2.1 Central Arctic Ocean ecoregion – Ecosystem Overview

Table of contents

Ecoregion description

The Central Arctic Ocean ecoregion (Figure 1) mostly comprises high seas areas remote from any landmass, including deep basins and slopes up to depths of approximately 500 m, as well as 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.

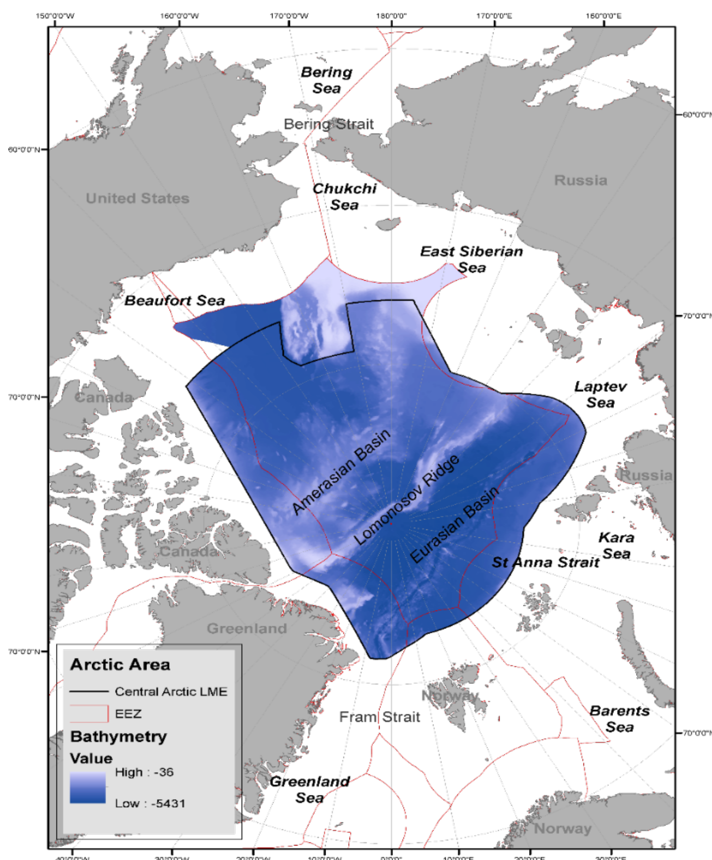

Figure 1 The Central Arctic Ocean ecoregion (in blue, with depth gradient), adjacent seas, and Exclusive Economic Zones (EEZs).

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.

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.

International governance of the Arctic Ocean under UNCLOS and other treaties (e.g. those concerning climate change) have been strengthened over the last decade through several regional agreements such as: 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 in the high seas of the ecoregion until 2037 at the earliest. This will depend on scientific assessments documenting commercial viability of resources 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.

As the ecoregion is largely understudied, information from adjacent seas and nearby areas was used to inform this ecosystem overview.

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 (via the Fram Strait and the 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.

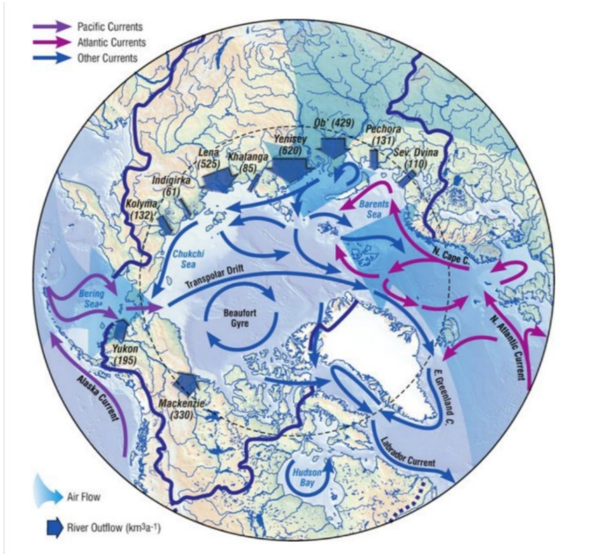

Figure 2 The major air and ocean currents towards and in the Arctic Ocean, as well as the dominant river inflow.

