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4. Synthesis: Status and trends of Arctic marine biodiversity and monitoring

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Arctic marine ecosystems are highly dynamic and affected by a wide variety of human activities and their consequences, not least climate change. Arctic marine ecosystems are warming twice as fast as the global average (Hoegh-Guldberg and Bruno 2010). Monitoring the status and trends of Arctic biodiversity and attributing causes of change is thus challenging. Complexity, logistics, funding, international coordination, and availability of expertise and technology combine to limit the available knowledge. These limitations affect biotic groups unevenly, with some groups better studied than others, and the information presented in Chapter 3 reflects this. Thus, while some Circumpolar Biodiversity Monitoring Program (CBMP) Marine Expert Networks have many years of more or less standardised monitoring to draw on (i.e., seabirds, marine mammals), others are still at the stage of mapping biodiversity and identifying new taxa, and have very little information on time series (i.e., sea ice biota and plankton). Synthesizing the information from all CBMP Marine Expert Networks into a coherent picture of status and trends of Arctic marine biodiversity is therefore difficult, and the present treatment is inevitably incomplete.

Several recent publications have reviewed the state of Arctic marine ecosystems and their biodiversity (Meltotte 2013, Jørgensen et al. 2016). The release of the *Arctic Biodiversity Assessment* (ABA) provided the baseline against which to identify emerging trends and conduct targeted assessments. The aim of this chapter is not to replicate these efforts, but rather to summarise the limited information available on status and trends in biodiversity and the drivers of these changes, as well as provide an overview of the current state of Arctic marine biodiversity monitoring. The SAMBR provides the first of a series of targeted assessments helping to build upon and further develop our knowledge

and understanding of the status and trends in Arctic marine biodiversity, and to examine how to improve biodiversity monitoring efforts.

The outcomes of the report, including the cooperation to date and the data generated, represent an important step towards improving coordination of marine monitoring across the circumpolar Arctic. Its outcomes will feed into and inform other Arctic Council and circumpolar initiatives e.g., the implementation of the Arctic Council's Framework for a Pan-Arctic Network of Marine Protected Areas (PAME 2015), the Adaptation Actions for a Changing Arctic (AAC) and the planned Integrated Ecosystem Assessment for the Central Arctic Ocean being conducted by the International Council for the Exploration of the Seas (ICES), Arctic Monitoring and Assessment Programme (AMAP), Protection of the Arctic Marine Environment (PAME) and CAFF.

4.1 Status and trends in Arctic marine biodiversity

This section summarizes the available information from the CBMP Marine Expert Networks on recent status and trends in biodiversity (e.g., numbers of species, absolute or relative abundance of particular species). For several Expert Networks, the available information is quite limited, and it is therefore difficult to draw general conclusions. In particular, information on spatial variation in trends is limited for most groups, and thus general trends in the Arctic marine region often remain obscure. This section describes the actual changes and trends identified by the Expert Networks; a discussion of the wider implications of these trends can be found in Chapter 4.2.



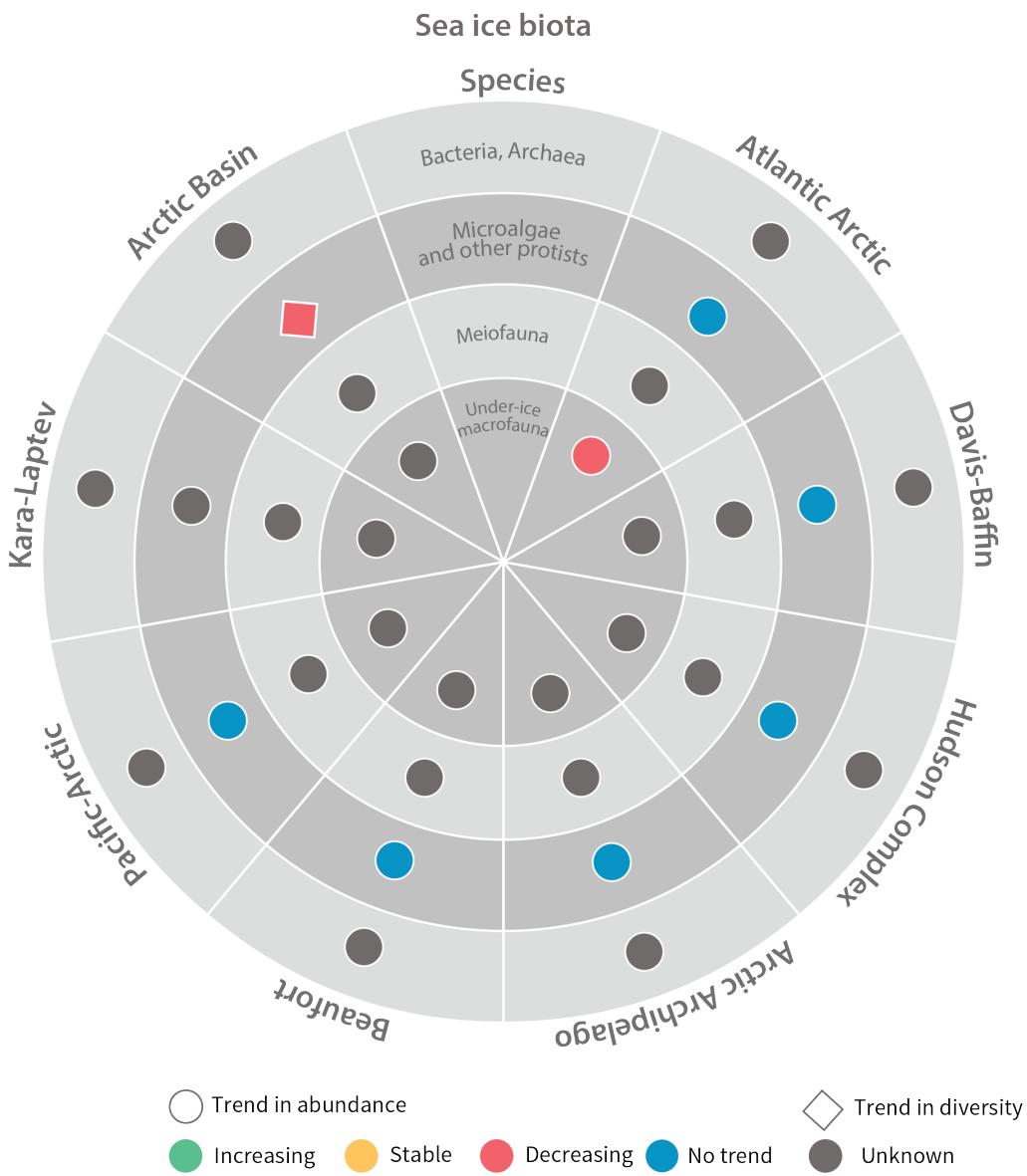


Figure 4.1: Trends in abundance or diversity of sea ice biota Focal Ecosystem Components across each Arctic Marine Area.

4.1.1 Sea ice biota

Many different organisms live in and under sea ice, including microbes, single-celled algae, and small multicellular animals. The status of sea ice biota is generally poorly known due to logistical difficulties, and new species are still being described and their distribution documented. Many species present in sea ice are specialists that only occur in this habitat, whereas others also occur in the water column or sediment. Most ice algae documented in sea ice are large diatoms and dinoflagellates, but this may reflect current knowledge more than real patterns. Meiofauna (animals < 0.5 mm) belong to many different taxonomic groups, and are typically more abundant near land because larvae of benthic organisms also occur in ice. The composition of meiofauna communities appears to vary geographically. The most well-known larger animals living below sea ice are amphipods belonging to the family Gammaridae, which also appear to show large spatial and temporal variations in abundance.

Few time series are available for sea ice biota, which limits our understanding of how these species have changed over time (Fig. 4.1). Studies in the central Arctic Basin have demonstrated a change in community structure of ice algae, with fewer pennate diatoms and more dinoflagellates in recent years (Fig. 3.1.8). This change may be related to the reduction in sea ice thickness. Around Svalbard, a large decline in sympagic amphipods has been observed since the mid-1990s (Fig. 3.1.7) and this has been linked to the decline in multi-year ice. Amphipod abundance is now so low that quantitative sampling by previous quantitative collection techniques is impossible. This may reflect a change towards a seasonal ice community, with greater dependence on recruitment from the sea floor in shallow area and/or the water column and thus favouring planktonic or benthic forms over sea ice specialists.

