The Second World Ocean Assessment

WORLD OCEAN ASSESSMENT II

Volume I

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Chapter 7K
High-latitude ice

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Keynote points

- High-latitude ice habitats are characterized by high, but geographically variable, declines in sea ice extent as a consequence of climate change.
- The loss of Arctic sea ice habitat and Antarctic ice shelves allows expansion of both pelagic and benthic species into the newly open water environments.
- In general, however, many ice-dependent species are decreasing in abundance and their spatial distributions may also be reducing, in particular in the Arctic.
- Decreasing sea ice extent in the Arctic provides increased opportunities for a range of human activities, including fishing, navigation and hydrocarbon exploration, with positive implications for several Sustainable Development Goals.[1]
- Many of those activities, however, will remain marginal for some time as a seasonally ice-free Arctic is not expected until later in the century.
- Decreasing sea ice will, however, reduce local community access to subsistence hunting opportunities.

1. Introduction

The present subchapter contains an update to chapter 46 of the first *World Ocean Assessment* (United Nations, 2017a). It also extends the coverage of high-latitude sea ice environments to include a discussion of habitats associated with icebergs and ice shelves. The subchapter overlaps with the high-latitude biodiversity aspects of many of the subchapters in chapter 6 of the present Assessment. However, in the present subchapter, the emphasis is on the use of marine ice habitats and interactions between organisms within those habitats. Furthermore, because high-latitude ice is intrinsically both a coastal and open ocean habitat, it interacts with several other habitats (e.g., benthic, open ocean and coastal-related habitats) that are covered in other subchapters of chapter 7 of the present Assessment.

The baseline state for the discussion of high-latitude ice habitats in the first Assessment (United Nations, 2017b) was one of massive and rapid change. That degree of change is, to some extent, intrinsic to the habitat itself, which experiences strong seasonal fluctuations between minimal ice coverage in high summer and maximal ice coverage in late winter. However, the mean sea ice habitat itself was altering dramatically, with ice extent, ice thickness and mean ice age all declining rapidly in the Arctic. In the Southern Ocean, change in the sea ice habitat was less notable, although several ice shelves on the Antarctic Peninsula had collapsed over previous decades (Vaughan and others, 2013). Those changes to habitats had concomitant responses in associated ecosystems (United Nations, 2017b). Iconic marine and terrestrial species that have adapted to the sea ice habitat, for example, polar bears, narwhals, seals and various seabirds, were found to be in decline both in abundance and geographic distribution. Sea ice algae were identified as playing a major role in the primary production of those habitats; the expansion of open ocean environments led to increased phytoplankton blooms. Both of those changes implied an altered base to the high-latitude food chain. In general, the expansion of open ocean environments was leading to a concomitant increase

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[1] See General Assembly resolution 70/1.

in the abundance and geographic distribution of open ocean species. In the Southern Ocean, it was uncertain whether changes in sea ice habitats were affecting keystone species and, in particular, krill populations.

While major advances in the understanding of marine biological polar sciences (Robinson, 2009; Stoddart, 2010) during the International Polar Year (2007–2008) provided novel information for the first Assessment, advances in knowledge available for the second *World Ocean Assessment* have been the result of a variety of more limited initiatives.

2. Description of the environmental changes between 2010 and 2020

The overriding environmental change in the high-latitude ice habitat since the first Assessment has been a continuation of past change (figure I; see also chap. 5 of the present Assessment). The greatest advances in knowledge, capacity and the establishment of trends are largely associated with national and international programmes, such as the Multidisciplinary Drifting Observatory for the Study of Arctic Climate (MOSAiC) and the Antarctic Circumnavigation Expedition, and long-standing international organizations, such as the multinational Arctic Council and the Commission for the Conservation of Antarctic Marine Living Resources. Annual, and regularly scheduled, summaries of Arctic change, including ice habitats, are issued by States – for example, the *Arctic Report Card* of the United States National Oceanic and Atmospheric Administration (Richter-Menge and others, 2019) and the *State of the Arctic Ocean Report 2019* of Fisheries and Oceans Canada (Niemi and others, 2019) – and by international committees – for example, the “State of Arctic science report” of the International Arctic Science Committee (2020) and the Scientific Committee for Antarctic Research (2020). More global summaries, again including ice habitat change, are issued through the American Meteorological Society (Blunden and Arndt, 2019). The Arctic Council has produced 25-year pan-Arctic summaries of changes in the cryosphere (Arctic Monitoring and Assessment Programme (AMAP), 2017) and biodiversity (Conservation of Arctic Flora and Fauna Programme (CAFF), 2017).

