3.4 Marine fishes

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Snapshot

- Pelagic and benthic fish species are important in Arctic marine ecosystems because they transfer energy to predators such as seabirds, marine mammals, as well as people.
- Northward range expansions are underway and pose unknown consequences for Arctic species and their interactions such as predation and competition.
- Fishes are affected by environmental conditions such as temperature, sea ice availability and salinity, and are constrained by prey availability and predator pressure, which can be influenced by climate change
- The ecologically important polar cod declined in the Barents Sea from 2004 to 2015, potentially because of predation from Atlantic cod, a more southern species. The 2016 survey showed a notable increase in abundance, driven by an unusually high abundance of one-year-old fish.
- Indices and monitoring programs based on harvested species or that rely on fishery-related data are inherently affected by changes in stock size and exploitation rate, making them imperfect sources.
- Northward expanding capelin is less lipid-rich and has led to changes in seabird diet in northern Hudson Bay and may affect marine mammals.
- Greenland halibut have undergone declines and subsequent recoveries over the last two decades in the northeast Atlantic.

3.4.1 Introduction

Arctic marine fish communities are changing as the result of altered environmental conditions. Elevated ocean temperatures and altered stratification, wave action and the availability of ice habitats are driving changes in habitat use patterns. Changes in habitat allow the northward expansion of bordering species, often altering competitive and predator-prey interactions. For example, the northward movement of capelin (a complex of *Mallotus* species) in Canadian Arctic waters represents the appearance of a competitor for current keystone forage fishes such as polar cod (*Boreogadus saida*), whereas the expansion of Atlantic cod (*Gadus morhua*) has led to greater predation pressure on polar cod in the northern Barents Sea.

Anthropogenic threats to Arctic marine fishes are likewise changing. Increased accessibility because of reduced sea ice concentration, extent and changes in the timing of melt and onset are creating new opportunities for fishing, petrochemical and mineral exploration and extraction, transportation and tourism. Additional vessel traffic creates increased noise, erosion and pollution. Of particular note, commercial fisheries, such as those targeting the valuable Greenland halibut (*Reinhardtius hippoglossoides*), have the potential to expand spatially following changes in species distributions or as previously inaccessible areas become ice-free for extended periods.

The 2013 *Arctic Biodiversity Assessment* (ABA) listed 633 species of marine fishes that have been recorded in the Arctic Ocean and adjacent seas (Christiansen et al. 2013). Approximately 10% are harvested commercially and are assessed for the purpose of providing quota advice. Much less is known about the other 90%, and the ABA revealed fundamental knowledge gaps in taxonomic status and species distributions. Large areas of the Arctic have never been surveyed for marine fish biodiversity. Monitoring programs for marine fishes or communities occur in relatively restricted areas and frequently focus on commercial fisheries (Fig. 3.4.1). Short-term biodiversity surveys have occurred sporadically, and are generally unsuited for monitoring changes in biodiversity over time.

Here we selected three marine fish Focal Ecosystem Components (FECs) that were listed in the Marine Biodiversity Monitoring Plan (Gill et al. 2011): polar cod, Greenland halibut and the capelin complex. Polar cod is an Arctic species with a circumpolar distribution whereas capelin and Greenland halibut are Arctic–boreal fishes found in Atlantic and Pacific, as well as Arctic waters (Mecklenburg et al. 2013). Within this chapter the terms Arctic, Arctic–boreal, and boreal when applied to fish species, identify the zoogeographic group to which a species belongs. The selection of marine fish FECs is intended to draw attention to a few species that are of particular ecological, subsistence or commercial importance throughout the Arctic.

Capelin and polar cod are important, widely dispersed forage fishes. The latter species was discussed in the ABA report and is of special relevance to the Arctic because of its close linkage with sea ice. Greenland halibut and capelin are harvested commercially in large areas of the Arctic. Together, these selected FECs illustrate changes occurring in marine fish taxa and consequences for food webs and subsistence and commercial fisheries. This report focuses on changes in Arctic biodiversity and related drivers since the 2013 ABA, which examined overall patterns in marine fish biodiversity in the Arctic Ocean and adjacent seas and examined a few fishery-targeted species in greater detail (Christiansen et al. 2013). The analysis relied on a 2011 synthesis of Arctic marine fish biodiversity (Mecklenburg et al. 2011), a number of regional annotated species checklists and previously unpublished data from research, surveys and monitoring undertaken by ichthyologist and fishery science authors.

3.4.2 Current monitoring

Data on species distributions and abundances are derived from governmental, academic or industry-related field programs. Governmental programs often have longer time series, good consistency in methods and equipment for specimen collection, and function for ongoing monitoring. Academic programs are typified by short time series and methods can vary considerably among studies. Industry-related programs are normally conducted by consulting companies contracted by natural resource-extraction companies. Data collection methods are often standardized, but time frames are usually short (< 5 years). Databases are managed by agencies or entities that conduct marine fish surveys, monitoring and assessments, and identifying and accessing these databases often poses a difficult legal exercise. Within this chapter, surveys are considered short-term assessments of fish communities and species distributions; these programs are suitable for collecting baseline data on species and ecosystems. Monitoring programs involve long-term data collection that is suitable for assessing changes in populations, species or communities, ideally together with data on environmental conditions to detect causal relationships for observed changes.

Surveys of marine fish biodiversity are needed throughout the Arctic. Large areas of the Arctic remain unsurveyed and while short duration (one to several years) surveys can provide essential information on marine fish distributions and abundance patterns, only long-term programs can be used to monitor changes in biodiversity (e.g., species distributions and ranges, community composition).

Canada has a large Arctic territory. Primary marine fish biodiversity surveys have been completed in much of the eastern and western portions of the Canadian Arctic, but marine fish distributions in the Canadian Arctic Archipelago remain largely unknown. Monitoring programs that are suitable for assessing changes in marine fish biodiversity are currently limited to Baffin Bay, Davis Strait and inshore waters on the east coast of Baffin Island. Annual multispecies bottom trawl surveys are conducted in Baffin Bay and Davis Strait, primarily to support stock assessments for Greenland halibut and northern and striped shrimp (*Pandalus borealis* and *P. montagui*, respectively). These surveys are effectively used to monitor benthic fish and invertebrate biodiversity (Jørgensen et al. 2011), but the spatial extent and depth range (200-1600 m) sampled are focused on the ranges of the target species. Between 2012 and 2014, the Beaufort Regional Ecological Assessment (BREA), Fisheries and Oceans Canada (DFO), conducted a thorough survey of marine fishes in the Canadian portion of the southern Beaufort Sea. This survey collected valuable information on fish distributions, but unless the survey continues in the future, there is no ongoing marine fish biodiversity monitoring in the Canadian Beaufort Sea. Disparate surveys conducted by government, academia and industry can be cobbled together in other areas for meta-analyses, but this approach is problematic for robust biodiversity monitoring.

The Greenland Institute of Natural Resources, Nuuk, conducts annual multi-species bottom trawl surveys in Baffin Bay, Davis Strait, Denmark Strait and in inshore waters of West Greenland. Greenland and Canada use the same vessel for Greenland

Polar cod.
Photo: Shawn Harper, University of Alaska, Fairbanks

Capelin.
Photo: Carsten Egevang/ARC-PIC.com

Greenland halibut.
Photo: Fernando Ugarte

Figure 3.4.1. Map of contemporary marine fish data sources. Green squares indicate data from benthic trawl monitoring efforts, blue squares indicate data from benthic trawl surveys, while red triangles indicate data from pelagic trawl monitoring efforts.

halibut surveys in Davis Strait-Baffin Bay; the two countries regularly combine their data for stock assessments and have conducted joint assessments of marine fish biodiversity (Jørgensen et al. 2011). Arctic waters off northeast Greenland are regularly monitored by UiT, The Arctic University of Norway as part of the TUNU Euro-Arctic marine fishes – diversity and adaptation program (Christiansen 2012). This also includes the area around Jan Mayen Island (Arctic and Atlantic water), the Svalbard Archipelago (Atlantic and Arctic water) and, whenever feasible, the Franz Josef Land Archipelago (Arctic water).

The surface waters, continental shelf and slope bottom in the Icelandic Exclusive Economic Zone (EEZ) are fairly well covered by five annual trawl-based monitoring programs that are conducted by the Marine Research Institute. There are also regular monitoring programs for Atlantic cod (annual gillnet), scallop (biannual dredge) and several pelagic fishes (annual acoustics and pelagic trawl). All of these programs occur primarily to assess commercial stocks; however, all fishes caught are identified to species and counted (Björnsson et al. 2007, Marine Research Institute 2010), and individual lengths are measured for a sub-sample of each species from each tow. However, fish communities in deep waters below 1,500 m and the mid-water realm are poorly known due to a lack of commercially important species. A few irregular and single-year surveys have been conducted to examine marine fishes in areas outside the core area.

Norway's Exclusive Economic Zone encompasses three large marine ecosystems, two of which, the Norwegian Sea (the northern part only) and the Barents Sea, fall within the Circumpolar Biodiversity Monitoring Program's (CBMP) Atlantic Arctic Marine Area (AMA) boundary (red outline in Fig. 3.4.1). These two seas sustain large fisheries, and commercially important fish stocks are monitored annually by the Institute of Marine Research (IMR), Bergen, Norway, to provide stock assessment and quota advice. Monitoring in the Norwegian Sea is a joint effort between Norway, Greenland, the Faroe Islands and Iceland. The main monitoring program in the Barents Sea is a joint effort between Norway and Russia. During Institute of Marine Research (IMR) programs, all fishes including non-commercial species are identified, tallied and weighed, but time series have not been developed for most non-commercial species because historical data are unreliable and little effort has been made to create time series. Furthermore, there are ongoing problems with species identification, especially of Arctic marine fishes, and the area assessed in the northern regions has been variable, partially because of variation in sea ice cover or the spatial distribution of the target species.

The Arctic marine waters of the U.S. are the northern Bering Sea, the eastern Chukchi Sea and the western Beaufort Sea. The Russian–American Long-Term Census of the Arctic (RUSALCA), a joint program of the National Oceanic and Atmospheric Administration (NOAA) Arctic Research Program and the Russian Academy of Sciences, conducted multidisciplinary surveys in 2004, 2009 and 2012 focused on both the Russian (western) and eastern waters of Bering Strait northward through the Chukchi Sea. In 2009, the expedition reached the eastern East Siberian Sea and the continental slope of the Arctic Ocean. Larval, juvenile and adult fishes were collected. One of the main focuses of the fish investigations was to explore under-studied waters to determine species presence and abundance. Following a hiatus since the 1970s in surveys and monitoring of the Arctic region, NOAA Fisheries established a plan for the management of fish resources in the Arctic waters of the U.S. in 2009 (NOAA 2009). Information provided includes NOAA's 5-Year Action Plan, with reporting to the public via NOAA's Arctic website (NOAA 2017). Recent NOAA fish surveys in the Arctic include the U.S. Beaufort Sea in 2008 and the U.S. Chukchi Sea in 2007 and 2012. In addition to surveys, the NOAA Arctic Research Program has sponsored, in conjunction with RUSALCA, studies of voucher specimens from historical and recent expeditions in the Arctic and adjacent waters in museums throughout the Northern Hemisphere, and molecular genetic studies contributing to the determination of species and resolution of taxonomic problems affecting assessments of biodiversity. The taxonomic and distributional baselines produced from the RUSALCA investigations in the Pacific Arctic were recently published, including analysis of taxonomic issues, geographic distributions and a guide to species identification (Mecklenburg and Steinke 2015, Mecklenburg et al. 2016).

The University of Alaska Fairbanks (UAF) has recently conducted fisheries research in the eastern Chukchi Sea (e.g., Norcross et al. 2013) and western Beaufort Sea. The most recent UAF surveys in the Beaufort Sea were conducted in 2012–2014 in conjunction with Canada (BREA) in a transboundary program. Voucher specimens from the UAF surveys, including those in the Beaufort Sea in 2012–2014, were examined and the information was incorporated in the Pacific Arctic baseline documents (Mecklenburg and Steinke 2015, Mecklenburg et al. 2016).

