WORKSHOP FOR THE REVISION OF THE ECOSYSTEM OVERVIEW OF THE CENTRAL ARCTIC OCEAN ECOREGION (WKCAO; OUTPUTS FROM 2024 MEETING)

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i Executive summary

A dedicated workshop was organised for the revision of the Ecosystem Overview of the Central Arctic Ocean (WKCAO).

The Ecosystem Overview of the Central Arctic Ocean (CAO) aims to determine the main human activities that cause pressures impacting the ecosystem components. The first Ecosystem Overview for this ecoregion was published in December 2021 (update in 2022). The current revision is based on the new Cooperative Research Report for the CAO that provides an extensive overview of the current human activities and their pressures in this ecoregion and the vulnerability of the ecosystem components for these pressures.

The workshop's main objective was to discuss and further develop the driver - pressure – ecosystem state approach and pressure assessment process that examines and scores all direct pressures and human activities for the Central Arctic Ocean ecoregion, which forms the basis for the wire diagram in the Ecosystem Overview.

The results showed that in the Central Arctic Ocean, climate change is the overarching driver of the ecosystem state. Furthermore, contaminants and marine litter are transported to the ecoregion via ocean currents, rivers and air, where they may pose limited effects. Local ship-related activities may affect marine mammals when they happen to simultaneously frequent the same small part of the CAO.

Extensive knowledge gaps exist with regards to spatial, temporal and trend information, both for the ecosystem components as well as for the human activities and their pressures. Therefore, information from the surrounding shelf seas needed to be applied to fuel expert judgement.

Keywords: workshop, Central Arctic Ocean, Ecosystem Overview, human activities, pressures

ii Expert group information

Expert group name	Workshop for the revision of the Ecosystem Overview of the Central Arctic Ocean ecoregion (WKCAO))
Expert group cycle	Annual
Year cycle started	2024
Reporting year in cycle	1/1
Chair	Martine van den Heuvel-Greve, the Netherlands
Meeting venue and date	24 October 2024, Copenhagen, Denmark (11 participants)

1 Introduction

A dedicated workshop for the revision of the Ecosystem Overview of the Central Arctic Ocean (WKCAO) was organised on 24 October 2024 at the ICES headquarters in Copenhagen, Denmark.

The Ecosystem Overview of the Central Arctic Ocean (CAO) aims to determine the main human activities that cause pressures impacting the ecosystem components. The first Ecosystem Overview for this ecoregion was published in December 2021, with an update in 2022. Over the past years, experts from the ICES/PICES/PAME Working Group on Integrated Ecosystem Assessment (IEA) for the Central Arctic Ocean (WGICA) have further compiled extensive information on the current state of pressures and human activities in the CAO, as well as the current knowledge on vulnerabilities of ecosystem components in this ecoregion. This information is published in a second Cooperative Research Report (CRR2) from WGICA (Jørgensen *et al*., 2025). Based on this recently compiled information, a revision of the existing Ecosystem Overview was initiated. For this, the ICES technical guidelines methodology was applied using the ICES Technical Guidelines for ICES Ecosystem Overviews.

During the workshop the updated pressure assessment was discussed, the new sections of Climate Change and Socio-Economic status addressed, and a check was made which existing text parts needed updates.

The results showed that in the Central Arctic Ocean, climate change is the overarching driver of the ecosystem state. Furthermore, contaminants and marine litter are transported to the ecoregion via ocean currents, rivers and air, where they may pose limited effects. Local ship-related activities may affect marine mammals when they happen to frequent a small part of the CAO in the same time.

1.1 Agenda for the WKCAO 24 October 2024

Time	Agenda item	ToR
09:00	Welcome, ICES code of conduct, and introduction round	
09:15	Introduction of the Ecosystem Overview	
09:30	Discussion: Pressure diagram	ToR b
11:00	Discussion: where does current text needs updates?	ToR a
12:00	Lunch and homework	
15:00	Recap of morning part	
15:15	Discussion: new section ‘Social and economic context’	ToR a
16:30	Discussion: revision of section ‘Climate change effects’	ToR a
17:30	Planning and task division (‘who does what and when?’)	
18:00	Closure	

2 Results

2.1 Stage 1

The original scoring assessment for the CAO ecoregion, taking into account sectors, pressures and ecosystem components, was conducted in sequential online groups in the spring of 2024 for the CRR2 report (Central Arctic Ocean ecoregion – Ecosystem Overview; Jørgensen *et al*., 2025).

Prior to the WKCAO workshop, the detailed scoring list from this assessment, consisting of 914 lines (Annex 3), was condensed to facilitate the application in the Ecosystem Overview scoring assessment. Compression consisted of merging scores from separate species or species groups into groups per ecosystem component. For instance, seabirds and marine mammals that received separate scores in the CRR2 report, such as 'seabirds – ice obligatory' and 'whales – narwhal' were now combined with others into separate lines for 'seabirds' and 'marine mammals', keeping the most vulnerable score as final score for the combined line, using the precautionary principle. A difference between scores of species or species groups was only observed for the 'degree of impact' (for the link between 'contaminants' and 'seabirds') and the 'spatial overlap' (for the link between 'noise' and 'marine mammals'). Information on this was added in the 'comments' column (Table 1).

The condensed scoring list resulted in a total of 83 connections with an Impact Risk Score of more than 0.00001 (Annex 4) and 19 connections with a Risk Score of >0.0001 (Table 1). Normally, a cut-off value for Risk Scores of >0.1 is applied to identify the top links in the ecoregion, but because the CAO is a highly remote region with currently very limited human activities a lower cut-off value of >0.0001 was used (Table 1).

Table 1 Top links with Risk score >0.0001. For the full list see Annex 4.

Sector	Pressure	Ecological Characteristic	Overlap	Frequency	DoI	Confidence	Comments	Impact Risk Score_EO	IR relative contribution_EO
Global sources	Contaminating compounds	Seabirds	W	P	C	1	Most vulnerable: ice obligated birds. Seasonal and transients have 'L' score for DoI.	0.13	42.606
Research	Noise	Marine mammals	W	O	C	1	W' for narwhal, 'L' for ringed seal and beluga, 'S' for bowhead.	0.04	14.060
Global sources	Contaminating compounds	Ice habitat and associated biota	W	P	L	1	Includes: algae, invertebrates, microbes	0.01	3.277
Global sources	Contaminating compounds	Benthic habitat and associated biota	W	P	L	1	Includes: hard bottom, soft bottom benthos, microbes	0.01	3.277
Global sources	Contaminating compounds	Fish	W	P	L	1	Includes: ice obligated, benthic, benthopelagic, mesopelagic fish	0.01	3.277
Global sources	Contaminating compounds	Pelagic habitat and associated biota	W	P	L	1	Includes: phytoplankton, zooplankton	0.01	3.277
Global sources	Contaminating compounds	Marine mammals	W	P	L	1	Includes: polar bear, ringed seal, beluga, bowhead, narwhal	0.01	3.277
Global sources	Contaminating compounds	Squid	W	P	L	1		0.01	3.277
Global sources	Marine litter, incl microplast	Benthic habitat and associated biota	W	P	L	1	Includes: hard bottom, soft bottom benthos, microbes	0.01	3.277
Global sources	Marine litter, incl microplast	Fish	W	P	L	1	Includes: ice obligated, benthic, benthopelagic, mesopelagic fish	0.01	3.277
Global sources	Marine litter, incl microplast	Ice habitat and associated biota	W	P	L	1	Includes: algae, invertebrates, microbes	0.01	3.277
Global sources	Marine litter, incl microplast	Marine mammals	W	P	L	1	Includes: polar bear, ringed seal, beluga, bowhead, narwhal	0.01	3.277
Global sources	Marine litter, incl microplast	Seabirds	W	P	L	1	Includes: ice obligated bird, seasonal and transients	0.01	3.277
Global sources	Marine litter, incl microplast	Squid	W	P	L	1		0.01	3.277
Global sources	Marine litter, incl microplast	Pelagic habitat and associated biota	W	P	L	1	Includes: phytoplankton, zooplankton	0.01	3.277
Military	Noise	Marine mammals	S	O	C	1	Includes: ringed seal, beluga, bowhead, narwhal. Ringed seal scored 'O', rest 'R' for frequency	0.00129	0.422
Research	Extraction of species	Benthic habitat and associated biota	S	R	C	1	Includes: hard bottom benthos	0.00031	0.102
Research	Physical seabed disturbance	Benthic habitat and associated biota	S	R	C	1	Includes: hard and soft bottom benthos	0.00031	0.102
Tourism and recreation	Noise	Marine mammals	S	R	C	2	Includes: bowhead, narwhal, ringed seal	0.00031	0.102

2.2 Stage 2

Furthermore, the compiled list of 19 connections from Stage 1 was used to complete the SecPress and SecEcoChar sheets, based on the procedures as described in the technical guidelines (Table 2 and Table 3). This resulted in the top list and ranks, that were used to develop the pressure diagram (Table 4 and Table 5).

Table 2 SecPress sheet for the Central Arctic Ocean ecoregion (2024)

Type	Physical damage	Other physical disturbance					Contamination by hazardous substances	Biological disturbance		
Pressure	Abrasion	Noise	Marine Litter	Artificial light pollution	Disturbance by people	Unintended injury	Introduction of Contaminating compounds	Introduction of non-indigenous species (NIS)	Species Extraction	Number of pressures per sector	Percent of pressures realised per sector
Sector / Human Activities											
Global sources			X				X	X		3	23%
Military	X	X	X		X	X	X	X		7	54%
Research	X	X	X	X	X	X	X	X	X	9	69%
Tourism/Recreation	X	X	X	X	X	X	X	X		8	62%
Number of sectors causing this pressure	3	3	4	2	3	3	4	4	1		
Percent of sectors causing this pressure	16%	16%	21%	11%	16%	16%	21%	21%	5%		

Table 3 PressEcoChar sheet for the Central Arctic Ocean ecoregion (2024).

Insert X where there is an interaction		Ecological Characteristic	Benthic Habitat (& assoc. biota)	Pelagic Habitats (& assoc. biota)	Ice Habitats (& assoc. biota)	Marine Mammals	Fish	Seabirds	Cephalopods	Number of ecological characteristics affected by each pressure	Percent of ecological characteristics affected
Type	Pressure	Short Description	The ecological or environmental area of	The ecological or environmental area of	Habitat associated with ice. The ecosystem	a mammal that lives in marine, or in some	Limbless cold-blooded vertebrate animals with	Birds that are adapted to life within the marine	Any member of the class Cephalopoda, such as a		
	Abrasion	Abrasion pressures relate to disturbance of the substrate at or below the surface of the seabed;	x		x	?	x			4	57%
Other physical disturbance	Noise	Ocean noise refers to sounds made by human activities that can temporarily or				x	x			2	29%
	Marine Litter	Marine litter originates from numerous sources and consists of different materials including metal,	x	x	x	x	x	x	x	7	100%
	Artificial light pollution							x			
	Disturbance by people					x					
	Unintended injury					x		x			
Contamination by hazardous substances	Introduction of Contaminating compounds	Examples of this pressure include discharges from ships, from hydrocarbon exploration and	x	x	x	x	x	x	x	7	100%
Biological disturbance	Invasive species	The direct or indirect introduction of NIS, e.g. Chinese mitten crab Eriochier sinensis, slipper		x	x	?				3	43%
	Species Extraction	The commercial exploitation of fish and shellfish stocks, including smaller scale harvesting,	x							1	14%
		Number of pressures affecting this Eco Characteristic	4	3	4	7	4	4	2		
		Percent of pressures affecting this Eco Characteristic	31%	23%	31%	54%	31%	31%	15%		

Table 4 Top links for human activities for the Central Arctic Ocean ecoregion (2024).

Row Labels	Sum of Impact Risk Score	Sum of IR relative contribution
Global sources	0.26000	85.21154
Military	0.00129	0.42180
Research	0.04352	14.26441
Tourism and recreation	0.00031	0.10225
Grand Total	**0.305123**	**100**

Table 5 Top links for pressures for the Central Arctic Ocean ecoregion (2024)

Row Labels	Sum of Impact Risk Score	Sum of IR relative contribution
Contaminating compounds	0.1900	62.2700
Extraction of species	0.0003	0.1023
Marine litter, incl microplast	0.0700	22.9416
Noise	0.0445	14.5840
Physical seabed disturbance	0.0003	0.1023
Grand Total	**0.305123**	**100**

2.3 Stage 3

During the workshop on 24 October 2024, the pressure diagram approach and scores were discussed. The precautionary principle approach for condensing the scores (Stage 1) as well as the SecPress and SecEcoChar sheets were adopted. Additionally, tasks were divided to revise and update the existing text of the Ecosystem Overview (in particular 'Climate change effects') and

add a new section on 'Social and economic context'. The WKCAO final draft of the complete revised EO was delivered to the ADGEO on 9 March 2025.

