Chapter 46. High-Latitude Ice and the Biodiversity Dependent on it

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1. Description of the ice systems and their biodiversity

1.1 Annual ice and multi-year ice

The high-latitude ocean areas are ice-covered for much or all of the year. Multi-year ice and annual ice have different physical and chemical properties that make them also differ in terms of their ecological communities. The multi-year ice, in particular, is globally unique, and supports unique communities of ice algae and species of larger invertebrates, fish, birds and mammals wholly or largely dependent on the multi-year ice and on multi-year and annual ice margins. Sea ice is a technical term that refers to floating ice formed by the freezing of seawater. This chapter uses "high-latitude ice" as a more generic term for a variety of critically important high-latitude marine habitats, which include ice shelves, pack ice, sea ice, and the highly mobile ice edge. These forms of high-latitude ice complement and modify other types of habitats, including extensive shallow ocean shelves and towering coastal cliffs (CAFF, 2013. Meltofte, 2013).

The Arctic Ocean is unique in that it contains a deep ocean basin, which until recently was almost completely covered in multi-year ice (chapter 36H). No other area in the world has such an ice-dominated deep ocean. The Southern Ocean is unique in that it contains both icebergs (floating freshwater ice) calved from glaciers and ice shelves and sea ice. Also there is no limit to the northwards extension of the winter pack ice. Thus seasonal variations are much larger in the Antarctic (Ropelewski 1983). Three biogeographic regions have been recognised in the Antarctic, defined by differences in ice cover (Treguer and Jaques, 1992): ice-free, seasonally or permanently covered by high-latitude ice.

1.2 Biodiversity associated with the ice

The high-latitude ice-covered ecosystems host globally significant arrays of biodiversity, and the size and nature of these ecosystems make them of critical importance to the biological, chemical and physical balance of the globe (ACIA 2005). Biodiversity in these systems presents remarkable adaptations to survive both extreme cold and highly variable climatic conditions. Iconic ice-adapted species such as polar bear, narwhal, walrus, seals, penguins and seabirds have adapted to different ice conditions, including extreme examples such as the emperor penguin living among thousands of lesser known species that are adapted to greater or lesser degrees to exploit the habitats created by high-latitude ice (Meltofte, 2013; De Broyer et al. (eds.) 2014).

1.2.1 Primary production and lower trophic level communities

These high-latitude seas are relatively low in biological productivity, and ice algal communities, unique to these latitudes, play a particularly important role in system dynamics. Ice algae are estimated to contribute to more than 50 per cent of the primary production in the permanently ice covered central Arctic (Gosselin et al. 1997, Sakshaug 2004). Ice algae can be divided into communities on the surface, interior and bottom of the ice (Horner et al. 1992). In addition to microalgae, bacteria are an important component of the ice-algal community, but many other groups of organisms (e.g. archaea, fungi, ciliates, kinetoplastids, choanoflagellates, amoebae, heliozoans, foraminiferans and some protists that belong to no known group) also occur in ice communities (Lizotte 2003). Poulin et al. (2010) reported a total of 1027 sympagic taxa in the Arctic Ocean. Many of the dominant ice algae are diatoms that sink and are eaten by different benthic organisms or broken down by bacteria (Boetius et al., 2013), thus creating a link between ice and bottom ecosystems. In the Southern Ocean, the distribution of primary productivity is associated with frontal zones, areas of broken sea ice, and with the divergences linked to the bottom topography, with high horizontal variability at the local scale while the vertical distribution is more regular. Chlorophyll concentration is practically nil below 250 m with maxima around 50 m. This general pattern is highly modified in coastal areas (El-Sayed, 1970).

The primary productivity in the Antarctic is much lower than might be expected given the nutrient concentrations observed. Early in Antarctic research the factors regulating the distribution of primary producers have been discussed (Hart, 1934). In coastal waters nutrients might reach very high values (El-Sayed 1985, Holm-Hansen 1985) and phytoplankton blooms have been observed to deplete these high concentrations (Nelson and Smith 1986, Bienatti et al. 1977).

