WORKING GROUP ON CUMULATIVE EFFECTS ASSESSMENT APPROACHES IN MANAGEMENT (WGCEAM; outputs from 2024 meeting)

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International Council for the Exploration of the Sea
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H.C. Andersens Boulevard 44-46
DK-1553 Copenhagen V
Denmark
Telephone (+45) 33 38 67 00
Telefax (+45) 33 93 42 15
www.ices.dk
info@ices.dk

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Editors

Roland Cormier • Gerjan Piet • Vanessa Stelzenmüller

Authors

Adrian Judd • Alejandra Vargas-Fonesca • Andrew Kenny • Andy Stock • Charlotte Scholten • Christina O'Donnel • Daniel Wood • Debbi Pedreschi • Denise O´Sullivan • Elisa Furlan • Gerjan Piet • Jennifer Rehren • Lena Bergström • Michael Elliott • Roland Cormier • Salomé Fabi-Ruiz • Silvana Birchenough • Vanessa Stelzenmüller • Virginia Morejon

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Contents

i Executive summary

The Working Group on Cumulative Effects Assessments in Management (WGCEAM) was established to develop a common framework for cumulative assessments to be applied in the context of ecosystem-based management.

The objective was to develop a cumulative effects assessment framework to inform ecosystem-based management initiatives and demonstrate its application through regional case studies. Within the context of environmental policies, blue growth, and regional conventions, the framework is intended to inform strategic aspects of planning and management processes such as marine spatial planning and integrated marine management. It starts with the need to identify priorities across of the causal relationships between activities, their pressures on ecosystem components within the boundaries of an assessment area. The priority causal relationships are then used to establish vulnerability profiles based on exposure and effect potential calculation. Subsequently, exposure and effect potential clusters are used to characterize the pressures that should be subjected to management. Ultimately, the pressures based on the vulnerability profile of ecosystem components can be used to inform regulatory advisory processes for the activities generating these pressures. The case studies demonstrate that the framework can be used as guidance in a variety of impacts risk assessments for species and habitats in the North Sea, the German North Sea, and the Celtic Sea. The Canadian case studies also show that the framework does work for regulatory advisory processes to assess environmental impacts and the reliability and the effectiveness of technical measures. Guided by this framework, future work should be addressed through specific expert groups given the different management context and objectives that require.

ii Expert group information

Expert group name	Working Group on Cumulative Effects Assessment Approaches in Management (WGCEAM)
Expert group cycle	Multiannual
Year cycle started	2022
Reporting year in cycle	3/3
Chairs	Roland Cormier, Canada
	Vanessa Stelzenmüller, Germany
	GerJan Piet, Netherlands
Meeting venues and dates	24–27 October 2022, online meeting, 10 participants
	23–25 October 2023, online meeting, 14 participants
	6–7 November 2024, online meeting, 7 participants

1 Working group terms of reference

The **Working Group on Cumulative Effects Assessment Approaches in Management (WGCEAM)** has met annually between 2022 and 2024. All meetings were held virtual and lasted for 3 hours each day starting at noon Central European Time. However, the times may be flexible as there will be ongoing work outside these timeframes.

The terms reference (ToRs) for WGCEAM were:

a) Demonstrate the application of the ICES CEA framework in one or more regional case studies;
b) Review the scientific advancements and current management practice in addressing cumulative effects to identify data and knowledge needs;
c) Identify linkages between CEA framework and other ICES products and liaise with other fora or expert groups both within ICES (i.e. Secretariat, Data Centre or expert groups) as well as outside ICES.

Summary of work plan

Year 1

Ongoing work will focus on the application of the CEA framework in case study areas such as the North Sea, Canadian bioregions and Celtic Sea. Those areas will serve as test areas to identify strength and weaknesses of the framework. These regions are data rich and will allow for a full application of the framework to identify areas with increased risk of cumulative effects as well as data needs.

Year 2

The results of the case study applications will also feed in a review which aims to synthesis the scientific advancements and map those to current management practice in e.g. marine planning and stakeholder needs. The review will reveal knowledge gaps and guides the development of decision support tools.

Year 3

Emphasis will be on the provision of guidance on data and knowledge needs when applying the common framework. This guidance on the application of the framework together with the identified action points will foster the integration of CEAs as part of ecosystem advice provided by ICES.

2 Cumulative effects assessment framework – a brief introduction

Starting in 2019, WGCEAM developed a Cumulative Effects Assessment (CEA) framework to support strategic decision making in an ecosystem-based management context such as marine spatial planning (MSP) or the implementation of programs of measures to achieve good environmental status (GES). The CEA framework is designed to assess the vulnerabilities of ecosystem components to cumulative or collected pressures generated by human activities for given ecosystem and management context (Figure 1); (ICES, 2020).

The framework is informed by existing status assessments (e.g. MSFD, EOAR) providing focus or more weighting to those ecosystem components found to be in poor status. This framework is different from those existing status assessments in that the vulnerabilities of each ecosystem component to potential effects are based on the prioritisation of key causal relationships and key prevailing pressures (Upper left box of Figure 1); (Piet *et al.*, 2021). Following standard risk-based assessment practices, vulnerability is based on the exposure and effect potential (De Lange *et al.*, 2010). In this framework, exposure is a function of the spatial and temporal overlap of the pressure and the ecosystem component. The effect potential is a function of the pressure load and the inherent resistance and recovery potential of the ecosystem component (Upper right box of Figure 1); (Piet *et al.*, 2023). This information is then integrated into a vulnerability profile which ranks the vulnerabilities of all pressure/ecosystem component combinations occurring in that ecosystem.

Adapted from DFO (DFO, 2013b), a four-quadrant schematic representation exposure/effect potential is used to identify clusters of pressure/component vulnerabilities for management strategies that could be considered by planners and managers (lower right box of Figure 1); (Pedreschi *et al.*, 2023; Piet *et al.*, 2023). The pressure/component vulnerabilities in the upper left quadrant indicative the need to reduce the load of a pressure. In contrast to pressure/component vulnerabilities in the lower right quadrant being indicative of the need to reduce the spatial and/or temporal overlap between the pressures and the components. As a conceptual approach, it provides the strategic setting needed in strategic decision making to identify the activities that are contributing to a given pressure and that might be considered in regulatory processes (lower left box of Figure 1); (Cormier, Tunney and Mallet, 2022; Elliott, Borja and Cormier, 2023).

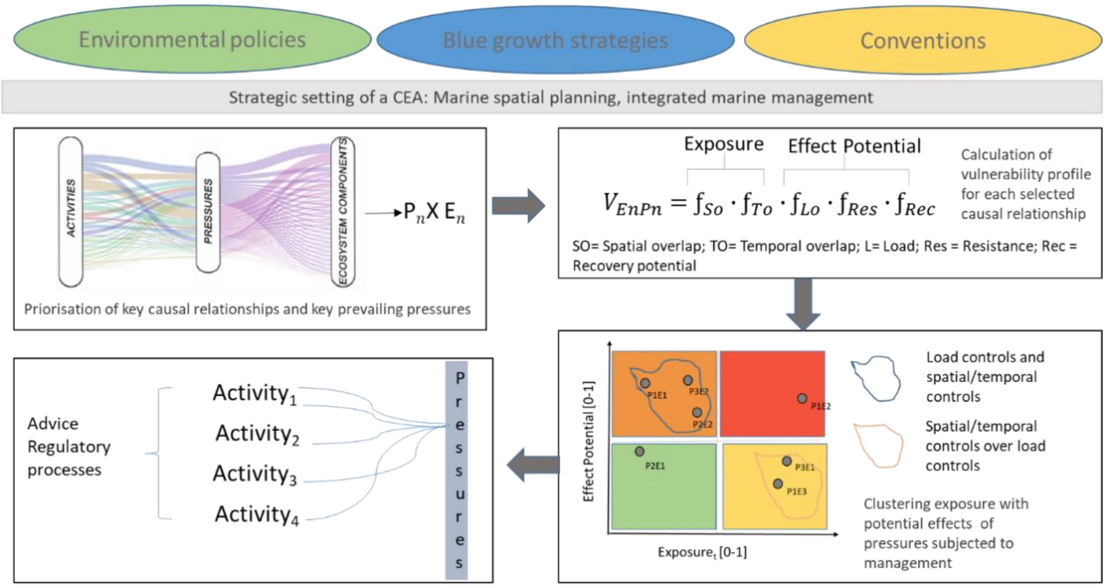

Figure 1. CEA framework to support strategic decision making in the context of an ecosystem approach to marine management (ICES, 2019).

3 CEA framework case studies (ToR a)

Key to the work program of the group was the application of the CEA framework in case studies. In total four case studies were conducted in the course of WGCEAM. The case studies comprise the North Sea region, the German EEZ of the North Sea, the Celtic Sea and the Gulf of St Lawrence (Canada). Below the framework implementation and key results are summarised for each case study.

3.1 North Sea region

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.

Material & methods

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. This 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. That is why 2 categories of activities are distinguished in the quick scan and this is summarized point by point below.

- All activities (36) as in the CIA method in the version of Piet *et al.* (submitted) and the associated CIA database. This version is largely based on estimated exposures.
- Top 9 activities (activities for which a real Exposure is available calculated from GIS). 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.

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

Future Scenarios

Main (top 9) human activities (and their different phases) are included in the CIA using the future 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.* (2021). For wind farms, baseline and future scenarios have been reassessed by WMR in April 2023 using data provided by RWS (see Annex 3 for more information on the wind farm scenarios and underlying data). Using this recent RWS data, a map of offshore wind farm areas in different stages of development was developed (Figure 2). Two main phases can be distinguished:

1. Development zones, which are areas designated for wind energy development (the shaded areas in Figure 2);
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 in Figure 2).

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.* (submitted) was also used for the future scenarios.

Table 1. Scenario values (% of study area) for the main human activities in the North Sea.

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/anchor-ing	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/anchor-ing	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

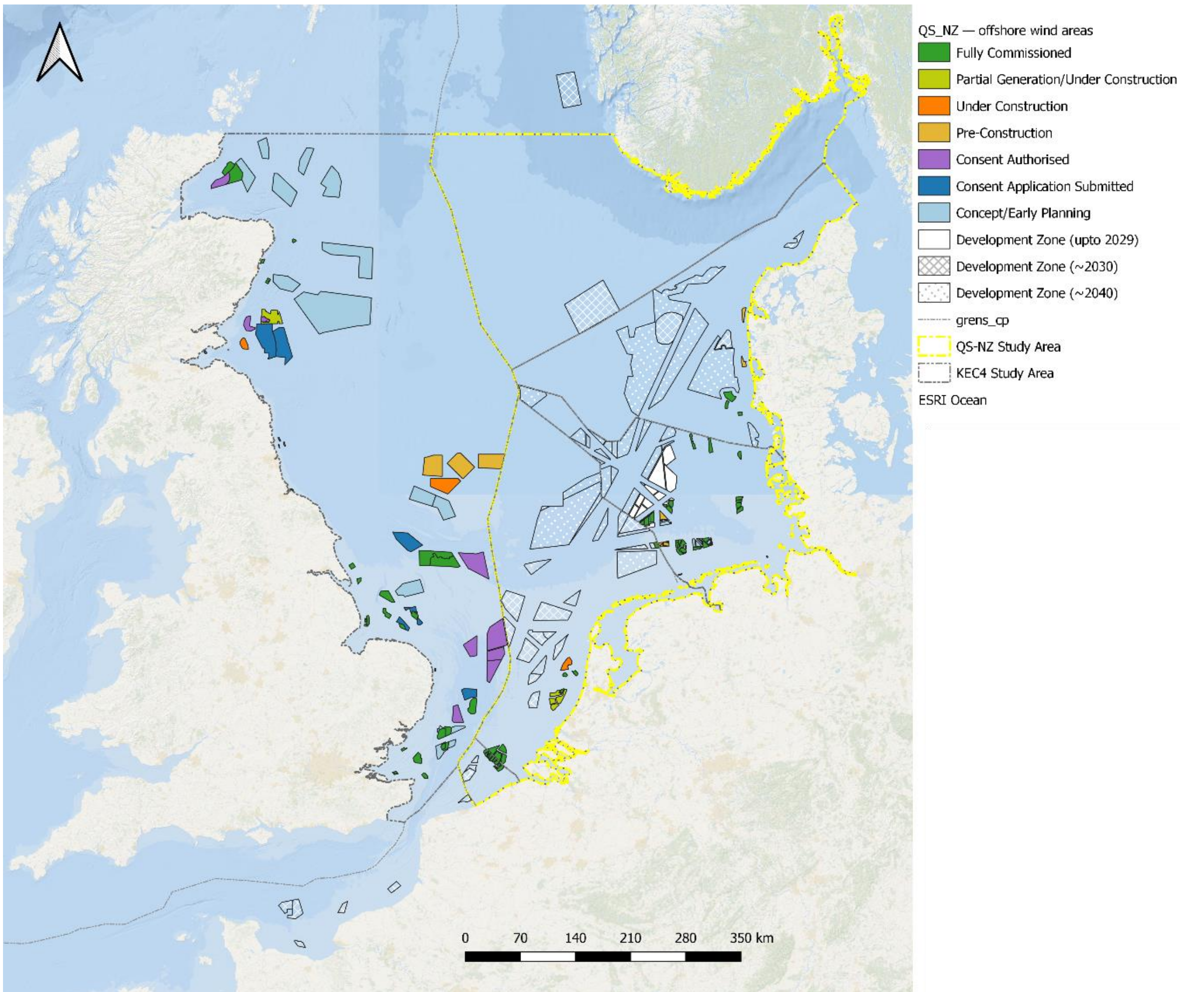

Figure 2. Map of offshore wind farm areas in different stages of development. Based on the information provided by RWS and elaborated by WMR in April 2023.