3 Highest impact risk pressures

The ecoregion currently and historically has fewer human activities than other ecoregions. This is due to the ice cover, the depth of the ocean, the harsh climate, remote location, and the absence of land and human settlements near the ecoregion.

Contaminating compounds (62.3%), Marine litter (including microplastics) (22.9%) and Noise (14.6%) received the highest pressure scores, accounting for 99,8% of the total impact (Table 5).

Both Contaminating compounds and Marine litter are mainly a result of Global sources (activities outside the ecoregion). Local activities, such as scientific icebreakers, tourism and recreation, and military shipping, result in the emission of noise. Areas where shipping activities mainly overlap with distributions of marine mammals and birds are specific parts of the CAO, for instance directly north of the Barents Sea, Beaufort Sea and Chukchi Sea.

Under the Agreement to Prevent Unregulated High Seas Fisheries in the Central Arctic Ocean (2018), the parties have agreed not to permit their vessels to engage in commercial fishing on the High Seas of the ecoregion until scientific assessments document the commercial viability of resources some of which are yet to be discovered.

There is insufficient data to give an overview on 'Threatened and declining species and habitats' in the Central Arctic Ocean, although the disappearance of multi-year sea-ice may be adopted as declining habitat in a future update.

4 Improvement of scientific base for future revisions

Because of the remoteness and difficult access to the ecoregion, the impact assessment is hampered by low data availability. Both baseline data and long-term observations are lacking for most of the CAO. This means that the understanding of current species distribution in the CAO is generally poor, both in space and time, and even less for species interactions, food web dynamics, and impacts and adaptation of species, food webs and ecosystems to climate change and other human related stressors. Many of the applied data for this EO are derived from surrounding areas or even further away.

Therefore, baseline data and long-term observations in the ecoregion are urgently needed for better informed future revisions.

5 Central Arctic Ocean ecoregion – Ecosystem Overview

This section contains the contributions of WKCAO to the science underpinning the advice in the Central Arctic Ocean ecoregion ecosystem overview (ICES, 2025). This section was reviewed by three independent external reviewers before being drafted into the advice by the Advice Drafting Group (ADGEO 2025). The external reviewers merged consensus report and ADGEO 2025 output can be found in supplementary documents 1 and 2, respectively.

This section is structured with the same subsections as the ecosystem overview. Sections marked with n/a are sections to which the group did not contribute.

5.1 Key signals

N/A

5.2 Ecoregion description

The Central Arctic Ocean ecoregion (Figure 1) mostly comprises deep sea areas remote from any landmass and some shallower shelf areas of the bordering Beaufort/Chukchi and East Siberian/Laptev seas. The boundary of the ecoregion follows the outer slopes on the Eurasian side from the Chukchi Sea to the Barents Sea, the shelf edge of north Greenland and the Canadian High Arctic, and runs along the 76°N parallel or the 200-mile Exclusive Economic Zones (EEZs) in the Beaufort/Chukchi seas.

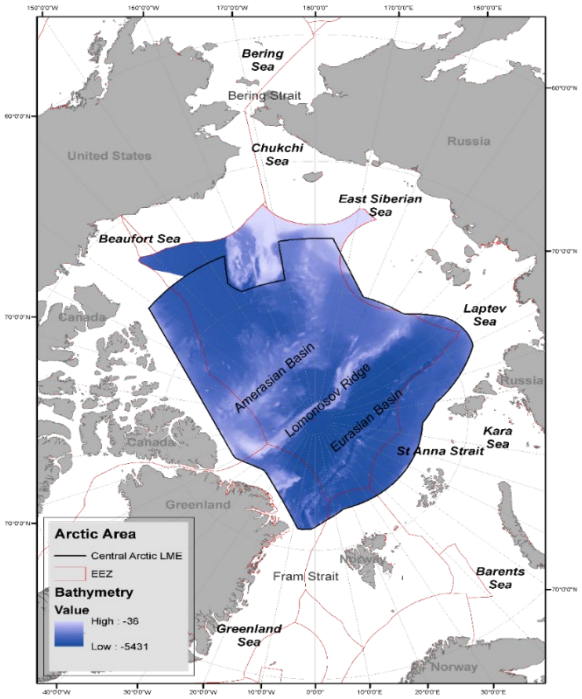

Figure 1 The Central Arctic Ocean ecoregion (in blue, with depth gradient), consisting of the High Seas and Large Marine Ecosystem boundaries. Furthermore, the surrounding shelf seas and Exclusive Economic Zones (EEZs) are represented.

The Central Arctic Ocean ecoregion seabed consists of two large deep basins (between 3800 and 4500 m deep), the Eurasian Basin, and the Amerasian Basin, separated by the Lomonosov Ridge. This ~1300 m deep ridge consists of steep slopes rising about 3000 m above the seabed (Dietz and Shumway, 1961).

The Arctic Ocean is governed by the 1982 Law of the Sea Convention (UNCLOS). The areas within the EEZs and the continental shelves are under the jurisdiction of the coastal states: the Russian Federation, the United States, Canada, the Kingdom of Denmark (Greenland), and the Kingdom of Norway. There are pending claims made to the UN Continental Shelf Commission (CLCS) from coastal states regarding the outer limits of their continental shelves. The Central Arctic Ocean High Seas exists as an international legal zone beyond the EEZs and sovereign jurisdictions of the surrounding states.

International governance of the Arctic Ocean under UNCLOS and other treaties (including those concerning climate change) have been strengthened over the last decade by the Agreement on Cooperation on Marine Oil Pollution Preparedness and Response in the Arctic (2013), the International Code for Ships Operating in Polar Waters (Polar Code; 2017), the Agreement on Enhancing International Arctic Scientific Cooperation (2017), and the Agreement to Prevent Unregulated High Seas Fisheries in the Central Arctic Ocean (2018). Under the latter, the parties will not permit their vessels to engage in commercial fishing on the High Seas of the ecoregion until scientific assessments document the commercial viability of resources some of which are yet to be discovered.

The Arctic states, consisting of the coastal states plus Finland, Iceland, and Sweden, carry the role of stewards of the region in the Arctic Council.

Because the ecoregion is largely inaccessible due to sea ice and, therefore understudied, information from adjacent seas was regularly used to inform this ecosystem overview.

5.2.1 Oceanography

The key physical factors affecting hydrography of this ecoregion are the strong seasonal cycle, low temperatures, extensive permanent and seasonal ice cover, a large supply of freshwater from melting ice and rivers, and the input of heat and salt from adjacent oceans.

The main inflowing marine water comes through the Atlantic Gateway (Fram Strait and Saint Anna Trough), and the Pacific Gateway (Bering Strait; Figure 2). The Lomonosov Ridge maintains a boundary between Atlantic and Pacific water masses. The circulation is anticyclonic within the Amerasian Basin (the Beaufort Gyre), and the Transpolar Drift from the northern border of the Russian Arctic shelf seas runs towards the Fram Strait.

The ecoregion receives about 10% of the world's freshwater discharge. The sea ice and river run-off cause a strong stratification, which is strongest in the Amerasian Basin. A major part of the suspended sediments discharged from these rivers is deposited on the seabed, forming sediment layers up to 1000 m thick (Mikkelsen *et al.*, 2005).

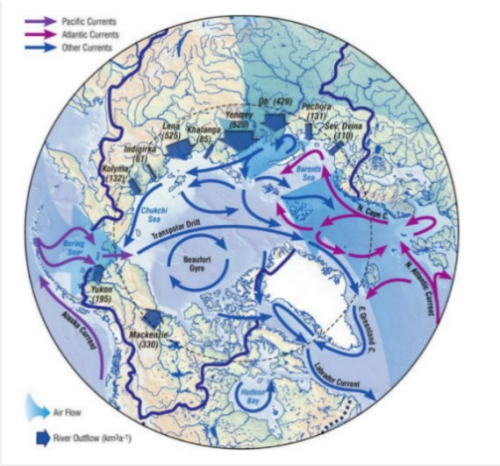

Figure 2 The major air and ocean currents towards and in the Arctic Ocean, as well as the dominant river inflow (reproduced, with permission, from Prowse et al. (2009). © The Royal Swedish Academy of Sciences).

5.3 Pressures

The Central Arctic Ocean ecoregion currently and historically has fewer human activities than other ecoregions. This is due to the ice cover, the depth of the ocean, the harsh climate, remote location, and the absence of land and human settlements near the ecoregion.

The main human pressures affecting the ecoregion are mainly the introduction of contaminating compounds and underwater noise, and to a much lesser extent marine litter, extraction of species and physical seabird disturbance (Figure 3). Both contaminating compounds and marine litter are mainly a result of global sources. Local activities, such as scientific icebreakers, tourism, and military shipping, result in the emission of noise. Areas where shipping activities mainly overlap with distributions of marine mammals and birds are the parts of the CAO directly north of the Barents, Beaufort, and Chukchi seas (Jørgensen, 2025).

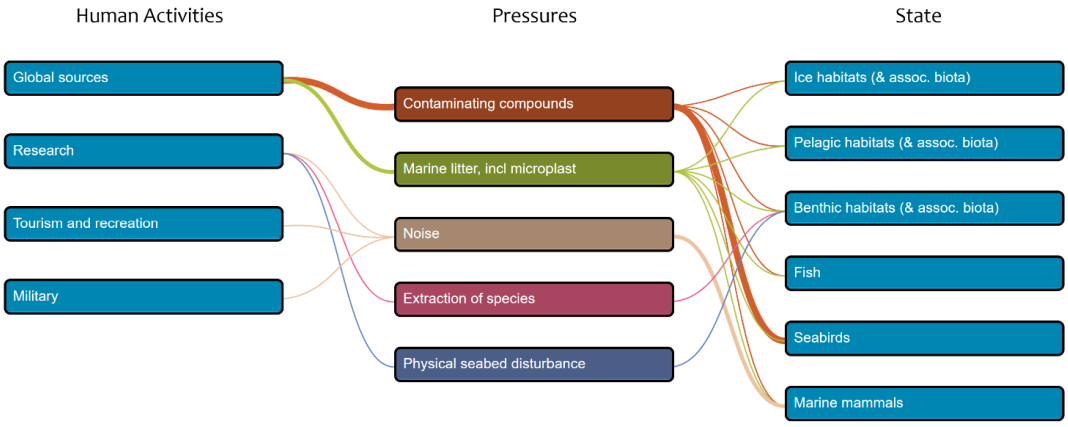

Figure 3 Overview of the major regional human activities, pressures, and ecosystem state components for the Central Arctic Ocean. The width of lines indicates the relative importance of the main individual links. The scaled strength of the pressures should be understood as a relative strength between the human activities listed, and not as an assessment of the intensity of the pressure on the ecosystem. Due to the difference of scales, climate change is not represented as a regional pressure, but climate change affects human activities, the intensity of the pressures, and some aspects of state, as well as the links between these. As the ecoregion is largely understudied, information from adjacent seas and nearby areas was used to inform the assessment of regional human activities and associated pressures.

5.3.1 Introduction of contaminating compounds

The areas in and around the CAO are a sink for contaminants transported from lower latitudes (AMAP, 1998). Chemical contaminants are carried north by ocean currents, rivers, and atmospheric air masses. The accumulation of contaminating compounds in the deep Arctic Ocean is facilitated by the surface transport and subsequent cooling (and sinking) of warm Atlantic water into the Arctic, and the wind-driven clockwise circulation in the Beaufort Gyre, which accumulates and sinks surface water down into the water column. Contaminants that bioaccumulate in food webs, such as mercury, polyclorinated biphenyls (PCBs), and per- and polyfluoralkylated substances (PFAS), are currently of main concern.

Little information is available on contaminant levels in the abiotic compartments of the CAO. In seawater, PFAS were mainly found in the Polar Mixed Layer and halocline (150 m below the surface) (Yeung *et al.*, 2017), mercury concentrations predominantly at subsurface depths of ~100-300 m (AMAP, 2021), and PCBs in the deep water (Sobek & Gustafsson 2014). For PFAS, it was estimated that 30% of the PFOS discharges from North America and Europe had reached the CAO, with the deep ocean being the ultimate sink with levels expected to increase (Yeung *et al.*, 2017; Zhang *et al.*, 2017). In sediment inorganic Hg(II) is the dominant form of mercury in Arctic marine sediments (Soerensen *et al.*, 2016). PFAS concentrations in surface sediments were found to be low to moderate compared with other coastal and marine sediments worldwide (Kahkashan *et al.*, 2019).

Contaminant data in biota of the CAO is severely lacking. Therefore, information from surrounding information was applied. High levels of mercury and polychlorinated biphenyls (PCBs) can be found in seabirds and top predators in Arctic areas adjacent to the ecoregion, with ice-associated seabirds such as the ivory gull, Pagophila eburnean, being mainly at risk of contaminant effects (Jørgensen, 2025; Lucia *et al.*, 2015; Dietz *et al.*, 2019; Albert *et al.*, 2021; Hoondert *et al.*, 2021; Chastel *et al.*, 2022).

