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EDITED BY
Pierre Pepin,
Fisheries and Oceans Canada (DFO), Canada

REVIEWED BY
Jan Marcin Weslawski,
Polish Academy of Sciences (PAN), Poland
Simon Jungblut,
University of Bremen, Germany

*CORRESPONDENCE
Ole Arve Misund
✉ ole.arve.misund@npolar.no

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Area-based management in polar oceans for biodiversity conservation and enhanced sustainability of fisheries

Ole Arve Misund[1,2]*, Haakon Hop[1] and Cecilie von Quillfeldt[1]

[1]Norwegian Polar Institute, Fram Centre, Tromsø, Norway, [2]UiT The Arctic University of Norway, Tromsø, Norway

The Polar areas of the Arctic and Antarctic are the coolers of the world. In the Arctic there is floating sea ice covering the more than 4,000 m deep central Arctic Ocean surrounded by islands like Greenland with a thick ice sheet, and Svalbard and other high-Arctic Islands with glaciers. Antarctica is a large continent (about 14.2 mill. km^2) with a huge ice sheet, and seasonal sea ice in the surrounding, more than 4,000 m deep, Southern Ocean. The shallow marginal seas like the Barents Sea and the Bering Sea, are influenced by relatively warm, nutrient-rich sea currents, with associated plankton, from lower latitudes and therefore very productive. In the European Arctic there are rich fisheries in salmonids, clupeoids, gadoids, and crustaceans. The circulation of the Southern Ocean is dominated by the strong Antarctic Circumpolar Current, and there is a high abundance of plankton, krill, fish, seabirds, penguins, seals, and whales. The large Antarctic krill resources are subject to a fishery limited to about 600,000 tons annually. Through the working groups PAME and CAFF of the Arctic Council there are ongoing processes for area-based management in Arctic waters. In the territorial waters of the Arctic nations, many examples exist of different categories of Marine Protected Areas (MPA) with different degrees of protection. For the central Arctic Ocean there is an agreement from 2021 of no fishing for the next 15 years until the potential resources in the area has been properly mapped and assessed scientifically. In the Barents Sea, there is a system of temporary real-time closures of large areas for Danish seining and bottom trawling to protect juvenile fishes. The Antarctic Treaty, the Environment Protection Committee, and the Convention of Conservation of Living Marine Resources have been backdrops for ongoing processes to further develop area-based management in the Southern Ocean. Just two marine protected areas are established, but there are several Antarctic Specially Protected Areas (ASPA) and Antarctic Specially Managed Areas (ASMA), both which may have marine components. There are also proposals for several new MPAs. Recently, large areas in the Weddell Sea were discovered to be spawning habitats for icefish (*Neopagetopsis ionah*). This species lay fertilized eggs in a nest on the bottom substrate, and guard them until hatching. Any kind of active bottom fishing gears or other bottom gears would easily disturb and destroy their habitats. Thus, such areas need protection to conserve vulnerable biodiversity.

KEYWORDS

Arctic, Antarctica, area-based management, marine protected areas, biodiversity, conservation, sustainable fisheries

1 Introduction

The Arctic and the Antarctic circumpolar regions are the coolers of the world. Geographically, the polar regions of the world are generally defined by the Arctic being the area north of the Arctic Circle at about 66 ° 34′ N and Antarctica the area south of the Antarctic Circle at 66 ° 34′ S. Yet there are several other functional definitions of the Arctic related to the July 10 °C isotherm, the tree line or the extent of permafrost.

Both the polar regions have sea-ice cover. In the Arctic, there is drifting seasonal and multiyear sea ice covering the about 4,000 m deep Central Arctic Ocean surrounded by islands like Greenland with a thick ice sheet, and Svalbard and other high-Arctic Islands with glaciers. Antarctica is a large continent (about 14.2 mill. km^2) with a huge ice sheet, and mostly seasonal sea ice in the surrounding Southern Ocean. There are fundamental differences between the polar regions related to physical geography, oceanography, biodiversity, human presence and governance (e.g., Hunt et al., 2016; McCormack et al., 2021; Ingvaldsen et al., 2024). In both regions, there are areas with large marine production and substantial fisheries. In the Arctic, the most important fishery areas are in the marginal seas, such as the Barents and Bering seas. In the Antarctic, fisheries occur in the cold waters of the Southern Ocean, particularly around the subantarctic islands and in the Ross Sea (Collins et al., 2010; di Blasi et al., 2021).

The two polar regions are fundamentally different geologically and geographically. This has allowed for different degrees of evolution and diversification of species. The Arctic Ocean contains a relatively young, cold ecosystem, with multiyear, perennial ice cover for 700,000 years and persistent year-round ice cover a period after the last ice age, about 4–5,000 years ago (de Vernal et al., 2020; Jakobsson, 2020). The Antarctic system is much older, since the polar ice cap began to form about 33.6 million years ago, during the Oligocene epoch, as global climate cooled and Antarctica became isolated at the South Pole (Houben et al., 2013).

The different ages of these ecosystems have influenced the degree of adaptive radiation for fish species to survive and reproduce in cold ecosystem. The Arctic Ocean has an estimated 240 fish species, although only 85 of these are considered Arctic in a zoogeographic term, whereas the rest are boreal or widely distributed (Mecklenburg et al., 2011; Lynghammar et al., 2024). The Antarctic region contains a much larger share of endemic fishes, due to its long-term isolation, about 320 fish species, dominated by nothothenoids (Eastman and McCune, 2000). The Central Arctic Ocean is structured by inflow of warm water masses from lower latitudes, and consequently also compensating outflow of cold, polar water masses through the Bering-, Davis-, and Fram straits (Hunt et al., 2016). However, due to the more or less permanent ice cover and vertical stratification, the production in the Central Arctic Ocean is low (Polyakov et al., 2020). The rather shallow Arctic marginal seas like the Barents Sea and the Bering Sea are influenced by warm, nutrient-rich sea currents with advected plankton from lower latitudes, and are therefore very productive (Gerland et al., 2023).