When interpreting trends in monitoring data, it is essential that the exploitation history of the subject species or community is taken into consideration to understand whether historical data represent unexploited or altered states. This is particularly true in cases where fisheries once existed but have been discontinued, or when subsistence fisheries are conducted with little scientific documentation (Zeller et al. 2011, Misund et al. 2016). The incorporation of Traditional Knowledge (TK) and fishers' knowledge (Armitage et al. 2011) in study planning, analyses and decision making can be beneficial for placing surveys and their results in appropriate contexts.

The Food and Agriculture Organization of the United Nations (FAO), the International Council for the Exploration of the Sea (ICES) and the Northwest Atlantic Fisheries Organization (NAFO) maintain publically accessible databases on fish harvests and fish stock assessments. The FAO database is useful for finding information on total harvests of commercially important species that inhabit the Arctic, but the FAO areas are very large, rendering the database useless for estimating spatial distributions. Species identification in the FAO database is also an issue (Lleonart et al. 2006). For example, there are no records of ice cod (*Arctogadus glacialis*), only polar cod. Given their strong morphological similarities and frequent co-occurrence in trawl hauls, it is therefore likely that a portion of the reported polar cod catch is actually ice cod. FAO area 18 covers the high Arctic, but data on marine fish catches in that area have been shown to be highly inaccurate and the records do not include indigenous subsistence catches (Zeller et al. 2011). The NAFO and ICES catch databases record catches on smaller spatial scales, making them more useful for analyzing changes in harvesting patterns in Atlantic Arctic regions. In addition to fisheries management databases, several open biodiversity databases have been created, including the Ocean Biogeographic Information System, the Global Biodiversity Information Facility, FishSource and the Sea Around Us Project.

3.4.3 Status and trends of FECs

Checklists and identification guides for marine fishes in the Arctic

Up-to-date checklists and identification guides are essential tools for monitoring biodiversity. A group of ichthyologists and fishery biologists recently assessed species presence in the Arctic region and produced an annotated list, with common names in several languages, which was made available online by CAFF (Mecklenburg et al. 2013). This list is being revised for a 2nd edition. An atlas and guide in progress will provide global distribution maps, identification features and assessment of taxonomic issues pertaining to all marine fishes documented to occur in the Arctic region; publication is scheduled for 2018 (Mecklenburg et al. in prep.).

Marine fishes occurring in the waters off eastern Siberia, Russian Federation, Alaska, U.S., and the Yukon and Northwest Territories, Canada were assessed for the recently published baseline summary (Mecklenburg and Steinke 2015) and distributional atlas and identification guide to *Pacific Arctic Marine Fishes* (Mecklenburg et al. 2016). These works expand and update the information on Arctic fishes provided in the compendium on *Fishes of Alaska* (Mecklenburg et al. 2002), and are being expanded to include the Atlantic Arctic marine fishes for the pan-Arctic atlas (Mecklenburg et al. in prep.).

For Canada, the Coad and Reist (2004) annotated checklist of Arctic marine fishes of Canada is expected to be published in expanded form with dot-distribution maps early in 2017 as an Atlas of Canadian Arctic Fishes (Coad et al. in press).

The distribution of fishes around Greenland was recently assessed from scientific and fishery surveys, including literature and voucher specimens in the University of Copenhagen collection (Møller et al. 2010).

A book of all fish species known to occur in Icelandic waters is published regularly (Jónsson and Pálsson 2013) and, between editions, an article is published annually to report any new records (e.g., Pálsson 2014).

Fish diversity around Jan Mayen was assessed from IMR data and voucher collections at the University of Bergen (Wienerroither et al. 2011b). New data have also been incorporated in recent treatments on fishes of the Faroe Islands (Mouritsen 2007) and Norway (Pethon 2005). Fishes of Norwegian and Russian waters of the Barents Sea were treated in two atlases of information from IMR investigations: one from summer fish collections and one from winter collections (Wienerroither et al. 2011a, 2013).

Original data and summaries of published information on fishes of the Kara Sea have been provided in Borkin et al. (2008) and Dolgov (2013). An annotated catalog of *Fishes of Russian Seas* provides taxonomic synonymies as well as summary information on geographic distributions for all the marine waters of Russia, based on the collections in the Russian Academy of Sciences as well as the scientific literature (Parin et al. 2014).

*Figure 3.4.2. Distribution of polar cod (*Boreogadus saida*) based on participation in research sampling, examination of museum voucher collections and the literature (Mecklenburg et al. 2011, 2014, 2016; Mecklenburg and Steinke 2015). Map shows the maximum distribution observed from point data and includes both common and rare locations.*

Polar cod

Polar cod is the most abundant cod species around the Arctic. It is a key ecological species in the Arctic Ocean due to its pan-Arctic distribution (Fig. 3.4.2), large standing stocks and role as an energy transmitter to higher trophic levels (Bradstreet et al. 1986, Hop and Gjøsæter 2013). In bottom trawl surveys on Arctic continental shelves, it is typically one of the most numerous fishes caught and often the most numerous. Polar cod was the most abundant fish species in RUSALCA catches in the Chukchi Sea in 2009 and 2012, and in 2004 it was the fourth most abundant species (Mecklenburg et al. 2016). In deeper waters, it is not as abundant in bottom trawls but concentrates under the sea ice (Karamushko 2012, Mecklenburg et al. 2014). Polar cod feed on ice-associated fauna as well as shrimp, zooplankton, particularly hyperiid amphipods and *Calanus* copepods (Lønne and Gulliksen 1989, Hop and Gjøsæter 2013, Dalpadado et al. 2016, Majewski et al. 2016) and small fishes, and use the ice as a refuge from predation and as spawning habitat (Gradinger and Bluhm 2004, Gradinger et al. 2010). One-year-old polar cod follow the sea ice drift (David et al. 2015). Polar cod has antifreeze agents in its blood, which makes it possible for this species to use sea ice as habitat (Osuga and Feeney 1978).

Despite its circumpolar distribution, polar cod exhibits little genetic variation. DNA barcodes from the East Siberian and Chukchi seas eastward to the Greenland Sea illustrate this low variation. Although genetic variation has been found at both pan-Arctic and regional scales, and polar cod is clearly not genetically homogeneous across its range, the general structure is weak and population subdivisions, although they may exist, have not been revealed (Nelson and Bouchard 2013). No division into species or subspecies has been proposed and the Arctic zoogeographic pattern of polar cod is clear (Fig. 3.4.2).

Due to its particular characteristics, polar cod is a suitable indicator species for monitoring Arctic marine fish communities, as well as Arctic food webs in general. However, few monitoring time series exist for polar cod, except in the Barents Sea, where it is harvested commercially (Hop and Gjøsæter 2013). Acoustic time series data on the Barents Sea population dates back to 1986, but these data are inconsistent in spatial coverage and the sampling programs primarily targeted capelin (Ajiad et al. 2011). Since 2004, more comprehensive and reliable data are showing declines in Barents Sea polar cod (Fig. 3.4.3). Losses of sea ice habitat may have contributed to the recent poor recruitment (low 0-group index, Fig. 3.4.3). The 0-group index for 2013-2015 was < 10% of the average from 1980-2012 (4360 million individuals). Recruitment failure, migration, together with increased predation pressure from northward expanding Atlantic cod may have impacted the survival of polar cod (Box 3.4.3; Kjesbu et al. 2014, Ingvaldsen et al. 2015). A survey completed in 2016 showed a notable increase in polar cod biomass to 900,000 t, a level last seen in 2009, primarily because of an unusually high catch of age one fish (Joint Russian-Norwegian Ecosystem Survey unpubl. data, autumn 2004-2016). Studies and data are also available on polar cod from regular monitoring in Iceland (Ástþórsson 2015). As in the Barents Sea, these programs target other species such as Atlantic cod and northern shrimp, and therefore do not necessarily cover the entire distribution range of polar cod. It is still undetermined if the polar cod population in Icelandic waters is declining due to increasing water temperatures.

Polar cod is the only true Arctic species that has sustained considerable, although highly variable, commercial fisheries (Fig. 3.4.4). Fisheries expanded quite rapidly in the late 1960s, reaching 348.4 kt in 1971, but have fluctuated considerably since then at around 20 kt y^{-1}. Polar cod have primarily been fished by Russian vessels in the Barents Sea, but Norway, Germany and Greenland have also fished polar cod, albeit at much lower levels. Polar cod is considered a low value species by the Norwegian fleet and is harvested for fishmeal and oil (Cohen et al. 1990), but in Russia at least part of the harvest is meant for human consumption. In addition to harvest in directed fisheries, unreported bycatch of polar cod could be considerable in shrimp (Garcia 2007) and capelin fisheries (Vilhjálmsson et al. 2005).

Box 3.4.2: Polar cod and capelin

Polar cod and capelin are expected to respond differently to climate change based on key differences in life history characteristics and habitat associations (reviewed in Hop and Gjøsæter 2013). Reductions in sea ice will likely alter the reproductive success of polar cod due to loss of sea ice habitat for spawning (Bouchard and Fortier 2011), larval development (Bradstreet 1982) and as a predator refuge (Gradinger and Bluhm 2004). In contrast, periods of relatively warm water temperatures and reduced sea ice extent favour the northward expansion and increased abundance of capelin (Rose 2005a) leading to increased co-occurrence with polar cod (e.g., Orlova et al. 2009). Negative effects of sea ice declines on polar cod may be further compounded by interspecific competition with capelin for zooplankton resources, particularly large *Calanus* copepods (Orlova et al. 2009, Hop and Gjøsæter 2013, McNicholl et al. 2016). The consequences of interspecific competition and direct pressures from reductions in sea ice extent are likely to be significant given the key role of polar cod in Arctic marine food webs (e.g., Welch et al. 1992). Ongoing monitoring and collection of new baseline data are needed to report on patterns in polar cod and capelin distributions and abundances as key indicators of climate variability and impacts in Arctic marine ecosystems.

Polar cod.
Photo: Shawn Harper, University of Alaska, Fairbanks

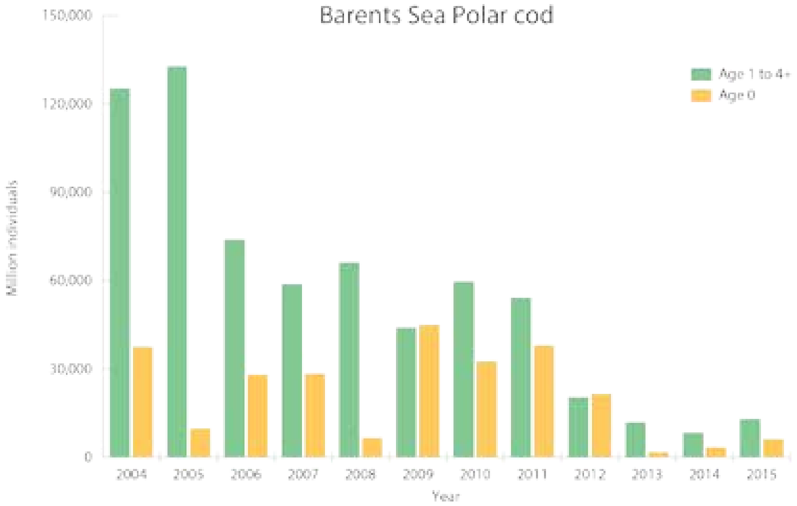


Figure 3.4.3. Polar cod in the Barents Sea. Acoustic estimate of polar cod 1-year-old and older (green) and pelagic trawl index of age 0-group abundance (yellow). Source: Joint IMR-PINRO ecosystem survey (Prozorkevich 2016).

