their aggregation level.

Ecosystem components	Aggregation level
Sublittoral sediment	Habitat type
Littoral sediment	Habitat type
Littoral rock and other hard substrata	Habitat type
Circalittoral rock and other hard substrata	Habitat type
Infralittoral rock and other hard substrata	Habitat type
Deep-seabed	Habitat type
Pelagic water column	Habitat type
Fish and cephalopods	Species group
Birds	Species group
Marine mammals	Species group
Red-throated diver	Bird species
Black-throated diver	Bird species
Black-legged kittiwake	Bird species
Northern gannet	Bird species
Atlantic puffin	Bird species
Razorbill	Bird species
Great black-backed gull	Bird species
Northern fulmar	Bird species
Common scoter	Bird species
Herring gull	Bird species
Little gull	Bird species
Lesser black-backed gull	Bird species
Common guillemot	Bird species
Sandwich tern	Bird species
Great cormorant	Bird species
Great skua	Bird species
Harbour porpoise	Mammal species
Grey seal	Mammal species

Data input

<u>Species density distribution for Exposure</u>

Spatially specific data are available for the habitat types (EMODnet), and the 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.

Seabird species density maps for the international North Sea were recently calculated by Soudijn et al. (2022) based on monitoring data from ESAS + MWTL for the period 1991-2020. These bird species density maps were used for assessment of collision mortality and habitat loss due to offshore wind farms by respectively Potiek et al. (2022) and Soudijn et al. (2022) and were also used for the 16 selected bird species in the current quick scan.

<u>Species sensitivity for Effect potential</u>

To account for the sensitivity of each selected bird species to collision and displacement (Effect Potential) species specific information was used from literature (Bowgen & Cook, 2018; Cook et al., 2018; Leopold et al., 2014; Potiek et al., 2022; Soudijn et al., 2022), see Table 3. To account for the sensitivity to collision, use was made of avoidance rates (the proportion of birds taking action to avoid collision). These rates were used to calculate the collision risk, i.e. the percentage of birds overlapping with a wind farm area that will die from collision, assuming birds that are not able to avoid collision die. To account for the sensitivity to displacement, relative displacement risk scores (RDRS) were used that reflect the fraction of exposed birds that will die from displacement. RDRS were derived by Leopold et al. (2014) and also used by Soudijn et al. (2022) in a KEC 4.0 study The RDRS were used as displacement risk, i.e. the percentage of birds overlapping with a wind farm area that will die from displacement (which is caused by the pressure "disturbance (visual) of species")

Table 3 Species sensitivity of birds for collision and displacement caused by OWF.

Species	Collision Risk (%)	Displacement Risk (%)
Red-throated Diver	0.50 #	8 #
Black-throated diver	0.56 #	8 #
Black-legged kittiwake	0.80 **	1.6 #
Northern gannet	1.10 **	0.8 #
Atlantic puffin	0.03 #	2.4 #
Razorbill	0.04 #	3.6 #
Great black-backed gull	0.50 **	1.6 #
Northern fulmar	0.11 #	0.4 #
Common scoter	0.30 #	8 #
Herring gull	0.50 **	0.8 #
Little gull	0.50 *	1.2 #
Lesser black-backed gull	0.20 **	0.8 #
Common guillemot	0.09 #	3.6 #
Sandwich tern	1.00 *	2.4 #
Great cormorant	0.70 #	1.2 #
Great skua	0.50 *	0.8 #

Leopold et al. (2014)
* Potiek et al. (2022)
** Cook et al. (2018); Potiek et al. (2022)

Impact Risk calculations

In this study 3 types of Impact Risk calculations will by performed by application of SCAIRM and the 3 data input options listed in section 2.4.3. An overview of these Impact Risk calculations is shown in the table below. The results will be presented in Chapter 3.

Impact risk calculation types	Study area	Calculated scenarios	Ecosystem components	Results sections
1) Impact risk of human activities for species groups and habitats	Greater North Sea (OSPAR area II)	2022 (baseline/ current), 2030, 2040	3 species groups and 7 habitats (see Table 2)	3.1
2) Impact risk of human activities for selected species	Greater North Sea (OSPAR area II)	2022 (baseline/ current), 2030, 2040	16 bird species and 2 mammal species (see Table 2)	3.2.1
3) Impact Risk of OWF for selected species	Greater North Sea (OSPAR area II)	2022 (baseline/ current), 2030, 2040	16 bird species and 2 mammal species (see Table 2)	3.2.2

3 Results

3.1 Impact Risk of human activities for North Sea species groups and habitats

Based on the results of the calculations for the baseline and future scenarios in chapter 2 (data option 1 in section 2.4.3, corresponding Impact Risk calculation type 1 in section 2.6, scenario values in Table 1), benthic trawling poses the highest risk for the ecosystem components of the North Sea for the base line as well as future developments (Figure 6). The contribution of wind farms to the Impact Risk is relatively small compared to some other human activities, but relatively large compared to many other activities clustered in the "other" category of activities, which is also shown in Figure 7. Compared to the other activities OWF construction contributes ~1% to the total impact risk (unweighted average for all ecosystem components), which increases marginally over time. For operational OWFs the average contribution to impact risk is 0.7% in the base scenario, which increases to 1.0% in the period 2023-2030 and 1.6% in the period 2031-2040. Specifically for the birds, the contribution to the total impact of OWF construction varies between 1.5% and 1.6%, for mammals this is between 3.5% and 3.7%. For the operational phase of OWF contribution to the total impact for birds increases from 2.6%, to 4.3% and finally 7.4% for each of the successive scenarios. For mammals this starts at 0.86% and increases to 1.0% and finally 1.4% for the successive scenarios.

Of all ecosystem components, fish (and cephalopods) are most impacted by the combined human activities. The Impact Risk of the main human activities in the future scenarios shows a similar pattern compared to the Impact Risk of the baseline (Figure 6) but the total Impact Risk on the North Sea decreases (Table 4). This is mainly caused by the decrease in benthic trawling expected for the future scenarios. There are differences per ecosystem component, however. Although the total Impact Risk is lower in future scenarios compared to the baseline, the Impact Risk for birds is higher. Also, a small increase for the littoral habitats in the 2040 scenario is shown (Table 4).

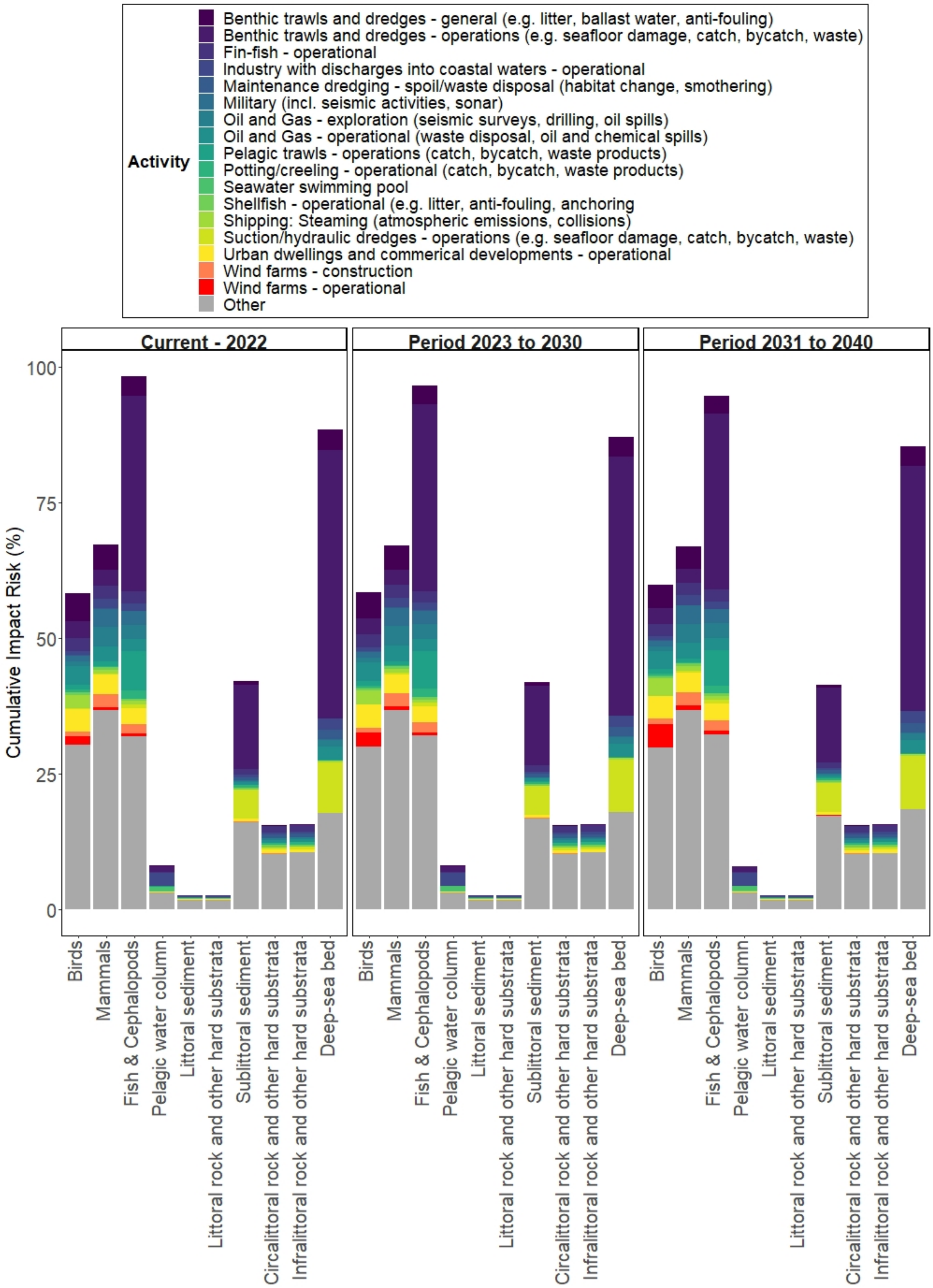


Figure 6 Cumulative impact risk (% of population or habitat quality) of human activities on ecological components of the North Sea according to baseline (left), scenario for 2030 (middle) and scenario for 2040 (right). The 16 main activity-phase combinations are shown separately. The other activities are combined in "other".

Table 4 Change in cumulative impact risk (%) of human activities on ecological components in two future scenarios (2030, 2040) relative to the baseline (2022). An increase is shown in bold.

Ecological component	Change in impact risk (%) 2030 vs. 2022	Change in impact risk (%) 2040 vs. 2022
Birds	**0.4%**	**2.9%**
Mammals	-0.3%	-0.4%
Fish & Cephalopods	-1.7%	-3.7%
Pelagic water column	-0.8%	-1.7%
Littoral sediment	0.0%	**0.2%**
Littoral rock and other hard substrata	0.0%	**0.2%**
Sublittoral sediment	-0.6%	-1.6%
Circalittoral rock and other hard substrata	-0.2%	0.0%
Infralittoral rock and other hard substrata	-0.2%	0.0%
Deep-seabed	-1.6%	-3.6%

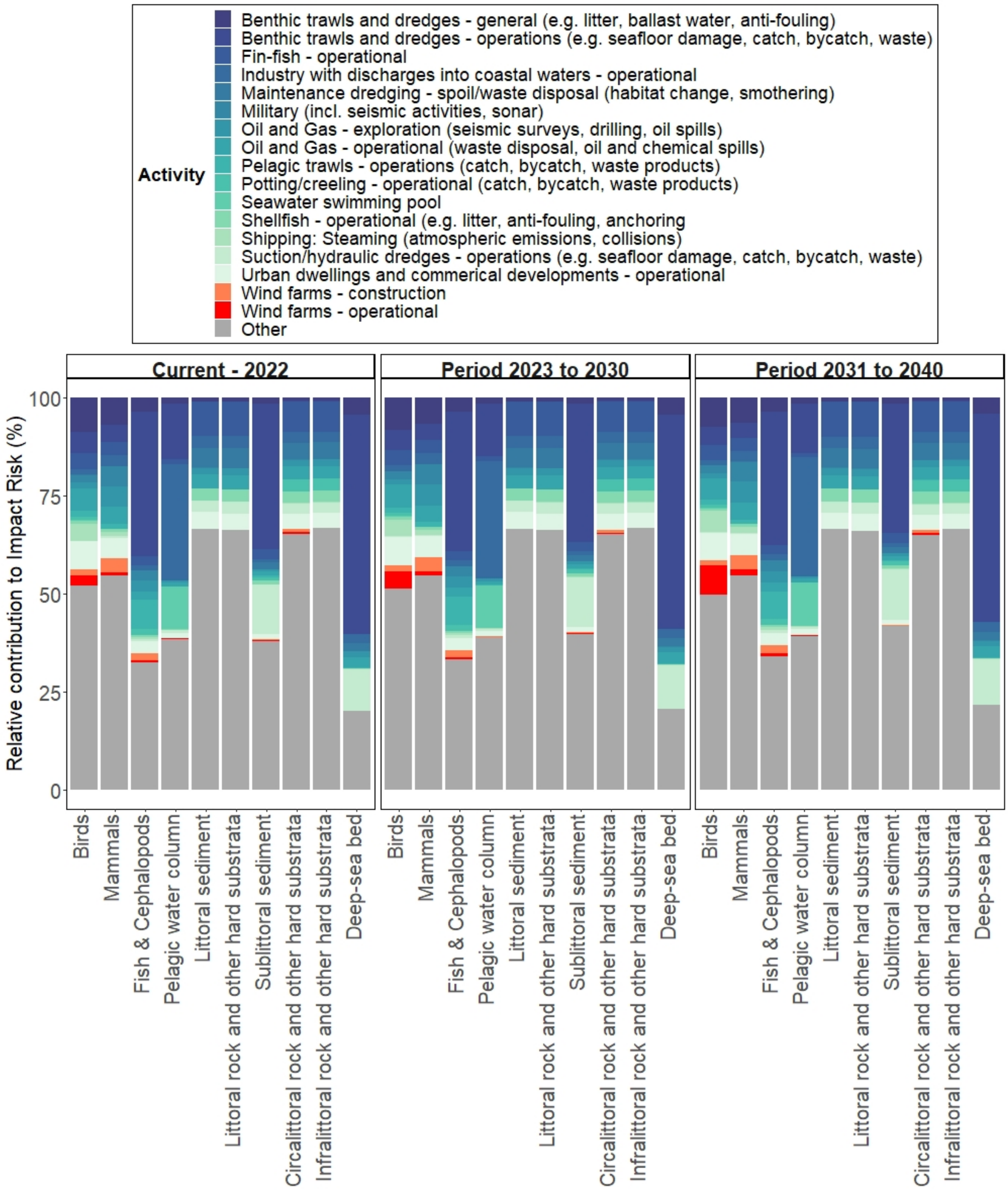


Figure 7 Relative contribution to impact risk (%) of human activities on ecological components of the North Sea, according to baseline (left), scenario for 2030 (middle) and scenario for 2040 (right). The 16 main activity-phase combinations are shown separately. The other pressures are combined in "Other".