The marginal ice zone (MIZ), at and near the ice edge, is a highly productive area for phytoplankton (Sakshaug & Holm-Hansen, 1984, Sakshaug & Skjoldal 1989). Stable water masses due to ice melt coupled with high nutrient availability and light result in an intense phytoplankton bloom. As water masses become stratified due to surface heating, nutrient flow from below is inhibited. Consequently, the bloom in marginal ice areas starts earlier than in adjacent areas never experiencing high-latitude ice. The bloom follows the ice edge as it retreats in the spring. This “spring bloom” can occur in autumn in the areas of maximum ice retreat (Falk-Petersen et al. 2008). The ice-edge bloom is likely to weaken with time over the season (Wassmann et al. 2006).

Arctic planktonic herbivores, such as *Calanus hyperboreus*, are able to utilize the vast area of the Arctic Ocean and to feed and store lipids for over-wintering until the sun disappears in October (Falk-Petersen et al. 2008). In the Antarctic the same pattern of seasonal feeding expended in reproductive processes and lipid storage is followed by a suite of herbivores (De Broyer et al. (eds.) 2014) such as euphausiids (i.e. *Euphausia superba, Thysanoessa macrura),* copepods and salps (i.e. *Calanus simillimus, C.propinquus, C. acutus, Salpa thompsoni).*

Around the annual ice, in general there are steep gradients in temperature, salinity, light and nutrient concentrations creating different habitats throughout the ice, the 0.2 m on the lower ice surface having the most favourable conditions for growth among the interior communities (Arrigo 2003). However, with respect to biomass and contribution to primary production, the sub-ice community is the most important in annual ice. In addition there are seasonal trends and inter-annual variations in species composition, biomass and production as a result of several factors, including light, age and origin of the ice (e.g., distance to land and water depth). Thus, there is a high spatial heterogeneity when larger areas are considered.

Sea-ice algae start their growth ahead of phytoplankton. An extended growth season in the Arctic areas forms ice algal communities that are grazed actively by both ice fauna and zooplankton and may be an important component of the diet of some species during the winter. Ice algae contribute 4–26 percent of total primary production in seasonally ice-covered waters (Gosselin et al. 1997, Sakshaug 2004). *Apherusa glacial* is probably the most numerous amphipod species in the central Arctic Ocean. *Onisimus glacialis* may be common in some areas. In the Antarctic sea ice the calanoid copepods are dominant while larvae of *E. superba* benefit from ice for overwintering; to date no species fully dependent on high-latitude ice has been identified (Arndt & Swadling, 2006).

1.2.2 Macrofauna

The ice structure and surfaces include a number of larger invertebrates that also are believed to live their entire life connected to the multi-year ice (e.g. nematode worms, rotifers and other small soft-bodied animals within the ice and amphipodes on the underside), Some of these dominate the biomass of macroinvertebrates (Arndt & Swadling 2006) and are the important food items for high-latitude fish. Antarctic euphausiid larvae spend the winter in close association with icebergs or sea ice. The permanent pack-ice zone of the Southern Ocean represents the habitat for a highly confined community of seabirds, the most unvarying of any seabird assemblage in the Southern Hemisphere (Ribic and Ainley, 1988). It is composed of Adélie and Emperor penguins, Snow and Antarctic petrels, with the addition during the summer of South Polar skua and Wilson's storm-petrel.

In the Arctic, Polar bears Ursus maritimus are highly dependent on high-latitude ice and are therefore particularly vulnerable to changes in ice extent, duration and thickness. Three ice-associated cetacean species also reside year-round in the Arctic, mostly connected to the marginal ice zone, including the Bowhead whale (*Balaena mysticetus*) that is assessed as highly endangered in part of its range. The reproduction of some Antarctic seal species is also linked to extent of ice (e.g. *Lobodon carcinophagus, Leptonychotes weddellii)* while others are temporarily associated to ice for rest and refuge. Penguin species also use icebergs or sea ice during foraging trips and follow the ice border in winter. Permanent ice shelves strongly modify the habitats and the sea bottom fauna below the shelves (Gutt et al. 2013, Lipps et al., 1977; Lipps et al., 1979; Post et al., 2014).

