Working Group on Integrated Ecosystem Assessment of the Greenland Sea (WGIEAGS)

Stedmon, Colin; Boje, Jesper; Christensen, Helle Torp; Nogueira, Adriana ; Winding, Mie S.; Jónsson, Steingrímur; Friis Møller, Eva; Sejr, Mikael; Mosbech, Anders; Post, Søren

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International Council for the Exploration of the Sea
Conseil International pour l'Exploration de la Mer

H.C. Andersens Boulevard 44-46
DK-1553 Copenhagen V
Denmark
Telephone (+45) 33 38 67 00
Telefax (+45) 33 93 42 15
www.ices.dk
info@ices.dk

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Editors

Jesper Boje ● Colin Stedmon

Authors

Aqqalu Asvid-Rosing ● Martin Blicher ● Jesper Boje ● Helle Torp Christensen ● Jørgen Schou Christiansen ● Margrete Emblemsvåg ● Anne Kirstine Frie ● Steingrimur Jónsson ● Eva Friis Møller Anders Mosbech ● Peter Munk ● Adriana Nogueira ● Thomas Juul Pedersen ● Søren Post ● Mikael Sejr Colin Stedmon ● Mie S Winding

ICES CIEM
International Council for the Exploration of the Sea
Conseil International pour l'Exploration de la Mer

Contents

i Executive summary

WGIEAGS works to provide an Ecosystem Overview and identify trends, knowledge gaps and research priorities for the region. The Greenland Sea ICES ecoregion encompasses both open sea and shelf waters along the Eastern coast of Greenland from Cape Farewell in the south to the northern boundary of Kong Frederiks VIII's Land in the Fram Strait. The region is experiencing change in the form of northward extension of Atlantic waters and freshening of surface waters. Several oceanic fisheries on widely distributed fish species take place in the region. WGIEAGS is focused on assessing the linkages between the physical, chemical and biological oceanographic conditions to the distribution and productivity of fish stocks in the region. The aim for the first meeting was to assemble the available data, report on status and trends, provide the basis for the Ecosystem Overview for the region and identify research and monitoring needs for a future integrated ecosystem assessment.

Information on phytoplankton was mostly achieved from research cruises for inshore and coastal areas and remote sensing for offshore areas, which allowed a rather broad description. Data on zooplankton is also mainly available from sporadic research cruises. In the northern part of the ecoregion, most focus has been on the open Greenland Sea, and the coastal region of Young Sound. In the southern part, Icelandic fishery and zooplankton surveys extend into the ecoregion. Recently the Greenland Institute of Natural Resources (GNIR) has also collected zooplankton data during their fishery surveys. Historical records of benthos from Greenland waters down to 1000 m depth exists from investigations in late 1900s and early 2000s, however vast areas remain unstudied. In 2015, a program for long-term and large-scale monitoring of marine bottom-living invertebrate fauna were launched in the southern part of the region, which together with seabed mapping allows an initial detection of potential Vulnerable Marine Ecosystems. Limited information from fisheries operating with active bottom gears are also available. Knowledge on fisheries and commercially exploited fish species is generally good based on annual scientific surveys and logbooks from the fishery from the past 3-4 decades. Fisheries and surveys on demersal fish species are mainly in the southern part of the ecoregion while pelagic species are surveyed and fished more northerly. Information received on marine mammals is presently limited to seals in the southern part of the ecoregion from various investigations. Data on birds are scarce and derived from various expeditions dating back to the 1990s. Most effort has been carried out in the Northern part of the ecoregion, while little or no data are available from the offshore part of the southern ecoregion.

While data availability in the Greenland Sea is patchy and differ widely across trophic levels, the efforts of WGIEAGS to bring together this information will better elucidate ecological patterns and changes in this ecoregion and help identify gaps in knowledge that can be resolved.

ii Expert group information

Expert group name	Working Group on Integrated Ecosystem Assessment of the Greenland Sea (WGIEAGS)
Expert group cycle	Multiannual fixed term
Year cycle started	2020
Reporting year in cycle	1/3
Chair(s)	Jesper Boje, Denmark
	Colin Stedmon, Denmark
Meeting venue(s) and dates	11-13 February 2020, ICES HQ, Copenhagen, Denmark (22 participants)

1 ToRs and progression

1.1 Terms of Reference (ToR)

ToR	Description	Background	Links to the seven ICES science priority areas as proposed by SCICOM	Duration	Expected Deliverables
A	Assemble relevent data for describing spatial and temporal changes in the Greenland Sea	The database will contain physical, chemical and biological (incl. higher trophic levels) oceanographic data.	1.1	Years 1-3	Merged database. Metadata to be reported to ICES.
B	Review and consider methodological approaches and analytical tools for conducting integrated ecosystem assessment for the Greenland Sea	Before starting data analysis, basic discussions on suitable methodological/analytical approaches are required. This can be started after initial datasets are assembled.	1.1	Years 1-3	Report to ICES
C	Report on the status and trends of the Greenland Sea, based on integrated analysis of multivariate datasets, incl. associated with major hydroclimatic changes and human activities	This ToR will be based on activities and advancements of the above. It is a hope to produse scientific manuscript.	1.1	Years 2-3	Report to ICES. Manuscript to be submitted to peer-reviewed science journal
D	Prepare an Ecosystem Overview for the Greenland Sea	This is advisory requirement.	1.3	Year 1	Ecosystem Overview submitted to ICES
E	Identify knowledge gaps and priority research needs to improve future integrated ecosystem assessments. Provide recommendations for improvement of data collection and monitoring in the ecoregion	To further advance the IEA for the region, identification of knowledge and data gaps is inevitable, together with considering improvements in data collection.	1.1, 3.1, 3.2	Year 3	Report to ICES

1.2 ToR progress

a) Database: Group members that were able to attend the first meeting have started the process of gathering and sharing data. This includes obtaining that available in public databases, drawing on data from individual research projects and programmes, and data

from fish landings. Work is ongoing and this task will extend across the three years of the WG.

b) Review of path towards an integrated ecosystem assessment. During the first WG meeting initial steps were taken to map the activities and pressures that were most relevant for the region. This will contribute to the first Ecosystem Overview but also to an iterative process of developing an approach for an integrated ecosystem assessment. Work is ongoing and this task will extend across the three years of the WG.

c) Manuscript on status and trends in the region: This task is to be initiated in 2021, once the dataset is assembled, and delivered in 2022.

d) Prepare an Ecosystem Overview: The EO is in preparation and the first draft will be delivered to ICES before summer. It should be noted that the group expect to update this over the coming years as it is clear that compared to other ICES regions, there is a considerably poorer data coverage.

e) Identify knowledge gaps and research needs: To be completed in 2022.

2 Ecosystem Description

2.1 Geographical boundaries

The Greenland Sea ICES Ecoregion essentially follows the Greenland Exclusive Economic Zone (EEZ) for East Greenland spanning from 56.39N (east of ~42W) in the south to 81.5 N in the North (Figure 1). The ecosystem area stretches over 2000 km from north to south, from the Arctic Ocean to the sub-polar gyre. Much of the region comprises of continental shelf waters. The neighbouring ocean basins, partly included in the region, are the Irminger Sea, Iceland Sea and Greenland Sea.

The region borders six other ICES Ecoregions: Oceanic North East Atlantic, Iceland Sea, Norwegian Sea, Barents Sea and Arctic Ocean. The focus of the WG is placed on coastal and shelf sea waters (extending seaward of coastal state baseline) and therefore for now excludes fjord and archipelago waters along the Greenland coastline.

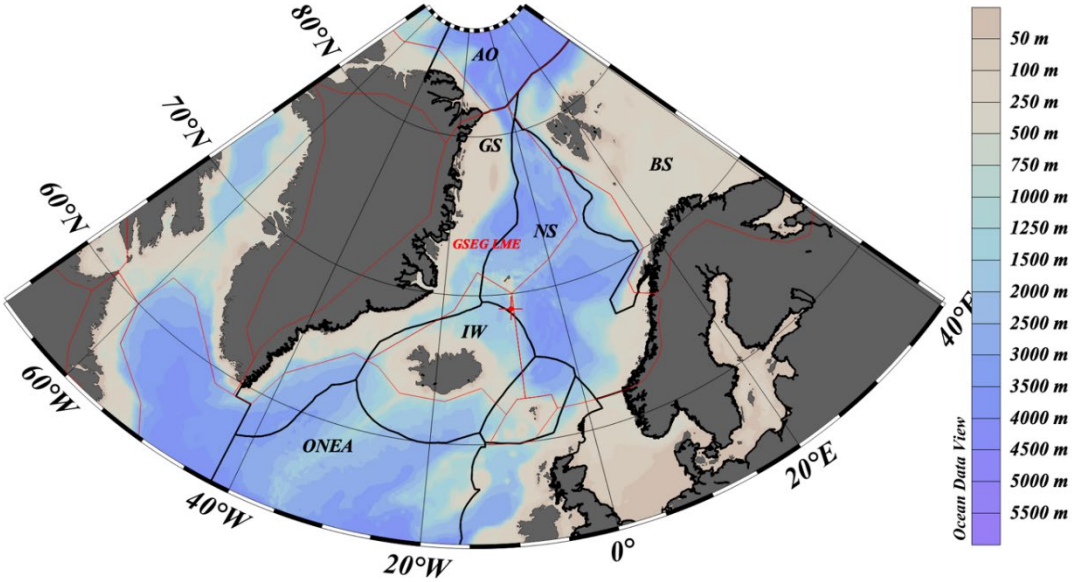

Figure 1 Map of northern ICES Ecoregions outlined in black. AO: Arctic Ocean; GS: Greenland Sea; BS: Barents Sea; NS: Norwegian Sea; IW: Icelandic Waters; ONEA: Oceanic North East Atlantic. The Greenland Sea and East Greenland Large Marine Ecosystem defined by PAME is shown in red.

The Greenland Sea Ecoregion (GSE) overlaps with Region 1, the Arctic Waters, of OSPAR (Oslo-Paris commission for protecting the North East Atlantic). This Region 1 also extends over ICES ecoregions Iceland Sea, Norwegian Sea, Faroes, Barents Sea and Arctic Ocean. The GSE further includes some of the Northeast Atlantic Fisheries Commission (NEAFC) areas in waters south of Iceland and in the Norwegian Sea area of the Ecoregion.

The GSE covers the Greenland EEZ, and within this area the coastal nation has control of all economic resources, including fishing, mining, oil exploration. The fisheries in the ecoregion are managed by Greenland, with some pelagic fisheries managed by the North East Atlantic Fisheries Commission (NEAFC). Fisheries advice is provided by the International Council for the Exploration of the Sea (ICES). Environmental issues are managed by Greenland authorities and through OSPAR, based on advice provided by OSPAR, and ICES. Hunting on marine mammals

are managed by Greenland and international commissions. The International Whaling Commission (IWC) has regulations for the conservation and harvest of whales in the area. Issues related to marine mammals are also considered in cooperation under the North Atlantic Marine Mammal Commission (NAMMCO). Further, international shipping is managed under the International Maritime Organization (IMO).

2.2 Oceanographic conditions

In two areas the shelf extends across the whole ecoregion: Denmark Strait (67°N) and Fram Strait 79°N) (Figure 1). Typical cross sections of the bathymetry in the region are shown in Figure 2. The width of the shelf decreases when proceeding southwards, and the southern areas includes to a larger extent the oceanic waters above depths greater than 2000m contrary to the shelf regions which typically are of depths <500m.

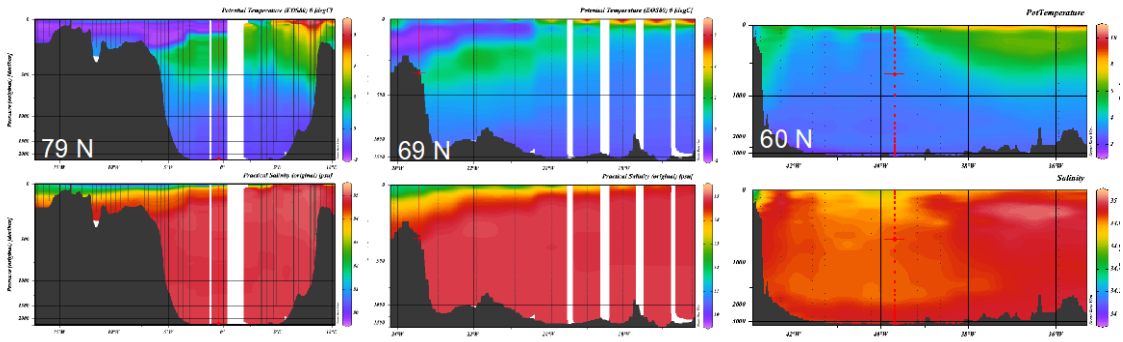

Figure 2 Examples of latitudinal cross sections of the ecoregion at 79, 69 and 60 N. The top sections are potential temperature and the lower section are salinity. Data originates from public databases. Note the eastern end of each section extends beyond into neighbouring the ecoregions. Black lines indicate position of profiles. White bands indicate area with no interpolated data.

The Denmark Strait separates the ecoregion into two subregions of different basic characteristics, notably with respect to ice coverage, influence of polar and Atlantic waters and anthropogenic activity.

In the northern part, the Polar Waters (PW) coming from the Arctic Ocean cover a large part of the surface waters of the shelf (Figure 2). These have a temperature < 0 °C and are less saline than Atlantic waters. The flow causes a strong stratification on the shelf that limits vertical mixing of the water from deeper layers. A cyclonic circulation is seen beyond the shelf in the Greenland and Iceland Seas. This water is also cold but has higher salinity and a weaker seasonal vertical stratification than in areas of PW.

The southward flow of PW constitutes the East Greenland Current (EGC) that extends along the whole ecosystem from Fram Strait to Cape Farewell at the southern tip of Greenland (Figure 3). Below the PW, especially over the slope break at ca. 300 m depth, a water mass both warmer and more saline than PW can be seen. This is often referred to as Modified Atlantic Water (MAW). This water has its origins in the Atlantic but has been transported north into the Arctic by the West Spitsbergen Current and recirculated north of the Fram Strait. From there it flows southwards along the shelf break.

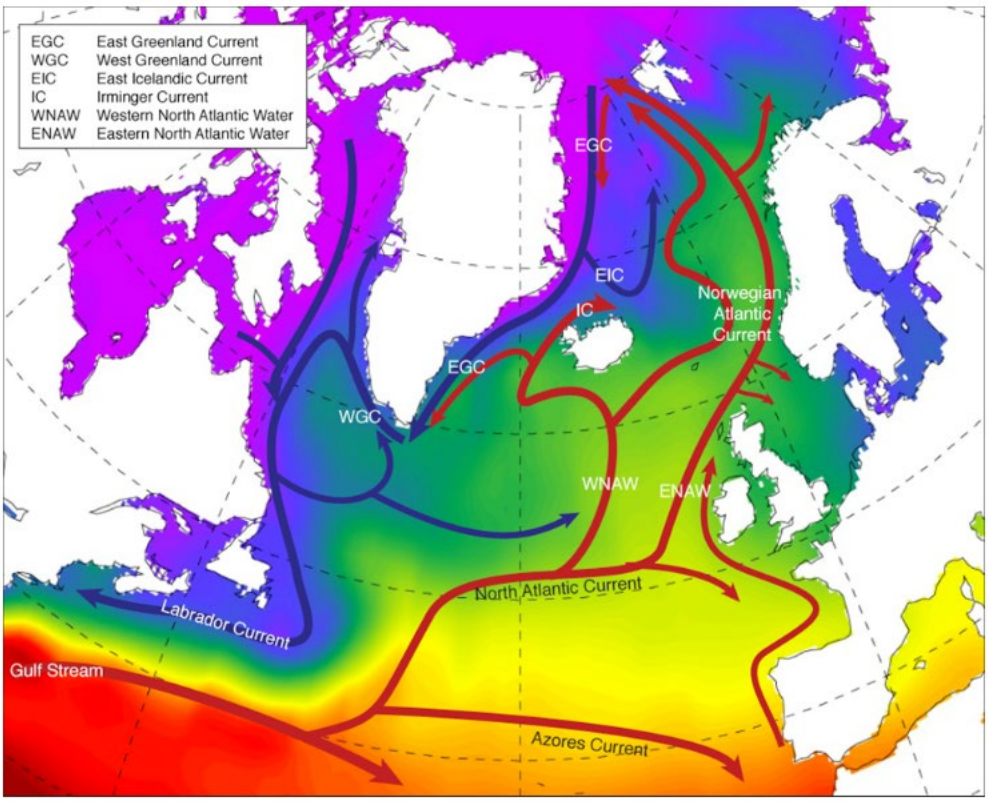

Figure 3 General pattern of surface ocean circulation in the region (0-1000m). Blue arrows represent cold currents from Polar region and red arrows warm currents from the subtropical gyre (Gonzalez-Pola, *el al.* 2019).

In the South there is no sign of the MAW and the polar waters are suppressed to a narrow coastal region on the shelf. Here warmer and more saline Atlantic waters originating from the sub-tropical gyre and transported by the Irminger Current are more prevalent (Figure 2 and Figure 3). This water flows along Iceland's west coast and great part of this subsequently flows towards Greenland where it meets the PW of the EGC where after these flow side by side southwards along the shelf and slope.

A large extent of the ecoregion experiences seasonal sea ice coverage (Figure 4). In late summer the ice retreats and then only covers the NW area of the Fram Strait. The East Greenland Current transports a large amount of Arctic Ocean pack ice during the summer months. These waters also receive ice from glacial calving at the coast of Greenland.

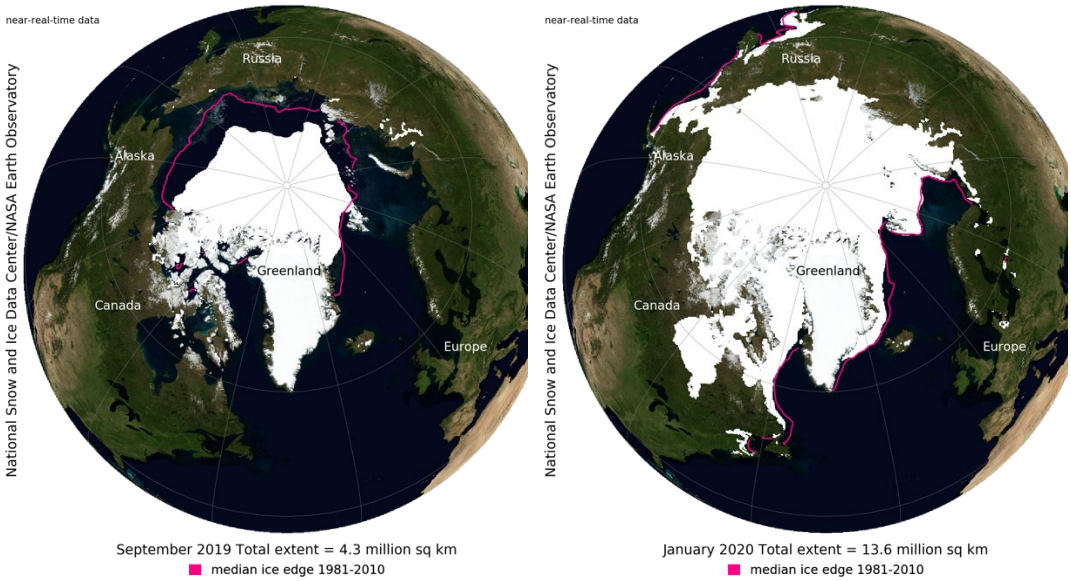

Figure 4. Sea ice extent during the last minimum (September 2019) and in January 2020, towards the sea ice maximum expected in March. The pink line shows the median ice edge for the given month based on data from 1981-2010. Source: http://nsidc.org/data/seaice_index Credit: Sea Ice Index, National Snow and Ice Data Center.

