Chapter 36G. Arctic Ocean

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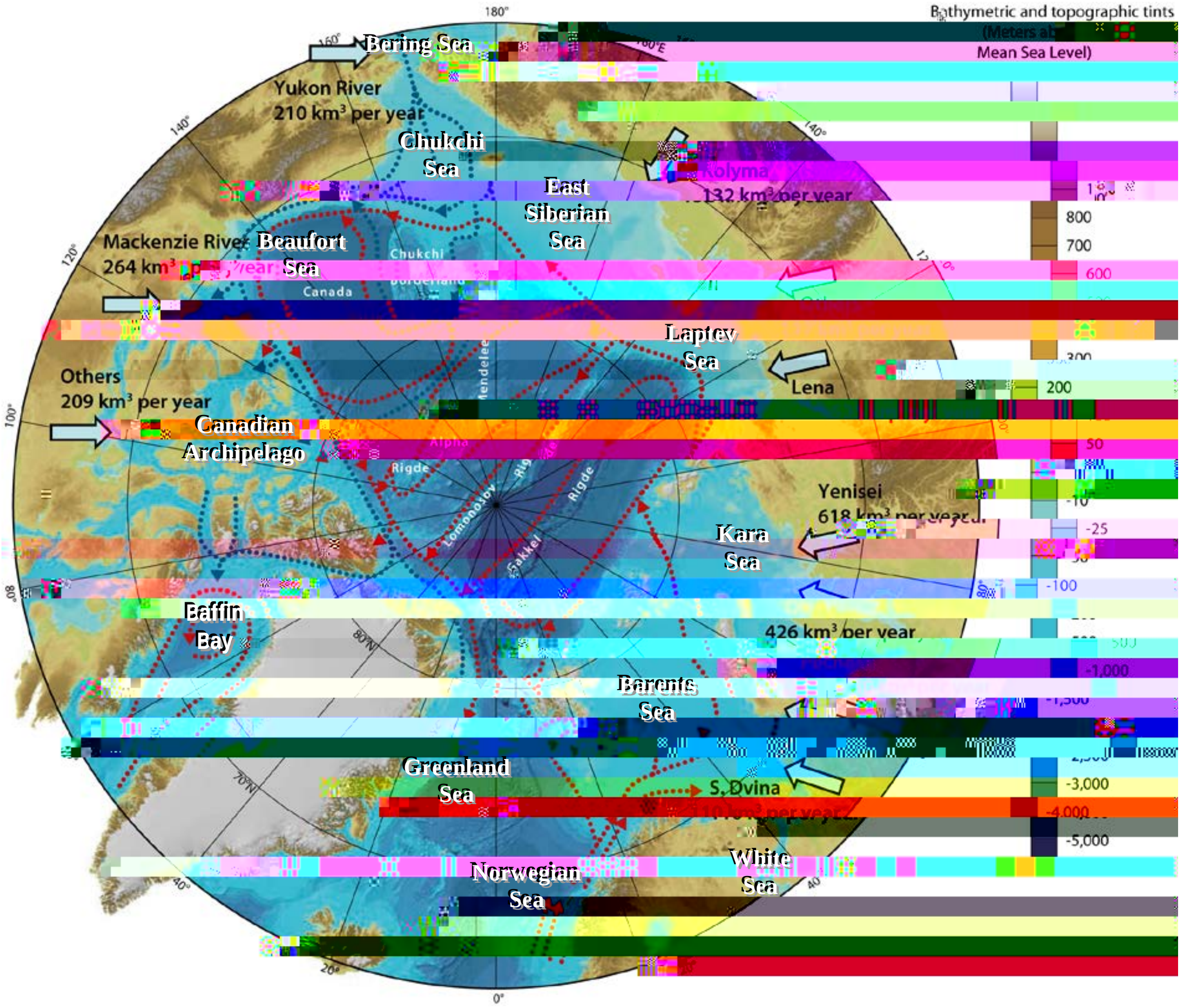
1. Introduction