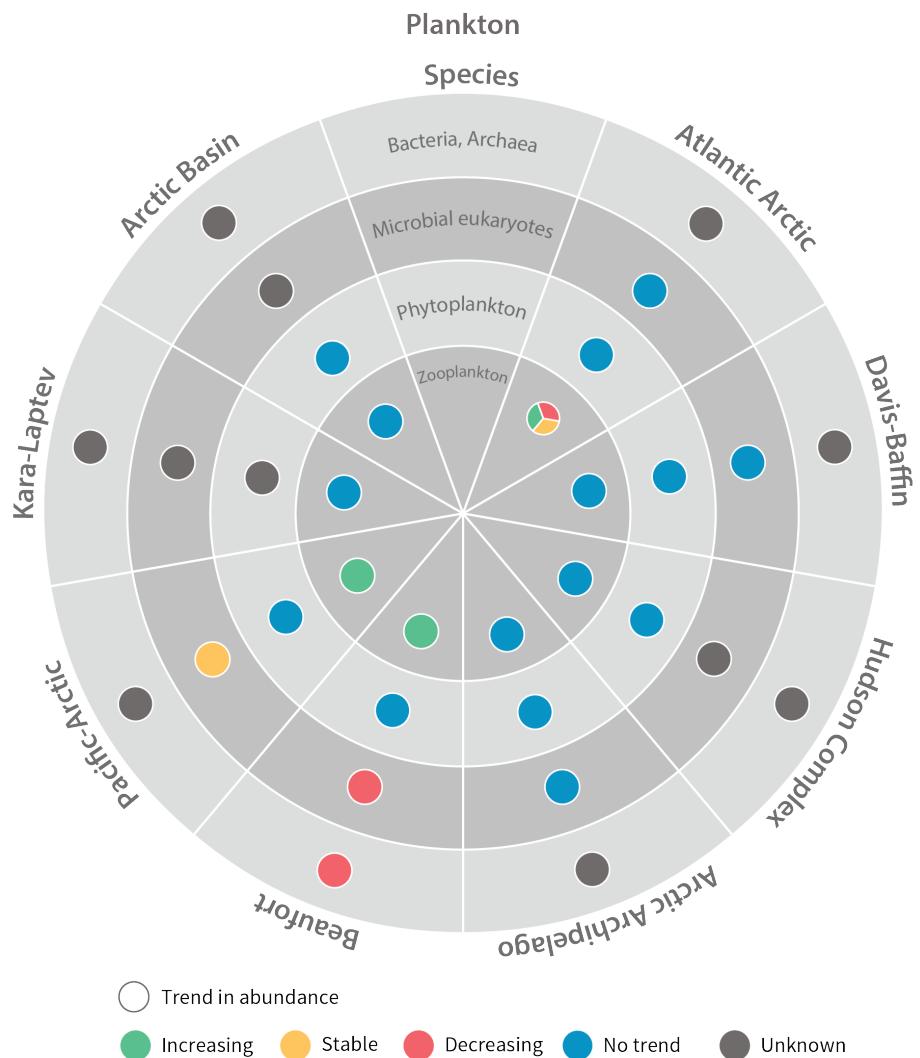


Figure 4.2: Trends in abundance of plankton Focal Ecosystem Components across each Arctic Marine Area.

4.1.2 Plankton

The status of planktonic biodiversity in the Arctic is insufficiently known, particularly for the microbial forms (Bacteria, Archaea and small eukaryotes) where distribution and relative abundance are still being documented through molecular techniques. Arctic phytoplankton is highly diverse, with many species and groups represented; many of these species are mixotrophic and can also act as consumers. Diatoms often dominate the spring bloom, whereas chlorophytes are common during summer, including the ubiquitous *Micromonas*. In the zooplankton, large copepods of the genus *Calanus* and its relatives are specifically important for energy transfer to higher trophic levels, due to their abundance and high energy content in the form of stored lipids.

The available information on trends for plankton differs substantially between species groups (Fig. 4.2). For microbial plankton, the use of molecular techniques is generally so recent that no time series exist. One study from the Beaufort Sea showed large differences in species composition before and after the 2007 sea ice minimum (Comeau et al. 2011).

More time series are available for groups that can be studied using traditional techniques. Short time series show complex

inter-annual variation in phytoplankton composition in two fjords in Svalbard (Kongsfjorden and Rijpfjorden), and this is likely linked to variation in Atlantic water inflow (Fig. 3.2.5). The best data exist for the larger copepods (genus *Calanus* and relatives). In the Chukchi Sea, increases have been documented of four species of large copepods, including the high Arctic *Calanus glacialis*, concurrent with increasing ocean temperature (Fig. 3.2.6). Detailed studies in Young Sund in the Greenland Sea show a change in dominant copepods from the near-shore *Pseudocalanus* to the oceanic *Microcalanus*, probably caused by increased flushing of the fjord due to less sea ice (Fig. 3.2.7). The ratio between the high Arctic *Calanus glacialis* and the boreal *C. finmarchicus* has varied in Kongsfjorden in Svalbard, linked to annual differences in temperature (Fig. 3.2.9). In the Barents Sea, there has been a decrease in *C. glacialis*, as well as changes in the species composition of amphipods and krill towards more southern species.

Overall, these results confirm that plankton communities are highly sensitive to climatic forcing and that further rapid changes in species composition can be expected (cf. Hays et al. 2005). Such changes potentially have wide-ranging implications for higher trophic levels, as the plankton community varies seasonally with species of different sizes and nutritional values for predators.

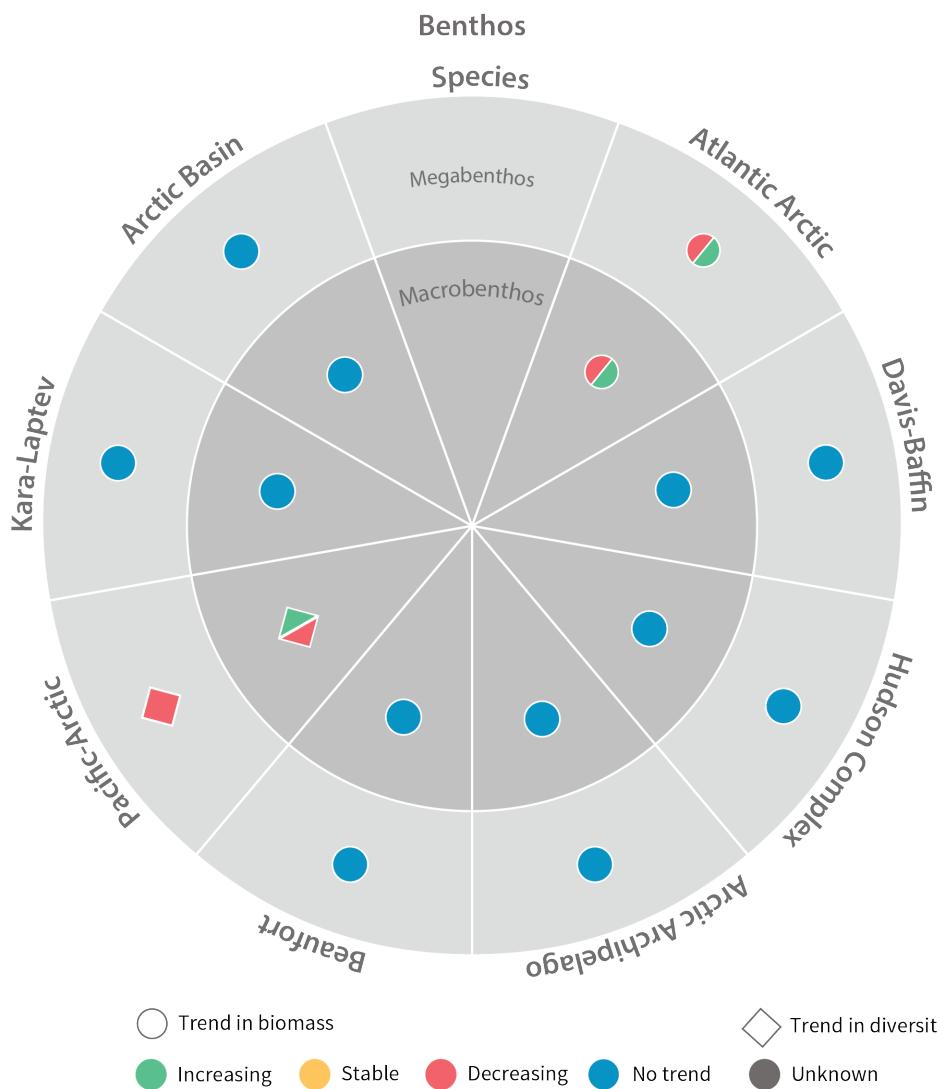


Figure 4.3: Trends in biomass or diversity of benthic Focal Ecosystem Components across each Arctic Marine Area.

4.1.3 Benthos

The ocean floor is inhabited by many different organisms from microbes to large invertebrates. All these organisms depend on food supply derived from planktonic (or sea ice) communities in the overlying water column. Tiny animals (meiofauna) and microbes consume the organic material (detritus) and release nutrients, and at the same time serve as food for larger animals, such as worms, bivalves and crustaceans. However, sufficient survey data only exist to assess status and trends for the larger animals, macro- and megabenthos, and even for these groups biodiversity is incompletely known and species lists are still expanding.

Few time series exist of benthos species composition or abundance, despite significant levels of research (Fig. 4.3). Many benthic organisms are long-lived (up to > 500 years for the bivalve ocean quahog (*Arctica islandica*), Butler et al. 2013) and sessile (e.g. corals), while others

are mobile (e.g., crabs). These species integrate long-term variation in conditions in the water column over long time spans. Permanent changes (i.e., not seasonal) in benthic communities can therefore be quite slow.

The best-studied region of the Arctic in terms of benthos is the Barents Sea. The extensive time series concern, among others, macrobenthos biomass, which has shown complex spatial patterns of change over shorter and longer time spans (Figs. 3.3.2, 3.3.3). This is probably due to new species entering the Barents Sea (snow crab (*Chionoecetes opilio*), king crab (*Paralithodes camtschaticus*)) or Arctic species generally being replaced by more boreal species. Similarly, there are complex long-term changes in benthos biomass in the Chukchi and northern Bering Seas that may have implications for the food availability for sea ducks and walrus (Fig. 3.3.6).