The relatively high contribution of benthic trawling to Impact Risk is also reflected by the main pressures on the ecosystem components of the North Sea; extraction of flora and/or fauna and abrasion/damage (Figure 8). The risk of pressures differs greatly among the ecosystem components, which is also shown on a relative scale (Figure 9). For birds, the first 8 pressures of the 13 pressures listed in Figure 9 are the pressures exerting the most Impact Risk.

Main pressures (together responsible for nearly all Impact Risk) caused by OWF are collision, displacement by disturbance of species, (continuous and impulsive) noise, introduction of (non-) synthetic compounds, input of light and electromagnetic changes. Other sectoral activities than OWF contributing to these pressures with relatively high Impact Risk are e.g. oil & gas and military, mainly related to noise, input of light and introduction of (non-) synthetic compounds. A relatively high contribution to the Impact Risk of the pressure disturbance is from shipping whereas other forms of renewable energy (tidal and wave energy) highly contribute to collision.

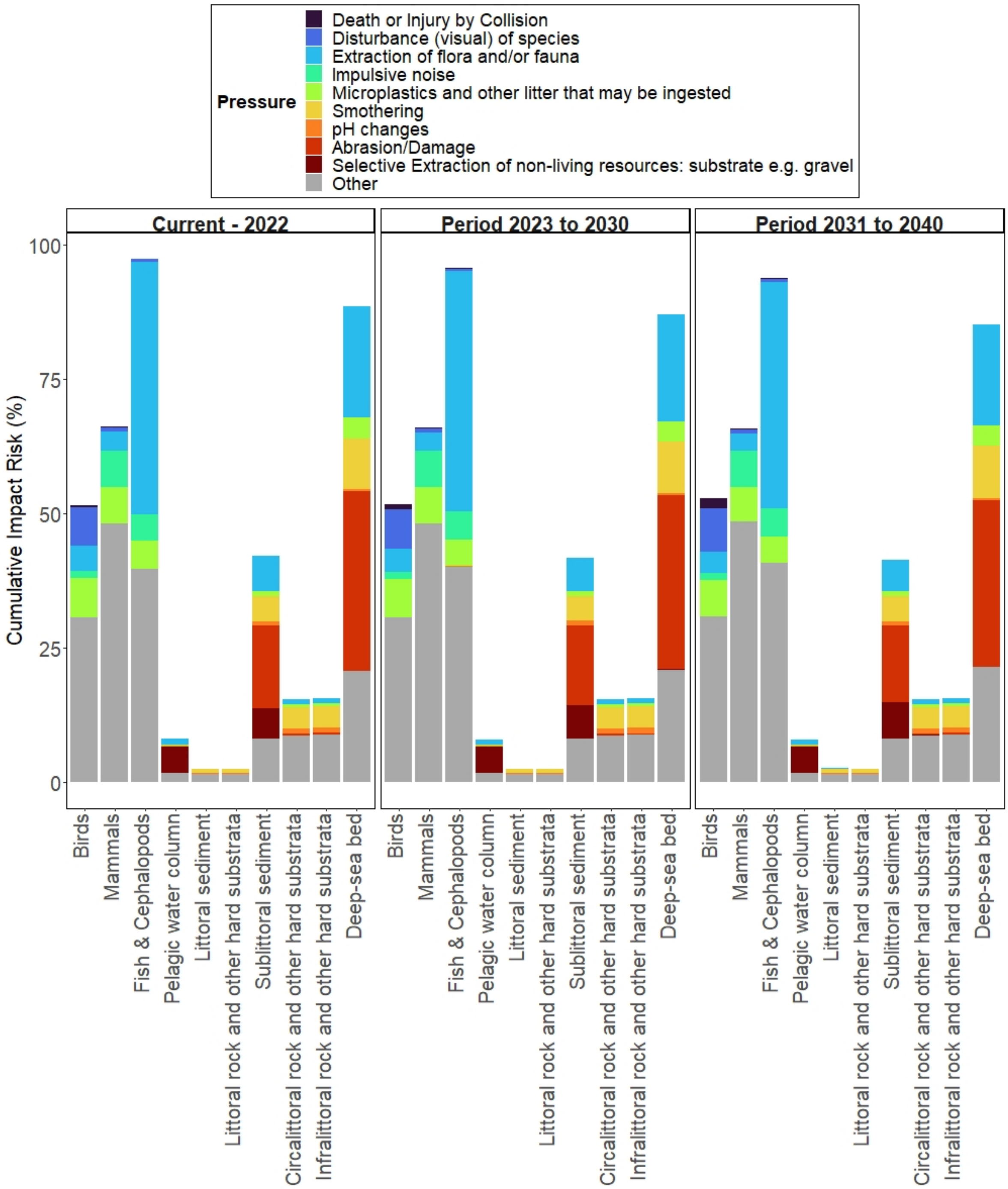


Figure 8 Cumulative impact risk (% of population or habitat quality) of pressures on ecological components of the North Sea, according to baseline (left), scenario for 2030 (middle) and scenario for 2040 (right). The 8 main pressures (top 5 per EC) are shown separately. The other pressures are combined in "other".

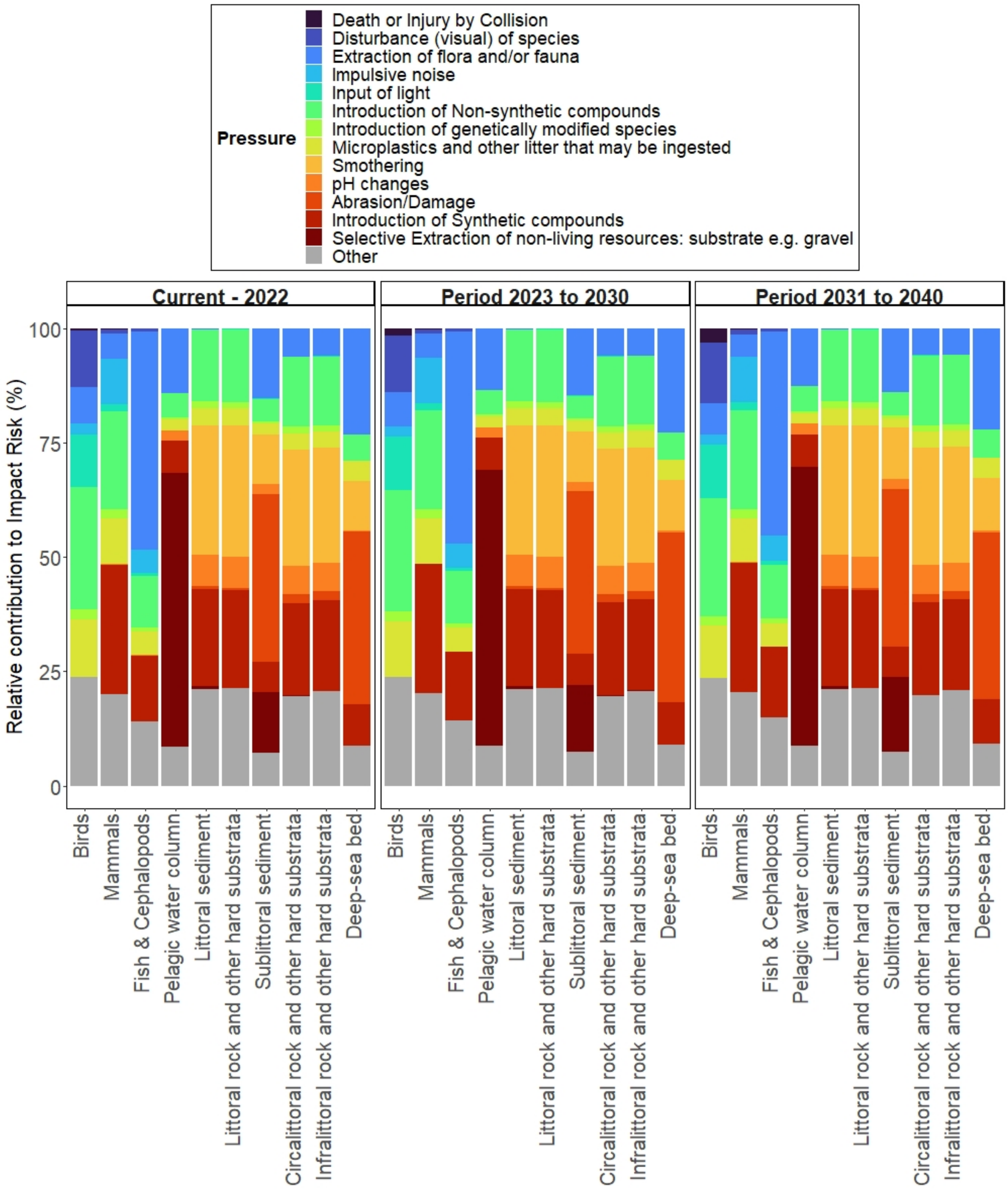


Figure 9 Relative contribution to impact risk (%) of pressures on ecological components of the North Sea, according to baseline (left), scenario for 2030 (middle) and scenario for 2040 (right). The 13 main pressures are shown separately. The other pressures are combined in "other".

3.2 Impact Risk of human activities for North Sea species

This section describes the Impact Risk at a higher level of detail compared to the previous section, which is at the species level for birds and mammals (Table 5). For benthic communities, pelagic water column associated biota and fish & cephalopods, a higher level of detail was not feasible within this quick scan. Therefore, data input for these ecosystem components was not changed and consequently the output presented is at the level of habitats and group.

Table 5 Data input options (see section 2.4.3) used to assess the Impact Risk of human activities for North Sea ecosystem components

	Offshore wind			Other activities		
Ecosystem component	Option	Exposure	Sensitivity	Option	Exposure	Sensitivity
Birds	3	Species	Species*	1	Group	Group
Marine mammals	2	Species	Group	1	Group	Group

* Sensitivity to collision and disturbance were assessed specifically for species. Other pressures were assessed for birds as a group.

3.2.1 Impact Risk of all human activities for selected species

The Impact Risk of the human activities on the North Sea differs per species and per scenario (Figure 10). The Red-throated diver, Black-throated diver, Common scoter, Razorbill and Common guillemot are subjected to the highest Impact Risk, whereas Northern fulmar has the least risk to impact. In the future scenarios the Impact Risk increases for all species compared to the baseline, especially in the period 2030-2040.

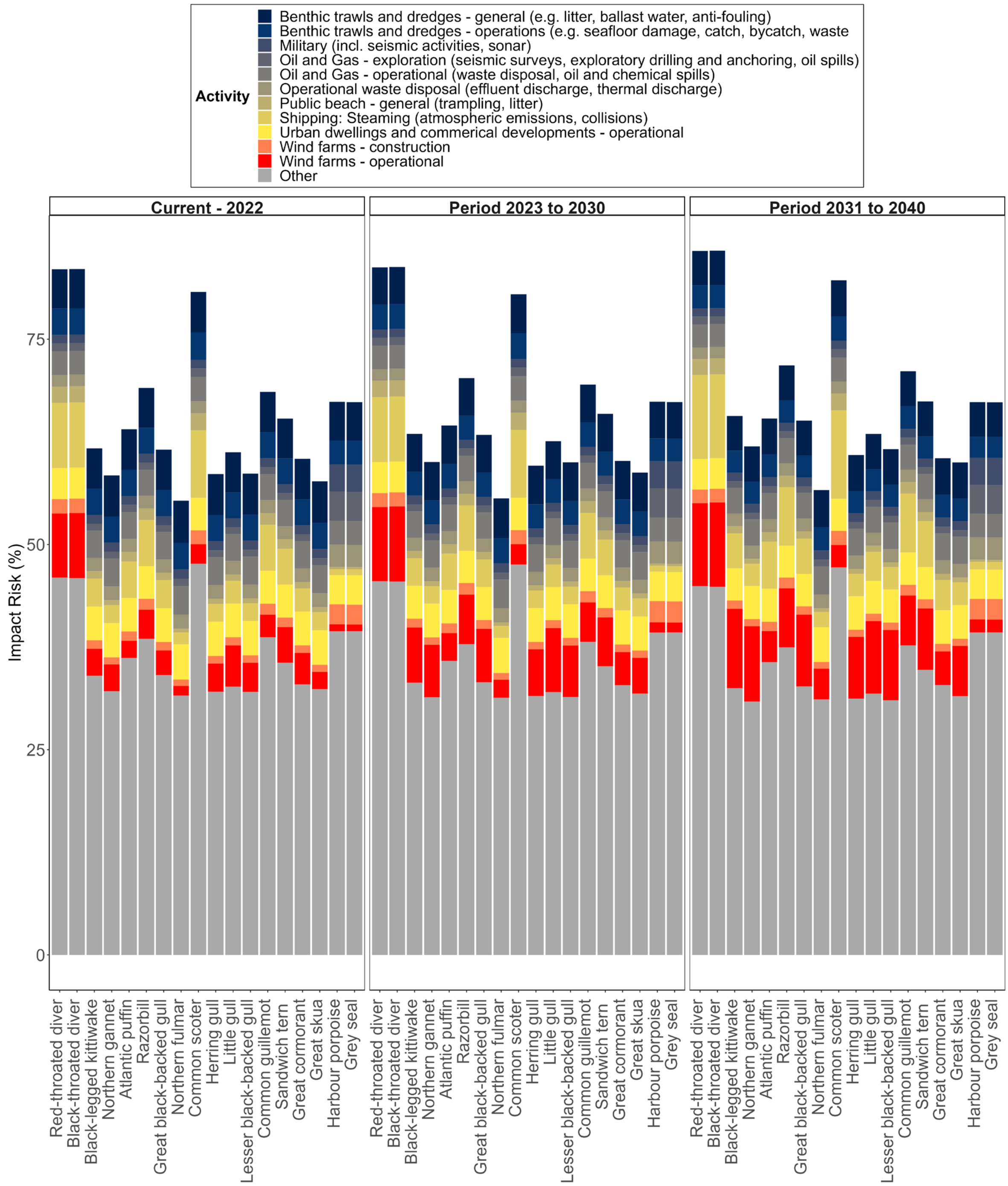


Figure 10 Cumulative impact risk of human activities on bird and mammal species in the baseline (2022, left) and two future scenarios (2030 middle, 2040 right). The 11 main activity-phase combinations are shown separately. The other activities are combined in "other".

The Impact Risk of future scenarios compared to the baseline (i.e. change in Impact Risk) differs per species (Figure 11 and Table 6).

In general, both future scenarios (2030 and 2040) are quite comparable concerning ranking of the bird species based on the increase in cumulative Impact Risk as compared to the baseline. Bird species with the highest future increase in cumulative impact risk are: Black-legged kittiwake, Great black-backed gull, Northern gannet, Lesser black-backed gull, Herring gull.