The Antarctic continent is surrounded by a rather narrow, shallow coastal shelf that extends out to the Southern Ocean that is more than 4,000 m deep in some areas (Thompson et al., 2018). The circulation of the Southern Ocean is dominated by the strong Antarctic Circumpolar Current (ACC) with a strength of more than 100 Sverdrup, the strongest ocean current on the planet (Armitage et al., 2018). This current acts like a physical barrier that limits exchange and influence of lower latitude sea water masses in Antarctica (Hunt et al., 2016). There is a high degree of patchiness in both diversity and abundance in Antarctica, but generally the diversity of higher trophic levels is low in the seasonally ice-covered areas (Griffiths, 2010) and, likewise, in the more or less permanently sea-ice covered areas in the Arctic (Bluhm et al., 2011). In the marginal ice zone, i.e., where the sea ice melts, breaks up and withdraws during summer, at the ice edge and in coastal areas of polar areas, the production and the biodiversity are high with animals on both the sea ice and in the water (Eamer et al., 2013; CAFF, 2017). The benthic production and diversity are also higher near this margin because of the downward carbon export from the seasonal production (Wassmann and Reigstad, 2011).

In the European Arctic, there are rich fisheries in the Barents Sea for capelin (*Mallotus villousus*), herring (*Clupea harengus*), gadoids like cod (*Gadus morhua*), haddock (*Melanogrammus aeglefinus*) and saithe (*Pollachius virens*), and of crustaceans like shrimp (*Pandalus borealis*; Misund et al., 2016). During the last decades, fisheries for red king crab (*Paralithodes camtschaticus*) and snow crab (*Chinoecetes opilio*) have developed along the coast of Northern Norway and in the central Barents Sea (Norwegian Government, 2024; Fernandez et al., 2025; Hansen et al., 2025). In the North Pacific, there are rich fisheries for Alaska pollock (*Gadus calcogrammus*), pacific cod (*Gadus macrocephalus*), salmonids, red king crab and snow crab, particularly in the Bering Sea. Arctic fisheries in the eastern North Atlantic are managed through annual quotas recommended by ICES (2023), whereas the western Atlantic is managed by the Western Central Atlantic Fishery Commission (WECAFC), and the Bering Sea fisheries are jointly managed by The North Pacific Fishery Management Council (NPFMC) and NOAA Fisheries.

Antarctic fisheries are reviewed annually by the Commission for the Conservation of the Antarctic Marine Living Resources (CCAMLR) and agreed limits for the current fishing season are defined in Conservation Measures (http://www.ccamlr.org). This applies to the large Antarctic krill (*Euphausia superba*) stock, which in a rather limited area in the West Antarctica has been estimated to about 65 million tons. A fishing quota is issued annually to about 600,000 tons. Longline fisheries are also conducted for Patagonian toothfish (*Dissostichus eleginoides*) and Antarctic toothfish (*Dissostichus mawsoni*).

In times of climate change, these cold and remote polar areas are considered for conservation. Marine Protected Areas (MPAs) and Other Effective area-based Conservation Measures (OECMs) are important tools for biodiversity conservation (Maxwell et al., 2020). Similarly, there is an increasing recognition of marine protected areas and OECMs as effective tools for improving sustainability of fisheries.

In the following, area-based management in the polar regions for biodiversity conservation is outlined, with possible effects for enhanced sustainability of fisheries. Since these regions involve many nations, the governance of the regions is described.

2 Policy and practice review

2.1 Arctic governance

Eight countries have parts of their territory in the Arctic. This includes Canada, the United States, Russia, Finland, Sweden, Denmark (incl. The Faroe Islands and Greenland), Norway and Iceland. About four million people live in the Arctic. About 10% of these are indigenous populations like the Sami's in Norway, Sweden, Finland and Northwestern Russia, the Nenets in northern Siberia, and the Inuits in Alaska, Canada and Greenland. There are substantial economic activities related to energy resources (oil and gas), minerals, fisheries, shipping, tourism, and the traditional livelihood activities of the indigenous populations as hunting, gathering and reindeer herding. Both commercial and subsistence fisheries are conducted in different regions of the Arctic, although targeting different species. Commercial landings mostly include codfishes, redfishes (*Sebastes* sp.), capelin and Greenland halibut (*Reinhardtius hippoglossoides*), whereas subsistence fishery include anadromous salmonids, such as Arctic char (*Salvelinus alpinus*) to a greater extent as well as Greenland halibut (Harris et al., 2016; Hayashi and Delaney, 2024). Nations and unions that do not border the Arctic like China, the European Union (EU), South Korea and Japan are not directly involved in fisheries or resource extractions but have substantial interests in the Arctic related to shipping and research, and, thus, are active in Arctic affairs (Moe, 2016; Young, 2019).

The sovereign countries that constitute the Arctic or have interests in the Arctic cooperate on bilateral and multilateral levels through several international treaties and soft-law arrangements (Moe, 2016; Koivurova and Shibata, 2023). Generally, Arctic fisheries are managed nationally or bi- or multi-nationally through Regional Fisheries Commissions (RMFCs). To cooperate on fisheries research and management in the Northern Atlantic, 20 countries are members of the International Council for the Exploration of the Sea (ICES). In the Northern Pacific, the Arctic (Canada, Russia, USA) and near-Arctic states (China, Korea and Japan) cooperate on fisheries research and management through the North Pacific Marine Science Organization (PICES). An active arena for cooperation on environmental issues in the Arctic has been the soft-law agreement the Arctic Council (Koivurova and Shibata, 2023).

2.2 Antarctic governance

No countries have parts of their marine territories in Antarctica. However, seven countries claim territories on the Antarctic continent. These claims is "resting" as long as the continent is governed through the international community of the Antarctic Treaty (Memolli et al., 2024). The fundamental principle of the Antarctic Treaty, from 1959, is that the continent shall be used for peaceful activity only and freedom of scientific activity to the best of humankind. To be a signatory nation to the Antarctic Treaty, nations must have scientific activity on the continent. Twelve countries took part in the development of and signed the Antarctic Treaty that was ratified in 1961. These countries all had research activities and were present in Antarctica in the second geophysical year 1957–59. At present there are 58 signatories to the Antarctic Treaty of which 29 have consultative status, and 29 have non-consultative status being invited to the consultative meetings (http://www.ats.aq). There are no indigenous populations in Antarctica, but human presence on a rotation basis in the many research stations. Thus, scientific activities entail the most important permanent human presence in Antarctica, and no activity should have a substantial negative impact (Memolli et al., 2024). The Protocol for Environmental Protection to the Antarctic Treaty from 1991 designates Antarctica as a natural reserve devoted to peace and science and limits economic activity through prohibition of exploitation of minerals. The economic activities in Antarctica are related to fisheries for krill and toothfish, tourism (expedition cruises and land-based expeditions), and research support logistics (Memolli et al., 2024). Science is, therefore, given a preamble.