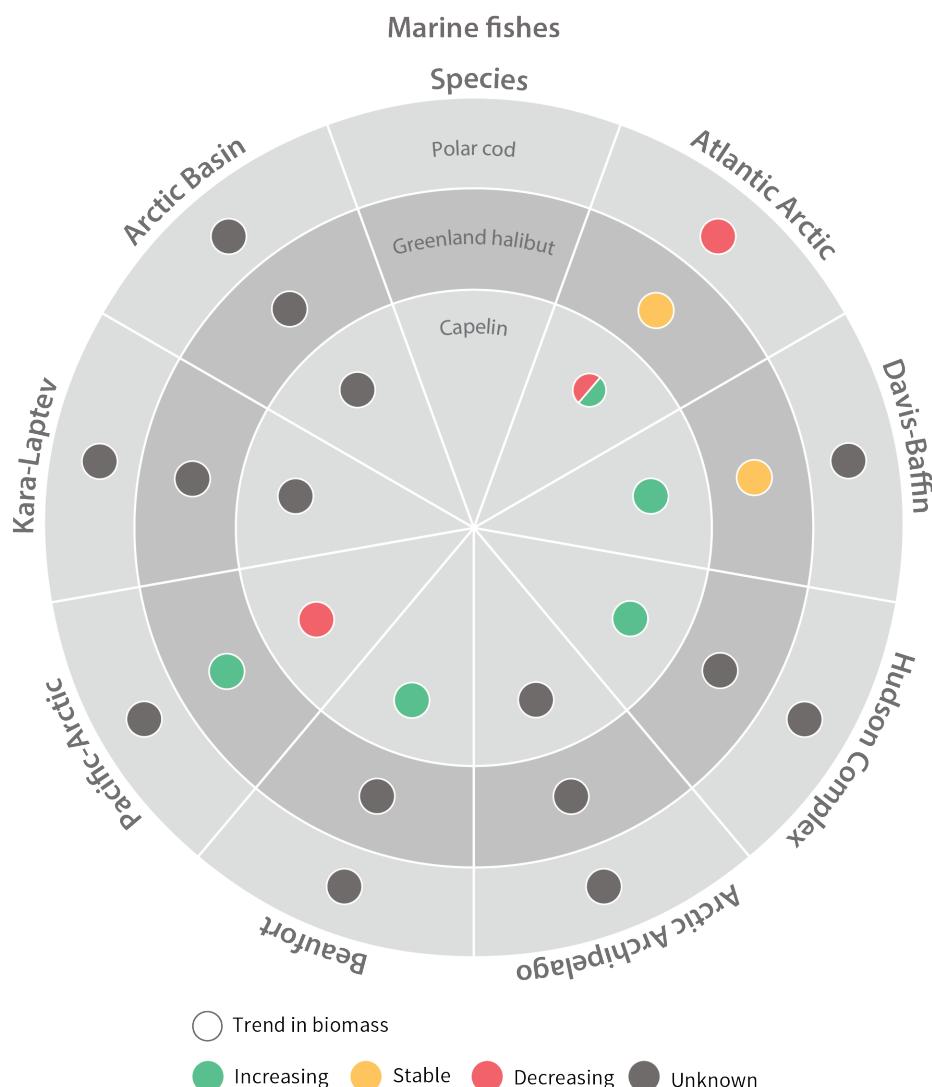


Figure 4.4: Trends in biomass of marine fish Focal Ecosystem Components across each Arctic Marine Area.

4.1.4 Fishes

Fish biodiversity in the marine Arctic is surprisingly poorly known. A large number of species have been documented, but in many cases their distribution, abundance and relationships are largely unknown. Only the few species of commercial interest have been studied extensively. The most important of these in the area covered by this report are capelin (*Mallotus villosus*), polar cod (*Boreogadus saida*) and Greenland halibut (*Reinhardtius hippoglossoides*).

There are few fishery-independent long-term studies of fish abundance or biomass in the Arctic (Fig. 4.4). Monitoring in the Barents Sea has shown a large decline in polar cod since 2005 (Fig. 3.4.3), probably due to poor recruitment

related to decline in sea ice, predation from Atlantic cod (*Gadus morhua*), and competition from capelin. On the other hand, capelin increases in recent years throughout the high Arctic have been associated with warming trends, although the capelin stocks typically vary periodically from high abundance to very low (references in Chapter 3.4). Capelin and polar cod stocks in the Arctic vary considerably among years, and the most recent data (Russian-Norwegian Ecosystem Survey and Marine Research Institute of Iceland, unpubl. data 2016) show an increase in polar cod and decline in capelin in the Barents Sea, as well as a decline in Icelandic capelin (Chapter 3.4). Greenland halibut stocks are generally stable or growing and therefore this species still does not yet seem to be adversely affected by climate change.

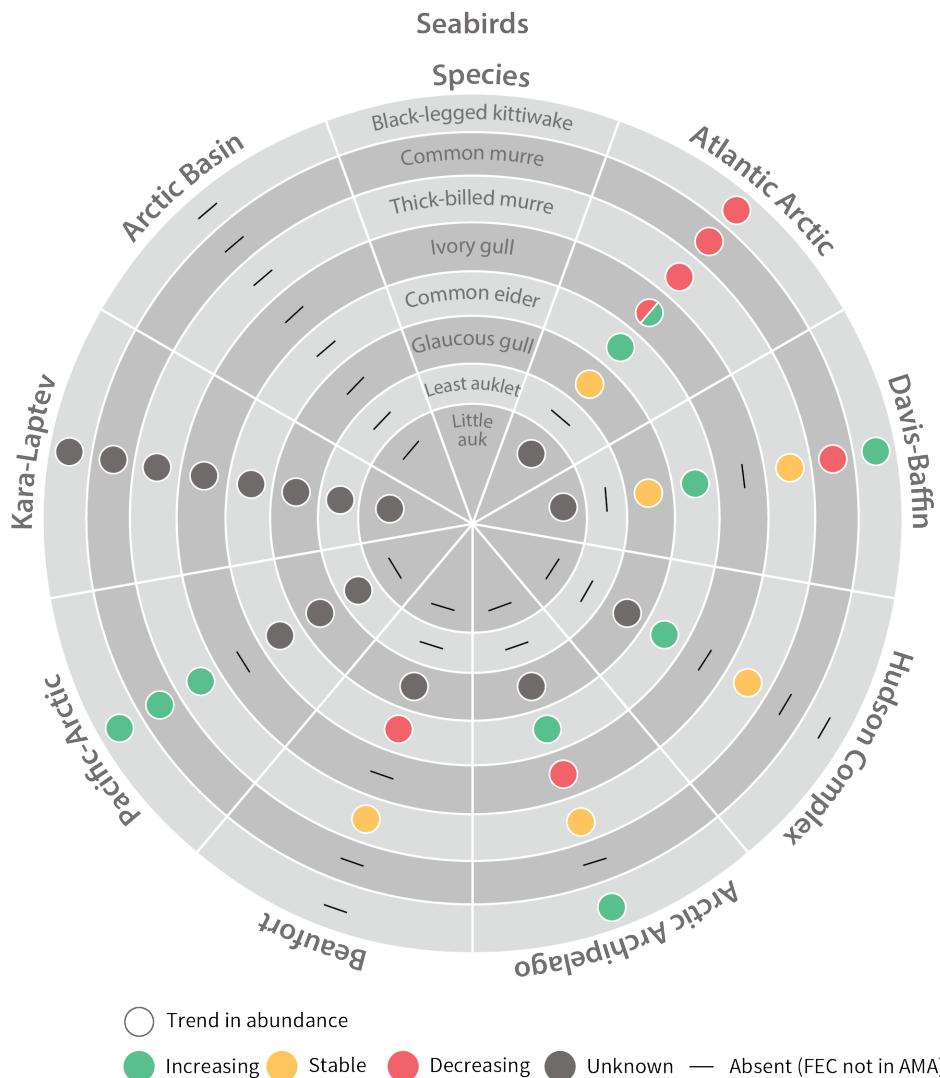


Figure 4.5: Trends in abundance of seabird Focal Ecosystem Components across each Arctic Marine Area.

4.1.5 Seabirds

Around 30 species of seabirds breed in the Arctic as defined here, and most of these are migratory and leave Arctic waters during the winter. The most diverse groups are gulls and auks. Some species are extremely numerous, particularly the little auk which occurs in millions in northern Baffin Bay. Other species are rare and local in occurrence. Seabirds have different ecological roles, and eight species have been selected as priorities for monitoring to reflect this diversity, representing the following five functional groups (see Chapter 3.5): diving piscivores, diving planktivores, surface piscivores, benthic feeders, and omnivores.

Seabird population trends are relatively well known, although not for all species (Table 3.5.2, Fig. 4.5). Several of the monitored species have shown widespread declines in recent years, at least in parts of the Arctic. The piscivorous common murre (*Uria aalge*), thick-billed murre (*Uria lomvia*) and black-legged kittiwake (*Rissa tridactyla*) (Fig. 3.5.3) have declined particularly in the Atlantic Arctic (and to

some extent Davis Strait-Baffin Bay), and the two latter species are subjects of detailed investigations. These declines are consistent with wider changes in the pelagic ecosystem in the North Atlantic, affecting seabirds over a wide range (Frederiksen 2010, Frederiksen et al. 2013). A similar geographical pattern is apparent for the omnivorous glaucous gull (*Larus hyperboreus*) and the benthic feeder common eider (*Somateria mollissima*), whereas the ivory gull (*Pagophila eburnea*) has declined throughout its Arctic range. At local levels, some observed changes are counterintuitive. For example, planktivorous seabirds have increased offshore in the Chukchi Sea relative to piscivorous species (Chapter 3.5, Box 1), which is opposite to what is expected in a general warming scenario with less sea ice (cf. Hunt et al. 2002). However, the increase in planktivorous seabirds is consistent with the increase observed for large copepods in the same area, even for the High Arctic *Calanus glacialis* (Fig. 3.2.6). In contrast, most of the seabird species that nest in the Chukchi are piscivorous, thus their response to ecosystem changes might lag behind that of planktivorous post-breeding migrants.