Bird species with the lowest future increase in cumulative impact risk are: Great cormorant, Common scoter, Red-throated and Black-throated diver, Atlantic puffin, Northern fulmar.

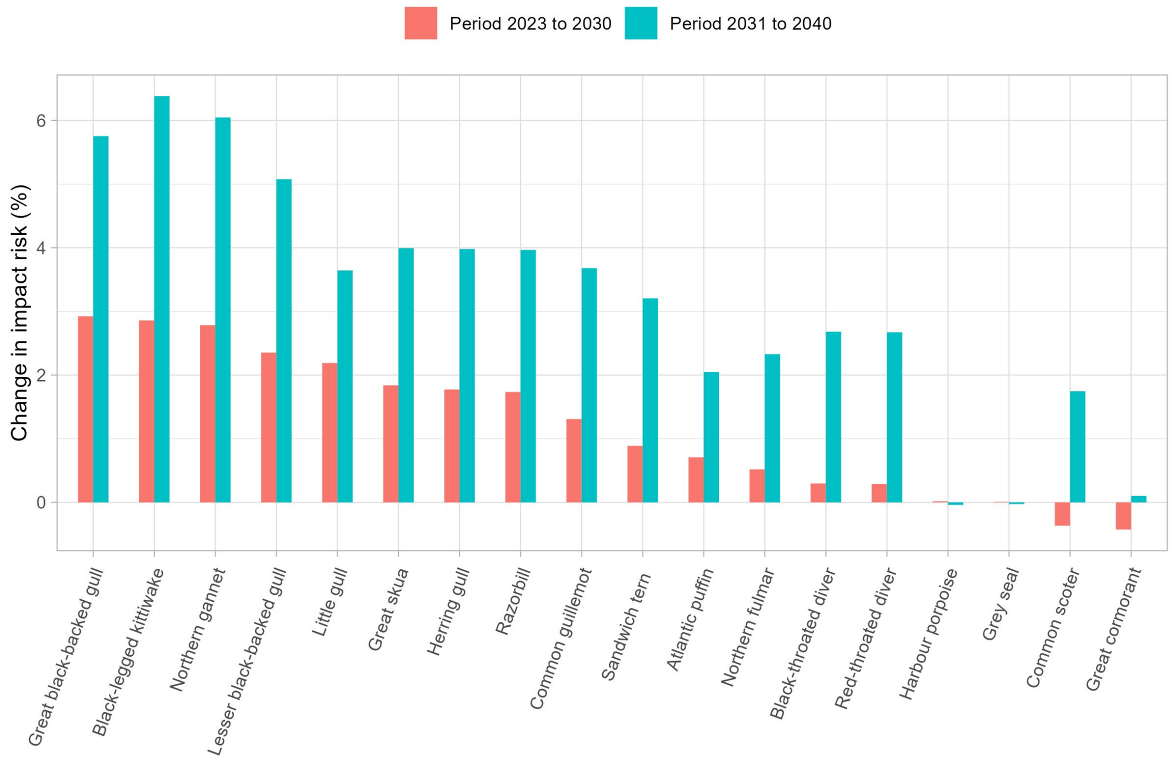


Figure 11 Change in cumulative impact risk of human activities on bird and mammal species in two future scenarios (2030, 2040) relative to the baseline (2022).

Table 6 Change in cumulative impact risk of human activities on bird and mammal species in two future scenarios (2030, 2040) relative to the baseline (2022).

species	Change 2030/2022 (%)	Change 2040/2022 (%)
Great black-backed gull	2.9%	5.8%
Black-legged kittiwake	2.9%	6.4%
Northern gannet	2.8%	6.0%
Lesser black-backed gull	2.4%	5.1%
Little gull	2.2%	3.6%
Great skua	1.8%	4.0%
Herring gull	1.8%	4.0%
Razorbill	1.7%	4.0%
Common guillemot	1.3%	3.7%
Sandwich tern	0.9%	3.2%
Atlantic puffin	0.7%	2.0%
Northern fulmar	0.5%	2.3%
Black-throated diver	0.3%	2.7%
Red-throated diver	0.3%	2.7%
Harbour porpoise	0.0%	0.0%
Grey seal	0.0%	0.0%
Common scoter	-0.4%	1.7%
Great cormorant	-0.4%	0.1%

The offshore energy development contributes most to the change in Impact Risk (Figure 12). Impact Risk from offshore wind farms increases in the future scenarios with a higher increase expected for birds than for mammals. For the marine mammal species this is mainly related to the construction of wind farms and for the bird species the operational wind farms contribute most to the change in Impact Risk. Other activities for which the Impact Risk increases in future scenarios for both birds and mammals are shipping, extraction of materials (e.g. sand), telecoms & electricity and aquaculture. Activities for which the Impact Risk decreases in future scenarios are oil & gas and fishing. For marine mammals the net change in Impact Risk is negligible whereas for birds the net change is an increase for most species in both future scenarios (Table 10). This means that for mammals the size of increase in Impact Risk from offshore wind farms is similar to the size of decrease in Impact Risk from oil & gas and shipping. However, for birds the size of increase in Impact Risk from offshore wind farms is higher than the size of decrease in Impact Risk from oil & gas and shipping. Exception is for the Common scoter and Great cormorant for which the Impact Risk is expected to decrease for 2022-2030 although the longer term scenario (2022-2040) will lead to an increase in Impact Risk.

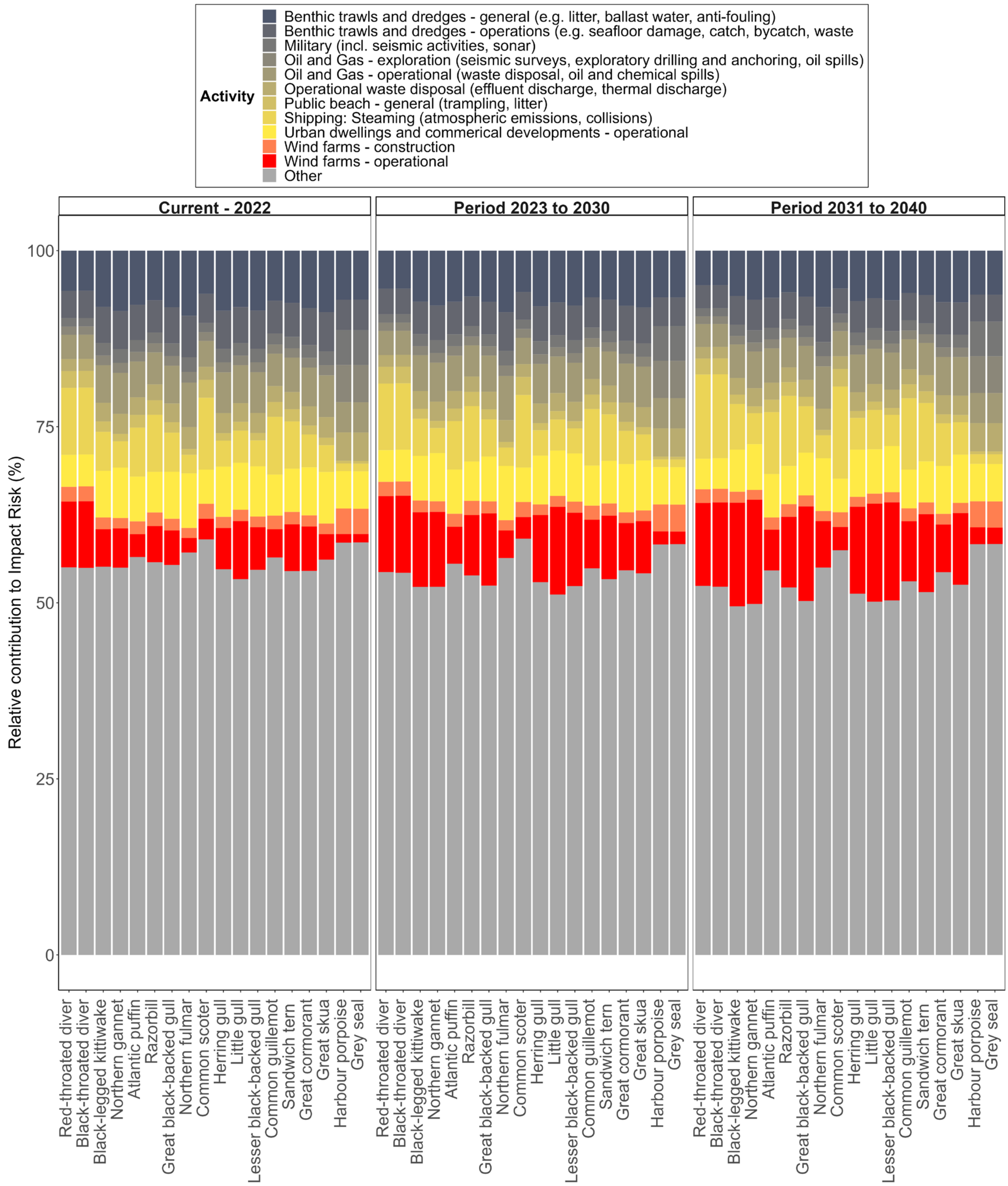


Figure 12 Relative contribution to impact risk (%) of human activities on 16 bird and 2 mammal species of the North Sea species in the baseline (2022, left) and two future scenarios (2030 middle, 2040 right). The 11 main activity-phase combinations are shown separately. The other pressures are combined in "other".

The Impact Risk of the pressures of all human activities (Figure 13) again shows that the Red-throated diver, Black-throated diver and Common Scoter are subjected to the highest Impact Risk, whereas Northern fulmar has the least Impact Risk. For birds, disturbance and input of light pose the highest risk. Most significant changes in the contribution to Impact Risk for the future scenarios are the increase of impulsive noise for marine mammals (caused by offshore wind development) and increase of barrier to species movement, disturbance and death or injury by collision for birds (caused by offshore wind development and shipping). For marine mammals in the baseline scenario, most Impact Risk is posed by the introduction of (non)synthetic compounds (see also Figure 14).

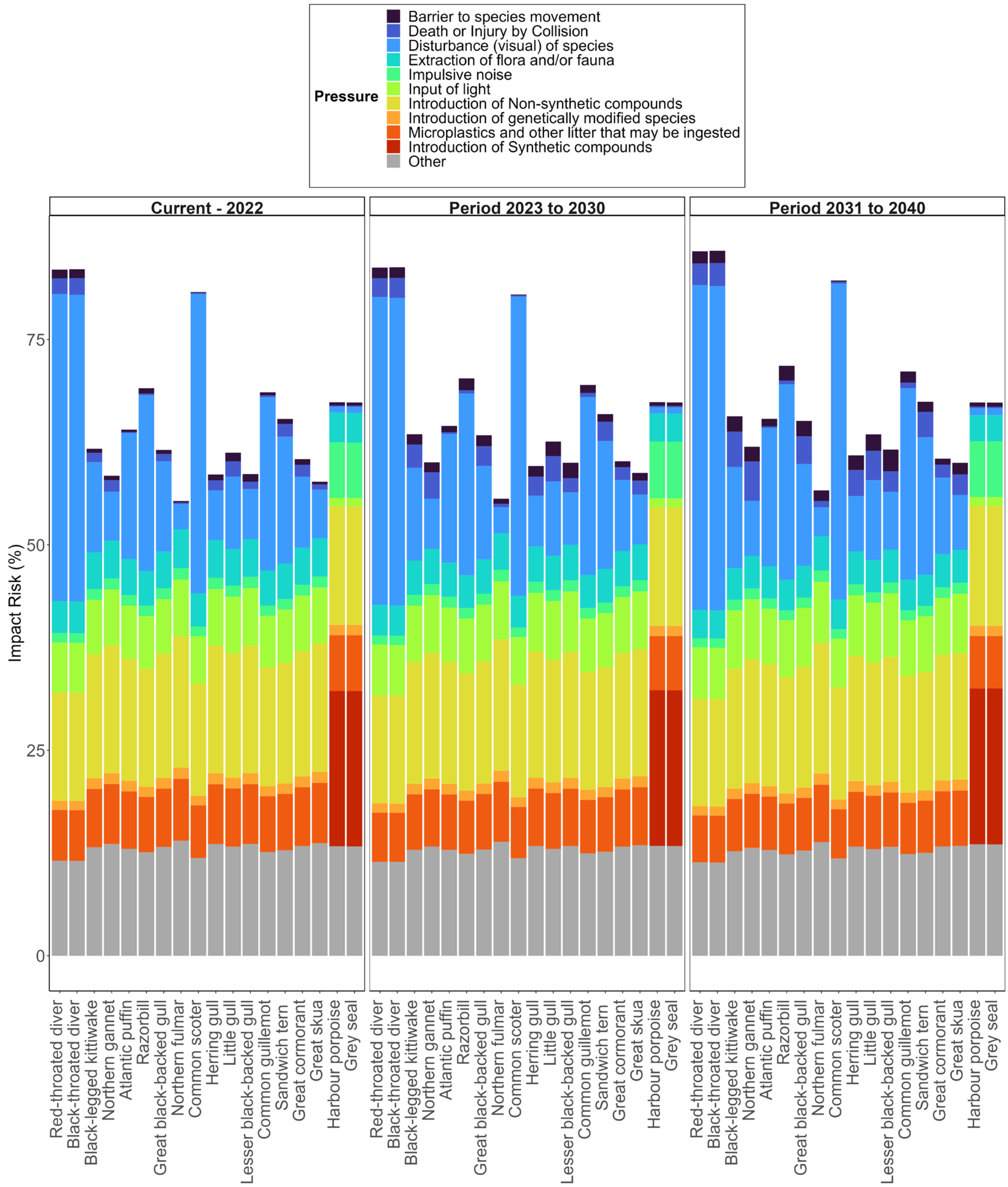


Figure 13 Cumulative impact risk of pressures on bird and mammal species in the baseline (2022) and two future scenarios (2030, 2040). The 10 main pressures are shown separately by colour. The other pressures are combined in "other" in grey.