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.* (submitted) 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.

Nr		Ecosystem components	Aggregation level	
A1		Sublittoral sediment	Habitat type	
A2		Circalittoral rock and other hard substrata	Habitat type	
A3		Pelagic water column	Habitat type	
A4		Fish and cephalopods	Group	
A5		Birds	Group	
A6		Marine mammals	Group	
B1		Red-throated diver	Bird species	
B2		Black-throated diver	Bird species	
B3		Black-legged kittiwake	Bird species	
B4		Northern gannet	Bird species	
B5		Atlantic puffin	Bird species	
B6		Razorbill	Bird species	
B7		Great black-backed gull	Bird species	
B8		Northern fulmar	Bird species	
B9		Common scoter	Bird species	
B10		Herring gull	Bird species	
B11		Little gull	Bird species	
B12		Lesser black-backed gull	Bird species	
B13		Common guillemot	Bird species	
B14		Sandwich tern	Bird species	
B15		Great cormorant	Bird species	
B16		Great skua	Bird species	
B17		Harbour porpoise	Mammal species	
B18		Grey seal	Mammal species	

Species density distribution for Exposure

Spatially specific data are available for the two habitat types sublittoral sediment and circalittoral rock and other hard substrata (EMODnet), and the selected bird and mammal species (SCANS-III, AquaMaps), but not for the species groups fish, birds, 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.

Species sensitivity for Effect potential

In order to account for the sensitivity of each selected bird species to collision and displacement (Effect Potential) the following elaboration has been included in SCAIRM.

The default collision risk, i.e. the probability of interaction (i.e. actual contact that causes the effect) for seabirds in wind farms within SCAIRM is assumed to be 1%, which is based on the lowest recommended avoidance rate (the proportion of birds taking action to avoid collision, also accounting for uncertainty arising as a result of other factors including weather conditions and model error) of 0.99 (Bowgen & Cook, 2018; Cook *et al.*, 2018). For the underlying assessment at the species level (Table 3) we used total avoidance rates of 0.998 for lesser black-backed gull, 0.995 for herring gull, 0.995 for great black-backed gull, 0.992 for black-legged kittiwake and 0.989 for northern gannet (Cook *et al.*, 2018). For other seabird species, i.e. species that are not included in Cook *et al.* (2018), we used avoidance rates as used by Potiek *et al.* (2022) or Leopold *et al.* (2014).

The impact of displacement (which is caused by the pressure "disturbance (visual) of species") also differs at the species level. Within SCAIRM, the sensitivity to disturbance is assumed to be 1% for all species groups. This value reflects the proportion of the exposed population that will die from the consequences of disturbance. In order to estimate the impact at the species level, we used the relative displacement risk score (RDRS) as derived by Leopold *et al.* (2014) and also used by Soudijn *et al.* (2022) in a KEC 4.0 study (Table 3). The RDRS indicates the fraction of exposed birds that will die from displacement assuming that 10% of the displaced birds may die. This is an arbitrary choice, made by Bradbury *et al.* (2014), and adapted within KEC (Leopold *et al.*, 2014; Soudijn *et al.*, 2022) to address lack of information.

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)**

Results

Based on the results for the baseline and future scenario calculations benthic trawling poses the highest risk for the ecosystem components of the North Sea (Figure 3) for the base line as well as future developments. 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.

Of all ecosystem components, fish (and cephalopods) are most impacted. 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 3) but the total Impact Risk on the North Sea decreases. 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 is shown.

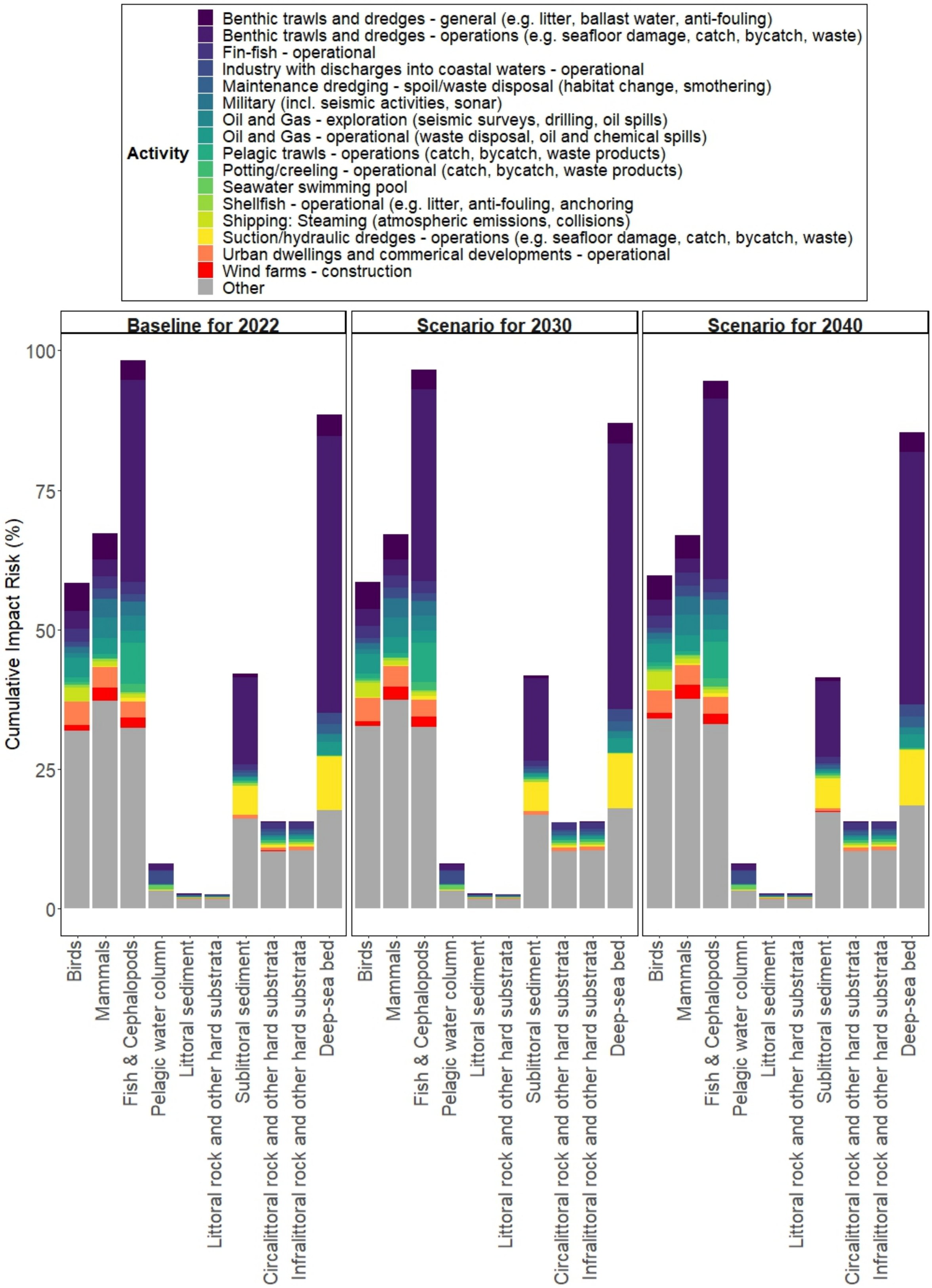

Figure 3. Cumulative impact risk (% of population or habitat quality) of human activities on ecological components of the North Sea according to baseline (left), scenario for 2030 (middle) and scenario for 2040 (right). The 17 main activity-phase combinations are shown separately. The other activities are combined in "other". Top 3 contributing activities per ecosystem component coloured.

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 is presented here against their EU status (Table 4). 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 4). 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 4. 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 and of OWF on bird species in future scenarios (2030, 2040) relative to the 2022 baseline.

	EU population		Change in IR of all activities		Change in IR of OWF	
Species	**Status**	**Trend**	**2030**	**2040**	**2030**	**2040**
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%

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 (i.e. 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.

3.2 German EEZ of the North Sea

The German North Sea differs in several aspects from the wider North Sea area including some critical environmental factors that influence key drivers of the system. Most notably, the German waters are shallow, with depths ranging from 15–30 meters. As a result, the area does not host deep-sea bed habitats which are amongst the most vulnerable habitats to cumulative impacts. The shallow nature of the area also limits the development of floating wind farms in the region.

The relatively small size of the German North Sea compared to neighbouring countries intensifies the potential impact of efforts to achieve greenhouse gas neutrality. The planned expansion of offshore wind farms is expected to cover a larger proportion of the German North Sea, with projections suggesting approximately 22% of its area could be occupied by wind farms by 2040. In contrast, countries like Denmark and the Netherlands are estimated to allocate only 10–15% of their North Sea territories to such developments. This could result in large differences in the exposure and impact risk from this sector.

The German North Sea has also experienced one of the strongest increases in temperature compared to the wider North Sea, indicating that climate change effects might be more pronounced in the region. This warming is contributing to significant species shifts and increases in local biodiversity (https://www.awi.de/en/themen/the-changing-face-of-the-north-sea.html). While climate change is not manageable at the local scale it adds to the cumulative impacts of the system.

Moreover, the bad environmental status of the German North Sea coastal and transitional waters (https://www.umweltbundesamt.de/en/data/environmental-indicators/indicator-ecological-status-of-transitional-coastal), indicates significant environmental challenges in this region and calls for focused cumulative impact assessment at the regional level. To address these challenges, we conducted a rapid cumulative impact assessment using the SCAIRM method and contrasted the results with the wider North Sea case study as well as drew conclusions on the next steps for a full German North Sea SCAIRM assessment.

Material & methods

Selection of primary activities and pressures

We used the ODEMM (Options for Delivering Ecosystem-Based Marine Management) linkage framework (White *et al.*, 2013) to select relevant primary activities taking place in the German North Sea. There were a few primary activities deemed relevant but excluded from this rapid assessment due to insufficient knowledge and data. This included for example the tourism sector and its activities. The ODEMM framework was also used to identify pressures exerted by the selected activities (Koss *et al.*, 2011), which were subsequently aligned with the SCAIRM terminology.

Spatial information of activities, pressures, and ecosystem components

Spatial information was available for most of the primary activities, mammals, fish, and habitats. For the pressures, we did not obtain direct spatial information and relied on the use of the dispersal factor. This was specifically true for land-based activities. To better understand the uncertainty in the assessment, a pedigree was assigned to each activity and ecosystem component layer (Table 5). A large part of the data obtained represented high-quality local information (Figure 4). Mammals consisted only of harbour porpoise since seal surveys are usually performed on land and it is difficult to extrapolate their distribution off the coast. Fish & Cephalopods were represented as species richness maps for demersal and pelagic fish. Habitat information was aggregated to group level for simplicity.