Marine mammals

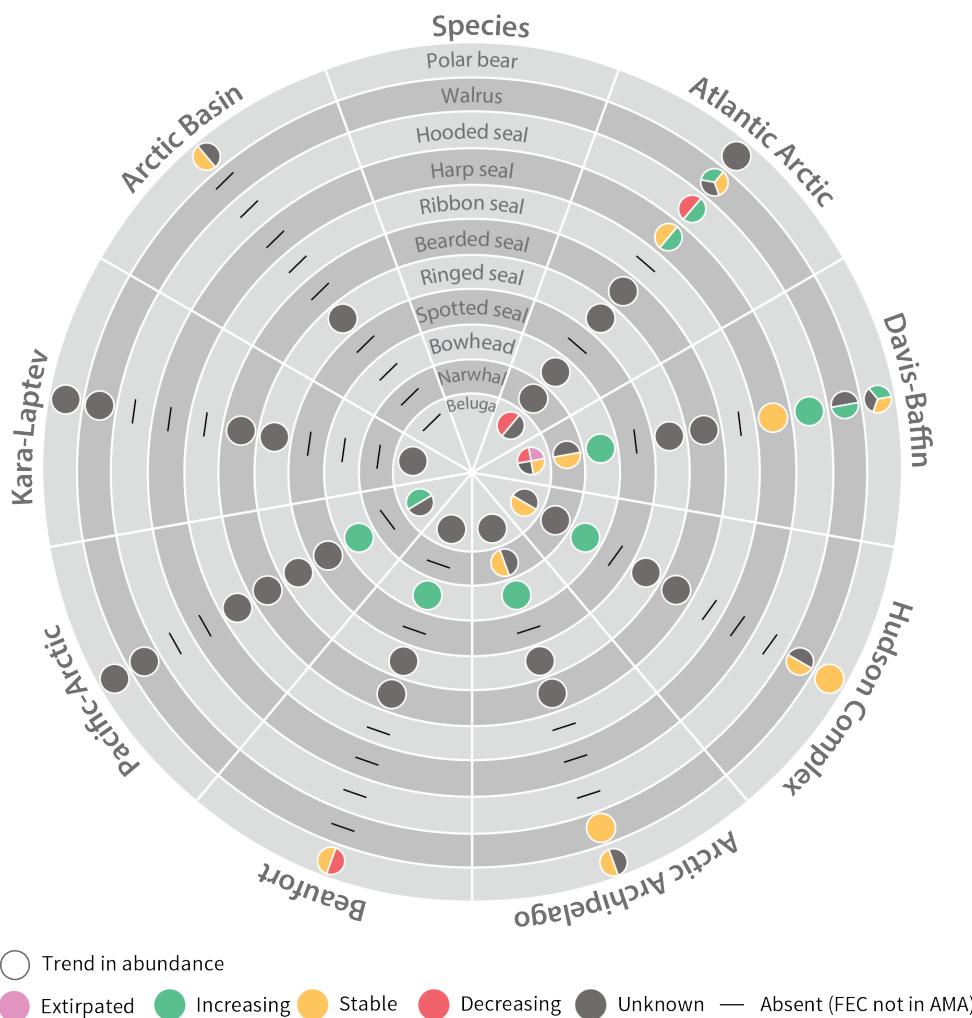


Figure 4.6: Trends in abundance of marine mammal Focal Ecosystem Components across each Arctic Marine Area.

4.1.6 Marine mammals

Eleven species of marine mammals (seals, whales and polar bear (*Ursus maritimus*)) are regarded as Arctic and associate with sea ice for at least part of their life cycle. Four of these are sub-Arctic seals that migrate into the Arctic (two each in the Pacific and Atlantic), while the remaining seven are circumpolar and occur in the Arctic year-round. All species and most populations are, or have been, harvested by humans on a large scale. The current status of some species is still affected by past harvest, for instance hooded seal (*Cystophora cristata*) in the Greenland Sea. Overall, one quarter of all populations (or half of those for which sufficient information exists) are regarded as reduced in size because of unsustainable hunting in the past. In most cases, quotas regulate current harvest, and in many indigenous communities, traditional management practices are still used to govern harvest activities (ICC-Alaska 2015).

Trends are known for approximately half of Arctic marine mammal stocks (Fig. 3.6.2, Table 3.6.1, Fig. 4.6). In general, trends for wide-ranging species (e.g., ringed seal (*Pusa hispida*), bearded seal *Erignathus barbatus*), and ribbon

seal (*Phoca fasciata*) are least understood, while distinct populations or stocks that occur in well-defined geographic areas more often have documented trend information (e.g., narwhal (*Monodon monoceros*) and some polar bear populations). Most populations with known status are increasing or stable, but e.g. those of beluga (*Delphinapterus leucas*) in the White Sea, polar bear in the southern Beaufort Sea, and hooded seal in the Greenland Sea are declining. Because many stocks were reduced by past unsustainable harvest, harvest history has to be included as an important driver of observed trends. Many stocks are still recovering from past harvest (e.g., bowhead whale (*Balaena mysticetus*), walrus (*Odobenus rosmarus*)), while others have not been able to do so, probably due to climate change (e.g., Greenland Sea hooded seal).

For some species, there is considerable regional variation in trends in e.g., body condition. For example, ringed seals experience reduced body condition and reproduction in Hudson Bay and the eastern Beaufort Sea, whereas no decline in body condition has been observed off Alaska (references in Chapter 3.5).

4.2 Evidence for the impacts of drivers on Arctic marine biodiversity

4.2.1 Observed and expected impacts of climate change

Several reviews have assessed the evidence for observed climate-driven changes in Arctic marine biodiversity (e.g., Wassmann et al. 2011, Post et al. 2013). Rather than attempting another review, key contributions from the CBMP Marine Expert Networks are highlighted (referenced to sections of Chapter 3) and placed in a broader ecosystem context. More details about specific cases can be found in Chapter 3. A short description and review of changes and trends in physical drivers and anthropogenic stressors can be found in Chapter 2.

Increasing ocean temperature

Physiological changes among key primary producers may have strong implications for higher trophic levels. In the pelagic realm, increasing temperatures are expected to affect the composition of phytoplankton communities, with flagellates favoured over diatoms (Chapter 3.2). This may have cascading effects on zooplankton communities, where different species and groups are adapted to feed on specific types of algae. In turn, these changes in zooplankton species composition may affect planktivorous fish and seabirds, some of which depend on large, lipid-rich copepod species for growth and successful reproduction (ICES 2016; Chapter 3.5). At the same time, increased primary productivity (due to a longer ice-free season and more wind-driven upwellings) will favour increased zooplankton stocks, but this may be counteracted by increased stratification due to ice melt and limited nutrients, particularly in the Arctic Basin (Chapter 3.2). Regional variation is expected in the relative role of these two processes. If strong algal blooms become increasingly common in Arctic waters, this could have impacts e.g. on seabirds and fish, due to either toxic effects or increased turbidity affecting foraging for visual predators (Chapter 3.5).

Indirectly, increasing temperatures are likely to lead to range shifts in Arctic species, and many such shifts have already been observed. An important example concerns the boreal copepod *Calanus finmarchicus*, which in the Atlantic Arctic is expected to expand northwards at the expense of its larger relatives *C. glacialis* and *C. hyperboreus* (Stempniewicz et al. 2007, Kjellerup et al. 2012). Similarly, capelin is likely to expand northwards into the Arctic at the expanse of polar cod (Chapter 3.4; Hop and Gjøsæter 2013) and indeed this process has already been observed throughout the Arctic (Chapter 3.4). The shift in dominance from polar cod to capelin has led to changes in seabird diet in northern Hudson Bay (Gaston and Elliott 2014) and may also affect the food base for marine mammals, as capelin may be less lipid-rich than polar cod, at least seasonally (Chapter 3.6; Hop and Gjøsæter 2013). While pelagic and deep-water species are able to spread northward into the Arctic Ocean as temperatures increase, this may not be the case for species linked to shelf regions, including benthos, fishes and seabirds (Chapters 3.3, 3.4, 3.5).

At the same time, new species are entering the Arctic from more southern areas as temperatures increase, and this may affect Arctic biodiversity in many different ways. Fish species from warmer waters have been documented in many areas (Chapter 3.4). Pelagic fish predators such as Atlantic mackerel (*Scomber scombrus*) and bluefin tuna (*Thunnus thynnus*) have recently arrived in Arctic waters off Greenland, and mackerel has been observed off Svalbard (MacKenzie et al. 2014, Berge et al. 2015); this may lead to changes in predation pressure on pelagic fishes as well as in human fisheries. ‘New’ (often migratory) species of cetaceans may act as competitors (e.g., minke whale (*Balaenoptera acutorostrata*) and humpback whale (*Megaptera novaeangliae*)) or predators (killer whale (*Orcinus orca*)) of resident Arctic specialists (Chapter 3.6). In northern parts of the Barents Sea, a pronounced ‘borealisation’ of demersal communities has been observed, i.e. an increased dominance of boreal species (Chapter 3.3). Atlantic cod has also expanded into the northern Barents Sea and this has led to increased overlap with and predation on polar cod (Chapter 3.4, Box 1). In the Pacific sector, several boreal or temperate seabird species have become increasingly common as non-breeders in the Chukchi Sea (Chapter 3.5).