Antarctic fisheries are managed through the Convention for the Conservation of the Antarctic Marine Living Resources (CCAMLR) established in 1982. The objective of CCAMLR is to conserve Antarctic marine life, and an ecosystem approach is practiced. Harvesting is not excluded as long as it is carried out in a sustainable manner and effects on other components of the ecosystem are accounted for. The management decisions on annual quotas and other fishery-regulation mechanisms are based on independent scientific advice developed though the scientific committee of CCAMLR (Hughes et al., 2023).

The Scientific Committee for Antarctic Research (SCAR), established in 1958, is an active body to develop and organize scientific activities across countries which participate in Antarctic research. During the annual consultative meetings on the Antarctic Treaty (ATCM) and CCAMLR, SCAR informs about the scientific activities, important findings and independent, science-based policy advice (Hughes et al., 2023).

2.3 Biodiversity conservation

Overarching drivers like climate change, geopolitical tension and the need for resources ultimately put pressures on the polar areas in general and on vulnerable polar biodiversity and ecosystems in particular. Therefore, there is a recognized need to keep large parts of the polar areas protected from various human activities.

In the marginal ice zone and the coastal areas of the Arctic there is generally a high biodiversity in regions influenced by northwards-flowing, warm ocean currents with advected organisms. In colder areas of the Arctic coast there can still be high biodiversity, but the diversity of middle- and upper tropic level species are somewhat lower (Hunt et al., 2006; Bluhm et al., 2011). Abundant pelagic fish species, such as polar cod (*Boreogadus saida*) and capelin, have keystone functions in Arctic and sub-Arctic food webs, respectively (Welch et al., 1992; Hop and Gjøsæter, 2013). An equivalent midtrophic fish feeding mode in the Antarctic system would be that of the Antarctic silverfish (*Pleuragramma antarctica*; Carling et al., 2021). Humans are present all around the Arctic coasts and hunt seals, whales and in some areas also the polar bears (*Ursus maritimus*; Darnis et al., 2012; Moore and Stabeno, 2015). In some areas of the Arctic, it is prohibited to hunt polar bears, and rare species such as bowhead whales (*Balaena mysticetus*) and narwhals (*Monodon monoceros*), although subsistence quotas of these whales are taken by Inuits in Alaska, Canada and Greenland. To conserve marine biodiversity in the Arctic, MPAs and other area-based protection regulations have been established (CAFF/PAME, 2022; PAME, 2025).

The Arctic Council is the leading intergovernmental forum promoting cooperation, coordination, and interaction among the Arctic States, Arctic Indigenous Peoples, and other Arctic inhabitants on common Arctic issues, particularly on issues of sustainable development and environmental protection in the Arctic (https://arctic-council.org). One of the main objectives of the Arctic Council is to further facilitate the protection of identified vulnerable Arctic areas through collaborative initiatives and directions. This is done through working groups and programs with experts from the eight Arctic countries. The Protection of the Arctic Marine Environment working group (PAME, https://www.pame.is) has been active since the 1990s on issues like Arctic shipping, marine litter, marine protected areas, ecosystem approach to management, and resource exploration and development. The Conservation of Arctic Flora and Fauna program (CAFF, https://www.caff.is) of the Arctic Council developed a strategy and an action plan to establish a circumpolar network of protected areas (PAME, 2013). The Circumpolar Protected Areas Network (CPAN) shall protect important and unique nature areas. In 2017, CAFF and PAME working groups created a joint indicator report that provides an overview of the status and trends of Arctic protected areas (CAFF, 2017; CAFF and PAME, 2017). The report catalogs the extent of protected areas across the Arctic and the trends regarding establishment of protected areas. According to an updated report, 5.2% of the Arctic's marine areas was fully protected in 2021 (CAFF/PAME, 2022). This is much less than on land where 20.8% of the terrestrial ecosystems is protected. The extent of protected areas on land has almost doubled since 1980, while the extent of protected and conserved areas in the marine environment of the Artic has increased almost five-fold during the same period (CAFF/PAME, 2022).

Totally, 935,788 km^2 of marine areas in the Arctic are protected and conserved (CAFF/PAME, 2022). These areas are distributed across the Arctic seas, and are found off Alaska and in the Beaufort Sea, off the Siberian Coast, around Franz Josef Land, around Svalbard, Bear Island and Jan Mayen, along the coast of northeastern Greenland, in the Labrador Sea and in and around of the Canadian High Arctic Archipelago (Figure 1). Several of the marine MPAs are large, such as the area north of the Canadian High Arctic Islands.

The Parties to the United Nations Convention on Biological Diversity (CBD) adopted in 2010 the Aichi Biodiversity targets of 10% conservation of marine areas and 17% of terrestrial and inland water, especially areas of particular importance for biodiversity and ecosystem services by 2020 (https://www.cbd.int/sp/targets). In 2022, CBD raised these targets to 30% effectively conserved and managed areas through ecologically representative, well-connected and equitably governed systems of protected areas and other effective area-based conservation measures by 2030 as part of the Kunming-Montreal Global Biodiversity Framework (https://www.cbd.int/gbf).

Since the early 1970s, Norway has established national parks and nature reserves in Svalbard to protect the characteristic nature, cultural heritage sites, vulnerable biodiversity and nature itself. About 66% of the land area of the Svalbard archipelago is protected through these measures and 88% of the territorial waters around the Svalbard archipelago (Meld. St. 26, 2023–2024). The marine part of the natural parks and nature reserves in Svalbard and on the island of Jan Mayen are formally regarded as MPAs in the Oslo-Paris Convention (OSPAR; https://www.ospar.org).

As the sea ice on the Arctic Ocean diminishes and the waters become more open and accessible, there is a concern that unregulated fisheries may develop. In Illulisaat, Greenland in 2018, Canada, Denmark (incl. Greenland and the Faroe Islands), China, the EU, Iceland, Japan, South Korea, Norway, Russia, and the United States agreed that the high-seas area in the Central Arctic Ocean should not be opened for fishing until sufficient knowledge about the marine ecosystem and possible fish resources were acquired. The Central Arctic Ocean Fisheries Agreement (CAOFA) was ratified in 2021 and is valid for the following 15 years (Vylegzhanin et al., 2020).