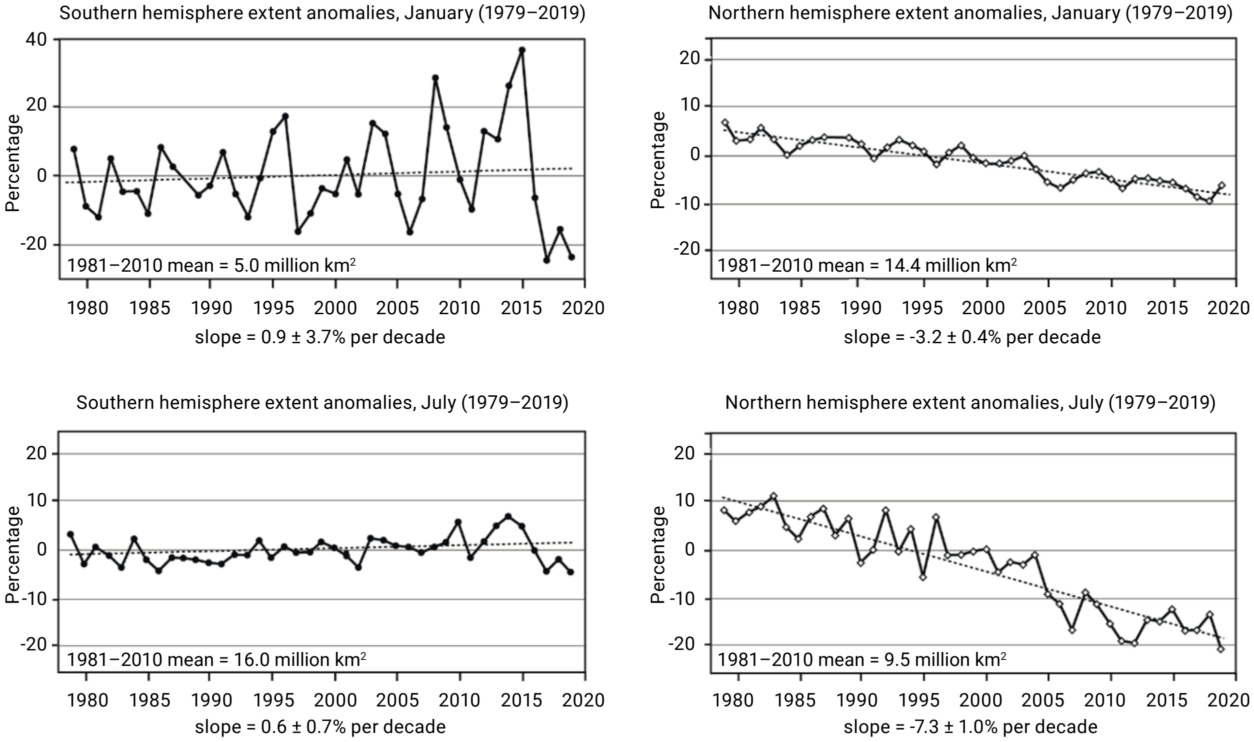
2.1. Sea ice habitats

In the Arctic, ongoing long-term declines in sea ice extent (see also chap. 5), both in summer and winter, have occurred. The summer Arctic sea ice extent has reached a new, reduced, mean position, although it may be temporary (Vaughan and others, 2013). The new minimum also applies to sea ice thickness, through the loss of significant amounts of multi-year ice after 2007, and the maintenance of the reduction in the years since then (Serreze and Meier, 2019). It is worth noting that, while there is general Arctic sea ice decline, the Pacific sector of the Arctic is losing its ice much more quickly than is the case for other sectors of the Arctic, including the Canadian Arctic archipelago (see figure X in chap. 5).