Local pollution in the CAO is expected to increase with greater shipping activity in the ecoregion. Oil spills from activities on the nearby continental shelves may also ultimately affect ecosystem components in the ecoregion.

5.3.2 Marine litter

Marine litter (e.g. plastic and microplastic) is transported by rivers, ocean currents and air masses into the ecoregion, with distant regions being a significant source to the Arctic Ocean (Bergmann *et al*., 2022). Moreover, sea ice may act as an important transport vector of plastic across the ocean surface (Bergmann *et al*., 2016; Peeken *et al*., 2018). Abandoned, lost or otherwise discarded fishing gear may drift into the CAO by ocean currents from the adjacent areas where active fisheries take place (PAME, 2019). Discharges from fishing and other vessels are considered most important, indicating where international agreements and mitigation can be most effective (Dewey and Mackie, 2023).

There is evidence of the occurrence of microplastics in marine sediments in the ecoregion (Kanhai *et al*., 2018). Microplastics have also been reported on ice floes from the Fram Strait (Bergmann *et al*., 2019), snow samples from Baffin Bay (Huntington *et al*., 2020), and in surface water, zooplankton, and sediment from the Canadian Arctic (Stern *et al*., 2020), providing evidence of atmospheric transport as suggested by simulations (Evangeliou *et al*., 2020). Litter density on the seabed of the Atlantic Gateway has increased between 2002 and 2014 (Bergmann and Klages, 2012; Bergmann *et al*, 2017; Tekman *et al*., 2017; Jørgensen, 2025). Research efforts are ongoing to examine litter in the water column and sediment.

In adjacent areas, plastics have been found ingested by Arctic wildlife such as seabirds and polar cod (*Boreogadus saida*) (Kühn *et al*., 2018; Halsband and Herzke, 2019; Baak *et al*., 2020), and seabirds and marine mammals were seen entangled in fisheries debris off northern Svalbard (Bergmann *et al*., 2017).

Litter and microplastics are considered to continuously drift into and eventually accumulate in the CAO, where they may have a low impact on the ecosystem components (Jørgensen, 2025).

5.3.3 Underwater noise

Underwater radiated noise from ships is the biggest contributor to underwater anthropogenic noise in the CAO. This includes noise as a result of engines, propellers and ice crushing, as well noise from scientific equipment and military operations. Ship noise is substantially higher than that of the natural acoustic environment of the polar regions, where ice melting and pressure cracking dominate the soundscape (PAME, 2019; PAME, 2021). Natural ambient underwater sound levels in the Arctic are generally higher during open water periods than when sea-ice is present (Halliday *et al*., 2021).

Scientific activities that are associated with noise production are related to geological and biological research, such as seismic data collection, sub-bottom profiling, borehole drilling, multi-beam surveys and fish echo sounding. Military activities include low frequency active sonar systems for submarine detection, testing of underwater ammunition and demolition of war remnants, such as bombs and mines. Sound propagates very well in Arctic waters. Effects can therefore be a result of activities many hundreds of kilometres away (Richardson *et al*., 1995), and also from adjacent areas (Thode *et al*., 2010; van der Schaar, 2017).

Noise pollution can cause behavioural and physiological effects in marine biota (Heide-Jørgensen *et al*., 2021; Williams *et al*., 2022), and mask ecologically important sounds (Eickmeier and Vallarta, 2023). Underwater noise may have a higher impact in the Arctic compared than in non-polar regions due to the combination of lower ambient sound levels and increased sensitivity of Arctic marine animals to underwater noise (Halliday *et al*., 2020; Miller *et al*., 2022). There has been limited measurements of the natural ambient sound in the ecoregion, but evidence from adjacent areas indicates a range of ambient noise levels – from very quiet under fast ice to

naturally very noisy in areas with either very active ice or high biological activity (e.g. large numbers of calling marine mammals [Ozanich *et al*., 2017]).

Shipping activities may overlap with the CAO distribution of narwhals and part of the beluga population for up to 4 months a year (Jørgensen, 2025) These marine mammals were scored with a risk of a population impact if exposed to enough noise during the time of year where they occupy areas in the CAO overlapping with human activities. A small population of approximately 800 narwhals has been recorded in the Northeast Atlantic (Vacquié-Garcia *et al*., 2017) representing the largest occurrence of narwhals in the CAO and Atlantic gateway area (NAMMCO, 2021).

5.3.4 Extraction of species

No commercial fishing is allowed in the high seas of the CAO, but research and scientific operations have sampled the CAO for decades using grabs, cores, nets, and, in the ice-free areas, trawls on the slopes. Such equipment collects vertebrate and invertebrate samples for scientific purposes. Current extraction activities are small, limited to less than 1 m^2 in sampling areas (Jørgensen, 2025).

5.3.5 Physical seabed disturbance

Currently no deep-sea mining is taking place in the CAO, though scientific expeditions may conduct geological and biological sampling using equipment such as borehole drills, trawls, sledges, grabs and sediment cores (Nikishin *et al*., 2021; Ramirez-Llodra *et al*., 2024). This can chronically impact the seabed by abrasion, smothering and substrate loss. The impact is considered low due to the limited spatial extent (Jørgensen, 2025).

Besides this, also in- and under-ice habitats can be affected by vessel movements in the sea-ice of the CAO. The impact is considered low due to the limited time transiting the ice and small spatial extent compared to the overall sea ice coverage. In the future, with the expected increase in human activities and further decrease in sea-ice, this may become larger.

5.4 Climate change effects

5.4.1 Evidence of ongoing effects – physical drives

Reduction in the extent, thickness and multiyear sea ice is the prevailing climate change signal in the ecoregion (Stroeve & Notz, 2018; IPCC, 2021; Kacimi & Kwok, 2022; Lindsay & Schweiger, 2015; Figure 5). This has led to an increase in the seasonal duration of open water in the ecoregion, a shift towards a smoother ice surface, with fewer pressure ridges and reduced surface drag (Krumpen *et al*., 2025). This sea ice reductions enhances ocean-atmosphere interactions and accelerates ice-albedo feedback processes.

Other observed climate-related changes include increases in freshwater content affecting water column stratification, and changes in the relative contribution of North Atlantic and North Pacific water masses in the ecoregion (Polyakov *et al*., 2020). Seawater temperatures are rising, with marked regional variability (Juranek, 2022). In addition, the Arctic Ocean is becoming more acidic (AMAP, 2019; Pörtner *et al*., 2019). Increasing freshwater input leads to the enhanced delivery of terrestrial materials – including carbon, hazardous chemicals, methane, viruses, and bacteria – into Arctic seas (Kipp *et al*., 2018; AMAP, 2021a). Permafrost thaw is an important, warming-induced pathway for contaminants such as persistent organic pollutants (POPs) and mercury into the CAO (AMAP, 2021a; 2021b).

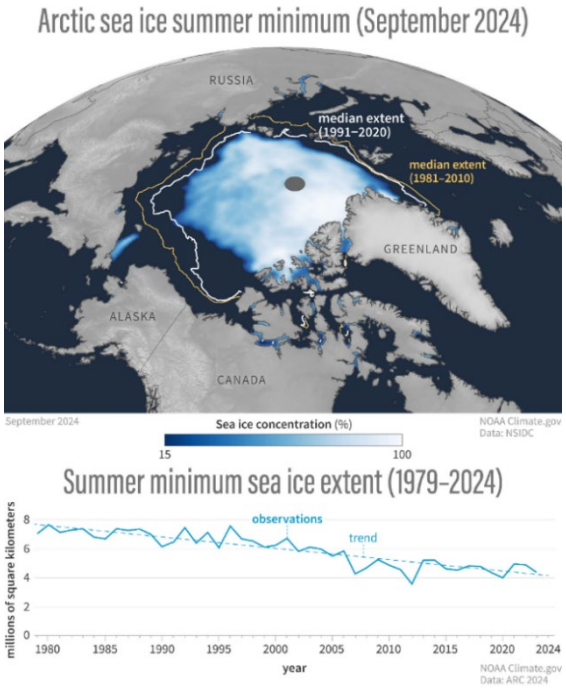

Figure 5 This map shows average sea ice concentration in September 2024. The sea ice extent was smaller than the median sea ice extent from 1991–2020 (white line) and from 1981–2010 (yellow line). Bottom: the observed annual sea ice extent in September from 1979–2024 (solid line) and the trend line (dashed line). Request permission: ©NOAA climate.gov based on the 2024 Arctic Report Card - Sea Ice.

5.4.2 Evidence of ongoing effects – ecosystem components

There are relatively few studies on the effect of climate change on ecosystems in the Arctic Ocean compared to other large marine biomes such as the Atlantic Ocean, with only two percent of those Arctic studies including the CAO (Deb & Bailey, 2023). Nonetheless, it is clear that sea-ice decline has already led to significant changes in both the distribution and abundance of species in and around the CAO ecoregion, from primary producers to top predators (CAFF, 2017).

Primary productivity has increased in areas where summer sea ice is lost, primarily in the periphery of the CAO (Ardyna & Arrigo, 2020). A reduction in multiyear ice and increase of first year ice has led to a decline in ice algal diversity (Melnikov *et al*., 2018). Similarly, significant effects of climate change have been reported on taxonomic diversity in Arctic Ocean microbial communities (reviewed by Deb & Bailey, 2023). Nutrient limitation is particularly relevant in the CAO, and may be the reason that chlorophyll standing stock in CAO surface waters has not increased between 1991 and 2015, whereas the more temperature-dependent carbon biomass did (Nöthig *et al*., 2020).

The Arctic **zooplankton** community is changing through the increased advection and establishment of boreal species, expanding northward from the shelf seas, Atlantic and Pacific gateways (reviewed by Polyakov *et al*., 2021). Multiple lines of evidence suggest that boreal species advected along the Arctic shelf slopes have already reached the CAO, though it is not clear to what extent they are permanently established there (Bluhm *et al*., 2020). A northward range shift of the ecologically important copepods *Calanus* spp. has been observed (Hunt *et al*., 2014; Ershova *et al*., 2021). Sympagic fauna have decreased in abundance and diversity over the past decades, due to loss of sea-ice habitat and disconnection of the sea-ice drift from recruitment areas on the shelf (Melnikov *et al*., 2018; Krumpen *et al*., 2019; Ehrlich *et al*., 2020; Hop *et al*., 2021).

A recent inventory of **benthic** datasets from the Arctic Ocean showed that data from the deep basins are extremely scarce, impeding any assessment of climate change effects over longer time spans (Ramirez-Llodra *et al*., 2024). Changes have, however, likely already happened due to the dependency of Arctic benthos on ice algae (Niemi *et al*., 2024) and overall primary production (Wiedmann *et al*., 2020), which have changed due to climate change effects such as sea-ice decline.

Likewise, comprehensive information, let alone time series, about the species composition, distribution and abundance of fish in the CAO do not exist. Fish are generally rare in the CAO (Snoeijs-Leijonmalm *et al*., 2022; Ingvaldsen *et al*., 2023), and only one species, polar cod, *Boreogadus saida*, has been shown to be widely distributed in the central basin at low abundance (David *et al*., 2016; Melnikov & Chernova, 2013). Based on expert judgement, there is a high likelihood that sea-ice decline, ocean warming, ocean acidification, changing prey fields, new competitors and new predators negatively influenced polar cod populations throughout the Arctic Ocean (Geoffroy *et al*., 2023).

Seabirds and marine mammals that depend on sea ice for habitat and/or food are negatively affected by climate change impacts for key processes like reproduction and rearing, leading to population declines (CAFF, 2017; Ramírez *et al*., 2017; Kuletz *et al*., 2020; Romano *et al*., 2020). Few seabirds roam deep into the CAO. However, Signals from peripheral populations suggest climate change negatively impacts Arctic endemic seabirds, mostly related to food web repercussions. For example, an Arctic-wide decline in populations of the thick-billed murre, *Uria lomvia*, has been linked to variations in sea surface temperature and prey availability (Irons *et al*., 2008). Furthermore, a dietary shift from polar cod to sculpin led to slower growth and higher mortalitiy of nestlings of Mandt's black guillemot, *Cepphus grylle mandti* (Divoky *et al*., 2015; 2021). The feeding migration of young ringed seals, *Pusa hispida*, has expanded into the CAO over the past decades, concurrent with the sea ice retreat (Hamilton *et al*., 2015). Furthermore, reproductive fitness of polar bears, *Ursus maritimus*, was reported to be compromised or reduced over the past decades (Durner *et al*., 2011; Laidre *et al*., 2020), with the populations predicted to be in decline (Stirling *et al*., 2011; Laidre *et al*., 2018; Johnson *et al*., 2020).