In the Southern Ocean, there is a high abundance of phytoplankton, zooplankton, krill, fish, seabirds, penguins, seals, and whales (SoE, 2011). Primary production is limited by low concentrations of iron (Moreau et al., 2023), however. Krill is the dominant food source for fish, seabirds, penguins and whales (Merkel et al., 2023). The top predators are the killer whale (*Orcinus orca*), the leopard seal (*Hydrurga leptonyx*), and partly also the elephant seal (*Mirounga angustirostris*). On land, there are no animal predators. The South Polar skua (*Stercorarius maccormicki*) takes the snow petrel (*Pagodroma nivea*) and Antarctic petrels (*Thalassioca antarctica*) and especially the eggs and chicks in the bird cliffs on the coast. To conserve biodiversity in Antarctica, only two Marine Protected Areas (MPA) have been established (Figure 2), but there are many areas designated as research blocks, management areas and small-scale research units with fishing restrictions. However, plans for several more Antarctic MPAs are ongoing (Liu, 2018; Boothroyd et al., 2024a,b). An overview of the proposals for new Antarctic MPAs in the Ross Sea, in East Antarctic, the Weddell Sea, and off the Antarctic Peninsula is provided by Brooks et al. (2021).

The Antarctic Treaty limits activity and resource exploration and exploitation (https://www.ats.aq). The Environmental Committee (CEP) follows the development of the Antarctic environment, considers closely how it is influenced by human activities and provides for the designation of Antarctic Specially Protected Areas (ASPA) and Antarctic Specially Managed Areas (ASMA; https://www.ats.aq/e/protected.html), of which some have a marine component. According to CEP "An area of Antarctic may be designated an ASPA to protect outstanding environmental, scientific, historic, aesthetic or wilderness values, any combination of those values, or ongoing or planned scientific research. An area where activities are being conducted or may be conducted in the future may be designated as an ASMA, to assist in the planning and co-ordination of activities, avoid possible conflicts, improve co-operation between Parties or minimize environmental impacts."

FIGURE 1
Marine protected areas in the Arctic classified according to their IUCN Management Category, 2021 (from CAFF/PAME, 2022). Areas in the unclassified category have not been formally assigned to IUCN Protected Areas Management Category, or OECMs that are not subject to IUCN Protected Areas Management Categories (with courtesy from the CAFF Secretariate in Akureyri, Iceland).

Of the two established marine protected areas, the Ross Sea region Marine Protected Area (RSrMPA) is the largest of its kind in the world (Brooks et al., 2021) covering altogether 2.09 million km^2 (https://cmir.ccamlr.org/node/1). This MPA is divided into a general protection zone, a special research zone, and a krill research zone (Figure 2). Biodiversity and marine ecosystem conservation are the main goals for the establishment of the RSrMPA, and fishing is prohibited in much of the area.

2.4 Sustainable fisheries

Worldwide fish stocks were subject to overfishing as fisheries became industrialized, and more so with technological advances in the latter part of the twentieth century. Since then, much effort has been attributed to develop more sustainable fisheries by annual quotes based on independent scientific advice, minimum fish-size limits, gear restrictions, reporting of fishing activities and control and inspection of fishing vessels and landings. The scientific

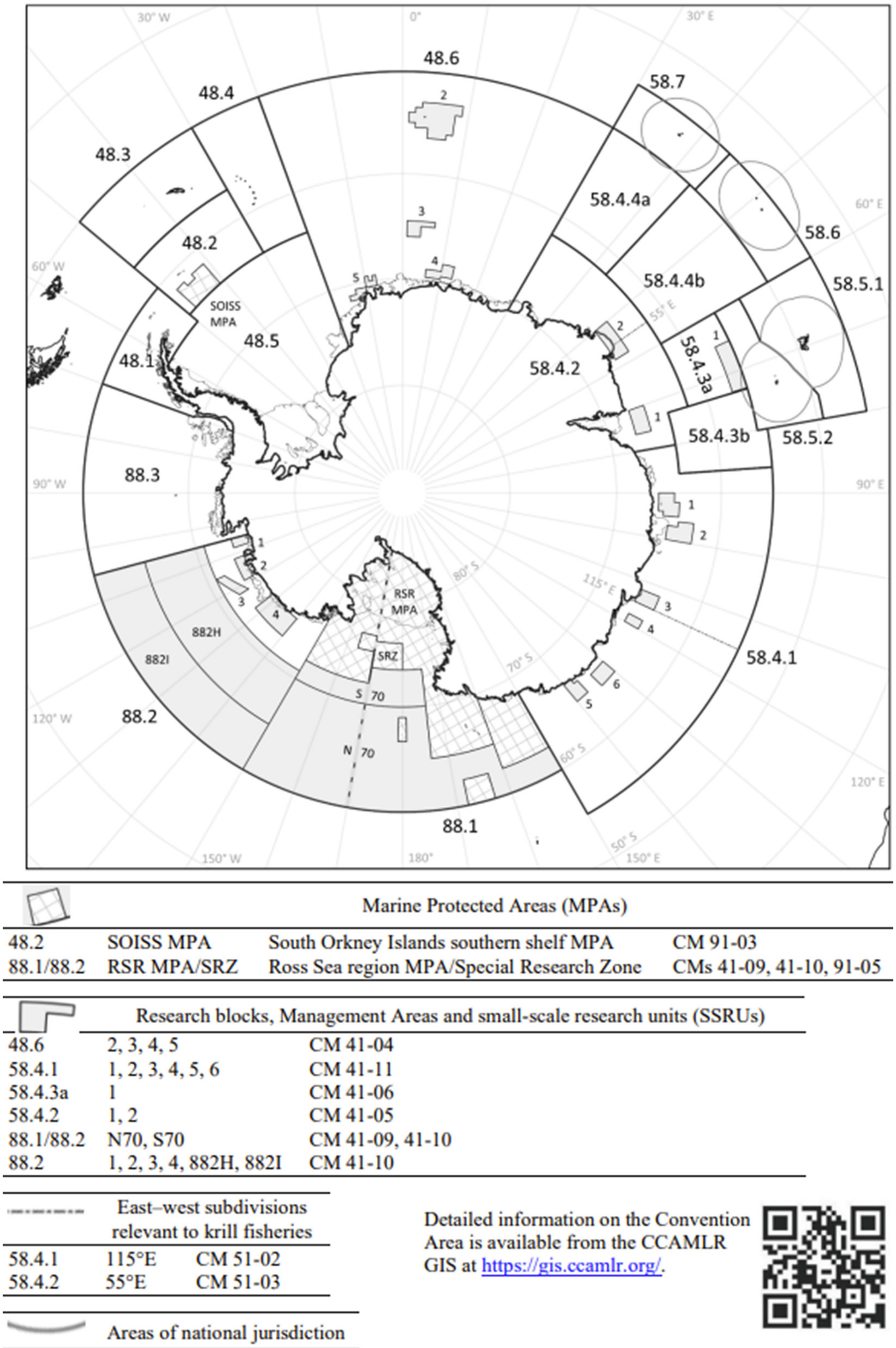

FIGURE 2
Antarctica and the CCAMLR statistical areas. The established MPAs are also shown.

advice is based on assessment models using data from independent scientific surveys combined with information on catches (Fréon and Misund, 1999). In more advanced cases, the assessments have incorporated precautionary measures, harvest control rules and ecosystem considerations (Gullestad et al., 2014). For larger commercially-important fish stocks in the polar regions, MPAs and OECMs have not been developed with the aim of improving sustainable fishing.