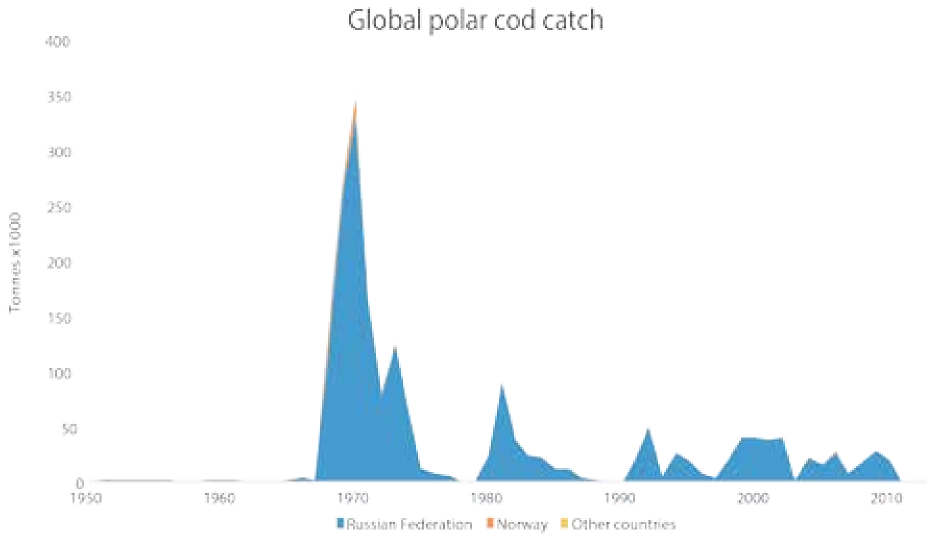
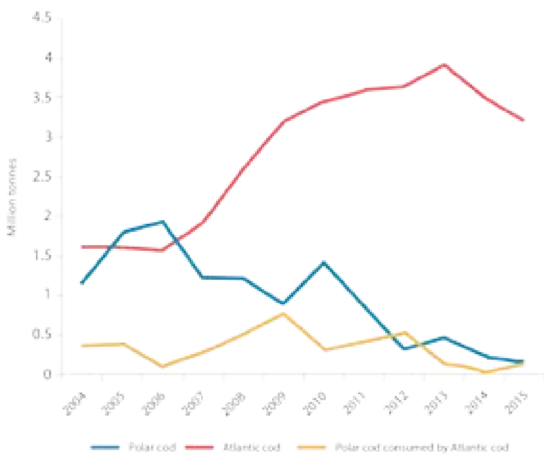


Figure 3.4.4. Global catches of polar cod from 1950 to 2011 (FAO 2015); 95% of the catches are from the Barents Sea.

Box 3.4.3: Polar cod and Atlantic cod in the Barents Sea

Atlantic cod is an important predator in shelf ecosystems of cold-temperate (boreal) North Atlantic waters. In the Barents Sea, the Atlantic cod has recently increased in both stock size and distribution area. Atlantic cod are currently found all over the Barents Sea shelf during summer, including the northern, colder parts that are inhabited by polar cod. This has led to increased spatial overlap between the two species. The larger-bodied Atlantic cod feeds effectively on polar cod in areas of overlap. The increased overlap has led to increased predation pressure on polar cod, most likely contributing to the observed population decline. Estimates of total consumption of polar cod by Atlantic cod peaked in 2009, exceeding 0.7 million tonnes (ICES 2016). In 2012, the estimated consumption was higher than the estimated standing stock (0.5 and 0.3 million tonnes, respectively). A high predation pressure can be withstood if polar cod recruitment is high. However, since 2013 there has been an almost complete recruitment failure of polar cod in the Barents Sea (Fig. 3.4.3).



Box figure 3.4.1 Estimated consumption of polar cod by Atlantic cod in the Barents Sea (yellow line) and biomass of the Atlantic cod stock in the Barents Sea (red line) (ICES 2016). The blue line is the biomass of the Barents Sea polar cod (Prozorkevich 2016).

Capelin

Capelin are pelagic forage fishes and play an important role in marine food webs in the Arctic as prey for Arctic marine mammals (Watts and Draper 1986, Dahl et al. 2000, Dolgov 2002, Bluhm and Gradinger 2008, Marcoux et al. 2012, Watt et al. 2013), seabirds (Erikstad 1990, Dolgov 2002, Gaston et al. 2003, Gjøsæter et al. 2009) and piscivorous fishes (Dempson et al. 2002, Dolgov 2002, Dennard et al. 2009, Harwood and Babaluk 2014). The migration of capelin at various life stages represents a significant transfer of energy between oceanic habitats and nearshore spawning grounds (Vilhjàlmsson 2002).

Populations of capelin represent several species, most of which are not completely resolved (Mecklenburg et al. 2011). The Pacific population was recently reclassified as a full species, the Pacific capelin (*M. catervarius*; Mecklenburg and Steinke 2015). Morphological and molecular data suggest a continuous distribution of Pacific capelin from the Sea of Japan, Sea of Okhotsk, the eastern Gulf of Alaska and the Bering Sea to the Laptev and East Siberian Seas and across Arctic Alaska and Canada to Davis Strait. Two populations that probably represent separate species include one from east Greenland to the Kara Sea, which is most likely the originally described *M. villosus*, and one from Hudson Bay, the Gulf of St. Lawrence and marine waters off Newfoundland, Labrador and Nova Scotia, which at present lacks a species name (Mecklenburg and Steinke 2015). Thus, we refer here to the capelin species complex, including the two or more unresolved, unnamed Atlantic species and the recently defined Pacific capelin. The overall distribution of the complex as well as that of the Pacific capelin is presented in Figure 3.4.5.

Several life history characteristics, including broad physiological limits, potential for fast population growth and thermal constraints on the timing of spawning, make capelin a relevant indicator of climate variability (Rose 2005a, b, Davoren et al. 2012). A variety of information sources indicates increasing trends in the abundance and distribution of capelin in Arctic waters. Capelin are

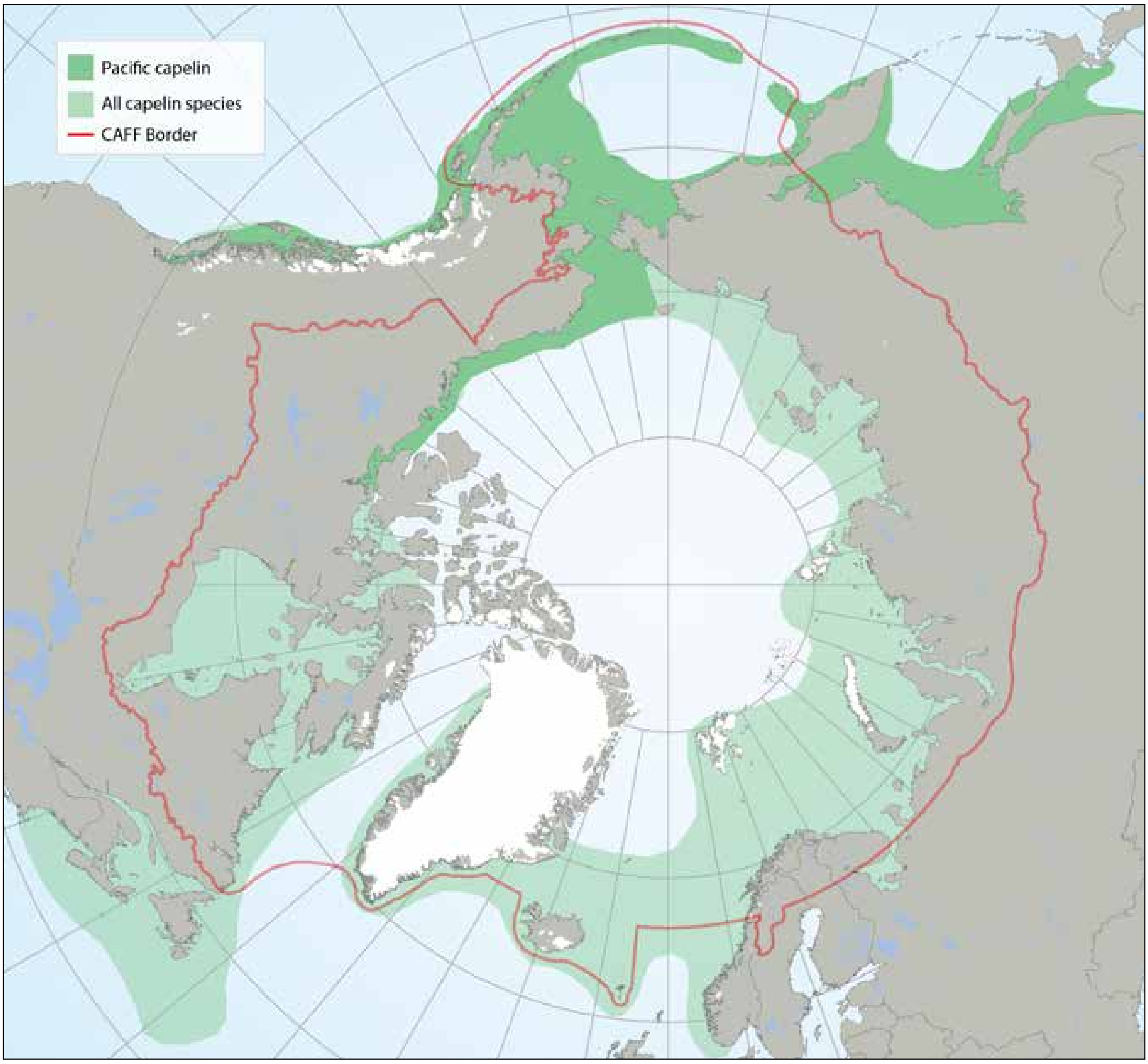


*Figure 3.4.5. Distributions of all capelin species (light green) and Pacific capelin (*Mallotus catervarius*; dark green pattern) based on participation in research sampling, examination of museum voucher collections, the literature and molecular genetic analysis (Mecklenburg and Steinke 2015, Mecklenburg et al. 2016). Map shows the maximum distribution observed from point data and includes both common and rare locations*

Box 3.4.1 Indigenous Knowledge and capelin

By Carolina Behe, Inuit Circumpolar Council-Alaska, Qaiyann Harcharek, Northslope Borough Wildlife Department, Dawn Miller and Marjorie Tahbone Indigenous Knowledge holders from Nome, Alaska

Capelin is a vital part of the ecosystem and is an important food source throughout the Arctic food web. In Alaska, capelin are often referred to as candlefish or cigar fish because of its heavy oil content (they are a fatty fish). In Iñupiaq (an Alaskan Inuit dialect), the name is paŋmaksraq, in Invialuktun (a Canadian Inuit dialect) the name is Anmagiak, and in Kalaallisut (a Greenlandic dialect) the name is Ammassaat.

Inuit Knowledge (Indigenous Knowledge held by Inuit) across the Arctic includes invaluable information on the capelin distribution, behavior, spawning periods, changes associated with change in water temperature, winds and currents, and knowledge of the role that capelin play in the overall food web. This includes the cultural and social importance that the animal holds within the Inuit culture.

Indigenous Knowledge holders in Alaska, Canada and Greenland have shared that this fish is sometimes found in the stomachs of piscivourous fish, such as Dolly Varden and salmon (Remnant and Thomas 1992, McDonald et al. 1995, Golder Associates Ltd. 2002, Brewster et al. 2010). Other marine mammals such as beluga, orcas and seals also rely on capelin as a food source (Remnant and Thomas 1992, McDonald et al. 1995, Olsvig and Mosbech 2003). In the Canadian Kugluktuk area, capelin spawn in shallow nearshore areas and the eggs come up on the beach (Golder Associates Ltd. 2002). Here, Inuit Knowledge shares that capelin are an important food source for ringed seals. When capelin become abundant on the coast in September the ringed seal also become abundant (Golder Associates Ltd. 2002).

On the North Slope of Alaska, from mid July to early August, schools of capelin let themselves wash ashore in the waves, and then wash back into the ocean. It is then, when people harvest them, scooping them from the beach or as they are washed to and from the beach. They are considered excellent food, but were in the past also widely used for dog food and fox trapping bait. The introduction of western culture, foods, cash and stores, meant that access to food was easier and there wasn't much need to spend the time and effort required to gather capelin, which many needed for a family meal. However today many people are experiencing a natural urge or instinct to reclaim their cultural identity, in this instance the gathering of capelin, and a new generation of harvesters is emerging (18-35 year-olds).

In the Nome, Alaska area capelin also come in with the currents in the spring and wash ashore. When birds, such as seagulls, begin to dive at the shore line, it is an indicator that the fish are there and people prepare to harvest. Some villages have reported a change in capelin associated with currents. For example, Raymond-Yakuobian (2013) reports that experts in in the Bering Strait region noted that capelin still come close to the beach but do not beach themselves or get pushed up by the waves like they used to.

This fish is an important food source for many Inuit. Especially those that do not have equipment to travel far from the shore to collect food. For the past couple of years, the fish have been coming in earlier and remaining a little bit longer. This year (2016) some people chose not to catch them, because the weather was not good for drying.