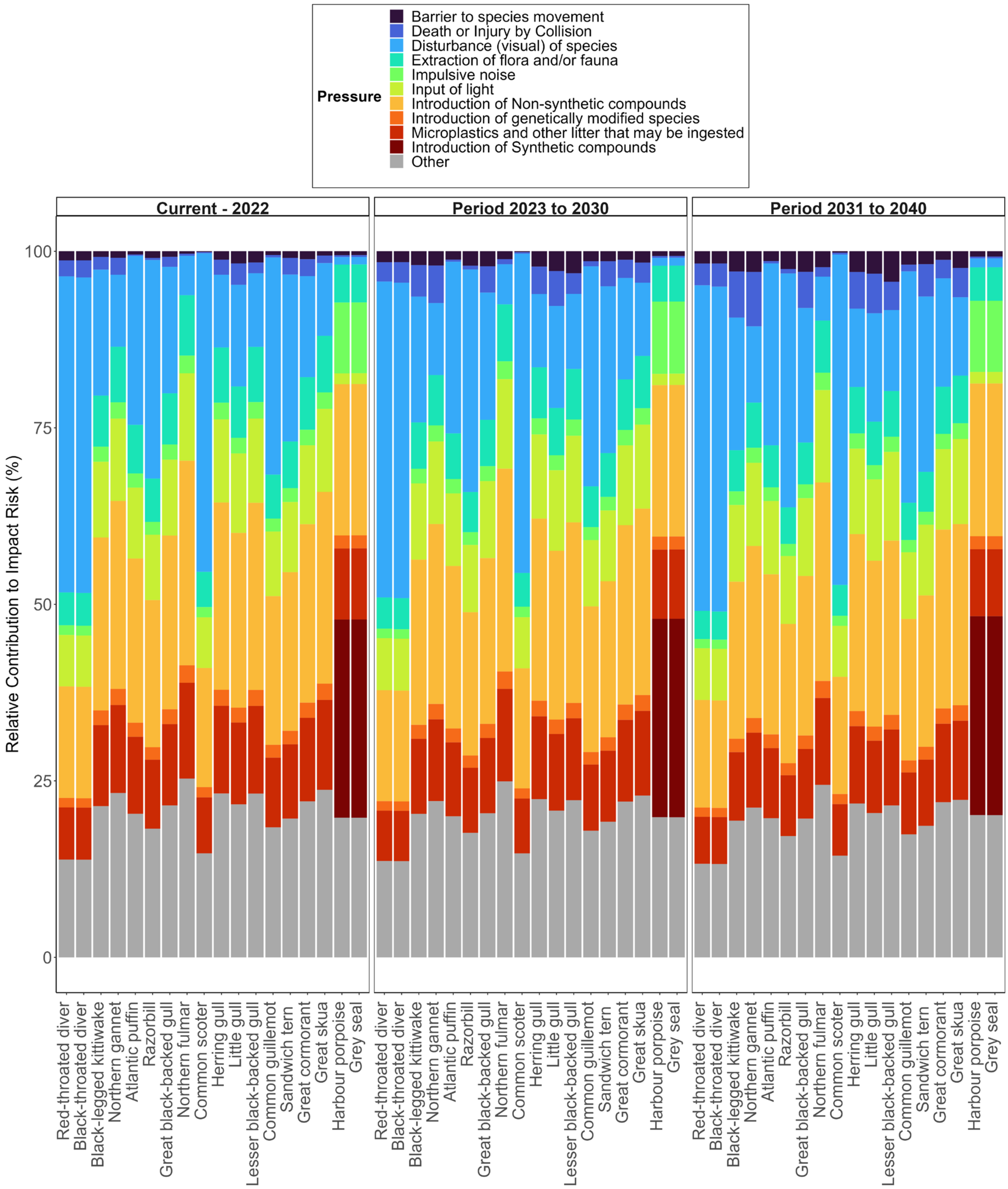


Figure 14 Relative contribution to impact risk (%) of pressures on bird and mammal species of the North Sea species in the baseline (2022) and two future scenarios (2030, 2040). The 10 main pressures are shown separately (in colour). The other pressures are combined in "other" (in grey).

3.2.2 Impact Risk of OWF for selected species

3.2.2.1 Exposure of selected species to offshore wind farms

For a selection of impact chains (i.e. those impact chains related to offshore wind energy and bird species or marine mammal species) the spatial overlap was estimated using the offshore wind energy data received from RWS and processed by WMR (*Figure* ***4***, Figure 5) and species density maps available at WMR (see section 2.6). Maps with spatial overlap (extent) of bird and mammal species with OWF in the operational phase in baseline as well as both future scenarios can be found in Annex 3. An aggregated value for the proportion of the ecosystem component co-occurring with the wind farm area was calculated for the baseline and each future scenario (Figure 15). This spatial overlap value combined with the dispersal of the pressure reflects the chance that the ecosystem component encounters the pressure and can therefore be referred to as likelihood (of encounter) (Piet et al., 2021a), or exposure.

The spatial overlap of the bird and mammal species with OWF in the operational phase is much higher than in the construction phase (Figure 15). Bird species vary in their exposure to wind farms, which is more apparent for the future scenarios. The highest increase in spatial overlap is expected for Northern fulmar (Figure 16). Great cormorant shows the smallest increase in spatial overlap for future scenarios (Figure 16). Red-throated diver, Black-throated diver and Sandwich tern are also among the species with a relatively low increase in spatial overlap. The marine mammals show a relatively high spatial overlap with wind farms in the operational phase which increases considerably in the future scenarios. There is not much difference between Grey seal and Harbour porpoise.

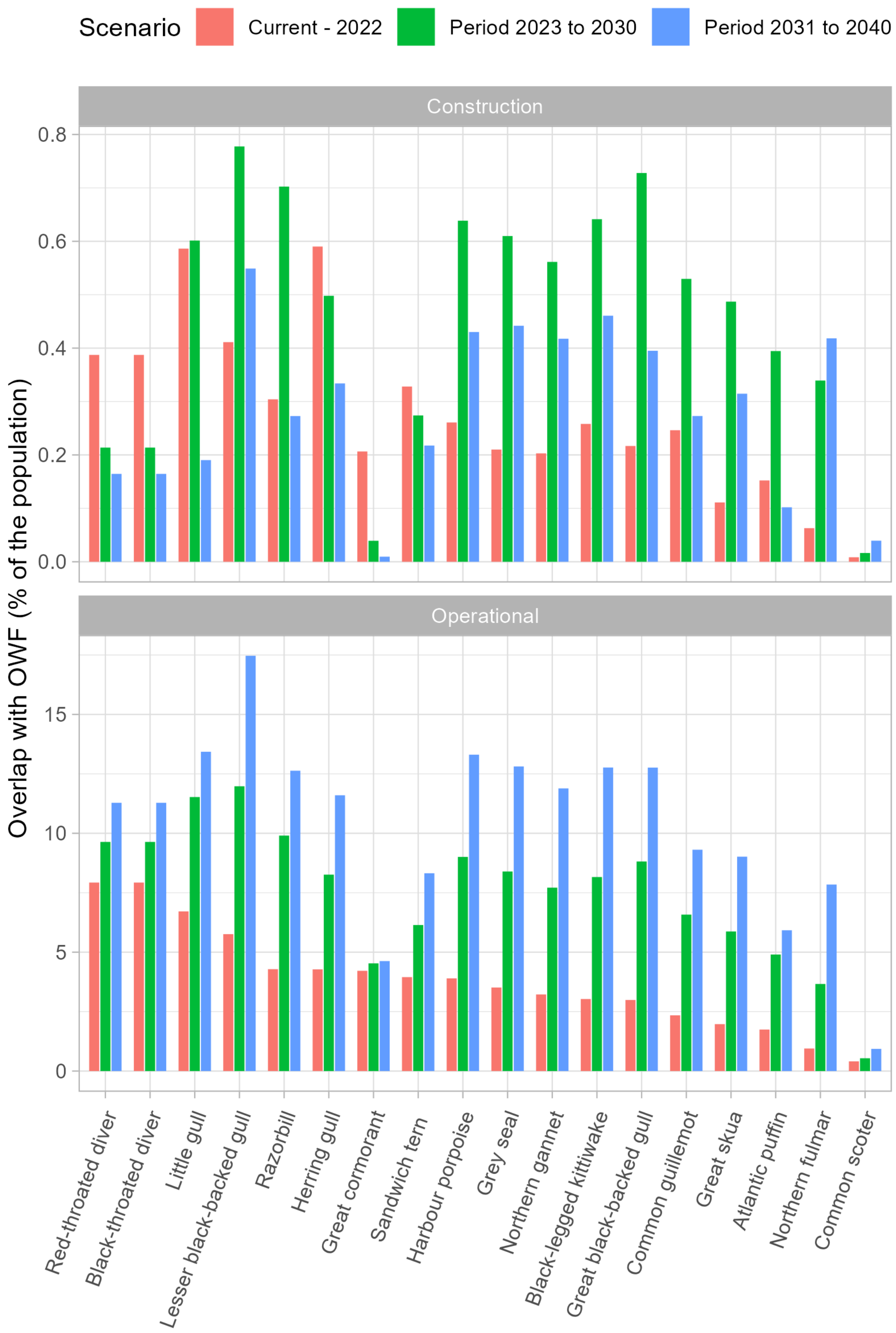


Figure 15 Spatial overlap (extent) of bird and mammal species with OWF in the construction phase (upper panel) and in the operational phase (lower panel). The species are assorted on the baseline of operational OWFs (2022) values from high to low.

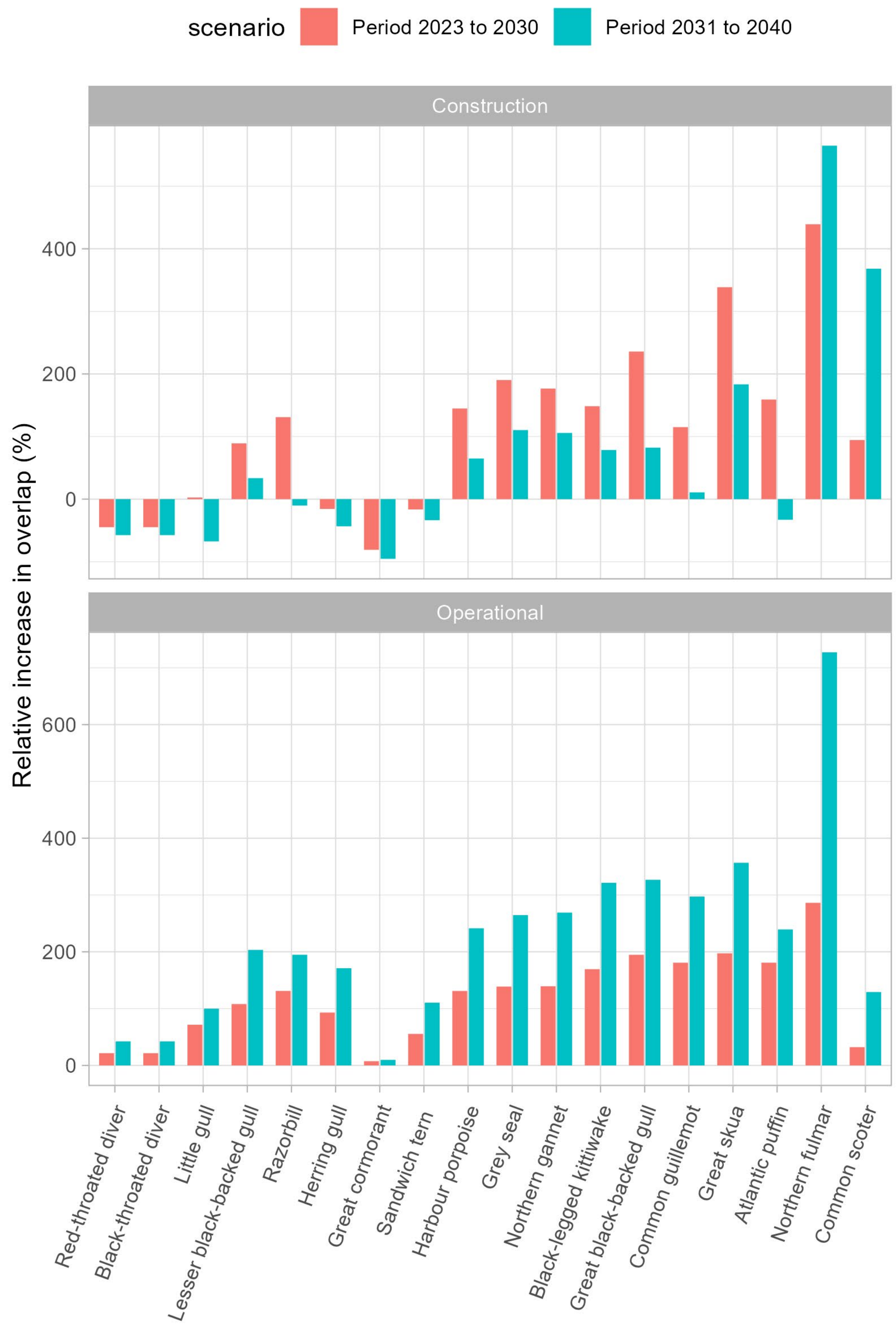


Figure 16 Relative increase in exposure (likelihood) of bird and mammal species to OWF in future scenarios in relation to the baseline of construction phase (upper panel) and operational OWFs (lower panel) (2022). The species are assorted on the baseline (2022) values for the operational phase from high to low (Figure 15).

3.2.2.2 Change in Impact Risk from offshore wind development for selected species

Up to 2030 among the bird species, Great black-backed gull, Black-legged kittiwake, Northern gannet, Great skua show the highest future (2030) increase in impact risk with respect to the baseline (2022). Bird species with the lowest future increase in impact risk are: Common scoter, Great cormorant, Red-throated diver and Black-throated diver. the Harbour porpoise and Grey seal show a moderate increase in Impact Risk compared to the baseline (Figure 17 and Table 7).

When taking a longer period into account (up to 2040), Black-legged kittiwake shows the highest increase in impact risk 150% increase compared to the baseline), closely followed by Northern gannet (145%) and Great black-backed gull (143%). The bird species with the lowest future increase in impact risk for this long-term scenario (2040) are the same as for 2030: Great cormorant, Common scoter, Red-throated diver and Black-throated diver.