5.4.3 Evidence of anticipated effects – physical drivers

Sea-ice decrease is expected to continue to decrease with a first ice-free day in the CAO potentially occurring before 2030 (Heuzé & Jahn, 2024). The CAO is expected to turn into a more open ocean with stronger currents and enhanced vertical mixing, impacting Arctic marine ecosystems and the downstream ocean circulation (Muilwijk *et al*., 2024).

5.4.4 Evidence of anticipated effects – ecosystem components

Due to sea ice thinning and the replacement of multiyear-ice with first-year ice, **primary productivity** in the CAO is expected to increase (Slagstad *et al*., 2015; Tedesco *et al*., 2019: Lannuzel *et al*., 2020), though predictions are uncertain due to the sensitivity of primary production predictions to nutrient budgets (Jeffery *et al*., 2020). Nutrient dynamics pose the greatest uncertainty in future predictions (Lannuzel *et al*., 2020). Some models predict increasing stratification and decreasing nutrients (Vancoppenolle *et al*., 2013; Tremblay *et al*., 2015), while others predict greater nutrient supply from atmospheric deposition (Lamarque *et al*., 2013), wind mixing (Xu *et al*., 2023), or advection along the slopes (Oziel *et al*., 2022).

The ongoing transformation of sea-ice habitats, coupled with borealization, is expected to significantly alter the biodiversity of Arctic metazoan consumers (Lannuzel *et al*., 2020). Sea ice changes may disrupt life cycles of sympagic organisms, particularly those unable to thrive in the

water column. In the Eastern Arctic, shorter ice-algae bloom periods will lead to reduced sympagic food availability for key species such as Calanus copepods (Søreide *et al*., 2010), ice-associated amphipods, and polar cod (Kohlbach *et al*., 2016; 2017). Consequently, in the seasonally ice-covered CAO, any potential increase in primary production is unlikely to sustain larger consumer populations. The decline in biodiversity could diminish the ecosystem's resilience to environmental disturbances and anthropogenic pressures (Lannuzel *et al*., 2020). The thinning of sea ice will have a great effect on the light regime. A recent modelling study projected that in 30 years, the total time spent by zooplankton in the under-ice habitat could be significantly reduced due to later freeze-up and earlier break-up of sea ice, potentially affecting their winter survival and disrupting carbon and nutrient fluxes in the food web (Flores *et al*., 2023).

As sub-polar and Atlantic **fish** extend their ranges northward, the biomass of polar cod and other cold-adapted fish native to the Arctic Ocean is projected to decline across many Arctic shelf regions (Fossheim *et al*., 2015; Haug *et al*., 2017; Steiner *et al*., 2019; Geoffroy *et al*., 2023). Model projections indicate that while polar cod biomass may temporarily increase at higher latitudes, overall polar cod biomass is expected to decline by more than 17% as a result of rising temperatures and the decline of sea-ice habitats under a high carbon emissions scenario (Steiner *et al*., 2019). The CAO may temporarily serve as a refuge, supporting short-term increases in the presence and abundance of both Arctic and boreal species capable of long-distance dispersal. Some pelagic fish from adjacent regions, such as beaked redfish (*Sebastes mentella*), Atlantic herring (*Clupea harengus*), Atlantic mackerel (*Scomber scombrus*), and capelin (*Mallotus villosus*), may extend their summer feeding migrations into the CAO (Hollowed *et al*., 2013; Haug *et al*., 2017).

The populations of Arctic endemics, including **beluga whales and polar bears**, are expected to decline as sub-polar species become more prevalent in Arctic waters (Lannuzel *et al*., 2020). The continued reduction of key prey species, such as polar cod, will likely exacerbate the decline of sympagic predators, including ringed seals, beluga whales, and polar bears — trends that are already being observed (Hamilton *et al*., 2015; O'Corry-Crowe *et al*., 2016; Geoffroy *et al*., 2023). Bioenergetic modelling suggests that 24 Arctic-breeding seabird species may transition to year-round residency in the High Arctic (Clairbaux *et al*., 2019). The long-term success of species migrating northward will ultimately depend on the availability of critical habitats, nutrients, and prey resources (McKeon *et al*., 2016). For instance, the distribution, behavior, and fitness of sympagic species like the ivory gull, *Pagophila eburnea*, are closely linked to sea ice extent and associated prey availability (Gilg *et al*., 2016).

5.4.5 Possible effects on strength of relationships between pressures (contaminants, noise, marine litter, extraction of species, physical seabed disturbance), human activity and/or ecosystem components

Contaminant concentrations in the CAO are expected to increase as a result of Climate Change due to the increased input of freshwater, permafrost thawing and glacier melt (Kipp *et al*., 2018; AMAP, 2021a, 2021b). Furthermore, Climate Change is creating opportunities for the development and expansion of various human activities in the ecoregion. Ship traffic is currently limited and largely restricted to scientific expeditions and icebreaker activities. In peripheral waters on the Russian side of the ecoregion and the Pacific gateway, however, ship traffic is increasing along the Northern Sea Route (NSR; Li *et al*., 2021). Additionally, geoengineering surveys occur in the adjacent Kara Sea. Increasing shipping will increase underwater noise and marine litter, as well as the risk of the accidental release of contaminants. With receding ice, exploratory fishing is expected to take place in accessible slope and shelf waters inside the EEZs of the coastal states, bordering the CAO ecoregion. To date, ocean mining interests have primarily focused on areas

outside the ecoregion, but may expand further into the Arctic. Similarly, oil extraction is ongoing in adjacent seas, and interests exist in oil exploration in shelf areas surrounding the ecoregion.

5.4.6 Key knowledge gaps for assessing climate change impacts on the ecoregion

Both baseline data and long-term observations are lacking for most of the CAO. This means that the understanding of current species distribution in the CAO is generally poor, both in space and time, and even less for species interactions, food web dynamics, and impacts and adaptation of species, food webs and ecosystems to climate change and other human related stressors. Many of the applied data for this EO are derived from surrounding areas or even further away.

5.5 Social and economic context

Shipping is the most important human activity in the ecoregion, consisting of commercial vessel transport, research expedition and tourism cruises (Jørgensen, 2025). All vessels come from areas outside the CAO as there are no coastlines or EEZs included in the ecoregion. Consistent with the 'ship-ice hypothesis' (Berkman *et al*., 2020), the predominance of ship types, sizes and nationalities into the Central Arctic Ocean High Seas is from open water areas in the Pacific sector north of the Bering Strait (Berkman *et al*., 2022). Commercial fishing is currently absent in the High Seas area of the CAO due to the fisheries agreement (CAOFA) and limited to no fishing in the Chuckchi Borderlands that are more than 300 meters of depth.

The CAO is connected to the surrounding coastlines via migratory species, such as marine mammals and birds, that frequent the CAO. Indigenous coastal communities rely heavily on subsistence fishing and hunting (Huntington *et al*., 2016), especially those with a high poverty rate. Effects on these migratory species taking place in the CAO can therefore also potentially negatively impact the subsistence activities of coastal communities. Furthermore, those local communities that benefit from tourism may experience decreased visits when migratory wildlife moves away (Palma *et al*., 2019).

Other relevant social-economic circumstances for the CAO are the UN continental shelf commission pending claims. Granting of these claims will significantly impact the management of the respective continental shelf systems and superjacent waters under the UN Convention on the Law of the Seas (UNCLOS). Additionally, exploration of the seabed for mineral resources may have more than minor or transitory impacts on the surrounding benthic ecosystems and their long-lived species, especially as framed with the 2023 Agreement on Marine Biological Diversity of Areas beyond National Jurisdiction (BBNJ Agreement).

5.6 State of the ecosystem

5.6.1 Sea ice habitat and associated biota (incl. foodweb)

Sea ice represents sympagic or ice-associated habitats for over 1000 species ranging from microbes to polar bears. The liquid-filled network of brine channels and pockets in sea ice is inhabited by a diversity of organisms ranging from bacteria and Archaea to unicellular and multicellular eukaryotes, termed sympagic pro- and eukaryotes (Bluhm *et al*., 2017). Unicellular sympagic eukaryotes, called sea-ice protists, are a phylogenetically diverse group which comprises photo-, mixo- and heterotrophic taxa (Booth and Horner, 1997; Melnikov *et al*., 2002; Poulin *et al*., 2011). Mixo- and heterotrophic taxa are commonly represented by species within the dinoflagellates and ciliates while the collective term ice algae is frequently used for

phototrophic protists in sea ice which are generally dominated by diatoms. Species number estimates range from 1027 to 1276 taxa across the Arctic (Poulin *et al*., 2011; Bluhm *et al*., 2017). The diversity of sea-ice protists is influenced by geographic location (Niemi *et al*., 2011; Hardge *et al*., 2017a), season and the age of sea ice. The older the ice, the more complex its structure, leading to increased diversity of the sea-ice inhabiting flora and fauna (Melnikov, 2009; Hardge *et al*., 2017b).

Sea-ice fauna includes nano-, micro- and meiofauna within sea-ice brine channels, and macrofauna in larger channels and crevices and at the ice-water interface. Meiofauna are small, multi-cellular organisms which live in brine channels and other small spaces (Bluhm *et al*., 2018; Ehrlich *et al*., 2020). Macrofauna are larger-bodied animals, including ice amphipods and (juvenile) polar cod (*Boreogadus saida*) (David *et al*., 2016; Ehrlich *et al*., 2020; Hop *et al*., 2021). Sea ice is also used by seabirds and marine mammals, which are addressed below. The inhabitants of sea ice can be either permanent or temporary/seasonal. The long-lived ice amphipod, Gammarus wilkitzkii, is permanent, whereas most other macrofauna are temporary. The smaller ice amphipod, *Apherusa glacialis*, was found to have pelagic occurrences during parts of the year (Kunisch *et al*., 2020), potentially, as a mechanism to avoid being lost from the ice completely during ice transport and melting (Drivdal *et al*., 2021).

Sea-ice coverage and associated ice algal production is a determinant of foodweb structure and functioning in the CAO (Kohlbach *et al*., 2016, 2022). The sympagic production is generally contributing with about half of the net primary production for the ecoregion (Gosselin *et al*., 1997; Fernendez-Mendez *et al*., 2015). However, more recent estimates have indicated a much lower contribution (<15 %; Kohlbach *et al*., 2025), which could be caused by earlier sea ice melt during spring (Perovic *et al*., 2020; Meier *et al*., 2021) and potential changes in the Arctic-wide connectivity in sympagic ecosystems due to more intensive melting and faster ice movements in thinner, more dynamic sea ice (Ehrlich *et al*., 2021).

Sympagic crustaceans (mainly ice amphipods) and meiofauna living inside sea ice brine channels largely depend on organic carbon synthesized by sea-ice protists. Stable isotopes, fatty acids and other trophic markers have shown strong dependence on sympagic carbon by ice amphipods and polar cod (Kohlbach *et al*., 2017, 2022; Vane *et al*., 2022).

Because of the reduction in sea ice thickness and extent, sea-ice algae (diatoms) have declined as well as the organisms that depend on them for energy (Brown *et al*., 2017; Bluhm *et al*., 2018; Hop *et al*., 2020, 2021a; Melnikov *et al*., 2018). The loss of sea ice and particularly the multiyear ice has resulted in reduced abundance of diatom species (Hop *et al*., 2020) as well as meiofauna in some regions of the CAO (Melnikov *et al*., 2012). The reduction in abundance from the 1980s to the 2010s is most pronounced for ice amphipods as well as benthic amphipods in sea ice (Hop *et al*., 2021). The dramatic decline in G. wilkitzkii has coincided with the disappearance of much of the multiyear sea ice, which is an important habitat for this long-lived species. Recent sampling in the waters east and north of Svalbard has found continued presence of A. glacialis, but almost no G. wilkitzkii (Ehrlich *et al*., 2020). Thus, the current and future situation will include reduced abundances of most ice fauna in thinner first-year ice.

Other threats to ice associated fauna are contamination and pollution. Industry and shipping may cause oil spills in areas of sea ice, and this can affect all organisms residing in and below sea ice (Camus & Olsen, 2008). Some parts of the year are considered more critical than others, such as the winter when food sources are limited. Winter is also the time when polar cod spawn below the sea ice, and early life stages of this species are particularly sensitive to toxic oil compounds, which can cause increased malformations and mortality (Bender *et al*., 2021). Microplastics have been found in sea ice (Peeken *et al*., 2018) and can be ingested by both Gammarid amphipods (Iannilli *et al*., 2019) and polar cod (Kühn *et al*., 2018) with unknown consequences for sympagic food webs.