Higher sea temperatures, combined with reduced sea ice coverage, is also likely to allow movements of organisms (e.g., fish) between the north Atlantic and Pacific Oceans, with unpredictable consequences for resident species and ecosystems (Mecklenburg et al. 2014, Wisz et al. 2015). Likewise, establishment and spread of non-native species may be facilitated.

An increase in contagious diseases affecting seabirds and potentially pinnipeds on their terrestrial breeding grounds may also be linked to increasing temperatures, for example the recent occurrence of avian cholera in the northern Bering Sea and in the Arctic Archipelago (Chapter 3.5, Descamps et al. 2012).

Reduction in sea ice

Species tightly linked to sea ice, often referred to as sympagic biota, are expected to lose habitat and contract their distributional ranges. As an example, polar cod and ice cod (*Arctogadus glacialis*), which are the most widespread and important sympagic fish species, are expected to lose much of their year-round habitat (Chapter 3.4). Because these are ecologically very important, this will affect their predators, which include many species of marine mammals and seabirds (Chapters 3.6 and 3.5). Among sea ice biota more generally, the decline in multi-year ice will affect species composition (Chapter 3.1). This implies that specialist species strictly linked to ice are disfavoured, while more generalist species, able to thrive also in pelagic environments, are expected to increase.

The primary productivity of microalgae may increase with thinning ice (leading to higher light penetration) or stronger upwelling (due to retreating ice), but this may be counteracted by less ice and stronger stratification due to increased freshwater influence, either from melting ice or river runoff (Chapter 3.1 and 3.2). At the same time, increased freshwater influence may favour brackish water (and smaller) species at the expense of marine species (Chapter 3.1).

and 3.2). Changes in relative contribution of ice algae and phytoplankton to the primary productivity may potentially lead to reduced benthic-pelagic coupling, which in turn may affect benthos (Chapter 3.3) and lead to reduced food supply for species such as shrimp and walrus (Chapters 3.3 Box 3, 3.6).

For most species of marine mammal, seasonal pack ice is the most important habitat feature. Declines in seasonal ice cover may thus lead to reductions in breeding sites for seals and to a loss of haul-out sites for walrus that may affect their opportunities for foraging during both breeding season and winter (Chapter 3.6). Observed patterns of change can be complex and difficult to interpret, for example harp seals have increased due to recovery from past harvest, but the population increase combined with declining sea ice has at the same time led to density-dependent declines in condition and reproduction (Chapter 3.6, Stenson et al. 2016). As the decline in sea ice cover shows large regional variation, stocks of ice-dependent seals are also likely to show highly different trends, with possible extirpation of some stocks (Chapter 3.6).

A well-known consequence of reductions in sea ice cover is the loss of polar bear habitat (Chapter 3.6). This has been demonstrated to have negative consequences for the bears, because they rely on ice as hunting grounds to access seals, a highly nutritious food source. Observed and expected consequences include reduced body condition, lower survival, and ultimately population declines (Stirling and Derocher 2012). Indirect effects have already been observed, in the form of increased polar bear predation on ground-nesting birds, e.g., common eider (Iverson et al. 2014, Prop et al. 2015). As sea ice cover diminishes, polar bears are forced to spend time on land, which increases interactions with coastal communities (Chapter 3.6).

Some seabirds also rely on access to foraging at or near the ice edge during the summer breeding season. The retraction of the summer sea ice edge has in some cases led to problems for associated seabird populations, notably black guillemots (*Cephus grylle*) in Alaska (Divoky et al. 2015).

Changes in currents

Global increases in ocean temperature are likely to cause some major currents to strengthen and others to weaken (Chapter 2), which can have implications for biota. As an example, changes in the strength of the Subpolar Gyre southeast of Greenland have been statistically linked to declines in the Spitsbergen thick-billed murre population, although the potential mechanism is unknown (Chapter 3.5, Descamps et al. 2013).

Inuit hold a great amount of knowledge about ocean currents. It is easy to appreciate the extent of knowledge that would be held by a group of people that are culturally and spiritually tied to the ocean and that greatly rely on it for food from time immemorial. Inuit have observed changes in currents over time. Raymond-Yakoubian et al. (2014b) provide a report on use of Bering Strait region ocean currents. Within the report, Indigenous peoples of the Bering Strait region of Alaska share the significance of the ocean and changes that

have been observed: "Changing weather and ocean currents have altered the off-shore sea floor, sometimes creating large dips where clams, for instance, become trapped and therefore do not wash ashore in as large numbers as in the past". The change in ocean currents is directly related to change in sea ice and storms. Raymond-Yakoubian et al. (2014a) further report that, "Communities have also reported stronger storms in recent years. These storms move a lot of water (and ice) around, and appear to also be changing the nearshore sea floor. Residents of Wales and Shishmaref report that 'dips' and 'valleys' have developed offshore from their communities. These changes in the sea floor may impact ice formation, where ice piles, and the availability of clams."

4.2.2 Other major anthropogenic stressors

Many of the drivers and threats listed in this section interact with climate change, either because the associated human activities are expected to change in intensity or spatial distribution as the climate warms, or because chemical or biological reactions and pathways are likely to change. Furthermore, the various stressors will interact among themselves in complex ways, and there is therefore a need to address also cumulative impacts across stressors (see Chapter 2.4).

Ocean acidification

Arctic oceans are expected to be particularly vulnerable to the effects of ocean acidification (AMAP 2013). While acidification itself is monitored in some parts of the Arctic (Chierici et al. 2016), there is currently no monitoring of the biological effects and, thus, little specific evidence to inform an assessment of the importance of this driver for biodiversity. Few studies have investigated the potential impact of ocean acidification on Arctic species, especially studies on the entire life cycle and from across the entire Arctic. However, those that exist point to likely ecosystem effects of ocean acidification in the Arctic. For Arctic primary producers, increased pCO₂ may cause an increase in gross primary productivity (though only at low temperatures; Holding et al. 2015), and a shift in community composition with potential to indirectly affect the trophic transfer to grazers (Tarling et al. 2016). Recent studies on the dominant zooplankton taxa in the Arctic, calanoid copepods and pteropods, show mixed effects. Calcifying pteropods appear to be quite sensitive to increased pCO₂, with decreased calcification, increased respiration, increased mortality in juveniles and adults, and decreased recruitment (Browman et al. 2013). On the other hand, many life stages of non-calcifying *Calanus* copepods are tolerant to realistic future pCO₂ levels, including their naupliar development and growth (Bailey et al. 2016) as well as adult respiration and ingestion (Hildebrandt et al. 2014). Arctic benthic calcifiers, including molluscs, echinoderms and crabs, are generally negatively affected by increased pCO₂ (Browman et al. 2013), with the potential to put at risk the many fish species which prey on them at some point in their lives (Mathis et al. 2015). Atlantic cod, which is moving north into the European Arctic, also appears to be affected by increased pCO₂ during its early life phases (Stiasny et al. 2016).

Contaminants

High levels of contaminants have been shown to pose health risks for marine mammals such as polar bears (Sonne 2010) and for the human communities that depend on them (Chapter 3.6, Sonne et al. 2013). At the population level, specific contaminants have been shown to have consequences for predators such as the glaucous gull (Erikstad et al. 2013) and black-legged kittiwake (Goutte et al. 2015). Contaminant burdens can interact with climate change in different ways, either because changes in the physical environment may lead to increased exposure to contaminants, e.g. polar bears affected by reduction in sea ice (Jenssen et al. 2015), or because of climate-related changes in pollutant pathways, e.g. increased biomagnification of pollutants through food webs as sub-Arctic prey species become more common (McKinney et al. 2015).

Industrial developments and activities

Noise is one of the most widespread impacts of industrial activities, including seismic surveys, drilling and shipping. Noise is expected to primarily affect marine mammals, which use sound for underwater communication and foraging (Richardson et al. 1995, Miller et al. 2015). Noise may cause redistribution of marine mammals, particularly whales, thus affecting human communities (Chapter 3.6). If animals are prevented from accessing important foraging areas, there is a potential for population-level impacts.

In addition to noise and the risk of oil spills, increased shipping in the Arctic may also lead to disturbance and habitat loss for seabirds and marine mammals. Direct mortality can occur through vessel strikes of whales (Chapter 3.6) and of seabirds during inclement weather or darkness (Chapter 3.5).

Invasive alien species

The introduction and spread of invasive alien species is regarded as one of the most important threats to biodiversity worldwide. Shipping is the main source of introduction of potentially invasive species in marine environments. So far, there are few examples of invasive marine species becoming established in the Arctic. However, in the Barents Sea two large non-native crab species (snow and king crab) have become very numerous and are under suspicion of affecting benthic communities (Chapter 3.3, Oug et al. 2011).

While the king crab was intentionally introduced from the North Pacific in the 1960s by Russian scientists to create a new and valuable fishing resource in the Barents Sea (Orlov and Karpevich, 1965, Orlov and Ivanov, 1978), the snow crab was originally assumed to be introduced to the Barents Sea via ballast water (Kuzmin 2000, Alvsvåg et al. 2008). However, recent analysis of genetic data from circumpolar samples (Bering Sea, Beaufort Sea, Chukchi Sea, east Canada, West Greenland and Barents Sea) indicate that the snow crabs now observed in the Barents Sea derive from a natural invasion, possibly from the east, i.e., Novaya Zemlya/Kara Sea (G. Dahle, pers. comm.). The potential effects of the two species on benthic ecosystems and fisheries are disputed, with some researchers arguing caution while others conclude that no major effects are likely (Britayev et al. 2010, Oug et al. 2011,

Falk-Petersen et al. 2011, Dvoretsky and Dvoretsky 2015). Invasive terrestrial predators can be a very serious threat to ground-nesting seabirds, but so far few examples are known from the areas covered by this report.