1.1 State

The Central Arctic Ocean and the marginal seas such as

moved poleward into Arctic Seas. These patterns likely represent both altered distributions resulting from climate change and previously occurring but unsampled species. (Mueter et al., 2013). As targeted boreal stocks move into as yet unexploited parts of the seas, Arctic fish species turn up as unprecedented by-



The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

Figure 1. The deep Central Arctic Ocean and the marginal seas such as the Chukchi, East Siberian, Laptev, Kara, White, Greenland, Beaufort, Barents, Norwegian and Bering Seas, Baffin Bay and the Canadian Archipelago. Blue arrows show freshwater inflow, red arrows water circulation. (adapted from CAFF 2013, Arctic Biodiversity Assessment, figure 14.1).

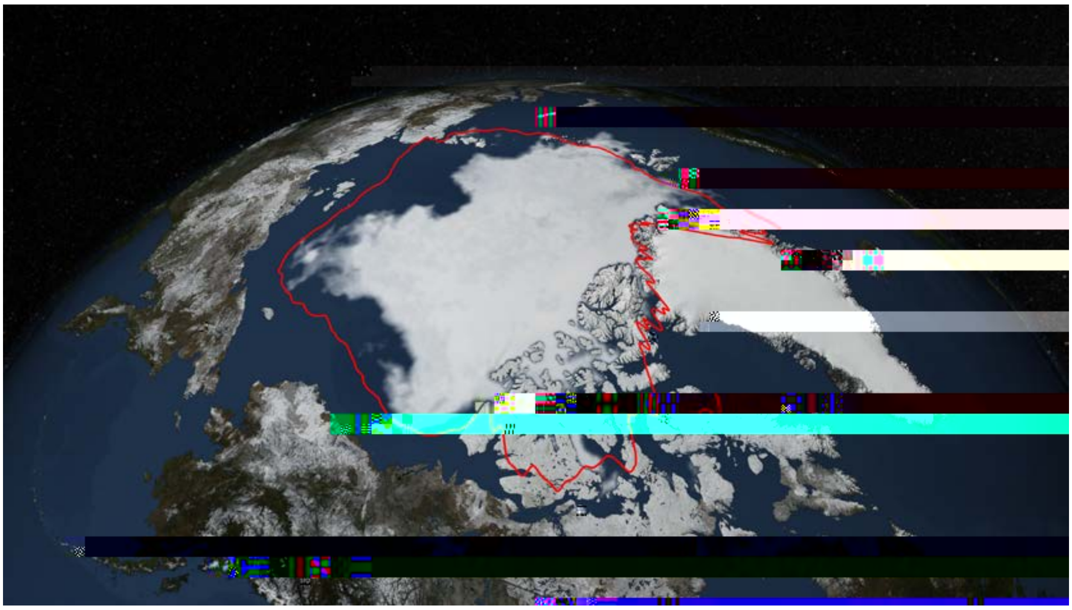


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Figure 2. Sea ice acts as an air conditioner for the planet, reflecting energy from the Sun. On September 17, the Arctic Sea ice reached its minimum extent for 2014 — at 1.94 million square miles (5.02 million square kilometres) the sixth lowest extent of the satellite record. With warmer temperatures and thinner, less resilient ice, the Arctic sea ice is on a downward trend. The red line in the still image indicates the average ice extent over the 30 year period between 1981 and 2011. NASA/Goddard Scientific Visualization Studio, 2014. Printed with permission from NASA's Earth Science News Team patrick.lynch@nasa.gov.