5.6.2 Pelagic habitat and associated biota (incl. foodweb)

The ecoregion is an oligotrophic system with a strong seasonal variation in primary production (Leu *et al*., 2015; Randelhoff *et al*., 2020). The average total annual primary production of the ecoregion's basins is low, about 13 gC m–2 y–1 (Wiedmann *et al*., 2020), with the nutrient-rich shelves having higher productivity (> 70 gC m–2 y–1). The phytoplankton seasonal succession is characterized by first blooms of sympagic diatoms, followed by pelagic diatoms in the areas of the retreating ice edges, and thereafter other flagellates. The phytoplankton dynamics over the last decades can be characterized as more frequent autumn blooms (Ardyna *et al*., 2020), earlier spring blooms (Horvat *et al*., 2017) and enhanced under-ice blooms (Arrigo *et al*., 2012; Assmy *et al*., 2017).

Primary producers have patchy, but wide distribution across the CAO. While a few cells will be present in the water column year-round, higher biomasses (e.g. blooms) occur during spring and summer (Jørgensen, 2025). Accordingly, zooplankton exhibit distinct spatial variability in the CAO due to ocean currents, bathymetry, sea-ice coverage and nutrient distribution, with strong vertical layering (Kosobokova *et al*., 1998, 2011; Bluhm *et al*., 2015; Hop *et al*., 2021b). While vertical migration is usually tied to the diel cycle of the sun in lower latitudes, it becomes a seasonal vertical migration in the CAO between the polar night and the polar day, with intermittent periods of diel vertical migration during the twilight periods in autumn and spring (e.g. Berge *et al*., 2020; Flores *et al*., 2023). A significant part of the populations of several species of ecologically important Arctic copepods (e.g. *Calanus glacialis* and *C. hyperboreus*) migrate several hundred meters in depth to survive the polar night in dormancy, returning to the surface during the polar day to feed on ice algae and phytoplankton (Conover & Siferd, 1993; Falk-Petersen *et al*., 2009; Daase *et al*., 2013). The seasonal variability of zooplankton community structure in the CAO reflects the strong variability in irradiance, sea-ice cover and associated primary productivity pulses with abundance and taxonomic diversity in surface waters peaking during early summer (Leu *et al*., 2015; CAFF, 2017; Hop *et al*., 2021b). During this period, filter-feeding appendicularians and other gelatinous zooplankton such as chaetognaths and comb jellies can reach high biomass, locally accounting for over 40% of the biomass of the epipelagic zooplankton community (Ehrlich *et al*., 2020, 2021).

The zooplankton community of the ecoregion is diverse and contains epi- and mesopelagic communities from both Atlantic and Pacific waters. The greatest number of zooplankton species is found in the deep zones (Kosobokova and Hopcroft, 2010). Smaller copepods (such as *Oithona similis, Triconia borealis*, and *Microcalanus spp*.) dominate the epipelagic mesozooplankton in abundance, whereas larger Calanus species (*C. hyperboreus*, *C. glacialis*, and *C. finmarchicus*) account for most of the biomass (Rutzen & Hopcroft, 2018; Hop *et al*., 2021b). Mesozooplankton (0.02 mm – 20 mm) communities in the CAO are usually dominated by copepods, among which are several genera that are considerably larger than most copepods at lower latitudes, including *Calanus spp*., *Metridia spp.* and *Paraeuchaeta spp.* (Kosobokova & Hirche, 2000; Bluhm *et al*., 2011; Flores *et al*., 2019). Microzooplankton (< 0.01 mm) and macrozooplankton (> 20 mm) are notoriously under-sampled in the CAO. Among the most abundant microzooplankton taxa are radiolarians and copepod nauplii (i.e., *O. similis, Oncaea borealis* and *Microcalanus pygmaeus*) (Hopcroft *et al*., 2005; Hop *et al*., 2021b). Macrozooplankton in the CAO include amphipods (e.g. *Themisto spp*.), krill (*Thysanoessa spp*.), shrimp (e.g. *Hymenodora glacialis*), chaetognaths (e.g. *Eukrohnia hamata*) and jellyfish, including ctenophores, hydromedusae, and siphonophores. Several primarily sympagic species can temporarily join the zooplankton, such as the ice amphipod *A. glacialis* (Berge *et al*., 2012; Kunisch *et al*., 2020).

The taxonomic composition of zooplankton communities in the two CAO basins are influenced by zooplankton biomass from the Atlantic Ocean brought by the Arctic Circumpolar Boundary Current (Bluhm *et al*., 2015, 2020; Wassmann *et al*., 2020). The zooplankton community in the

Eurasian basin is more strongly influenced by inflowing Atlantic water, having Atlantic species (e.g. *C. finmarchicus*) alongside Arctic endemics such as *C. hyperboreus* and *C. glacialis* (Ershova *et al*., 2021). In the Amerasian Basin, the Atlantic influence is weaker and Pacific species, such as *Neocalanus spp*. and *Metridia pacifica* contribute to the zooplankton community (Kosobokova & Hirche, 2000; Kosobokova, 2003; Bluhm *et al*., 2015). Strong stratification inhibits nutrient replenishment to surface waters, resulting in lower primary productivity and zooplankton biomass compared to the Eurasian Basin (Kohlbach *et al*., 2025).

Primary productivity has increased with the loss of summer sea ice (Ardyna & Arrigo, 2020). The distribution and abundance of endemic Arctic zooplankton is changing. Accelerating sea-ice decline, ocean warming and changing distributions of water masses are advancing the borealisation of zooplankton communities from the periphery towards the CAO (Ershova *et al*., 2021). Gelatinous zooplankton may also be increasing in Arctic waters, including large species such as the lion's mane jellyfish (*Cyanea capitata*) and the helmet jelly (*Periphylla periphylla*) (Crawford, 2016; Geoffroy *et al*., 2018). However, to which extent the zooplankton community has already changed in the CAO is difficult to assess due to a lack of (quasi-) time series data.

5.6.3 Benthic habitat and associated biota (incl. foodweb)

Benthic habitats in the CAO are diverse and include extensive abyssal plains, shallower shelf areas, soft sediments, and glacial drop stones as well as seamounts, ridges, and active vent fields. Limited time series information is available to assess the status of benthic habitats in the ecoregion, though it is anticipated that most are still generally unaffected by local human activity, but they may serve as a sink for pollution from global sources.

The benthic invertebrate faunal diversity of the ecoregion reflects the diversity of benthic habitats. Prominent fauna include: sponges and the associated benthic biota of seamounts, ridge fauna (including chemoautotrophs at vents), sessile fauna and their predators associated with glacial drop stones, hyperbenthic and abysso-pelagic taxa associated with the thin benthic boundary layer, benthic invertebrate biota associated with the overlying marginal ice zone, and meio- and macro-benthos in soft sediments of the vast abyssal plains (Paul and Menzies, 1974; Kröncke, 1994; Mayer and Piepenburg, 1996; Kröncke *et al*., 2000; Schewe, 2001; Edmonds *et al*., 2003; Renaud *et al*., 2006; Raskoff *et al*., 2010; Bluhm *et al*., 2011; Rybakova *et al*., 2019; Zhulay *et al*., 2019; Bünz *et al*., 2020; Ramirez-Llodra *et al*., 2024). A 2011 benthic species inventory from various data sources for the CAO (at depths of greater than 500 m) presented more than 1125 taxa morphologically identified (Bluhm *et al*., 2011). The inventory was dominated by arthropods (>350 taxa), foraminiferans (~200), annelids (~200), and nematodes (>100; Bluhm *et al*., 2011), with a few hundred additional taxa added in a more recent inventory (Ramirez-Llodra *et al*., 2024). Molecular sequence data from Arctic deep-sea benthos is poorly represented in global sequence data bases.

The benthic community structure differs among the upper and lower slope, the basin, chemosynthetic habitats, and the adjacent shelf seas hard-substrate communities in any of those habitat types (Vedenin *et al*., 2018; Wiedmann *et al*., 2020; Morganti *et al*., 2022; Ramirez-Llodra *et al*., 2024). Observations in the Chukchi Borderland indicate a decrease in taxon richness, biomass, and density of epifauna with increasing depth (Zhulay *et al*., 2019).

Status and trends of benthic communities are generally lacking within the ecoregion. The single available time series in the Arctic deep sea is from HAUSGARTEN, a long-term observatory (25 years in 2025) in eastern Fram Strait. That time series indicates that it takes several years to establish a faunal inventory of an Arctic deep-sea site, yet suggests that the benthic community does respond to warm water anomalies that increased benthic abundance and taxonomic and functional diversity, likely related to increased surface primary production (Górska *et al*., 2022).

5.6.4 Fish and cephalopods

Knowledge about the fish community in the ecoregion is rare with a general lack of data in the CAO in Mecklenburg *et al*., 2018), but has benefitted greatly from observations during the MOSAiC expedition (2019-2020). Small gadoids (mainly polar cod, Boreogadus saida, and Ice cod, Arctogadus glacialis) are found in the sea-ice covered areas within the ecoregion, and eelpouts (*Zoarcidae*) have been observed associated with the seabed (Snoeijs-Leijonmalm *et al*., 2020). A deep-scattering layer that likely contains fish has been recorded at mesopelagic depths throughout the ecoregion. The first observations of Atlantic cod (*Gadus morhua*), have been reported in the ecoregion (Snoeijs-Leijonmalm *et al*., 2022). The Armhook squid (*Gonatus fabricii*), lanternfish (*Benthosema glaciale*), and black seasnail (*Paraliparis bathybius*), were also observed in the deep-scattering layer (Snoeijs-Leijonmalm *et al*., 2022). Genetic analyses of Atlantic cod caught in the CAO showed that the fish originated from populations spawning along the northern Norwegian coast, and were not a result of a CAO-specific population that had been isolated through immigration. In the Chuckchi Sea, located adjacent to the CAO, shifts in the larval fish assemblage towards a more boreal community have been observed following warming and sea-ice loss (Axler *et al*., 2023).

5.6.5 Seabirds

Seabird abundance is extremely low in the ecoregion and mainly consists of migratory species, although large numbers of seabirds occur in adjacent shelf regions. At least 30 species of seabirds have been recorded in the ecoregion, with two species being in their natural summer habitat (ivory gull and Ross' gull [*Rhodostethia rosea*]). Six other species commonly occur, though in low numbers, along the ice edge (northern fulmar [*Fulmarus glacialis*], black-legged kittiwake [*Rissa tridactyla*], glaucous gull [*Larus hyperboreus*], Arctic skua [*Stercorarius parasiticus*], dovekie [*Alle alle*], and black guillemot [*Cepphus grylle*]. These eight species include surface foragers and divers, which are primarily piscivores. Birds from breeding colonies in adjacent areas do not generally forage into the ecoregion during breeding, because the distance is too long, with the possible exception of ivory gulls (Dumas *et al*., 2022).

There are strong signals that some Pacific seabirds are shifting their distribution northward (Kuletz *et al*., 2020), remaining longer along the ecoregion slope regions during summer and changing their migration patterns (McKeon *et al*., 2016). At least a portion of one population of black-legged kittiwake (*R. tridactyla*) has been documented to travel over the Arctic from a colony in the Barents Region to overwintering sites in the Chukchi and Bering seas, and more cross-Arctic migrations of kittiwakes could occur as sea ice declines (Ezhov *et al*., 2021). In general, reduced sea ice facilitate increases in cross-Arctic migration as more open water increases potential access to prey, making such transits possible (Clairbaux *et al*., 2019, Kuletz *et al*., 2024).

5.6.6 Marine mammals

During periods of year-round ice coverage, observations of marine mammals in the CAO have been limited to very low numbers of ringed seals and polar bears. Recent retreats of the sea ice have been accompanied by increased observations of several ice-dependent species including polar bears, narwhals (*Monodon monoceros*), ringed seals, and hooded seals (*Cystophora cristata*). Very few dedicated abundance surveys of marine mammals have been conducted in this area and precise trend information therefore does not exist.

A 2015 marine mammal survey north of Svalbard showed that most polar bears in this area are now foraging on the southern border of the Eurasian Basin (Aars *et al*., 2017). Few seals were observed, but subsequent assessments of the bears' nutritional status suggest that a suitable prey

base has been available over the last years. A rather large concentration of narwhals was also documented in this area for the first time (Vacquié-Garcia *et al*., 2017).

Gateways and shelf areas adjacent to the ecoregion are documented feeding areas for all eleven ice-dependent Arctic marine mammal species (walruses [*Odobenus rosmarus*], bearded seals [*Erignathus barbatus*], ringed seals, harp seals [*Pagophilus groenlandicus*], hooded seals, ribbon seals [*Histriophoca fasciata*], spotted seals [*Phoca largha*], beluga whales [*Delphinapterus leucas*], narwhals, bowhead whales [*Balaena mysticetus*] and polar bears). In addition, other species like grey whales (*Eschrichtius robustus*), humpback whales (*Megaptera novaeangliae*), fin whales (*Balaenoptera physalus*), blue whales (*Balaenoptera musculus*), minke whales (*Balaenoptera acutorostrata*), and killer whales (*Orcinus orca*) are increasingly observed in the border areas of the ecoregion during summer. Of these, grey whales have been considered endemic to the Pacific since the 18th century when the Atlantic grey whale population went extinct. Over the past decade, however, at least three grey whales are known to have entered the Atlantic Ocean, most likely via the shelf and slope areas bordering the ecoregion (Hoelzel *et al*., 2021; Manfrini *et al*., 2023). This illustrates the increased potential for long distance species exchange, population mixing, and pathogen transfer between Arctic marine mammal communities due to reduced ice cover in the ecoregion.