Drying capelin. Photo: Marjorie Tahbone commercially exploited in Arctic and sub-Arctic regions (Fig. 3.4.6), and recently, all major stocks exhibited northerly range displacements associated with periods of warmer water temperature and reduced sea ice extent (Rose 2005a, b, Pálsson et al. 2012, Ingvaldsen and Gjøsæter 2013). Similar trends of increasing occurrence and abundance of capelin are documented from the eastern Canadian Arctic and Hudson Bay complex based on long-term changes in the diets of marine mammals (Marcoux et al. 2012, Chambellant et al. 2013, Young and Ferguson 2014), fishes and seabirds (Gaston et al. 2003, Gaston and Elliott 2014). In addition, community-based observations suggest increased frequency of capelin occurrence in the coastal Beaufort Sea since the early 2000s based on observations of spawning events and predation by Arctic char (*Salvelinus alpinus*; (Paulatuk Hunters and Trappers Committee unpubl. Data). New survey data have provided valuable baselines of capelin occurrence and/or abundance in data-poor regions of the offshore Beaufort and Chukchi Seas (Logerwell et al. 2015, McNicholl et al. 2016).

Potential consequences of the increasing role of capelin and associated declines of polar cod in the diets of piscivorous seabirds and marine mammals are unknown, but may represent significant impacts on Arctic ecosystems. For example, while the two species have comparable body size and energetic content (reviewed in Hop and Gjøsæter 2013), and occupy similar trophic positions (Hop et al. 2002, Marcoux et al. 2012), capelin populations fluctuate widely and can exert strong bottom-up effects on predator populations (e.g., Gjøsæter et al. 2009, Hop and Gjøsæter 2013). Further, increased abundance of capelin in Arctic waters may exert additional pressure through intraspecific competition on populations of polar cod that are already negatively influenced by climate related changes with regards to habitat availability (Box 3.4.2).

In the northeast Atlantic, capelin and Atlantic cod are linked together in a close predator-prey relationship and the largest Atlantic cod stocks in the world occur where capelin is available as food (Vilhjálmsson 1997, Howell and Filin 2014, Rose and Rowe 2015). In general, the capelin has a more northerly distribution than the Atlantic cod, but needs to migrate to warmer shallow waters to spawn. It is during this period that northern Atlantic cod stocks feed intensely on capelin (Vilhjàlmsson 2002). Capelin fisheries are managed with this interaction in mind; sufficient capelin is allowed to escape the fisheries to be able to spawn and provide food for Atlantic cod and other species.

Capelin is one of the most fished fish species in the world, ranking 12th in 2013 (FAO 2015). In 1977, it was the second most fished species in the world after Alaska pollock (*Gadus chalcogrammus*). In a global comparison of fisheries, capelin is therefore a major species. The vast majority of catches occur in the northeast Atlantic from the Icelandic and Barents Sea stocks (Fig. 3.4.6). Catches in the northwest Atlantic are much lower and catches in the Pacific are negligible. Because of its short lifespan (five to seven years, Hansen 1943), fisheries generally harvest from mainly one cohort per year. Capelin fisheries are therefore characterized by large annual fluctuations depending on recruitment. In Iceland, for example, annual fisheries have fluctuated from zero to more than one million tonnes, and can exceed the combined catches of all other species.

Capelin stocks are assessed in the North Atlantic by ICES, NAFO and DFO. Assessments for the northeast Pacific are available from NOAA Alaska Fisheries Science Center. The stocks are generally considered well managed, but two issues complicate management (Vilhjálmsson 2002, Rose 2005, Ingvaldsen and Gjøsæter 2013). First, quotas are highly variable between years because of capelin's short life cycle, with maturation at age two to five (Hansen 1943), and highly fluctuating abundance. Second, when quotas are set it is important to keep in mind that capelin represents key forage for other more valuable commercial species, especially Atlantic cod and Greenland halibut. Any generalization on the current status of capelin stocks has to be considered cautiously due to the extreme fluctuations observed in the stocks. However, stocks off Newfoundland, Canada are growing after a long period of depletion. The northeast Pacific stock is large in comparison over the long-term, while the Icelandic and Barents Sea stocks are small.

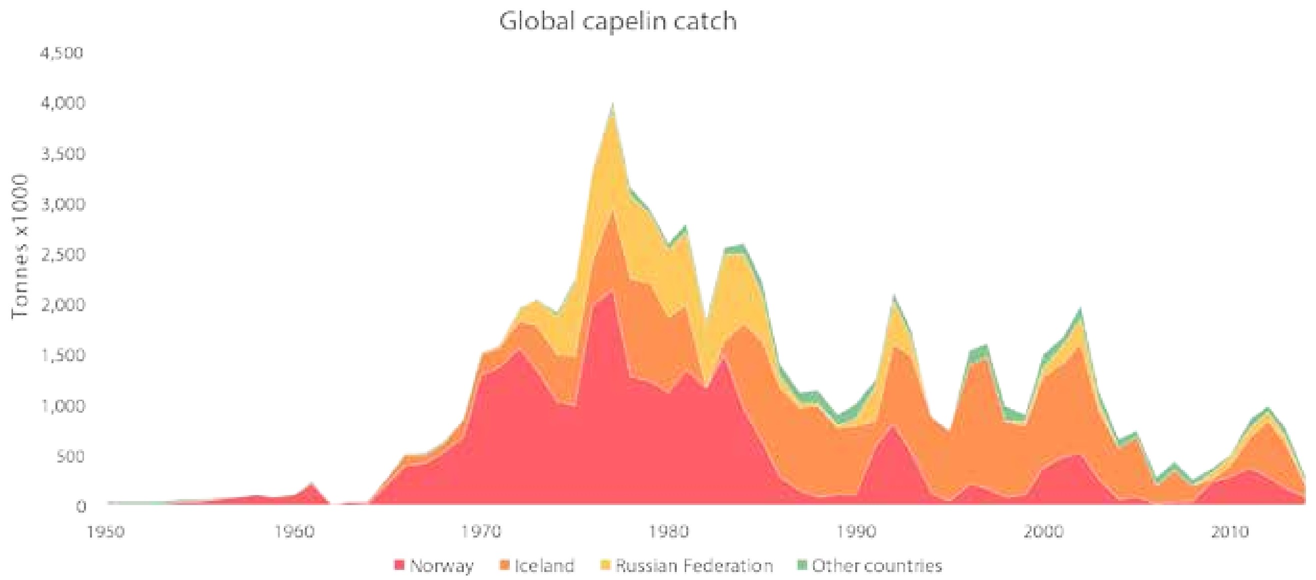


Figure 3.4.6. Global catches of all capelin species from 1950 to 2011 (FAO 2015).

Greenland halibut

Greenland halibut is a top predator, feeding on a variety of smaller species, including polar cod and capelin (Sólmundsson 2007). It is basically a benthic species, closely associated with the sea floor, but unlike other flatfishes it swims with ventral side downward like a non-flatfish and is wide-ranging in its behavior. Although there are gaps in its distribution between the Atlantic and Pacific and some taxonomists have long maintained that two species with slight morphological differences are represented, molecular genetic evidence has verified that only one species is represented (Mecklenburg et al. 2011, 2014, 2016, Roy et al. 2014). Northeast Atlantic stocks that are assessed separately probably originate from common nursery areas around Spitsbergen (Albert and Vollen 2015).

Large juvenile and adult Greenland halibut are typically found in water depths from 200 to 2000 m and in waters deeper than the continental shelf break. Catches at shallow depths on the shelf usually comprise juveniles (Bowering and Nedreaas 2000). In the Pacific Arctic, typically only juveniles are found on the shelf and they are not found there every year; for instance, juveniles were absent from RUSALCA trawl catches on the Chukchi shelf in 2004 and 2012, but were present in 2009. Relatively large individuals are common, although not abundant, on the upper slope in the Chukchi and Beaufort seas (Mecklenburg et al. 2014). This species is more abundant elsewhere in the Arctic and in the Pacific south of the Chukchi Sea, including the southern Bering Sea. On the eastern shelf of Baffin Island, immature Greenland halibut are regularly found throughout the open water season at depths as shallow as 400 m. Tagging studies have shown large-scale movements by adult Greenland halibut, with tagged individuals moving from Baffin Bay to the Grand Banks and western Iceland (Boje 2002). Greenland halibut have pelagic eggs and larvae; spawning generally occurs over several months in the winter (Gundersen et al. 2010, Sohn et al. 2010) and juveniles move higher in the water column as they develop, until settling in the late summer or autumn (Jensen 1935). This prolonged pelagic phase exposes eggs and larvae to a different suite of stressors than those affecting adults (pelagic versus primarily benthic).

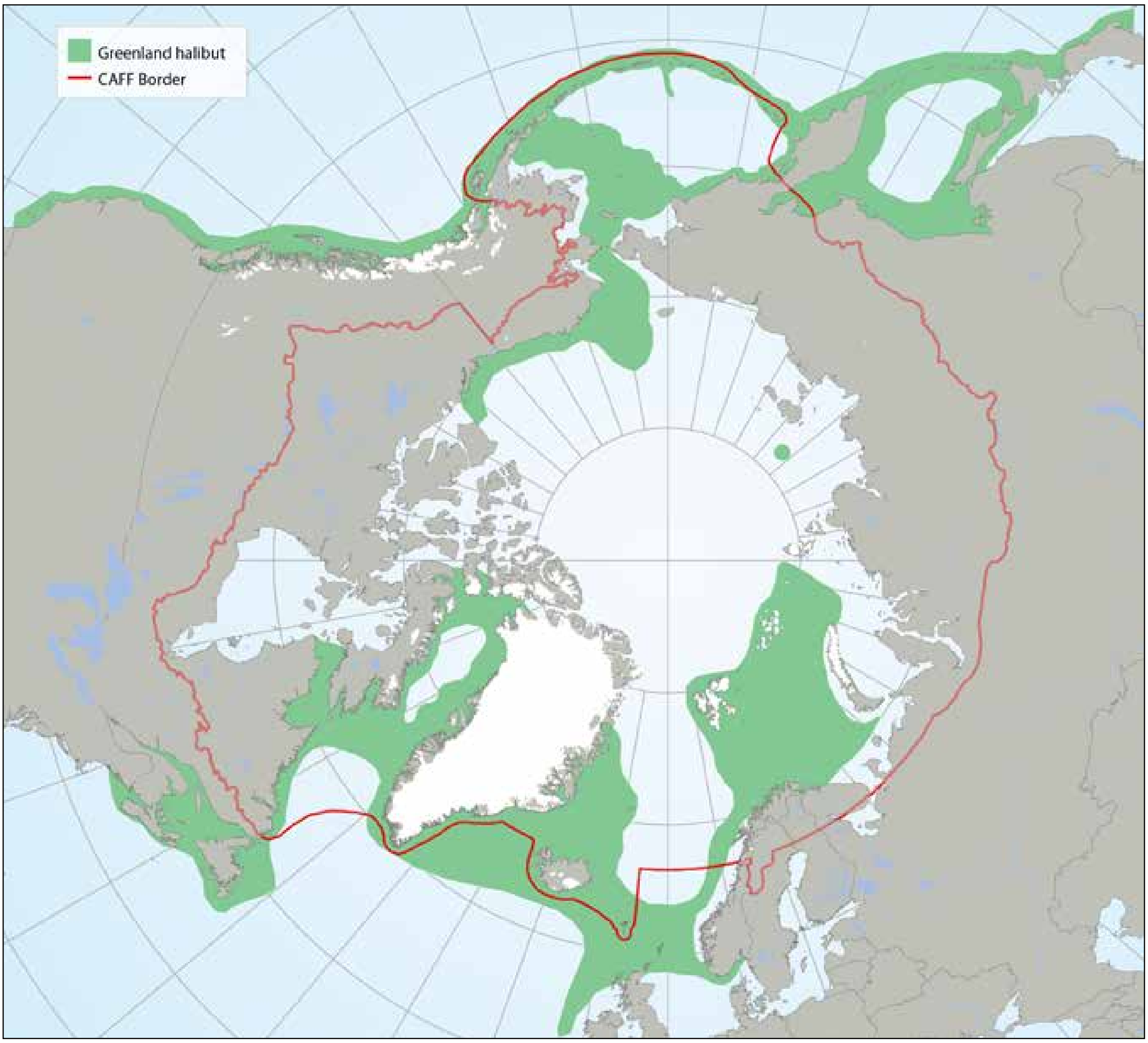


*Figure 3.4.7. Distribution of Greenland halibut (*Reinhardtius hippoglossoides*) based on participation in research sampling, examination of museum voucher collections, literature and molecular genetic analysis (Mecklenburg et al. 2011, 2014, 2016, Mecklenburg and Steinke 2015). Map shows the maximum distribution observed from point data and includes both common and rare locations.*