In the Southern Ocean, although there has been strong inter-annual variability, similar to that noted in the first Assessment, there has essentially been no long-term change in the sea ice extent for summer or winter (figure I; see also chap. 5). From 2017 to 2019, however, January (minimum) levels have been consistently below the levels registered since satellite records began in 1979, especially in the regular ice-covered zones of the Weddell Sea and the Amundsen Sea. That may be a consequence of recent oceanographic warming in the Southern Ocean (Meehl and others, 2019).

Figure I

Trends in summer and winter sea ice extent for both the northern and southern hemisphere polar regions since satellite imagery became available in 1979



Sources: Fetterer and others, 2017; and the National Snow and Ice Data Center sea ice index, available at https://nsidc.org/data/seaice_index/compare_trends, which provides daily and monthly updates of Arctic and Antarctic sea ice extents and trends.

Note: The slope of the trend line in each panel is shown; the northern hemisphere trends are statistically significant at the 0.01 level, while the southern hemisphere trends are not significant.

The rapidly changing nature of the physical environment, combined with the relative inaccessibility of the polar oceans, means that studies have largely focused on climate change scenarios (see also chap. 5), especially at the base of the trophic system, rather than the identification of historical change. Limited studies of sea ice brine communities suggest no change as yet in relation to increased CO_2 concentrations or decreased pH (McMinn and others, 2017). However, phytoplankton productivity under the sea ice has been found to be unexpectedly high (Arrigo and others, 2012). Such changes may have positive impacts on benthic organisms and upper ocean organisms by increasing the food supply of particulate organic carbon to lower trophic levels (Oxtoby and others, 2017; Yasuhara and others, 2012; Xu and others, 2018). Diatoms from within the sea ice have been found to sustain under-ice production during winter in the northeast Chukchi Shelf (Koch and others, 2020).

The impact of the decreasing Arctic sea ice on populations of marine mammals and seabirds is species-specific and depends on the extent to which individual species rely on the sea ice habitat. While the ivory gull (*Pagophila eburnea*) has been identified as utilizing the Arctic's marginal ice zone and nearby open sea, Gilg and others (2016) found that approximately 80 per cent of seabird species were foraging in the increasingly rare high-concentration sea ice. That variable use of ice habitat may indicate adaptability under a changing climate.

Decreasing Arctic sea ice has led to general reductions of approximately 10 per cent in seabird numbers in the Bering Sea (Renner and others, 2016). There is some evidence that, as prey habitats are changing, species such as the beluga whale (*Delphinapterus leucas*) are exploiting expanded marine habitats (Hauser and others, 2018) and are generally showing flexible feeding responses to environmental change (O'Corry-Crowe and others, 2016). In contrast, the reduction in sea ice has reduced the abundance of the ringed seal (*Pusa hispida*) in Hudson Bay (Ferguson and others, 2017), and their distributional range in the Svalbard Archipelago has also contracted, which is leading to a major reduction in range overlap in those islands with the Arctic's top predator, the polar bear (*Ursus maritimus*). In response, polar bears have been observed feeding increasingly on ground-nesting birds (Hamilton and others, 2017) and whale carcasses (Pagano and others, 2020), with a concomitant increase in energy expenditure. In the Antarctic, the rapid warming has been shown to lead to the southward movement of krill (*Euphausia superba*) populations, with decreases in density, but increases in individual body length (Atkinson and others, 2019). Hückstädt and others (2020) suggest that that is likely to have negative consequences for species dependent on krill, such as the crabeater seal (*Lobodon carcinophaga*).