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Annex 1: List of participants

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Annex 2: Resolution

2023/WK/IEASG05 The Workshop for the revision of the Ecosystem Overview of the Central Arctic Ocean ecoregion (WKCAO), chaired by Martine van den Heuvel-Greve*, the Netherlands, will hold a (hybrid) workshop on 24 October 2024 in Copenhagen, Denmark, and work intersessionally online to:

a) Review the draft Ecosystem Overview (EO) of the Central Arctic Ocean ecoregion, as prepared intersessionally by the WKCAO chair;

b) Discuss and further develop a wire diagram informed by a driver - pressure – ecosystem state approach using a linkage framework and pressure assessment process that examines and scores all direct pressures and human activities for the Central Arctic Ocean ecoregion following the ICES technical guidelines methodology; this will be based on previous expert analysis.

c) Prepare a draft advice on the Central Arctic Ocean EO;

d) List gaps in knowledge for the Central Arctic Ocean and identify operational products to potentially improve the scientific basis of the advice for future iterations of the Central Arctic Ocean EO.

In their work, WKCAO shall describe the main environmental drivers for the ecoregion and link the main region-specific human activities to pressures on the ecosystem. The workshop will link these pressures to the state/impact of the ecosystem components (ice habitat and associated biota, pelagic habitat and associated biota, benthic habitat and associated biota, cephalopods, fish, seabirds and marine mammals). When possible/appropriate temporal trends of each ecosystem component will also be described.

WKCAO will provide a science report 10 days after the workshop and report this to the attention of ACOM and SCICOM together with the revised Ecosystem Overview for the Central Arctic Ocean ecoregion to be delivered as advice in 2025.

Supporting information

Priority	The overviews are seen as a progression towards operational implementation of the ecosystem approach and as such are aimed at informing expert working groups and assisting Regional Seas Conventions and policy makers. ACOM aims to develop this product for all ICES ecoregions. The EOs should be prepared according to the ICES Technical Guidelines for Ecosystem Overviews. This workshop is an essential step to underpin a sound scientific basis for the management of the Central Arctic Ocean ecoregion by recording sources of information and discussions on the decisions by the experts. The work of this workshop will feed directly into Advisory process and will allow comparison between different ecoregions. Consequently, these activities are considered to have a very high priority. The ICES EOs are an integral part of ICES strategic plan to implement the Ecosystem Based Management (EBM). The revision of the EO for the Central Arctic Ocean ecoregion will contribute to implementing EBM in the region and will be aimed at informing both the scientific

	community as well as states and intergovernmental management authorities and organizations.
Scientific justification	Environments and ecosystems vary over time, sometimes with a trend and sometimes with a step change. The regional ecosystem overviews are intended to provide advisory groups with information on natural variability, trends and step changes in the dynamics of their respective ecosystems based on the best available evidence that are expected to influence the advice. They will also summarize the impacts that human activities have on the state of living and non-living resources of the ecosystem components through the main pressures in the region. This information needs to consider both spatial and temporal variability, with priority given to changes that would lead to the most significant modifications to the advice. To support emerging policy developments, those developing advice on the impacts of specific sectors (e.g. fisheries catch options, contaminants, by-catch, seabird abundance, sensitive areas etc.) will need to understand and respond to the implications of their advice for a range of ecosystem components and attributes, with priority given to those impacts that may compromise known management objectives. This development of ecosystem overviews is one of a number of ICES initiatives to integrate the advice on managing the human impacts on marine ecosystems of the ICES area. Risk assessment methods will be used to obtain a better understanding of the distribution and scale of anthropogenic pressures across the marine system and to estimate their impacts. The process will be iterative with a number of phases which will increase the relevance, impact and quality of the ecosystem overviews.
Resource requirements	ICES Data Centre, Secretariat and Advice process.
Participants	The participation should reflect the diverse scientific competence needed to fulfil the objectives of the workshop. Participants join the workshop at national expense. Participation of stakeholders is not committed.
Secretariat facilities	Data Centre, Secretariat support.
Financial	This work will be done at national cost.
Linkages to advisory committees	The EOs are part of the ICES advice and the product of the workshop will enter into the ICES Advisory process to be approved by ACOM.
Linkages to other committees or groups	Several ICES working groups may contribute with text and data to the content of this EO (WGSOCIAL, WGECON, SICCME, etc.) as well as ACOM, SCICOM, IEA, FRSG, HUDISG, HAPISG.
Linkages to other organizations	The work of this group may be used or is closely aligned with work under WGICA, PAME (Arctic Council) and PICES.

Annex 3: Full list of scores – CRR2 report

Full list of the scores from the CRR2 report (Jørgensen, 2025). All lines that recorded 'no overlap' were omitted from the list to save space.

Sector	Pressure	Ecological Characteristic	Overlap	Frequency	DoI	Confidence	Impact Risk Score
Global sources	Contaminating compounds	Seabirds - ice obligated	W	P	C	1	0.13
Research	Noise	Whales - narwhal	W	O	C	1	0.04
Research	Noise	Ringed seal	L	O	C	1	0.02
Research	Noise	Whales - beluga	L	O	C	1	0.02
Global sources	Contaminating compounds	Algae - ice obligated	W	P	L	1	0.01
Global sources	Contaminating compounds	Benthos - hardbottom	W	P	L	1	0.01
Global sources	Contaminating compounds	Benthos - softbottom	W	P	L	1	0.01
Global sources	Contaminating compounds	Fish - ice obligated	W	P	L	1	0.01
Global sources	Contaminating compounds	Fish - benthic, benthopelagic	W	P	L	1	0.01
Global sources	Contaminating compounds	Fish - mesopelagic	W	P	L	1	0.01
Global sources	Contaminating compounds	Invertebrates - ice obligated	W	P	L	1	0.01
Global sources	Contaminating compounds	Microbes - ice, pelagic	W	P	L	1	0.01
Global sources	Contaminating compounds	Microbes - seafloor	W	P	L	1	0.01
Global sources	Contaminating compounds	Phytoplankton	W	P	L	1	0.01
Global sources	Contaminating compounds	Polar Bear	W	P	L	1	0.01
Global sources	Contaminating compounds	Ringed seal	W	P	L	1	0.01
Global sources	Contaminating compounds	Seabirds - seasonal	W	P	L	1	0.01
Global sources	Contaminating compounds	Seabirds - transients	W	P	L	1	0.01

Global sources	Contaminating compounds	Squid	W	P	L	1	0.01
Global sources	Contaminating compounds	Whales - beluga	W	P	L	1	0.01
Global sources	Contaminating compounds	Whales - bowhead	W	P	L	1	0.01
Global sources	Contaminating compounds	Whales - narwhal	W	P	L	1	0.01
Global sources	Contaminating compounds	Zooplankton	W	P	L	1	0.01
Global sources	Marine litter, incl microplast	Benthos - hardbottom	W	P	L	1	0.01
Global sources	Marine litter, incl microplast	Benthos - softbottom	W	P	L	1	0.01
Global sources	Marine litter, incl microplast	Fish - ice obligated	W	P	L	1	0.01
Global sources	Marine litter, incl microplast	Fish - benthic, benthopelagic	W	P	L	1	0.01
Global sources	Marine litter, incl microplast	Fish - mesopelagic	W	P	L	1	0.01
Global sources	Marine litter, incl microplast	Invertebrates - ice obligated	W	P	L	1	0.01
Global sources	Marine litter, incl microplast	Microbes - ice, pelagic	W	P	L	1	0.01
Global sources	Marine litter, incl microplast	Polar Bear	W	P	L	1	0.01
Global sources	Marine litter, incl microplast	Ringed seal	W	P	L	1	0.01
Global sources	Marine litter, incl microplast	Seabirds - ice obligated	W	P	L	1	0.01
Global sources	Marine litter, incl microplast	Seabirds - seasonal	W	P	L	1	0.01
Global sources	Marine litter, incl microplast	Seabirds - transients	W	P	L	1	0.01
Global sources	Marine litter, incl microplast	Squid	W	P	L	1	0.01
Global sources	Marine litter, incl microplast	Whales - beluga	W	P	L	1	0.01
Global sources	Marine litter, incl microplast	Whales - bowhead	W	P	L	1	0.01
Global sources	Marine litter, incl microplast	Whales - narwhal	W	P	L	1	0.01

Global sources	Marine litter, incl microplast	Zooplankton	W	P	L	1	0.01
Military	Noise	Ringed seal	S	O	C	1	0.001287
Research	Noise	Whales - bowhead	S	O	C	1	0.001287
Research	Extraction of species	Benthos - hardbottom	S	R	C	1	0.000312
Military	Noise	Whales - beluga	S	R	C	1	0.000312
Military	Noise	Whales - bowhead	S	R	C	1	0.000312
Tourism and recreation	Noise	Whales - bowhead	S	R	C	2	0.000312
Military	Noise	Whales - narwhals	S	R	C	1	0.000312
Tourism and recreation	Noise	Whales - narwhals	S	R	C	2	0.000312
Research	Physical seabed disturbance	Benthos - hardbottom	S	R	C	1	0.000312
Research	Physical seabed disturbance	Benthos - softbottom	S	R	C	1	0.000312
Research	Contaminating compounds	Algae - ice obligated	S	O	L	1	0.000099
Research	Contaminating compounds	Fish - ice obligated	S	O	L	2	0.000099
Research	Contaminating compounds	Invertebrates - ice obligated	S	O	L	1	0.000099
Research	Contaminating compounds	Microbes - ice, pelagic	S	O	L	1	0.000099
Research	Contaminating compounds	Phytoplankton	S	O	L	1	0.000099
Research	Contaminating compounds	Polar Bear	S	O	L	2	0.000099
Research	Contaminating compounds	Ringed seal	S	O	L	2	0.000099
Research	Contaminating compounds	Seabirds - ice obligated	S	O	L	1	0.000099
Research	Contaminating compounds	Seabirds - seasonal	S	O	L	1	0.000099

Research	**Contaminating compounds**	**Squid**	**S**	**O**	**L**	**1**	**0.000099**
Research	**Contaminating compounds**	**Whales - beluga**	**S**	**O**	**L**	**2**	**0.000099**
Research	**Contaminating compounds**	**Whales - bowhead**	**S**	**O**	**L**	**1**	**0.000099**
Research	**Contaminating compounds**	**Whales - narwhals**	**S**	**O**	**L**	**1**	**0.000099**
Research	**Contaminating compounds**	**Zooplankton**	**S**	**O**	**L**	**1**	**0.000099**
Research	**Extraction of species**	**Fish - ice obligated**	**S**	**O**	**L**	2	**0.000099**
Research	**Extraction of species**	**Fish - mesopelagic**	**S**	**O**	**L**	2	**0.000099**
Research	**Extraction of species**	**Invertebrates - ice obligated**	**S**	**O**	**L**	**1**	**0.000099**
Research	**Extraction of species**	**Squid**	**S**	**O**	**L**	**1**	**0.000099**
Research	**Extraction of species**	**Zooplankton**	**S**	**O**	**L**	**1**	**0.000099**
Research	**Introduction of non-indigenous species**	**Microbes - ice, pelagic**	**S**	**O**	**L**	**1**	**0.000099**
Research	**Introduction of non-indigenous species**	**Ringed seal**	**S**	O	L	**1**	**0.000099**
Research	**Introduction of non-indigenous species**	**Whales - beluga**	**S**	O	L	**1**	**0.000099**
Research	**Introduction of non-indigenous species**	**Whales - bowhead**	**S**	O	L	**1**	**0.000099**
Research	**Introduction of non-indigenous species**	**Whales - narwhals**	**S**	O	L	**1**	**0.000099**
Research	**Marine litter, incl microplast**	**Fish - ice obligated**	**S**	**O**	**L**	**1**	**0.000099**
Research	**Marine litter, incl microplast**	**Fish - benthic, benthopelagic**	**S**	**O**	**L**	**1**	**0.000099**
Research	**Marine litter, incl microplast**	**Fish - mesopelagic**	**S**	**O**	**L**	**1**	**0.000099**
Research	**Marine litter, incl microplast**	**Invertebrates - ice obligated**	**S**	**O**	**L**	**1**	**0.000099**