Table 5. Uncertainty assessment of the data for activities and ecosystem components expressed in pedigrees.

	Pedigree	General data uncertainty	Uncertainty related to the spatial resolution and extent	Uncertainty related to the temporal resolution and extent
Low	1	The data used to create the layer represents the German North Sea. It is a direct measure of the layer.	The data represents a high-resolution grid.	The data is recent (2020-2024) and covers more than 3 years.
Medium	2	The data used to create the layer represents the German North Sea. It is an indirect measure of the layer.	The data represents a low-resolution grid, Or the data represents point data which has been appropriately interpolated.	The data is recent (2020-2024) but represents only one year.
High	3	The data used to create the layer does not represent the German North Sea but information is taken from another area.	The data only covers part of the German North Sea or represents scarce data points which require extrapolation or strong interpolation.	The data does not represent the recent period and/or is not covering an entire year but only snapshots of the year or does not cover the relevant seasons of a year.
Model data	5	The data is from the EwE model or another complex ecosystem model.		

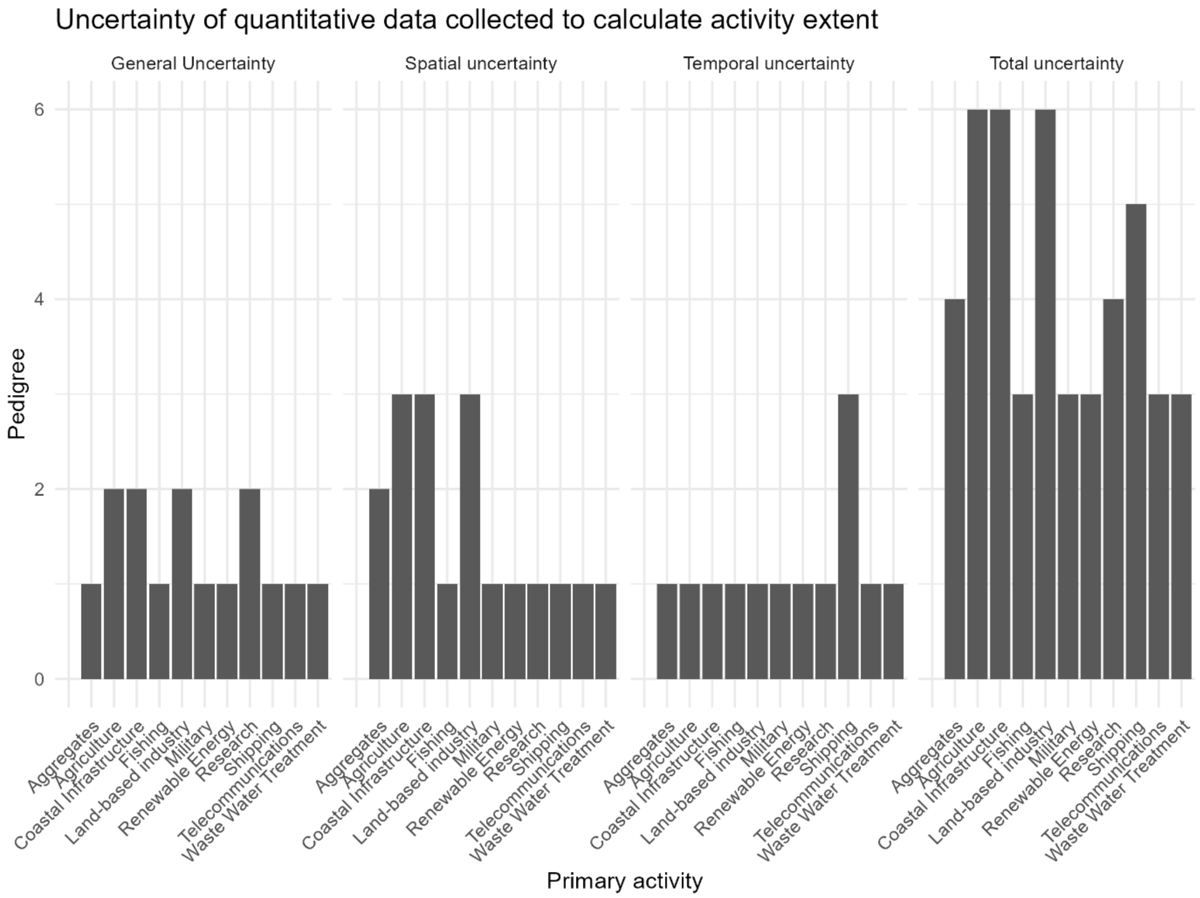

Figure 4. Pedigree of the spatial data to calculate the extent of primary activities.

Calculation of Effect Potential and Exposure

Exposure for each linkage chain was calculated based on the overlap between the activity and the ecosystem component and the pressure-specific dispersal factor used in the North Sea SCAIRM assessment. Likewise, estimates of the parameters hazard, behaviour, and resilience were obtained from the North Sea SCAIRM case study as they are less area-specific. Magnitude and frequency have been largely based on regional information and expert judgement but were also complemented and compared with the magnitude and frequencies defined in the North Sea SCAIRM assessment.

Results

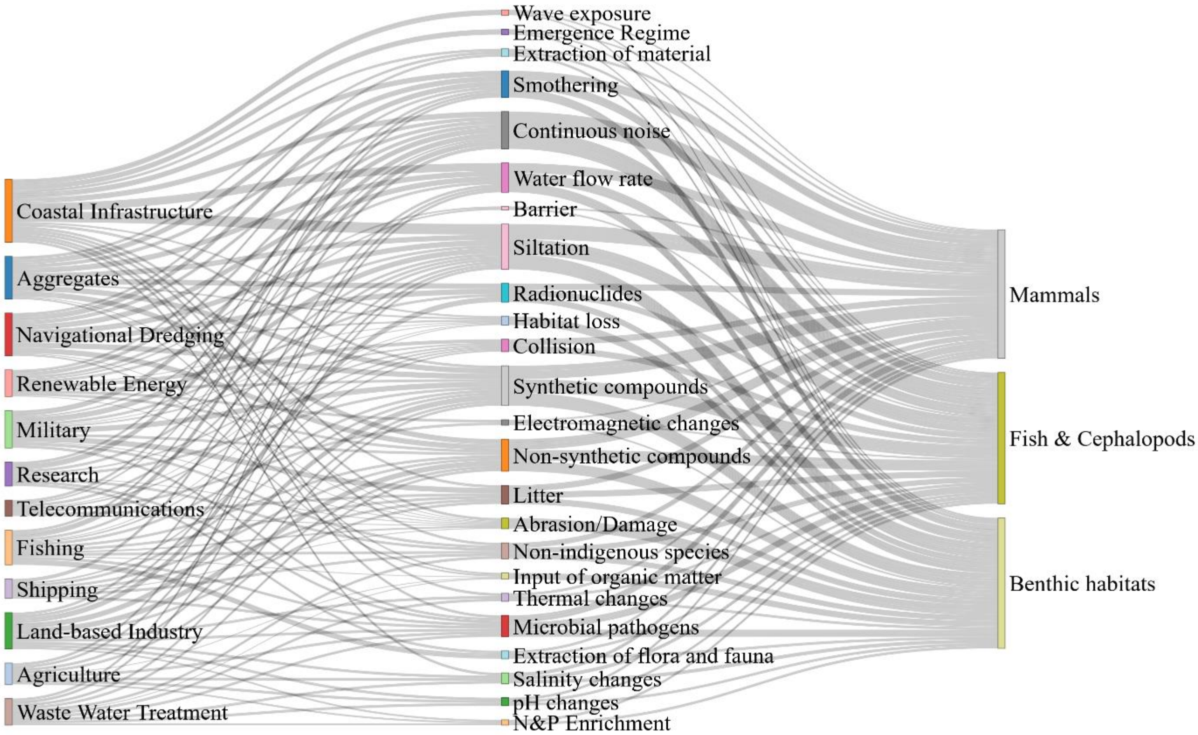

Figure 5. Sankey diagram representing the linkages between the primary activities, pressures, and ecosystem components defined and analysed for the German North Sea case study.

We identified 12 German North Sea relevant primary activities for which enough data and knowledge were available to perform a rapid assessment of cumulative impacts (Figure 5). Some primary activities were considered relevant but were not included due to a lack of information, including the tourism sector. This is particularly important, as the North Sea case study shows that this primary activity contributes considerably to the overall impact risk (Piet *et al.*, 2023). While the primary activities with the most linkages were coastal infrastructure and aggregate extraction, they were not among the main contributors to the impact risk across pressures and ecosystem components (Figure 6). Particularly, aggregate extraction is of lesser importance in the German North Sea compared to other regions of the North Sea (https://oap.ospar.org/en/versions/1899-en-1-0-0-extraction-non-living-resources/) as Germany has only a few active extraction sites.

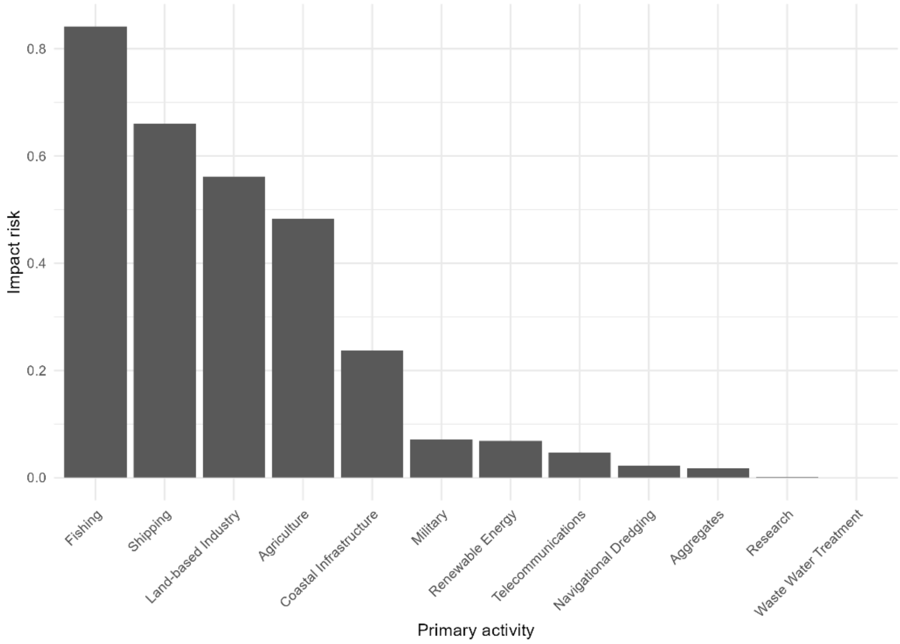

Figure 6. Impact risk across ecosystem components and pressures for each primary activity.

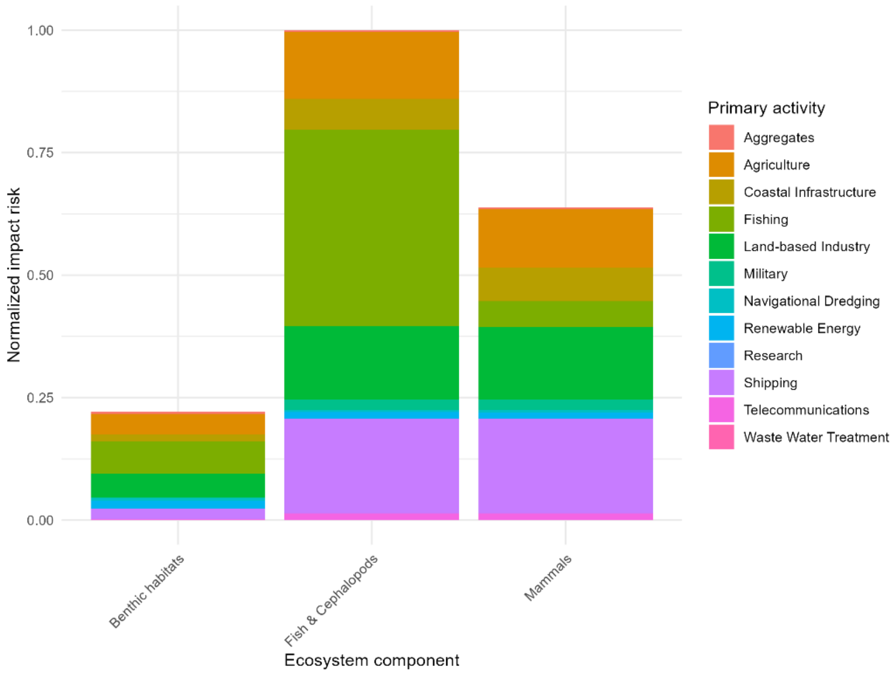

Figure 7. Normalized impact risk for each ecosystem component and primary activity.