2.2. Ice shelf and iceberg habitats

The ice habitats of both ice shelves and icebergs extend up to hundreds of metres below the ocean surface, which means that their marine signatures are very different from those of sea ice, both in terms of their impact on the surrounding ocean and in the type of habitat that their subaerial and submarine surfaces provide. Ice shelves provide stable breeding platforms with direct access to the ocean where terminal thickness allows, and they have been utilized by species that are dependent on ice shelves for breeding – the emperor penguin (*Aptenodytes forsteri*), for example – for many years (Wienecke, 2012; Fretwell and others, 2014). The subaerial surfaces of ice shelves provide habitats for microbial mats, especially where aeolian or glacially entrained sediments are present (Mueller and others, 2006), thus providing a mechanism for long-distance transport of the organisms (Cefarelli and others, 2016). However, it is the dark environments under ice shelves that provide the surprisingly diverse habitats. Most of them are in the benthos, to which material from the ice shelves can provide nutrients (Hawes and others, 2018), leading to microbial activity (Vick-Majors and others, 2016) and a range of species present in the meiobenthos (Pawlowski and others, 2005; Ingole and Singh, 2010). Some organisms utilize the submarine ice shelf surface more directly. They include the bald rockcod (*Pagothenia borchgrevinki*), which forages for prey along the ice surface (Gutt, 2002), and the sea anemone (*Edwardsiella andrillae*), which uses the ice surface as a supporting substrate (Daly and others, 2013; Murray and others, 2016). The break-up of ice shelves in both the Arctic and Antarctic has led to the regional loss of that unique, dark environment, but significant biodiversity has spread into the regions newly exposed to surface inputs, leading to major carbon drawdown (Barnes and others, 2018).

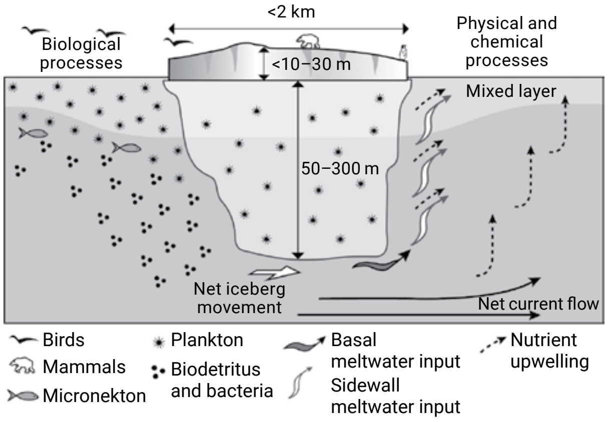
Icebergs vary in size, from free-floating fractures from ice shelves, in particular but not exclusively in the Antarctic, to fragments of ice a few tens of metres in size broken off from the calving terminus of a tidewater glacier. As ecosystems, they therefore vary in their marine contribution greatly. At one extreme, they are effectively free-moving pieces of ice shelves, with the capacity for significant seabird nesting and feeding platforms in both the Antarctic (Ruhl and others, 2011; Joiris, 2018) and the Arctic. In the latter, both the ivory gull (Nachtsheim and others, 2016) and the kittiwake (*Rissa tridactyla*; Joiris, 2018) have been found in abundance on and near icebergs of various sizes. It has been speculated that past movement of giant icebergs in the Antarctic may have helped to facilitate the distribution of the Adélie penguin (*Pygoscelis adeliae*) through ice transport (Shepherd and others, 2005). Such large icebergs can also have negative impacts on ecosystems. If a giant iceberg grounds for long periods off an existing penguin colony, its presence, and the associated spread of fast ice, can block the passage of individual birds, preventing access to foraging grounds and leading to considerable chick mortality (Kooyman and others, 2007; Wilson and others, 2016). In addition, the grounding and scouring of bottom sediments by large icebergs is a physical disturbance and has a serious impact on benthic organisms (Kaiser and others, 2013; Yasuhara and others, 2007). In areas with frequent iceberg passage, such as extensive areas along the coastlines of Antarctica and Greenland (Bigg, 2015), as much as 30 per cent of the seabed may be disturbed in any one year, with up to two thirds of the benthic fauna in that area killed (Barnes, 2017). With an ecosystem recovery time of several years, the destruction could lead to significant loss in the short term in the ability of the area to act as a carbon store, in particular in shallow seas (Barnes and others, 2018).