Key signals

- Climate change is the dominant and overarching driver in the ecoregion. Observed climate-related changes include decreases in sea ice extent and thickness, changes in salinity and freshwater content that affect water column stratification, the relative contributions/mixing of North Atlantic and North Pacific water masses in the ecoregion, and subregional increases in seawater temperature.
- The summer minimum sea ice extent decreased by a third in 2007–2020 relative to the 1979–2000 period. Old sea ice (> five years) decreased from 30% to 2% between 1979 and 2018. Mean sea ice thickness declined by 65% between 1975 and 2012.
- Receding sea ice has led to changes in both the range and abundance of species from primary producers to top predators. Examples include an increase in phytoplankton biomass, a reduction in the diversity and biomass of ice-associated algae and the expansion of the feeding migration of young ringed seals (*Pusa hispida*) into the ecoregion.
- Climate-related changes in both the ecoregion and adjacent seas are playing a key role in facilitating long-distance species exchange, population mixing, and pathogen transfer between the Pacific and Atlantic oceans.
- Ice-dependent fish and marine mammals are experiencing increased competition with boreal species for habitat and food throughout the ecoregion.
- The ecoregion has fewer human activities than other ecoregions and is a sink for contaminants and litter transported from global sources via ocean currents, rivers, and air.
- Climate change is affecting contaminant pathways and loading to the ecoregion and adjacent seas.
- Future perspective: sea ice loss is creating opportunities for the development and expansion of human activities in the ecoregion.

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 and remote location, and the absence of land and human settlements.

The main human pressures affecting the ecoregion are the introduction of contaminating compounds, marine litter, the introduction of non-indigenous species and underwater noise. Some of the activities causing these are scientific icebreakers, tourism, and military shipping.

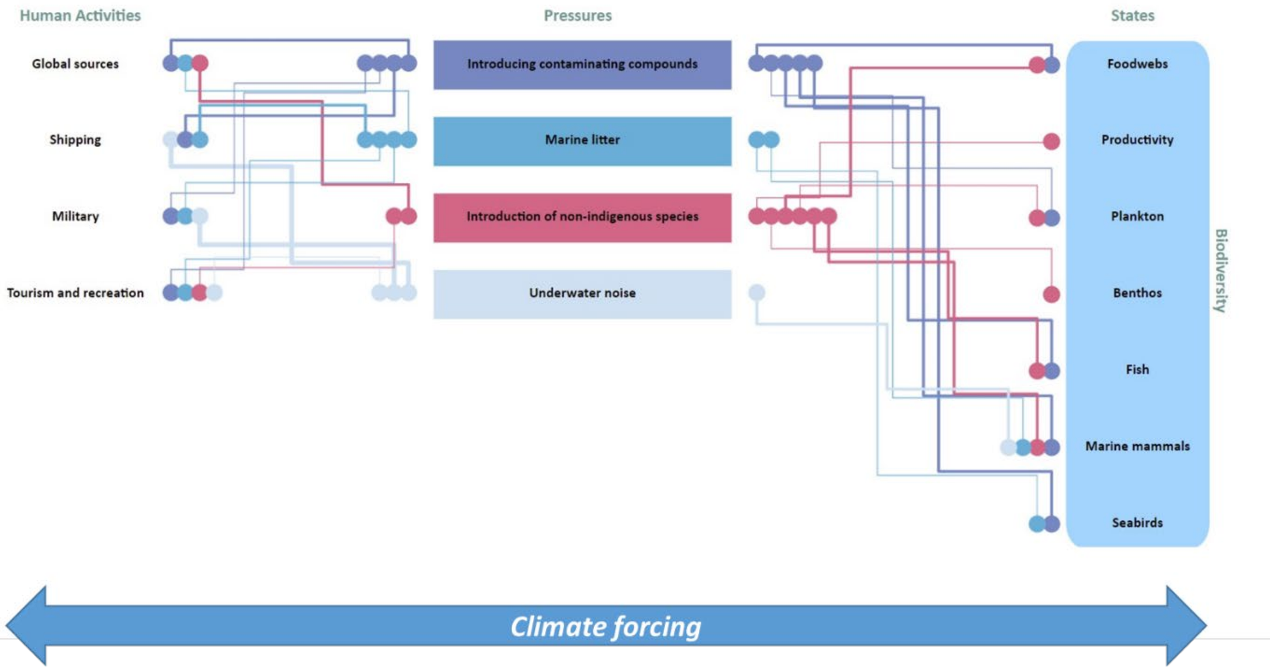

Figure 3 Overview of the major regional pressures, human activities, and ecosystem state components for the Central Arctic Ocean. The width of lines indicates the relative importance of the main individual links. The scaled strength of the pressures should be understood as a relative strength between 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 activites and associated pressures.