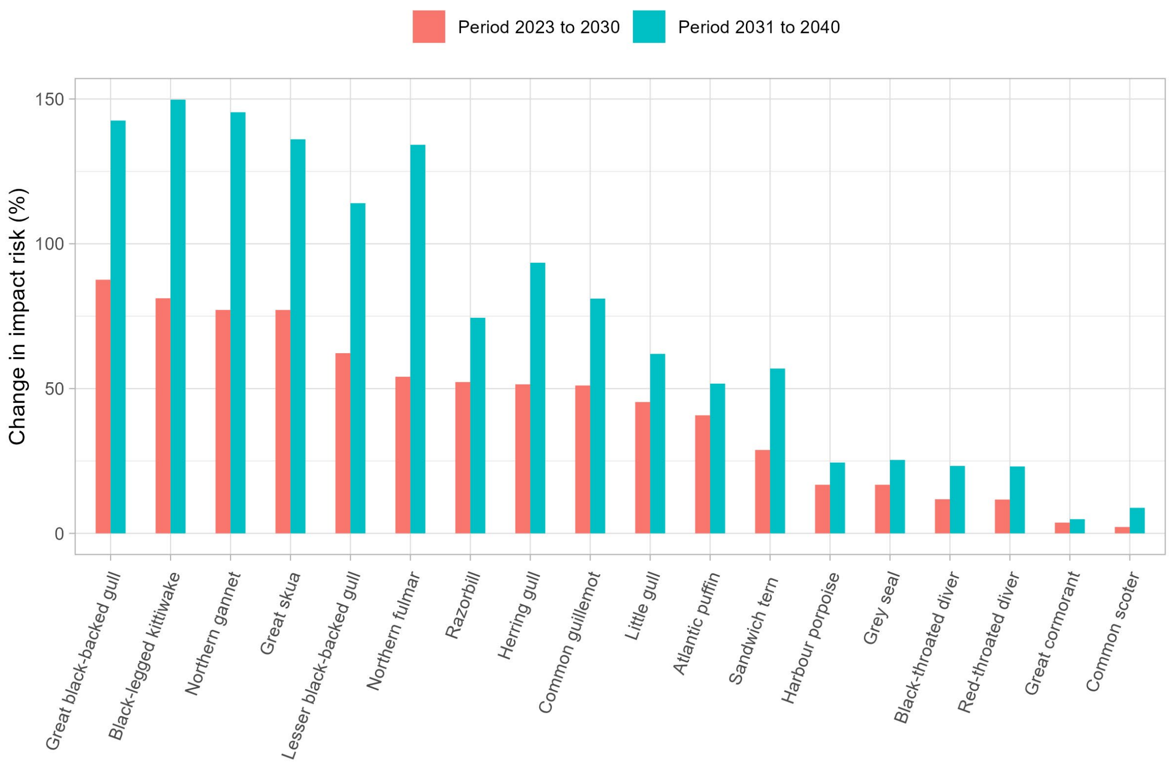


Figure 17 Change in impact risk (%) of OWF on bird and mammal species in two future scenarios (2030, 2040) relative to the baseline (2022). The species are assorted on the 2030/2022 values from high to low.

Table 7 Change in impact risk of OWF on bird and mammal species in two future scenarios (2030, 2040) relative to the baseline (2022).

species	Change 2030/2022 (%)	Change 2040/2022 (%)
Great black-backed gull	88%	143%
Black-legged kittiwake	81%	150%
Northern gannet	77%	145%
Great skua	77%	136%
Lesser black-backed gull	62%	114%
Northern fulmar	54%	134%
Razorbill	52%	74%
Herring gull	51%	93%
Common guillemot	51%	81%
Little gull	45%	62%
Atlantic puffin	41%	52%
Sandwich tern	29%	57%
Harbour porpoise	17%	24%
Grey seal	17%	25%
Black-throated diver	12%	23%
Red-throated diver	12%	23%
Great cormorant	4%	5%
Common scoter	2%	9%

3.2.3 Impact Risk against population status of selected bird species

The expected increase in Impact Risk for bird species from all activities and from OWF in future scenarios (section 3.2.1 and 3.2.2.2, respectively) is presented here against their EU status (Table 8). Note that the status and trend shown here are for European populations and therewith includes the North Sea as well as the Celtic Sea.

Threatened populations
There are 3 bird species with a threatened population status (Black-legged kittiwake, Herring gull, Northern fulmar) with relatively high increase in impact of OWF (Impact Risk in future scenarios increases by 51-150% compared to the Impact Risk in 2022, Table 8). Two (Black-legged kittiwake, Herring gull) of these species also have a relatively high increase (2-6%) in cumulative Impact Risk from human activities combined. One bird species has a near threatened population status (Great black backed gull) and is among the bird species with the highest increase in Impact Risk in future developments for OWF (88-143%) as well as for human activities combined (3-6%). These species with (nearly) threatened populations should receive special attention in protection measures including mitigation of OWF impacts.

Secure but declining populations
There is one species with a secure population status but a declining trend (Lesser black-backed gull) which faces a relatively high future increase in Impact Risk caused by OWF (62-114%) and by all activities combined (2-5%). The Common scoter has an unknown population status and a declining trend but the increase in Impact Risk is expected to be limited in the future (2-9% from OWF and 0-2% from all human activities). The populations of Little gull and Sandwich tern are secure but the trend is unknown. The increase in Impact Risk for these species is expected to be 29-62% from OWF and 1-4% from all human activities).

Secure populations
All other bird species (half of the selected bird species) have a secure population status and a stable or increasing trend. All these species are expected to face an increase in Impact Risk by future developments of OWF ranging from 4-5% for Great cormorant to 77-145% for Northern gannet. The change in Impact Risk caused by all human activities combined for these species ranges from -0.4-0.1% for Great cormorant to 3-6% for Northern gannet.

Table 8 The conservation status and (short term) trend of each bird species in the EU (Birds Directive 2009/147/EC, Article 12 reporting (2013-2018), EC (2021)) against the expected change in cumulative Impact Risk (IR) of human activities (Table 6) and of OWF (Table 7) on bird species in future scenarios relative to the baseline.

	EU population		**Change in IR of all activities**		**Change in IR of OWF**	
Species	**Status**	**Trend**	**2030/2022**	**2040/2022**	**2030/2022**	**2040/2022**
Black-legged kittiwake	Threatened	Decline	3%	6%	81%	150%
Herring gull	Threatened	Decline	2%	4%	51%	93%
Northern fulmar	Threatened	Decline	1%	2%	54%	134%
Great black-backed gull	Near Threatened	Decline	3%	6%	88%	143%
Common scoter	Unknown	Decline	-0.4%	2%	2%	9%
Lesser black-backed gull	Secure	Decline	2%	5%	62%	114%
Little gull	Secure	Unknown	2%	4%	45%	62%
Sandwich tern	Secure	Unknown	1%	3%	29%	57%
Northern gannet	Secure	Increase	3%	6%	77%	145%
Great skua	Secure	Increase	2%	4%	77%	136%
Razorbill	Secure	Increase	2%	4%	52%	74%
Common guillemot	Secure	Increase	1%	4%	51%	81%
Atlantic puffin	Secure	Increase	1%	2%	41%	52%
Black-throated diver	Secure	Increase	0.3%	3%	12%	23%
Red-throated diver	Secure	Stable	0.3%	3%	12%	23%
Great cormorant	Secure	Stable	-0.4%	0.1%	4%	5%

4 Conclusions

The conclusions that can be drawn from this quick scan are presented with a focus on OWF but also considering all other human activities. Marine biodiversity was represented at a relatively crude level by species groups and habitats and more detailed bird and mammal species.

Impact Risk of human activities for North Sea species groups and habitats

- Future scenarios for all human activities show a decrease in cumulative Impact Risk for the majority of the ecological components considered in this study, which is most pronounced for fish and deep seabed. On the other hand, for some ecological components an increase is predicted, especially for birds, which can be ascribed to the impact of OWF.
- On the basis of all human activities combined, benthic trawling poses the highest risk for the ecosystem components of the North Sea. The contribution of wind farms to the cumulative Impact Risk is at the moment (baseline: 2022) relatively small (~1% to the total impact risk (unweighted average for all ecosystem components)), which increases marginally over time. For birds and mammals, the contribution of OWF to the cumulative Impact Risk is higher. The operational phase of OWF causes the highest Impact Risk for birds, ranging from 2.6% for the baseline, 4.3% for 2030 and 7.4% for 2040. For mammals highest Impact Risk is caused by the construction phase, between 3.5 and 3.7% for the baseline and the two future scenarios.
- Mammals, fish & cephalopods, pelagic water column, and sublittoral sediment also experience an increased future impact of OWF but that effect is compensated by the decrease in some other human activities (fishing, oil and gas).

Impact Risk of human activities for North Sea species

- Threatened populations
    - There are four bird species that currently have an unfavourable conservation status and trend in the EU. These are Black legged kittiwake, Great black backed gull, Northern fulmar and Herring gull. These threatened species should receive special attention in protection measures.
- Related to all human activities
    - Bird species with the highest baseline (2022) cumulative impact risk are: Red-throated and Black-throated diver, Little gull, Sandwich tern, Razorbill.
    - Bird species with the highest increase in cumulative impact risk in future scenarios are: Black-legged kittiwake, Great black-backed gull, Northern gannet, Lesser black-backed gull, Herring gull.
    - The two mammal species (Grey seal and Harbour porpoise) receive a comparable baseline cumulative Impact Risk that falls well within the range of Impact Risk received by the bird species.
    - For marine mammals the net change in Impact Risk of future scenarios compared to the baseline is negligible, due to a balanced Impact Risks from increasing and decreasing activities.
- Related to OWF
    - The Harbour porpoise and Grey seal show a moderate increase in Impact Risk in future scenarios compared to the baseline.
    - Bird species with the highest increase in Impact Risk by OWF in future scenarios are: Black-legged kittiwake, Great black-backed gull, Northern gannet, Great skua, Northern fulmar.
    - Among the bird species that are expected to receive a relatively high Impact Risk by OWF in the future there are species that currently have an unfavourable conservation status and trend in the EU (black legged kittiwake, Great black backed gull, Northern fulmar and Herring gull). These species should receive special attention regarding mitigation of OWF impacts.

- Bird species with the lowest future increase in cumulative impact risk are: Great cormorant, Common scoter, Red-throated and Black-throated diver, Sandwich tern, Atlantic puffin.
- Increase in Impact Risk in future scenarios for OWF is strongly related to increase in spatial overlap with OWF but there are deviations due to species specific sensitivity to OWF, with relatively sensitive species like black legged kittiwake, Northern gannet, Herring gull and relatively less sensitive species like Northern fulmar, Common guillemot, Atlantic puffin.
- Bird species vary in their spatial overlap with OWF due to difference in relative population density distribution.
- Bird species with the highest future increase with respect to the baseline (2022) in spatial overlap with OWF are: Northern fulmar, Great skua, Great black-backed gull, Black-legged kittiwake and Common guillemot.
- Bird species with the lowest future increase with respect to the baseline (2022) in spatial overlap with OWF are: Great cormorant, Red-throated and Black-throated diver, Little gull, Sandwich tern and Common scoter.

5 Quality Assurance

Wageningen Marine Research utilises an ISO 9001:2015 certified quality management system. The organisation has been certified since 27 February 2001. The certification was issued by DNV.

References

Borgwardt F., L. Robinson, D. Trauner, H. Teixeira, A. Nogueira, A. Lillebø, G. Piet, M. Kuemmerlen, T. O'Higgins, H. McDonald, J. Arevalo-Torres, A. Barbosa, A. Iglesi-as-Campos, T. Hein, F. Culhane (2019). Exploring variability in environmental IR from human activities across aquatic ecosystems. Science of The Total Environment 652: 1396–1408.

Bowgen, K. & Cook, A. (2018). Bird Collision Avoidance: Empirical evidence and impact assessments. JNCC Report No. 614, JNCC, Peterborough, ISSN 0963-8091.

Cook, A.S.C.P., E.M. Humphreys, F. Bennet, E.A. Masden & N.H.K. Burton (2018). Quantifying avian avoidance of offshore wind turbines: Current evidence and key knowledge gaps. Marine Environmental Research 140: 278-288.

EC (2021). Population trend of bird species: datasets from Article 12, Birds Directive 2009/147/EC reporting (2013-2018) - tabular - Apr. 2021. Downloaded 11 October 2023 at https://sdi.eea.europa.eu/data/7b25f644-63a6-4aff-9440-a76ab952907b

Halpern, B. S., and Fujita, R. (2013). Assumptions, challenges, and future directions in cumulative impact analysis. Ecosphere, 4.

Judd, A. D., Backhaus, T., and Goodsir, F. (2015). An effective set of principles for practical implementation of marine cumulative effects assessment. Environmental Science & Policy, 54: 254-262.

Knights A. M., Koss R. S., Robinson L. A. (2013). Identifying common pressure pathways from a complex network of human activities to support ecosystem-based management, Ecological Applications, vol. 23 (pg. 755-765).

Knights, A.M. G.J. Piet, R.H. Jongbloed, J.E. Tamis, L. White, E. Akoglu, L. Boicenco, T. Churilova, O. Kryvenko, V. Fleming-Lehtinen, J.-M. Leppanen, B.S. Galil, F. Goodsir, M. Goren, P. Margonski, S. Moncheva, T. Oguz, K.N. Papadopoulou, O. Setälä, C.J. Smith, K. Stefanova, F. Timofte & L.A. Robinson (2015). An exposure-effect approach for evaluating ecosystem-wide risks from human activities. – ICES Journal of Marine Sci-ence, 72: 1105–1115. doi:10.1093/icesjms/fsu245.

Leopold, M.F., M. Booman, M.P. Collier, N. Davaasuren, R.C. Fijn, A. Gyimesi, J. de Jong, R.H. Jongbloed, B. Jonge Poerink, J.C. Kleyheeg-Hartman, K.L. Krijgsveld, S. Lagerveld, R. Lensink, M.J.M. Poot, J.T. van der Wal & M. Scholl (2014). A first approach to deal with cumulative effects on birds and bats of offshore wind farms and other human activities in the Southern North Sea. IMARES report C166/14.

Long, R.D., Charles, A., Stephenson, R.L. (2015). Key principles of marine ecosystem-based management. Mar. Policy, 57, pp. 53-60.

Piet, G. J., Jongbloed, R. H., Knights, A. M., Tamis, J. E., Paijmans, A. J., van der Sluis, M. T., de Vries, P., et al. (2015). Evaluation of ecosystem-based marine management strategies based on risk assessment. Biological Conservation, 186: 158-166.

Piet, G. J., Knights, A. M., Jongbloed, R. H., Tamis, J. E., de Vries, P., and Robinson, L. A. (2017). Ecological risk assessments to guide decision-making: Methodology matters. Environmental Science & Policy, 68: 1-9.

Piet, G. J., Culhane, F., Jongbloed, R., Robinson, L., Rumes, B., and Tamis, J. (2019). An integrated risk-based assessment of the North Sea to guide ecosystem-based management. Science of the Total Environment, 654: 694-704.

Piet, G.J., Tamis, J.E., Volwater, J., de Vries, P., van der Wal, J.T. & Jongbloed, R.H. (2021a). A roadmap towards quantitative cumulative impact assessments: every step of the way. Sci. Total Environ. 784, 146847. doi:10.1016/j.scitotenv.2021.146847

Piet G.J., Tamis J.E., van der Wal J.T., Jongbloed R.H. (2021b). Cumulative impacts of wind farms on the North Sea ecosystem. Wageningen Marine Research report C081/21. https://doi.org/10.18174/556024

Piet G., Grundlehner A, Jongbloed R, Tamis J, Vries de P (2023). SCAIRM: a Spatial Cumulative Assessment of Impact Risk for Management. Ecological Indicators 157, 111157, https://doi.org/10.1016/j.ecolind.2023.111157

Potiek, A., J.J. Leemans, R.P. Middelveld & A. Gyimesi (2022). Cumulative impact assessment of collisions with existing and planned offshore wind turbines in the southern North Sea. Analysis of additional mortality using collision rate modelling and impact assessment based on population modelling for the KEC 4.0. Report 21-205. Bureau Waardenburg, Culemborg.