The melting of icebergs allows for the input of nutrients and trace elements that are held in or on the ice into the water, creating a distinctive and productive local ecosystem (Smith and others, 2007; Smith and others, 2013). The melting process, with its associated upwelling of relatively fresh plumes, aids the input of nutrients into the surface waters (figure II), which can have chlorophyll concentrations that are 4–10 times above the background level. In association, near icebergs, there is an elevated bacterial population and a community composition that is different from that in the undisturbed water nearby (Kaufmann and others, 2011; Dinasquet and others, 2017). Further away, the combination of increased nutrients around the iceberg (Helly and others, 2011), as well as iron (Raiswell and others, 2008; De Jong and others, 2015) and silica (Hawkings and others, 2017) from the englacial debris released by the melting, leads to increases in phytoplankton levels (Vernet and others, 2011) and potential impacts on carbon sequestration (Cefarelli and others, 2016; Duprat and others, 2016).

The decay of ice shelves (e.g., Fettweis and others, 2017; Rignot and others, 2019) would be expected to lead to greater iceberg numbers; however, comprehensive, long-term iceberg number estimates both in the Arctic and Antarctic are lacking. Records of icebergs off Newfoundland (Bigg and others, 2014) and satellite-derived records of medium-small icebergs north of 66° S in the Southern Ocean (Tournadre and others, 2016) both report increasing numbers. The calving of giant icebergs (> 18 km in length) from ice shelves in the Antarctic, while very episodic in nature, also shows some evidence of recent increases in both number (figure III; see also the Antarctic Iceberg Tracking Database) and magnitude.

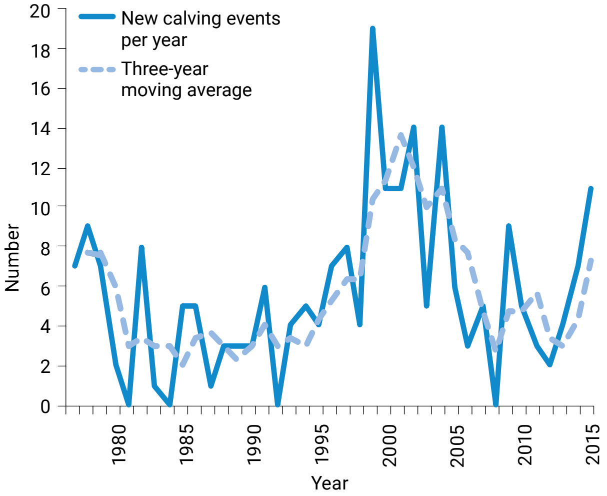
The likely increase in icebergs in both hemispheres has probably led to increased production and impact on coastal benthic ecosystems in recent years, but there is currently little evidence, with information on the impacts of iceberg flux largely derived from the Southern Ocean.

Figure II
Arctic/Antarctic ecosystem on and around an iceberg



Source: Bigg, 2015. Reprinted with permission.

Figure III
Number of annual Antarctic giant iceberg calving events



Sources: See Budge and Long, 2017; and the Antarctic Iceberg Tracking Database, available at www.scp.byu.edu/data/iceberg.

Note: Giant icebergs are greater than 18 km in one length dimension, but there is no consistent area/volume estimate available over the timescale.

3. Economic and social consequences

Historically, high-latitude ice habitats have experienced low levels of human activity, principally by indigenous inhabitants of the Arctic and its periphery. The continuing retreat of the habitat as a result of global warming, and the advance of human use of polar regions, is rapidly changing the relevance of the habitat for humanity, with associated economic and social consequences. While the decrease in sea ice increases opportunities for transoceanic shipping and the exploitation of sea floor hydrocarbon resources, the main driver for increased use of the Arctic so far is fishing (Eguíluz and others, 2016). More open ocean species can move north into now ice-free waters, increasing fishing opportunities, although the fish that rely on the sea ice habitat, such as polar cod (*Boreogadus saida*), will likely become less common (Christiansen, 2017). There are currently few marine protected areas in the Arctic offering protection from fishing or other exploitation (Harris and others, 2018), although a ban on Arctic fishing, instituted by an international agreement that was signed in October 2018, will limit the expansion of fishing activities in the Arctic for the next decade or more once 10 countries have ratified the agreement (European Commission, 2019). As of June 2020, however, only eight countries had done so. The initiative links directly to Sustainable Development Goal 14.