2.3 Oceanographic Trends

This ecoregion is among the least studied of the ICES ecoregions and there is a lack of regular observations, making long-term trends difficult to identify.

The sea ice cover and thickness in the Arctic have been diminishing over several decades and especially during summer this is reflected in the sea ice cover along East Greenland. This leads to larger areas of open water during longer time periods (Figure 5)

The amount of freshwater in the central Arctic Ocean has been increasing over the last two decades due to a strong Polar high pressure (Rabe *el al.* 2011). A weakening of the high pressure system upstream of this region might lead to more outflow of freshwater through Fram Strait causing serious changes to the ecosystem as happened during the late sixties and early seventies (Dickson *el al.* 1988; Curry 2005).

Furthermore, increased melting of the Greenland Ice Sheet over the last two decades (Khan *el al.* 2014) will increase the amount of freshwater flowing to the ecosystem, however, this is probably still a minor source (12 mSv) compared to water and ice inflow from the Arctic Ocean (Dodd *el al.* 2009).

The Atlantic water (AW) flowing poleward in the northern North Atlantic has over the last two decades been warmer and more saline than during the period since the late sixties. This has been observed in the Irminger Sea and is apparently accompanied by ecosystem changes (Valtýsson and Jonsson 2018). This shift in the properties of the AW have been related to the AMO (Atlantic Multidecadal Oscillation). Some of the increase in temperature is probably also related to climate change, but it is difficult to separate the two effects.

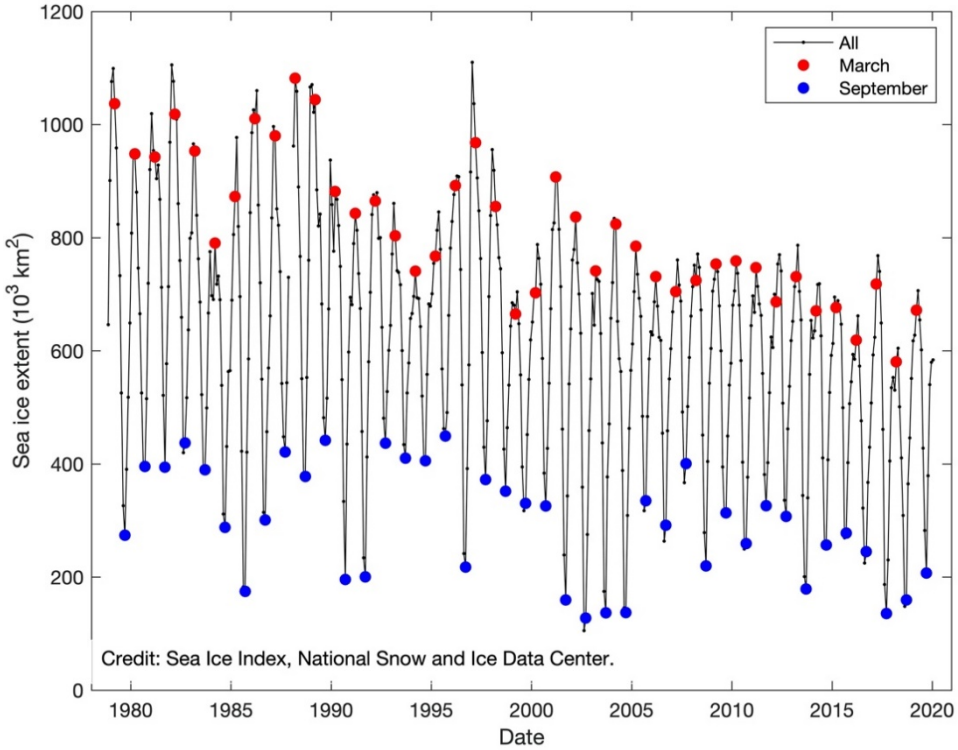

Figure 5. Monthly average sea ice extent for Greenland region (Meier *el al.* 2007) which corresponds to an area covering the Greenland Sea, Iceland Water, and western part of the Norwegian Sea ICES ecoregions.

Recent summary of physical oceanographic conditions in the North Atlantic has identified notable changes in surface water temperatures in the ecoregion (Gonzalez-Pola, *el al.* 2019). Surface waters on the narrow southeast Greenland shelf and in the region North of Denmark Strait for much of the year are 1-2 ◦C warmer than the mean conditions for 1981-2010. In contrast surface waters in North Atlantic and the southeastern reaches of the region have cooled by up to 2 ◦C in spring, summer and fall. There are also changes occurring in surface salinity with open waters of the Greenland Sea showing evidence of increasing in salinity and the East Greenland shelf waters and Irminger Sea surface waters evidence of freshening (Gonzalez-Pola, *el al.* 2019).

2.4 Phytoplankton

The southward transport of Arctic waters and sea ice greatly impacts the overall physical environment (e.g. temperature, salinity, stratification and incoming light) and the nutrient supply, and thereby also affects the primary production and phytoplankton species composition along the shelf region of the Greenland Sea. There are no sustained observation programs for phytoplankton in offshore East Greenland shelf regions. Existing data and knowledge on phytoplankton from the region are therefore based on research cruises and remote sensing products. The latter provide surface chlorophyll and modelled primary production. A fjord/near-coast monitoring programme at Zackenberg in Northeast Greenland, which is part of the "Greenland Ecosystem Monitoring" (GEM; www.g-e-m.dk), represents the only marine monitoring programme covering phytoplankton in East Greenland (Rysgaard and Glud 2007; Krawczyk *el al.* 2015; Holding *el al.* 2019).

In offshore waters with bottom depths greater than the photic zone (ca. >40 m), i.e. beyond the depth range of macroalgae and benthic diatoms, phytoplankton constitute the only primary

producers and the sole source of marine carbon for the higher trophic levels, such as zooplankton, fish, seabirds and marine mammals. The East Greenland shelf region covers high-Arctic to sub-Arctic conditions and pose a southward transport pathway for drifting planktonic organisms. Between the Fram and Denmark straits, diatoms typically dominate the phytoplankton community in May when the seasonal light is increasing, and sufficient nutrients are available in the water column (Richardson *el al.* 2005). Afterwards, smaller flagellated phytoplankton take over and dominate the species composition throughout summer in open water areas. While the incoming light remains the limiting factor for phytoplankton productivity during the autumn and winter months, nutrient supply to the photic zone controls productivity during summer (Richardson *el al.* 2005; Michel *el al.* 2015).

The cold, fresher outflow of Arctic Water through the Fram Strait is generally low in nitrogen, which poses a limit for the magnitude of primary production (Codispoti *el al.* 2013). A different scenario of primary production has been observed along ice edges in summer, where abrupt increase in incoming light, due to ice breakup or retreat, combined with available nutrients results in diatom blooms (Richardson *el al.* 2005; Michel *el al.* 2015; Qu *el al.* 2016; Mayot *el al.* 2018, 2020). Low nutrient availability in surface waters during summer forces phytoplankton biomass deeper down the water column, creating deep chlorophyll maxima, which remains photosynthetically active (Møller *el al.* 2019). These important deep chlorophyll maxima remain largely undetectable by remote sensing, thus when using this methodology there is a risk of underestimating phytoplankton biomass and productivity. Nonetheless, remote sensing products represent the best available proxy of spatio-temporal patterns and interannual variability in phytoplankton dynamics (Figure 6).

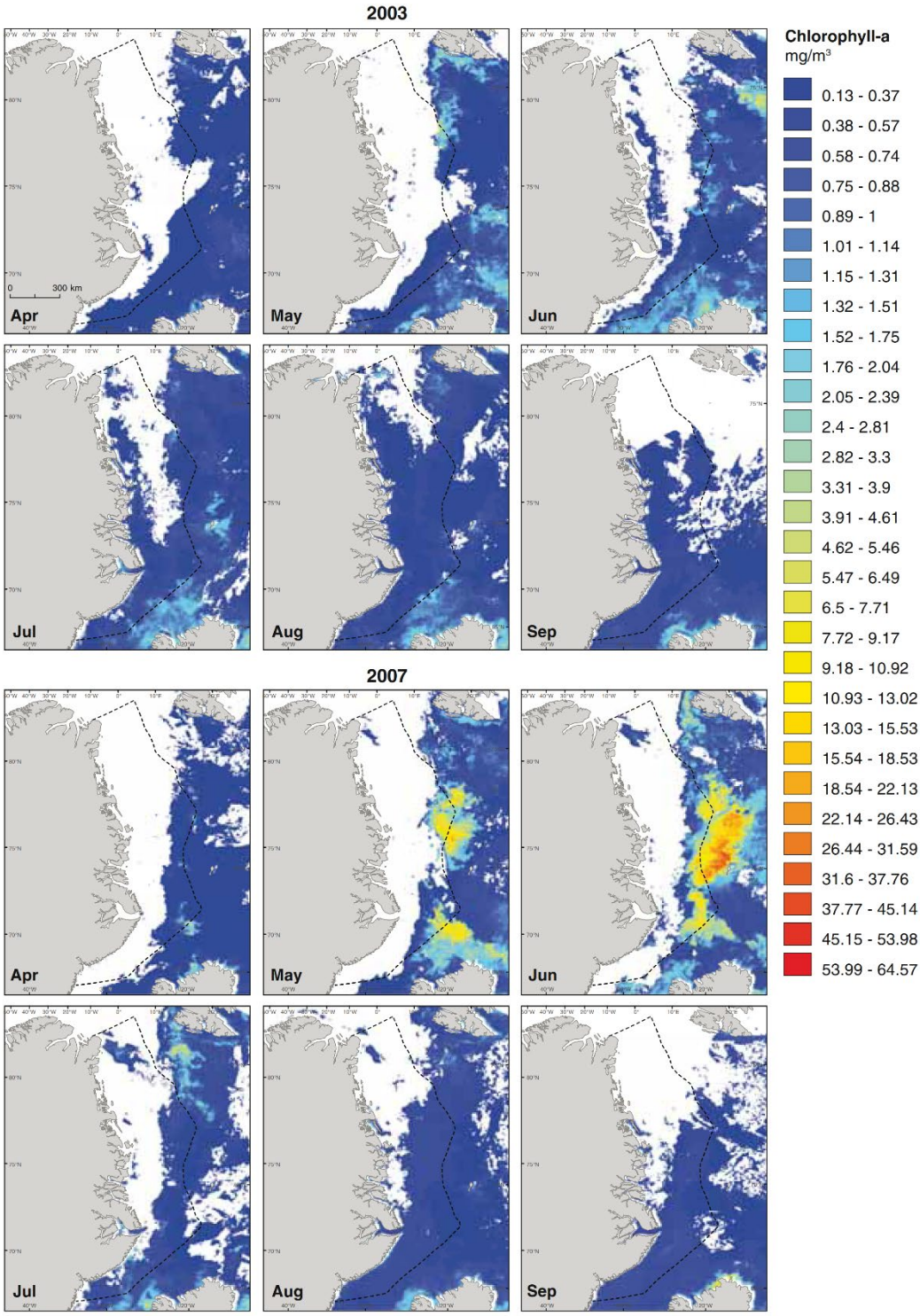

Figure 6 Estimated monthly mean surface chlorophyll concentration in the April-September 2003 (upper two rows) and April-September 2007 (lower two rows) in the western Greenland Sea. The maps are based on level 3 data from the MODIS Aqua satellite sensor and downloaded from OceanColorWeb (https://oceancolor.gsfc.nasa.gov). The spatial resolution used was 4 km, 16-bit satellite readings were converted to chlorophyll concentrations using the equation: Chl (mg/m³) = exp10 ((0.000058137756*scale-dreading)$^{-2}$). White areas represent lacking data, due to e.g. sea ice, lack of light or high cloud concentration (Boertmann *el al.* 2009)

During summer, the near-coast waters of the Greenland Sea, originating from the cold East Greenland Current, are dominated by diatoms (Krawczyk *el al.* 2015). In contrast, the warmer and more saline offshore waters of the Greenland Sea are characterized by both diatoms and

silicoflagellates during summer, particularly the subsurface Modified Atlantic Water can be dominated by silicoflagellates suggesting a link between silicoflagellates and waters of Atlantic origin (Krawczyk *el al.* 2015). The same study found diatoms silicoflagellates and dinoflagellates in the waters of the mid Denmark Strait, further south.

A recent biological oceanographic survey during late summer indicated distinct frontal zones representing biological hot spots, transcending from phytoplankton through zooplankton up to sea birds (Møller *el al.* 2019). Higher nutrient replenishment, induced by frontal mixing of the water column, result in elevated phytoplankton biomass and productivity, which in turn supports the highest concentrations of zooplankton and sea birds across the shelf.

2.5 Zooplankton

The area consists of zones with different physical regimes, and correspondingly the length of productive season and the intensity of plankton production shows high variability. As for phytoplankton, data on zooplankton is mainly available from sporadic research cruises. In the northern part of the ecoregion, most focus has been on the open Greenland Sea (Hirche 1991; Richter 1995; Møller el al. 2006), the North East polynya (e.g. (Hirche el al. 1994; Ashjian el al. 1995) and the coastal region of Young Sound (Rysgaard el al. 1999; Middelbo el al. 2018b). In the southern part, Icelandic fishery- and zooplankton- surveys extend into the ecoregion (Gislason and Silva 2012), and recently the Greenland Institute of Natural Resources (GNIR) collected zooplankton data during their fishery surveys. Apart from a monitoring of mesozooplankton in the fjord system at Young Sound, carried out since 2003, there are no time-series of data for zooplankton and micronekton in the area. Measurements from Young Sound showed changes in both sea ice coverage and freshwater content during 2003 to 2015, but no major trends were apparent for copepod species composition, suggesting a relative resilient pelagic community (Middelbo el al. 2018a). However, the zooplankton community composition is clearly influenced by the origin of the water masses; waters of Atlantic origin dominated by Atlantic copepod species, while those of polar origin are dominated by polar copepod species (Hirche el al. 1994; Møller el al. 2019). The same pattern is found further south, although the Atlantic contribution is usually stronger here (Gislason and Silva 2012; Espinasse el al. 2017).

Copepods dominate the mesozooplankton biomass both in the northern and southern part of the ecoregion and one of the most important zooplankton groups, both in numbers and biomass, is the genus *Calanus*. Their biomasses are generally highest along the shelf break area (Møller *el al.* 2019). Other abundant copepods species are *Pseudocalanus* spp., *Microcalanus* spp., *Oithona similis*, *Oncaea borealis* and *Metridia longa*. Other abundant zooplankton groups are Larvaceans (*Oikopleura* spp, *Fritillaria borealia*), Chaetognatha (*Eukhronia hamata*, *Sagitta* spp.) and meroplankton larvae. The macrozooplankton is dominated by krill (*Meganyctiphanes norvegica*, *Thysanoëssa inermis*, *Thysanoëssa longicaudata*), amphipods (*Themisto libellula*, *Themisto abyssorum*) and Chaetognatha.

The dominating genus *Calanus* show a large shift in the vertical distribution between summer and winter. All the three *Calanus* species present in the area spend spring and early summer grazing in the surface waters to build up their lipid stores, which are later used to fuel winter hibernation (Lee el al. 2006; Falk-Petersen el al. 2009). However, species have different phenology and consequently they reach their maximum abundance in the surface/bottom waters at different times of the year. This means that differences in the *Calanus* community composition between areas, or changes in this due to shifting ocean currents and/or climate, potentially will impact the dynamics of higher trophic levels. This impact will be linked to the availability of *Calanus* as prey

in certain depths of the water column (Laidre el al. 2007; Varpe and Fiksen 2010; Møller el al. 2018).

2.6 Benthic Environment

A large number of benthic studies were conducted in Greenland waters, including East Greenland, by Danish research expeditions in the late 19th century and the first half of the 20th century. The Natural History Museum of Denmark (NHM) has compiled the large amounts of historical records of benthos from Greenland waters down to 1000 m depth. This work was done to provide a regional baseline, but it seems never to have reached a larger audience. Recently, a CAFF's *State of the Marine Biodiversity Report* (Jørgensen el al. 2017) summarize that the complete dataset cover more than 2100 species of benthic invertebrates, with arthropods, molluscs and polychaetes representing 55% of the species. However, the state of knowledge is strongly limited by sampling effort. There is a significant correlation between the number of sampling stations in each of 18 sub-regions and the number of species registered in these sub-regions (Figure 7). This is also the case if we only consider East Greenland, where vast areas remain unstudied. Still, this extensive data compilation is a valuable baseline for contemporary and future benthic studies in Greenland.

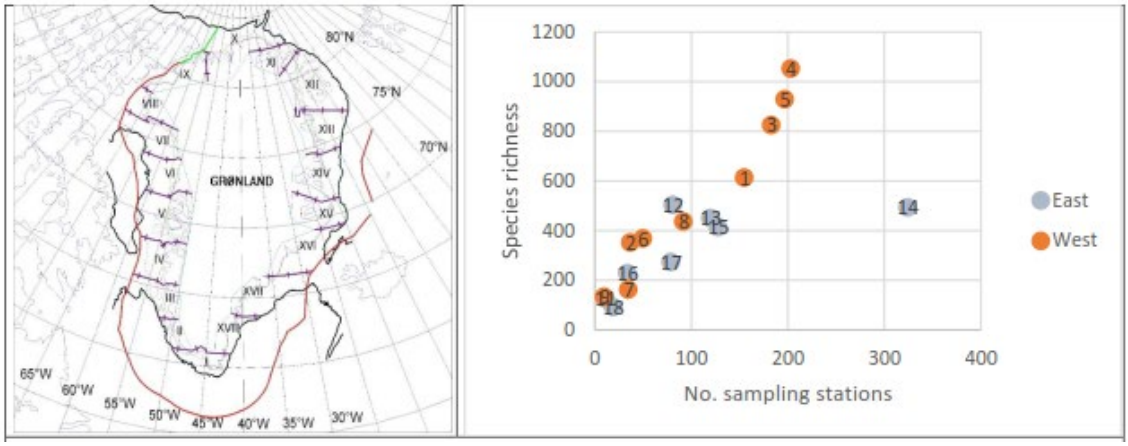

Figure 7. Left: Map of Greenland illustrating the 18 regions defined by the Natural History Museum. Right: Number of species registered in each of the 18 subregions (label numbers) plotted against the number of stations. Modified from Tendal & Schiøtte (2003).