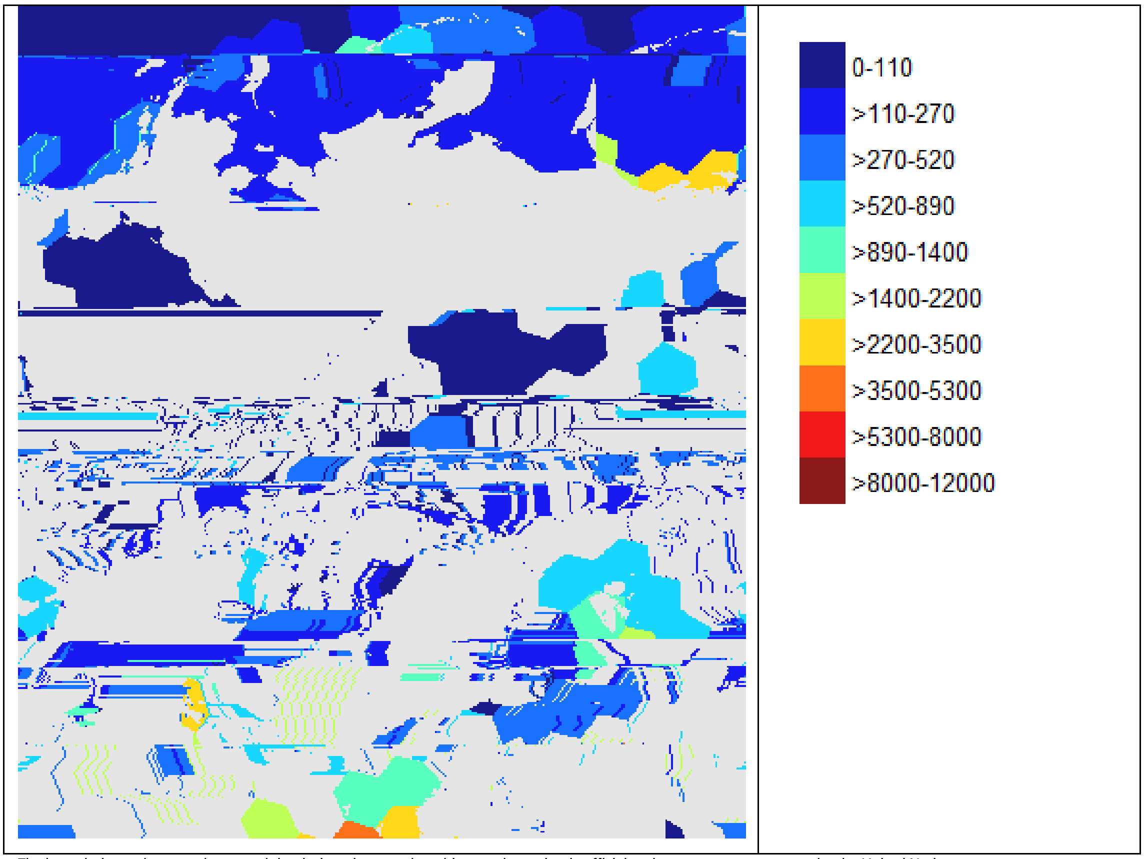

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Figure 3. Pan-Arctic map showing the number of marine species from the OBIS database in a gridded view of hexagonal cells (OBIS, 2015).

2. Primary producers

General information on primary producers

Primary producers (algae) in Arctic marine waters are dominated by small, solitary photosynthetic cells containing different types of pigments, and reproducing by the formation of spores and gametes (Daniëls et al., 2013). They consist of numerous heterogeneous and evolutionarily different groups (Adl et al., 2012) and include both single-celled organisms (microalgae) and multicellular organisms (macroalgae). In addition, the prokaryotic Cyanobacteria also occur throughout the ocean. Microalgae occur as solitary cells or form colonies with different shape and structure. The size varies between 0.2 and 200 µm, a few up to 400 µm (pico: < 2µm, nano: 2-20 µm, micro: 20-200 µm). Macroalgae are seaweeds that are visible to the naked eye, take a wide range of forms, and range from simple crusts, foliose and filamentous forms with simple branching structures, to more complex forms with highly specialized structures for light capture, reproduction, support, flotation, and attachment (Diaz-Pulido and McCook, 2008).

2.1 Introduction

Arctic microalgae can be divided by function (e.g., ice algae and phytoplankton). Phytoplankton live suspended in the upper layer of the water column, but ice algae live attached to ice crystals, in the interstitial water between crystals, or associated with the under-surface of the ice (Horner et al., 1988).