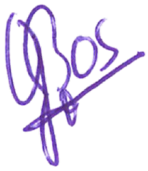
Soudijn, F. H., van Donk, S., Leopold, M. F., van der Wal, J. T., & Hin, V. (2022). Cumulative population-level effects of habitat loss on seabirds 'Kader Ecologie en Cumulatie 4.0'. (Wageningen Marine Research report; No. C007/22). Wageningen Marine Research. https://doi.org/10.18174/565601

Justification

Report C074/23
Project Number: 4315100214 / 4315100219

The scientific quality of this report has been peer reviewed by a colleague scientist and a member of the Management Team of Wageningen Marine Research

Approved: O.G. Bos, PhD
Marine ecologist

Signature: 

Date: 21st of November, 2023

Approved: A.M. Mouissie, PhD
Business Manager Projects

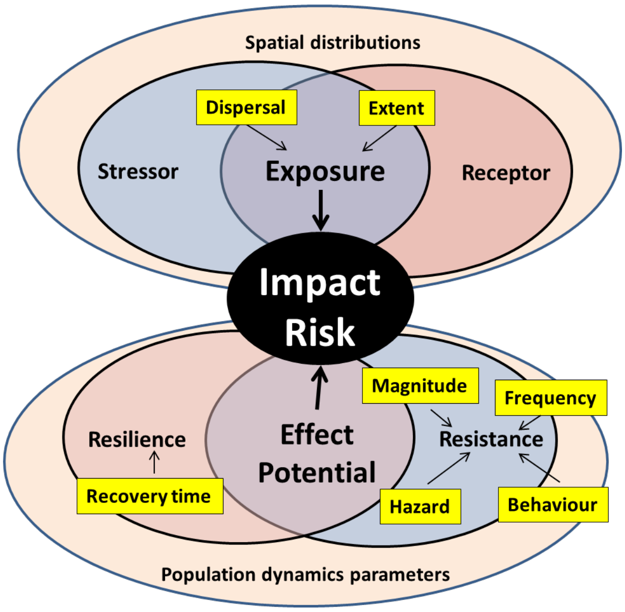
Signature: 

Date: 21st of November, 2023

Annex 1 SCAIRM: a Spatial Cumulative Assessment of Impact Risk for Management

At the basis of SCAIRM[2] is a linkage framework, consisting of impact chains that link causes to impacts via the main elements: activities, pressures and ecosystem components (e.g. "bottom trawl fishing" -> "abrasion/damage" -> "benthic community"). SCAIRM is based on the EU MSFD[3]. Human **activities** are sectoral at their basic level (e.g. fishing, renewable energy) which can be sub-divided into operations. **Pressures** (e.g. abrasion, noise) represent the mechanism through which human activities interact with the ecosystem. The **ecosystem components** include (at the most basic level) pelagic habitats, benthic habitats and species groups (birds, mammals, reptiles, fish, cephalopods).

Impact Risk (IR) as the change in equilibrium state of the receptor caused by a stressor is the key concept that allows cumulation across pressures. Impact Risk can be estimated per impact chain as Exposure*Effect Potential (*Figure 18*) using the spatial distributions of the stressor (i.e. activities-pressure), the spatial distributions of the receptor (i.e. ecosystem component) and population dynamics parameters. The SCAIRM output is basically an aggregation of Impact Risk across impact chains and thus cumulative pressures[1].



<u>Extent</u> = the overlap between the A and the EC; <u>Dispersal</u>= the potential of the P to spread and increase its spatial overlap with an EC beyond that of the Extent; <u>Hazard</u> = the relative depletion of the EC from a single interaction with the P at maximum magnitude; <u>Magnitude</u> = the average strength in the assessment area of the P where it is co-occurring with the EC; <u>Behaviour</u> = behavioural response (e.g. avoidance) when an ecosystem component and a pressure co-occur in space and time determining the likelihood of interaction (i.e. actual contact that causes the effect); <u>Frequency</u> = the average number of occurrences per year of the P in the area co-occurring with the EC (only applies in case of an intermittent interaction mechanism); <u>Recovery time</u> = the number of years after impact until full recovery (to the EC's original undisturbed state).

Figure 18 Calculation of Impact Risk from Exposure and Effect Potential which, in turn, can be estimated from respectively the spatial distributions of the stressor (i.e. activities-pressure) and receptor (i.e. ecosystem component) and population dynamics parameters resilience and resistance if quantitative information is available. If lacking, these can be estimated from the boxed terms using categorical scores based on expert judgement (Piet et al., 2023)[1].

[2] Piet et al. (2023). SCAIRM: A spatial cumulative assessment of impact risk for management, Ecol. Indic. 157, 111157, https://doi.org/10.1016/j.ecolind.2023.111157

[3] EU Marine Strategy Framework Directive: Commission Directive (EU) 2017/845 and Commission Decision (EU) 2017/848 f

Annex 2 Offshore wind scenarios

Two different sources of information were used for the offshore wind scenarios:

- Offshore plans in the North Seas Offshore Grids (NSOG)[4], further referred to as "Targets" or "non-GIS"
- Geographical information provided by RWS, further referred to as "GIS data"

Targets in the NSOG sea basin

The wind energy capacity on the North Sea is planned to expand from 7.7 GW in 2017 to a maximum of 183.5 GW in 2050 (Table 9). According to the targets, most development will take place from 2030 to 2040. In this decade the offshore wind capacity is intended to increase by max. 70.2 GW. Assuming a development of 10 MW per km^2, the area required for this capacity will expand from 969 km^2 in 2017 to 18350 km^2 in 2050 (Table 10).

Table 9 Offshore wind energy capacity (GW) development based on the offshore plans in the North Seas Offshore Grids (NSOG) sea-basin [as of 20 Feb 2023].

Country	2017	2030	2040	2050
NL	1.0	16.0	50.0#	70.0#
BE	0.9	5.8	8.0	8.0
DK	1.3	5.3	19.3	35.5
DE	4.7	26.4	46.4	70.0
Total	7.7	53.5	123.7	183.5

maximum values for NL; average values for NL are 40.0 GW for 2040 and 54.0 GW for 2050

Table 10 Scenarios for offshore wind farms (OWF) based on the of OWF-target data from the tables provided by RWS. (Different representation of the data in Table 9)

Year	Capacity (GW)	Area (km^2)
2017	7.665	969
2030	53.471	5347 #
2040	123.671	12367 #
2050	183.500	18350 #

based on the assumption of 10 MW per km^2

GIS data used to derive spatial planned OWF

The analyses of the spatial OWF data provided by RWS and elaborated by WMR to produce a OWF map for the North Sea (see *Figure **4*** and Figure 5) reveals slightly different capacities (Table 11) as compared to the capacities based on the offshore wind energy plans in the NSOG sea-basin (Table 9). The capacity in 2030 is ca. 10 GW higher and in 2040 ca. 10 GW lower based on the spatial data compared to the plans. It should be noted that in the spatial OWF data set provided by RWS, GIS for OWF is not available for the period beyond 2040 up to 2050. Therefore, a scenario for 2050 could not be included in the quick scan.

[4] https://energy.ec.europa.eu/system/files/2022-09/220912_NSEC_Joint_Statement_Dublin_Ministerial.pdf

Table 11 Offshore wind energy capacity (GW) for countries based on the spatial data from the GIS provided by RWS and integrated by WMR.

Country	2022	2023-2030	2031-2040
Belgium	2.256	5.756	8.147
Denmark	1.120	8.226	22.226
Germany	6.908	19.463	46.465
Netherlands	4.400	25.388	47.599
Norway	0	1.500	3.000
United Kingdom	13.174	42.668	53.668
Total (excl. UK)	14.684	60.333	127.437
Total (incl. UK)	27.858	103.001	181.105

The expected size of the wind farm areas resulting from the analyses of the spatial data provided by RWS and integrated by WMR (Table 12) is 10964 km^2 which is somewhat smaller than the area estimated using the plans for the NSOG sea-basin (12367 km^2 in 2040, Table 10). Both capacity and area size based on the spatial data are presented in Table 13.

Table 12 Cumulative Offshore wind farm area (km^2) for countries based on the spatial data from the GIS provided by RWS and integrated by WMR, using target capacities and available space.

Country	2022	2023-2030	2031-2040
Belgium	287	635	635 #
Denmark	151	916	2415
Germany	912	2335	5447
Netherlands	575	2952	5366
Norway	0	156	312
United Kingdom	1632	4933	6127
Total (excl. UK)	1925	6994	14175
Total (incl. UK)	3557	11927	20302

surface area for OWF is adjusted tot this value due to the maximum area available for the Belgian part of the North Sea

Table 13 Scenarios for OWF based on the spatial data from the GIS provided by RWS and integrated by WMR. (Different representation of the data in Table 11 and Table 12.

Year	Capacity (MW)	Area (km^2)
2017 (former baseline #) (Realised)	7665	969
2022 (baseline) (Realised)	27857	3558
2030 (Planning)	103001	11927
2040 (Planning)	181105	20302

based on the study of Piet et al. (2021b)

Table 14 Overview of data for OWF Operational and the Extent (% of study area) used in the scenario calculations of the quick scan.

Year	Capacity (GW)	Area (km2)	Extent (% of study area)
2022 (baseline) (Realised)	27.9	3558	0.8%
2030 (Planning)	103	11927	2.6%
2040 (Planning/)	181	20302	4.5%
2030 (/Target)	53.5	5347	2.1%
2040 (/Target)	123.7	12367	4.9%
2050 (/Target) #	183.5	18350	7.2%

this year (scenario) is not included in the Impact Risk calculations of this quick scan

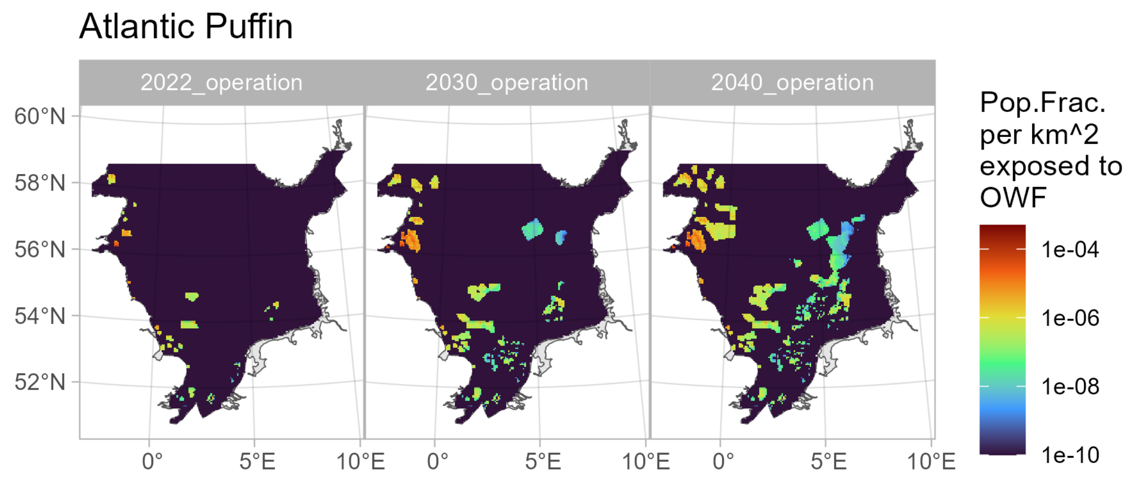
Table 15 Overview of data for OWF Construction and the Extent (% of study area) used in the scenario calculations of the quick scan.

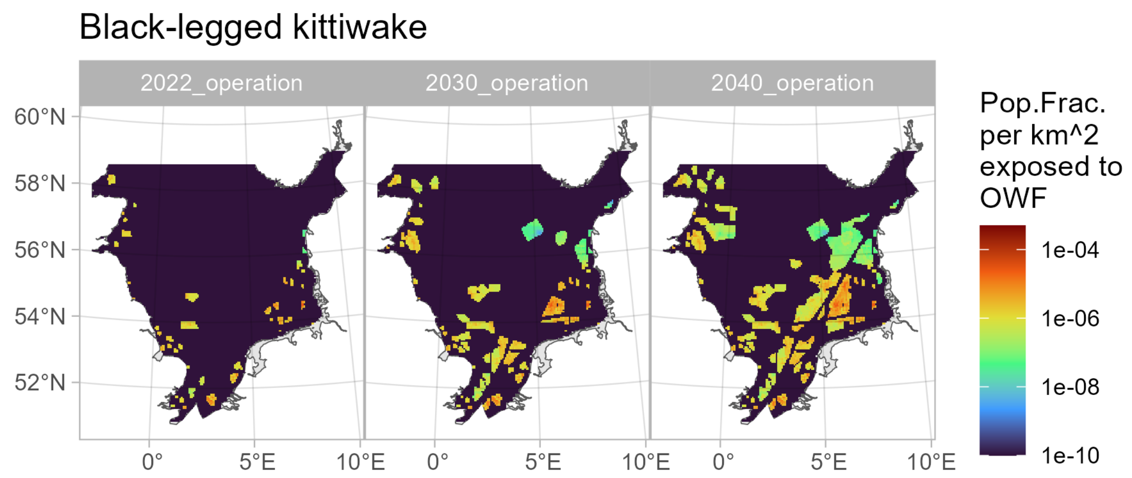
Year	Capacity (GW)	Years	Capacity (GW)/year	Area (km2)	Area (km2)/year	Extent (% of study area)
2022 (baseline) (Realised)	5.3	2	2.6	630	315	0.07%
2030 (Planning)	75	8	9.4	8272	1034	0.23%
2040 (Planning)	78	10	7.8	8375	851	0.19%
2030 (Target)	39	8	4.8	3495	437	0.17%
2040 (Target)	70	10	7.0	7020	702	0.28%
2050 (Target)#	60	10	6.0	5983	598	0.24%