Seabed mapping on the Greenland shelf has documented a complex topography in a mix of seven different substrate categories covering the entire spectrum from soft clay and mud, to sand, gravel and solid rock (Gougeon el al. 2017). However, the benthos sampling approached employed has not reflected the diversity of the physical habitat. Until recently, the majority of benthos information available from Greenland consisted of macroinfauna collected with scientific grabs, typically sampling 0.1 m^2 of soft seabed. Consequently, there has until recently been very little knowledge about benthos communities with an affinity to hard and mixed seabed substrates, and about large benthic organisms (megafauna) typically occurring in relatively low densities. These components contribute to a complex habitat structure and may ultimately support ecosystem services by creating micro-habitats and nursery grounds for a diverse range of associated fauna, including fish and shellfish.

In 2015, GINR launched a program for long-term and large-scale monitoring of marine bottom-living invertebrate fauna, a program that covers the shelf area of the southern component of the ecoregion (Figure 8). This was done by integrating a "trawl bycatch-program" on national fisheries assessment surveys in Greenland waters, which enabled collection of information about

focal components of the benthic community on the continental shelf and slope at depths from *c.* 50 to 1500 meters. Fisheries surveys are conducted annually in East Greenland from 59°30′N up to 67°N (Blicher and Arboe 2017; Jørgensen el al. 2017). The bycatch of benthic invertebrates in assessment trawl hauls are analysed and identified to highest possible taxonomic resolution (Figure 9).

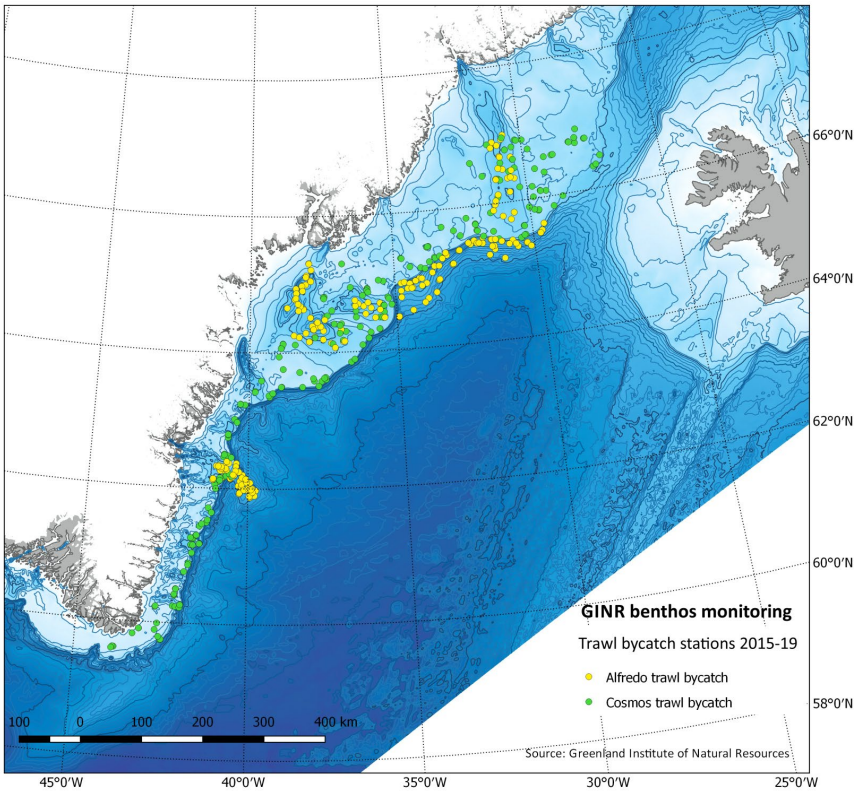

Figure 8. Overview of GINR's assessment trawl stations (n = 423) where the bycatch of benthic invertebrates has been identified by specialist taxonomists.

To this date, more than 450 benthos species/taxa have been registered as trawl bycatch in East Greenland waters by an international team of benthos taxonomists involved in the program. Despite the low catch-efficiency of the used commercial-type demersal trawls and the programs geographical restriction to the fisheries survey areas, the method has proven effective for qualitative and semi-quantitative documentation of large-scale distributions of benthic megafauna (Jørgensen el al. 2014; Blicher and Arboe 2017). The program enables an initial detection of potential Vulnerable Marine Ecosystems (*VME*, www.FAO.org), valuable ecosystem components or areas subject to dramatic changes (e.g. biodiversity hot spots, coral or sponge gardens, nursery grounds). As a management action, a detection of potential focus areas based on the standard observations can be followed up by more targeted benthos research (e.g. photo/video, beam trawl, grab, acoustics). Due to limited ship-time, such additional sampling has to date only been carried out off West Greenland.

The available trawl bycatch data from East Greenland point to a species rich and structurally complex benthos community with high biomasses of large sessile species, including VME indicator taxa, such as corals and sponges. The highest concentrations of *Geodia* spp. sponges registered in Greenland waters, are found on the continental shelf between 64 and 67°N in East Greenland (Klitgaard & Tendal 2004, Blicher & Arboe 2017). Accidental high catches in commercial trawl hauls is a well-known phenomenon among fishermen known as "Ostur" when (Figure 9).

Soft corals and Gorgonian corals (Alcyonacea) are also observed frequently in this area, particularly along the shelf edge. A dense concentration of another group of VME indicators, Sea Pen (Pennatulacea), have been observed in the shelf area between 65 and 67°N (Figure 10). The majority of large catches of VME indicators are from outside the main footprint of bottom trawling (logbook data not shown). Thus, if the spatial coverage of the fishery changes, without considering any spatial management of the seabed, conflicts with VME habitats are likely. More targeted research will be needed to accurately describe these bottom habitats, including their spatial distribution and ecological role.

Figure 9 Left: Large bycatch of sponges ("Ostur") in a demersal trawl. Mid: a trawl catch primarily consisting of sponges and redfish emptied on the trawl deck. Right: In situ image of large sponge, Geodia sp. and Gorgonian coral, Paragorgia arborea on the Greenland shelf (Photos: Martin Blicher and Nanette Hammeken Arboe).

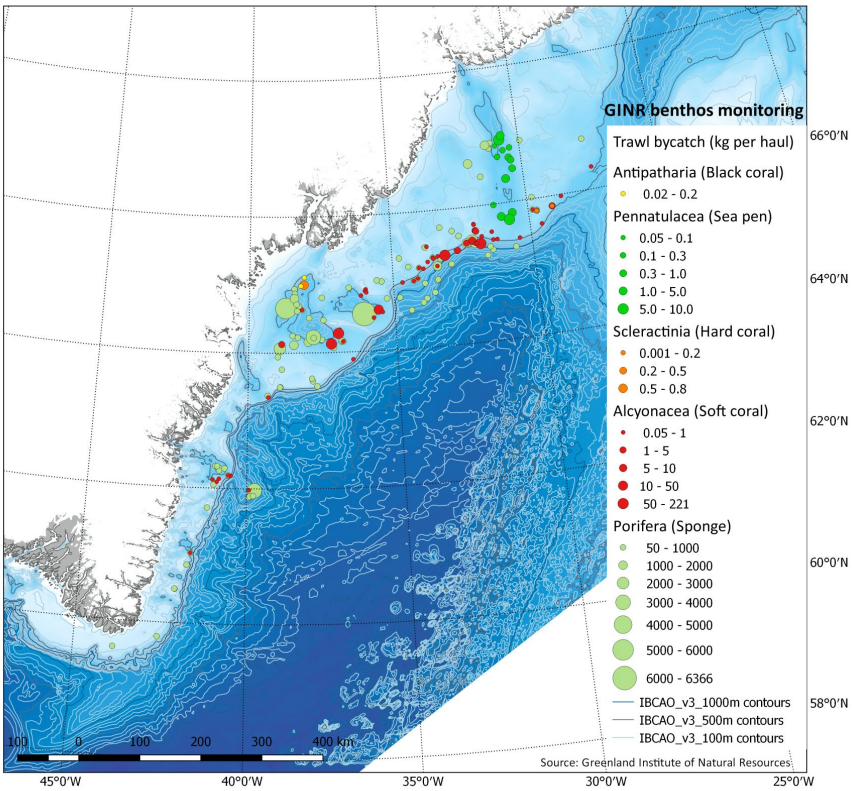

Figure 10. Overview of large observations of corals and sponges collected as trawl bycatch on fisheries assessment surveys conducted by GINR in East Greenland. Species-level information is stored in GINR's benthos database. Modified from (Blicher & Hammeken Arboe 2017).

2.7 Area based studies – TUNU project in Northeast Greenland

The international "TUNU-Programme: Euro-Arctic Ocean Fishes – diversity and conservation" at UiT–The Arctic University of Norway, conducts regular marine biological expeditions to the barely studied fjords and adjacent shelf in Northeast Greenland (latitudes 70–80 °N) (Christiansen 2012) (Table 1, Figure 11). In this high Arctic region, which comprises the Northeast Greenland National Park, the programme build time series (2002–) and biodiversity baselines for fishes across biological scales from genes to communities – all initiatives within the framework of ocean climate. The TUNU-VI and TUNU-VII expeditions conducted systematic investigations on invertebrate benthos and plankton in addition to fishes. Since the TUNU-III Expedition in 2007, marine geology studies complement the biological studies of seafloor habitats. The TUNU-VIII Expedition scheduled for August 2020 is postponed to 2021 due to COIVD-19.

Table 1 TUNU expeditions. Preliminary overview of locations for biology (BIO) and oceanography (OCE) in Northeast Greenland spanning the years 2002–2017. Note: one location may comprise several stations (i.e. gear operations), each with a specific-ID. Locations cover depths between shore and 1500 m and between latitudes 70° and 80 °N. Selected locations have been visited regularly as part of a first time series for the area.

TUNU-Expedition	Year	TUNU- BIO	TUNU-OCE
Pre-TUNU	2002	12	23
TUNU-I	2003	21	22
TUNU-II	2005	7	15
TUNU-III	2007	4	16
TUNU-IV	2010	15	14
TUNU-V	2013	8	22
TUNU-VI	2015	9	12
TUNU-VII	2017	9	12
TUNU *in toto*	2002-2017	85	136

Recent studies suggest that fishes and invertebrates such as Atlantic cod (*Gadus morhua*), beaked redfish (*Sebastes mentella*), capelin (*Mallotus villosus*) and deepwater prawn (*Pandalus borealis*) move from the Barents Sea to the Northeast Greenland shelf via the Return Atlantic Current across the Fram Strait (Christiansen 2016; Andrews el al. 2019; Gjøsæter el al. 2020). The magnitude and regularity of this faunal connection between the Greenland Sea and the Barents Sea need further study especially in light of ocean warming and the resulting northward spreading of biota. Such shared living resources may affect future fisheries management across political borders between Norway and Greenland.

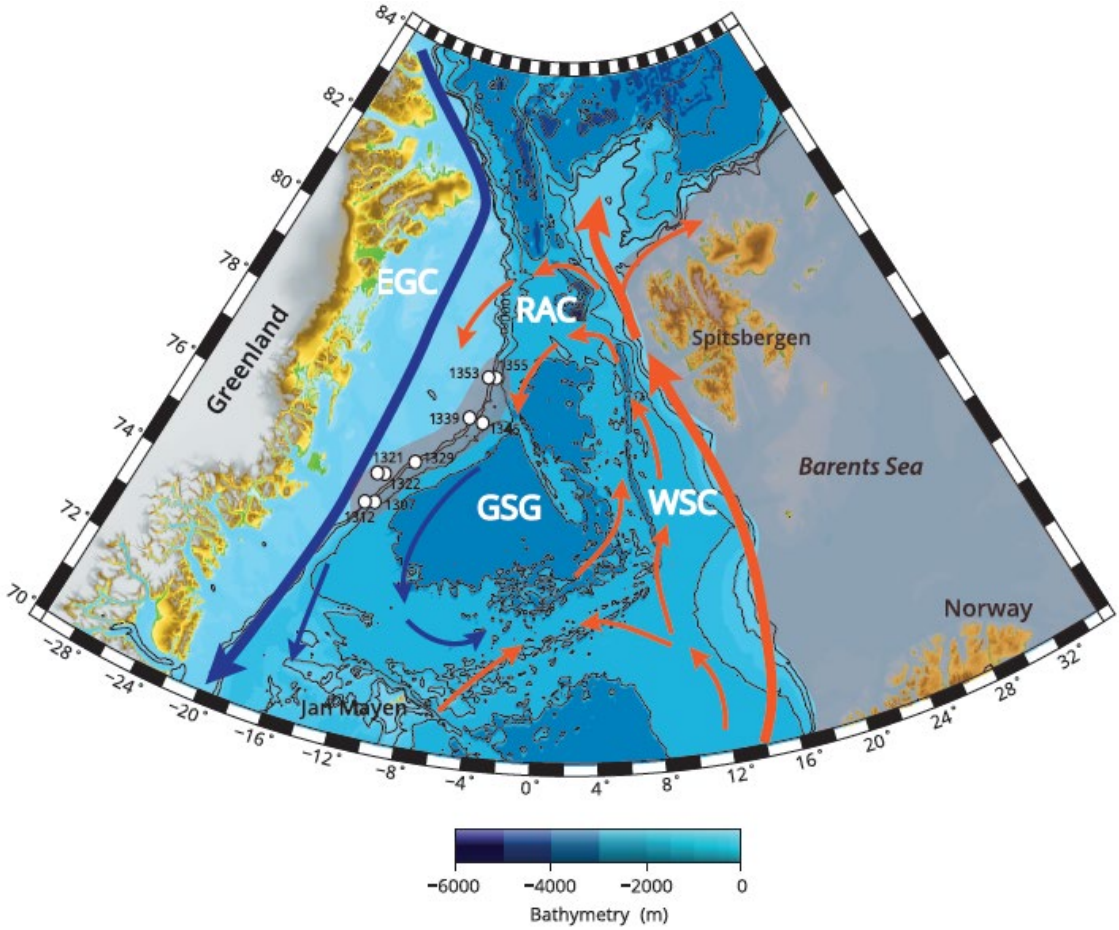

Figure 11 Locations visited during the TUNU-VI Expedition 5–17 August 2015. Grey shades delineate the extant distribution of Atlantic cod (Gadus morhua) on the Northeast Greenland shelf break and in the Barents Sea. EGC=East Greenland Current (Arctic), GSG=Greenland Sea Gyre, RAC=Return Atlantic Current, WSC=West Spitsbergen Current (Atlantic). Figure from Christiansen *el al.* (2016).

2.7.1 Data contribution

TUNU has gathered exceptional baseline data on biodiversity and oceanography within the fjords and across the shelf in Northeast Greenland. The TUNU data are the first of their kind, and so the TUNU-area has become an Arctic key-site in the Circumpolar Biodiversity Monitoring Programme (CBMP, http://www.caff.is/monitoring) commissioned by the Arctic Council. Data comprise:

- Baseline data on biodiversity for fishes, benthos and plankton
- Baseline data on oceanographic conditions
- Bathymetry and multibeam maps of sea floor habitats (Department of Geology, UiT)
- The TUNU-Museum Collection with voucher specimens of primarily fishes (Univ. Museum Bergen)
- Time series for selected locations (years 2002–2021)

After quality check of data, the TUNU data will be made public available through ICES and WGIEAGS – this in agreement with the authorizations given by the Government of Greenland.

3 Fishes in East Greenland

3.1 History and development of fishery in East Greenland

Since the mid-20th century East Greenland has been an important fishing area for many nations. The main target species are Greenland halibut (Reinhardtius hippoglossoides), Northern shrimp (Pandalus borealis), cod (Gadus morhua) and redfish (Sebastes mentella and S. norvegicus).

Along with observed changes in the environmental conditions, the spatial distribution of the target species and thereby the fishery is expected to change. Changes in the environment have been reported for east Greenland (Våge *el al.* 2018) and for high latitudes ecosystems (Fossheim *el al.* 2015, Kortsch *el al.* 2015, Lind *el al.* 2018) in the same time period. New species such as Atlantic mackerel (Scomber scombrus) and Atlantic herring (Clupea harengus) are becoming increasingly important. As described above, a frontal zone between the cold low saline Polar Current and the warmer and more saline Irminger Current dominate the waters off East Greenland, and annual variability of these two current systems results in longitudinal change of the frontal zone and consequently in a change in fish distribution. For example, analyses of the spatial distribution of the fisheries over a 20 years period based on detailed logbook information, shows a spatial northward displacement of northern shrimp while a great decline in catches is taking place. Contrary, the fishery for cod is displaced southward and catches increase in the same period (Figure 12). The spatial distribution and catch level of Greenland halibut is relatively stable during the time series.

During the last decades significant pelagic fishery has been introduced in the area. During this spatial changes in a westward direction are apparent. In 2007, the first landings of herring was recorded followed by the introduction of a fishery on Atlantic mackerel in 2011 (Figure 12). The change from shrimp to cod and the presence of pelagic species are expected to continue during future periods of climate related changes in the environment. In the following the main fish species of high or some commercial importance will be described with focus on their distribution, biology, fishery and ecological role.

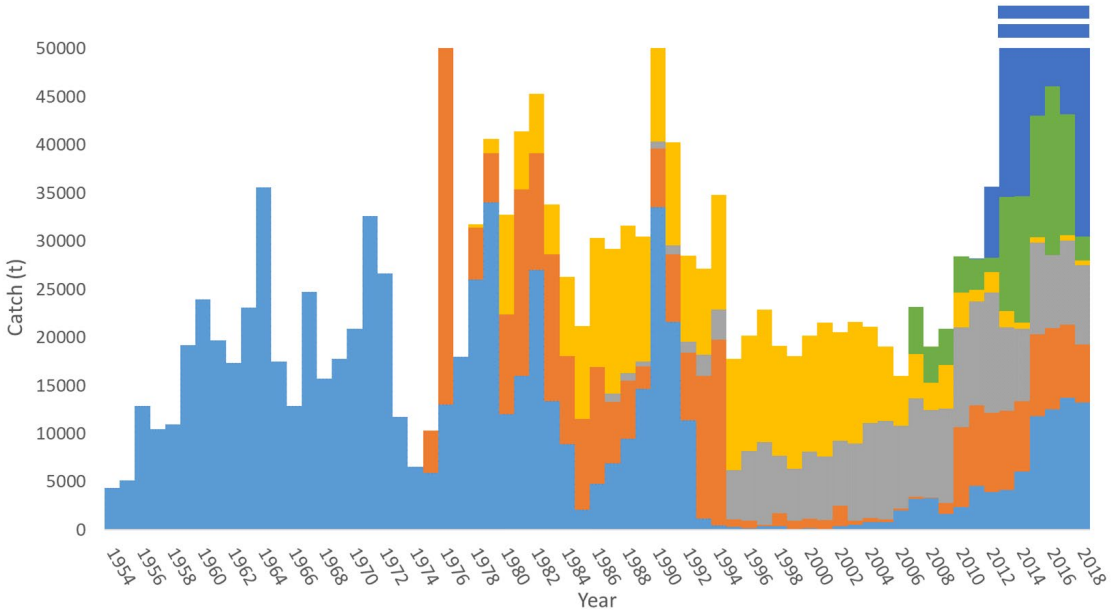

Figure 12. Development in catch (t) from the first recorded landings for cod in 1954 until present. Cod (Gadus morhua) light blue, Redfish (Sebastes mentella and Sebastes norvegicus combined) orange, Northern shrimp (Pandalus borealis) yellow, Greenland halibut (Reinhardtius hippoglossoides) grey, Atlantic herring (Clupea harengus) green and Atlantic mackerel (Scomber scombrus) dark blue.