2.2 Status

The study of phytoplankton, ice algae and macroalgae of Arctic seas dates back more than one hundred years (e.g., Ehrenberg, 1841; Cleve, 1873; Kjellmann, 1883; Rosenvinge, 1898). Early studies concentrated on diversity and on temporal changes in species composition or distribution relative to oceanographic structure, and were of local or regional character. Poulin et al. (2010) reported 2,016 taxa with 1,874 phytoplankton and 1,027 sympagic (ice algae) taxa in Arctic waters. Daniëls et al. (2013) concluded that few biodiversity assessments of benthic microalgae exist across the Arctic, but estimate ca. 215 seaweed species. Most of the algal species in the Arctic are cold water or temperate species, although some are distributed globally and a few are warm water species (Hasle and Syvertsen, 1996; von Quillfeldt, 1996). The species composition in different Arctic areas is often comparable, which is likely to be due to advection (horizontal transportation) of cells by the currents in the Arctic (Carmack and Swift, 1990; Abelmann, 1992). Differences occur on a smaller scale, often as a result of local environmental conditions (Cota et al., 1991; von Quillfeldt, 2000). Prominent forcing factors on species diversity in the Arctic include the extreme seasonality of light, combined with sea-ice distribution (Bluhm et al., 2011), but the result (increase/d40(o)-1.9(f)-olo9ns a s-1(c)4ma(o)-2()( )9((w)6(arm communities or sometimes in older ice, whereas the majority of colonial algae, except for *Melosira arctica*, are most common in sub-ice communities of one-year-old ice and in more offshore areas (Dunbar and Acreman, 1980; De Sève and Dunbar, 1990; von Quillfeldt, 1996; von Quillfeldt et al., 2003). Irradiance is the most important factor in determining abundance of ice algae. Snow depth and ice thickness control light in sea ice and thereby algal abundance, as does the ice structure (Gosselin et al., 1997; Robineau et al., 1997; Krembs et al., 2000). Ice algae are distributed throughout the ice during winter and become concentrated at the bottom in spring as a result of brine drainage and active migration of cells through brine channels (Hsiao, 1980; Horner, 1985). Furthermore, a south-north spatial gradient similar to the seasonally dependent gradient in the species composition is often observed. The oldest and most specialized ice community occurs in the far north (Syvertsen, 1991).

Lüning (1990) divided Arctic seaweeds into flora with a distinct vegetation structure; many species are distributed throughout the Arctic, and a few are found only within the Arctic Basin. Macroalgal (multi celled algae attached to the seabed) diversity decreases with increasing latitude and from the Atlantic to the Pacific sector (Pedersen, 2011). Temperature is a primary factor in macroalgal distribution (Lüning, 1990). Wulff et al. (2011) emphasized that macroalgae can be of either Atlantic or Pacific origin, but more macroalgae are of Pacific origin than previously thought. Substratum characteristics are important for the distribution of benthic algae (Zacher et al., 2011.) Along the Russian Arctic coast are areas where a soft substratum prevails and macroalgae are absent (Lüning, 1990). Areas exposed to mechanical effects of sea ice or icebergs will also be devoid of macroalgae (Gutt, 2001; Wulff et al., 2011). The Arctic is also strongly affected by marked changes in surface salinity due to melting of sea ice and freshwater input from rivers. Thus, macroalgae must be able to withstand large variations in salinity over the year. Fricke et al. (2008) described the succession of macroalgal communities in the Arctic

Some surveys indicate that climate-mediated changes appear to be occurring, but geographical differences are also found. For example, less sea ice and an increase in atmospheric low-pressure systems that generate stronger winds (and deeper mixing of the upper ocean), as well as a warming and freshening of the surface layer are likely to favour smaller species (Sakshaug, 2004; Li et al., 2009; Tremblay et al., 2012). However, Terrado et al. (2012) found that some small-celled phytoplankton species were specifically adapted to colder waters, and are likely to be vulnerable to ongoing effects of surface-layer warming. Altered discharge rates of rivers and accompanying changes of composition will also affect the composition of the phytoplankton (Kraberg et al., 2013). *Emiliania huxleyi*, a prymnesiophyte, has become increasingly important: t   t j064(a)

Atlantic and Pa

present in the surface layer, remained high in these shallower areas (Raskoff et al., 2010).

pellets, moults, discarded mucus-feeding structures), which is important for transport of surface productivity necessary to feed the deep benthic communities.