2. Changes to these systems and their biodiversity

2.1 Changes in the ice structures

These high-latitude ecosystems are undergoing change at a more rapid rate than other places on the globe, threatening the existence of ecosystems such as multi-year high-latitude ice. In the past 100 years, average Arctic temperatures have increased at twice the average global rate (IPCC 2007). Recent changes in Arctic and Antarctic sea-ice cover, driven by climate change including rising temperatures and winds (Stammerjohn et al., 2012), have affected the timing of ice break-up in spring and freeze-up in autumn, as well as the extent and type of ice present in different areas at specific dates. Overall, multi-year ice is rapidly being replaced by first-year ice. The extent of Arctic ice is shrinking in all seasons, but especially in the summer. In some regions of the Antarctic ice shelves are rapidly disappearing, while the maximum extension of winter ice appears to increase (Turner et al., 2009, pg. 130).

In the Arctic Ocean multi-year ice changed from covering more than two-thirds of the Arctic Ocean to less than one-third in less than a decade. For instance, multi-year ice now occupies only part of the deep areas of the Arctic Ocean beyond areas within the national jurisdiction of Canada and is projected to be virtually ice-free in summer within 30 years, with multi-year ice persisting mainly between islands of Canada and in the narrow straits between Canada and Greenland, Denmark (Meltofte, 2013). Similar projections of a largely ice-free Arctic Ocean in summer have been made from the Arctic-Pacific interface as well (Overland and Wand 2013). The multi-year ice that remains is also much younger than previously as the oldest multi-year ice classes have declined more than other classes (AMAP 2011), and even if conditions changed to allow the return of the lost/declined ice cover, it would take many years to return to the state of just a few decades ago.

2.2 Changes in biodiversity

A change in timing and duration of the ice edge bloom increases the probability of a "mismatch" in productivity, which may have severe consequences for zooplankton that are dependent on this bloom today, with potential cascading effects throughout the ecosystem. However, the timing of ice formation and melt also influences the distribution and intensity of the primary production in the water column. Such primary production is likely to increase in areas with less ice but may then become limited by nutrient availability, including trace nutrients such as iron.

Boreal species of algae, invertebrates, fish, mammals (Kaschner et al., 2011) and birds are expanding into these higher latitudes, while some ice-adapted species are losing habitat along the edges of their ranges. Changes are too rapid for evolutionary adaptation, so species with inborn capacity to adjust their physiology or behaviour will fare better. Species with limited distribution, specialized feeding or breeding requirements, and/or high reliance on high-latitude ice for part of their life cycle are particularly vulnerable (Meltofte, 2013. In the Antarctic, seal and penguin species dependent on ice distribution seem to be likely to respond to changes in extreme events, as had happened in some years of anomalous El Niño – Southern oscillation events. Significant declines in ice – even at the regional or local scales – may lead to the replacement of antarctic by subantarctic species (Turner et al., 2009, pg. xxv).

Krill plays a central role in the trophic structure of Antarctic ecosystems. Its abundance and distribution depend on the coupling of reproductive events and oceanic circulation. It is not clear to what extent its population declined and which are the factors involved (Ainley et al., 2005; 2007). The decrease in krill abundance and the increase in salps abundance are thought to be related with changes in ice cover (Loeb et al., 1997).

There are indications that populations of *Pleuragramma antarcticum*, a key fish species of the trophic web, and whose reproduction is closely associated to high-latitude ice, declined at some localities, to be replaced by myctophids, a new food item for predators (Turner et al. 2009, pg. 360).

3. Implications and risks

Reduced high-latitude ice, especially a shift towards less multi-year ice, will affect the species composition in these waters. With decreasing ice cover, the effects on the ice fauna will be strongest at the edges of the multi-year high latitude ice. Seasonal/annual ice has to be colonized every year, as opposed to multiyear ice. In addition, multi-year ice has ice specialists that do not occur in younger ice (von Quillfeldt et al. 2009). The previously very low biological production of the deep basins may also change in this region as light, temperature and storminess increase and currents shift. In addition, wind-driven mixing of the ocean is more efficient over open water and over the thinner, more-mobile, seasonal ice than over multi-year ice, with the potential to also increase productivity.

Due to low reproductive rates and long lifetime, it has been predicted that the polar bears will not be able to adapt to the current fast warming of the Arctic and become extirpated from most of their range within the next 100 years (Gorbunov and Belikov, 2008; Schliebe et al., 2008). Other Arctic ice dependent species such as ringed seal (Kovacs et al. 2008), possibly narwhal, Ross gull (Blomquist & Elander, 1981, Hjort et al., 1997) and ivory gull (Gilg et al., 2010) are also expected to decrease as high-latitude ice, especially multi-year ice, decreases.