3.1.1 Northern shrimp (Pandalus borealis)

3.1.1.1 Biology and distribution

Northern shrimp (Pandalus borealis) is an expansive species (Bergström 2000) with a circumpolar occurrence. In East Greenland shrimps are distributed along the entire coastline from the south and up to 70°N and are most common at 100-600 m in depth (Horsted 1978; Bergström 2000). The preferred habitat is muddy bottom, and the bottom water temperature optimum in Greenland waters is between 2 °C and 4 °C (Bergstöm 2000). The Northern shrimps are highly mobile both horizontally and vertically, showing a diurnal migration, i.e. foraging at the bottom during daytime and in the water column during the night (Horsted and Smidt 1956).

Northern shrimp is a protandric hermaphrodite. In East Greenland waters, the juveniles mature as males at about 3-5 years of age, remain so for 2-3 years, and then undergoes transition to female at an age of 5 to 8 years (Horsted and Smidt 1956; Wieland 2004).

Mating and spawning occur during July to September, the egg-bearing period lasts 8 to 10 months, depending on the temperature in the bottom water. The larvae hatch in April to June of the following year (Horsted 1978; Shumway *el al.* 1985; Bergstrøm and Wilhjámsson 2006). Spawning occurs during April in inshore shallow waters (Horsted 1978). The newly hatched larvae live freely in the upper part of the water column. During spring and summer, the larvae pass through six planktonic stages over a period of three to four months. In the last larval stages, the larvae settle on the bottom and become immature (juvenile) shrimps (Shumway *el al.* 1985; Storm and Pedersen 2003).

3.1.1.2 Fishery

Access to the fishing grounds at East Greenland depends on ice conditions and a multinational fleet exploits the stock. During the recent ten years, vessels from Greenland, EU, the Faroe Islands and Norway have fished in the Greenland EEZ.

Technical regulation includes minimum legal mesh size of at least 40 mm for both Greenlandic and foreign trawlers and sorting grids with 22-mm bar spacing to reduce bycatch of fish. Discard of shrimp is prohibited. The fishery started in 1978 and during the period from 1985 to 2003, total catches fluctuated between 9 000 and 15 000 tonnes. Since 2004, total catch has decreased considerably to only 547 t in 2018 (Figure 13). However, in the first half year of 2019, catches significantly increased to 1579 t (Riget 2019).

The fishery was originally conducted north of 65°N in the Dohrnbank-Stredebank area on both sides of the territorial midline between Greenland and Iceland and on the slopes of Storfjord Deep. In 1993, a fishery was also initiated south of 65°N in various smaller areas extending south to the Cap Farewell. Since 2013, little to no fishery has been conducted south of 65°N (Figure 14).

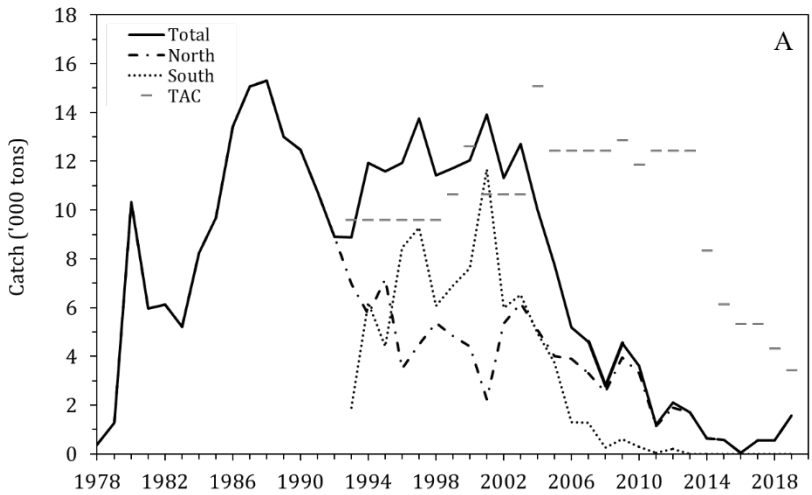

Figure 13. Catch by shrimp trawlers fishing in Denmark Strait/off East Greenland. Series are given for the areas north and south of 65N and overall. (Data for 2019 is part-years data, until July).

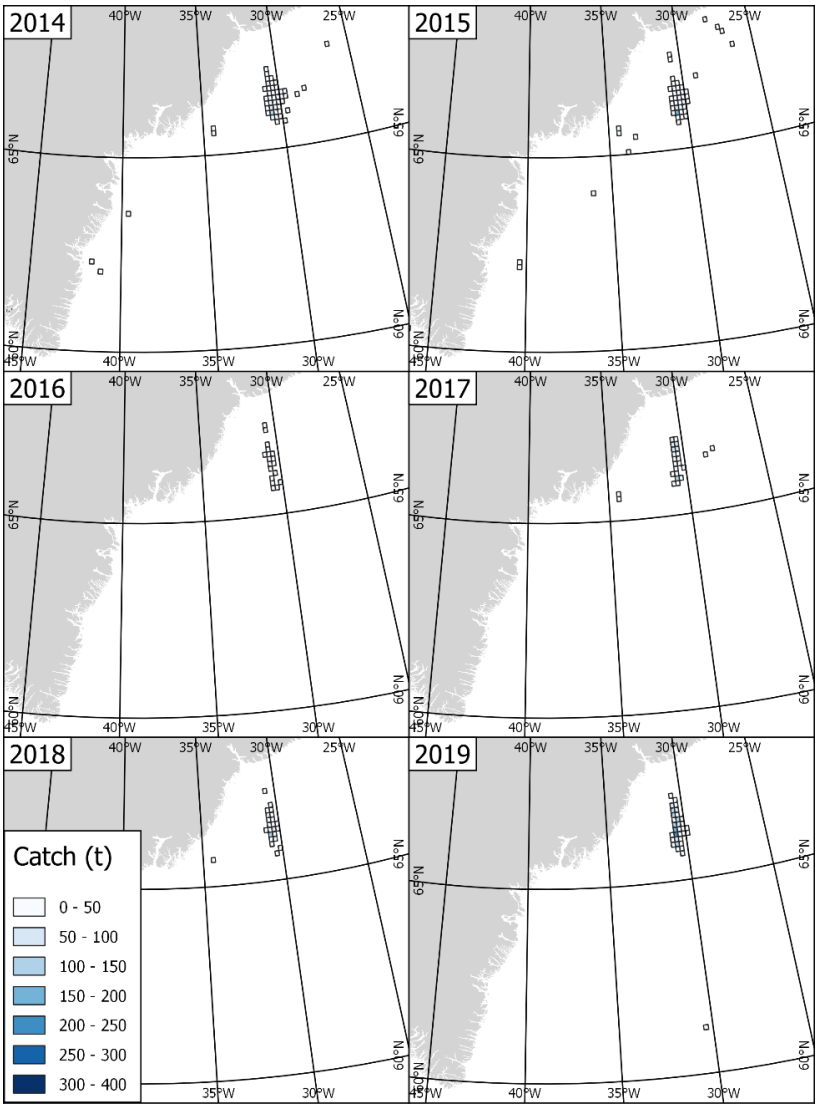

Figure 14. Thematic mapping of different levels of catch in the shrimp fishery in Denmark Strait/off East Greenland 2013-2019 (2019 until July)..

3.1.1.3 Management

Northern shrimp off East Greenland in ICES Div. XIVb and Va is assessed as a single population by evaluation of fishery dependent and fishery-independent data. Thus, data from an annual survey series has been available since 2008; however, no survey were performed in the period 2017 to 2019. The assessment is based on indices from survey and logbooks. The stock is managed by catch quotas in the Greenlandic zone.

3.1.1.4 Ecosystem aspects

Changes in the physical and biological conditions for shrimp might have an effect on the population size and distribution. However, for the time being, the impact of potential changing water temperature and food availability on the shrimp population in East Greenland is unknown.

The northern shrimp are omnivores and predate on worms, dead organic material, algae and zooplankton, and serve as food for large fish such as cod and Greenland halibut (Parsons 2005). There is a tight relationship between the occurrence of cod and the disappearance of shrimps (Worm and Myers 2003). Nevertheless, in recent years the estimated biomass of cod has been low and the removal of shrimp by cod at the East Coast in unknown.

3.1.2 Capelin

3.1.2.1 Biology and distribution

The capelin is a small pelagic schooling fish. It is a cold-water species that inhabits arctic and subarctic waters in the North Atlantic and North Pacific. Capelin in the Iceland-East Greenland-Jan Mayen area is considered to be a separate stock. Capelin is a relatively short-lived fish being 4-5 years. Capelin reaches maturity-at-age 2–4. The main part of each year-class matures and spawns at age 3. The remainder of the year-class spawns at age 4. Capelin are demersal spawners that deposit their eggs on fine gravel at 10–150 m depth (Vilhjálmsson 2002). The main spawning areas are off the southeast, south and west coast of Iceland. Spawning peaks in March in the main spawning areas but somewhat later (April) elsewhere. The larvae hatch after approximately three weeks and drift toward the nursery areas. Most juveniles are found on or close to the continental shelf. Until early 2000s, the nursery areas were located northwest, north and northeast of Iceland, and on the East Greenland plateau, west of the Denmark Strait. Since the early 2000s, the nursery areas have expanded to colder waters near east Greenland. Maturing capelin usually undertakes extensive migrations in spring and summer to the feeding areas north of the nursery areas. The summer–autumn distribution of the maturing stock has, like juvenile population, shifted west since the early 2000s. Southern return migration in September–October leads the adults to the shelf edge off the northwest Iceland where they are found in November.

3.1.2.2 Fishery

The capelin fishery is an international fishery mostly within the Iceland EEZ mainly using large purse seiners while a smaller fraction is caught with pelagic trawl. The catch is for both consumption and reduction. Beside Iceland, Norway, Greenland and Faroe Islands are the fishing nations. Most of the fishery takes place in the autumn and winter due to good access of schools of capelin and due to the better condition of the fish in this period.

3.1.2.3 Management

Capelin in the Iceland-East Greenland-Jan Mayen area is TAC managed by a tri-lateral agreement between Iceland, Greenland and Faroe Islands. An initial TAC based on monitoring of immature fish is set from the beginning of the fishing year (late June) until it is replaced by a preliminary TAC in late autumn or winter. The latter is based on an autumn survey of the mature stock and a final TAC set in February/March based on updated information of the mature stock. The fishing year ends by 31st of March. The reasoning behind this TAC schedule is the short life span of capelin and an objective of keeping the spawning stock above safe limits in order to ensure a high probability of a good recruitment to the stock.

3.1.2.4 Ecosystem aspects

Capelin are pelagic, migratory, planktivorous fish, and changes of their physical and biological environment may have profound effects on their abundance, migrations, distribution, and growth. As in other areas, capelin play a key role in the marine ecosystem in the area. They not only fall prey to several species of marine mammals and seabirds, but they are also the main single item in the diet of Icelandic cod and of importance as food for several other commercial fish species in Icelandic and Greenland waters. Capelin is a planktivore that mainly eat copepods, euphausiids and amphipods (Gjøsæter 1998; Carscadden *el al.* 2001; Vilhjálmsson 2002). Generally, the importance of copepods decreases with capelin size and that of euphausiids and amphipods increases. The main copepod species eaten by small larval and juvenile capelin is *Calanus finmarchicus, Oithona spp, Temora spp, Acartia spp, Oncaea borealis and Pseudocalanus elongatus*. The importance of each species differs according to areas and size of the capelin. Later in the season, there is a shift from smaller to larger food items. *C. finmarchicus, C. hyperboreus and euphausids* (mainly *Thysanoessa inermis*) become increasingly important in the stomachs of larger

capelin. Capelin are considered particularly sensitive to the ever-changing hydrobiological conditions of the seas where they feed. However, the relationships between zooplankton abundance, and abundances of capelin could not be proven significant during a multiyear study (Vilhjálmsson 2002).

3.1.3 Mackerel

Atlantic mackerel (*Scomber scombrus*) occurs on both sides of the North Atlantic and has traditionally been grouped into five spawning components, some of which have been thought to be isolated natal homing populations. In the Northeast Atlantic (NEA), mackerel spawns from the Portuguese waters in the south to Iceland in the north and from Hatton Bank in the west to Kattegat in the east. Despite the lack of complete spatial or temporal separation, NEA mackerel is divided into three distinct entities, namely the Southern, Western and North Sea spawning components (ICES 1977; 2013.a). Spawning starts in January/February in Iberian Peninsula waters and ends in July to the northwest of Scotland and in the North Sea (ICES, 2013a). While spawning intensity varies locally from day to day (Bakken, 1977; Iversen, 1981), it seems to form one large spatio-temporal continuum on the larger scale.

Post larval mackerel feed on a variety of zooplankton and small fish. They generally eat quite large prey compared to their own size (Pepin *el al.*, 1987; Langoy *el al.*, 2006). Feeding patterns during later stages vary seasonally, spatially and with size. Mackerel stops feeding almost completely during winter. Main zooplankton prey species in the North Sea are: Copepods (mainly *Calanus finmarchicus*), euphausiids (mainly *Meganyctiphanes norvegica*), while primary fish prey species are: sandeel, herring, sprat, and Norway pout (Walsh and Rankine, 1979; Mehl and Westgård, 1983; ICES, 1989; ICES, 1997). In the Norwegian Sea euphausiids, copepods (mainly *Calanus finmarchicus* and *Oithona*), *Limacina retroversa, Maurolicus muelleri,* amphipods, Appendicularia and capelin are the main diet during the summer feeding migration (Prokopchuk and Sentyabov, 2006; Langoy *el al.*, 2010). The mackerel is opportunistic, and from one year to the next they may exploit any available oceanic areas for feeding purposes (Langøy el al. 2012). A westwards and northwards expansion of populations has been observed in the Nordic Seas in recent years (since 2007), as far as Icelandic and south Greenlandic waters in the west and as far north as Spitsbergen (Nøttestad, 2014). Historically, expansions into Icelandic waters are known to coincide with periods of warm waters (Astthorsson *el al.*, 2012).

While spawning occurs widely on the shelf and shelf edge from the Bay of Biscay to the southern Norwegian Sea, most of the egg production is concentrated in two core spawning areas. One elongated area is seen along the shelf break from Spanish and Portuguese waters in January to March, and another is seen around southwest Ireland to the west of Scotland where spawning peaked in April (Beare and Reid, 2002; Iversen, 2002), however the spawning peak has shifted to March in the most recent years. In the central North Sea spawning takes place in May–July.

Mackerel performs extensive migrations between spawning grounds, feeding grounds and overwintering areas. The migration pattern has changed substantially through time. During the feeding migration in summer (3rd quarter) the larger fish reaches furthest to the north and west (Holst and Iversen, 1992; Nøttestad *el al.*, 1999; Anon 2009; ICES, 2009) as far as East Greenland and the Norwegian Sea. Similarly, the larger mackerel also arrive to the feeding areas (observed in eastern Danish waters) earlier and leave later than smaller mackerel (Jansen and Gislason, 2011). The mackerel return in late summer and early autumn from the feeding areas on the European shelf and in the Nordic Seas, and aggregate through late autumn and early winter along the continental shelf edge.

3.1.3.1 Fishery

Fishery for mackerel in the east Greenland area is a relatively new fishery that began in 2011. This fishery is limited to the summer season from ultimo June to September when the mackerel has migrated to the northern and western feeding grounds. Pelagic trawling and to a lesser degree purse seining are conducted from large freeze factory vessels. Total catches taken from the NEA mackerel stock has in recent years been more than one million tonnes while in East Greenland waters catches are around 50 thousand tonnes.

3.1.3.2 Management

The NEA mackerel stock is managed by the coastal states under the Northeast Atlantic Fisheries Organization (NEAFC), since the stock is widely distributed outside national EEZs. More nations in the Northeast Atlantic are aiming to agree on a TAC management, however, for a decade they have not succeeded in such common TAC and autonomous quotas are therefore set by each nation, resulting in total TAC well in excess of the advised TAC.

3.1.4 Herring

3.1.4.1 Biology and distribution

The Norwegian spring-spawning herring (*Clupea harengus*) is the largest herring stock in the world. It is widely distributed and highly migratory throughout large parts of the NE Atlantic during its lifespan (Dragesund el al. 1997). The herring spawns along the Norwegian west coast in February-March. The larvae drift north and northeast and distribute as 0–group in fjords along the Norwegian coast and in the Barents Sea. The Barents Sea is by far the most important juvenile area for the large year classes (Dragesund 1970; Holst and Slotte 1998), and is the basis for the large production-potential of the stock. Most of the young herring leave the Barents Sea at 3 years age and feed in the northeastern Norwegian Sea for 1–2 years before recruiting to the spawning stock (Holst and Slotte 1998). When mature, the young herring starts joining the adult feeding migration in the Norwegian Sea. The feeding migration starts just after spawning with a maximum feeding intensity and condition increase occurring from late May until early July (Homrum *el al.*, 2016). After the dispersed feeding migration the herring concentrate in one or more wintering areas in September-October. After the wintering, the spawning migration starts around mid-January. A characteristic feature of this herring stock is a very flexible and varying migration pattern. In May the herring is migrating westwards into the Norwegian Sea for summer feeding and the main concentrations are found in the central part of this area. In July the herring spread out over a wide area. They are then feeding around the fringes of the Norwegian Sea, particularly in the northern and western region, while almost no herring are observed in the central region. In this period herring is abundant in East Greenland waters.

3.1.4.2 Fishery

The fishery is carried out all year-round by purse-seines and pelagic trawlers. The catches are used as well for reduction purposes and human consumption.

3.1.4.3 Management

The fishery is regulated by the Coastal States. The TAC is set by the Coastal States and derived from an agreed long-term management plan under the Northeast Atlantic Fisheries Organization (NEAFC). The Coastal States also agree on the allocation of the TAC into national quota. The Coastal States involved are the European Union, Faroe Islands, Iceland, Norway and the Russian Federation. However, since 2013 there has been no agreement due to shift in stock distribution (and territorial claims) which has led to autonomous quotas (and catches) in excess of the advice.

3.1.4.4 Ecosystem aspects

Due to the excessive size of the stock, it is considered to have a major impact on the ecosystems in the North Atlantic. Herring is a pelagic planktivore that feed on copepods and other macroplankton and is prey species for larger pelagic fish, such as mackerel (herring larvae and juveniles), and for seabirds and whales.