Research	**Marine litter, incl microplast**	**Microbes - ice, pelagic**	**S**	**O**	**L**	**1**	**0.000099**
Research	**Marine litter, incl microplast**	**Seabirds - ice obligated**	**S**	**O**	**L**	**2**	**0.000099**
Research	**Marine litter, incl microplast**	**Seabirds - seasonal**	**S**	**O**	**L**	**2**	**0.000099**
Research	**Marine litter, incl microplast**	**Seabirds - transients**	**S**	**O**	**L**	**2**	**0.000099**
Research	**Marine litter, incl microplast**	**Squid**	**S**	**O**	**L**	**1**	**0.000099**
Research	**Marine litter, incl microplast**	**Whales - beluga**	**S**	**O**	**L**	**1**	**0.000099**
Research	**Marine litter, incl microplast**	**Whales - bowhead**	**S**	**O**	**L**	**1**	**0.000099**
Research	**Marine litter, incl microplast**	**Whales - narwhals**	**S**	**O**	**L**	**1**	**0.000099**
Research	**Marine litter, incl microplast**	**Zooplankton**	**S**	**O**	**L**	**1**	**0.000099**
Research	**Noise**	**Fish - ice obligated**	**S**	**O**	**L**	**1**	**0.000099**
Research	**Noise**	**Fish - benthic, benthopelagic**	**S**	**O**	**L**	1	**0.000099**
Research	**Noise**	**Fish - mesopelagic**	**S**	**O**	**L**	**1**	**0.000099**
Research	**Noise**	**Polar Bear**	**S**	**O**	**L**	**2**	**0.000099**
Tourism and recreation	**Noise**	**Ringed seal**	**S**	O	L	**2**	**0.000099**
Research	**Unintented injury and mortality**	**Fish - ice obligated**	**S**	**O**	**L**	1	**0.000099**
Military	**Artificial light pollution**	**Seabirds - ice obligated**	**S**	**R**	**L**	**1**	**0.000024**
Research	**Artificial light pollution**	**Seabirds - ice obligated**	**S**	**R**	**L**	**1**	**0.000024**
Tourism and recreation	**Artificial light pollution**	**Seabirds - ice obligated**	**S**	**R**	**L**	**1**	**0.000024**
Military	**Artificial light pollution**	**Seabirds - seasonal**	**S**	**R**	**L**	**1**	**0.000024**
Research	**Artificial light pollution**	**Seabirds - seasonal**	**S**	**R**	**L**	**1**	**0.000024**

Tourism and recreation	**Artificial light pollution**	**Seabirds - seasonal**	**S**	**R**	**L**	**1**	**0.000024**
Military	**Contaminating compounds**	**Algae - ice obligated**	**S**	**R**	**L**	**1**	**0.000024**
Tourism and recreation	**Contaminating compounds**	**Algae - ice obligated**	**S**	**R**	**L**	**1**	**0.000024**
Military	**Contaminating compounds**	**Fish - ice obligated**	**S**	**R**	**L**	2	**0.000024**
Tourism and recreation	**Contaminating compounds**	**Fish - ice obligated**	**S**	**R**	**L**	2	**0.000024**
Military	**Contaminating compounds**	**Invertebrates - ice obligated**	**S**	**R**	**L**	1	**0.000024**
Tourism and recreation	**Contaminating compounds**	**Invertebrates - ice obligated**	**S**	**R**	**L**	1	**0.000024**
Military	**Contaminating compounds**	**Microbes - ice, pelagic**	**S**	**R**	**L**	**1**	**0.000024**
Tourism and recreation	**Contaminating compounds**	**Microbes - ice, pelagic**	**S**	**R**	**L**	**1**	**0.000024**
Military	**Contaminating compounds**	**Phytoplankton**	**S**	**R**	**L**	**1**	**0.000024**
Tourism and recreation	**Contaminating compounds**	**Phytoplankton**	**S**	**R**	**L**	**1**	**0.000024**
Tourism and recreation	**Contaminating compounds**	**Polar Bear**	**S**	**R**	**L**	**1**	**0.000024**
Military	**Contaminating compounds**	**Polar Bear**	**S**	**R**	**L**	**1**	**0.000024**
Tourism and recreation	**Contaminating compounds**	**Ringed seal**	**S**	**R**	**L**	**1**	**0.000024**
Military	**Contaminating compounds**	**Ringed seal**	**S**	**R**	**L**	**1**	**0.000024**
Military	**Contaminating compounds**	**Seabirds - ice obligated**	**S**	**R**	**L**	**1**	**0.000024**
Tourism and recreation	**Contaminating compounds**	**Seabirds - ice obligated**	**S**	**R**	**L**	**1**	**0.000024**

Military	**Contaminating compounds**	**Seabirds - seasonal**	**S**	**R**	**L**	**1**	**0.000024**
Tourism and recreation	**Contaminating compounds**	**Seabirds - seasonal**	**S**	**R**	**L**	**1**	**0.000024**
Military	**Contaminating compounds**	**Squid**	**S**	**R**	**L**	1	**0.000024**
Tourism and recreation	**Contaminating compounds**	**Squid**	**S**	**R**	**L**	1	**0.000024**
Military	**Contaminating compounds**	**Whales - beluga**	**S**	**R**	**L**	**1**	**0.000024**
Tourism and recreation	**Contaminating compounds**	**Whales - bowhead**	**S**	**R**	**L**	**2**	**0.000024**
Military	**Contaminating compounds**	**Whales - bowhead**	**S**	**R**	**L**	**1**	**0.000024**
Tourism and recreation	**Contaminating compounds**	**Whales - narwhals**	**S**	**R**	**L**	**1**	**0.000024**
Military	**Contaminating compounds**	**Whales - narwhals**	**S**	**R**	**L**	**1**	**0.000024**
Military	**Contaminating compounds**	**Zooplankton**	**S**	**R**	**L**	1	**0.000024**
Tourism and recreation	**Contaminating compounds**	**Zooplankton**	**S**	**R**	**L**	1	**0.000024**
Research	**Extraction of species**	**Benthos - softbottom**	**S**	**R**	**L**	**1**	**0.000024**
Research	**Extraction of species**	**Fish - benthic, benthopelagic**	**S**	**R**	**L**	2	**0.000024**
Research	**Human presence**	**Polar Bear**	**S**	**R**	**L**	**3**	**0.000024**
Military	**Introduction of non-indigenous species**	**Microbes - ice, pelagic**	**S**	**R**	**L**	**1**	**0.000024**
Tourism and recreation	**Introduction of non-indigenous species**	**Microbes - ice, pelagic**	**S**	**R**	**L**	**1**	**0.000024**
Military	**Introduction of non-indigenous species**	**Ringed seal**	**S**	R	L	**1**	**0.000024**

Tourism and recreation	**Introduction of non-indigenous species**	**Ringed seal**	**S**	R	L	**1**	**0.000024**
Military	**Introduction of non-indigenous species**	**Whales - beluga**	**S**	R	L	**1**	**0.000024**
Military	**Introduction of non-indigenous species**	**Whales - bowhead**	**S**	R	L	**1**	**0.000024**
Tourism and recreation	**Introduction of non-indigenous species**	**Whales - bowhead**	**S**	R	L	**1**	**0.000024**
Military	**Introduction of non-indigenous species**	**Whales - narwhal**	**S**	R	L	**1**	**0.000024**
Tourism and recreation	**Introduction of non-indigenous species**	**Whales - narwhal**	**S**	R	L	**1**	**0.000024**
Military	**Marine litter, incl microplast**	**Benthos - softbottom**	**S**	**R**	**L**	**1**	**0.000024**
Research	**Marine litter, incl microplast**	**Benthos - softbottom**	**S**	**R**	**L**	**1**	**0.000024**
Tourism and recreation	**Marine litter, incl microplast**	**Benthos - softbottom**	**S**	**R**	**L**	**1**	**0.000024**
Military	**Marine litter, incl microplast**	**Fish - ice obligated**	**S**	**R**	**L**	**1**	**0.000024**
Tourism and recreation	**Marine litter, incl microplast**	**Fish - ice obligated**	**S**	**R**	**L**	**1**	**0.000024**
Military	**Marine litter, incl microplast**	**Fish - benthic, benthopelagic**	**S**	**R**	**L**	**1**	**0.000024**
Tourism and recreation	**Marine litter, incl microplast**	**Fish - benthic, benthopelagic**	**S**	**R**	**L**	**1**	**0.000024**
Military	**Marine litter, incl microplast**	**Fish - mesopelagic**	**S**	**R**	**L**	**1**	**0.000024**
Tourism and recreation	**Marine litter, incl microplast**	**Fish - mesopelagic**	**S**	**R**	**L**	**1**	**0.000024**
Military	**Marine litter, incl microplast**	**Invertebrates - ice obligated**	**S**	**R**	**L**	**1**	**0.000024**
Tourism and recreation	**Marine litter, incl microplast**	**Invertebrates - ice obligated**	**S**	**R**	**L**	**1**	**0.000024**

Military	Marine litter, incl microplast	Microbes - ice, pelagic	S	R	L	1	0.000024
Tourism and recreation	Marine litter, incl microplast	Microbes - ice, pelagic	S	R	L	1	0.000024
Military	Marine litter, incl microplast	Seabirds - ice obligated	S	R	L	1	0.000024
Tourism and recreation	Marine litter, incl microplast	Seabirds - ice obligated	S	R	L	2	0.000024
Military	Marine litter, incl microplast	Seabirds - seasonal	S	R	L	1	0.000024
Tourism and recreation	Marine litter, incl microplast	Seabirds - seasonal	S	R	L	2	0.000024
Military	Marine litter, incl microplast	Seabirds - transients	S	R	L	1	0.000024
Tourism and recreation	Marine litter, incl microplast	Seabirds - transients	S	R	L	2	0.000024
Military	Marine litter, incl microplast	Squid	S	R	L	1	0.000024
Tourism and recreation	Marine litter, incl microplast	Squid	S	R	L	1	0.000024
Military	Marine litter, incl microplast	Whales - beluga	S	R	L	1	0.000024
Military	Marine litter, incl microplast	Whales - bowhead	S	R	L	1	0.000024
Tourism and recreation	Marine litter, incl microplast	Whales - bowhead	S	R	L	1	0.000024
Military	Marine litter, incl microplast	Whales - narwhals	S	R	L	1	0.000024
Tourism and recreation	Marine litter, incl microplast	Whales - narwhals	S	R	L	1	0.000024
Military	Marine litter, incl microplast	Zooplankton	S	R	L	1	0.000024
Tourism and recreation	Marine litter, incl microplast	Zooplankton	S	R	L	1	0.000024
Military	Noise	Fish - ice obligated	S	R	L	1	0.000024

Military	**Noise**	**Fish - benthic, benthopelagic**	**S**	**R**	**L**	**1**	**0.000024**
Military	**Noise**	**Fish - mesopelagic**	**S**	**R**	**L**	**1**	**0.000024**
Research	**Physical seabed disturbance**	**Fish - benthic, benthopelagic**	**S**	**R**	**L**	1	**0.000024**
Military	**Unintented injury and mortality**	**Fish - ice obligated**	**S**	**R**	**L**	1	**0.000024**
Tourism and recreation	**Unintented injury and mortality**	**Fish - ice obligated**	**S**	**R**	**L**	1	**0.000024**
Military	**Unintented injury and mortality**	**Whales - bowhead**	**S**	**R**	**L**	**1**	**0.000024**
Tourism and recreation	**Unintented injury and mortality**	**Whales - bowhead**	**S**	**R**	**L**	**1**	**0.000024**

Annex 4: Full list of condensed scores – CRR2

Sector	Pressure	Ecological Characteristic	Overlap	Frequency	DoI	Comments	Impact Risk Score	IR relative contribution
Global sources	**Contaminating compounds**	**Seabirds**	**W**	**P**	**C**	Most vulnerable: ice obligated birds. Seasonal and transients have 'L' score for DoI.	**0.13**	**42.176**
Research	**Noise**	**Marine mammals**	**W**	**O**	**C**	W' for narwhal, 'L' for ringed seal and beluga, 'S' for bowhead.	**0.04**	**13.918**
Global sources	**Contaminating compounds**	**Ice habitat and associated biota**	**W**	**P**	**L**	Includes: algae, invertebrates, microbes	**0.01**	**3.244**
Global sources	**Contaminating compounds**	**Benthic habitat and associated biota**	**W**	**P**	**L**	Includes: hard bottom, soft bottom benthos, microbes	**0.01**	**3.244**
Global sources	**Contaminating compounds**	**Fish**	**W**	**P**	**L**	Includes: ice obligated, benthic, benthopelagic, mesopelagic fish	**0.01**	**3.244**
Global sources	**Contaminating compounds**	**Pelagic habitat and associated biota**	**W**	**P**	**L**	Includes: phytoplankton, zooplankton	**0.01**	**3.244**
Global sources	**Contaminating compounds**	**Marine mammals**	**W**	**P**	**L**	Includes: polar bear, ringed seal, beluga, bowhead, narwhal	**0.01**	**3.244**
Global sources	**Contaminating compounds**	**Squid**	**W**	**P**	**L**		**0.01**	**3.244**
Global sources	**Marine litter, incl microplast**	**Benthic habitat and associated biota**	**W**	**P**	**L**	Includes: hard bottom, soft bottom benthos, microbes	**0.01**	**3.244**
Global sources	**Marine litter, incl microplast**	**Fish**	**W**	**P**	**L**	Includes: ice obligated, benthic, benthopelagic, mesopelagic fish	**0.01**	**3.244**
Global sources	**Marine litter, incl microplast**	**Ice habitat and associated biota**	**W**	**P**	**L**	Includes: algae, invertebrates, microbes	**0.01**	**3.244**