The largest impact risks across pressures and ecosystem components were caused by the primary activities fishing and shipping (Figure 6). Fishing had the strongest impact on fish and cephalopods, while shipping notably affected mammals (Figure 7). These finding align with the North Sea-wide case study, which identified fishing as a major contributor. Similar to the broader North Sea case, fish was the ecosystem component with the highest impact risk, followed by mammals. However, the overall impact risk for the habitat component is much lower in the German North Sea, primarily due to the absence of deep-sea bed habitats, which are particularly vulnerable to fishing impacts. It has to be noted that the resilience of fish and mammals is estimated to be the same. However, considering the population dynamics of both components it appears that fish would mature earlier, grow faster, and are more fecund, likely leading to shorter recovery time and higher resilience. This parameter may thus require a more differentiated estimation.

Interestingly, coastal infrastructure (which includes port facilities, artificial reefs, and beach replenishment) has a much lower impact risk compared to the land-based industry and agricultural sectors (Figure 8). This discrepancy appears to stem from the frequency of the primary activities, which is used to calculate the depletion rate. This parameter is crucial as it exponentiates the interaction of hazard, magnitude, and behaviour, indicating a strong sensitivity of the results to the estimation of the parameters and highlighting the need for careful analysis and revision. It has also to be noticed that these three sectors were among the ones with the highest uncertainty regarding their extent.

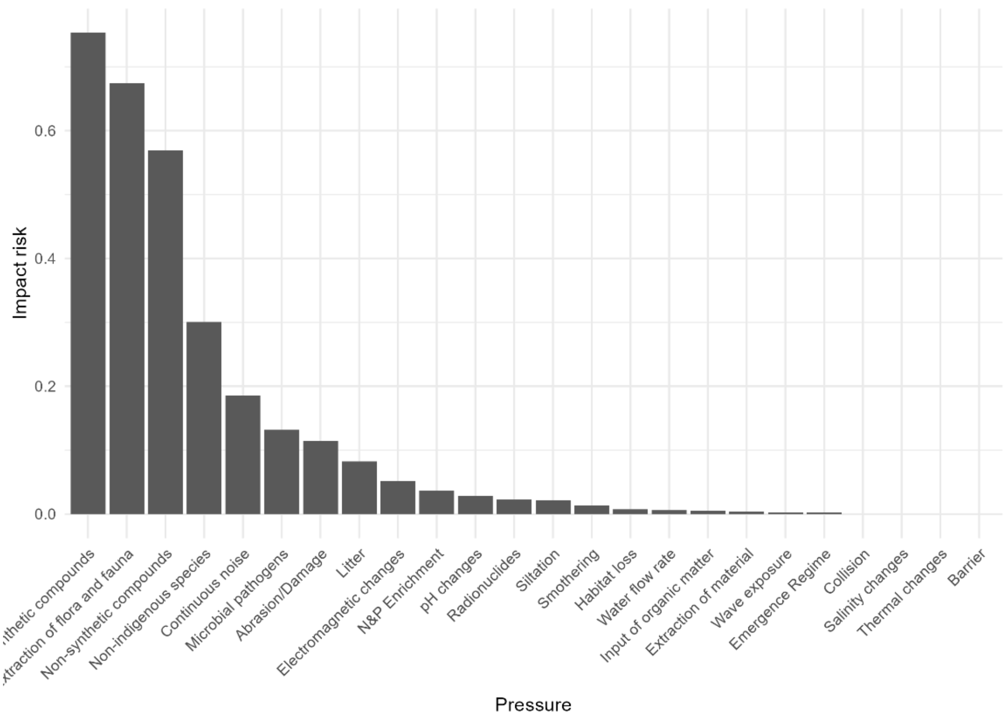

Figure 8. Impact risk across ecosystem components and primary activities for each pressure.

We identified 24 pressures associated with the analysed primary activities, among which siltation, continuous noise and introduction of non-synthetic and synthetic compounds are shared among multiple primary activities (Figure 5). The latter two have indeed the largest number of linkages and together with the extraction of living resources contributed to the highest impact risk. The low impact risk from N&P enrichment is somewhat surprising as eutrophication remains a critical problem since no parts of the German North Sea have achieved good environmental status yet (https://hub.hereon.de/portal/sharing/rest/content/items/99996b6005f04318b3239b199a70d23a/data). This largely stems from the very few linkages between the primary activities and the pressure, which needs careful revision.

Conclusions

The rapid assessment of the German North Sea case study has, where possible, been based on local data to quantify the exposure of the activities/pressures and ecosystem components. Most of the information, however, is based on the primary activity level and reliance on dispersal factors from the SCAIRM framework was necessary. Important primary activities such as tourism are still missing and better spatial information on the specific activities and pressures are needed. The assessment further needs to be extended to include birds and pelagic habitats. The pedigree associated with the spatial data to calculate the extent is an important aspect of the assessment as it quantifies the confidence with specific linkages. This should be extended to other parameter estimates, as it can provide valuable insights into highly important yet uncertain linkages, helping to prioritize data collection efforts.

The regionally varying parameters magnitude and frequency were adjusted for several linkages reflecting the German North Sea but they need to be further verified and extended to all linkages to better understand regional challenges. Furthermore, the current rapid assessment strongly relies on qualitatively estimating the different parameters. However, the strength of SCAIRM is to allow for the use of quantitative and qualitative information. One of the key parameters to estimate is the depletion rate and further steps should entail the integration of quantitative information on the response of ecosystem components to pressures.

While the results for major primary activities, such as fishing, are similar at the German scale compared to the North Sea-wide scale, some primary activities are more pronounced in areas outside the German North Sea, including aggregate extraction and pelagic trawling. There are also regional differences in ecosystem components that are crucial for adapting regional management. For example, the shallow nature of the German North Sea, and the resulting absence of deep-sea bed habitats, leads to different impact risks at the German scale compared to the North Sea-wide scale. Moreover, the scenarios depicted in the North Sea case study may be very different for the German North Sea, since the fishery sector is expected to show a much stronger decline (Stelzenmüller *et al.*, 2024) than predicted for the North Sea case study. Furthermore, Germany's ambitious expansion targets, combined with the relatively small area of the German North Sea, may result in higher exposure and, consequently, greater impact risks. A comprehensive assessment of the German North Sea would therefore help in better identifying the regional challenges and future cumulative impact risks that need to be addressed.

3.3 Celtic Sea

The Celtic Sea case study area examined for WGCEAM is the same area as that assessed in the Mission Atlantic and GES4SEAS projects. The case study area covers the Celtic Sea proper and the Atlantic shelf on the western coast of Ireland (Figure 9). Located on the western edge of Europe, this is a dynamic case study area and its high connectance with other water bodies means it can be affected by many factors including global marine currents (Pedreschi *et al.*, 2023).

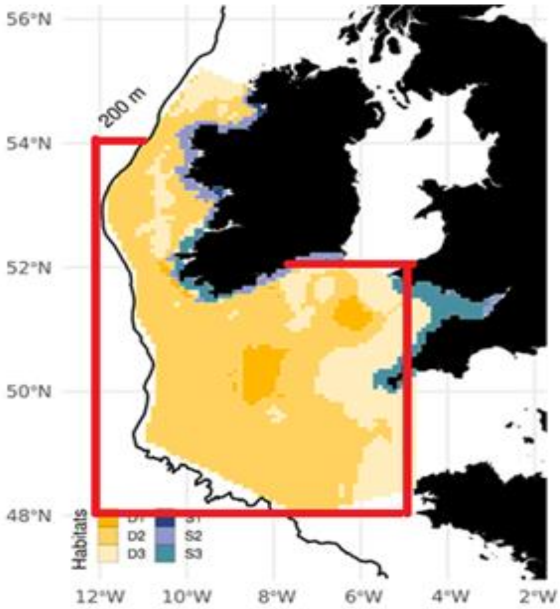

Figure 9. Celtic Sea case study area (Strath E2E, Jack Laverick).

Using a linkage framework from a modified ODEMM (Options for Delivering Ecosystem-Based Marine Management) assessment previously completed for the Celtic Sea (Pedreschi *et al.*, 2023), the WGCEAM CEA framework was used to complete this assessment. A risk assessment was completed, and vulnerability was assessed using the SCAIRM method (Piet *et al.*, 2023). This assessment was completed qualitatively using expert judgement; no quantitative data were used. The linkage framework consisted of 17 human activities, 22 pressures, and 26 ecosystem components. Each linkage chain in the framework was scored for spatial extent, dispersal, frequency, hazard, magnitude, behaviour, resilience and persistence, then Impact Risk (IR) was calculated for each chain. The following table depicts the top five each of activities, pressures and ecosystem components when examining the sum of Impact Risk (Table 6).

Table 6. Table showing the top 5 Activities, Pressures and Ecosystem Components according to the sum of Impact Risk calculated for each.

Activity	Pressure	Ecosystem Component
Fishing	Bycatch	Demersal Elasmobranchs
Waste Water	Species Extraction	Shallow Sediment
Land-based Industry	Litter (Macro)	Shallow Mud
Shipping	Abrasion	Shallow Rock & Reef
Coastal Infrastructure	Litter (Micro)	Shelf Sediment

All of the top 5 pressures are associated with one or more of the top 5 activities which would be expected. The top 5 ecosystem components include one species group and four habitat types. The top 5 activities, pressures and ecosystem components also match quite closely with the ODEMM-based assessment of this case study area completed by Pedreschi *et al.* (2023). Fishing, Wastewater, Land-Based Industry and Shipping were all included in the top 5 activities in the previous assessment, though that assessment included Tourism/Recreation in the top 5 and this assessment included Coastal Infrastructure. All 5 of the top pressures are also included in the top 5 pressures found by Pedreschi *et al.* (2023), though as Litter was not split into Macro and Micro in that assessment, they also included Incidental Loss in their top 5. Finally, four of the top 5 ecosystem components in this assessment matched the previous assessment, though Demersal Elasmobranchs was replaced by Shelf Rock & Reef in the previous assessment. The current SCAIRM assessment has identified the top 5 activities, pressures and ecosystem components based on Impact Risk and, this assessment quite closely with the previous ODEMM-based assessment for the same area. This current SCAIRM assessment is a draft assessment; final consistency checks are still to be completed.

3.4 Gulf of St Lawrence

Roland Cormier

Canadian marine and freshwater case studies undertaken the lower left box of Figure 1 of the framework. This work is currently in line with the science of effectiveness we are pursuing for mitigation measures to achieve fish and fish habitat protection policy objectives (DFO, 2019). The premise is that without reliable and effective technical measures, it is unlikely that expected outcomes outlined in regulation, standards, or guideline would be objectives (Cormier, Elliott and Borja, 2022; Cormier, Tunney and Mallet, 2022). Based on the risk management approach in the policy (DFO, 2025), the regulatory advisory process (Figure 1) is to identify the technical measures to prevent (avoid), reduce the spatial scale, duration, or intensity (mitigate), or counterbalance the unavoidable (offset) “harmful impacts to fish and fish habitat” in consideration to “any cumulative harmful impacts on fish and fish habitat that are likely to result from the work, undertaking or activity in combination with other works, undertakings, or activities that have been or are being carried out”.

Although this framework is about “management” within the context of an assessment and planning for a particular human activity within the context of multiple human activities and their pressures to occurring in a regional sea as described above, the regulatory advisory process would still follow the same four boxes of Figure 1. Within the specificity of the spatial and temporal footprint of the phases of a project proposal (e.g. construction, operation, modification, decommissioning, or abandonment), impact assessment also considers the causal relationships and the key prevailing pressures as pathways of effects (Upper left box Figure 1); (DFO, 2021). Exposure and effect potential (Upper right box Figure 1) are assessed in the terms of the specific worksite activities and the different pressures that are generated for each phase of the project in terms the load, resistance, and recovery potential within the footprint of the project (DFO, 2013a, 2013b). Ultimately, a graphic representation similar to the effects potential to exposure of the lower right box of Figure 1 is used to establish the most critical technical measures needed to address the potential effects (DFO, 2014a, 2015) which is then used to identify the technical measures needed for the project to be undertaken taking into account the scientific, management, and operational uncertainties (DFO, 2014b).