3.1.5 Pelagic redfish, Deep Pelagic beaked redfish

3.1.5.1 Biology and distribution

The deep pelagic beaked redfish (*Sebastes mentella*) stock is distributed mostly in pelagic habitats within NAFO divisions 1–2, and ICES Subareas 5, 12, 14 at depths >500 m, but it is also found in demersal habitats west of the Faroe Islands (ICES, 2010). Stock ID for *Sebastes mentella* in the East Greenland area, Irminger Sea and around Iceland is based on a review in 2009 (ICES 2009a),and ICES has defined two pelagic stocks of *S.mentella* in the Irminger Sea and adjacent waters:

1. a Deep Pelagic stock (NAFO 1-2, ICES 5, 12, 14 >500 m) primarily pelagic habitats, and including demersal habitats west of the Faroe Islands;
2. a Shallow Pelagic stock (NAFO 1-2, ICES 5, 12, 14 <500 m) extends to ICES 1 and 2, but primarily pelagic habitats, and includes demersal habitats east ofthe Faroe Islands;

Beaked redfish is an ovoviviparous fish species, in which eggs are fertilized, develop and hatch internally. The male and female mate several months before the female extrudes the larvae. The females carry sperm and non-fecundated eggs for months before fertilization takes place in spring (Sorokin, 1961). Beaked redfish produce many small larvae that are extruded soon after they hatch from eggs and disperse widely as plankton. The extrusion of larvae may take place over several days or weeks in a number of batches. It occurs in large areas of the Irminger Sea during April and May, peaking in late April and early May (Shibanov *el al.* 1984; Pavlov *el al.* 1989). The main area of extrusion is found south of 65°N and east of 32°W (Magnússon and Magnússon 1977; Magnússon 1980, Zakharov 1966; Shibanov *el al.* 1995). The location of the mating grounds is unknown, but mating adults are found at the slopes. The adults of the deep pelagic stock move northwards and are found in May-July close to and within the Icelandic EEZ and on the continental shelf of Iceland. The international fishing fleet targets this adult population, with the main fishing areas being both close to the Icelandic-Greenland EEZ's and within Icelandic waters. The larvae are pelagic and drift northward in the surface layer and towards the continental slope of West- and East-Greenland. The nursery areas are believed to be situated on the continental shelf off East-Greenland and to some extent off West-Greenland (Figure 15). It is unknown to what extent juveniles recruit to the different stocks. Larvae drift to the continental shelf of East Greenland and to some extent to West Greenland, where they settle to the bottom. It is difficult to distinguish from the sibling species golden redfish (S. norvegicus), which occupies the same nursery areas. Juveniles are predominantly distributed on the continental shelf of West- and East Greenland. Adults are found in the open ocean. Age of recruitment to the fishery of both stocks is believed to be near maturity, possibly between ages 8-12 years.

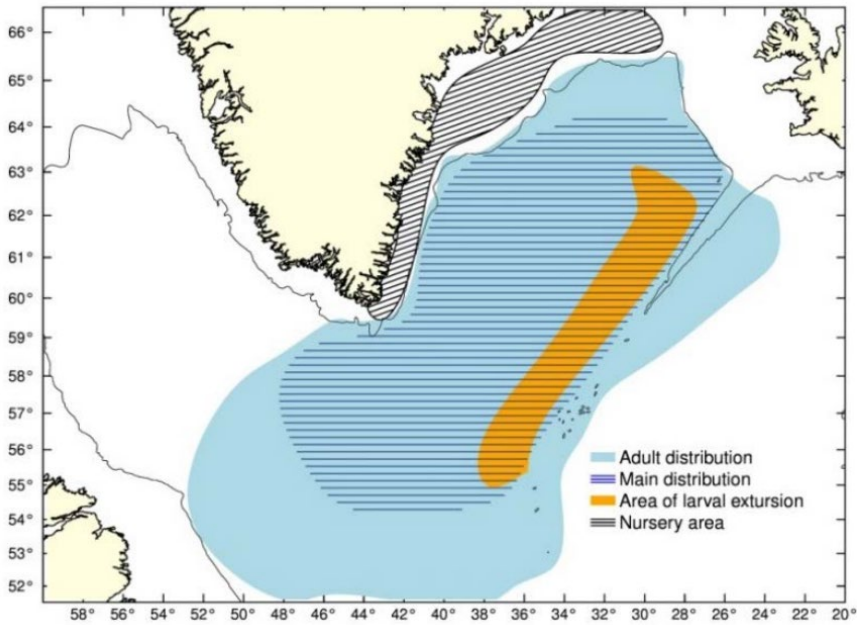

Figure 15. Distribution of the two pelagic S.mentella species, shallow and deep pelagic redfish.

3.1.5.2 Fishery

The fishery for deep pelagic redfish started in the early 1990s and grew quickly, with vessels from Iceland, Faroese, Germany, Norway, Portugal and Russia (Sigurðsson et. al, 2006). In 1995, 17 nations participated in the fishery, but nine of them retired soon or have participated occasionally. In the period 1992-1996, the fishery gradually shifted from the traditional redfish fishing grounds towards greater depths, developing a clear seasonal spatial pattern. The fleets moved systematically to different areas and depths as the season progressed, fishing the deep component in the north-eastern Irminger Sea (north of 61°N and east of 32°W) during the first months of the fishing season, or from April to mid-June, and moving to the shallow fishing grounds later in the season. Fishing is scarce between November and late March or early April. Annual landings increased quickly from 59 tonnes in 1991 to nearly 140,000 t in 1996, stabilizing at 85,000-105,000 t during the period 1997-2004, when some countries ceased fishing. From 2005 onwards, annual landings have declined. A large percentage of annual landings (66% on average) were taken in ICES division 14 (East Greenland) in 1991- 2015.Total catches were between 23,000 and 70,000 t since 2005, and the percentages of catch taken in ICES division 14.b for these years are among the highest, reaching 86% in 2010 and being practically 100% in 2012.

3.1.5.3 Management

North East Atlantic Fisheries Commission (NEAFC) is the international management body for this stock. NEAFC is a constitution of the main fishing nations in the North Atlantic, presently EU, Russia, Norway, Iceland, Faroe Islands and Greenland. A TAC management has been aimed on since 1996 but for the past two decades there has been no agreement among the parties resulting in autonomous quotas altogether being higher than biologically advised. Scientific disagreements on stock structure is likely the main cause for an agreement. This regime has led to total annual catches far above the advised.

3.1.5.4 Ecosystem aspects

Little is known about the trophic interactions in the Irminger Sea. However, a study by Petursdottir *el al.* (2008) shows that Euphausiids (*M. norwegica*) and *Calanus* spp. appear to play an important role in the diet of beaked redfish in pelagic ecosystem on the Reykjanes ridge.

Pedersen and Riget (1993) investigated stomach contents of beaked redfish in West Greenland waters and found planktonic crustaceans such as hyperiids, copepods and euphausiids to be the main food items in small redfish (5-19cm). Among shallow stock adults, the main food items are dominant plankton crustaceans such as amphipods, copepods and euphausids. Cephalopods (small squids), shrimp (P. borealis) and small fish (redfish included) are also important food items (Pedersen and Riget, 1993; Magnusson and Magnusson 1995). There are indication that Sebastes spp. play an important role as a prey item for Greenland halibut (Orr and Bowering, 1997; Solmundsson, 2007) and adult harp and hooded seals during pelagic feeding (Haug *el al.*, 2007; Tucker *el al.*, 2009). The prey items in these studies were, however, not species-specific observations.

3.1.6 Blue whiting

3.1.6.1 Biology and distribution

The blue whiting (Micromesistius poutassou) is a small gadoid meso-pelagic fish distributed throughout most of the North Atlantic, though with the highest densities in the East. Waters around Greenland acts as a peripherally area of its distribution. Blue whiting is often encountered along shelf edges at several hundred meters. Depth distribution varies with life stages, but adults are commonly found at depths of 300-500 meters (Bailey 1982; Stensholt *el al.* 2002). Several genetically distinct stocks appear in the North Altantic (Ryan *el al.* 2005; Was *el al.* 2008), but the stock delineation of fish in Greenland is currently unknown. It has been speculated that fish in Greenland belongs to a local minor stock in Icelandic waters(Bailey 1982; Schöne 1982), however this is very uncertain. Spawning takes place during winter and early spring, with the majority happening west of the British Isles. Spawning time is typically delayed with increasing latitudes. Post spawning, majority of the fish leaves the spawning grounds and conduct summer feeding migrations spread out in the North Atlantic. In Greenland waters, spawning has so far not been documented and it seems most likely not to occur, as no ripening fish have been identified and most adults leave the area during wintertime (Post and Jansen 2019). Highest densities within Greenland are found in East Greenland along the shelf-edge south of Dohrn Bank (~65.2 °N, 31.1 °W), but have been observed from 59.4 °N – 71.0 °N along the coast of West Greenland. Also juvenile zero year old's are present in Greenland waters, where most are found in southwest Greenland (Post and Jansen 2019).

3.1.6.2 Fishery

The blue whiting fishery is commercially important and was the 3rd largest in the world in the early 2000s (FAO 2011). Short after, the stock and the fishery almost collapsed, but most recently rebuild to higher levels (ICES 2019). The main fishery takes place at the primary spawning grounds west of the British Isles, in the Norwegian Sea and between the Faroe Islands and Ireland on pre- and post-spawning fish (ICES 2019). The fishery within Greenland is very limited and most of the Greenlandic catches are taken outside its EEZ, primarily in international and Faroese territorial waters.

3.1.6.3 Management

A long-term management strategy has been agreed by the European Union, the Faroe Islands, Iceland, and Norway in 2016 (Anon 2016; ICES 2019), which ICES has evaluated to be precautionary. There is no separate management plan for it in Greenland.

3.1.6.4 Ecosystem aspects

By virtue of its abundance, blue whiting can play a major role in the ecosystem. Its importance as a predator is not fully known but there has been a decline in the amount of zooplankton (especially isopods) in the Norwegian Sea in recent decades, which may be linked to large

occurrences of pelagic fish, such as blue whiting (ICES 2010a; b). During the larval stage, there is evidence that it competes with larvae of different cod and myctophids (Bailey 1982). In the adult stage, blue whiting has been shown to overlap in distribution and share diet with herring and mackerel in the Norwegian Sea, and therefore have some competition with other large pelagic fish stock (Langøy *el al.* 2012). As these three species are also present in East Greenland, this could also be the case here. However, the size of competition in different areas and on stock level is still uncertain. So far, no studies have documented it to be an important prey species in Greenland waters.

3.1.7 Cod

3.1.7.1 Biology and distribution

Cod found in East Greenland is belonging to one of four separate Greenland stocks and defined by its spawning area in offshore East Greenland and offshore Icelandic waters (Therkildsen *el al.*, 2013). A substantial part of the offspring from the East Greenland and Icelandic component settles along the western coast of Greenland and subsequently migrate back when reaching maturity at age of 5–7 years. These drifts events are believed to occur irregularly (Buch *el al.*, 1994; Schopka, 1994) and of varying intensity. Tagging information and recent studies clearly demonstrate this spawning migration (Storr-Paulsen *el al.*, 2004; Bonanomi *el al.*, 2016). The information also illustrates that the spawning migration is a one-way event; i.e. when the fish have migrated from West Greenland to East Greenland/Iceland, they do not return. Instead, the cod appear to continue a northward migration with age, such that the oldest cod are found in the northern part of the area in East Greenland. The dynamics between East Greenland and Iceland is largely unknown, however, an extensive analysis of tagging results from the period 2003–2016 suggest that 50% of cod in East Greenland migrate to Iceland (Hedeholm, 2018).

3.1.7.2 Fishery

The fishery in East Greenland started in 1954 as a trawl fishery (Horsted, 2000). Landings of about 30–60 kt dominated until the early 1970s, followed by a decrease to 10– 30 kt until the early 1990s supported by the large year classes 1973 and 1984 from Iceland. Due to overfishing, deteriorating environmental conditions and emigration to Iceland the stock size declined and the fishery completely collapsed in the early 1990s. For more than a decade (from mid-90´s) catches were close to null, and cod was only caught as bycatch in the redfish fishery until the mid-2000s.

The cod fishery in East Greenland has traditionally been a bottom trawl fishery, but in recent decades the longliners have been taken an increasing share of the TAC, amounting to approximately 1/3 of the total landings. The majority of landings are taken by Greenland with EU, Norway and the Faroe Islands landing minor quantums. Since discards are not taking place landings are equivalent to catches.

Trawlers fished 60% of the total catch almost exclusively (80%) in East Greenland in two areas north of 64°N; Kleine Bank between 64–65°N ; 36–38°W and on Dohrn Bank in a small area between 65–66°N ; 29–31°W on the edge of the continental shelf. The longline fishery is more evenly distributed than the trawl fishery and extended from Julianehåbs Bight in SouthWest Greenland (60°N, 1F) to Dohrn Bank (66°N, Q1Q2) in East Greenland .

3.1.7.3 Management

The East Greenland cod is a national stock within Greenland EEZ and managed by Greenland by means of fleet specific quotas. Total TAC is set by Greenland authorities. The stock has been very low since the early 1990s but has in recent years shown signs of recovery. No directed offshore fishery was allowed for the period 1993–2005, except for some minor allocations to Norway and the Faroe Islands. After an experimental fishery in East Greenland in 2007, when dense

concentrations of large spawning cod were found, East Greenland has been subject to several area closures to protect the spawners. In 2011 a management plan was implemented that allowed a small experimental fishery of 5000 tons per year in the period 2011–2013 in all offshore areas in Greenland (both West and East). In 2014 a new management plan replaced the management plan for 2011–2013. This stipulated a maximum TAC of 10 000 tonnes unless survey results clearly suggested that more or less could be taken from the stock. TAC increased to 18 000 tonnes in 2015 due to an increase in survey biomass, but has since lowered. Presently, the stock is in a healthy condition with a biomass above the MSY $B_{trigger}$ and a fishing mortality below F_{msy}.

In the offshore fisheries vessels are above 75BT/120BT and restricted to areas more than 3 nm off the baseline. Mesh size in the trawl fishery is 140 mm and no sorting grid is used. There is no regulation on hook size in the longline fishery.

3.1.7.4 Ecosystem aspects

Studies show that fish is the dominant prey group and that cannibalism is limited to the largest cod (Hedeholm *el al.*, 2016). Cod off Iceland and West Greenland rely heavily on capelin as prey, which was not evident for East Greenland cod, possibly because of timing issue. As the stock appears to be highly influenced by stock dynamics in the adjacent Icelandic area (Wieland and Hovgård, 2002), ecosystem variability will propagate to Greenland through variable inflow of larvae. These inflow events are significantly influenced by environmental factors like air and sea surface temperatures in the Dohrn Bank region during spawning, the zonal wind component in the region between Iceland and Greenland during the first summer (Stein and Borokov, 2004), as well as the size of the Iceland cod stock.

3.1.8 Beaked redfish (Sebastes mentella)

3.1.8.1 Biology and distribution

ICES has classified this redfish stock as Greenlandic slope *Sebastes mentella,* a separate biological stock as a temporary measure while stock ID studies is ongoing to relate the population to the adjacent demersal *S.mentella* stocks. The stock affinities of *Sebastes mentella* in the East Greenland – Iceland area has been subject to many discussions and presently the general perception is the existence of two pelagic stocks and two demersal stocks, of which the East Greenland shelf stock is the one demersal stock. *Sebastes mentella* is an ovoviviparous species. The female carries sperm and eggs for months, and extrude larvae in April-May in the Irminger Sea (Cadrin *el al.* 2010), but the exact mating site of the different stocks is unknown. The larvae are planktonic, and drift to the nursery areas on the Greenland slope were they settle on the bottom (Magnússon and Magnússon, 1995). This slope area from approx. 63°N to 65°N constitutes a common nursery ground for more *S.mentella* stocks (pelagic stocks and the Icelandic slope stock) as well as the *S.norvegicus* stock. All Sebastes species are slow growing and late maturing and recruit to the fishery at ages 8 to 12 years.

3.1.8.2 Fishery

The fishery for *S. mentella* on the Greenland slope is conducted almost exclusively with bottom trawl. In the 1980's and 1990's the fishery had catches as high as 19,000 tonnes (1981 and 1994).The fishery has declined after 1995 and remained below 1,000 tonnes per year until 2009. British, Faroese, Norwegian and Greenland vessels and occasionally German vessels (ICES, 2011), have dominated the fishery. Since 2009, a directed fishery was resumed for demersal *S. mentella*, with the majority being taken by Greenland and Norwegian vessels. The directed fishery in recent years is in a limited area at 64°N 36°W and just northeast of there at 64° 30′ N - 65°N and 35°W on depths between 400 and 500 meters. In the years before 2009, *S. mentella* were caught as bycatch in the Greenland halibut fishery, and at greater depths (ICES, 2011). The redfish

fishery on the East Greenland slope is close to Greenland halibut and cod fishing grounds, only separated by depths on the slope.

3.1.8.3 Management

Beaked redfish on East Greenland slopes is a national stock within Greenland EEZ and managed by Greenland by means of fleet specific quotas. Greenland authorities set total TAC. Apart from Greenland, the European Union, Norway and Faroe Islands are allowed fishing opportunities for cod in East Greenland. The state of the stock is unknown due to lack of defined reference points.

Sorting grids are mandatory in the shrimp fishery since 2002 due to high historical bycatches of juvenile redfish. Since this implementation, bycatches of redfish have decreased. With the recent lack of recruits in the area and the use of sorting grids, bycatches in the shrimp fishery has been negligible.

3.1.8.4 Ecosystem aspects

S. mentella feeding was investigated on the West Greenland slope and it was found that planktonic crusteceans (i.e. hyperiids, copepods and euphausiids) dominated the diet in smaller fish (5-19 cm, Pedersen and Riget, 1993). In adult fish (31-33 cm) from the Reykjanes ridge Petursdottir *el al.* (2008a) found indications that *S. mentella* fed heavily on the euphausiid *M. norvegica*. In the Greenland slope area adult feeding on amphipods, copepods, cephalopods, shrimps and fish (including cannibalism) are probably also important (Pedersen and Riget, 1993). Redfish spp. have been shown to comprise a significant part of the diet in both harp and hooded seals (Haug *el al.* 2007; Tucker *el al.* 2009). Greenland halibut feeding on *S. mentella* has been documented in Iceland waters (Solmundsson, 2007) but data from the West Greenland shelf does not indicate that *Sebastes spp*. is an important prey item (Greenland Institute of Natural Resources, Unpublished data).