The reduction in ice cover in the Arctic is creating the potential for increased utilization of natural resources, including fish stocks, including in the central portion of the Arctic Ocean beyond national jurisdiction (Lin et al. 2012, Arctic Nations 2013). Among non-renewable natural resources, the Arctic is estimated to contain a quarter of the world's remaining oil and gas reserves, the development of which is expected to increase.

Already, 10 per cent of the world's oil and 25 percent of the world's natural gas is produced in the Arctic, with the majority coming from the Russian Federation (AMAP 2007, see also chapter 21 of this Assessment).

In the Antarctic, the sea-ice cover is predicted to decrease by 33 per cent in this century (Turner et al., 2009, pg. 384) as well as coastal ice shelves. This would imply a significant stress for marine organisms but no species might be singled out as candidate for extinction in this period. Signy Island and some sites at the West Antarctic Peninsula have witnessed an explosion of the fur-seal numbers that may be related to decreased ice cover resulting in increasing areas available for resting and moulting, but which may also be related to population increases; the growing seal population in Signy Island has had deleterious impacts on the local terrestrial vegetation (Turner et al., 2009, pg. 360).

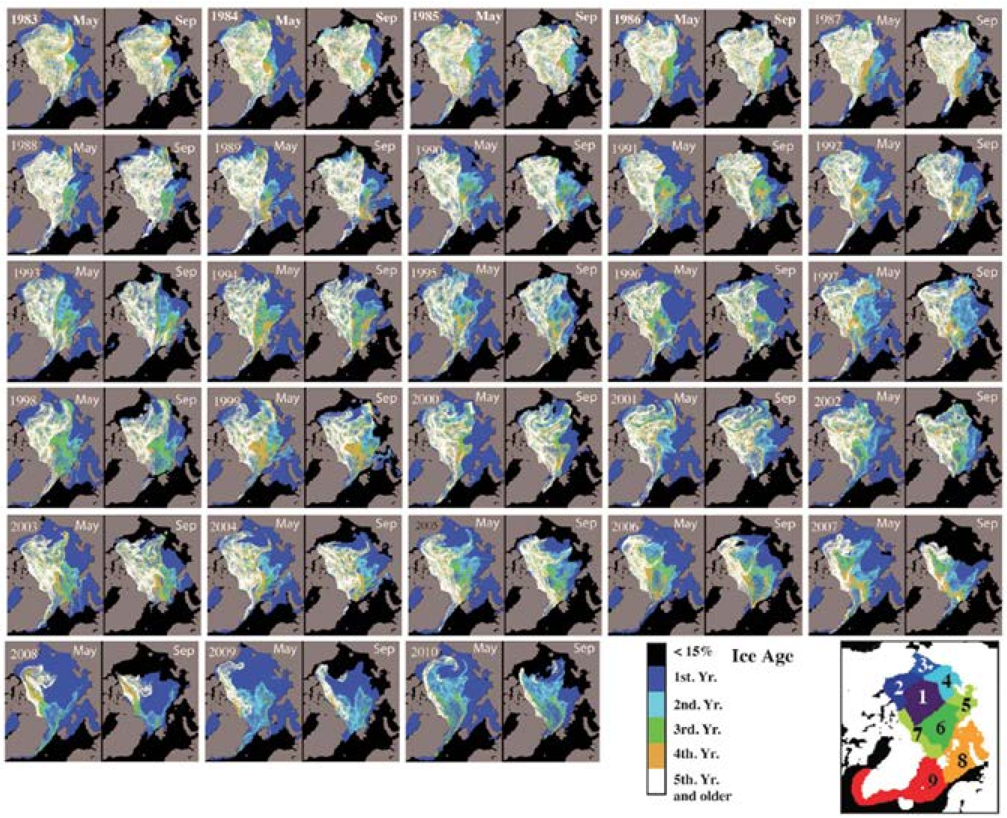

Figure 1. Multi-year Arctic sea-ice 1983 – 2010 (taken from Maslanik et al. 2011).

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