Introduction of contaminating compounds

The areas in and around the ecoregion are a sink for pollutants transported from lower latitudes. Pollution is 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. Chemical compounds that bioaccumulate in foodwebs, such as mercury and persistent organic pollutants (POPs), are currently the main concern. High levels of mercury and polychlorinated biphenyls (PCBs) are found in seabirds and top predators in Arctic areas adjacent to the ecoregion, and these have population effects on marine mammals such as polar bears (*Ursus maritimus*). Additional pollutants of concern include flame retardants, pesticides, per- and polyfluoroalkyl substances (PFAS) are also of concern.

Pollution from local sources is increasing with a growing number of human activities. Oil spills from activities on the continental shelves may also affect ecosystem components in the ecoregion.

Marine litter

Macro- and microplastic are transported by rivers, ocean currents and air masses into the ecoregion. Plastics have been found in sea ice, which may act as an important transport vector across the ocean surface and down the water column. There is evidence of the occurrence of microplastics in marine sediments in the ecoregion. Microplastics have also been reported on ice floes from the Fram Strait, snow samples from Baffin Bay, and in surface water, zooplankton, and sediment from the Canadian Arctic, providing evidence of atmospheric transport as suggested by simulations. Litter density on the seabed of the Atlantic Gateway has increased between 2002 and 2014.

Information on marine litter in the ecoregion is currently limited, but 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*), and seabirds and marine mammals were seen entangled in fisheries debris off northern Svalbard.

Introduction of non-indigenous species (NIS)

There are currently no reports of the presence of NIS in the ecoregion, although there also has been no dedicated NIS monitoring. At least 34 NIS have been observed in adjacent Arctic marine waters (Figure 4), as well as numerous cryptogenic species (having uncertain origin due to poor baseline data in the Arctic and/or poorly studied biogeography and taxonomy of microscopic marine species). Ship biofouling and natural currents are the most likely mechanisms for the introduction of NIS to the ecoregion. Receding sea ice and warmer waters are expected to increase and facilitate both the transport and establishment of NIS in the ecoregion.

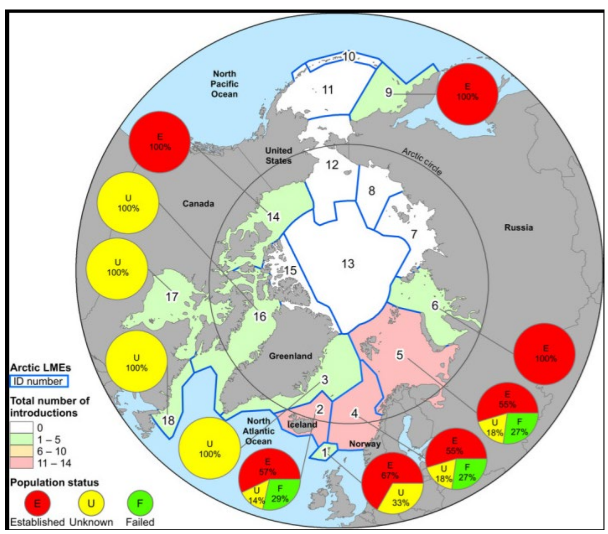

Figure 4 Map illustrating the large marine ecosystems (LMEs) of the Arctic as defined by the Arctic Council's Protection of the Arctic Marine Environment Working Group (PAME, 2013; Chan *et al.*, 2019). ID numbers: 1 = Faroe Islands, 2 = Iceland Shelf, 3 = Greenland Sea East-Greenland, 4 = Norwegian Sea, 5 = Barents Sea, 6 = Kara Sea, 7 = Laptev Sea, 8 = East Siberian Sea, 9 = East Bering Sea, 10 = Aleutian Islands, 11 = West Bering Sea, 12 = Northern Bering Chukchi Sea, 13 = Central Arctic Ocean, 14 = Beaufort Sea, 15 = Canadian High Arctic-North Greenland, 16 = Canadian East Arctic-West Greenland, 17 = Hudson Bay, and 18 = Labrador-Newfoundland. Also shown are the total number of introduction events (n = 54) and the population status of NIS in each introduced region.