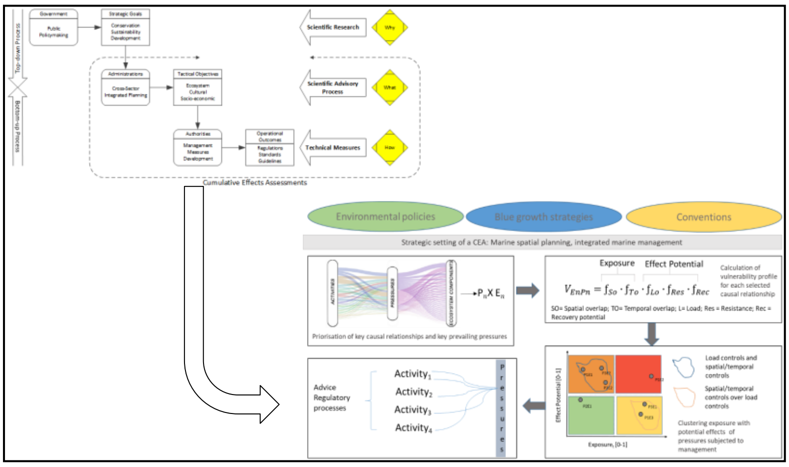

Figure 10. Integration of the cumulative effects framework (Adapted from Cormier *et al.*, 2017; DFO, 2022)

However, the considerations for cumulative harmful impacts to fish and fish habitat still requires an understanding of the current state of the fish and habitat generated from an integrated planning process to set the context for the assessment of the project being proposed (Cormier *et al.*, 2022; Hodgson *et al.*, 2022). Thus, the project level information generated from tracking and monitoring of past projects are still needed to feed into a planning process to understand the context of proposed projects.

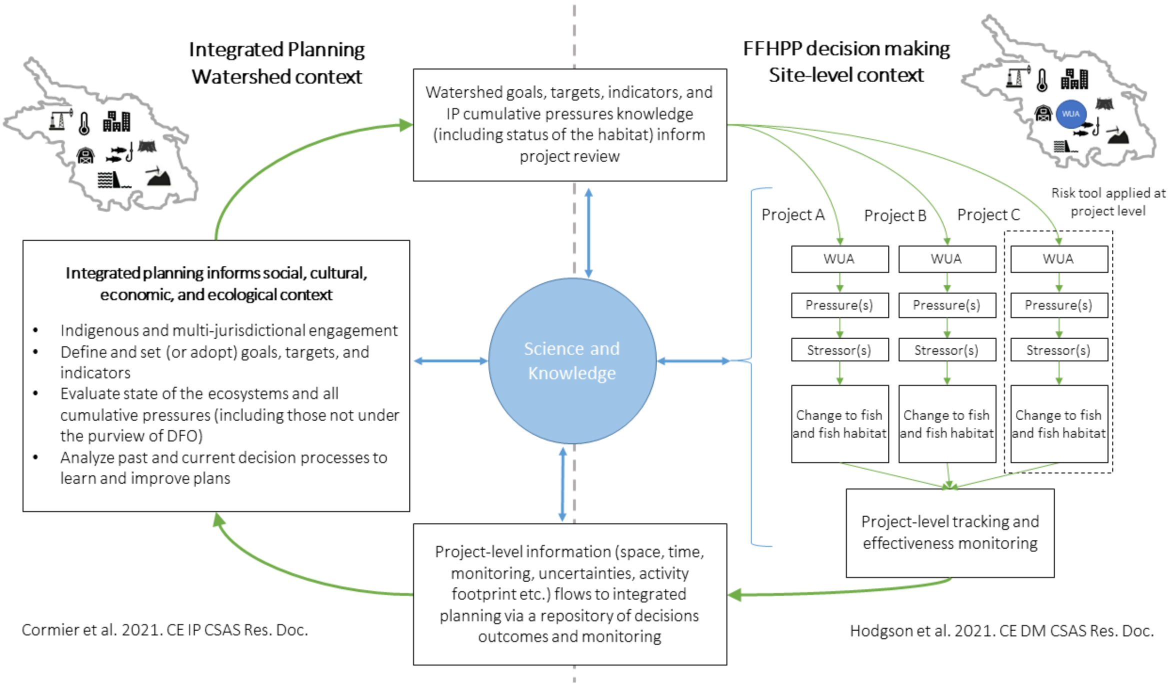

Figure 11. Information cycle between planning and worksite decision (DFO, 2022).

Based on science advisory report (DFO, 2022), cumulative effects assessments used in planning to inform regulatory decisions is a relatively new concept. Such assessments require as much a holistic view of ecological and management processes as is often thought for ecosystem-based management. Although there is significant amount of data that is generated from project tracking and monitoring including the ecosystem scientific research, uncertainty continues to be a challenge given the wide range of indicators and sampling protocols used for monitoring and the difficulties to integrate and interpolate such data for the purpose of such assessments.

In addition, there is continued need to monitor pressures and their relevant indicators – for example the EU Marine Strategy Framework Directive (MSFD); (EU, 2017b, 2017a). As mentioned earlier in this document, data on the spatial and temporal distribution of pressure by activities are a key component to establish thresholds and determine the reliability and effectiveness of technical measures. Using the MSFD as an example, thresholds for pressures thresholds could feed directly in the development of output controls to subsequently study the reliability and effectiveness of the input controls and the spatial and temporal distribution control of the program of measures.

4 Scoping for future scientific advancements and good management practice in addressing cumulative effects (ToR b)

The concept of socio-ecological systems (SES), where human wellbeing depends on the state of ecosystem components and the related services they provide, is shown in Figure 12. Components or elements of such SES are determined by the resource used, thus fisheries SES are often described around the targeted species and the related types of fisheries (actors); (Stelzenmüller *et al.*, 2024). SES can be characterised by the integration of biogeophysical and socio-cultural processes, their complexity, and levels of self-organisation, as well as nonlinear and unpredictable dynamics with feedbacks between environmental, as well as socio-economic and socio-cultural processes (Leenhardt *et al.*, 2015; Colding and Barthel, 2019). As illustrated in Figure 12, the state of ecosystem health forms the central part in such combined natural-human systems.

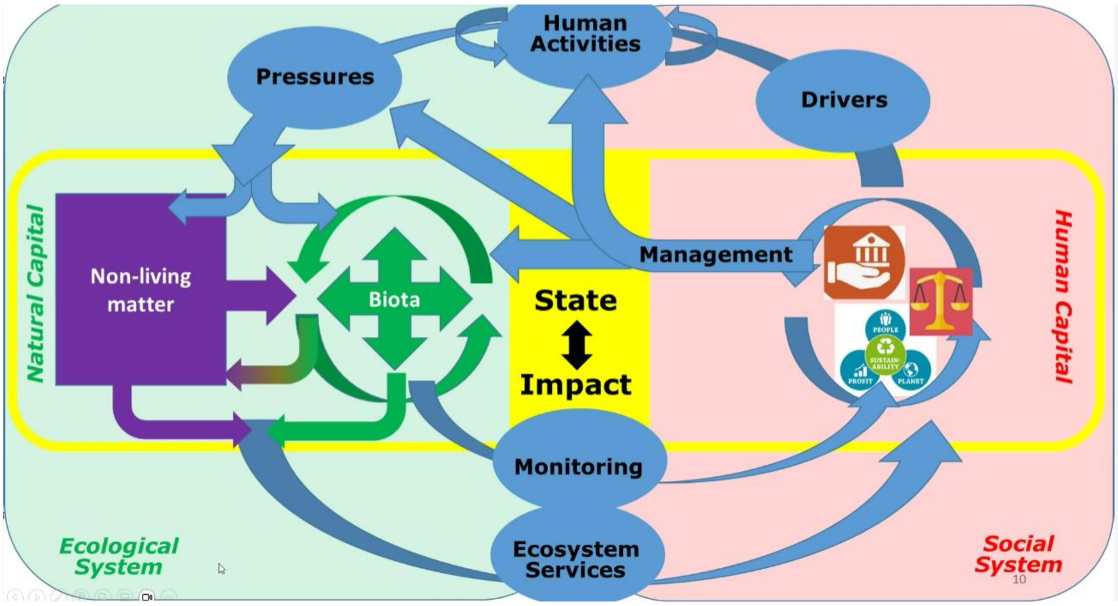

Figure 12. Illustration of the connected spheres and the ecosystem state as a pillar of socio-ecological systems.

In general, cumulative impact assessments (CIA) or CEA should inform multi-sectoral management processes such as for example national MSP processes on the risk of combined adverse effects of multiple human activities and the related pressures. The WGCEAM framework therefore combines the assessment of the state of receptors or assessment end points with the need to regulate human activities to lower the overall pressure loads.

While the demands, processes and context for CEA differ for between governance advice, marine spatial planning processes or regulatory procedures (Stelzenmüller *et al.*, 2020), there are however, some common elements or principles for any given CEA. As illustrated in Figure 13 those key elements comprise the knowledge of causal pathways between multiple human activities, their pressures and the expected effect sizes and adverse impacts as well as related management measures.

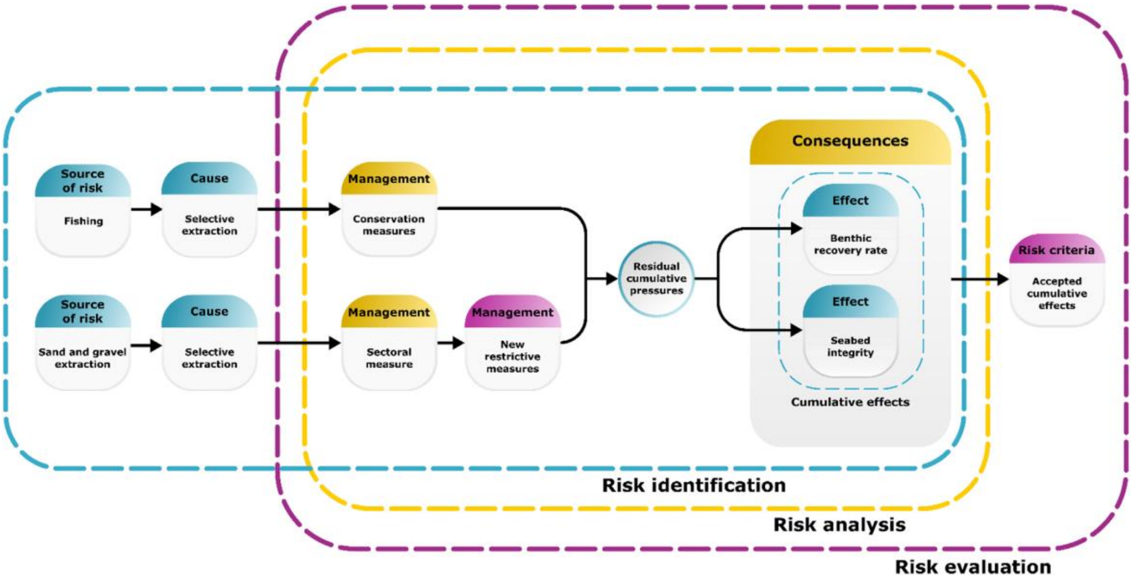

Figure 13. General illustration of two theoretical cause-effect pathways showing the links between two human activities (e.g. fishing and aggregate extraction), their common pressure (e.g. selective extraction), sector specific management measures (e.g. conservation measures, sectoral measure), cumulative residual pressures (total selective pressure load in the system despite management measures) and measurable state change of ecosystem components (e.g. benthic recovery, seabed recovery); (taken from (Taken from Stelzenmüller *et al.*, 2020).