3.3 Climate Change and Oceanographic Drivers Affecting Zooplankton.

Climate-induced changes in the timing and extent of sea-ice melt and breakup could have far-reaching effects on zooplankton structure and function within the pelagic food web, including coupling with the benthos and air-breathing vertebrates. The end of dormancy and initiation of feeding for lipid storage to fuel reproduction in the large Arctic copepods is linked to the ice-edge bloom. Because lipid dynamics differ in North Atlantic congeners, the "Atlantification" of the Arctic may be favoured by early and extensive breakup of the ice. The Atlantic species, which do not build up lipid reserves extensively prior to spawning, as do the Arctic endemics, may not provide adequate food for predators.

Increased ultra-violet (UV) radiation may have extensive effects d4(f)-c0eefdT4(o)-2(6)-(e)3spe

unpublished species-level data sets, together encompassing 14 of the 19 marine Arctic shelf regions and comprising 2,636 species, including 847 Arthropoda, 668 Annelida (669 if we include the new species described by Olivier et al., 2013), 392 Mollusca, 228 Echinodermata, and 501 species of other phyla. Furthermore, gross estimates of the expected species numbers of the major four phyla were computed on a regional scale. Some areas,

bottom complexity through the smoothening of sediments and removal of biogenic structures (Collie et al., 1997; Collie et al., 2000; Thrush et al.

from the sea for breeding. Depending on how widely the Arctic region is defined, total fish diversity ranges from 242 to 633 marine fish species (from 106 families) and 18-49 freshwater species that occur in marine/brackish waters (Chernova, 2011; Mecklenburg et al., 2011; Christiansen et al., 2013). Marine species comprise 88-90 per cent of total fish diversity. Species numbers in the Arctic are rather low, for both marine and freshwater species compared to the total number of fish species globally (approximately 16 and 12 thousand, respectively); 92 per cent of Arctic species are bony fishes; cartilaginous fishes (sharks and skate) comprise only 8 per cent. Most Arctic species are teleost (fishes with bony skeletons) fishes (92 per cent); cartilaginous (having a skeleton composed either entirely or mainly of cartilage) fishes (sharks and skates) comprise only 8 per cent (Lynghammar et al., 2013).

Fish diversity declines from the Arctic gateway regions near the Atlantic and Pacific Oceans, such as the Norwegian and Barents Seas (Atlantic) and Bering and Chukchi Seas (Pacific) to the farthest and most strictly Arctic seas. This diversity gradient is driven primarily by the presence of many boreal species in the Arctic gateway seas; such species cannot reproduce under the consistently colder conditions of the high Arctic. This spatial pattern holds in both the Eurasian and North American shelf seas (Karamushko, 2012; Christensen and Reist, 2013; Coad and Reist, 2004).

From a zoogeographic point of view, only 10.6 per cent of the bony fishes are considered as being strictly Arctic, and able to reproduce in waters below 0°C, whereas 72.2 per cent are boreal or Arctic-boreal species. Demersal fish species prevail in the group of strictly Arctic species (which includes 64 species or 14 per cent of the global marine fish fauna) (Chernova, 2011; Christensen and Reist, 2013).

Species composition and structure of fish communities vary in different depth zones and regions. Coastal brackish areas are usually inhabited by freshwater and anadromous fishes (whitefish, char, etc.). Fjords provide important habitats for fishes in some areas of the Arctic Seas, particularly along steep, bedrock-dominated coasts, such as are found in Greenland, Spitsbergen/Svalbard, Norther ds <</MCID 33sdr <</MC2(v)7(a

species for many larger fish and marine mammals. Although the most abundant species are widely distributed in the Arctic and adjacent waters, the demersal fauna of the Arctic pseudo-abyss (the zone from 200 to 500–1,000 m in different parts of the ocean; characterized by a mixture of fauna) is represented mainly by endemic species (Chernova, 2011).

unfished areas if used in ways that contact habitat features (e.g., Anderson and Clarke, 2003; Rice et al., 2006).