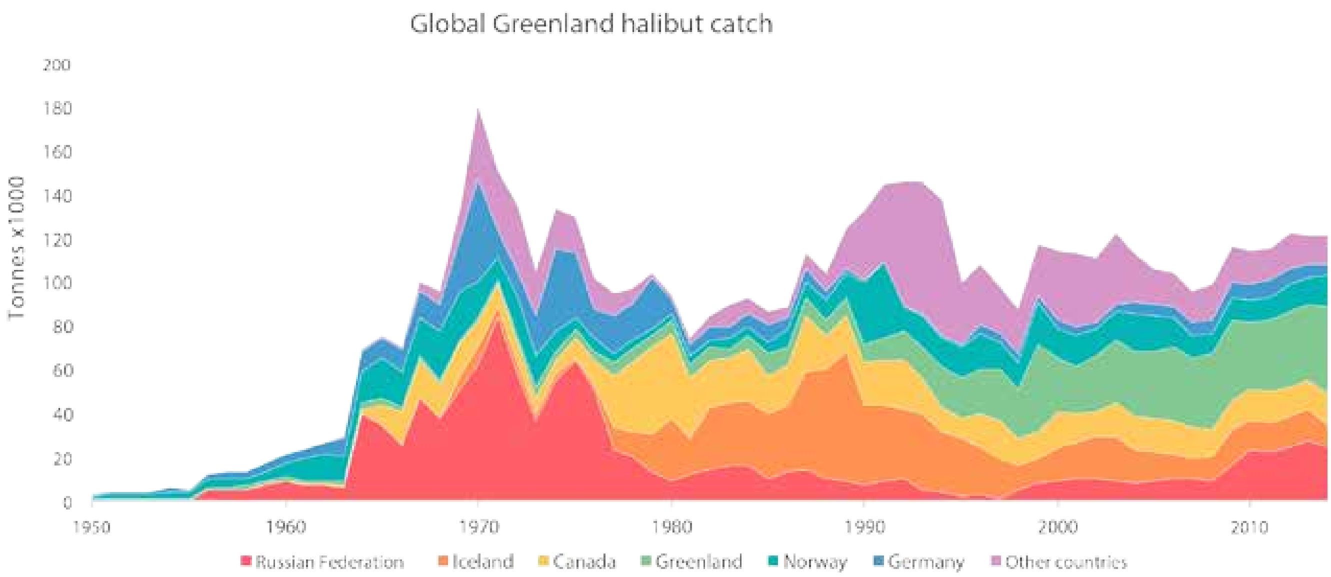


Figure 3.4.8. Global catches of Greenland halibut (FAO 2015).

Communities in the high north have relied on Greenland halibut throughout history as a valuable subsistence resource. Some commercial fisheries have been conducted north of Norway and along the Russian Murman coast since the 17th Century (Lajus et al. 2005). However, large-scale commercial fisheries are rather recent and started with Norwegian longliners (Godø and Haug 1989, Nedreaas and Smirnov 2004). In the mid 1960s, catches increased substantially when Soviet and German deep-water trawlers joined the fishery. Later, Canadian, Icelandic and Greenlandic trawlers, longliners and gillnetters joined as well. Several other nations participate on a smaller scale, including distant fleets from Spain, Portugal, Estonia and Poland. Old catch records for Greenland halibut are not considered reliable as the species might not have been differentiated from Atlantic halibut or were classified with "various pleuronectiformes" (Godø and Haug 1989).

Greenland halibut is one of the most valuable fishes in the Arctic. Per unit weight, Greenland halibut is two and a half times more valuable than Atlantic cod (Directorate of Fisheries Iceland 2015), which is already valuable. Greenland halibut is currently commercially fished in the Arctic waters of Canada, the Faroe Islands, Greenland, Iceland, Norway and Russia (Fig. 3.4.8). The largest fisheries are currently conducted by Greenland. Similar amounts are fished in the northeast and northwest Atlantic, but the catch in the north Pacific is much lower. For the last 40 years, fisheries have fluctuated around 100 kt y^{-1}, with several nations participating in the fisheries.

Stocks of Greenland halibut are assessed in the North Atlantic by ICES, NAFO and DFO. Formal assessments for the northeast Pacific are available from NOAA Alaska Fisheries Science Center. Greenland halibut stocks are generally considered well managed, but stock assessments have been hindered by difficulties in age-determination of individual fish (Treble et al. 2008). Fisheries in eastern Greenland, Iceland and the Faroe Islands harvest from a single stock. This northeast Arctic stock has undergone considerable declines since a maximum harvest in 1988, but rebuilding efforts have been successful (ICES 2015a). The stock trend for Bering Sea Greenland Halibut is very similar, with a long decline from 1993 to 2010 and subsequent increase (NPFMC 2015). The stock in the Barents Sea is considered to be in good condition and growing considerably since the 1990s (ICES 2015b). The Greenland halibut fishery in Baffin Bay and Davis Strait that is conducted by Canada and Greenland has been relatively stable (Jørgensen and Treble 2015).

The history of exploitation for Greenland halibut demonstrates the interest and energy related to expanding Arctic commercial fisheries. Fishing seasons and areas in Arctic waters can be heavily dictated by sea ice conditions. Reductions in the extent, duration and thickness of sea ice provide opportunities for the extension of fishing seasons and the expansion of fishing footprints, which will lead to new impacts on Arctic marine ecosystems.

The species is subjected to different stressors during its life stages as individuals' progress from pelagic to essentially benthic lifestyles. The value and apparent resilience of Greenland halibut practically ensure that fisheries will continue and likely expand in the future. Taken together, these factors make Greenland halibut a useful species for assessing fishery impacts on target species and supporting ecosystems in the Arctic.

3.4.4 Drivers of observed trends

The three marine fish FECs discussed here are indicative of different changes that are occurring in the Arctic and demonstrate the varied responses observed among species.

Polar cod has declined rapidly in the Barents Sea in the last decade and the stock is currently at a very low level (Fig. 3.4.3) although a survey in 2016 showed a notable increase in polar cod biomass, primarily because of an unusually high catch of age-one fish (Joint Russian-Norwegian Ecosystem Survey unpubl. data, autumn 2004-2016). There is no evidence of declines in other areas, but data are lacking. Catches of polar cod have declined since a peak in the 1970s (Fig. 3.4.4) and most of the catches are from the Barents Sea. The current harvest of polar cod is negligible and has not contributed to the recent decline. In addition to fishing

Fishing boat, Greenland. Photo: Carsten Egevang/ARC-PIC.com

pressure, polar cod is being affected by the northward expansion of boreal species, such as Atlantic cod, which impose new predatory or competitive pressures, and changes in sea ice, which provides important habitat for spawning and protection from predators.

Capelin stocks throughout the Arctic are shifting northward and have exhibited rapid demographic changes. Capelin stocks are typified by large interannual fluctuations, making it difficult to detect trends in abundance, but the recent environmentally-driven northward displacement of capelin is a consequence of changes in sea ice and water temperature. Greenland halibut has undergone declines and subsequent recovery over the last two decades in the northeast Arctic. Populations in the Barents Sea, Baffin Bay and Davis Strait are considered stable or increasing. Greenland halibut has supported various commercial fisheries, which have been spatially and temporally limited by sea ice duration and extent.

Most of the drivers affecting marine fishes in the Arctic are linked, directly or indirectly, to climate change. As ocean temperatures increase, the distributions of zoogeographical groups can change both south to north (Wassmann et al. 2011, Hollowed et al. 2013) and across Pacific and Atlantic Arctic waters (Mecklenburg et al. 2014, Wisz et al. 2015). Increases in the relative abundance of warmer water species have already been documented in the Bering Sea (Mueter and Litzow 2008), Barents Sea (Fossheim et al. 2015), Eastern Canadian Arctic (Mullowney et al. 2014), Greenlandic (MacKenzie et al. 2014) and Icelandic waters (Stefánsdóttir et al. 2010, Valdimarsson et al. 2012). Spatial overlap among species from different zoogeographical groups will increase as the distributions of fish species shift northward because larger-bodied boreal species are shifting northwards at a faster rate than Arctic species are retreating. This can cause increased predation on Arctic species, higher competition for food and possibly elevated risk of disease (Harvell et al. 1999, Bradley et al. 2005). As a consequence, food web structure becomes altered (Kortsch et al. 2015). The increasing inter-specific overlap and consequent predation by Atlantic cod on polar cod in the Barents Sea is illustrative of this pattern (Box 3.4.3), and there has been an overall decline in occurrence of Arctic fishes in the Barents Sea from 2004 to 2015 (Johannesen et al. 2017). Similarly, the northward expansion of capelin in some areas of the Arctic has resulted in novel competition with polar cod for zooplankton prey (Box 3.4.2). In addition to the direct effect on polar cod, this change in the marine fish community can have bottom-up effects on marine mammals, seabirds and piscivorous fishes that experience a change in their prey field and consequently their diet and nutritional status.

The effects of acidification on Arctic fishes are still unclear, but recent studies on Atlantic cod showed higher juvenile mortality with elevated acidification (Stiasny et al. 2016). The geographic extent, temporal extent and thickness of sea ice all have influence on Arctic marine fishes. Sympagic species, such as polar cod use sea ice as a critical habitat and reductions in sea ice cover and concentration, or changes in the timing of freeze-up and break-up, represent a loss of spawning habitat and refuges from predation (Bradstreet 1982, Gradinger and Bluhm 2004, Bouchard and Fortier 2011). Because polar cod rely on sea ice for spawning habitat and refuge from predation, changes in sea ice conditions can have fitness consequences for polar cod. The marginal ice zone is particularly relevant in this regard. Sea ice cover, thickness and concentration are limiting factors for marine fish surveys and fisheries (Bowering and Nedreaas 2000, Albert et al. 2001). Increase in the duration of the ice-free period permits fisheries to operate for longer periods within a year and reductions in sea ice extent allow access to previously unsurveyed habitats. Decreases in sea ice concentration and thickness allow smaller vessels to fish commercially without risking ice damage. Sea ice cover can also provide refuge from fisheries, protecting both fish stocks and ecologically important bottom features such as corals and sponge beds (Garcia et al. 2006).

Northward advance of valuable boreal species, retreat of Arctic species and increased accessibility due to less ice cover will increase the total fishing pressure and open new areas for fishing in northern areas. Overfishing of target fish species is generally not of concern, as these fisheries are considered well managed (ICES 2015a, ICES 2015b, NPFMC 2015). However, side effects, such as possible damage from bottom trawling to important benthic ecosystems and bycatch of vulnerable Arctic fishes are of concern (Christiansen et al. 2014). Greenland halibut fisheries have been generally stable. The decline in the northeast Arctic stock marks a notable decline in a commercial Greenland halibut fishery, but the subsequent recovery of the stock demonstrates the resilience of this species to harvest. The pan-Arctic distribution of Greenland halibut makes the expansion of current commercial fisheries likely as sea ice continues to decline. Greenland halibut are fished using bottom trawls, gillnets and longlines, all of which contact the sea bottom, albeit with substantially different intensity. Previously unexplored or exploited areas in the Arctic may harbour sensitive coral and sponge communities that provide important marine fish habitat. Given our generally poor understanding of the reproductive ecology of marine fishes in the Arctic and the drivers of marine fish productivity, bottom contact surveys and fisheries in new areas must proceed with considerable forethought. The central Arctic Ocean is of particular interest for fisheries because it falls outside the boundaries of national EEZs. Most of this area is currently inaccessible to fisheries due to almost constant ice cover, but the area could open-up and attract international fishing fleets (Pan and Huntington 2016).