4.1 Scoping exercise

To synthesis key requirements for scientific advancement and CEA implementation, a scoping meeting was organised in the course of the final WGCEAM meeting. In particular the upcoming request of the Greater North Sea Basin Initiative (GNSBI) to conduct a basin scale CEA showed the need to define a common understanding in the good practice in the operationalisation of CIA/CEA. A total number of 43 participants were counted for the two online meetings which were conducted on the 4th and 5th of November 2024. The participants consisted out of representatives of national authorities for MSP, environmental management, OSPAR, European Environment Agency (EEA), various ICES expert groups and academia in general.

To identify data and knowledge needs for CEA/CIA in relation to current management applications we defined four types of common management applications that come with specific requirements and thereby allow to provide an overview of the current knowledge base and its gaps to guide future scientific advancements. The scoping exercise aimed to provide common principles and the required knowledge for cumulative impact assessments. To that end WGCEAM brought together the relevant parties within the science-policy interface with the purpose to start making the knowledge base fit for purpose in the advisory process:

- Science producing the advice, i.e. the experts familiar with the various tools focussing on cumulative impacts (or effects) assessments and integrated multi-sectoral ecosystem-based management including marine (or maritime) spatial planning. These experts should provide an overview of relevant tools with their knowledge requirements and output they can provide.
- Policy as the recipients of advice, i.e. managers or decision-makers with knowledge of the (types of) management decisions that need to be informed now or in the near future for their marine waters and the (type of) advice they expect to receive.

An example request for advice came from the Greater North Sea Basin Initiative (GNSBI) with the following Terms of Reference:

a) Provide an overview of relevant cumulative impacts assessments (including those used within OSPAR, NSEC, ICES, relevant European research projects and national approaches) aimed at an applied setting and informing management decisions;

b) Define common principles for cumulative impacts assessments in relation to the expected applications and the types of management decisions that need to be informed. Identify criteria for the evaluation of the available cumulative impacts assessments;

c) Provide recommendations for the application of the most suitable tool(s) for cumulative impact assessments on, at least, the Greater North Sea and Celtic Seas including a process to further develop the required knowledge base with the aim to:

    - o Identify the main anthropogenic threats that compromise the achievement of GES
    - o Evaluate planning scenarios of offshore wind and other human activities
    - o Inform MSP decision-making on a sea basin level
    - o Evaluate management measures aimed at mitigating human activities and their pressures
    - o Assess the effectiveness of the MSFD Program of Measures to reduce human-induced impacts

A Miro scoping exercise was conducted to solicit input on the following questions. What do you think are:

1) Strengths of known CIA tool(s) relevant for intended GNSBI applications
2) Common principles to guide future developments in relation to
    1) CIA knowledge base
    2) CIA science advice
3) Specific applications of CIA and known best practices

Results

From that input we distinguished four types of applications that come with specific knowledge requirements, and these were applied to arrange the strengths of know CIA tools and best practices for their use (Table 7).

In addition, some general statements were received that may apply to each of the applications:

- o Strengths from known CIA
    - Symphony already has nice GUI (Graphical User Interface)
    - SCAIRM has good level of detail
- o Considerations/Weaknesses/Concerns/Issues
    - Additive ≠ Cumulative. This is not necessarily a methodological issue (dependent on the choice of CIA tool) but rather data availability, however frequently approaches are labelled as cumulative but only take multiple pressure, or at best, additive considerations into account
    - Complex interactions should not be reduced to single number. The appropriate level of detail needs to be balanced with information availability and end-user requirements
    - Endogenic (manageable) versus exogenic pressures: Climate is not a pressure that can be managed at sea basin level and should therefore be treated as (change in) context that may affect the spatial distribution of species or the Pressure-State relationships. Avian influenza may cause an impact on certain bird populations both within and outside the

  sea basin but should only be included if local (sea basin) management can intervene to reduce impact risk. However, exclusion of any relevant pressures/concerns should be transparently documented.
  - Operationality is key: further developments of the CIA (e.g. transition towards more data-driven) should not interfere with its operationality.
- Recommendations/Suggestions
  - Evaluate practical applications to guide improvements (with 5 endorsements)
  - CIA should facilitate engagement with local / regional experts to ensure buy-in / acceptance of outputs
  - Resourcing needed from various sources (national and institutions)
  - Limit application to a subset of the linkage framework, e.g. seafloor
  - Consider both good and poor practices. Examples of poor practices are possibly more informative.
  - Benefit from application of the same generic information across ecosystems
  - Make use of existing frameworks and approaches that may be relevant

The different statements to identify common principles to guide future CIA developments in relation to (1) the required knowledge base or (2) its use to provide science advice are shown in respectively Table 8 and Table 9. The relevance of the common principles based on the number of statements and their endorsements is shown in Figure 14.

The main outcomes of this scoping exercise in relation to common principles were:

- It is considered essential for science to estimate uncertainty that comes with the use of the best available science, i.e. expert-judgement or data-driven, and use this to communicate on the confidence in the outcome of the assessment as part of the requirement for full transparency. The estimation of uncertainty for expert-judgement or data-driven parameters should also facilitate and guide the process towards more data-driven CIA where a new parametrisation of any particular impact chain should always result in a decreased uncertainty and hence an increase in the confidence of the outcome.
- Transparency involves making the assumptions, limitations and quality of the CIA (and hence its output) explicit. Ideally it should allow the recipients of advice to drill down into the information that is at the basis of the presented results. If better information is found to exist, i.e. with lower uncertainty, it should replace the initial information.
- Integration is primarily on the structure of the CIA and how this determines its use as part of Integrated Ecosystem Assessment (IEA) and in relation to EBM and/or MSP and specifically applies to the categories of A-P-S and how the various concepts align with how they are used elsewhere. It is specifically about its positioning in the SES and linking it to other models (e.g. foodweb models or cost-benefit assessments). It also implies that all the EBM principles (Long *et al.* 2015) are relevant for the development of CIA and its capacity to provide science advice. This is strongly linked to the use of consistent terminology and the implementation practices.
- The implementation practices primarily involve the process of that integration as part of IEA and in relation to EBM.
- The use of consistent terminology is required for the integration of CIA with other science approaches in the IEA process but also to understand how findings reported in the scientific literature can be used to parametrise the CIA tool as it becomes more data-driven.

- Flexibility is linked to the principles of uncertainty and transparency in that if it emerges that better information is available it should be incorporated. This should always result in a lower uncertainty and increased confidence.
- Transferability involves the transfer of a particular CIA approach to other ecosystems but also the exchange of parameters of P-S relationships that can be assumed generic between ecosystems.

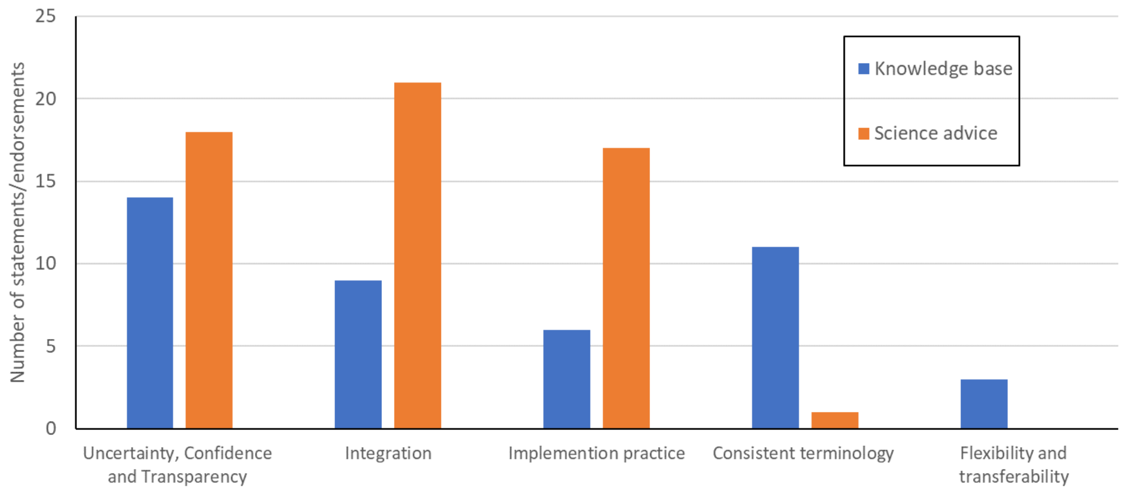

Figure 14. Relevance of the common principles based on the number of statements and their endorsements. For specific statements related to the principles, see tables 2 and 3.

Table 7. Input received from participants on two questions in relation to four different potential applications for science advice based on CIA. The number between brackets (x) gives the number of times other participants endorsed the statement.

Applications	Strengths/weaknesses known CIA tools	Known best practices
Identify the main anthropogenic threats that compromise the achievement of GES	• Comparison among ecosystems: ICES Ecosystem Overviews. Easy to implement (6) • Part of Integrated Ecosystem Assessment scoping to drive further models, e.g. foodweb models to cover indirect effects. (5) • CIA combined with Integrated Ecosystem Assessment (4) • MSFD support: OSPAR / HELCOM	• There is an advantage of having a common risk assessment approach across Ecosystem Overviews (currently in place) • Halpern is used by EEA and globally
Evaluate planning scenarios of offshore wind and other human activities	• SCAIRM was applied to evaluate OWF (and other activities) planning scenarios in the North Sea	• Planning OWF scenarios embedded into MSP (6) • Include sectoral development scenarios • Scenarios from ECOMAR and Symphony • Need for multi-sectoral scenarios
Inform MSP decision-making on a sea basin level	• Maps are key. Spatial CIA are required (20) • Confidence in spatial information • Spatial information essential to link various EU legislation (5)	• Ecological hotspots or high-pressure areas (13), Identify Nature conservation/restoration areas (9), less impacted areas for MPAs (9) • Strategic: Supporting cross-sectoral decision-making (5) • Include Multi-use (5) • Assessment of planning alternatives (4) • Apply data-based maps (3)
Evaluate management measures aimed at mitigating human activities and their pressures / Assess the effectiveness of the MSFD Program of Measures	• BowTie allows comparison of different measures (2) • EBA requires more quantitative information • Caution for redundancy as more detailed operations/actions are included	• Strategic: Supporting cross-sectoral decision-making (5) • CIA as part of transdisciplinary approaches (4) • Apply BowTie. But how does this inform on effectiveness? • Trade-offs • Consider different scales.

Table 8. Statements and the common principles to guide future CIA developments derived from them in relation to the required knowledge base.

Principle	Statement
Uncertainty, Confidence and Transparency	Confidence assessments should be mandatory
	Document all decisions transparently, document methods transparently
	Explicitly detail assumptions and weaknesses
	Confidence information is needed
	Impact risk should be assessed and clearly defined - Key indicator for CIA results, its interpretation should be understood
	comparisons with state assessments should be always made
	Uncertainty in information should be available
Terminology	Vocabulary: Use MSFD, INSPIRE etc. for maximising policy relevance. Do not reinvent
	Use MSFD annex III for categorisation of elements
Flexibility and transferability	Needs to be applicable to data poor and data rich regions
	Include that it should be used for quantitative and qualitative scenario development and testing
Implementation practice	Consider doing participatory modelling for including stakeholders
	How to communicate the CEA outputs/ need for data to non-CEA specialists?
	Include stakeholders!!!!
	Improve linkages to policy by identifying and specifying operational objectives
	Identify knowledge gaps with SCAIRM and bow tie
	GAP analysis following the assessment
	CEA/CIA should always be data driven
Integration	Includes multiple and integrative approaches including qualitative and quantitative data and approaches
	Additive models (e.g., Halpern) should be integrated with more complex interactions between pressure
	Include social and economic information: socio-ecological systems approach
	Include indirect effects
	Make sure the system is for skills rich/poor areas as well as data rich/poor areas

Table 9. Statements and the common principles to guide future CIA developments derived from them in relation to its use and capacity to provide science advice.