Harvest (direct and indirect effects)

Many species of fish, seabirds and marine mammals have been harvested by both local communities and international fleets for centuries. Some stocks of fishes, large whales and seals were reduced to a small fraction of their original sizes, and their current trajectories are still to some extent related to recovery from past overexploitation (Chapters 3.4, 3.6). This complicates the interpretation of current trends in relation to environmental drivers. Some seabird populations are still affected by harvest in addition to other stressors, but in most cases harvest has declined substantially (Chapter 3.5, Merkel 2010).

The spatial extent of industrial-scale fisheries has until now been limited by the extent of sea ice. As the ice retreats, there is potential for expansion into previously unfished areas. The main species expected to be of interest to fisheries in the Arctic Basin is the Greenland halibut (Chapter 3.4).

Trawl fisheries have profound impacts on benthic habitats, their biodiversity and connections throughout the food web (Chapter 2). In the Barents Sea, declines in benthic biomass have been linked to the intensity of bottom trawling (Chapter 3.3) and this is likely also important in other parts of the Atlantic Arctic. There is a concern about future impacts of trawling in previously unfished areas (Jørgensen et al. 2015), which become available as a consequence of climate change (Chapter 3.3). The benthos composition is being monitored as the ice retreats, and this is unveiling sea pens (*Cnidaria, Pennatulacea, Umbellula encrinus*) and other large-bodied upraised species easily caught and therefore vulnerable to bottom trawling. Along the western shelf of Norway, there is a risk of strong impacts on cold-water corals and sponges (Chapter 3.3), and large aggregations of sponges have been observed on the slope from the western shelf of Norway and northward along western and northern Svalbard and further east toward the Kara Sea.

Bycatch in gill nets may have negative effects on some species of seabirds locally, e.g., in Iceland, Norway and Canada (Chapter 3.5, Fangel et al. 2015, Hedd et al. 2016), but currently seems to be of less concern in other parts of the Arctic (e.g., Merkel 2011), probably due to the spatial distribution of particular fisheries relative to seabird concentrations. Development of nearshore gillnet fisheries in e.g., the Pacific Arctic, could lead to increased bycatch with potentially major impacts on seabird populations.

4.2.3 Links to non-Arctic ecosystems

Many seabirds and marine mammals spend the summer in the Arctic, but leave when seasonal ice cover and darkness set in. They spend the northern winter in areas ranging from the sub-Arctic (e.g., thick-billed murre, Frederiksen et al. 2016) to the Southern Ocean (e.g. Arctic tern (*Sterna paradisaea*), Egevang et al. 2010). Several studies have suggested causal links between conditions in wintering areas and population trends or demography of Arctic-breeding seabirds (Descamps

Table 4.1: Comparison of FECs as defined in the CBMP Marine Plan and those reported on in the State of the Arctic Marine Biodiversity Report (SAMBR)

FECs as defined in the CBMP Marine Plan		FECs used in SAMBR	
Marine mammal		FECs used in SAMBR	
Walrus	<i>Odobenus rosmarus</i>	Beluga	<i>Delphinapterus leucas</i>
Ringed seal	<i>Pusa hispida</i>	Narwhal	<i>Monodon monoceros</i>
Beluga	<i>Delphinapterus leucas</i>	Bowhead whale	<i>Balaena mysticetus</i>
Bowhead whale	<i>Balaena mysticetus</i>	Spotted seal	<i>Phoca largha</i>
Polar bear	<i>Ursus maritimus</i>	Ringed seal	<i>Pusa hispida</i>
		Bearded seal	<i>Erignathus barbatus</i>
		Ribbon seal	<i>Phoca fasciata</i>
		Harp seal	<i>Phoca groenlandica</i>
		Hooded seal	<i>Cystophora cristata</i>
		Walrus	<i>Odobenus rosmarus</i>
		Polar bear	<i>Ursus maritimus</i>
Seabirds		Seabirds	
Black-legged kittiwake	<i>Rissa tridactyla</i>	Glaucous gull	<i>Larus hyperboreus</i>
Common murre	<i>Uria aalge</i>	Ivory gull	<i>Pagophila eburnea</i>
Thick-billed murre	<i>Uria lomvia</i>	Least auklet	<i>Aethia pusilla</i>
Common eider	<i>Somateria mollissima</i>	Little auk	<i>Alle alle</i>
		Common murre	<i>Uria aalge</i>
		Thick-billed murre	<i>Uria lomvia</i>
		Black-legged kittiwake	<i>Rissa tridactyla</i>
		Common eider	<i>Somateria mollissima</i>
Fishes		Fishes	
Capelin	<i>Mallotus villosus</i> spp.	Capelin	<i>Mallotus villosus</i> spp.
Polar cod	<i>Boreogadus saida</i>	Polar cod	<i>Boreogadus saida</i>
Greenland halibut	<i>Reinhardtius hippoglossoides</i>	Greenland halibut	<i>Reinhardtius hippoglossoides</i>
Pelagic fish			
Salmon			
Arctic char			
Benthic and demersal fish			
Ice cod	<i>Arctogadus glacialis</i>		
Atlantic cod	<i>Gadus morhua</i>		
Alaska pollock	<i>Gadus chalcogrammus</i>		
Bering flounder	<i>Hippoglossoides robustus</i>		
Shorthorn sculpin and related sculpin	<i>Myoxocephalus scorpius</i>		
Benthos		Benthos	
Macrofauna and megafauna		Macrobenthos	
Macroalgae		Megabenthos	
Meiofauna and microbes			
Plankton		Plankton	
Phytoplankton		Phytoplankton and larger protists	
Protists (e.g., microzooplankton)		Microbial eukaryotes	
Microbes (Archaea, Bacteria)		Bacteria and Archaea	
Zooplankton (e.g., meso- and macrozooplankton)		Zooplankton	
Sea ice biota		Sea ice biota	
Diatoms		Prokaryotic microbes, including Archaea and Bacteria	
Dinoflagellates		Ice algae and other single-celled eukaryotes	
Flagellates		Ice meiofauna	
Interstitial diatoms		Macrofauna: Under-ice amphipods	
Interstitial and under-ice layer invertebrates		<i>Note: Sea ice associated fish, specifically polar cod and ice cod, are included in the fish chapter. Viruses and fungi were excluded</i>	

et al. 2013, Reiertsen et al. 2014). In addition, some southern-hemisphere seabird species spend their non-breeding season in the Arctic summer and may comprise half of all seabirds in some regions, e.g. Short-tailed shearwaters (*Ardenna tenuirostris*) in the northern Bering and Chukchi Seas (Chapter 3.5).

Just as conditions in non-Arctic wintering areas may affect populations of Arctic-breeding birds or mammals, numbers wintering in specific areas may change because of changes in population size or migratory behaviour of Arctic animals. There are as of yet no documented cases of major changes in migration behaviour of Arctic-breeding seabirds or marine mammals. However, some species of ducks breeding in the Siberian tundra and wintering at sea have shortened their migration in response to declines in winter ice cover, leading to declines in numbers wintering in former core areas (e.g., Steller's eider (*Polysticta stelleri*), Aarvak et al. 2013). Beluga in Hudson Bay varied the timing of their migration from year to year, apparently in response to variations in temperature (Bailleul et al. 2012).

Phytoplankton originating from the Arctic Ocean may play a role in spring bloom in the North Atlantic (Chapter 3.2). Luddington et al. (2016) found that autumn communities of diatoms in the Canadian Arctic were similar to those in the North Atlantic in the following spring, suggesting large-scale advection of planktonic algae. These links are likely to change in response to further global warming.

4.3 The state of Arctic marine biodiversity monitoring

4.3.1 Adequacy of existing monitoring

The coverage of existing biodiversity monitoring in Arctic marine ecosystems, both in terms of current efforts and available time series, varies considerably among geographical areas and taxonomic groups (Fig. 4.7). This variation reflects that the CBMP *Arctic Marine Biodiversity Monitoring Plan* (Gill et al. 2011, *CBMP Marine Plan*) is an umbrella program based on existing, national and regional monitoring efforts. Other factors affecting coverage and the ability to deliver robust monitoring time series include extremely high natural variability in time and space, particularly for microscopic organisms, as well as changing views on the taxonomical resolution needed for monitoring. For example, although some zooplankton time series extend back to the 1960s, parts of the data are simply recorded as 'zooplankton' or 'copepods' rather than identified to the species level. This inconsistency makes it very difficult to draw firm conclusions about long-term changes in abundance and distribution of specific species.

While some networks are still documenting the existing biodiversity in the marine Arctic, others have good background knowledge of the identity and range of most or all species. However, both trends in abundance (Chapter 4.1) and underlying drivers (Chapter 4.2) are relatively poorly known.

The Traditional Knowledge (TK) of peoples living along and off the Arctic Ocean is an invaluable resource for our

understanding of changes in Arctic marine ecosystems. TK holders have a considerable wealth of information that is needed to increase our knowledge of interconnected systems. For example, TK has identified decreasing volumes of benthic prey, particularly clams, and an increasing volume of pelagic fishes, or simply sand, in walrus stomachs (Chapter 3.3). However, monitoring programs often struggle to find a way in which to effectively utilize TK. The *CBMP Marine Plan* worked to address this issue by engaging and including TK within its design, but the lack of funding support and capacity hindered effective incorporation of TK within the *CBMP Marine Plan*.