Underwater noise

The main human sources of underwater noise in the ecoregion are ship traffic and the seismic surveys used in oil and gas exploration; these often propagate noise into the ecoregion from adjacent areas. Powerful military sonars operate in Arctic waters although their use is not publicly documented. These sonars are known to cause extensive disturbance to many species of deep-diving whale and have led to mass strandings.

Sound propagates very well in Arctic waters, and the effects (e.g. behavioural disturbance and the masking of other ecologically important sounds) of such sound can occur many hundreds of kilometres away. There has been limited measurement 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.

Climate change impacts

Observed climate-related changes include decreases in sea ice extent and thickness, salinity and freshwater content affecting water column stratification, and the relative contributions/mixing of North Atlantic and North Pacific water masses in the ecoregion, as well as subregional increases in seawater temperature. These come with associated changes in the distribution and abundance of species, with implications for foodweb structure and dynamics.

A reduction in the extent and thickness of sea ice is the prevailing climate change signal in the ecoregion. Sea ice extent has dramatically diminished in the past decades, leading to an increase in the seasonal duration of open water in the ecoregion (Figure 5). The mean summer minimum of sea ice extent in 2007–2020 was much lower than in 1979–2000 ($4.6 \pm 0.5 \times 10^6$ km^2 and $6.9 \pm 0.5 \times 10^6$ km^2, respectively [figures 5 and 6]). Old sea ice (> five years) decreased from 30% to 2%, while first-year ice increased from 40% to 70% between 1979 and 2018. Mean sea ice thickness declined by 65% (from 3.59 to 1.25 m) between 1975 and 2012.

Receding ice has already led to significant changes in both the range and abundance of species in and around the ecoregion, from primary producers to top predators. Primary productivity has increased in areas associated with the loss of summer sea ice. A reduction in multiyear ice and increase of first-year ice has led to a decline in sympagic algal diversity. Models suggest future increase in sympagic algal productivity because of the thinning of sea ice and enhanced light availability but also limitations by nutrients and ice as a substrate. Sea ice reduction and increasing water temperature were suggested to negatively influence polar cod recruitment in the adjacent Barents Sea. Seabirds and marine mammals that depend on sea ice for habitat and/or food are negatively affected for key processes like reproduction and rearing. The feeding migration of young ringed seals has expanded into the ecoregion over the past decades, concurrent with the sea ice retreat. As sea ice cover heavily influences ambient noise levels both directly (e.g. cracking and vibration) and indirectly (e.g. by limiting shipping activity), the rapid changes in ice conditions also have implications for ambient noise levels.

Since 2000, the stratification in the Eurasian Basin has been reduced, potentially altering nutrient fluxes and primary production. In the Amerasian basin, a stronger influx of Pacific waters has increased heat and freshwater content in the Beaufort Gyre and facilitated the expansion of Pacific species into the ecoregion. The increased seasonal duration of open water is expected to enhance primary production around the basin with subregional differences caused by changes in stratification that affect nutrient availability.

As a potential Arctic refuge, the ecoregion may experience at least short-term increases in the occurrence and abundance of both Arctic and boreal species that are capable of long-range dispersal. Some pelagic fish that occur in adjacent areas like beaked redfish (*Sebastes mentella*), Atlantic herring (*Clupea harengus*), Atlantic mackerel (*Scomber scombrus*), and Atlantic Capelin (*Mallotus villosus*) may eventually extend their summer feeding migrations into the ecoregion. Ice-dependent fish and marine mammals are experiencing increased competition from boreal species in and around the ecoregion. There is evidence of the occurrence of unusually large abundances of Atlantic cod (*Gadus morhua*) and other boreal species in the adjacent area (the Atlantic Gateway), which has likely contributed to the decline of polar cod and other Arctic fish species. The long-term success of species' northward migration strategy will depend on the continued availability of key habitat, nutrients, and prey. For example, the distribution, behaviour, and fitness of sympagic species, such as the ivory gull (*Pagophila eburnean*), are strongly affected by declines in sea ice and associated prey. Bioenergetic modelling suggests that 24 Arctic-breeding seabird species may shift to year-round High Arctic residency.

Increasing freshwater input also leads to the enhanced delivery of terrestrial materials – including carbon, hazardous chemicals, methane, viruses, and bacteria – into the Arctic seas. Permafrost thaw is an important, warming-induced pathway for contaminants such as POPs and mercury into the Arctic Ocean.