Under continuous ocean warming conditions, shifts of native species and new appearances of warm-water species may result in changes to fish community structure and subsequently to trophic pathways, depending on the sensitivity and adaptive capacity of the affected species (Hollowed et al. 2013). Higher water temperatures may cause an increase in the abundance and proportion of boreal species in the Arctic community. The deep Central Basin will probably be affected less than the shallower shelf seas of the Arctic, as most abundant boreal species are demersal or neritic (the relatively shallow part of the ocean above the drop-off of the continental shelf, approximately 200 m in depth) and such species are not likely to be found in areas deeper than 800-1000 m (Dolgov and Karsakov, 2011).

Occasional appearances of new species have been observed in the Arctic for decades, but these are apparently becoming more frequent. In 1950s, pink salmon was introduced from the Pacific to the Barents and White Seas (Atlas of Russian freshwater fishes, 2002). Norwegian pollock *Theragra finnmarchica* has been known in the Barents Sea since the 1950s (Christiansen et al., 2005;

Barents Sea (Standal, 2003). Furthermore, the presence of foraging schools of ommastrephid squid (Golikov et al., 2012) could indicate an important shift in the pelagic food web of the Arctic.

6. Mamma

6.2 *Trends*

There is a history spanning several centuries of commercial whaling and seal hunting in the Arctic. In some cases, over-harvesting has reduced Arctic marine mammal populations to low numbers and contracted their ranges. Two of the three hooded seal populations were subjected to intense commercial hunting over the past two centuries. In the East Greenland Sea a substantial decrease in hooded seal abundance took place between the 1940s and 1980s (ICES, 2008), and recent surveys suggest that a downward trend continues. Regulation of commercial harvests has led to stabilization or recovery of some other marine mammal populations. All bowhead whale populations were severely depleted by commercial whaling, which began [illegible]

1980s and 2005 (Hammill and Stenson, 2007), but the NE Atlantic hooded seal population has declined by 85-90 per cent over the last 40-60 years (Øigård et al., 2010). For nineteen polar bear subpopulations, seven are declining, four are stable, one is increasing, and insufficient data are available to determine a

7.1

7.2 Trends

Most Arctic seabird populations for which reliable information is available have shown negative trends in recent years. These current trends are superimposed on a situation where several important populations were substantially depressed by fisheries gillnets is also a significant problem in some areas (Bustnes and Tertitski, 2000; Merkel, 2004b; Merkel, 2011) and may be a more widespread concern.

Some recent changes in the status of Arctic seabirds have been linked with climate changes, mostly ascribed to causes operating through the food chain (Durant et al., 2004; Durant et al., 2006; Sandvik et al., 2005; Irons et al., 2008), but direct effects have been documented in a few cases: White et al. (2011) showed that expansion of the great cormorant population in central West Greenland may be related to increased sea-surface temperature. Several potential causes of the decline of ivory gulls in Canada have been identified: mortality from hunting of adults in Greenland (Stenhouse et al., 2004), high levels of mercury in eggs (Braune et al., 2006) and changes in ice conditions (Gilchrist et al., 2008; Environment Canada, 2010). In Hudson Bay in recent years a combination of warm summer weather and earlier emergence by mosquitoes caused the death or reproductive failure among thick-billed murres (Gaston et al., 2002). In addition, polar bears, coming ashore earlier than usual, ate many eggs, chicks and adults of murres and common eiders, leading to complete reproductive failure at some colonies (Gaston and Elliott, 2013; Iverson et al., 2014). Such mortality has increased sharply over the past three decades. arspt2(an)-a(a)20l

8. Socioeconomic Aspects

8.1 Biodiversity and ecosystem services in the Arctic

Biodiversity, whether it is functional, genetic or species-based, plays a role in fundamental processes of nature, i.e., so-called ecosystem processes or intermediate ecosystem services[1], which feed into all final ecosystem services, whether these are provisioning, regulating or cultural services. These latter services contribute directly to human wellbeing, and these benefits can often be valued in economic terms.