3.1.9 Golden redfish (Sebastes norvegicus)

3.1.9.1 Biology and distribution

Golden redfish is ovoviviparous, meaning that eggs are fertilized, develop and hatch internally. The male and female mate several months before the female extrudes the larvae. The females carry sperm and non-fecundated eggs for months before fertilization takes place in winter. Females are thought to have a determinate fecundity. Golden redfish produce many, small larvae (37–350 thousand larvae) that are extruded soon after they hatch from eggs and disperse widely as zooplankton (Jónsson and Pálsson, 2006). The extrusion of larvae may take place over several days or weeks in a number of batches. Golden redfish is, like most redfish species, long-lived, slow-growing and late maturing. Males mature at age 8–10 at size 31–34 cm, whereas females mature age 12– 15 at size 35–37 cm (Jónsson and Pálsson, 2006).

Golden redfish (*Sebastes norvegicus*) on the continental shelves of East Greenland, Iceland and Faroe Islands (ICES Subareas 5 and Division 14.b) is considered one separate stock. This stock definition is based on the location of copulation and extrusion area (Magnússon and Magnússon, 1977; Magnússon, 1980; ICES, 1983). The few population genetic studies that have been conducted do not provide definitive results (Nedreaas *el al.*, 1994; Pampoulie *el al.*, 2009). The main nursery areas are off East Greenland and Iceland (Figure 16). Changes in distribution over time and migrations within the distribution area are considered insignificant; however, the main part of the stock is distributed in Iceland and East Greenland waters.

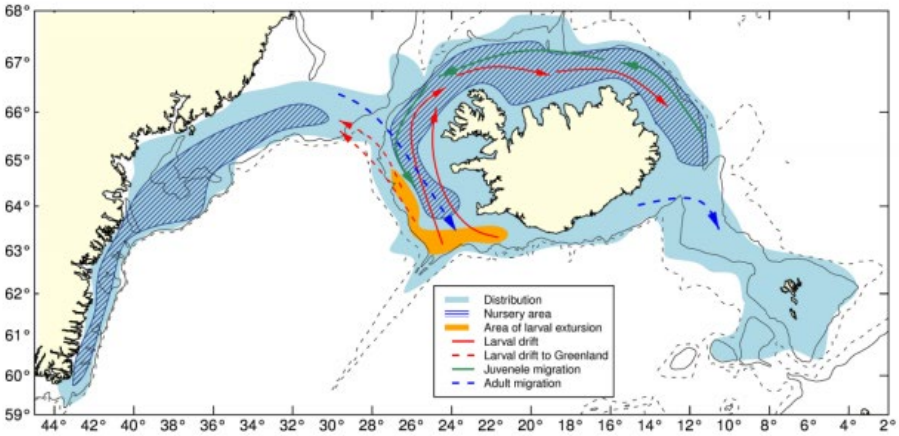

Figure 16 Distribution of golden redfish off southeast Greenland.

3.1.9.2 Fishery

Fishery for golden redfish is conducted by use of large bottom trawlers in a mixed fishery for golden redfish and beaked redfish. The fishery for golden redfish in East-Greenland waters started in the early 1950s, where landings peaked in 1955 at about 80,000 t. Again in 1976 the landings increased suddenly to 54,000 t mainly because of increased redfish fishery of the former Soviet Union. Thus, until early 1980s the fishery was mainly conducted by West-Germany, except in 1976 when the former USSR exceeded the catches of West-Germany. Since then the fishery declined to less than 5000 t and from 1995 to 2009 and landings were 200 t or less, mainly taken as bycatch in the shrimp fishery. In 2010, landings increased considerably, mainly due to increased *S. mentella* fishery in the area. Annual landings increased in 2010–2015 and peaked in 2016 at 5442 t. In recent years catches have been less than 500 t.

3.1.9.3 Management

Redfish and cod in Subarea 14 are found in the same areas and depths and historically these species have been taken in the same fisheries. Any redfish fishery may therefore affect cod. Presently advice is that no fishery should take place on offshore cod in Greenland waters. The Golden redfish is managed mutually between Iceland and Greenland by a management plan. The stock is in a good condition being above MSY Btrigger, but fishing mortality is presently above Fmsy.

East Greenland is an important nursery area for most redfish stocks in the area. Measures to protect juvenile are continued by means of sorting grids in the shrimp fishery. Despite this measure, surveys of redfish in the stock area have since 2009 consistently shown very low abundance of young redfish (< 30 cm). The absence of any indications of any incoming cohorts raises concerns about the future productivity of the stock.

As a measures to protect spawning cod bottom trawling was prohibited north of 62oN and in 2012 this regulation was changed to a trawling ban for cod in the first half of the year.

3.1.9.4 Ecosystem aspects

The food of golden redfish consists of dominant plankton crustaceans such as amphipods, copepods, calanoids, and euphausids (Pálsson, 1983).

3.1.10 Greenland halibut (Reinhardtius hippoglossoides)

3.1.10.1 Biology and distribution

Greenland halibut is a relatively slow growing deep sea fish that matures at an age of 8-10 years. The distribution reflects the preferred depths of 500 m to 2000 m.

Present perception of the stock is distributed from East Greenland over Iceland to Faroe Islands. Various stock ID studies suggest that the stock is not so well defined but may have strong connectivity to the adjacent stocks in the Barents Sea and in West Greenland. The spawning grounds are poorly defined but assumed to be west of Iceland at the slopes of the Reykjanes Ridge at depths more than 1000-2000 m. The scientific basis for the assumption on this spawning ground is weak and based only on a few observed spawning fish and on distribution of eggs and larvae. 0-group surveys suggest that recruits are supplied to East Greenland and might also drift to West Greenland. Nursery grounds have not been found in the entire stock area. Tag-recapture experiments have shown migrations of adult fish from Greenland to Iceland and also a mix within Icelandic waters, which supports a drift of larvae from west of Iceland to both Greenland and to north of Iceland. Tagging also suggest occasional migrations of adult fish from East Greenland and Iceland to Faroe Islands.

3.1.10.2 Fishery

The fishery for Greenland halibut in East Greenland is a directed fishery, nearly almost exclusively carried out by use of trawl besides a minor longline fishery. Since 1995 the contribution from longlines has decreased to less than 10% of annual catches. The fishery and catches have catches have continuously increased since the early 1990s from less than 1000 t to around 8-10,000 t in the last decade (Figure 17).

Historically, foreign fleets took the bulk of the catches but in recent years the German fleet is the main contributor to the catches while Greenland, Norway, Russia and Faroe Islands are the remaining players.

Since 2005 the fishery expanded to a northern fishing ground between 67 °N and 68°30′N at the continental slope between 500 and 1000 m. From 1996, the southern fishing ground (south of 62°N lat) had a significant and increasing role for the fishery comprised about 50% of total fishing effort and 70% of catches. The fishery was historically conducted throughout the year, but in recent years the bulk is in spring/early summer. Poor weather and ice conditions in autumn and winter often restrict fishing activity.

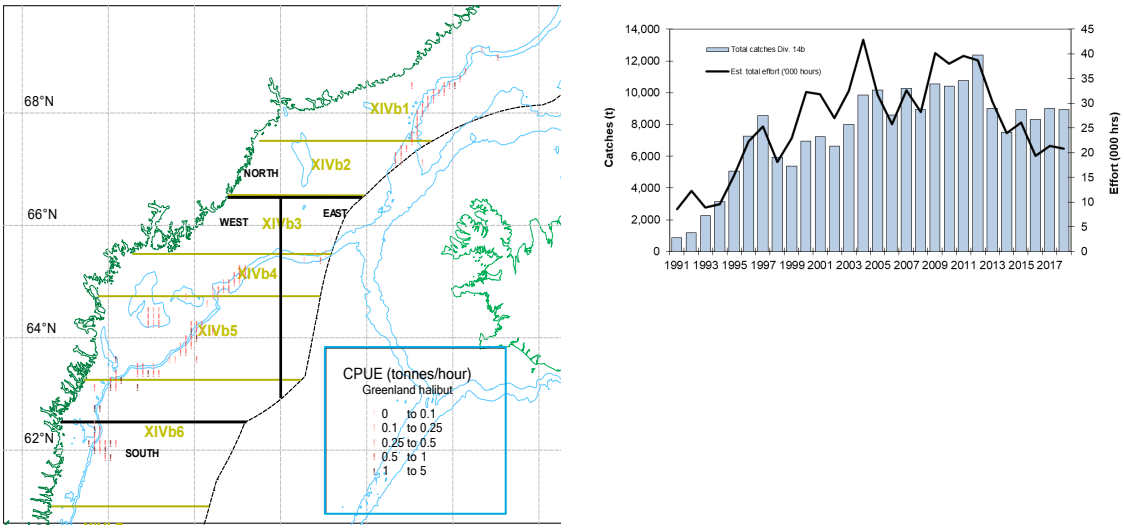

Figure 17 Left: Distribution of fishery for Greenland halibut in 2018 . Right: Annual catches and associated effort in the fishery for Greenland halibut since 1991.

3.1.10.3 Management

The Greenland halibut stock in East Greenland, Iceland and Faroe Islands was until 2018 managed bilateral between Greenland and Iceland, but since then unilateral managed by national TACs. Overall, the total catches have mainly followed the scientific advice since 2010.

3.1.10.4 Ecosystem aspects

Greenland halibut is one of the top predators in the ecosystem and very abundant over a wide geographical range from Cape Farewell up to 69-70°N and at deeper waters from 200 to 2000 m. Small crustaceans are the main prey of Greenland halibut below 20 cm in length, with an increasing shift towards small fish, shrimps and cephalopods with increasing predator length (Yang & Livingston 1988). Individuals larger than about 80 cm are mainly piscivorous. Most prey species are pelagic or semi-pelagic nektonic animals, which is thought to indicate off-bottom predation (e.g. Haug & Gulliksen 1982; Bowering & Lilly 1992). Shrimps, eelpouts (*Lycodes* spp.), capelin (*Mallotus villosus*), ophiuroids and amphipods are recorded as main preys in Icelandic waters (Saemundsson 1926). Solmundsson (2007) found that west of Iceland the main diet was capelin, 'other fish' and shrimp, with an increasing share of the latter two with size of Greenland halibut. The other fish category here included cannibalism, which the author suggest is due to low abundance of other large fish prey items in the early 1990s.

3.1.11 Roughhead grenadier (Macrourus berglax)

3.1.11.1 Biology and distribution

Literature based mostly on survey data from Canadian waters indicates that this is a long-lived, slow-growing species, of low fecundity and vulnerable to overfishing (Devine and Haedrich 2008) Gonzalez-Costas, 2010). Age estimations from otoliths have found specimens of up to 23 years (Savvatimsky 1984) and the species has been classified as of concern due to a decline of >90% of the survey index within Canadian waters over a period of 15 years (Cosewic 2007).

The population structure of roughhead grenadier in the Northeast Atlantic is poorly known. The species occurs at small abundance in some areas, mostly to the North of 60°N. The assessment unit considered by ICES is the whole Northeast Atlantic, this does not postulate anything about the population structure (ICES 2019a).

3.1.11.2 Fishery

Catches of roughead grenadier have been probably underestimated due to incorrect species identification with roundnose grenadier. There are no catches of roughhead grenadier reported between 1999 and 2004. From 2005 to 2013 the average catch was 7.9 t, whereas it increased to an average of 71.4 t between 2014 and 2018 (Figure 18). Before 2014, the catch is dominated by trawlers, but from 2014 and onwards catches are strongly dominated by longliners from February to April. From 2014 until 2018 reported catches of roughhead grenadier on longlines are much higher, which could be linked to the onset of targeted longline fishery after tusk in 2014 (Nielsen *el al.* 2019a).

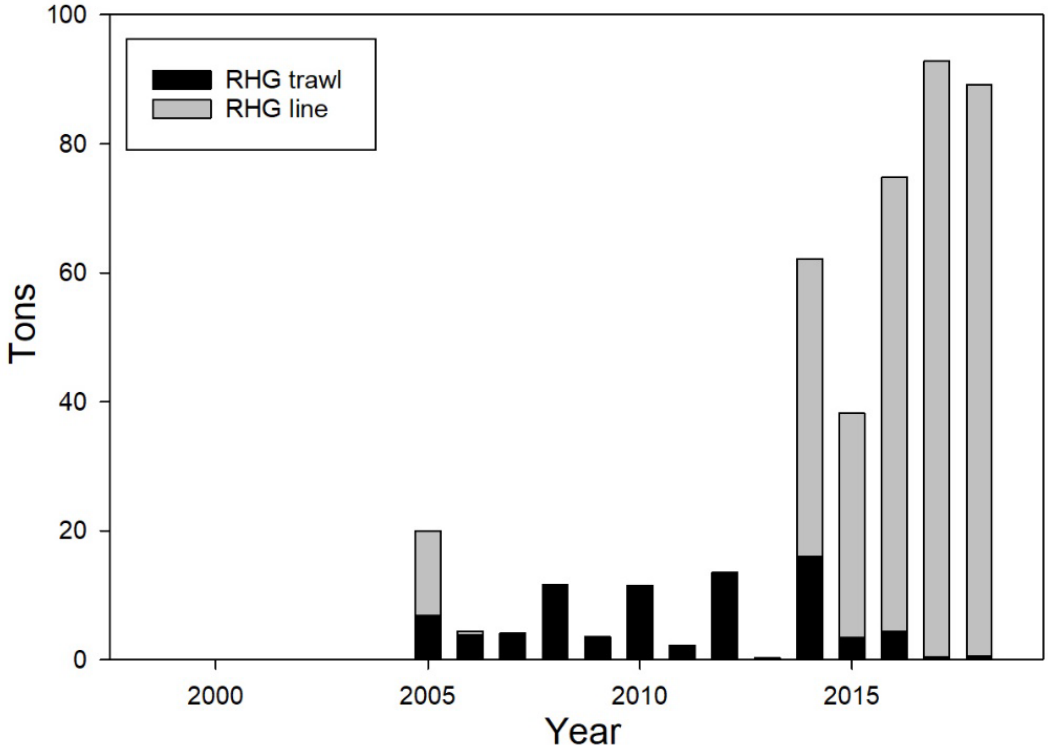

Figure 18. Trawl and longline catches of roughhead grenadier (t) in East Greenland (ICES 14b) from 1999 to 2018.

3.1.11.3 Management

There is no known management plan for roughhead grenadier in any ICES area. A combined TAC is set for both grenadier, roughhead and roundnose grenadiers from 2007. TAC has been decreasing from 3000 t in 2007 to 1000 t for the period 2010-2018. In eastern Greenland, TAC of roundnose and roughead grenadier combined was set in 3000 t in 2007, and it has been 1000 t since 2010. This TAC has been set by the Greenland Government and is not based on a biological assessment (Nielsen *el al.* 2019b).

3.1.12 Roundnose grenadier (Coryphaenoides rupestris)

3.1.12.1 Biology and distribution

Roundnose grenadier in subdivisions 14.b.2 and 5.a.2, is not considered as a demographic stock or a genetic population because it includes Artic and Atlantic areas in which roundnose grenadier was found to be genetically different. This unit might thus only be considered as an aggregations of areas where roundnose grenadier occurs at low to moderate density and is not subject to significant continuous exploitation (ICES, 2019).

3.1.12.2 Fishery

There is no directed fishery for roundnose grenadier. Landings of roundnose grenadier in subdivisions 14.b.2 and 5.a.2 are mostly small bycatch by Greenland, Germany and Norway during the Greenland halibut trawl fisheries for other species (Figure 19). Landings from Subdivision 14.b.2 (Greenland and Icelandic waters) in 1990–2016 varied from 1 to 126. National catch statistics of Greenland were used to update catches in subarea 14.b.2 from 1999 to 2018. It may include both landings from Greenland and other countries vessels, wherefore it was unclear whether this implies double count with landings reported by other countries. A potential over-reporting is suspected for roundnose grenadier, as the scientific survey has revealed that roughhead grenadier is present in bigger amounts in ICES 14.b.2. – a trend which is not supported by catches (ICES, 2019a). In 2015 catch was 38 t that mainly was taken by Greenland.

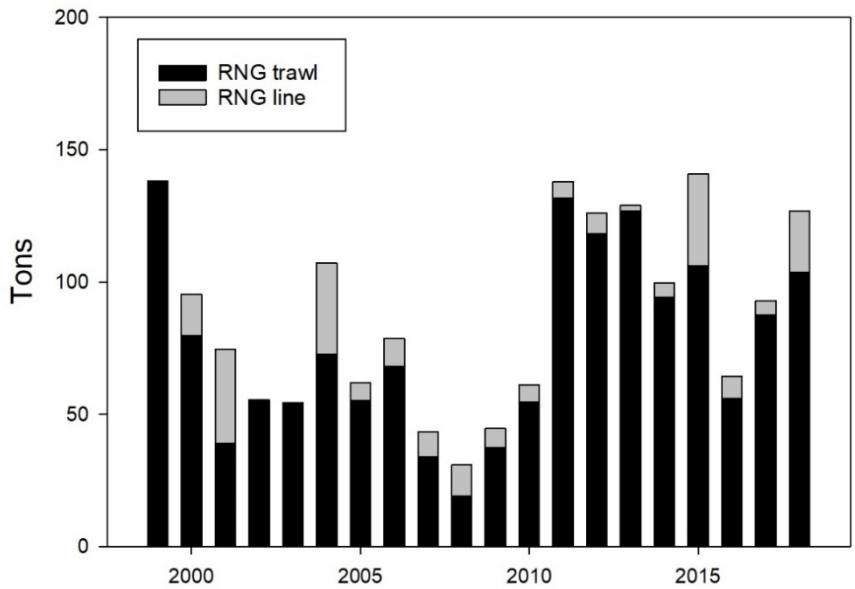

Figure 19. Trawl and longline catches of roundnose grenadier (t) in East Greenland (ICES 14b) from 1999 to 2018.

3.1.12.3 Management

A combined TAC is set for both grenadier, roughhead and roundnose grenadiers from 2007. TAC has been decreasing from 3000 t in 2007 to 1000 t for the period 2010-2018.

3.1.13 Tusk (*Brosme brosme*)

3.1.13.1 Biology and distribution

Tusk in Icelandic and Greenland waters (ICES Division 5.a and Subarea 14, respectively) is considered as one stock unit and is separated from the tusk found on the mid-Atlantic Ridge, on Rockall (6.b), and in Divisions 1 and 2. This stock discrimination is based on genetic investigation

(Knutsen *el al.*, 2009) and was reviewed at the WGDEEP meeting in 2007. The biomass of the tusk stock has been low until 2010 From 2010 until 2016, the biomass has been distinctly higher ranging from 78.8 t (2014) to 504.0 t (2013). The overall length distribution for all years are based on relatively low sample sizes (N<100) but it appears that a mode between 40-50 cm is dominating all years.

3.1.13.2 Fishery

The tusk fishery in the Greenland area of ICES Subarea 14 has historically been very small, with less than 100 t caught annually (Figure 20). The tusk has been caught as bycatch in other fisheries. Catches has been increasing in the Greenland area since 2015. For the time being, these catches are not included in the stock assessment.