Nevertheless, there are important area elements in the management of fisheries in polar regions to improve sustainability of fisheries. Since the mid-1980s, a Real Time Closure (RTC) program has been developed for the Barents Sea fisheries (Gullestad et al., 2015). The purpose of the RTC program is to protect juvenile fish from beeing caught before reaching their minimum landing size, and in addition reducing the fishing pressure on fish populations with a critically low population size like the redfish. The RTC program is financed by the fishing industry, at first through an annual quota assigned for operating the program, and since 2014 through an annual fee on first-hand sales of fish. The program is operated by the Directorate of Fisheries' Sea Surveillance Service in Tromsø. Commercial vessels are charted annually to investigate fishing grounds where the fishing fleet is operating and with trained inspectors onboard. According to certain criteria, large areas can be rapidly closed for fishing based on the results from the charted vessel (Figure 3). In the Northern shrimp trawl fishery, the criteria is a limit of maximum number of juvenile fish per 10 kg of shrimp caught. Specifically, if there are more than 8 juvenile cod, 20 juvenile haddock, 3 juvenile redfish, or 3 juvenile Greenland halibut per 10 kg shrimp. In the trawl fisheries targeting cod, haddock, and saithe (*Pollachius virens*), the criterion is up to 15% juvenile fish in numbers. For the Barents Sea winter fishery for capelin using pelagic trawls or purse seine, there is a criterion for how much cod per catch of capelin, and similarly a criterion for how many redfish can be caught in directed fisheries for cod.

In addition to the Barents Sea temporary closures, there has been a substantial improvement in the species and size-selectivity of the Barents Sea trawl fisheries for shrimps and the gadoids by introduction of the size-selective, co-called "Nordmøre" sorting grid, in shrimp trawls (Isaksen et al., 1992; Larsen et al., 2022) and the size-selection grids in bottom trawls for the gadoids (Larsen and Isaksen, 1993).

More recently, regulations with a view to protecting vulnerable marine ecosystems have been introduced by the Directorate of Fisheries, Norway. The regulations apply when fishing with bottom gear in Norway's territorial waters, Norway's economic zone including the fishing zone around Jan Mayen and the fish protection zone around Svalbard. This has involved the closure of 10 zones to fishing with gear that touches the bottom, and the introduction of defined new fishing areas, within which fishing is only permitted if a special permit has been applied for and granted (Figure 3).

The Barents Sea fish stocks are shared and managed jointly by Norway and Russia through the Norwegian Russian Fisheries Commission. There is a common understanding that protection of juvenile fish is a central element in sustainable fisheries management (Misund, 2025). Discarding of juvenile fish is prohibited by law in both countries (Gullestad et al., 2015). Restrictions regarding minimum landing sizes, mandatory use of sorting grids in bottom trawls and the criteria and procedures for RTC in the Barents Sea fisheries are discussed and jointly agreed in the Norwegian Russian Fisheries commission.

Over the years, the effect of the temporary closures and the development of more species and size-selective trawl fisheries have been important in the development of the large Northeast Arctic cod stock (i.e., a management name for Atlantic cod) in the Barents Sea. From the late 1940's the mean age of cod at landing decreased from 7.8 to 5.3 years in the mid 1970s and then increased gradually to 6.8 years in the early 2010s. The corresponding average weight at landing decreased proportionally from 3.2 kg in the late 1940s to 1.8 kg only in the mid 1970s and then increased gradually again to 3.3 kg in the early 2010s. Gullestad et al. (2015) concluded that the 1.5 years increase in mean age at landing has given an 18% increase in total yield, provided that all other factors (i.e., natural mortality, annual growth rate) influencing the fish population have been equal.

As was the case in other productive waters, Antarctic fish stocks were overfished in the 1960–1970s (Aronson et al., 2011). Through the establishment of CCAMLR in early 1980s and the relatively strong fishery regulations executed by the convention, Antarctic fisheries are now quite sustainable, even if many of the demersal fish population are still at a much lower biomass level due to overfishing. Among the strong fishery regulations imposed by CCAMLR are the prohibition of bottom trawling or operation of fishing gears that interacts and impact the bottom. This is primarily a gear-regulating mechanism, but with a strongly imbedded area-limiting element.

In Antarctica, there is also a certain area element in the management of the large fishery for Antarctic krill (Constable et al., 2000; Constable and Nicol, 2002). This is done to prevent local depletion of krill in areas where penguins and other krill predators are dependent of krill as their main food source. At present, CCAMLR issues a total quota of Antarctic krill of 5.61 mill. tons in the statistical areas 48.1–4, but until the Commission has defined smaller management units, the total catch in statistical areas 48.1–4 shall be limited to 620,000 tons (CCAMLR, 2024b). The necessity of the area-based regulation of the Antarctic krill fishery is underlined by knowledge on the interaction with krill and its predators (Freer et al., 2025).

2.5 Discussion

The existing MPAs in the polar regions are established primarily to conserve biodiversity and vulnerable marine ecosystems. We are still far from achieving the CBD target of conserving 30% of the polar marine areas. However, substantial OECMs have been established to improve the sustainability of Arctic fisheries, as the RTC system operated in the Barents Sea that also helps biodiversity conservation. Even if the OECMs may help biodiversity conservation as a side effect, the protection mechanisms in OECMs are not strong enough to regard these kinds of area-based regulations as proper MPAs.