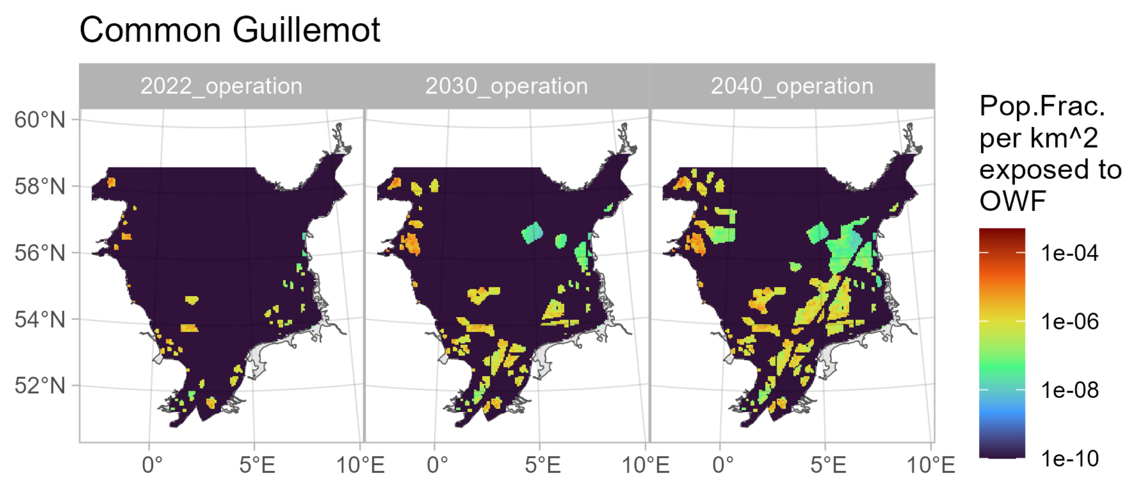
this year (scenario) is not included in the Impact Risk calculations of this quick scan

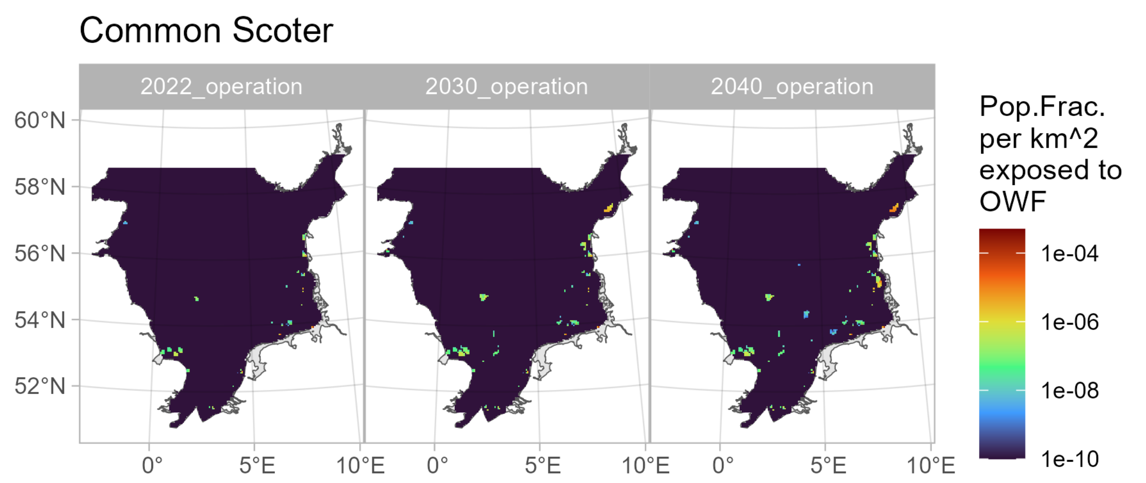
Annex 3 Maps with spatial overlap (extent) of bird and mammal species with OWF in the operational phase in future scenarios

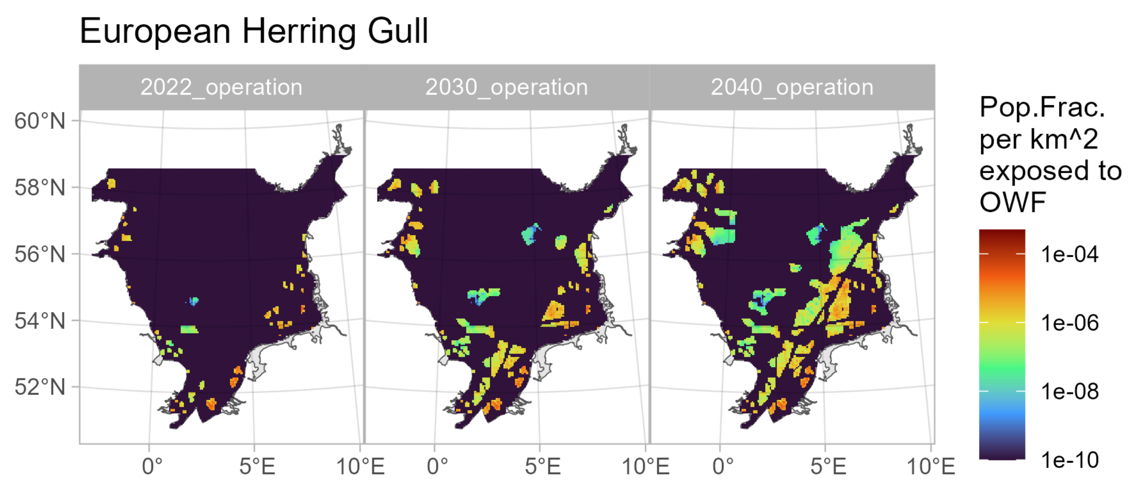
Maps below show the fraction of the population (in the North Sea study area) per square kilometre that is exposed to OWFs. This is thus a combination of the fraction of areas utilised by OWF and the population density. Note that the colour scales are identical in each plot and are on logarithmic scale. This means small differences in colour indicate large differences in overlap.



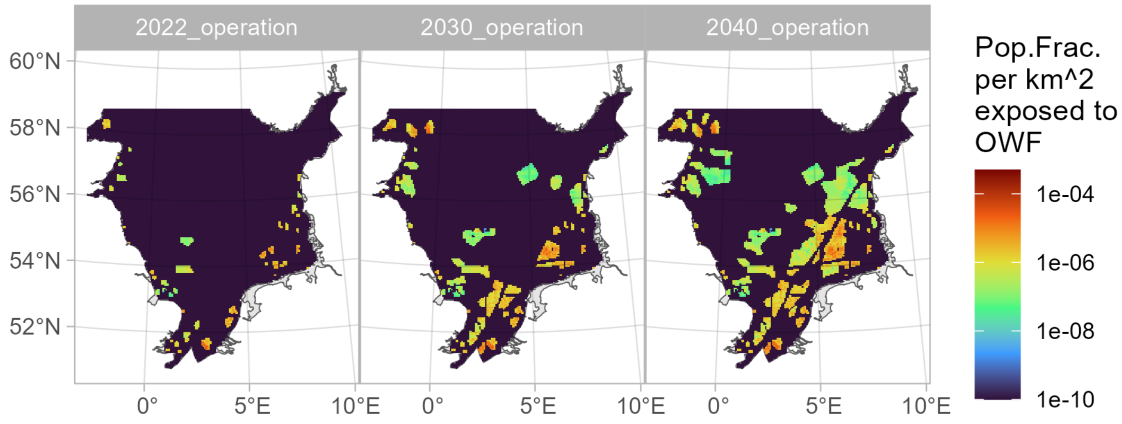



Common Guillemot
2022_operation
2030_operation
2040_operation
60°N
58°N
56°N
54°N
52°N
0°
5°E
10°E
Pop.Frac. per km^2 exposed to OWF
1e-04
1e-06
1e-08
1e-10

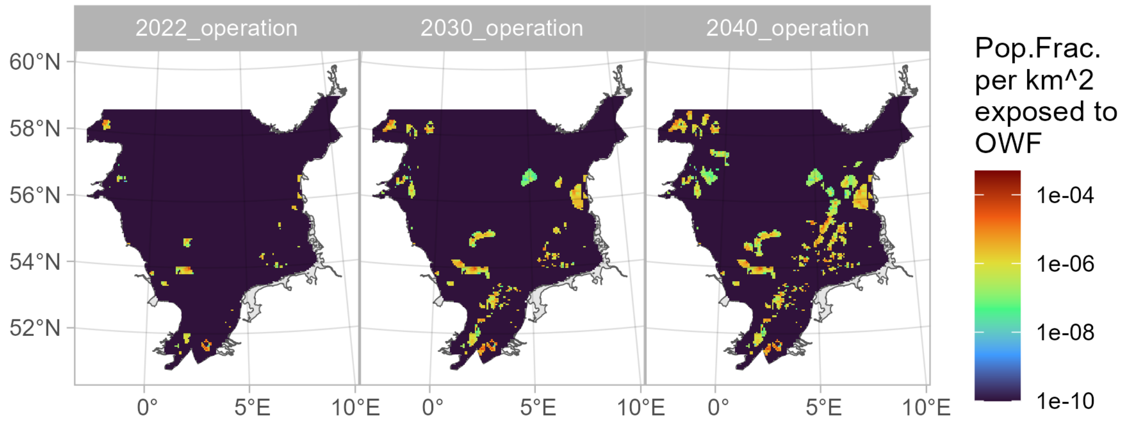

Common Scoter
2022_operation
2030_operation
2040_operation
60°N
58°N
56°N
54°N
52°N
0°
5°E
10°E
Pop.Frac. per km^2 exposed to OWF
1e-04
1e-06
1e-08
1e-10


European Herring Gull
2022_operation
2030_operation
2040_operation
60°N
58°N
56°N
54°N
52°N
0°
5°E
10°E
Pop.Frac. per km^2 exposed to OWF
1e-04
1e-06
1e-08
1e-10