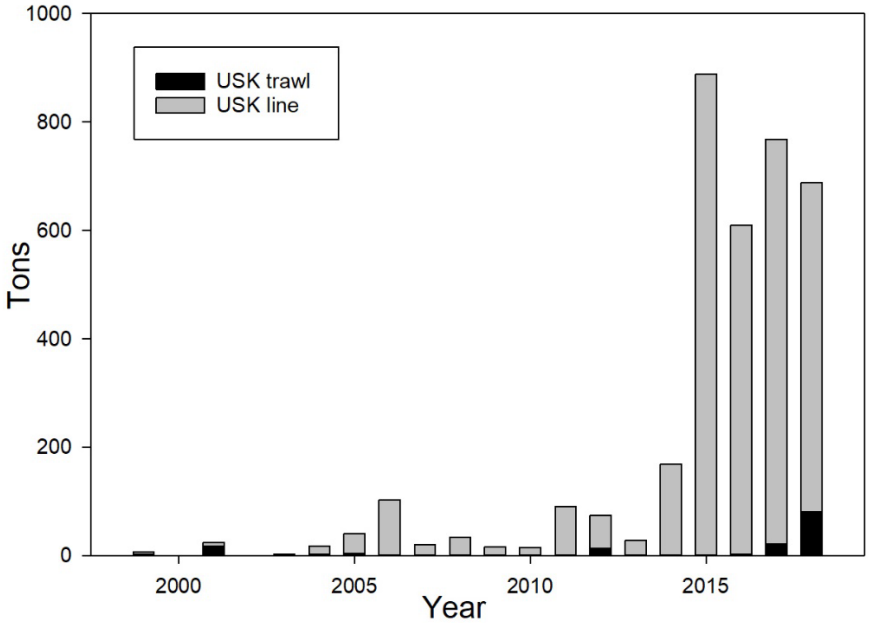

Figure 20. Trawl and longline catches of tusk (t) in East Greenland (ICES 14b) from 1999 to 2018.

3.1.13.3 Management

The Ministry of Fisheries from Iceland is responsible for management of the Icelandic fisheries and implementation of the legislation. Tusk was included into an individual transferable quota (ITQ) system in the 2001/2002 quota year. On the other hand, the government of Greenland set a 500 t TAC in 2014 was 500 t. The TAC was increased to 1500 t in 2015-2018 TAC.

4 Marine mammals

4.1 Diversity and basic characteristics of the marine mammal community

The list of marine mammals regularly occurring in East Greenland waters includes at least 10 whale species (narwhals (Monodon monodon), bowhead whales (Balaena mysticetus), harbour porpoises (Phocoena phocoena), white-beaked dolphins (Lagenorhyncus albirostris), minke whales (Balaenoptera acutorostrata), humpback whales (Megaptera novaeangliae), fin whales (Balaenoptera physalus), sperm whales (Physeter macrocephalus), killer whales (Orcinus orca), longfinned pilot whales (Globicephala melas), 6 pinniped species (ringed seals (Pusa hispida), harbour seals (Phoca vitulina), bearded seals (Erignatus barbatus), harp seals (Pagophilus groenlandicus), hooded seals (Cystophora cristata), walruses (Odobenus rosmarus)) and polar bears (Ursus maritimus).

Apart from harbour seals, all the pinniped species are ice dependent in the sense that maximum global population sizes are recorded in areas with at least seasonal ice cover. All 6 pinniped species pup in East Greenland waters -mainly on ice. Also, the ice dependent narwhals and bowhead whales are believed to calve in East Greenland waters (Boertman and Nielsen, 2010, NAMMCO, 2019a). The calving areas of the ice-independent whale species are likely not within East Greenland waters. This group includes highly migratory species like fin whales, humpback whales and minke whales, which are generally thought to reproduce in low latitudes in winter and feed in subarctic and arctic areas during summer. Some Northeast Atlantic humpback whales are known to belong to a very small population breeding in the Cape Verde archipelago off the coast of Senegal and others are breed in the Caribbean, but it is suspected that one or more additional undetected breeding grounds exist (e.g. Wenzel *el al.* 2020). Several studies show that some humpbacks, fin and minke whales overwinter in the subarctic areas of the Northeast Atlantic and male singing by fin and humpback whales has been recorded during the mating season (Magnusdottir *el al.*2014, Ahonen *el al.*, 2017). Observations of early and late fetuses in humpback whales caught in early spring off Northern Norway in the early 19th century (Ingebrigtsen 1929) further suggest that some cosmopolitan baleen whale species may both mate and calve in northern ice-free areas.

East Greenland coastal waters were historically often covered by dense pack ice in summer and were almost exclusively considered an important habitat for ice-dependent species (Hansen *el al.* 2018). In recent years, however, East Greenland waters have often been ice - free during summer and large numbers of cosmopolitan whale species like fin whales and humpback whales have been observed on the east Greenland shelf. The first comprehensive survey of whale abundance in this area was conducted in 2015 (Hansen *el al.* 2018). In addition, relatively recent abundance estimates are available for narwhals, bowhead whales, walruses and narwhals in East Greenland coastal waters (Boertman *el al.* 2015, NAMMCO 2018, NAMMCO 2019a) and for harp and hooded seals whelping on the pack ice off Northeast Greenland (ICES 2019). The most recent abundance estimates for marine mammals in East Greenland waters have been extracted from the listed sources and are presented in Figure 21.

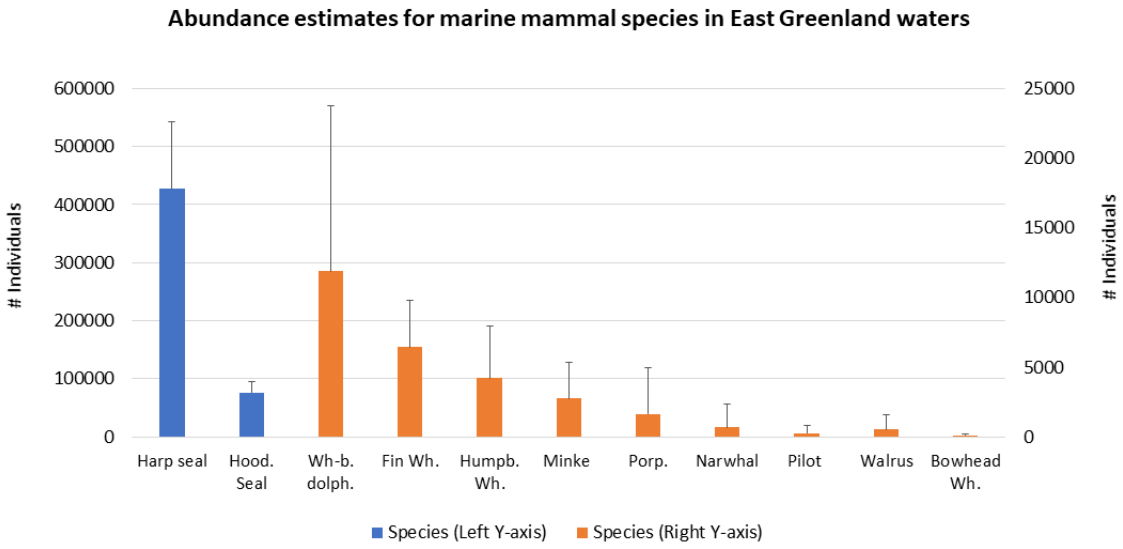

Figure 21. Most recent abundance estimates for 11 marine mammal species in East Greenland waters extracted from sources listed in the text. With the exception of walruses, error bars show approximate upper 95% confidence limit, either according to original reference or calculated as 2*standard deviation based on reported CVs or standard deviations. For walruses the error bar shows upper 90% confidence limit as reported in NAMMCO (2018).

4.2 Current exploitation and management

Marine mammal hunting is an important part of Greenlandic inuit culture and most species occurring in East Greenland coastal waters are subject to a local hunt, which is managed by the Greenland home rule based on research and advise from the Greenland institute of natural resources (GINR) and international scientific advisory bodies like NAMMCO, the IWC, ICES and the Polar Bear specialist Group under IUCN. In addition to the local hunt, harp and hooded seals are hunted by larger Norwegian sealing vessels in the pack ice off Northeast Greenland outside the EEZ of Greenland. Quotas for this hunt are set by the Norwegian government based on advice from ICES. Figure 22 a-c, shows offshore and inshore hunting statistics reported to WGHARP (ICES 2019) and the NAMMCO catch database (https://nammco.no/topics/120419_catch_db) organized according to annual maximum catches. Offshore catches only occur for harp and hooded seals and refer to catches taken by Norwegian and Russian sealers in the pack ice off Northeast Greenland. All other catches are local East Greenland catches.

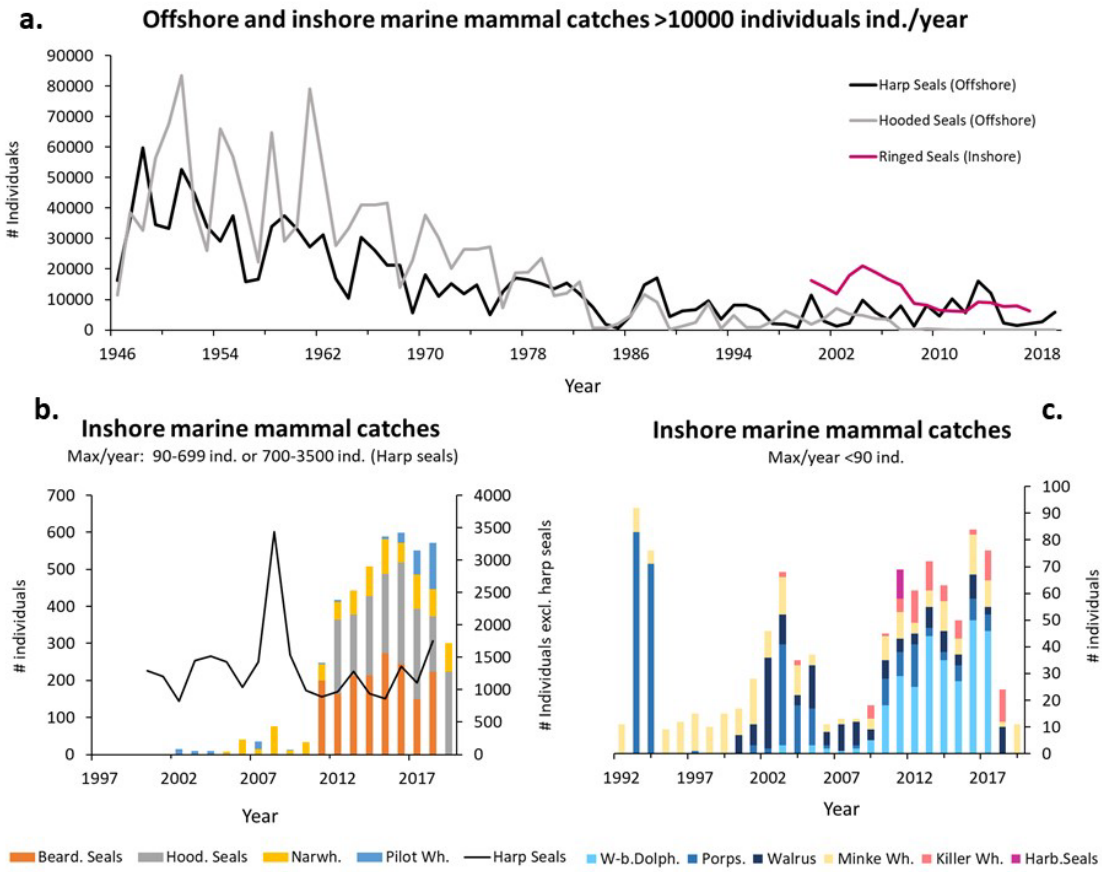

Figure 22 (a-c). Offshore and inshore annual catches of marine mammals in East Greenland waters based on reports from ICES (2019) (offshore catches of harp and hooded seals) and the NAMMCO catch database (all inshore catches).

4.3 Ecology

Due to their large body size and long residence time, fin whales and humpback whales represent the largest biomass among the marine mammals in the Greenland Sea and also have the highest consumption of prey (Figure 23). No diet data are available for the Greenland Sea area, but both species are generally known to prey on krill and small pelagic fish (e.g. Moore *el al.* 2019). In Icelandic waters fin whales appear to feed almost exclusively on krill, while humpback whales are closely associated with capelin (e.g. Moore *el al.* 2019, Gunnlaugsson and Vikingsson, 2014). For the past decades, the Icelandic capelin stock has summered in East Greenland waters (Palsson *el al.*, 2012) and are likely an important prey item for humpbacks in this area (Heide-Jørgensen *el al.* 2020 in prep.). The change in capelin distribution is one of several major ecological changes in the East Greenland Sea area over the past decades and a more detailed description of the effect of these changes on marine mammals in southeast Greenland is given in Heide-Jørgensen *el al.* (2020 in prep.).

Also minke whales are known to prey on a mix of crustaceans, capelin and other fish (e.g. Moore *el al.* 2019). The same is true for ringed and harp seals (Wathne *el al.*2000, Labansen *el al.* 2011, Enoksen *el al.* 2017)), but the large Greenland Sea harp seal population only spends a few months in the Greenland Sea area around breeding and moulting (Folkow *el al.*2004). White beaked dolphins are thought to be mainly piscivorous and show spatio-temporal overlaps with capelin and blue whiting in the Barents Sea (Fall and Skern-Mauritzen, 2014), but no data are available from other areas. Bowhead whales are thought to feed almost exclusively on crustaceans like copepods and krill (Heide-Jørgensen *el al.*2013a, Boertman *el al.* 2015). Unlike other baleen whales in

the North Atlantic, they appear to feed regularly on epibenthic aggregations of crustaceans and may therefore feed on overwintering stages (Heide-Jørgensen *el al.* 2013a).Only a few hundred bowhead whales inhabit the Northeast Atlantic and the Western Fram Strait appears to be an important habitat both in summer and winter (Stafford *el al.* 2012, De Boer *el al.* 2019, Kovacs *el al.* 2020).

Narwhals and hooded seals are deep divers known to feed on mesopelagic prey like Greenland halibut, redfish, polar cod, Gonatus fabricii and capelin (e.g. Tucker *el al.*2009, Heide-Jørgensen *el al.*2015). Diet data for the Greenland sea hooded seal population are, however, restricted to data collected in pack ice areas, whereas the main feeding effort likely occurs along continental slopes over most of the Northeast Atlantic (Folkow *el al.* 1996, Folkow and Blix 1999, Folkow *el al.* 2010, Vacquie-Garcia *el al.* 2017a). Based on observed dive patterns, capelin appears to be a more important prey to East Greenland narwhals than to narwhals in west Greenland (Watt *el al.* 2013). Other deep diving species off East Greenland are pilot whales and sperm whales, which also feed opportunistically on squid and fish (e.g. Martin and Clarke, 1986, Desportes and Mouritzen, 1993). Only three sperm whales were observed during the latest whale surveys in Southeast Greenland (Hansen *el al.* 2018), but more sperm whales occur further to the north and on the continental slopes (Pike *el al.* 2019). During the whaling period, stomach contents of sperm whales in this area were found to be dominated by fish, mainly lumpfish (Martin and Clarke, 1986). The Northern bottlenose whale (Hyperodon ampullatus) is a third deep diving whale species which is known to feed along the continental shelf of East Greenland, especially in the Denmark Strait area (e.g. Whitehead and Hooker 2012). They were not observed during the 2015 East Greenland survey (Hansen *el al.* 2018), but are regularly observed during Norwegian minke whale surveys in the area between the Denmark Strait and Svalbard (Leonhard and Øien 2020a, Leonhard and Øien 2020b) as well as the larger Norwegian Sea area.

Harbour seals are generally considered to be relatively shallow diving coastal seals, but satellite tagging of the harbour seals from a small population in Southeast Greenland has shown dives down to 600 meters and some offshore feeding excursions (Rosing-Asvid *el al.*2020). Harbour seals usually feed on a variety of small fish, but the diet in East Greenland is unknown. Greenlandic harbour porpoises also show unusually deep dive profiles and very long migrations along the coasts of East and west Greenland as well as to areas off the coasts of North America (Nielsen *el al.* 2018).

Based one telemetry study from the area (Rosing-Asvid and Dietz 2018) ringed seals are distributed inshore in fjords and bays and offshore to the edge of the continental shelf (total area approximately 300,000 km2), with densities likely to be highest inshore (probably at least twice as high as off shore). Densities found inshore in Scoresby Sund Fjord and in Kong Oscars Fjord in the southern part of the assessment area were 2.00 seals/km2 and 1.04 seals/km2, respectively (Born 1998). The average density in the total area (including offshore) is likely to be substantial less than 1 seal/km2.Ringed seals are small and eat less than harp seals. Stomach samples (n = 51) from the Greenland Sea area (a mixture of inshore and offshore samples) indicate that offshore they mainly feed on crustaceans and inshore mainly on fish (predominantly Polar cod (Boreogadus saida) and Themisto) (Table 2).

Bearded seal are found inshore in fjords and bays and offshore towards the edge of the continental shelf (total area approximately 300.000 km2). Bearded seals have been registered on surveys mainly targeted for narwhales, so their distribution area is known, but data are still too few to produce an estimate. They are not as evenly distributed as the ringed seals and they are much fewer in numbers. Current estimates are about 10% of the ringed seal population is used here.

Bearded seals are very large seals and part of their diet is not as energy rich as the fish that harp seals go for, so they have a high comnsumption to compensate. There are no studies of

consumption from the Greenland Sea area. A study from Svalbard found polar cod and sculpins (Cottidae spp.) to be the most important fish species, but invertebrates like Spider crab (Hyas Araneus), shrimps like (sabinea septemcarinatus) and (sclerocrangon boreas) were also very important (Hjelset *el al.* 1999). Sculpins and polar cod were also the main prey in a study from Arctic Canada (Finley and Evans 1983), and capelin (mallotus villosus) and various codfish were the main prey in the central Bering Sea (Antonelis *el al.* 1994), but in both these areas fish were supplemented by prey like crabs, clams and snails, which are prey that rarely end up in the stomach of other seal species. So based on these studies and the known species available an estimate of their diet would be 60 % fish, mainly polar cod and 40% invertebrates (Table 2). More detailed information on the diets and abundance of pinnipeds in East Greenland can be found in Rosing-Asvid (2020 in prep.).

For harp seal the migration patterns for both adult and young of the year has been described in detail from telemetry (Folkow *el al.* 2004) and (Rosing-Asvid and Zinglersen 2018). The numbers used in the table are rough estimates based on those studies. Close to all harp seals concentrates on the ice in the Greenland Sea in mid-late March and give birth there around 1. April. In May they moult on the ice in the Greenland Sea and in June-July they swim northward along the ice edge foraging. In August most of them swim out of Greenland waters and into the Barents Sea. In February some will head back toward the ice in the Greenland Sea and this migration become stronger and stronger until late March when most of the seals are there. The latest survey (ICES 2019e) gave an estimate of the population size to be 426 808.