Principle	Statement
Uncertainty, Confidence and Transparency	Transparency in limitations
	Assumptions. Be clear in articulating assumptions - to help understanding in how assessment products can be used - and their limitations

	Difference in availability of data quality: should not lead to effects with good data being classed more impacting than effects with poor data
	Ensure pros and cons of the approach are well documented and explained
	At start of CIA: Resolution of effects: it has to be made well clear why and how resolution was decided. Robust and transparent approach needed
	Consider what format information output is most useable for policy makers; a tool? or maps? etc.
	Specify operational objectives and thresholds!
	Clarify what you interpret by cumulative or need from CEA
	there is something about the balance between complexity/ simplify - it is important to illustrate the complexity - but also help if making sense - so non expert users are not completely overwhelmed.
	In the CIA we should be sure to inform on what we do not know
	Second. effect: decision on inclusion based in operationability threshold?
	that the outputs help communication between different sectors / nature restoration and conservation
	Clarity on basis of CIA: quantitative vs qualitative data, expert opinion, confidence, etc. Potential risks versus 'observed' risks
	in the CIA we should inform what it means (e.g. is it impacted? check state)
Terminology	Make sure there are common accepted lists of activities, pressures and measures
	Vocabulary: being transparent in terminology is important to help understanding across sectors (same words often have different meanings) (Note this is also on the knowledge base side and feel it should be in both)
Implementation practice	In General, the common principles should lead to comparability between national CIA results among different NS countries.
	Alignment as much as possible across ICES, OSPAR, NSEC, GNSBI would help simplify/steer the approach for marine planners to take.
	Accept that a couple of CEA projects doesn't mean that the CEA box has been ticked!
	CIA should be flexible and do not need long time periods to be prepared so they can be ready in the proper "political" timing
	there is a very difficult balance - scientists will work to the highest level of complexity whereas policy-makers often require transparency and simplicity
	Using CIA results to link to responsible policies, also beyond MSP
	Adhere to existing principles: e.g. ICES advisory principles, EBM principles etc.
	Policy-makers: engage scientists too
	CIA should look at interaction of different uses and pressures. e.g. fisheries pressure will increase in one place if energy infrastructure increases elsewhere
	All human activities should be included in the analysis to establish comprehensive analyses.

	A CIA should inform policy/decision makers that for MSP if additional activities get added (e.g. OWF), then based on the pressures and impact, what existing activities should be reduced or spatially relocated to ensure the cumulative impact on the ecosystem doesn't increase
	include socio-economic scenario testing
Integration	Better links to human welfare
	Make the link between MSP and achieving MSFD / env objectives
	Important decision on Ecosystem baseline: pristine state? Or already impacted state?
	An integrated "backsourcing" approach (e.g., Menegon *et al.* 2018) could be useful to manage pressures affecting specific areas, such as MPAs
	Future uses: CIA should at least perspectively include them (e.g. spaceport)

Synthesis and concluding remarks

Based on a brief review of the scientific advancements in developing CEA/CIA approaches we distinguished three main types that each come with a specific strengths and weaknesses in relation to potential applications (Table 10). Although unknown at the time of development SCAIRM combines these strengths into a single approach. The advantage of this is that a single CIA approach can be used for all these applications, but this comes with the disadvantage of being relatively information-heavy. However, the harmonized approaches based on expert-judgement or data allow a piecemeal transition toward more data-driven without compromising its operationality. As the most demanding CIA in terms of information with the potential to address each of the applications SCAIRM can therefore be used as the basis to develop the knowledge base as this allows the application of that information also as part of the other CIA types and thus advancement of the capacity to address the requests as reflected in the applications. Note, however, that for each of the applications separately other CIA approaches may be equally suited but come with lower requirements on the data availability.

Table 10. Characterisation of different broad types of CIA in relation to potential applications.

Applications	Overview types of CEA/CIA tools			
	Management (BowTie)	**Spatial**	**Comprehensive (ODEMM)**	**WGCEAM SCAIRM**
Identify the main anthropogenic threats	NA	Only those threats for which spatial information exists. Bias in data-poor ecosystem as little of the total risk is covered in the analysis Uncertainty mostly in effect potential estimate. How much threat is covered by the stressors included	Comprehensive Bigger uncertainty in the estimation of exposure and hence lower confidence.	Comprehensive Relatively information-heavy with low uncertainty and high confidence Piecemeal progress towards more data-driven captured in confidence levels
Evaluate planning scenarios of relevant human activities	NA	Only those activities for which spatial information exists. Scenarios link to the spatial distribution and intensity of the stressor	(Changes in) Spatial distribution can only be included in a very coarse manner Scenarios link to the magnitude and/or the frequency of the stressor	Scenarios can include changes in spatial distribution and hence spatial overlap and link to the magnitude and/or the frequency of the stressor. Design?
Inform MSP decision-making	NA	Sensitivity (overall and per ecosystem component) per gridcell Threat index from included stressors per gridcell	Impact Risk scores associated with the focal area. Contextual information illustrating potential cumulative effects and trade-offs.	Impact Risk from those A-P for which spatial information is available Contextual information illustrating potential cumulative effects and trade-offs.
Evaluate management measures, e.g. MSFD PoM	Indicates if a specific threat can be mitigated (Y/N), cannot assess the (expected) performance of management	Evaluate spatial management, e.g. MPAs	Evaluate all management except spatial	Evaluate all management, spatial only for those A-P for which spatial information is available

IEA, EBA and/or SES compliance?	Iso-standardized, use in industry	Depending on categorisation of stressors and receptors	Yes for IEA and EBM, can be used as a scoping tool. Can be further linked through to ecosystem services, indicators, drivers etc.	Sectoral activities defined such that they link to economics and to operations understood by stakeholders Management linked to governance actors through policy instruments

5 Identify linkages between CEA framework and other ICES products and liaise with other fora or expert groups both within and outside (ToR c)

ICES Working Group on Offshore Renewable Energy (WGORE)

WGORE has a Terms of Reference on Cumulative Effects Assessment (CEA) of offshore wind, wave, and tidal farms in the International Council for the Exploration of the Sea (ICES) area.

They are drafting a paper on the state of Cumulative Effects Assessment (CEA) within the offshore renewable energy sector. The paper is divided into three main sections: the need for realistic environmental assessments in offshore renewable energy, specifically CEAs; a discussion on how the term CEA is interpreted differently within the renewable energy planning, licensing, and deployment stages; and the steps necessary to achieve realistic environmental assessments for offshore renewables.

ICES Working Group on Offshore Wind Development and Fisheries (WGOWDF)

Pressure-State-Impact (PSI) work. WGOWDF are using a Drivers-Activities-Pressures-State-Impact-Responses (DaPSIR) framework. Their focus is on the linkages between Pressures and State, and Impact. They have broken the State-Impact into two stages: ecological Impacts (eI) and population Impacts (pI). They have begun collating evidence from the literature on the strength of each linkage to move away from assessments driven purely by expert judgement. The outputs are expected to be developed further in 2025 and published shortly thereafter.

Currently, WGOWDF is using a list of Pressures that is a mixture of sub-activities and pressures. WGCEAM (via Daniel Wood) has suggested moving towards the standardised list of Activities and Pressures developed in Good Environmental Status for the Seas (GES4SEAS) to aid integration with other work. This effort should produce an agreed list of environmental impacts, at least for fishing and offshore wind farms, which could be useful elsewhere and form part of a larger set of agreed environmental impacts.

OPSAR Intersessional Correspondence Group on Ecosystem Assessment Outlook – Cumulative Effects Assessment (ICG-EcoC)

OSPAR ICG-EcoC completed the cumulative effects assessment for QSR 2023.

All Thematic Assessments - OSPAR-OAP (Prod)

Ecosystem components were grouped into thematic assessments on the status of benthic habitats, fish, marine mammals, marine birds, and pelagic habitats. Bow-tie analysis was used to engage with stakeholders and identify the key activities and pressures. The ODEMM framework was then used to weight the linkages between Drivers-Activities-Pressures-State-Impact-Responses (DAPSIR) in Sankey diagrams (Figure 15).

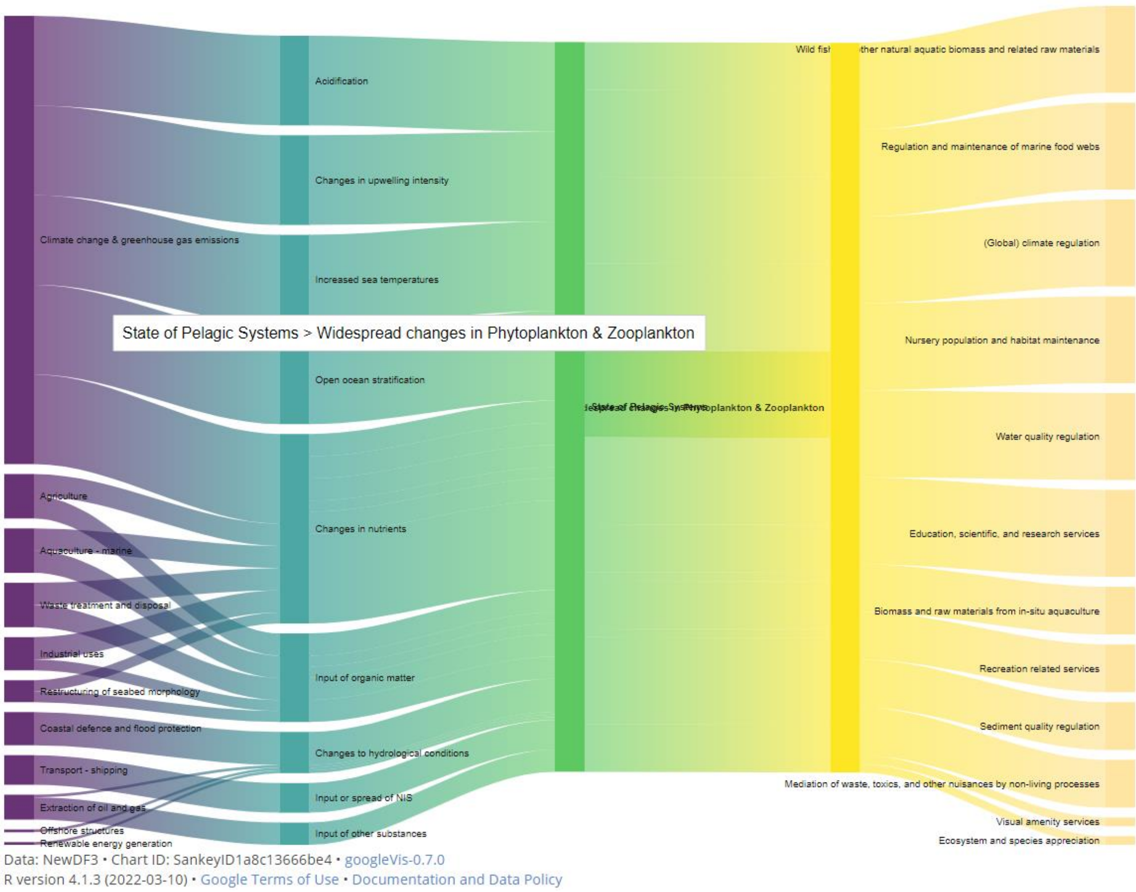

Figure 15. Example of weighted Sankey plot from the OSPAR QSR2023.

ICG-EcoC have recently started work on the next Intermediate Assessment, due in approximately 2028. They are proposing to use the Symphony approach to create heat maps, bringing in the risk assessment detail of SCAIRM.

Integrated Ecosystem Assessment as a framework for CEA/CIA.

Integrated Ecosystem Assessment (IEA) has been adopted by both ICES and NOAA, is a key tool for progressing EBM (Walther and Möllmann, 2014); (Levin *et al.*, 2014, 2009), with multiple ICES working groups focused on developing and progressing regional IEAs. IEA works to integrate relevant information from all aspects of the socio-ecological system, considering human activities and anthropogenic pressures, ecosystem changes, and social and ecological impacts. As such, IEA inherently includes cumulative effect considerations and concerns – however work is needed to make CEA/CIA approaches more explicit to ensure their application in practice.