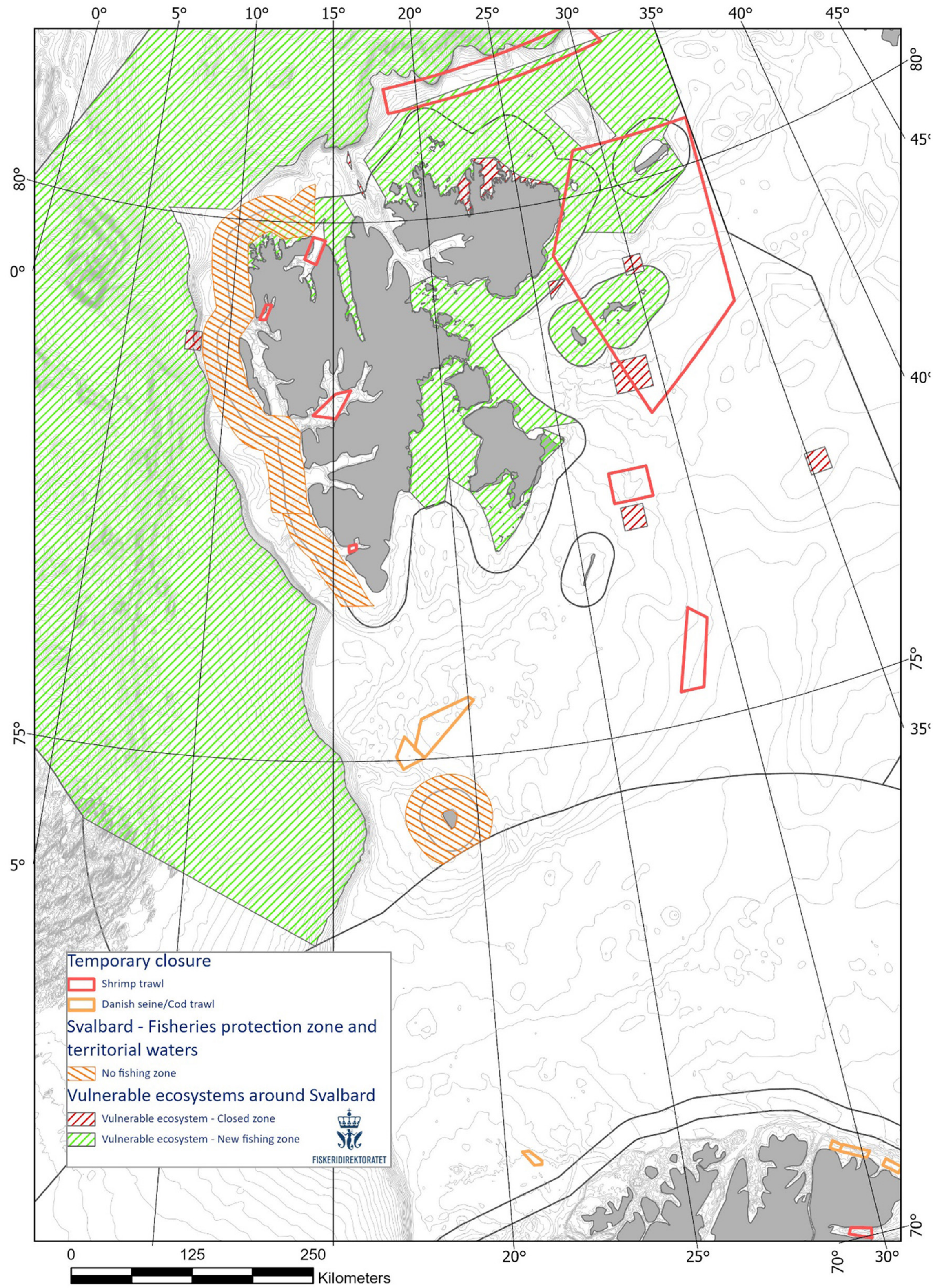

FIGURE 3
Areas closed for Danish seine fishing, and bottom trawling for cod and shrimp off the Norwegian Coast, in the Barents Sea and near Svalbard regulated trough the Real time Closure system as of May 2025. The No Fishing Zone in the territorial waters around Svalbard, and the Closed Zone in Vulnerable Ecosystems around Svalbard are also drawn. (with courtesy from the Directorate of Fisheries, Norway).

FIGURE 4
Male polar bear with a seal prey on a tall ice ridge at N88 ° 40′ observed from RV *Kronprins Haakon* in July 2022 (photo Kay Jørgensen).

2.5.1 Arctic area-based management considerations

In Arctic waters, there is a need for large MPAs if the 30% conservation target of marine areas should be aimed for. A potential candidate area that could be considered as a possible marine MPA in the Arctic is the CAOFA—area in the Central Arctic Ocean. Recent expeditions with icebreakers drifting along with the sea ice or icebreaking research vessels surveying the Central Arctic Ocean have shown that there is very little fish off the continental shelf in the European sector of the Central Arctic Ocean (Snoeijs-Leijonmalm et al., 2021, 2022; Ingvaldsen et al., 2023; Misund et al., 2025). Just sporadic catches of a few Atlantic cod and polar cod have been taken (Snoeijs-Leijonmalm et al., 2022; Ingvaldsen et al., 2023). However, polar cod associated with and seeking shelter in caves and structures in the sea ice are distributed all over the Central Arctic Ocean (David et al., 2016; Maes et al., 2025). The nations that agreed on the CAOFA declaration, which was ratified in 2021, implies that the area should be closed for fishing until 2036. The Marginal Ice Zone with seasonal ice-cover over the deep Arctic Ocean and the multiyear ice of the Central Arctic Ocean, are candidates for EBSAs (Ecologically or Biologically Significant Marine Areas in need of protection in open ocean waters and deep-sea habitats) in the Arctic (CBD, 2014). The High Seas of the Central Arctic Ocean has also been identified as worthy of additional data collection, analysis and consideration as having potential OUV (Outstanding Universal Value; Speer et al., 2017). OUV is what underpins the World Heritage Convention, a legally-binding international agreement focused on identifying, protecting, and preserving cultural and natural sites of outstanding universal value. It establishes a framework for international cooperation to safeguard these sites for present and future generations (https://whc.unesco.org/en/convention/).

Despite no fish resources of commercial value, the Central Arctic Ocean is a valuable habitat for several rare and endangered species like polar bear, narwhal and bowhead whale. The polar bears (Figure 4) use sea ice to move between high-Arctic Islands and even continents. Narwhals and bowhead whales (Figure 5) are found distributed in the leads in the sea-ice covered margins of the area (Vacquié-Garcia et al., 2017). Thus, to minimize anthropogenic-generated disturbances of the species in this remote area, the Central Arctic Ocean could be considered a candidate for a large high seas MPA. We are not the only ones thinking that this remote area could be considered for special protection in the years to come. While assembling the final part of this manuscript, the authors were contacted by a group of Arctic scientists asking for our signatures on an international campaign letter arguing for the protection of the Central Arctic Ocean.