Overall, the conclusion of all CBMP Marine Expert Networks is that current monitoring is not sufficient to describe status and trends for many of the Focal Ecosystem Components (FECs) defined in the *CBMP Marine Plan* (Fig. 4.7, Chapter 3). For some (seabirds and marine mammals) they were able to refine and expand upon the original list of FECs while for others (fish and benthos) they were unable to source enough data to report on all the FECs (Table 4.1).

For many taxa, regular monitoring is supplemented by research-driven data collection, but although the additional data collected in this way are extremely valuable, they remain an imperfect substitute for a well-designed monitoring program. It is a recurring theme that data collection relies on a combination of traditional methods requiring fieldcraft and taxonomical expertise, and advanced methods requiring substantial laboratory and/or computing resources. The outcomes of this process will be used to evaluate the *CBMP Marine Plan* and determine, after this first SAMBR, what changes and alterations are needed to improve its effectiveness and implementation.

Some functionally important groups (cf. Gill et al. 2011) are not covered by existing monitoring (e.g. benthic meiofauna and microbes), and besides the incomplete view of biodiversity obtained, this has implications for the ability of the *CBMP Marine Plan* to reflect changes in ecosystem structure and function (see also Chapter 4.1.3).

Biodiversity monitoring spans many levels of detail, from presence/absence surveys via quantitative sampling of abundance to detailed studies of survival, reproduction and other vital rates and related parameters. The choice of detail reflects existing knowledge, practical issues, the life histories of target organisms, and other factors. In particular, for long-lived, highly mobile organisms such as seabirds and marine mammals, large-scale changes in abundance are likely to be slow and affected by conditions over large areas, whereas local abundance can change very quickly, particularly outside breeding areas. Thus, neither local nor large-scale abundance tend to show clear relationships with identifiable drivers, except over long time spans. Monitoring of vital rates, diet or body condition is particularly useful for such organisms, as these parameters often show greater variation and can be related to specific environmental drivers (Anker-Nilssen et al. 2015, Irons et al. 2015). This is particularly the case for species where abundance is very difficult to estimate, e.g., cavity-nesting seabirds and many marine mammals. Monitoring of these additional parameters is improving for several species, but further efforts are needed to assess the status of many populations (Chapters 3.5, 3.6). Further consideration should

be given to how TK could contribute to our knowledge on these issues.

For economically important organisms such as commercial crab, shrimp and fish stocks, and marine mammals, harvest data have been collected for long periods, often spanning several decades and, in some cases, centuries. More recently, harvest data have also been collected for other hunted seabirds. Such data contain information on abundance of the target organism, but they are also affected by variation in harvest effort, legislation, technology as well as reporting intensity, thus complicating their interpretation (Moshøj 2014). Harvest data can therefore form a supplement to biodiversity monitoring, but are rarely in themselves sufficient to allow confident assessment of status, trends and drivers.

One option for supplementing official monitoring programs is an increased involvement of and collaboration with local residents. In many cases, indigenous and non-indigenous communities may work collaboratively with scientists to collect scientific measurements and this approach is already used to monitor the condition of marine mammals (Chapter 3.6). This approach is often referred to as "citizen science". Innovative use of recent technology can encourage more efficient monitoring linkages between local residents and scientists. As an example, the wide availability of mobile phones allows the development of apps that can harness the device's GPS capacity to collect accurate spatial information on wildlife encounters (Flora et al. 2016). Local residents are often the first to detect new species in specific areas, e.g. non-native species. Furthermore, residents in remote communities serve as 'first responders' to unusual mortality events, and can assist in efforts to document the extent of these events, such as occurred during a seabird mortality event near St. Lawrence Island, northern Bering Sea, in 2013 (Chapter 3.5).

It is important to note that there are monitoring methodologies within TK. Many communities, such as those on St. Lawrence Island, have monitored their environment from time immemorial. Collaboration between scientists and TK holders through a participatory approach will greatly aid in bringing forward information needed and enhance monitoring programs.

4.3.2 Standardisation and harmonization of national monitoring schemes

The CBMP Marine Plan recommends that participating monitoring institutions develop common, standardized protocols for Arctic marine monitoring as well as for appropriate storage and archiving of biological data collections, with permanent museum repositories holding geo-referenced samples, for analysis and reporting (Gill et al. 2011, Barry et al. 2013). The goal is to maximize the use of available data, both existing and future, while allowing flexibility to meet local and international monitoring needs.

Based on this approach, the CBMP Marine Expert Networks are striving to coordinate and standardize sampling methods across institutions and countries as well as to harmonize existing data. Harmonization in this context means combining data collected with different methods, either

through direct integration, combining derivative products, or through modelling.

Much work remains before the data collected under national schemes can be compared directly. Many of the CBMP Marine Expert Networks provide constructive suggestions for how to combine existing monitoring elements into a coherent program (Chapter 3), and several initiatives are already under way. For instance, pan-Arctic field guides are being developed for both benthic fauna and fish, and a database of historical population estimates of marine mammals has been compiled.

Internationally coordinated monitoring plans have been developed for some species and groups, but implementation lags behind. Examples include species-specific plans for ringed seal (Kovacs 2014), polar bear and beluga (Chapter 3.6), as well as the *Circumpolar Seabird Monitoring Plan* (Irons et al. 2015).

For some groups, standardization of gear as well as taxonomy is a prerequisite for obtaining comparable data, and this often represents a challenge due to different national or regional traditions. An important step forward is the common standardised approach that has been in use for megabenthos in the Barents Sea since 2005 and is being implemented in the wider Northeast Atlantic (pilot projects in Iceland and Greenland from 2015, the Faroe Islands likely from 2019), concurrent with groundfish surveys (Chapter 3.3), and followed by species identification workshops with development of identification literature and continuously updated photo guides. Attempts to build international collection of benthic species should be initiated. However, it is striking that information on non-commercial fish species collected during the same surveys is not used for biodiversity monitoring, at least not at the pan-Arctic level (Chapter 3.4). A similar approach exists in the Bering Sea, which could profitably be coordinated as far as possible with the Atlantic scheme.

For sea ice biota and plankton, a more synthetic sampling approach is recommended (Chapters 3.1 and 3.2), as current sampling often is fragmented by e.g., taxon, method or sub-habitat. In general, concurrent sampling of relevant physical parameters is also encouraged by the CBMP Marine Expert Networks. Many of these data, however, are costly and/or logistically difficult to collect; for example, the presence of sea ice limits the coverage of remote sensing programs for monitoring sea surface temperature and biological productivity.

A number of actions which would contribute towards standardization of methods include:

- Standardization of methodology for grab and trawl surveys of respectively macro- and megabenthos including development of standardised taxonomic identification across regions and species voucher collections;
- A formalized monitoring plan can build on existing national, annual groundfish-shellfish trawl surveys, such as implemented successfully in the Atlantic Arctic regions;
- Consistent methodology is required for monitoring of sea ice biota. Protocols need to be more

standardized for monitoring. These need to include all aspect from gear, collections, timing, sample preservation and processing, storage, and data management. Researchers in different projects should use a standardized sampling protocol to obtain samples, but a central receiving place as well as long-term funding for monitoring should be considered.

- Targeted surveys and individual tracking studies would improve our understanding of seabird interactions at sea, where seabirds spend most of their time.

CAFF, through its Arctic Biodiversity Data Service (ABDS), is working to facilitate application of common standards and processes to how Arctic biodiversity monitoring data are archived, structured and accessed.

Thus, progress on standardization of methods has been made, recommendations for improvements have been identified, and collating and processing of data has started. This constitutes a platform for continued improvement of the harmonization, integration and analysis of the data collected through the *CBMP Marine Plan*.

4.3.3 Ecosystem-based monitoring – are we getting there?

Ecosystem-based management (EBM): is defined by the Arctic Council as the comprehensive, integrated management of human activities based on best available scientific and traditional knowledge about the ecosystem and its dynamics, in order to identify and take action on influences that are critical to the health of ecosystems, thereby achieving sustainable use of ecosystem goods and services and maintenance of ecosystem integrity (Arctic Council 2013).

The Arctic Council is continuing to advance implementation of the Ecosystem Approach (EA) and to consider scientific and technical aspects related to the implementation of the EA to the management of the Arctic Large Marine Ecosystems. This includes elements of monitoring, integrated ecosystem assessment, and setting ecological objectives as part of the EA (PAME 2011).

- The monitoring needed to support and implement ecosystem-based management (Box 4.1) of (often marine) living resources. A well-known example is the European Union's Marine Strategy Framework Directive, which includes a large monitoring program aimed at assessing whether established goals of the directive are being met. Ideally, this monitoring program is coordinated across all sectors of anthropogenic impacts and scientific fields, including the physical environment and all levels of the ecosystem, so as to achieve an optimal description of ecosystem state and the pressures acting on it (Berg et al. 2015). However, the actual monitoring generally builds on already existing efforts and data series, and coordination and coverage are therefore rarely optimal.
- A site-based monitoring program that aims to collect data on all aspects of the local ecosystem(s), often including both abiotic and biotic aspects. Such monitoring programs are generally highly coordinated using a top-down planning approach. Well-known examples in the Arctic include Zackenberg Basic in north-east Greenland as part of the Greenland Ecosystem Monitoring (GEM) program and the Arctic Long Term Ecological Research at Toolik Lake in Alaska.

The main way in which the *CBMP Marine Plan* can be considered ecosystem-based is that the process of developing the program was based explicitly on a conceptual food web model as well as a detailed scoping process, where the CBMP Marine Expert Networks listed the FECs they considered most important to monitor and how this should be done. The selection of FECs has, in addition, been affected by data availability.