IEA consists of five stages: scoping, indicator development, risk analysis, management strategy evaluation, and ecosystem assessment (Samhouri *et al.*, 2014); (Levin *et al.*, 2014, 2009). Both qualitative and quantitative assessments can be used throughout these steps depending on the management need/ relevant question/ specified objectives. IEA provides an adaptable and iterative approach to:

- Integrate multiple methods and data streams
- Identify and integrate multiple perspectives and trade-offs
- Facilitate meaningful stakeholder engagement
- Ask and answer complex questions
- Work multi-disciplinarily to produce transdisciplinary outcomes
- Operationalise EBM and provide ecosystem-informed advice

Two key steps in IEAs are scoping and risk assessment. Within ICES and the Mission Atlantic project, these steps have been combined to provide a holistic integrative risk assessment approach that can be developed with, and/or reviewed by stakeholders to inform further steps and analyses. The assessment consists of a driver–pressure–state type of assessment adapted from the ODEMM project (Knights *et al.*, 2013; Pedreschi *et al.*, 2023) where all sectors, pressures, and ecosystem components relevant to the region are identified, their relationships (linkage chains) established, and assessed (for spatial and temporal overlap and degree of impact). The assessment is carried out through panel assessments, informed with data (e.g. maps) where they are available. The assignation of scores for each linkage chain allows ranking and a pressure or risk assessment to be carried out. The assessment does not consider uncertainty beyond evidence and/or confidence scores supporting the identified linkages. It identifies priority risks and pressures for the region, focusing the next steps of an IEA (i.e. scoping) and helping to direct where to focus future research efforts, including those of high risk and low knowledge. The next steps of the IEA include underpinning these key focal areas with data and/or modelling to answer stakeholder questions, identify trade-offs, and inform management actions. As such, this stage can also be used to identify and/or explore potential concerns and impacts from complex and interactive cumulative effects. The IEA iterative step-wise process provides an established framework that is fully in line with EBM principles, and within which CEA/CIA can be examined and assessed.

The ICES IEA groups have adopted the common risk assessment framework outlined above, the detailed of which are provided in the Technical Guidelines for developing the Ecosystem Overviews (key ICES advisory products: ICES 2023). The IEA framework allows for the inclusion of a range of methods, such as moving from the adapted-ODEMM approach to a more detailed SCARIM approach where knowledge and data are available, and for the inclusion of additional tools such as Bow-tie approaches to assess potential impacts of decisions/mitigation measures. As such, a new framework is not needed, but better integration and alignment across groups working on these topics may help to build capacity in this important and rapidly developing and expanding field.

The recently published ICES Framework for Ecosystem-Informed Science and Advice (FEISA: Roux & Pedreschi 2024) supports the use of IEA and outlines a set of principles which align with much of the outcomes from the Scoping exercise detailed herein. Core components of FEISA are risk assessment, indicator development and risk communication, all of which are relevant to the CEA/CIA work discussed herein. Additionally, FEISA provides the critical next step, identifying clear operational pathways for implementation of ecosystem-informed science into ICES advice.

6 Recommendations

- Future request on CEA/CIA should be addressed through specific expert groups and workshops that have the skills, data and knowledge (IEA / EAMSG groups, WGORE).
- Following the here defined principles for good practice in providing the knowledge base and advice for CIA comprising: 1) framing of the CEA context and defining objectives; 2) describing the roles of scientists and decision-makers; 3) reducing and structuring complexity; and 4) communicating uncertainty.
- Liaise with key EU projects such as GES4SEAS which produce ready to use tools which can help implementing CEA/CIAs. GES4SEAS toolbox.

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Annex 1: List of participants

WGCEAM 2024 meeting

Name	Institute	Country	Email
Gerjan Piet (chair)	Wageningen Marine Research	Netherlands	gerjan.piet@wur.nl
Vanessa Stelzenmüller (chair)	Thünen Institute of Sea Fisheries	Germany	vanessa.stelzenmueller@thuenen.de
Roland Cormier (chair)	Fisheries and Oceans Canada	Canada	roland.cormier@dfo-mpo.gc.ca
Debbi Pedreschi	Marine Institute	Ireland	debbi.pedreschi@marine.ie
Christina O'Don-nell	Marine Institute	Ireland	Christina.ODonnell@marine.ie
Virginia Morejon	Marine Institute	Ireland	virginia.morejon@ucdconnect.ie.
Daniel Wood	CEFAS	UK	daniel.wood@cefas.gov.uk

WGCEAM 2023 meeting

Name	Institute	Country	Email
Roland Cormier (chair)	Fisheries and Oceans Canada	Canada	Roland.Cormier@dfo-mpo.gc.ca
GerJan Piet (chair)	Wageningen Marine Research	Netherlands	gerjan.piet@wur.nl
Vanessa Stelzenmüller (chair)	Thünen Institute of Sea Fisheries	Germany	vanessa.stelzenmueller@thuenen.de
Jennifer Rehren	Thünen Institute of Sea Fisheries	Germany	jennifer.rehren@thuenen.de
Daniel Wood	CEFAS	UK	daniel.wood@cefas.gov.uk
Adrian Judd	CEFAS	UK	adrian.judd@cefas.gov.uk
Mike Elliott	IECS	UK	mike.elliott@iecs.ltd
Denise O´Sullivan	Marine Institute	Ireland	Denise.OSullivan@Marine.ie
Silvana Birchenough	MarineSpace	United Kingdom	silvana.birchenough@erm.com
Andy Stock	Standford	United States	astock@alumni.stanford.edu
Charlotte Scholten	NOIZ	The Neatherland	charlotte.scholten@nioz.nl
Alejandra Vargas-Fonesca	Nelson Mandela University	South Africa	ale@earthcollective.net
Salomé Fabi-Ruiz	IFREMER	France	Salome.fabri.ruiz@ifremer.fr
Lena Bergström	SLU	Sweden	Lena.bergstrom@slu.se

WGCEAM 2022 meeting

Name	Institute	Country	Email
Roland Cormier (chair)	Fisheries and Oceans Canada	Canada	Roland.Cormier@dfo-mpo.gc.ca
Michael Elliott	University of Hull	United Kingdom	Mike.Elliott@hull.ac.uk
Elisa Furlan	Centro Euro-Mediterraneo sui Cambiamenti Climatici	Italy	Elisa.Furlan@cmcc.it
Andrew Kenny	CEFAS	United Kingdom	Andrew.Kenny@cefas.co.uk
Christina O’Donnel	Marine Institute	Ireland	Christina.O'Donnell@marine.ie
Debbi Pedreschi	Marine Institute	Ireland	Debbi.Pedreschi@marine.ie
Gerjan Piet (chair)	Wageningen Marine Research	Netherlands	Gerjan.Piet@wur.nl
Jennifer Rehren	Thünen Institute of Sea Fisheries	Germany	Jennifer.Rehren@thuenen.de
Vanessa Stelzenmüller (chair)	Thünen Institute of Sea Fisheries	Germany	Vanessa.Stelzenmueller@thuenen.de
Alejandra Vargas-Fonseca	ConserBio Co-director	South Africa	ale@earthcollective.net

Annex 2: WGCEAM resolution

The **Working Group on Cumulative Effects Assessment Approaches in Management** (WGCEAM), chaired by Roland Cormier, Canada; GerJan Piet, Netherlands; and Vanessa Stelzenmüller, Germany; will work on ToRs and generate deliverables as listed in the Table below.

	Meeting dates	Venue	Reporting details	Comments (change in Chair, etc.)
Year 2022	24–28 October	Online meeting		
Year 2023	23–27 October	Online meeting		
Year 2024	4–8 November	Online meeting	Final report by 10 December to SCICOM	

ToR descriptors

ToR	Description	Background	Science Plan Codes	Duration	Expected Deliverables
a	Demonstrate the application of the ICES CEA framework in one or more regional case studies	To advance the development of a generic CEA methodology and identify real research gaps one or more case studies will be used as a proof of concept. Next to the North Sea and Canadian bioregion, the Celtic Sea will be one of regions where the CEA is conducted with the available knowledge base.	6.1, 6.2	Year1-3	Scientific paper describing the application of the CEA framework in one or more regional case studies.
b	Review the scientific advancements and current management practice in addresing cumulative effects to identify data and knowledge needs	The ICES framework provides practical guidelines on how to priorise and identify key pressures and human activities. A better understanding of the quantification of risk of adverse effects of current and future management scenarios is still lacking. This ToR aims to identify how methodological advancements are linked to actual stakeholder needs. Link to WGMPCZM.	6.1, 6.2	Year 2	Review paper
c	Identify linkages between CEA framework and other ICES products and liaise with other fora and/ or expert groups both within ICES (i.e. Secretariat, Data Centre or expert groups)	The assessment of cumulative effects is a central element for integrated marine management. Numerous ICES working groups and ICES products such as the ecosystem overviews are cross-referring this need. Under this ToR synergies and direct linkages will be identified. Further, the consolidation of a common CEA	6.2, 6.4, 6.5	Year 1-3	Identification of action points and linkages. Index of cumulative effects.

	as well as outside ICES. Investigate the development of a cumulative effects estimate for potential inclusion in the Ecosystem Overviews (EOs).	framework requires a continous collaborationa and exchange of expertise with other groups and fora working on CEAs.

Summary of the Work Plan

Year 1	Ongoing work will focus on the application of the CEA framework in case stuy areas such as the North Sea, Canadian bioregion and Celtic Sea. Those areas will serve as test areas to identify strengths and weaknesses of the framework. These regions are data rich and will allow for a full application of the framework to identify areas with increased risk of cumultative effects as well as data needs.
Year 2	The results of the case study applications will also feed in to a review which aims to synthesis the scientific advacements and map those to current management practice in e.g. marine planning and stakeholder needs. The review will reveal knowledge gaps and guides the development of decision support tools.
Year 3	Emphasis will be on the provision of guidance on data and knowledge needs when applying the common framework. This guidance on the application of the framework together with the identified action points will foster the integration of CEAs as part of ecosystem advice provided by ICES.

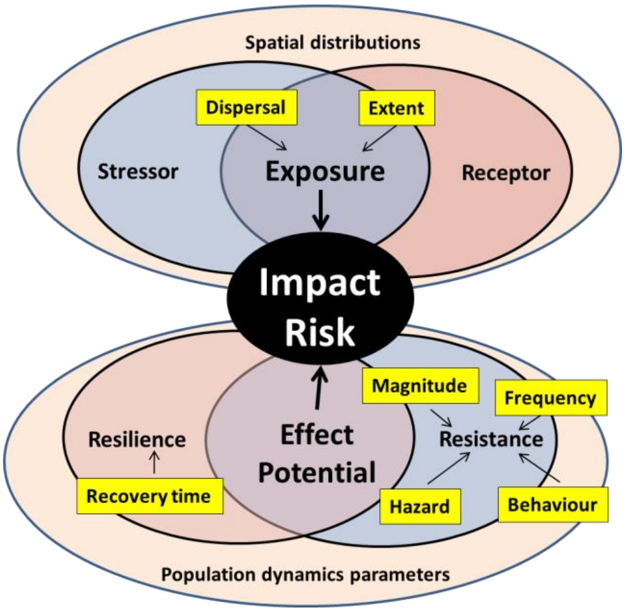
Supporting information

Priority	The current activities of this Group will lead ICES into issues related to the ecosystem effects of all marine human activities including fisheries, especially with regard to the application of the Precautionary Approach. Consequently, these activities are considered to have a very high priority.
Resource requirements	The research programmes which provide the main input to this group are already underway, and resources are already committed. The additional resource required to undertake additional activities in the framework of this group is negligible.
Participants	The Group is normally attended by some 10–20 members and guests.
Secretariat facilities	Standard EG support.
Financial	No financial implications.
Linkages to ACOM and groups under ACOM	There are no obvious direct linkages.
Linkages to other committees or groups	There is a very close working relationship with all the groups under HAPISG, in particular WGMPCZM, WGORE, WKTRADE. It is also very relevant to WGINOSE, WKTRANSPARENT, WGEAWESS.
Linkages to other organizations	There are strong linkages to the OSPAR and HELCOM work on CEAs.

Annex 3: SCAIRM: a Spatial Cumulative Assessment of Impact Risk for Management

At the basis of SCAIRM[1] 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[2]. 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 A1) 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].



Extent = the footprint of the stressor (A-P) and the receptor EC, where they overlap is the exposure extent.

Dispersal= the potential of the P to spread and increase its spatial overlap beyond that of the Extent;

Hazard = the relative depletion of the EC from a single interaction with the P at maximum magnitude; Magnitude = the average strength in the assessment area of the P where it is co-occurring with the EC; Behaviour = 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); Frequency = 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);

Recovery time = the number of years after impact until full recovery (to the EC's original undisturbed state).

Figure A1. 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

[1] 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

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

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]