2.5.2 Antarctic area-based management considerations

In Antarctica, there are several proposals for establishing new MPAs (Figure 6; Boothroyd et al., 2024a,b). One example

FIGURE 5
Bowhead whale feeding at the ice edge north of Svalbard at N80 ° 4′ E11 ° 5′ on 7 July 2025 (photo: Kristoffer Misund).

is a proposed MPA in Kong Håkon VII Hav off Dronning Maud Land (DML) as a priority area for conserving marine biodiversity (CCAMLR, 2024a; Phase II Weddell Sea proposal in Figure 6). Norway and other CCAMLR members have been working on this since 2019. A dedicated cruise to collect new knowledge of the marine ecosystem from the area was conducted with the icebreaking research vessel RV *Kronprins Haakon* in 2019, and a compilation of knowledge of the seascape off DML has been published (Lowther et al., 2022) to support the proposal. The proposal has been discussed in CCAMLR but has so far not gained consensus, which is also the case for three other MPA proposals in CCAMLR (Figure 6).

Recently, large areas in the Weddell Sea were discovered to be spawning habitats for the notothenoid icefish (*Neopagetopsis ionah*; Purser et al., 2022). This species lays fertilized eggs in a nest on the bottom substrate, and guards them until they hatch. Any kind of active bottom fishing gears or scrapes would easily disturb and destroy the habitats of these fishes. This is a strong example of areas that need protection to conserve vulnerable biodiversity. It can be argued that through the CCAMLR convention such areas are already protected from bottom trawling and fishing gears that may destroy bottom habitats. Even if the OECMs may help biodiversity conservation as a side effect, the protection mechanisms in OECMs are not strong enough to regard these kinds of area-based regulations as proper MPAs. Vulnerable Marine Ecosystems

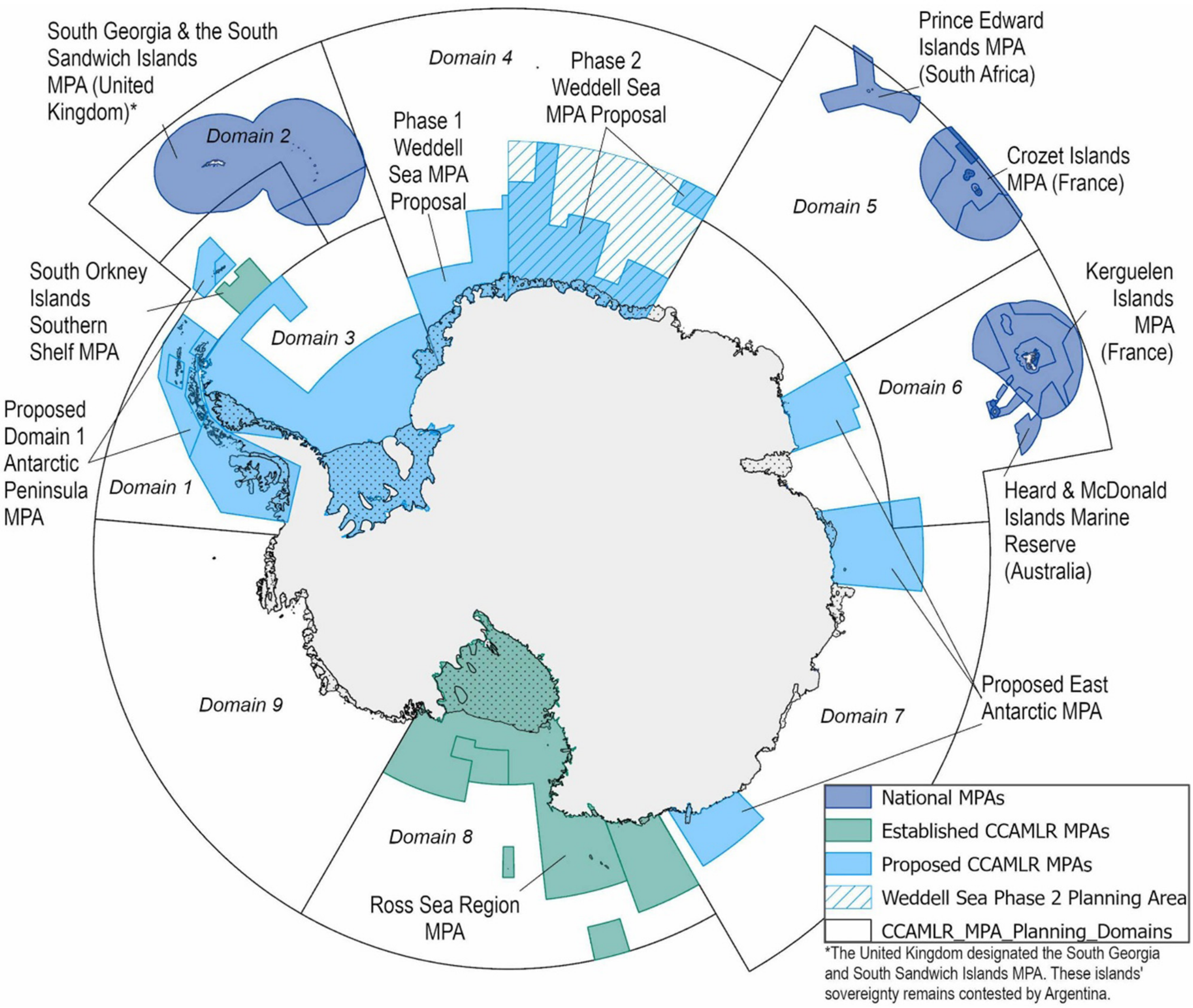

FIGURE 6
CAMLR Convention Area, showing the MPA planning domains, the existing CCAMLR MPAs, National MPAs, the proposed Weddell Sea MPA, East Antarctica MPA, Domain 1 (Antarctic Peninsula) MPA and the Domain 9 MPA planning region (after Boothroyd et al., 2024a,b). Planning domains: 1 = Western Peninsula-South Scotia Arc; 2 = North Scotia Arc; 3 = Weddell Sea Phase 1 and 2; 4 = Bouvet Maud; 5 = Crozet-del Cano; 6 = Kerguelen Plateau; 7 = Eastern Antarctica; 8 = Ross Sea; 9 = Amundsen-Bellingshausen.