Climate change is creating opportunities for the development and expansion of various human activities in the ecoregion. Ship traffic is currently very 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 due to liquid natural gas (LNG[1]) and crude oil transport, as well as trans-Arctic cargo shipping along the Northern Sea Route (NSR). Geoengineering surveys also 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 hazardous materials and the introduction of NIS.

At present, there are no indications that commercially exploitable fishery resources exist in the ecoregion. With receding ice, exploratory fishing is expected to occur in accessible slope and shelf waters inside the EEZs of the coastal states.

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 interest exists for oil exploration in many of the shelf areas surrounding the ecoregion.

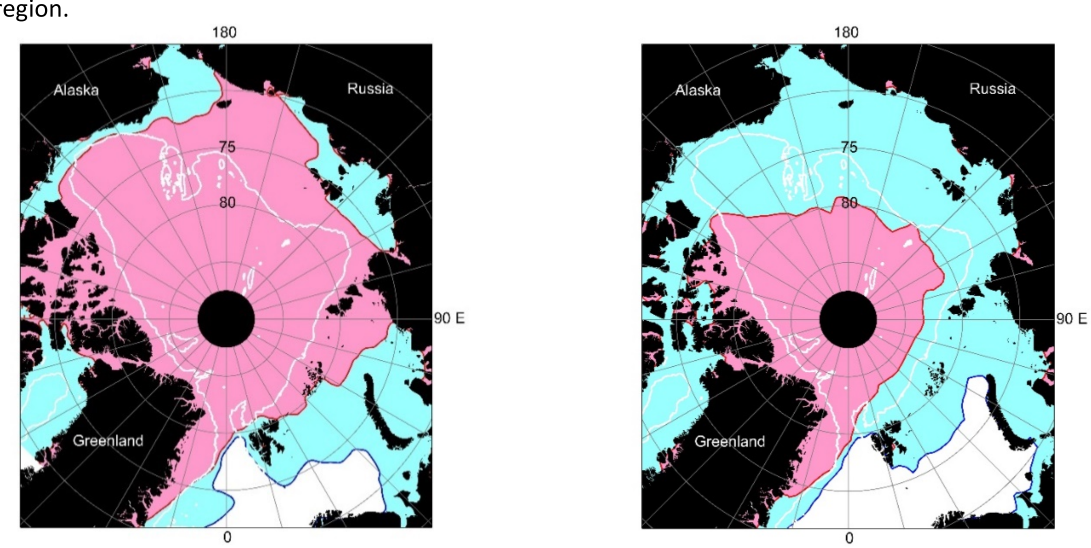

Figure 5 Sea ice extent (the border of 15% ice concentration) in the Arctic Ocean in 1979–2000 (left panel), and in 2012 (right panel). The pink area corresponds to the seasonal minimum in September. The blue area corresponds to the seasonal maximum in March. The white line denotes an isobath of 1000 m, which may be considered a rough approximation of the border of the Central Arctic Ocean.

[1] "Liquid natural gas" is originally extracted as a natural gas (CH4), processed into liquid form by the Yamal LNG Factory (Novatek) in Yamal Peninsula, and transported by liquid natural gas tankers.

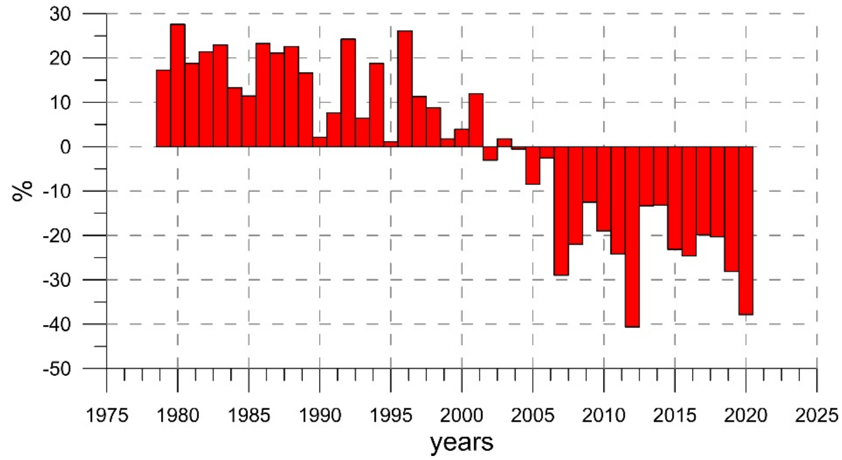

Figure 6 Anomaly of the minimum distribution of the Arctic sea ice extent (the border of ice concentration less than 15%) in September (%) relative to the average for the period of satellite observations (1979–2020).