3.4.5 Knowledge and monitoring gaps

Monitoring and even baseline assessments of Arctic marine fish biodiversity remain limited, but considerable progress has been made in recent years in conducting baseline biodiversity assessments (e.g. Møller et al. 2010, Mecklenburg et al. 2011, 2016, Wienerroither et al. 2011a, b, 2013; Jónsson and Pálsson 2013). Short-term data collections have provided occurrence data in many locations, but quantitative assessments and monitoring remain the exception instead of the norm. Surveys need to be conducted in previously un-assessed areas of the Arctic to provide baseline data. Areas that have been surveyed in the past, but not in recent years, need to be revisited to identify changes in local biodiversity. Regular biodiversity monitoring programs are needed throughout the Arctic, not only in areas that support commercial fisheries.
Accurate identification of fishes caught is essential to the success of monitoring efforts. The taxonomic uncertainties, which have made identification of some species difficult in the past, are a major focus of researchers around the Arctic. Several issues identified (e.g., Mecklenburg and Steinke 2015) have already been resolved. For instance, a recent molecular and morphological analysis reduced nine nominal species of *Gymnelus* eelpouts reputed to be present in the Arctic to two species (Mecklenburg and Anderson 2015). Many others remain to be resolved; for instance, the species limits and distributions of the capelin complex. Although such studies do not always pertain to "important" species, all species need to be accurately represented in biodiversity monitoring, and some may be more important ecologically than currently understood. The recently published atlas and guide to Pacific Arctic marine fishes coupled with the ongoing pan-Arctic atlas are intended to fill the distributional atlas and identification guide gaps.

Gaps in knowledge of the physical environment are also problematic. Seabed mapping is limited in Arctic waters. The spatial coverage of navigational charts covers the small fraction of the Arctic that experiences regular marine traffic, and in many cases the underlying data date back to the 1950s or 1960s (e.g., Canadian Arctic waters). Existing charts require updating to account for factors such as changes in global water levels and glacial rebound. With the opening of new waters due to reductions in sea ice extent and duration, hydrographic surveys need to be conducted to allow safe passage of commercial and recreational vessels. Hydrographic data are also essential for fish habitat mapping to support fisheries management within an ecosystem context.

3.4.6 Conclusions and key findings

- Conduct pan-Arctic taxonomic analyses to clarify zoogeographic patterns that are important for detecting and understanding change.
- Indices and monitoring programs based on harvested species or that rely on fishery-related data are inherently affected by changes in stock size, exploitation rates and exploitation history.
- TK holders have a considerable wealth of information regarding marine fish FECs that is needed to increase our knowledge of interconnected systems.
- Areas that are not fished commercially have been poorly surveyed, and when examined the programs are typically of short duration creating snap-shots of biodiversity but not being sufficient for monitoring changes.
- Ice conditions affect both species distributions and the ability to monitor Arctic marine fish biodiversity.
- Range expansions (northward) pose unknown consequences for resident species and inter-specific interactions (predator-prey, competitive). Species range expansions depend on changes in environmental conditions and are constrained by prey availability and predation pressure.
- The main commercial marine fishes in the Arctic, Greenland halibut and capelin, do not yet seem to be adversely affected by climate change although their distributions appear to be changing. However, boreal species moving north seem to be negatively affecting the abundances of polar cod. Little is known about effects on non-commercial marine fishes in the Arctic.
- Polar cod are both culturally and ecologically a keystone species. It is a valuable indicator species because it relies on sea ice as spawning habitat.
- Capelin provide a robust example of the northward expansion of Arctic-boreal species and the consequences for Arctic species. Capelin provide novel competition for other forage fishes and prey for piscivores.
- Greenland halibut are important predatory fish in the Arctic seas and they are commercially harvested in large areas of the Arctic. In some areas, it is the only commercially harvested fish species and therefore the sole reason for fishery-related ecosystem impacts. Greenland halibut and related fisheries have the potential to expand further into the Arctic Ocean with climate change, given the availability of suitable topography and prey.

References

Ajiad, A., Oganin, I.A. and Gjøsæter, H. 2011. Polar cod. *In:* T. Jakobsen and V.K. Ozhigin (eds.). The Barents Sea ecosystem, resources, management: Half a century of Russian-Norwegian cooperation. Tapir Academic Press, Trondheim, Norway, pp 315-328.

Albert, O.T. and Vollen, T. 2015. A major nursery area around the Svalbard archipelago provides recruits for the stocks in both Greenland halibut management areas in the Northeast Atlantic. ICES Journal of Marine Science, 72(3): 872–879.

Albert, O.T., Nilssen, E.M., Nedreaas, K.H. and Gundersen, A.C. 2001. Distribution and abundance of juvenile Northeast Arctic Greenland halibut (*Reinhardtius hippoglossoides*) in relation to survey coverage and the physical environment. ICES Journal of Marine Science, 58(5): 1053–1062.

Armitage, D., Berkes, F., Dale, A., Kocho-Schellenberg, E. and Patton, E. 2011. Co-management and the co-production of knowledge: Learning to adapt in Canada's Arctic. Global Environmental Change, 21(3): 995–1004.

Ástþórsson, Ó.S. 2015. Distribution, abundance and biology of polar cod, *Boreogadus saida*, in Iceland–East Greenland waters. Polar Biology, 39(6): 1–9.

Björnsson, H., Sólmundsson, J., Kristinsson, K., Steinarsson, B.Æ., Hjörleifsson, E., Jónsson, E. and Sigurðsson, Þ. 2007. Stofnmæling botnfiska á Íslandsmiðum (SMB) 1985-2006 og Stofnmæling botnfiska að haustlagi (SMH) 1996-2006: undirbúningur, framkvæmd og helstu niðurstöður (The Icelandic groundfish surveys in March 1985-2006 and in October 1996-2006). Hafrannsóknastofnunin Fjölrit, Reykjavik.

Bluhm, B.A. and Gradinger, R. 2008. Regional variability in food availability for Arctic marine mammals. Ecological Applications, 18(sp2): S77–S96.

Boje, J. 2002. Intermingling and seasonal migrations of Greenland halibut (*Reinhardtius hippoglossoides*) populations determined from tagging studies. Fishery Bulletin, 100(3): 414–422.

Borkin, I.V., Vasilev, A.V. and Chetirkina, O.Y. 2008. Ichthyofauna. *In*: The Ecosystem of the Kara Sea. PINRO, Murmansk, pp 130–206. [In Russian].

Bouchard, C. and Fortier, L. 2011. Circum-arctic comparison of the hatching season of polar cod *Boreogadus saida*: A test of the freshwater winter refuge hypothesis. Progress in Oceanography, 90(1-4): 105–116.

Bowering, W.R. and Nedreaas, K.H. 2000. A comparison of Greenland halibut (*Reinhardtius hippoglossoides* (Walbaum)) fisheries and distribution in the Northwest and Northeast Atlantic. Sarsia, 85(1), 61–76.

Bradley, M.J., Kutz, S.J., Jenkins, E. and O'Hara, T. M. 2005. The potential impact of climate change on infectious diseases of Arctic fauna. International Journal of Circumpolar Health, 64(5): 468-477.

Bradstreet, M.S.W. 1982. Occurrence, habitat use, and behaviour of seabirds, marine mammals and Arctic cod at the Pond Inlet ice edge. Arctic 35(1): 28–40.

Bradstreet, M., Finley, K., Sekerak, A., Griffiths, W., Evans, C., Fabijan, M. and Stallard, H. 1986. Aspects of the biology of Arctic cod (*Boreogadus saida*) and its importance in Arctic marine food chains. Canadian Technical Report of Fisheries and Aquatic Sciences 1491, Fishereis and Oceans Canada.

Brewster, K., George, C., Aiken, M. and Barrow Elders. 2010. Iñupiat knowledge of selected subsistence fish near Barrow, Alaska. Bureau of Land Management and the North Slope Borough Department of Wildlife Management, Barrow, Alaska.

Chambellant, M., Stirling, I. and Ferguson, S.H. 2013. Temporal variation in western Hudson Bay ringed seal (*Phoca hispida*) diet in relation to environment. Marine Ecology Progress Series, 481: 269–287.

Christiansen, J.S. 2012. The TUNU programme: Euro-Arctic marine fishes – diversity and adaptation. *In*: G. di Prisco and C. Verde (eds.). Adaptation and Evolution in Marine Environments, 1, From Pole to Pole. Springer-Verlag Berlin Heidelberg: 35-50.

Christiansen, J.S., Mecklenburg, C.W. and Karamushko, O.V. 2014. Arctic marine fishes and their fisheries in light of global change. Global Change Biology, 20(2): 352–359.

Christiansen, J.S., Reist, J.D., Brown, R.J., Brykov, V.A., Christensen, G., Christoffersen, K., Cott, P., Crane, P., Dempson, J.B., Docker, M., Dunmall, K., Finstad, A., Gallucci, V.F., Hammar, J., Harris, L.N., Heino, J., Ivanov, E., Karamushko, O.V., Kirillov, A., Kucheryavyy, A., Lehtonen, H., Lynghammar, A., Mecklenburg, C.W., Moller, P.D.R., Mustonen, T., Oleinik, A.G., Power, M., Reshetnikov, Y.S., Romanov, V.I., Sandlund, O., Sawatzky, C.D., Svenning, M., Swanson, H.K. and Wrona, F.J. 2013. Fishes. *In*: H. Meltofte (ed.). Arctic Biodiversity Assessment: Status and trends in Arctic biodiversity. Conservation of Arctic Flora and Fauna, Akureyri, Iceland: 193-245.

Coad, B.W. and Reist, J.D. 2004. Annotated list of the Arctic Marine Fishes of Canada. Canadian Manuscript Report of Fisheries and Aquatic Sciences, 2674: iv + 112 p.

Coad, B.W. In press. Marine fishes of Arctic Canada. University Toronto Press.

Cohen, D.M., Inada, T., Iwamoto, T. and Scialabba, N. 1990. Gadiform fishes of the world (Order Gadiformes). An annotated and illustrated catalogue of cods, hakes, grenadiers and other gadiform fishes known to date. Food and Agriculture Organization of the United Nations, 125(10).

Dahl, T.M., Lydersen, C., Kovacs, K.M., Falk-Petersen, S., Sargent, J., Gjertz, I. and Gulliksen, B. 2000. Fatty acid composition of the blubber in white whales (*Delphinapterus leucas*). Polar Biology, 23(6): 401–409.

Dalpadado, P., Hop, H., Rønning, J., Pavlov, V., Sperfeld, E., Buchholz, F., Rey, A. and Wold, A. 2016. Distribution and abundance of euphausiids and pelagic amphipods in Kongsfjorden, Isfjorden and Rijpfjorden (Svalbard) and changes in their importance as key prey in a warming marine ecosystem. Polar Biology, 39(10): 1765-1784.

David C., Lange B., Rabe B. and Flores H. 2015. Community structure of under-ice fauna in the Eurasian central Arctic Ocean in relation to environmental properties of sea-ice habitats. Marine Ecology Progress Series, 522: 15–32.

Davoren, G.K., Penton, P., Burke, C. and Montevecchi, W.A. 2012. Water temperature and timing of capelin spawning determine seabird diets. ICES Journal of Marine Science, 69(7): 1234–1241.

Dempson, J., Shears, M. and Bloom, M. 2002. Spatial and temporal variability in the diet of anadromous Arctic char, Salvelinus alpinus, in northern Labrador. Environmental Biology of Fishes, 64(1):49–62.

Dennard, S. T., McMeans, B.C. and Fisk, A.T. 2009. Preliminary assessment of Greenland halibut diet in Cumberland Sound using stable isotopes. Polar Biology, 32(6): 941–945.

Directorate of Fisheries, Iceland. 2015. Þorskígildisstuðlar. [Accessed 3 March 2017]

Dolgov, A.V. 2002. The role of capelin (*Mallotus villosus*) in the foodweb of the Barents Sea. ICES Journal of Marine Science, 59(5): 1034–1045.

Dolgov, A.V. 2013. Annotated list of fish-like vertebrates and fish of the Kara Sea. Journal of Ichthyology, 53(11): 914–922.

Erikstad, K.E. 1990. Winter diets of four seabird species in the Barents Sea after a crash in the capelin stock. Polar Biology, 10(8): 619–627.