The direct impact of sea level rise from glacier melting and the associated freeing of once frozen coastlines in the Arctic is affecting, yet providing many opportunities for, communities and industries (Richter-Menge and others, 2019). Negative impacts include the loss of coastal ice roads, the elevation of flood levels, changes in nesting areas and alongshore coastal sediment transport, a reduction in subsistence hunting ranges, the release of previously trapped pollutants and even the loss of some coastal communities. Potential economic opportunities include the opening up of areas for ocean fishing activity, maritime transportation and new shipping routes and enhanced opportunities for renewable energy installations, as well as increasing opportunities for hydrocarbon exploitation. Those opportunities, however, have the potential to increase the risks associated with the activities, for example, habitat contamination from catastrophes such as oil spills (Cappello and others, 2014). It is worth noting that oil encased in sea ice does not readily degrade (Loftus and others, 2020).

Over time, as ice-free and therefore viable routes through the Arctic north of the Russian Federation (the Northern Sea Route) expanded, so too the number of vessels using the routes increased, with over 70 vessels sailing through the Northern Sea Route in 2013. However, the number, if not the tonnage, of vessels using the route has decreased in recent years, not exceeding 40 since 2014 (Northern Sea Route Information Office, 2019; Centre for High North Logistics Information Office, n.d.).

Oil and gas activities in the Arctic are variable. Canada has recently expanded a moratorium on issuing new drilling licences in its Arctic exclusive economic zone to prohibit all offshore oil and gas activities until the end of 2021 (Vigliotti, 2019). In the Arctic waters of the United States, the analogous drilling ban introduced in 2016 was removed in 2017 but restored in 2019. Its future remains subject to legal appeal (Gilmer, 2020). Western Arctic waters of the Russian Federation have seen limited drilling in recent years, but expansion is on hold for economic reasons and as a result of sanctions, although recent reports suggest that drilling may resume in 2020 or 2021 (Staalesen, 2019).

Most changes observed in the Arctic ice habitat have mixed consequences in terms of the Sustainable Development Goals, with hydrocarbon exploitation providing greater access to energy sources (Goal 7) and, with increased shipping, tourism and fishing enhancing local economic activity (Goal 8). However, those activities may work against creating a sustainable environment enriched by biodiversity (Goal 14) by causing further climate change and emissions (Goal 13), with associated pollution (Goals 12 and 14).

Some fishing grounds in the Antarctic, such as those for krill, occur in coastal waters in the South Atlantic and the Weddell Sea, where sea ice has shown signs of decrease. The broader implications of those decreases on the broader ecosystem and associated fishing grounds, however, are not yet clear. Hydrocarbon exploration has started on the plateau surrounding the Falkland Islands (Malvinas)[2] (MacAulay, 2015), although assessment of the associated environmental risks has only just begun and the area lies outside of the Antarctic governance system (Bigg and others, 2018). In the light of the importance of krill as a food source for a growing aquaculture industry, long-term management strategies for that species are beginning to be implemented in the area protected by the Commission for the Conservation of Antarctic Marine Living Resources (Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR), 2019). Marine protected areas in some particular locations might help to address some of the management issues, and it will require more changes to be undertaken by the Antarctic Treaty System, in particular the Commission for the Conservation of Antarctic Marine Living Resources. A Ross Sea marine protected area was established in 2016, with other proposed marine protected areas, such as in the Weddell Sea and East Antarctica and near the Antarctic Peninsula, being considered by members of the Commission.

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[2] A dispute exists between the Governments of Argentina and the United Kingdom of Great Britain and Northern Ireland concerning sovereignty over the Falkland Islands (Malvinas).