Although the ecosystem processes/intermediate services of biodiversity may be essential for most final services, their values as such cannot be added to the value of benefits from final services, as this would imply a double counting. However, it is important to ascertain the significance of biodiversity as an intermediate service in order to ensure that human actions do not limit these services to such a degree that a loss in final services occurs, and that the value of this loss exceeds the value from the human actions that led to them. And despite the remote nature of the Arctic, ecosystem processes related to biodiversity taking place there may provide important services far removed in space and time.

Biodiversity may also be a final service and, for example, it may be included in

In a spatial context, Arctic biodiversity will therefore decline. In some areas, Arctic biodiversity will disappear, but species of boreal ecosystems will increasingly move northwards, increasing boreal biodiversity in these areas. However, the absolute biodiversity may increase, decrease or remain unchanged, due to the combination of extinction and immigration. Increased biodiversity may especially be the case in the shallow marginal seas of the Arctic, but also in a presumed interim period, where both Arctic and boreal species co-exist. This may temporally affect ecosystem processes/intermediate services. The biodiversity dynamics depend on a number of factors, such as immigration, extinctions, possible hybridization, competitive pressures and new pathogens/parasites, as well as human pressures (harvesting, bycatch of Arctic species in targeted harvests of boreal species, bioaccumulation of pollution, stress from ship traffic and oil exploitation, harvesting of eggs and birds, ocean acidification).

As the ice cover declines, the Arctic biodiversity comes under pressure, and some ecosystem services may be lost due to smaller and possibly fragmented suitable areas. This is particularly the case for species that have parts of their life cycle/ history strategy dependent on ice (e.g., seals nursing on ice). A loss of ecosystem processes/intermediate services involving failures in reproduction, predator-prey interactions and habitat composition is then likely.

8.3 Services to humans being affected

On current sub-Arctic shelf areas, where boreal species will become more prominent, ecosystem services, such as those related to fisheries, may increase. This may be advantageous for human coastal communities, indigenous and otherwise, by increasing or securing values connected to benefits of cultural and provisioning services from fisheries. Off-shelf areas may not give increased ecosystem services, despite ice-cover decline, due to stratification inhibiting the mixing of the water masses and thereby limiting the nutrients needed for productive ecosystems (Wassmann, 2011). However, great uncertainty remains regarding these future processes.

Ice decline will have consequences for Arctic biodiversity. This is particularly the case for species that spend part of their life cycle on land and part on ice (e.g., polar bears, seals and walrus). These species supply provisioning and cultural services for commercial and indigenous users in the Arctic, and cultural services for people worldwide due to existence values.

IPCC (2014) identifies a number of climatic change effects that are expected to affect directly the way of life of Arctic indigenous peoples. The indirect effects via marine biodiversity change are more uncertain. Yet as mentioned above, both positive effects regarding fisheries and negative effects in relation to marine mammals may be possible. Where, how, what, and when changes may arise are unsure, and point towards significant knowledge gaps with regard to socio-economic consequences of climate change for indigenous peoples.

8.4 Management

The loss or reduction of services from Arctic ecosystems points to the need to protect the remaining Arctic and Arctic ice areas against activities that might reduce biodiversity (pollution, diseases/parasites, physical and vocal stress); e.g., securing protection in relation to activities of exploitation (fish, oil, minerals, tourism) in ice areas, and transport routes through the Arctic and Arctic ice.

The final service losses likewise point to the need for adaptive and ecosystem based management efforts to limit negative effects of existing and potential human use. This involves sustainable management of current use of resources, and restrictions on aggregating anthropogenic effects in relation to vulnerable Arctic ecosystems and species. It is clear that we will discover and develop ecosystem services in the future that we are not aware of today. Optio

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