Food and Agriculture Organization (FAO). 2015. Fishery and Aquaculture Statistics. [Global capture production 1950-2013] Retrieved from FishStat software for fishery statistical time series. Fisheries and Aquacuture Department, Food and Agriculture Organization of the United Nations.

Fossheim, M., Primicerio, R., Johannesen, E., Ingvaldsen, R.B., Aschan, M.M. and Dolgov, A.V. 2015. Recent warming leads to rapid borealization of fish communities in the Arctic. Nature Climate Change, 5: 673–678.

Garcia, E. G. 2007. The Northern Shrimp (*Pandalus borealis*) Offshore Fishery in the Northeast Atlantic. Advances in Marine Biology, 52: 147–266.

Garcia, E.G., Ragnarsson, S.A., Steingrímsson, S.A., Nævestad, D., Haraldsson, H.T., Fosså, J.H., Tendal, O.S., Eiríksson, H, Skúladóttir, U., Frandsen, R. and Siegstad, H. 2006. Bottom trawling and scallop dredging in the Arctic: impacts of fishing on non-target species, vulnerable habitats and cultural heritage. Nordic Council of Ministers, Copenhagen, Denmark: 1-375.

Gaston, A.J. and Elliott, K.H. 2014. Seabird diet changes in northern Hudson Bay, 1981–2013, reflect the availability of schooling prey. Marine Ecology Progress Series, 513: 211–223.

Gaston, A.J., Woo, K. and Hipfner, J.M. 2003. Trends in forage fish populations in northern Hudson Bay since 1981, as determined from the diet of nestling thick-billed murres *Uria lomvia*. Arctic, 56(3): 227–233.

Gill, M.J., Crane, K., Hindrum, R., Arneberg, P., Bysveen, I., Denisenko, N.V., Gofman, V., Grant-Friedman, A., Guðmundsson, G., Hopcroft, R.R., Iken, K., Labansen, A., Liubina, O.S., Melnikov, I.A., Moore, S.E., Reist, J.D., Sirenko, B.I., Stow, J., Ugarte, F., Vongraven, D. and Watkins, J. 2011. Arctic Marine Biodiversity Monitoring Plan. CAFF Monitoring Series Report No. 3, Conservation of Arctic Flora and Fauna International Secretariat, Akureyri, Iceland.

Gjøsæter, H., Bogstad, B. and Tjelmeland, S. 2009. Ecosystem effects of the three capelin stock collapses in the Barents Sea. Marine Biology Research, 5: 40–53.

Godø, O.R. and Haug, T. 1989. A review of the natural history, fisheries, and management of Greenland halibut (*Reinhardtius hippoglossoides*) in the eastern Norwegian and Barents Seas. ICES Journal of Marine Science, 46(1): 62–75.

Golder Associates Ltd. 2002. Fisheries assessment of the proposed marine docking facility at Kugluktuk, Nunavut. Government of Nunavut, Department of Public Works and Services and Department of Government Transportation. Nunavut Imapct Review Board public registry.

Gradinger, R.R. and Bluhm, B.A. 2004. In-situ observations on the distribution and behavior of amphipods and Arctic cod (*Boreogadus saida*) under the sea ice of the High Arctic Canada Basin. Polar Biology, 27(10): 595–603.

Gradinger, R., Bluhm, B.A., Hopcroft, R.R., Gebruk, A.V., Kosobokova, K., Sirenko, B. and Weslawski J.M. 2010 Chapter 10. Marine life in the Arctic. *In*: A.D. McIntyre (ed.). Life in the world's oceans: diversity, distribution and abundance. Blackwell Publishing Ltd, Chichester, United Kingdom: 183-203.

Gundersen, A.C., Stenberg, C., Fossen, I., Lyberth, B., Boje, J. and Jørgensen, O.A. 2010. Sexual maturity cycle and spawning of Greenland halibut *Reinhardtius hippoglossoides* in the Davis Strait. Journal of Fish Biology, 77(1): 211–226.

Hansen P.M. 1943. Capelin (*Mallotus villosus*). International Council for the Exploration of the Sea, (1939-41): 121-24.

Harvell, C.D., Kim, K., Burkholder, J.M., Colwell, R.R., Epstein, P.R., Grimes, D.J. and Vasta, G.R. 1999. Emerging marine diseases: Climate links and anthropogenic factors. Science, 285(5433): 1505–1510.

Harwood, L.A. and Babaluk, J.A. 2014. Spawning, overwintering and summer feeding habitats used by anadromous Arctic char (*Salvelinus alpinus*) of the Hornaday River, Northwest Territories, Canada. Arctic, 67(4): 449–461.

Hollowed, A.B., Planque, B. and Loeng, H. 2013. Potential movement of fish and shellfish stocks from the sub-Arctic to the Arctic Ocean. Fisheries Oceanography, 22(5): 355–370.

Hop, H. and Gjøsæter, H. 2013. Polar cod (*Boreogadus saida*) and capelin (*Mallotus villosus*) as key species in marine food webs of the Arctic and the Barents Sea. Marine Biology Research, 9(9): 878–894.

Hop, H., Borgå, K., Gabrielsen, G.W., Kleivane, L. and Skaare, J.U. 2002. Food web magnification of persistent organic pollutants in poikilotherms and homeotherms from the Barents Sea. Environmental Science and Technology, 36(12): 2589–2597.

Howell, D. and Filin, A.A. 2014. Modelling the likely impacts of climate-driven changes in cod-capelin overlap in the Barents Sea. ICES Journal of Marine Science, 71(1): 72–80.

ICES. 2015a. Report of the North-Western Working Group (NWWG) 28 April-5 May 2015. ICES CM,2015/ACOM:07. International Council for the Exploration of the Sea, Copenhagen, Denmark.

ICES. 2015b. Report of the Arctic Fisheries Working Group (AFWG) 23-29 April, 2015. ICES C.M., 2015/ACOM:05. International Council for the Exploration of the Sea, Hamburg, Germany.

ICES. 2016. Report of the Arctic Fisheries Working Group (AFWG), 19-25 April 2016. ICES CM 2016/ACOM:06. International Council for the Exploration of the Sea, Copenhagen, Denmark.

Ingvaldsen, R.B. and Gjøsæter, H. 2013. Responses in spatial distribution of Barents Sea capelin to changes in stock size, ocean temperature and ice cover. Marine Biology Research, 9(9): 867–877.

Ingvaldsen, R.B., Bogstad, B., Dolgov, A.V., Ellingsen, K.E., Gjøsæter, H., Gradinger, R., Johannesen, E., Tveraa, T. and Yoccoz, N.G. 2015. Sources of uncertainties in cod distribution models. Nature Climate Change, 5(9): 788-789.

Jensen, A. 1935. The Greenland halibut (*Reinhardtius hippoglossides*), its development and migration. Kongelige Danske Videnskabernes Selskab Skrifter. 9: 1–32.

Johannesen, E., Mørk Langøy, H., Eriksen, E., Korsbrekke, K., Wienerroither, R., Fossheim, W., Wenneck de Lange, T., Dolgov, A., Prokhorova, T. and Prozorkevich, D. 2017. Arctic fishes in the Barents Sea 2004-2015: changes in abundance and distribution. IMR/PINRO Joint Report Series No x/2017.

Jónsson, G. and Pálsson, J. 2013. Íslenskir fiskar (Fishes of Iceland). Mál og menning, Reykjavík, Iceland.(In Icelandic)

Jørgensen, O.A. and Treble, M.A. 2015. Assessment of the Greenland halibut stock component in NAFO Subarea 0 + Division 1A Offshore + Divisions 1B-1F. Scientific Council Research Documents, Northwest Atlantic Fisheries Organization, 15/032:1-57.

Jørgensen, O.A., Hvingel, C. and Treble, M.A. 2011. Identification and mapping of bottom fish assemblages in Northern Baffin Bay. Journal of Northwest Atlantic Fishery Science, 43: 65–79.

Karamushko, O.V. 2012. Structure of ichthyofauna in the Arctic seas of Russia. *In*: Berichte zur Polar- und Meeresforschung. Reports on Polar and Marine Research. Arctic Marine Biology. Alfred-Wegener Institute for Polar and Marine Research, 640, pp 129–136.

Kjesbu, O.S., Bogstad, B., Devine, J.A., Gjøsæter, H., Howell, D., Ingvaldsen, R.B., Nash, R.D.M. and Skjæraasen, J.E. 2014. Synergies between climate and management for Atlantic cod fisheries at high latitudes. PNAS, 111(9): 3478-3483.

Kortsch S., Primicerio R., Fossheim M., Dolgov A.V. and Aschan M. 2015. Climate change alters the structure of arctic marine food webs due to poleward shifts of boreal generalists. Proceedings of the Royal Society B, 282(1814): 20151546.

Lajus, D.L., Lajus, J.A., Dmitrieva, Z.V., Kraikovski, A.V. and Alexandrov, D.A. 2005. The use of historical catch data to trace the influence of climate on fish populations: examples from the White and Barents Sea fisheries in the 17th and 18th centuries. ICES Journal of Marine Science, 62(7): 1426–1435.

Lleonart, J., Taconet, M. and Lamboeuf, M. 2006. Integrating information on marine species identification for fishery purposes. Marine Ecology Progress Series, 316, 231–238.

Logerwell, E., Busby, M., Carothers, C., Cotton, S., Duffy-Anderson, J., Farley, E., Goddard, P., Heintz, R., Holladay, B., Horne, J., Johnson, S., Lauth, B., Moulton, L., Neff, D., Norcross, B., Parker-Stetter, S., Seigle, J. and Sformo, T. 2015. Fish communities across a spectrum of habitats in the western Beaufort Sea and Chukchi Sea. Progress in Oceanography, 136: 115–132.

Lønne, O.J. and Gulliksen, B. 1989 Size, age and diet of polar cod, *Boreogadus saida* (Lepechin 1773), in ice covered waters. Polar Biology, 9(3): 187-91.

MacKenzie, B.R., Payne, M.R., Boje, J., Høyer, J.L. and Siegstad, H. 2014. A cascade of warming impacts brings bluefin tuna to Greenland waters. Global Change Biology, 20(8): 2484–2491.

Majewski, A.R., Walkusz, W., Lynn, B.R., Atchison, S., Eert, J. and Reist, J.D. 2016. Distribution and diet of demersal Arctic cod, *Boreogadus saida*, in relation to habitat characteristics in the Canadian Beaufort Sea. Polar Biology, 39(6): 1087-1098.

Marcoux, M., McMeans, B.C., Fisk, A.T. and Ferguson, S.H. 2012. Composition and temporal variation in the diet of beluga