4. Outlook

The outlook for polar ice habitats remains very much as it was for the first Assessment. Arctic sea ice is expected to continue to retreat and thin, with the prospect of a seasonally ice-free Arctic very likely within the twenty-first century, although the timing of that key environmental event is still very uncertain (Serreze and Meier, 2019). Antarctic sea ice, while currently stable, is projected to decrease over the century (Naughton and others, 2018), mostly because of ocean warming. The latter is expected to affect Antarctic ice shelves by encouraging subsurface melting of up to 41–129 per cent by the end of the century (Naughten and others, 2018), with associated increases in iceberg calving. Continued warming in the Arctic is expected to result in increased melting of the Greenland Ice Sheet (Barry, 2017) and probably increased, if episodic, iceberg production.

The decrease in sea ice and ice shelves will continue to open up opportunities for the expansion of both pelagic and sea floor species, which will benefit from wider and improved feeding conditions (Christiansen, 2017), while threatening the viability of fish, in particular the polar cod (see Christiansen, 2017), and marine mammal populations for sea ice-dependent species (United Nations, 2017a). Many studies suggest that sea ice algae will become vulnerable to climate change, with reduced biodiversity and population declines (Hardge and others, 2017; Kiko and others, 2017). On the other hand, phytoplankton blooms may become more widespread, at least early in the summer before nutrient limitation occurs, under thinner, more lead-prone, snow-covered sea ice in the Arctic Ocean (Assmy and others, 2017; see also chap. 6A of the present Assessment). Such changes may have more wide-ranging impacts on carbon export, with seasonal sea ice zones switching to carbon sinks (Abelmann and others, 2015; Rapp and others, 2018). Decreasing sea ice may also reduce inputs of plastics to the Arctic Ocean, as sea ice currently contains, in orders of magnitude, more microplastics than the Arctic Ocean itself (see chap. 12 of the present Assessment; also Kanhai and others, 2020). In the Southern Ocean, where sea ice has demonstrated little long-term trend to date, it is known that individual-level specialization is lowest at sites where the inter-annual variability in sea ice is highest (McMullin and others, 2017), suggesting that there is scope for adaptation in a more variable future climate.

The opening up of the Arctic to navigation, fishing and exploitation of the sea floor and deeper resources will have major implications for high-latitude ice ecosystems (Harris and others, 2018) and for human populations, including indigenous peoples, that are reliant on high-latitude ice habitats. It will also have implications for achieving a number of Sustainable Development Goals. However, despite the first vessel sailing through the Northern Sea Route in August 2017 without being accompanied by an icebreaker (High North News, 2018), it is likely that cargo shipping will continue to need accompaniment, unless it is an “ice class” vessel, for the foreseeable future (Kiiski and others, 2018). As a result, Arctic routes will likely remain of secondary importance for some decades. Other factors limiting the use of such new shipping routes are the potential negative impact of increased shipping on Arctic marine mammals (Hauser and others, 2018), the unwanted facilitation of the transfer of non-indigenous species and the possible complex radiative feedback of ship exhaust fumes on the Arctic climate (Stephenson and others, 2018), with the latter potentially slowing the tendency for increases in ice-free periods.

5. Key remaining knowledge and capacity-building gaps

The inaccessibility of the high latitudes means that the ice habitat remains relatively poorly understood. Sea ice environments are currently the best studied of the marine ice habitats considered in the present subchapter, but, even for sea ice, a comprehensive food web study is yet to be conducted. Many food web studies have focused on just one aspect (Dickinson and others, 2016). In general, the understanding of the three-dimensional nature of ice habitats (Bluhm and others, 2018), the range and number of species within them and their spatial and temporal variability is still very limited (Christiansen, 2017). The lack of data extends also to the impact of the presence or absence of such habitats on the surrounding ocean and carbon sequestration (Barnes, 2017).

Similarly, the difficulty of access to ice shelves, marine areas near glaciers (Zappalà and others, 2017) and, in particular, the submarine environment beneath them, makes gaining new information about that ice habitat rare. Much analysis has been, and will remain, from remote sensing, with new satellite systems promising to revolutionize first-order knowledge of the habitats. It will be important to ensure ready and universal access to the new data produced by the observing platforms in order to address current knowledge and capacity gaps.

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