(VMEs), originally recommended by the United Nations Open-Ended Informal Consultative Process on Oceans and the Law of the Sea (UNICPOLOS), has been adopted by CCAMLR (https://vmeregistry.ccamlr.org/). This suite of measures will restrict the distribution of bottom fisheries by closing areas to fishing, as well as those measures that have been specifically introduced to protect benthic communities. For example, finfish fishing is prohibited around the Antarctic Peninsula and the South Orkney Islands to protect finfish stocks that were depleted prior to the establishment of CCAMLR, although, pot fishing for crabs is permitted following a scientific research program. Bottom trawling in all high seas areas within the Convention Area has been prohibited along with a complete prohibition on the use of gillnets. The only current CCAMLR high-seas fisheries are pelagic trawling for krill, demersal longlines, and pots for crabs and finfish. For the latter gears, bottom fishing is prohibited in water shallower than 550 m around the entire Antarctic continent in order to protect shelf-based benthic systems. Such measure could become a basis for the establishment of future MPAs.

2.5.3 Climate change in the polar regions

For the Earth system, the polar regions are vital as the cooling parts of the world. With the accumulation of evidence for global climate change due to the release of greenhouse gases into the atmosphere, the warming of the polar regions and subsequent ice melting are growing concerns. Compared to pre-industrial global mean temperature average, there has been a 1.3 °C warming by 2023 (https://climateactiontracker.org/global/cat-thermometer/). Climate change is expected to affect these regions differently, with more rapid changes in the Arctic because of ongoing Atlantification, with warming of advected water masses and melting of sea ice (Polyakov et al., 2017, 2023). In the Arctic, climate change is already evident (Rantanen et al., 2022). The sea ice on the Arctic Ocean now covers just 60% of the area covered 40 years ago, and nearly 70% of the sea ice volume is lost in the same period (AMAP, 2017, 2025; Årthun et al., 2021; Stroeve et al., 2012). The sea ice has become younger and thinner. Due to the reduced albedo (i.e., effect caused by dark surfaces from more open waters and melt ponds), less radiation is reflected to the atmosphere and more heat is absorbed in the ocean.

The Antarctic marine system will respond much slower to global warming because of its isolation. From the substantial research effort in Antarctica, there is scientific evidence that the atmosphere and the Southern Ocean are warming, that there is a beginning acidification of the ocean (lowering of the pH level), that the cryosphere loose ice, and that sea level rise slowly because melting of ice on land (Chown et al., 2022). The Antarctic continent with its surrounding seas is large with regional differences in effects of warming. Thus, the effects of climate warming have been greater around the Antarctic Peninsula than in other regions of the Antarctic (Qu et al., 2012).

Warming will most likely continue to affect the global water cycle and lead to degradation of ecosystems and loss of biodiversity (Wassmann and Reigstad, 2011; Årthun et al., 2025). There are different scenarios for the projections of how global warming will develop according to the mitigation efforts that the world societies are able to develop and establish (Van Vuuren et al., 2008). In the Arctic Ocean, the biodiversity will likely increase with global warming because of an increased shift of boreal fish species to the Arctic (Kuletz et al., 2024), although Arctic keystone species, such as the polar cod, may dimmish because of loss of their cold-water habitats (Geoffroy et al., 2023). However, in the Antarctic and in the marginal seas, the loss of biodiversity because of a combination of climate warming and overexploitation will likely become more severe because of the larger number of endemic species and lack of life-cycle data for many of them (e.g., known spawning grounds).

2.5.4 Fisheries potential in polar regions

In the Arctic, the marine living resources are fully harvested at present. However, there are indications that increased open waters in the Arctic and Sub-Arctic may result in increased primary and secondary production (Wassmann and Reigstad, 2011). Therefore, biomass of some commercially-important fish stocks and new mix of species may become targeted (McBride et al., 2014).

On the coasts of central continents, there is a limit for how much can be produced and extracted. Possibly, more can be harvested and extracted from oceans, including polar areas. Traditional marine fisheries on the continental shelves and margins have leveled off at about 90 mill. tons., and many fish stocks are subject to overfishing (Hilborn et al., 2003). High seas fisheries, as many of those carried out in the polar regions, still play a negligible role in addressing global food security (Schiller et al., 2018). Further increase in harvesting of marine food resources must come from aquaculture or harvesting in the lower part of the marine food chain.

On the large Antarctic krill resources, with an estimated biomass of more than 65 mill. tons (Krafft et al., 2021), and subject to a rather limited fishery of about 600,000 tons annually, such a development may increase the drive for increased harvesting. Projections of the effects of climate change on existing species in the Southern Ocean are mixed and the potential for invasion of large and productive finfish species appears low (McBride et al., 2014).

2.5.5 Other factors influencing the polar regions

Increasing polarization and political tension in the world are affecting the polar regions. An increasing world population will be in need for energy, minerals and food resources, and the polar regions might become areas for exploitation and utilization. There are also speculations about the possibility of new transport routes between continents as the sea ice diminishes and the Arctic Ocean opens during the summer season. For many years the polar regions have been attractive for tourists, and the polar tourist industry is increasing both in the Arctic (Huntington et al., 2022; Varnajot and Lépy, 2024) and in the Antarctic (Liggett et al., 2011). These overarching drivers ultimately put pressure on the polar areas in general and on vulnerable polar biodiversity and ecosystems in particular. Therefore, there is a recognized need to keep large parts of the polar areas protected from various human activities.

2.6 Concluding remarks

The polar regions have become more connected to the rest of the world in the last decades through scientific activities, resource exploration and exploitation, and tourism. The resources needs of a growing world population imply increasing interest for the polar regions in the years to come. Currently, the polar regions are clearly impacted by ongoing climate change. Global temperature projections imply substantial impacts on the cryosphere leading to further ice melting on land and in the sea, loss of biodiversity and ecosystem changes. Urgent reductions of the discharges of greenhouse gasses are necessary, and there is a need for a "green shift" in the energy production of the world. However, such a shift should minimize environmental degradation. Therefore, the polar regions need special attention and a network of marine protected and conserved areas in the years to come. The nations of the world must intensify efforts to mitigate climate change and find ways to reduce geopolitical tension to be able to cope with the huge challenges ahead.

Author contributions

OM: Formal analysis, Methodology, Conceptualization, Funding acquisition, Writing – review & editing, Writing – original draft. HH: Writing – review & editing, Writing – original draft, Investigation, Supervision, Funding acquisition, Project administration. CQ: Writing – review & editing, Formal analysis, Resources, Supervision, Writing – original draft, Conceptualization.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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