Progress towards ecosystem-based monitoring in the *CBMP Marine Plan* can be evaluated using two criteria: improved coverage (spatial, seasonal, taxonomic, and functional) through coordination among CBMP Marine Expert Networks, and integration of results across the ecosystem levels in line with the defined food web model. Chapters 4.1 and 4.2 represent the first attempt at an integration of the results from the six Expert Networks. An important function of improved coverage is to support upscaling efforts. Methods to detect changes at scales from local to landscape are essential for understanding some of the overall changes relevant for Arctic biodiversity. In this first report, relatively little can be concluded on the circumpolar scale, but the data generated by the Expert Networks and the monitoring efforts started through the *CBMP Marine Plan* have the potential to increase the focus on modelling and upscaling.

A synthetic view of the coverage of the monitoring reported by the CBMP Marine Expert Networks reveals some clear gaps, where missing functional groups representing important trophic links, or more generally ecosystem functions, are covered poorly or not at all. These gaps are primarily due to logistical challenges or lack of expertise in specific fields. Examples include:

1. Larger pelagic crustaceans and other invertebrates. These organisms (e.g. hyperiid amphipods such as *Themisto* spp. and squid such as *Gonatus*

The *CBMP Marine Plan* employs an 'integrated ecosystem-based approach to monitoring' (Gill 2011: 14). Although this concept is not defined explicitly in the *CBMP Marine Plan*, it implies a holistic framework where prioritized elements (i.e., FECs) of marine ecosystems are monitored, and where information is integrated and contributes to decision-making (see also Chapter 1). As this report represents the first opportunity to assess the progress made under the *CBMP Marine Plan*, it is highly relevant to consider whether current monitoring can be considered 'ecosystem-based', and to what extent progress is being made in that direction. The term 'ecosystem-based monitoring' is used in different ways in the literature:

fabricii) are known to be important prey for many vertebrate predators, including fishes, mammals and birds (Chapters 3.4, 3.5 and 3.6). However, they are too mobile to be sampled quantitatively by plankton surveys (Chapter 3.2), and little information exists on their distribution, abundance and trends in the Arctic.

2. Benthic micro- and meiofauna are not covered by current monitoring efforts (Chapter 3.3). These groups are mainly responsible for remineralisation of nutrients in sediments and, thus, perform an extremely important ecosystem function. Their biodiversity is poorly known, and changes in species composition that may affect ecosystem processes may go unnoticed.
3. In the pelagic realm, there is currently no monitoring for Bacteria and Archaea (Chapter 3.2). Molecular monitoring of these taxa would be possible, but is not implemented. They are very important for ecosystem function, particularly with regard to remineralisation of nutrients.

Another issue is that the various taxonomic and functional groups in most cases are sampled independently, at different locations and times. Overarching questions, such as ‘who eats who’, are not always considered, and therefore

limited coordination occurs among various taxonomic and functional groups. This obviously complicates the integration of results. The challenge can be addressed through coordinated, location-based long-term surveys such as the Greenland Ecosystem Monitoring (GEM) program in Greenland or the Distributed Biological Observatory in the Pacific Arctic, but in the context of an Arctic-wide program such as the *CBMP Marine Plan*, it is difficult and expensive to achieve sufficient spatial coverage in this way. Steps forward in the direction of more synoptic sampling include benthic fishes and megabenthos now being sampled simultaneously during bottom trawl surveys in several countries (Chapters 3.3 and 3.4), and that in the Barents Sea observations on algae, zooplankton, mammals, birds, marine litter and the water environment are being done alongside both pelagic and bottom trawling (BarentsPortal 2016).

Overall, there is a tendency that the six CBMP Marine Expert Networks have focused on collecting and compiling pan-Arctic data within each expert network. Following the completion of the SAMBR, the Expert Networks should continue their work on data collation and harmonization, with added emphasis on increasing coordination and cooperation between the networks and inclusion of TK holders in order for the *CBMP Marine Plan* to fulfil its intention of being an ecosystem-based monitoring program.



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Annex 4.1: List of common and scientific species names

Common name used in this report	Alternative common name	Scientific name
Alaska pollock	Walleye pollock	<i>Gadus chalcogrammus</i>
Albatross		<i>Phoebastria spp.</i>
Ancient murrelet		<i>Synthliboramphus antiquus</i>
Arctic char	Arctic charr	<i>Salvelinus alpinus</i>
Arctic tern		<i>Sterna paradisaea</i>
Atlantic cod		<i>Gadus morhua</i>
Atlantic mackerel		<i>Scomber scombrus</i>
Atlantic puffin		<i>Fratercula arctica</i>
Auk		Member of the family <i>Alcidae</i>
Bearded seal		<i>Erignathus barbatus</i>
Beluga	White whale	<i>Delphinapterus leucas</i>
Bering flounder		<i>Hippoglossoides robustus</i>
Black guillemot		<i>Cephus grylle</i>
Black-legged kittiwake		<i>Rissa tridactyla</i>
Bluefin tuna		<i>Thunnus thynnus</i>
Bowhead whale		<i>Balaena mysticetus</i>
Capelin		<i>Mallotus villosus</i> (more recently split into several species)
Common eider		<i>Somateria mollissima</i>
Common gull		<i>Larus canus</i>
Common murre	Common guillemot	<i>Uria aalge</i>
Cormorant		Member of the family <i>Phalacrocoracidae</i>
Crested auklet		<i>Aethia cristatella</i>
Dolly Varden		<i>Salvelinus m. malma</i>
Eelpout		Member of the family <i>Zoarcidae</i>
European shag	Common shag	<i>Phalacrocorax aristotelis</i>
Fork-tailed storm petrel		<i>Oceanodroma furcata</i>
Glaucous gull		<i>Larus hyperboreus</i>
Glaucous-winged gull		<i>Larus glaucescens</i>
Great black-backed gull		<i>Larus marinus</i>
Great cormorant		<i>Phalacrocorax carbo</i>
Great skua		<i>Stercorarius skua</i>
Greenland halibut		<i>Reinhardtius hippoglossoides</i>
Grey seal		<i>Halichoerus grypus</i>
Gray whale	Grey whale	<i>Eschrichtius robustus</i>
Gull		Member of the family <i>Laridae</i>
Harbour porpoise	Harbor porpoise	<i>Phocoena phocoena</i>
Harbour seal	Common seal, harbor seal	<i>Phoca vitulina</i>
Harp seal		<i>Phoca groenlandica</i>
Herring gull		<i>Larus argentatus</i>
Hooded seal		<i>Cystophora cristata</i>
Humpback whale		<i>Megaptera novaeangliae</i>
Ice cod	Arctic cod, polar cod	<i>Arctogadus glacialis</i>
Iceland scallop		<i>Chlamys islandica</i>
Ivory gull		<i>Pagophila eburnea</i>
Killer whale	Orca	<i>Orcinus orca</i>

Common name used in this report	Alternative common name	Scientific name
King crab		<i>Paralithodes camtschaticus</i>
King eider		<i>Somateria spectabilis</i>
Krill		<i>Thysanoessa sp.</i>
Leach's storm petrel		<i>Oceanodroma leucorhoa</i>
Least auklet		<i>Aethia pusilla</i>
Lesser black-backed gull		<i>Larus fuscus</i>
Little auk	Dovekie	<i>Alle alle</i>
Long-tailed duck		<i>Clangula hyemalis</i>
Minke whale		<i>Balaenoptera acutorostrata</i>
Murre		<i>Uria spp.</i>
Narwhal		<i>Monodon monoceros</i>
Northern bottlenose whale		<i>Hyperoodon ampullatus</i>
Northern fulmar		<i>Fulmarus glacialis</i>
Northern gannet		<i>Morus bassanus</i>
Northern shrimp		<i>Pandalus borealis</i>
Ocean quahog	Icelandic cyprine	<i>Arctica islandica</i>
Pacific capelin		<i>Mallotus catervarius</i>
Pigeon guillemot		<i>Cephus columba</i>
Pilot whale	Long-finned pilot whale	<i>Globicephala melas</i>
Polar bear		<i>Ursus maritimus</i>
Polar cod	Arctic cod	<i>Boreogadus saida</i>
Razorbill		<i>Alca torda</i>
Ribbon seal		<i>Phoca fasciata</i>
Ringed seal		<i>Pusa hispida</i>
Sandeel	Sand lance	<i>Ammodytes spp.</i>
Sea cucumber		Member of the class <i>Holothuroidea</i>
Sea star	Starfish	Member of the class <i>Astroidea</i>
Sea urchin		<i>Strongylocentrotus sp.</i>
Shorthorn sculpin		<i>Myoxocephalus scorpius</i>
Short-tailed albatross		<i>Phoebastria albatrus</i>
Short-tailed shearwater		<i>Ardenna tenuirostris</i>
Striped shrimp		<i>Pandalus montagui</i>
Skua	Jaeger	Member of the family <i>Stercorariidae</i>
Snow crab		<i>Chionoecetes opilio</i>
Spectacled eider		<i>Somateria fischeri</i>
Sperm whale		<i>Physeter macrocephalus</i>
Sponge		Member of the phylum <i>Porifera</i>
Spotted seal		<i>Phoca largha</i>
Steller's eider		<i>Polysticta stelleri</i>
Tern		Member of the family <i>Sternidae</i>
Thick-billed murre	Brünnich's guillemot	<i>Uria lomvia</i>
Tubenose		Member of the order <i>Procellariiformes</i>
Tufted puffin		<i>Fratercula cirrhata</i>
Walrus		<i>Odobenus rosmarus</i>
White-beaked dolphin		<i>Lagenorhynchus albirostris</i>