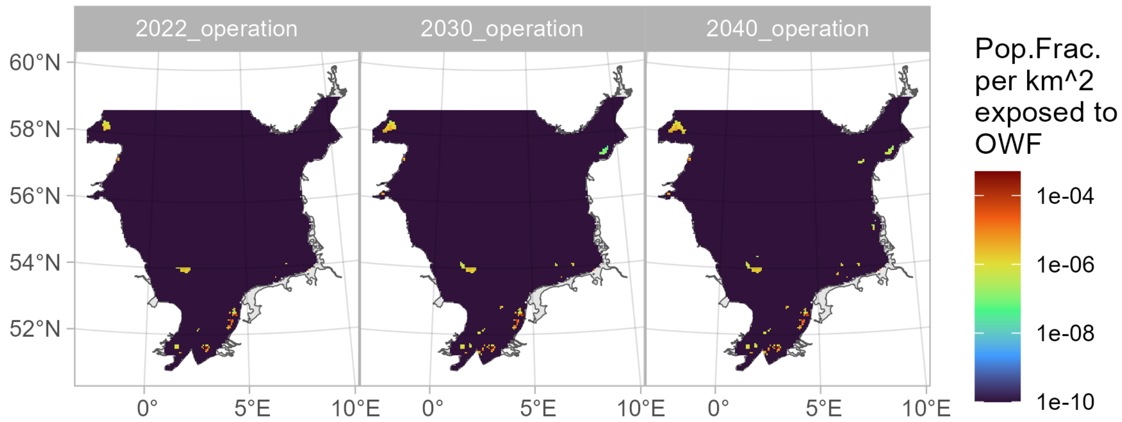
Great Black-backed Gull



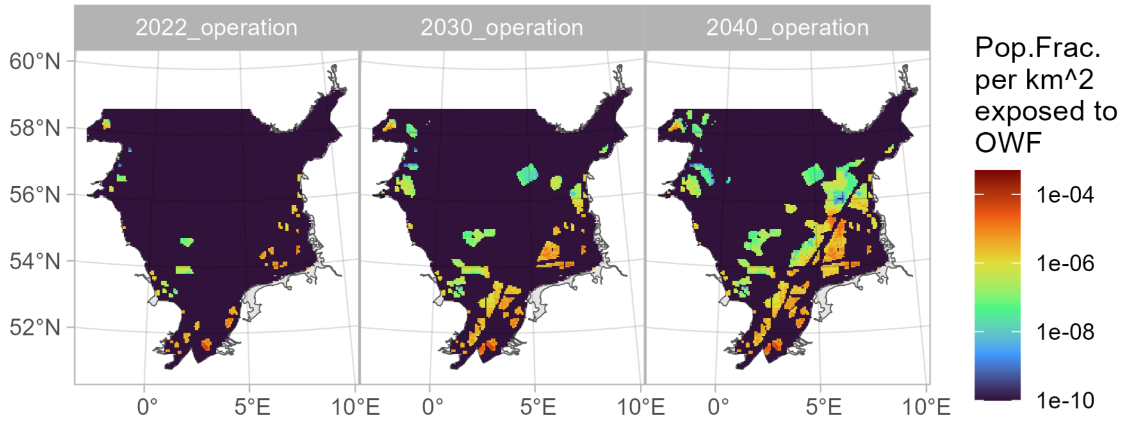
Great Skua



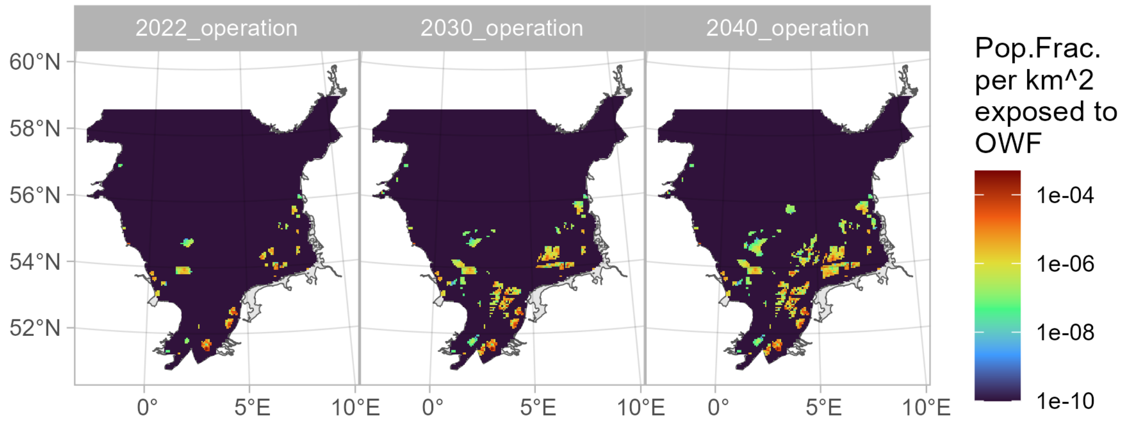
Great Cormorant



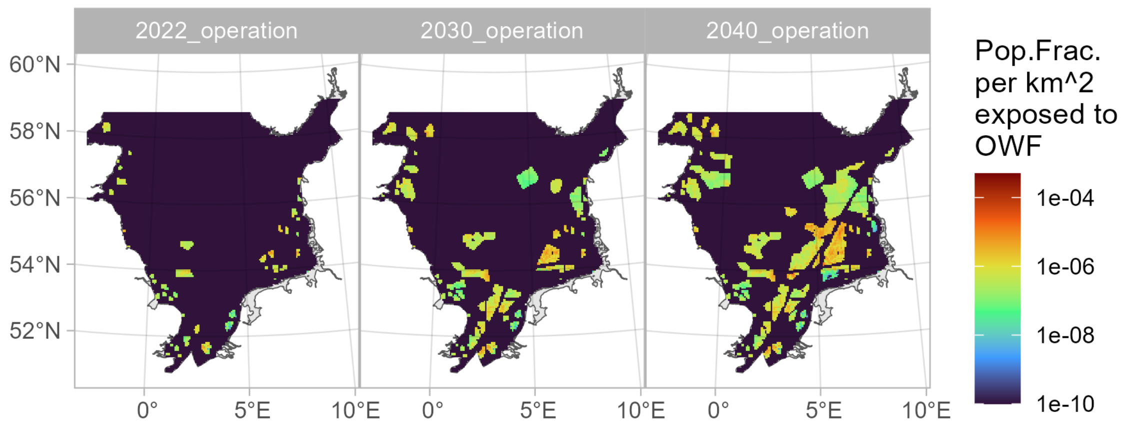
Lesser Black-backed Gull

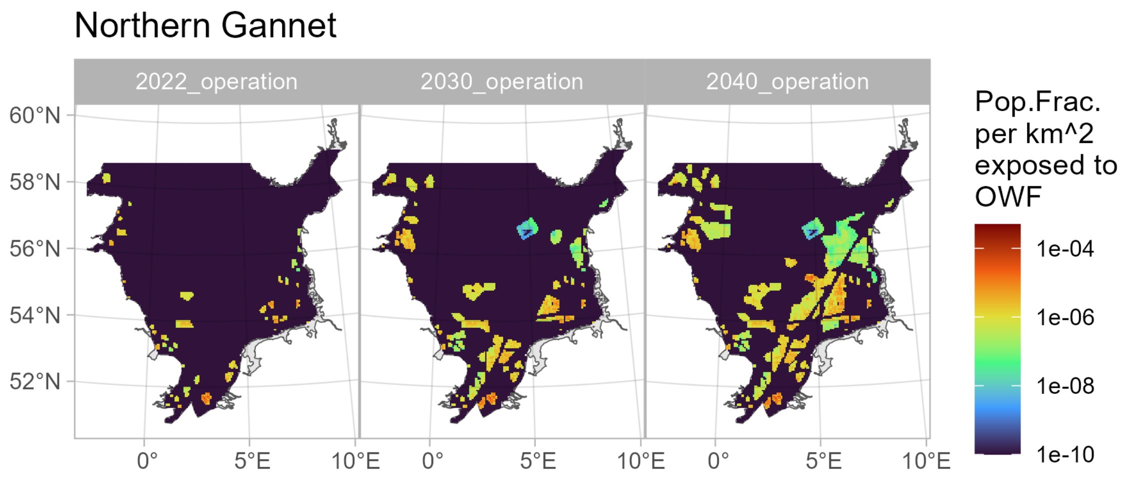


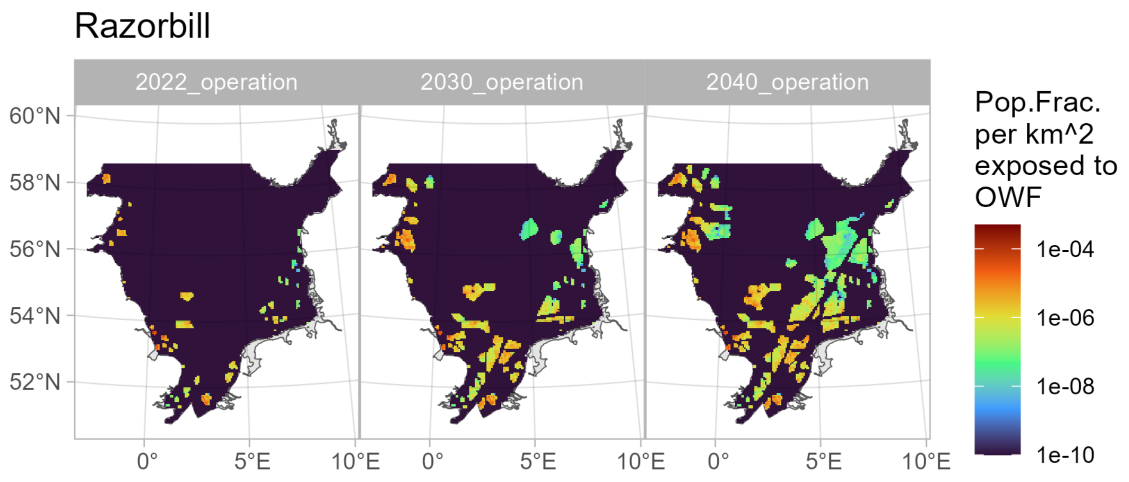
Little Gull

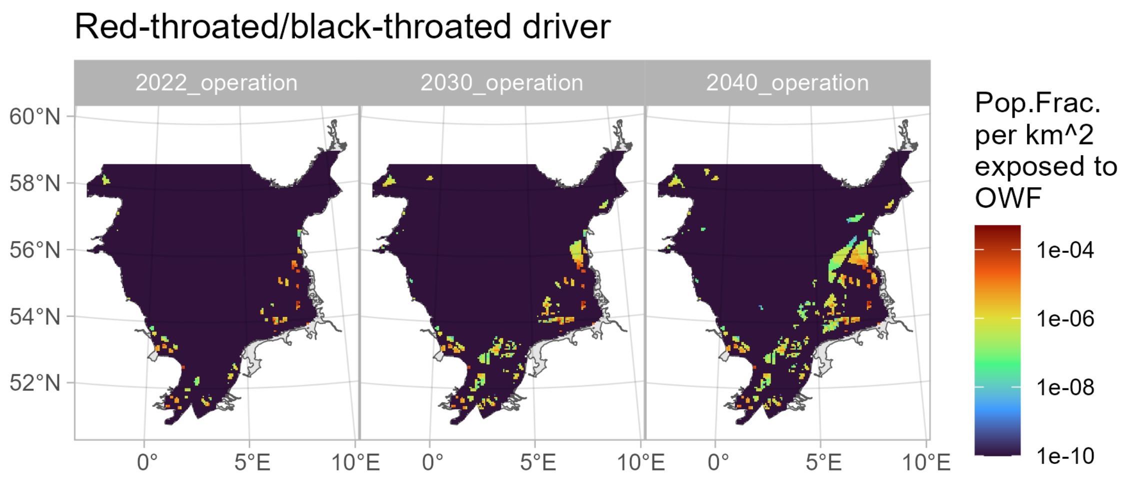


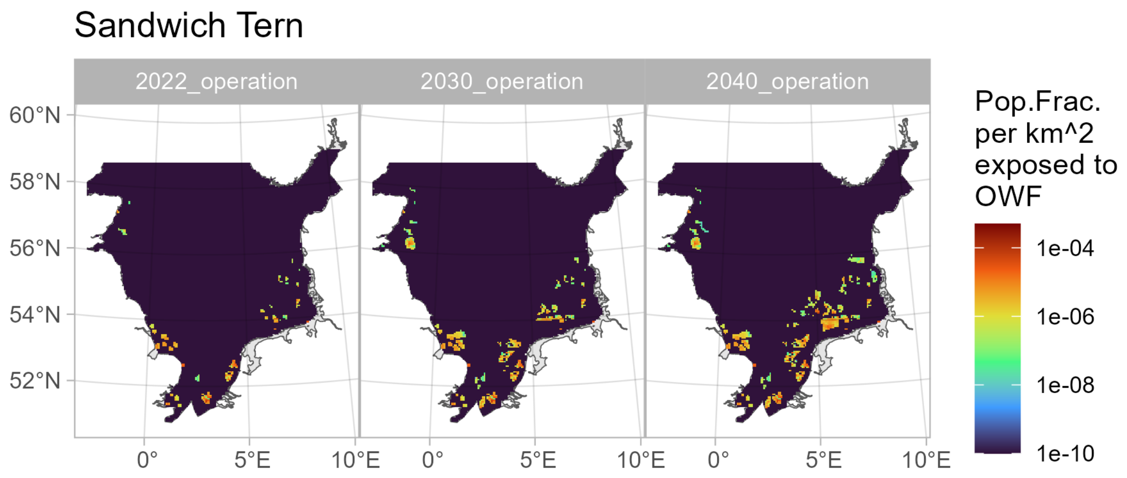
Northern fulmar

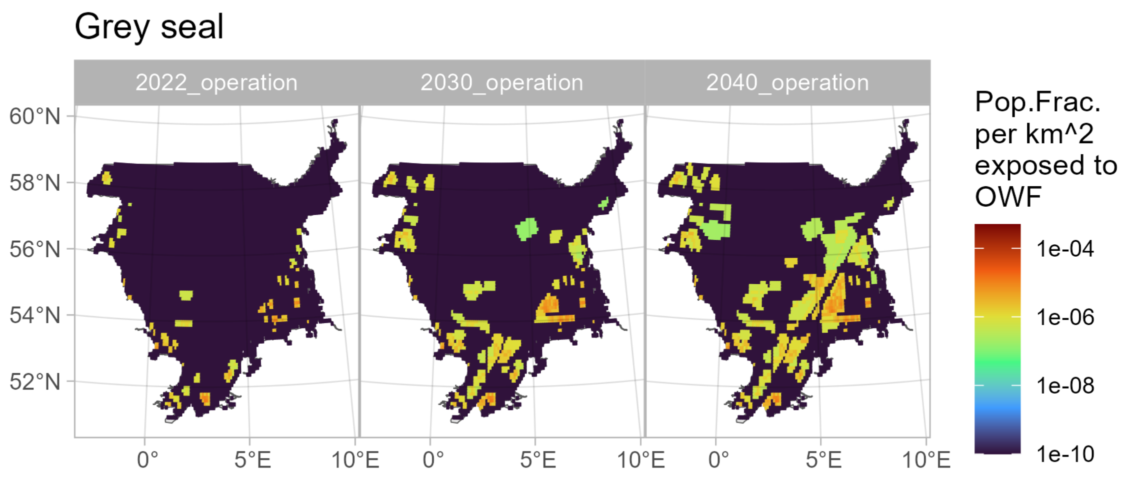


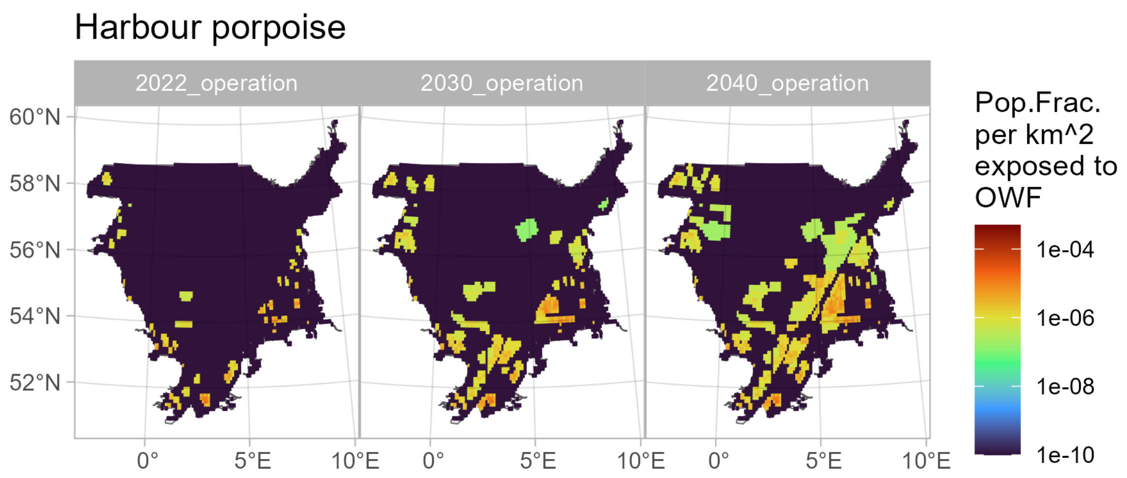

Northern Gannet
2022_operation
2030_operation
2040_operation
60°N
58°N
56°N
54°N
52°N
0°
5°E
10°E
Pop.Frac.
per km^2
exposed to
OWF
1e-04
1e-06
1e-08
1e-10


Razorbill
2022_operation
2030_operation
2040_operation
60°N
58°N
56°N
54°N
52°N
0°
5°E
10°E
Pop.Frac.
per km^2
exposed to
OWF
1e-04
1e-06
1e-08
1e-10


Red-throated/black-throated driver
2022_operation
2030_operation
2040_operation
60°N
58°N
56°N
54°N
52°N
0°
5°E
10°E
Pop.Frac.
per km^2
exposed to
OWF
1e-04
1e-06
1e-08
1e-10


Sandwich Tern
2022_operation
2030_operation
2040_operation
60°N
58°N
56°N
54°N
52°N
0°
5°E
10°E
Pop.Frac. per km^2 exposed to OWF
1e-04
1e-06
1e-08
1e-10


Grey seal
2022_operation
2030_operation
2040_operation
60°N
58°N
56°N
54°N
52°N
0°
5°E
10°E
Pop.Frac. per km^2 exposed to OWF
1e-04
1e-06
1e-08
1e-10


Harbour porpoise
2022_operation
2030_operation
2040_operation
60°N
58°N
56°N
54°N
52°N
0°
5°E
10°E
Pop.Frac. per km^2 exposed to OWF
1e-04
1e-06
1e-08
1e-10

Annex 4 Possibilities to develop a quick scan with SCAIRM for the Celtic Sea

Possibilities to develop a quick scan with SCAIRM for the Celtic Sea
First step would be to develop a linkage framework for the Celtic Sea, identifying all human activities, the ecosystem components to include (at the most basic level: pelagic habitats, benthic habitats and species groups (birds, mammals, reptiles, fish, and cephalopods)) and the mechanism through which human activities interact with the ecosystem, i.e. the pressures, resulting in impact chains. Next, the Impact Risk could be estimated per impact chain as Exposure*Effect Potential (Annex 1) using the spatial distributions of the stressor (i.e. activities-pressure), the spatial distributions of the receptor (i.e. ecosystem component) and population dynamics parameters. If quantitative information is limited, exposure and/or effect potential can be estimated using categorical scores based on expert judgement.

Recent developments for the Celtic Sea
A process has recently commenced as part of the HorizonEurope GES4SEAS project in which the SCAIRM method is shared with the Marine Institute in Ireland so that they can apply their region-specific data and expert judgement in order to develop a comparable CIA for the Celtic Seas. This is then expected to become another case study in the ICES WGCEAM.

Wageningen Marine Research
T +31 (0)317 48 7000
E: marine-research@wur.nl
www.wur.eu/marine-research

Visitors' address
- Ankerpark 27 1781 AG Den Helder
- Korringaweg 7, 4401 NT Yerseke
- Haringkade 1, 1976 CP IJmuiden

With knowledge, independent scientific research and advice, **Wageningen Marine Research** substantially contributes to more sustainable and more careful management, use and protection of natural riches in marine, coastal and freshwater areas.

Wageningen Marine Research is part of Wageningen University & Research. Wageningen University & Research is the collaboration between Wageningen University and the Wageningen Research Foundation and its mission is: 'To explore the potential for improving the quality of life'