whales, derived from stable isotopes. Marine Ecology Progress Series, 471: 283–29.
Marine Research Institute. 2010. Manuals for the Icelandic bottom trawl surveys in spring and autumn. Hafrannsóknastofnunin Fjölrit, 156, Reykjavik, Iceland: 1–125.
McDonald, M., Arragutainaq L. and Novalinga, Z. 1995. Traditional ecological knowledge of environmental changes in Hudson and James Bay. Part I. Hudson Bay Programme. Environmental Committee. Sanikiluaq, Nunavut.
McNicholl, D.M., Walkusz, W., Davoren, G.K., Majewski, A.R. and Reist, J.D. 2016. Dietary characteristics of co-occurring polar cod (*Boreogadus saida*) and capelin (*Mallotus villosus*) in the Canadian Arctic, Darnley Bay. Polar Biology, 39(6): 1099-1108.
Mecklenburg, C.W., Behe, C., Byrkjedal, I., Christiansen, J., Dolgov, A., Hedges, K.J., Johannesen, E., Karamushko, O.A., Lynghammar, A., Mecklenburg, T.A., Møller, P.R., Steinke, D. and Wienerroither, R.M. Marine Fishes of the Arctic. In progress.
Mecklenburg, C.W. and Anderson, M.E. 2015. Reassessment of multiple species of *Gymnelus* (Teleostei: Zoarcidae) in Pacific Arctic and boreal regions. Zootaxa, 3948(2): 263–278.
Mecklenburg, C.W. and Steinke, D. 2015. Ichthyofaunal baselines in the Pacific Arctic region and RUSALCA study area. Oceanography, 28(3): 158–189.
Mecklenburg, C.W., Mecklenburg, T.A. and Thorsteinson, L. K. 2002. Fishes of Alaska. American Fisheries Society, Bethesda, Maryland.
Mecklenburg, C.W., Møller, P.R. and Steinke, D. 2011. Biodiversity of arctic marine fishes: taxonomy and zoogeography. Marine Biodiversity, 41(1): 109–140.
Mecklenburg, C.W., Byrkjedal, I., Christiansen, J.S., Karamushko, O.V., Lynghammar, A. and Møller, P.R. 2013. List of Marine Fishes of the Arctic Region Annotated with Common Names and Zoogeographic Characterizations. Conservation of Arctic Flora and Fauna, Akureyri, Iceland: 35.
Mecklenburg, C.W., Byrkjedal, I., Karamushko, O.V. and Møller, P.R. 2014. Atlantic fishes in the Chukchi Borderland. Marine Biodiversity, 44(1): 127–150.
Mecklenburg, C.W., Mecklenburg, T.A., Sheiko, B.A. and Steinke, D. 2016. Pacific Arctic Marine Fishes. Conservation of Arctic Flora and Fauna, Akureyri, Iceland.
Misund, O.A., Heggland, K. Skogseth, R., Falck, E., Gjøsæter, H, Sundet, J., Watne, J. and Lønne, O.J. 2016. Norwegian fisheries in the Svalbard zone since 1980. Regulations, profitability and warming waters affect landings. Polar Science, 10(3): 312-322.
Mouritsen, R. (ed.). 2007. Fiskar undir Føroyum. Føroya Skúlabókagrunnur.
Mueter, F.J. and Litzow, M.A. 2008. Sea ice retreat alters the biogeography of the Bering Sea continental shelf. Ecological Applications, 18(2): 309–320.
Mullowney, D.R., Dawe, E.G., Colbourne, E.B. and Rose, G.A. 2014. A review of factors contributing to the decline of Newfoundland and Labrador snow crab (*Chionoecetes opilio*). Reviews in Fish Biology and Fisheries, 24(2): 639-657.
Møller, P.R., Nielsen, J.G., Knudsen, S.W., Poulsen, J.Y., Sunksen, K. and Jørgensen, O.A. 2010. A checklist of the fish fauna of Greenland waters. Zootaxa, 2378: 1-84.
Nedreaas, K.H. and Smirnov, O. 2004. Stock characteristics, fisheries and management of Greenland halibut (*Reinhardtius hippoglossoides* Walbaum) in the northeast Arctic. IMP/PINRO Joint Report Series, 1/2004, Institute of Marine Research.
Nelson, R.J. and Bouchard, C. 2013. Final report: Arctic cod (*Boreogadus saida*) population structure and connectivity as examined with molecular genetics. NPRB Project 1125. Québec-Océan, Dèpartement de Biologie, Université Laval, Québec, QC, Canada
NOAA. 2009. Fishery Management Plan for Fish Resources of the Arctic Management Area. North Pacific Fishery Management Council, Anchorage, Alaska.
NOAA 2017. NOAA Arctic Program. [Accessed 3 March 2017]
Norcross, B.L., Holladay, B.A. and Mecklenburg, C.W. 2013. Recent and Historical Distribution and Ecology of Demersal Fishes in the Chukchi Sea Planning Area. Final Report to the Coastal Marine Institute, Task Order M07AC12462, OCS Study BOEM 2012-073, Fairbanks Alaska.
North Pacific Fishery Management Council (NPFMC). 2015. Stock Assessment and Fishery Evaluation Report for the Groundfish Resources of the Bering Sea/Aleutian Islands regions. North Pacific Fishery Management Council, Anchorage, Alaska.
Olsvig, S. and Mosbech, A. 2003. Fiskeriressourcer på det lave vand i det nordlige Vestgrønland: En interviewundersøgelse om forekomsten og udnyttelsen af lodde, stenbider og ørred (Fishery Resources in the shallow waters of northern West Greenland). Arbejdsrapport, 180. Ministry of the Environment, Denmark.
Orlova, E.L., Dolgov, A.V., Rudneva, G.B., Oganin, I.A. and Konstantinova, L.L. 2009. Trophic relations of capelin *Mallotus villosus* and polar cod *Boreogadus saida* in the Barents Sea as a factor of impact on the ecosystem. Deep-Sea Research Part II, 56(21-22): 2054–2067.
Osuga, D.T. and Feeney, R.E. 1978. Antifreeze glycoproteins from Arctic fish. Journal of Biological Chemistry, 253(15): 5338–5343.
Pan, M. and Huntington, H.P. 2016. A precautionary approach to fisheries in the Central Arctic Ocean: Policy, science, and China. Marine Policy, 63: 153–157.
Parin, N.V., Evseenko, S.A. and Vasil'eva, E.D. 2014. Fishes of Russian seas: annotated catalogue. KMK Scientific Press Ltd, Moscow.
Pálsson, J. 2014. Sjaldséðir fiskar á Íslandsmiðum 2012 og 2013 (Rare fishes in Icelandic waters 2012 and 2013). Ægir, 106: 10–12.
Pálsson, Ó.K., Gíslason, Á., Guðfinnsson, H.G., Gunnarsson, B., Olafsdóttir, S.R., Pétursdóttir, H. and Valdimarsson, H. 2012. Ecosystem structure in the Iceland Sea and recent changes to the capelin (*Mallotus villosus*) population. ICES Journal of Marine Science, 69(7): 1242–1254.
Pethon, P. 2005. Aschehougs Store Fiskebok. Aschehoug, Oslo.
Prozorkevich, D. and Sunnana, K. (eds.). 2016. Survey report from the joint Norwegian/Russian ecosystem survey in the Barents Sea and adjacent waters, August-October 2015. IMR/PINRO Joint Report Series, 1/2016.
Raymond-Yakoubian, J. 2013. When the fish come, we go fishing: Local Ecological Knowledge of Non-Salmon Fish Used for Subsistence in the Bering Strait Region. Final Report for Study 10-151, Social Science Program, Natural Resources Division, Kawerak Incorporated.
Remnant, R.A. and Thomas, M.L. 1992. Inuit traditional knowledge of the distribution and biology of High Arctic narwhal and beluga. North/South Consultants Inc., Winnipeg, Canada/Greenland Joint Commission for the Conservation and Management of Beluga and Narwhal.
Rose, G.A. 2005a. On distributional responses of North Atlantic fish to climate change. ICES Journal of Marine Science, 62(7): 1360–1374.
Rose, G.A. 2005b. Capelin (*Mallotus villosus*) distribution and climate: A sea "canary" for marine ecosystem change. ICES Journal of Marine Science, 62(7): 1524–1530.
Rose, G.A. and Rowe, S. 2015. Northern cod comeback. Canadian Journal of Fisheries and Aquatic Sciences, 72(12): 1789–1798.
Roy, D., Hardie, D.C., Treble, M., Reist, J.D. and Ruzzante, D.E. 2014. Evidence supporting panmixia in Greenland halibut (*Reinhardtius hippoglossoides*) in the Northwest Atlantic. Canadian Journal of Fisheries and Aquatic Sciences, 71(5): 763-774.
Sohn, D., Ciannelli, L. and Duffy-Anderson, J.T. 2010. Distribution and drift pathways of Greenland halibut (*Reinhardtius hippoglossoides*) during early life stages in the eastern Bering Sea and Aleutian Islands. Fisheries Oceanography, 19(5): 339–353.
Sólmundsson, J. 2007. Trophic ecology of Greenland halibut (*Reinhardtius hippoglossoides*) on the Icelandic continental shelf and slope. Marine Biology Research, 3(4): 231–242.
Stiasny, M.H., Mittermayer, F.H., Sswat, M., Voss, R, Jutfelt, F., Chierici, M., Puvanendran, V., Mortensen, A., Reusch, T.B.H. and Clemmesen, C. 2016. Ocean Acidification Effects on Atlantic

Cod Larval Survival and Recruitment to the Fished Population. PLoS ONE, 11(8): e0155448.
Stefánsdóttir, L., Sólmundsson, J., Marteinsdóttir, G., Kristinsson, K. and Jónasson, J. P. 2010. Groundfish species diversity and assemblage structure in Icelandic waters during recent years of warming. Fisheries Oceanography, 19(1): 42–62.
Treble, M.A., Campana, S.E., Wastle, R.J., Jones, C.M. and Boje, J. 2008. Growth analysis and age validation of a deepwater Arctic fish, the Greenland halibut (*Reinhardtius hippoglossoides*). Canadian Journal of Fisheries and Aquatic Sciences, 65(6): 1047–1059.
Valdimarsson, H., Ástþórsson, Ó.S. and Pálsson, J. 2012. Hydrographic variability in Icelandic waters during recent decades and related changes in distribution of some fish species. ICES Journal of Marine Science, 69(5): 816–825.
Vilhjálmsson, H. 1997. Interactions between capelin (*Mallotus villosus*) and other species and the significance of such interactions for the management and harvesting of marine ecosystems in the northern North Atlantic. Rit Fiskideildar, Journal of the Marine Research Institute, 15(1): 32–63.
Vilhjálmsson, H. 2002. Capelin (*Mallotus villosus*) in the Iceland–East Greenland–Jan Mayen ecosystem. ICES Journal of Marine Science, 59(5): 870–883.
Vilhjálmsson, H., Hoel, A.H., Agnarsson, S., Árnason, R., Carscadden, J.E., Eide, A. and Jakobsson, J. 2005. Chapter 13: Fisheries and aquaculture. *In*: AMAP, CAFF, IASC (eds.). Arctic Climate Impact Assessment, Cambridge University Press, Cambridge: 691–780.
Wassmann, P., Duarte, C. M., Agustí, S. and Sejr, M. K. 2011. Footprints of climate change in the Arctic marine ecosystem. Global Change Biology, 17(2): 1235–1249.
Watt, C.A., Heide-Jørgensen, M.P. and Ferguson, S.H. 2013. How adaptable are narwhal: A comparison of foraging patterns among the world's three narwhal populations. Ecosphere 4(6): 1-15.
Watts, P.D. and Draper, B.A. 1986. Note on the behavior of beluga whales feeding on capelin. Arctic and Alpine Research, 18(4):439
Welch, H.E., Bergmann, M.A., Siferd, T.D., Martin, K.A., Curtis, M.F., Crawford, R.E., Conover, R.J. and Hop, H. 1992. Energy flow through the marine ecosystem of the Lancaster Sound region, Arctic Canada. Arctic, 45: 343–357.
Wienerroither, R., Johannesen, E., Dolgov, A., Byrkjedal, I., Bjelland, O., Drevetnyak, K., Eriksen, K.B., Høines, Å., Langhelle, G., Langøy, H., Prokhorova, T., Prozorkevich, D. and Wenneck, T. 2011a. Atlas of the Barents Sea fishes. IMR/PINRO Joint Report Series, 1/2011.
Wienerroither, R.M., Nedreaas, K., Uiblein, F., Christiansen, J.S., Byrkjedal, I. and Karamushko, O. 2011b. The marine fishes of Jan Mayen Island, Northeast Atlantic — past and present. Marine Biodiversity, 41: 395–411.
Wienerroither, R., Johannesen, E., Dolgov, A., Byrkjedal, I., Aglen, A., Bjelland, O., Drevetnyak, K., Eriksen, K.B., Høines, Å., Langhelle, G., Langøy, H., Murashko, P., Prokhorova, T., Prozorkevich, D., Smirnov, O. and Wenneck, T. 2013. Atlas of the Barents Sea fishes based on the winter survey. IMR-PINRO Joint Report Series 2/2013.
Wisz, M.S., Broennimann, O., Grønkjær, P., Møller, P.R., Olsen, S.M., Swingedouw, D. and Pellissier, L. 2015. Arctic warming will promote Atlantic-Pacific fish interchange. Nature Climate Change, 5: 261-265.
Young, B. and Ferguson, S.H. 2014. Using stable isotopes to understand changes in ringed seal foraging ecology as a response to a warming environment. Marine Mammal Science, 30(2): 706–725.
Zeller, D., Booth, S., Pakhomov, E., Swartz, W. and Pauly, D. 2011. Arctic fisheries catches in Russia, USA, and Canada: baselines for neglected ecosystems. Polar Biology, 34(7): 955–973.

Common eiders gather together in a polynya near the Belcher Islands, Nunavut, Canada.
Photo: Vicky Johnston, Environment and Climate Change Canada