Global sources	**Marine litter, incl microplast**	**Marine mammals**	**W**	**P**	**L**	Includes: polar bear, ringed seal, beluga, bowhead, narwhal	**0.01**	**3.244**
Global sources	**Marine litter, incl microplast**	**Seabirds**	**W**	**P**	**L**	Includes: ice obligated bird, seasonal and transients	**0.01**	**3.244**
Global sources	**Marine litter, incl microplast**	**Squid**	**W**	**P**	**L**		**0.01**	**3.244**
Global sources	**Marine litter, incl microplast**	**Pelagic habitat and associated biota**	**W**	**P**	**L**	Includes: phytoplankton, zooplankton	**0.01**	**3.244**
Military	**Noise**	**Marine mammals**	**S**	O	C	Includes: ringed seal, beluga, bowhead, narwhal. Ringed seal scored 'O', rest 'R' for frequency	**0.001287**	**0.418**
Research	**Extraction of species**	**Benthic habitat and associated biota**	**S**	**R**	**C**	Includes: hard bottom benthos	**0.000312**	**0.101**
Research	**Physical seabed disturbance**	**Benthic habitat and associated biota**	**S**	**R**	**C**	Includes: hard and soft bottom benthos	**0.000312**	**0.101**
Tourism and recreation	**Noise**	**Marine mammals**	**S**	R	**C**	Includes: bowhead, narwhal, ringed seal	**0.000312**	**0.101**
Research	**Contaminating compounds**	**Ice habitat and associated biota**	**S**	**O**	**L**	Includes: algae, invertebrates, microbes	**0.000099**	**0.032**
Research	**Contaminating compounds**	**Fish**	**S**	**O**	**L**	includes: ice obligate	**0.000099**	**0.032**
Research	**Contaminating compounds**	**Pelagic habitat and associated biota**	**S**	**O**	**L**	Includes: phytoplankton, zooplankton	**0.000099**	**0.032**
Research	**Contaminating compounds**	**Marine mammals**	**S**	**O**	**L**	Includes: polar bear, ringed seal, beluga, bowhead, narwhal	**0.000099**	**0.032**
Research	**Contaminating compounds**	**Seabirds**	**S**	**O**	**L**	Includes: ice obligate, seasonal	**0.000099**	**0.032**
Research	**Contaminating compounds**	**Squid**	**S**	**O**	**L**	small area, up to 4 month, low impact, high resilience,	**0.000099**	**0.032**

						pressure disapeard before 2 year		
Research	**Extraction of species**	**Fish**	**S**	**O**	**L**	Includes: ice obligate, mesopelagic	**0.000099**	**0.032**
Research	**Extraction of species**	**Ice habitat and associated biota**	**S**	**O**	**L**	Includes: invertebrates	**0.000099**	**0.032**
Research	**Extraction of species**	**Squid**	**S**	**O**	**L**		**0.000099**	**0.032**
Research	**Extraction of species**	**Pelagic habitat and associated biota**	**S**	**O**	**L**	Includes: zooplankton	**0.000099**	**0.032**
Research	**Introduction of non-indigenous species**	**Ice habitat and associated biota**	**S**	**O**	**L**	Includes: microbes	**0.000099**	**0.032**
Research	**Introduction of non-indigenous species**	**Marine mammals**	**S**	O	L	Includes: ringed seal, beluga, bowhead, narwhal	**0.000099**	**0.032**
Research	**Marine litter, incl microplast**	**Fish**	**S**	**O**	**L**	Includes; Ice obligate, benthic, benthopelagic, mesopelagic	**0.000099**	**0.032**
Research	**Marine litter, incl microplast**	**Ice habitat and associated biota**	**S**	**O**	**L**	Includes: invertebrates, microbes	**0.000099**	**0.032**
Research	**Marine litter, incl microplast**	**Seabirds**	**S**	**O**	**L**	Includes: ice obligate, seasonal, transients	**0.000099**	**0.032**
Research	**Marine litter, incl microplast**	**Squid**	**S**	**O**	**L**		**0.000099**	**0.032**
Research	**Marine litter, incl microplast**	**Marine mammals**	**S**	**O**	**L**	Includes: beluga, bowhead, narwhal	**0.000099**	**0.032**
Research	**Marine litter, incl microplast**	**Pelagic habitat and associated biota**	**S**	**O**	**L**	Includes: zooplankton	**0.000099**	**0.032**
Research	**Noise**	**Fish**	**S**	**O**	**L**	Includes: ice obligate, benthic, benthopelagic, mesopelagic	**0.000099**	**0.032**
Research	**Noise**	**Marine mammals**	**S**	**O**	**L**	Includes: polar bear	**0.000099**	**0.032**
Research	**Unintented injury and mortality**	**Fish**	**S**	**O**	**L**	Includes: ice obligate	**0.000099**	**0.032**

Military	**Artificial light pollution**	**Seabirds**	**S**	**R**	**L**	Includes: ice obligated bird, seasonal and transients	**0.000024**	**0.008**
Military	**Contaminating compounds**	**Ice habitat and associated biota**	**S**	**R**	**L**	Includes: algae, invertebrates, microbes	**0.000024**	**0.008**
Military	**Contaminating compounds**	**Fish**	**S**	**R**	**L**	Includes: ice obligated, benthic, benthopelagic, mesopelagic fish	**0.000024**	**0.008**
Military	**Contaminating compounds**	**Pelagic habitat and associated biota**	**S**	**R**	**L**	Includes: phytoplankton, zooplankton	**0.000024**	**0.008**
Military	**Contaminating compounds**	**Marine mammals**	**S**	**R**	**L**	Includes: polar bear, ringed seal, beluga, bowhead, narwhal.	**0.000024**	**0.008**
Military	**Contaminating compounds**	**Seabirds**	**S**	**R**	**L**	Includes: ice obligated bird, seasonal and transients	**0.000024**	**0.008**
Military	**Contaminating compounds**	**Squid**	**S**	**R**	**L**	We do not know where and how long	**0.000024**	**0.008**
Military	**Introduction of non-indigenous species**	**Ice habitat and associated biota**	**S**	**R**	**L**	Includes: algae, invertebrates, microbes	**0.000024**	**0.008**
Military	**Introduction of non-indigenous species**	**Marine mammals**	**S**	R	L	Includes: polar bear, ringed seal, beluga, bowhead, narwhal.	**0.000024**	**0.008**
Military	**Marine litter, incl microplast**	**Benthic habitat and associated biota**	**S**	**R**	**L**	Includes: hard bottom, soft bottom benthos, microbes	**0.000024**	**0.008**
Military	**Marine litter, incl microplast**	**Fish**	**S**	**R**	**L**	Includes: ice obligated, benthic, benthopelagic, mesopelagic fish	**0.000024**	**0.008**
Military	**Marine litter, incl microplast**	**Ice habitat and associated biota**	**S**	**R**	**L**	Includes: invertebrates, microbes	**0.000024**	**0.008**
Military	**Marine litter, incl microplast**	**Seabirds**	**S**	**R**	**L**	Includes: ice obligated bird, seasonal and transients	**0.000024**	**0.008**
Military	**Marine litter, incl microplast**	**Squid**	**S**	**R**	**L**		**0.000024**	**0.008**
Military	**Marine litter, incl microplast**	**Marine mammals**	**S**	**R**	**L**	Includes: beluga, bowhead, narwhal	**0.000024**	**0.008**

Military	**Marine litter, incl microplast**	**Pelagic habitat and associated biota**	**S**	**R**	**L**	Includes: pytoplankton	**0.000024**	**0.008**
Military	**Noise**	**Fish**	**S**	**R**	**L**	Includes: ice obligate, benthic, benthopelagic, mesopelagic	**0.000024**	**0.008**
Military	**Unintented injury and mortality**	**Fish ice obligated**	**S**	**R**	**L**	Includes: ice obligate	**0.000024**	**0.008**
Military	**Unintented injury and mortality**	**Marine mammals**	**S**	**R**	**L**	Includes: bowhead	**0.000024**	**0.008**
Research	**Artificial light pollution**	**Seabirds**	**S**	**R**	**L**	Includes: ice obligate, seasonal	**0.000024**	**0.008**
Research	**Extraction of species**	**Benthic habitat and associated biota**	**S**	**R**	**L**	Includes: soft bottom benthos	**0.000024**	**0.008**
Research	**Extraction of species**	**Fish**	**S**	**R**	**L**	Includes: benthic/benthopelagic	**0.000024**	**0.008**
Research	**Human presence**	**Marine mammals**	**S**	**R**	**L**	Includes: polar bear	**0.000024**	**0.008**
Research	**Marine litter, incl microplast**	**Benthic habitat and associated biota**	**S**	**R**	**L**	Includes: soft bottom benthos	**0.000024**	**0.008**
Research	**Physical seabed disturbance**	**Fish**	**S**	**R**	**L**	Includes: benthic/benthopelagic	**0.000024**	**0.008**
Tourism and recreation	**Artificial light pollution**	**Seabirds**	**S**	**R**	**L**	Includes: ice obligate, seasonal	**0.000024**	**0.008**
Tourism and recreation	**Contaminating compounds**	**Ice habitat and associated biota**	**S**	**R**	**L**	Includes: algae, invertebrates, microbes	**0.000024**	**0.008**
Tourism and recreation	**Contaminating compounds**	**Fish**	**S**	**R**	**L**	Includes: ice obligate	**0.000024**	**0.008**
Tourism and recreation	**Contaminating compounds**	**Pelagic habitat and associated biota**	**S**	**R**	**L**	Includes: phytoplankton, zooplankton	**0.000024**	**0.008**
Tourism and recreation	**Contaminating compounds**	**Marine mammals**	**S**	**R**	**L**	Includes: polar bear, ringed seal, bowhead, narwhal	**0.000024**	**0.008**

Tourism and recreation	**Contaminating compounds**	**Seabirds**	**S**	**R**	**L**	Includes: ice obligate, seasonal	**0.000024**	**0.008**
Tourism and recreation	**Contaminating compounds**	**Squid**	**S**	**R**	**L**		**0.000024**	**0.008**
Tourism and recreation	**Introduction of non-indigenous species**	**Ice habitat and associated biota**	**S**	**R**	**L**	Includes: microbes	**0.000024**	**0.008**
Tourism and recreation	**Introduction of non-indigenous species**	**Marine mammals**	**S**	R	L	Includes: ringed seal, bowhead, narwhal	**0.000024**	**0.008**
Tourism and recreation	**Marine litter, incl microplast**	**Benthic habitat and associated biota**	**S**	**R**	**L**	Includes: soft bottom benthos	**0.000024**	**0.008**
Tourism and recreation	**Marine litter, incl microplast**	**Fish**	**S**	**R**	**L**	Includes: ice obligate, benthic, benthopelagic, mesopelagic	**0.000024**	**0.008**
Tourism and recreation	**Marine litter, incl microplast**	**Ice habitat and associated biota**	**S**	**R**	**L**	Includes: invertebrates, microbes	**0.000024**	**0.008**
Tourism and recreation	**Marine litter, incl microplast**	**Seabirds**	**S**	**R**	**L**	Includes: ice obligate, seasonal, transients	**0.000024**	**0.008**
Tourism and recreation	**Marine litter, incl microplast**	**Squid**	**S**	**R**	**L**		**0.000024**	**0.008**
Tourism and recreation	**Marine litter, incl microplast**	**Marine mammals**	**S**	**R**	**L**	Includes: bowhead, narwhal	**0.000024**	**0.008**
Tourism and recreation	**Marine litter, incl microplast**	**Pelagic habitat and associated biota**	**S**	**R**	**L**	Includes: zooplankton	**0.000024**	**0.008**
Tourism and recreation	**Unintented injury and mortality**	**Fish**	**S**	**R**	**L**	Includes: ice obligate	**0.000024**	**0.008**
Tourism and recreation	**Unintented injury and mortality**	**Marine mammals**	**S**	**R**	**L**	Includes: bowhead	**0.000024**	**0.008**