State of the ecosystem

Habitats (substratum) and foodwebs

Sea ice is a key habitat feature of the ecoregion. Sea ice coverage and associated ice algal production is a determinant of foodweb structure and functioning in the Central Arctic Ocean. There are ongoing disruptive changes in ice-associated habitats and their biogeochemical processes, with increased productivity on the shelves supporting the growth of pelagic zooplankton species over sympagic invertebrates and a mismatch between primary producers and consumers in the basins affecting trophic and passive carbon flux. These changes are anticipated to have negative impacts for sympagic species and biodiversity.

Benthic habitats 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. Most are generally unaffected by local human activity but may serve as a sink for pollution from global sources.

Primary productivity

The ecoregion is an oligotrophic system with a strong seasonal variation in primary production. The average total annual primary production of the ecoregion basins is low, about 13 gC m^{-2} y^{-1}, with the sympagic algae accounting for about half of this production. The nutrient rich shelves have higher productivity (> 70 gC m^{-2} y^{-1}). Primary productivity has increased with the loss of summer sea ice.

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, earlier spring blooms and enhanced under-ice blooms.

Zooplankton

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. 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.

Sympagic crustaceans (mainly ice amphipods) and meiofauna living inside sea ice brine channels largely depend on organic carbon synthesized by sea ice protists. 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.

The core distribution patterns of *C. glacialis* and *C. finmarchicus* are shifting northwards with retreating sea ice and changing climatic conditions. With less sea ice, zooplankton may ascend earlier to surface waters to match earlier algal blooms, with extended pelagic production anticipated to favour all Calanus species.

Benthic invertebrates

The benthic invertebrate fauna of the ecoregion reflects the diversity of benthic habitats. It includes: sponges and the associated benthic biota of seamounts, ridge fauna (including chemoautotrophs), fauna 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. A 2011 benthic species inventory from various data sources for the central Arctic (existing at depths of greater than 500 m) identified more than 1125 taxa. The inventory was dominated by arthropods (366 taxa), foraminiferans (197), annelids (194), and nematodes (140).

The benthic community structure differs among the upper and lower slope, the basin, and the adjacent shelf seas. Observations in the Chukchi Borderland indicate a decrease in taxon richness, biomass, and density of epifauna with increasing depth.

Status and trends of benthic communities are generally lacking within the ecoregion.

Fish

Knowledge about the fish community in the ecoregion is virtually absent. Small gadoids (mainly polar cod and Arctic cod *Arctogadus glacialis*) are found in ice covered areas within the ecoregion, and eelpouts (Zoarcidae) have been observed associated with the seabed. An acoustic layer that may contain fish taxa has been recorded at mesopelagic depths in parts of the ecoregion.

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, with the possible exception of ivory gulls.
There are strong signals that some Pacific seabirds are shifting their distribution northward, remaining longer along the ecoregion slope regions during summer and changing their migration patterns.

Marine mammals

During periods of year-round ice coverage, observations of marine mammals in the Central Arctic Ocean ecoregion 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. 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.

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. 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.

Sources and acknowledgements

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The ICES/PICES/PAME Working Group on the Integrated Ecosystem Assessment for the Central Arctic Ocean (WGICA) contributed to the main sections of this overview.

The maps and figures in this document are produced as follows:

Figure 1: Produced by ICES Secretariat, Data used stems from:

- Exclusive Economic Zones. Marineregions.org (VLIZ).
- Depth contours. General Bathymetric Chart of the Oceans (GEBCO).
- Ecoregions. International Council for the Exploration of the Sea (ICES).
- Ports. Norwegian Institute of Marine Research (IMR).
- ICES areas. International Council for the Exploration of the Sea (ICES).

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Figure 3: Produced by ICES Secretariat.

Figure 4: Reproduced, with permission, from Chan *et al*., [2019].

Figure 5: Based on data from Cavalieri *et al*., [1996], updated yearly.

Figure 6: Based on data from https://nsidc.org.

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