The period with a large number of harp seals in the Greenland Sea include the breeding and the molting period, when the seals loose weight and eat little. The average consumption in that period is therefore set low compared with the period when most are in the Barents Sea. There are two studies of consumption from the Greenland Sea area. One from July-August, just around the time when many seals shift from the Greenland Sea to the Barents Sea (Haug *el al.* 2004). The stomachs in both periods were often empty, indicating that most of the seals were focused on migrating. Another study included samples from March-June, which is the breeding and molting period and most stomachs in this study were also empty (Potelov *el al.* 2000). The species found in both studies as the most important was Themisto sp. and second polar cod. One study also had squids (Gonatus fabricii) and (Ammodytes sp.) being important. There are no studies on the winter consumption of harp seals.

The hooded seal migration patterns have been described in detail using telemetry (Folkow *el al.* 2004). The seals spent around 26% of their time in the Greenland Sea. Hooded seals can swim long distances very fast and they make long excursions in and out of the Greenland Sea. The latest survey (ICES 2019b) gave an estimate of 76 623 individuals in the region.

The hooded seal is a large seal and consumption is expected to be somewhat higher than that of harp seals. There are two studies on the consumption by hooded seals in the Greenland Sea area (the same as for harp seals). The species found in both studies as the most important was squids (Gonatus fabricii) and polar cod. One of the studies also found Themisto and (Ammodytes sp.) being important. As with harp seals little is known about their winter consumption.

Killer whales occur regularly but in rather low numbers in East Greenland waters and no abundance estimate was calculated based on the 2015 survey off East Greenland (Hansen *el al.* 2018; Jourdain *el al.* 2019). Based on genetic analyses, these whales are thought to belong to a primarily piscivorous population also occurring in Norwegian and Icelandic waters (Foote *el al.* 2013a, Jourdain *el al.* 2019). In East Greenland, killer whales have been found to feed on harp seal pups in spring but contaminant levels suggest that they likely feed on lower trophic levels at other times of the year (Pedro *el al.*2019). Killer whales occasionally prey on harbour seals, harbour porpoises and grey seals in other parts of the Northeast Atlantic (Jourdain *el al.* 2017). There are

no confirmed cases of killer whale predation on larger whales in East Greenland waters or elsewhere in the Northeast Atlantic. In Eastern Canada, however, killer whales are believed to be an important predator on narwhals and bowhead whales (Ferguson *el al.*2012a and 2012b). Scars from killer whale teeth have also been observed on humpback whales, but this is significantly less common in the Northeast Atlantic (McCordick *el al.* 2014). Possibly, the presence of large pelagic fish stocks in the Northeast Atlantic reduces the killer whale predation pressure on marine mammals in this region compared to the Northwest Atlantic. In both areas, however, killer whales appear to have become more abundant in previously ice-covered areas and the increased level of contact with slow swimming arctic cetaceans may alter the predation patterns of some killer whale pods (Jourdain *el al.* 2019).

Another mammal eating predator is the polar bear, which has shown a shift in diet from ringed seals to harp and hooded seals in East Greenland over the past two decades (McKinney *el al.* 2013). This is likely largely driven by reductions in ice extent off northeast Greenland, increasing the accessibility of the pack ice breeding and moulting areas to the bears, which were previously feeding on ringed seals in coastal areas. Diet analyses suggest that the polar bears target hooded seals in particular and it cannot be excluded that increased natural predation may play a role in the lack of recovery of this population (Øigård *el al.* 2014).

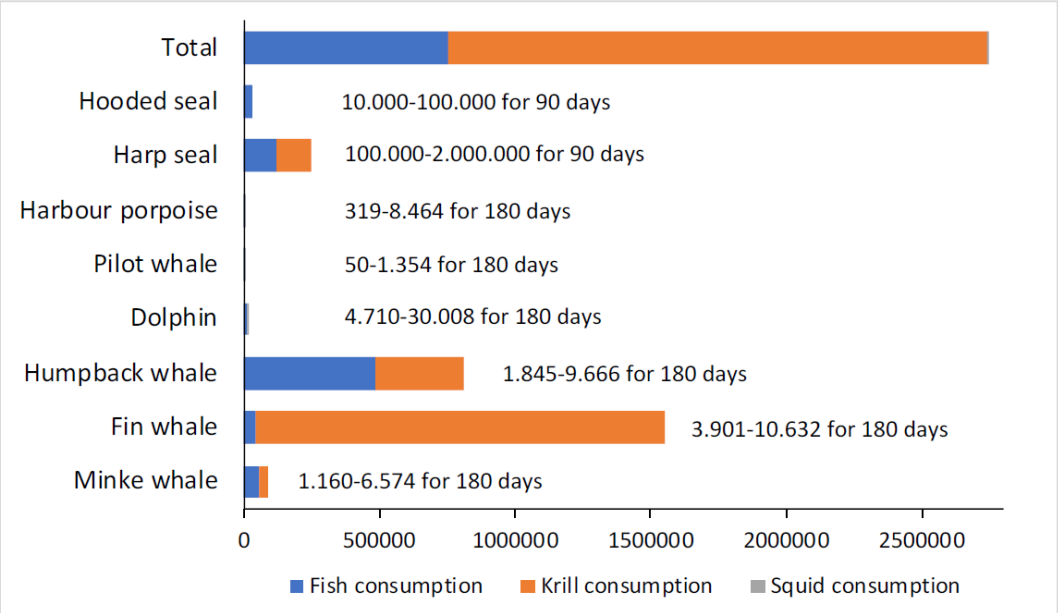

Figure 23. Annual consumption estimates for abundant marine mammal species with known population sizes in East Greenland waters. Assume duration of stay in East Greenland waters is shown for each species. For more detail see Heide-Jørgensen *el al.* (2020 *in prep.*) and Rosing-Asvid (2020 *in prep*).

4.4 Effects of hunting

Most of the marine mammal species in the Greenland Sea area have been subject to hunting, either by international fleets, local hunters or both. Historically, severe population declines have been associated with large scale commercial hunting, but local hunting may also have a significant impact on some species.

Commercial hunting for harp seals in the Greenland Sea whelping patches likely started as a supplement to the whaling operations in 18th century, but quickly reached high levels (Sergeant 1991). There are no catch records from the earliest period but from the 1860s to the mid-1980s,

reported annual catches ranged between 50,000 and 120,000 animals with an estimated proportion of pups of 50-60% (Sergeant 1991). After this period, catches declined to an annual level of 20,000-50,000 animals, which remained rather stable to the 1960s (Sergeant 1991 and Fig.). Quotas for harp seal catches in the Greenland Sea were introduced in 1970 along with protection of adult females on the breeding grounds. At this time total abundance was likely around 300,000 (Figure 23a) and has since increased by about 100,000 (ICES, 2019). Greenland Sea harp seals are genetically distinct from both Northwest Atlantic harp seals and Barents Sea harp seals (Carr *el al.* 2015). Sustainable quotas are still given to Norwegian sealing vessels, but for many years have only been partly taken (ICES 2019). The hunt is therefore unlikely to have caused the 50% drop in pup production estimated for the most recent survey in 2018 (see Figure 24a).

Whelping of Greenland Sea hooded seals overlap temporally and often spatially with whelping of harp seals (e.g. ICES, 2019). Some hooded seals have therefore probably always been caught during the harp seal hunt, but only from the 1920s have they been directly targeted and independently reported (Strøm 1949, ICES 2019). In the late 1940s and 50s average annual catches ranged between 18000 and 30000 animals, mainly pups (ICES 2019). Retrospective population modelling has estimated total population size of Greenland Sea hooded seals in 1946 at about 1.4 million with a strongly negative trend up to a population size of about 250000 in 1980 (Figure 4b). This decline is thought to be mainly caused by hunting (Øigård *el al.* 2014). The Greenland Sea hooded seal stock was completely protected from commercial hunting from 2006, but two pup production surveys conducted since then have not suggested any recovery (ICES 2019). No genetically significant differences have been found between hooded seal breeding areas across the North Atlantic (Coltman *el al.* 2007).

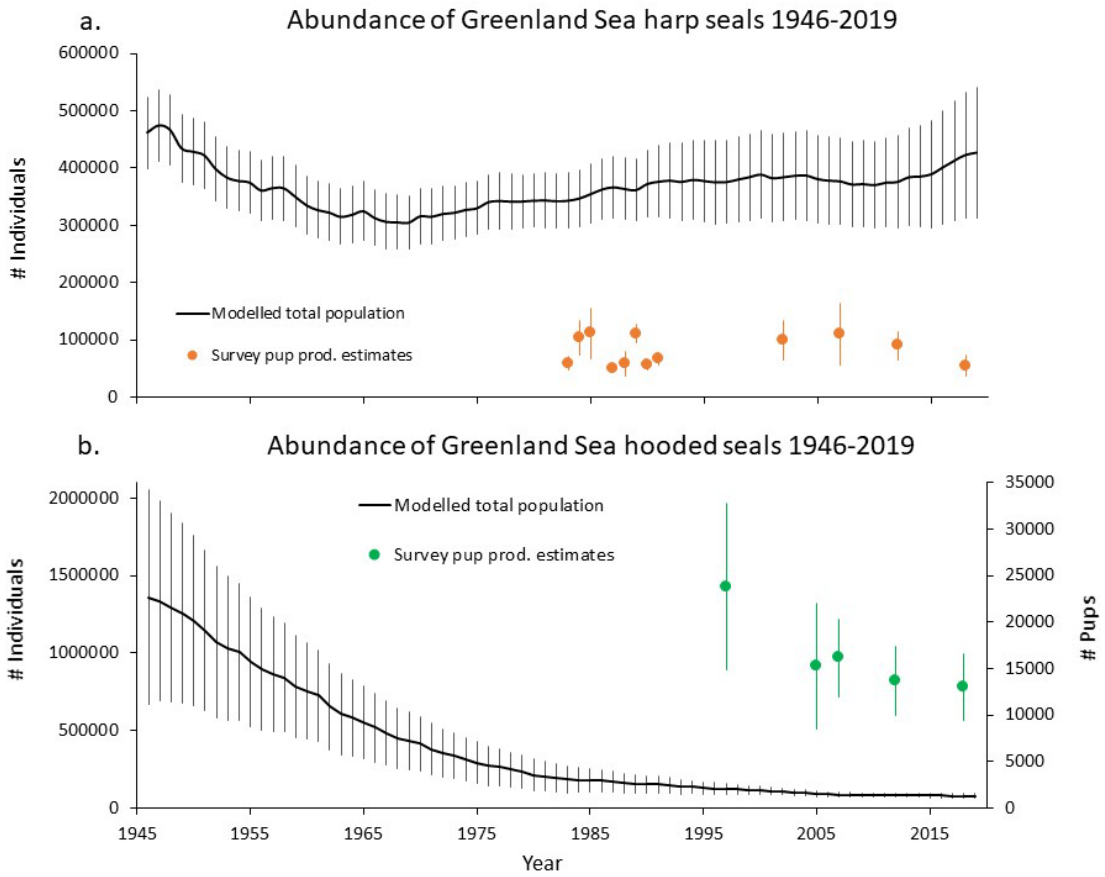

Figure 24 **Estimated total abundance of (a) Greenland Sea harp seals and (b) Greenland Sea hooded seals over the period 1946-2019 based on ICES (2019) and associated data available at**

http://www.mosj.no/no/fauna/hav/klappmyss.html **and** http://www.mosj.no/no/fauna/hav/gronlandssel-bestand.html**. Error bars show 95% confidence intervals.**

Narwhals are an important hunting species for the local population in East Greenland (e.g. Figure 22b), but until recently little was known about the total abundance of the genetically distinct East Greenland narwhal population (Louis *el al.* 2020).The first total census of narwhals in East Greenland was conducted in late summer 2008 and showed a continuous distribution from Scoresby Sound to Tasiilaq with denser concentrations in Scoresby sound, Kangerlussuaq fjord and Tasiilaq fjord (Heide-Jørgensen *el al.* 2010). The total abundance within this area has been estimated at 2764 (95% CI:935-8241) (NAMMCO 2019a, NAMMCO 2019b). New surveys in summer of 2016 suggest a decline to a total of 702 narwhals (95% CI 323-1649). No narwhals were observed in the southernmost area around Tasiilaq (GINR 2019, NAMMCO 2019a). Retrospective population modelling (NAMMCO 2019a) has estimated population size in 1955 at around 4000 animals (90% CI: 3050-5590), and hence a decline by more than 75 %. Based on modelled catch scenarios, the NAMMCO scientific council has a complete stop in the narwhal hunt in East Greenland (NAMMCO, 2019b). However, a quota of 50 narwhals has been set for 2020 (Naalakkersuisut, 2020, https://naalakkersuisut.gl/da /Naalakkersuisut/Nyheder/2020/01/0301Qilalugartassiissutit), declining by 10 each year to 2022. There is a possibility that some narwhals caught in early summer by hunters in Northeast Greenland belong to a different stock, but available tagging data suggest this is probably not the case and genetic profiles for these animals are so far not available (NAMMCO 2019a, GINR 2019). No genetic differences have been found among the traditional three main concentrations of narwhals in East Greenland, but due to the high degree of philopatry generally observed in narwhals, demographic separation is considered likely (NAMMCO 2019a). The number of management units have therefore been increased from 1 to 2 in 2009 and to 3 in 2017 (NAMMCO, 2019b). The decline in East Greenland narwhals is thought to be driven by both hunting and environmental changes (NAMMCO, 2019a).

The genetically distinct East Greenland walrus population was likely depleted by foreign sealers during the latter part of the 19th century and again by commercial hunting in the 1930s (Born *el al.* 1997, Witting and Born, 2014). Based on an estimated abundance of 1430 individuals in 2009 (Witting and Born, 2014), the East Greenland walrus population was thought to have fully recovered to pre-sealing levels. However, new surveys in 2017, registered much fewer animals than expected (NAMMCO, 2018). The currently accepted abundance estimate is 540 individuals (90% CI:300 - 1600) based on combined data for the period 2009-2017 (NAMMCO 2018). About 5-10 East Greenland walruses are hunted every year in a quota-regulated hunt around the settlements Tasiilaq and Itoqqortormiut (see Figure 22c). Almost all the hunted walruses are males (~90%), since females and calves are generally distributed too far north to be within reach of the hunters (NAMMCO 2018). The current hunt is therefore not believed to have a significant impact on population growth rates.

Harbour porpoises from a large population in west Greenland enter East Greenland waters (Nielsen *el al.* 2018, NAMMCO and IMR 2018). The West Greenland harbour porpoise population is genetically distinct from harbour porpoise populations in both Eastern Canada and Northern Europe, but it is unclear, if all harbour porpoises in East Greenland belong to the same population (NAMMCO and IMR 2018). In 2015, abundance of harbor porpoises was estimated at 1,642 (95% CI: 319-8,464) in East Greenland and 83321 (95% CI: 43,377-160,047) in West Greenland (Hansen *el al.* 2019).

For several coastal species of marine mammals in East Greenland, there are no survey-based abundance estimates. However, most of these species are hunted and trends in hunting statistics may be used as indications of population trends. One example is the genetically distinct population of harbour seals (Andersen and Olsen 2010), which was a popular hunting object in both East and West Greenland up to the 1950s (Rosing-Asvid 2010). From the 1960s to the 1990s, the

hunting statistics showed a declining trend and currently only a few harbour seals are observed in southeast Greenland (Rosing-Asvid 2010). In addition, about 50 harbour seals are known to inhabit a river in west Greenland, but the degree of genetic isolation of this population is unknown (Rosing-Asvid 2010). Increased ice occurrence in southeast Greenland during the period 1960-80 is thought to have given harbour seals some protection from hunting and allowed a certain population increase. However, large takes in a few ice-free years in 2005 and 2006, likely reduced the population again and in 2010, the catch was officially stopped (Rosing-Asvid 2010). The catch records from the NAMMCO database in Figure 22b only go back to 2011, but do show some catches occurring after 2010, possibly due to problems with species identification during the hunt. In West Greenland, 69 harbour seals were reported caught in 2011 (NAMMCO catch database not shown), but it is unclear, if these are from the same population as the harbour seals in East Greenland.

Ringed seals are the most frequently hunted marine mammal by local East Greenland hunters (Figure 22a). This hunt is not quota-regulated and levels of reported annual catches have varied from 13,000-16,000 over the period 1945-2006 to 7000-8000 since 2007. The reason for this decline is not clear. There is no information on trends in abundance for ringed seals in East Greenland an only a single point estimate of 28,000 seals in the King Oscars Fjord area in 1984 (Born *el al.* 1998). Using the density of ringed seals in this area as a guideline for other areas, a total population of about 100,000-200,000 ringed seals has been suggested for East Greenland waters (Rosing-Asvid 2020 in prep.). With an estimated maximum growth rate of 12% in pinnipeds (Wade 1998), it appears that the hunt could be a significant regulatory factor for this population.

Polar bears in East Greenland are considered a separate subpopulation due to limited exchange with other subpopulations according to data on movement of tagged animals (Wiig 1995, Wiig *el al.* 2003, Boertman and Mosbech 2011, Laidre *el al.* 2013). Interviews with local hunters suggest that the occurrence of polar bears near settlements has increased in recent years (Laidre *el al.* 2018), possibly indicating an increase in abundance or a change in distribution pattern.

In a long historical perspective, probably the most conspicuous hunting mediated decline in the North Atlantic is the near extermination of bowhead whales. Large numbers of bowhead whales were also hunted off East Greenland in the 19th century, particularly in the so called "Southern Whaling ground" around 70-75.5 ° N (Lydersen *el al.* 2012), which is thought to be an important summering (and nursing) ground for bowhead whales belonging to a larger stock distributed from East Greenland to Franz Josef land. This stock may have numbered up to 100,000 whales prior to the start of the Spitsbergen bowhead whaling period in the 17th century (Allen and Keay 2006). When the Atlantic bowhead whaling was stopped in 1911, the East Greenland-Spitsbergen bowhead stock was considered almost extinct (Boertman *el al.* 2015). It is possible, however, that the number of surviving whales was somewhat larger than estimated due to natural protection of whales inhabiting ice-covered areas and inaccessible polynyas such as the NEW. Since the 1990s, the number of sightings have, increased (Wiig *el al.* 2010) and in 2009 a survey conducted in the NEW polynya resulted in a population estimate of more than 100 individuals (Boertman *el al.* 2015). Another survey to the North of Svalbard in 2015 also registered sightings consistent with a population in the low hundreds (Vacquie-Garcia *el al.* 2017b). It is unclear, whether the apparent increase in sightings of bowhead whales in the East Greenland and Svalbard area is due to recovery of the original local population or recent immigration of animals from the Northwest Atlantic or the Pacific (Wiig *el al.* 2010). Low global phylogeographic genetic substructuring suggest extensive circumpolar connectivity in the past (Foote *el al.*2013b).

Balaenopterids like blue, fin and humpback whales were also severely depleted by hunting in the North Atlantic from the latter half of the 19th century to the end of the hunt around 1955 (e.g. Pike *el al.* 2020). Some of the hunting operations likely occurred in East Greenland waters, but

during the cold period prior to the 1920s, the East Greenland shelf was likely covered by ice during most of the summer (e.g. Divine and Dick, 2006). Balaenopterids occurring in these areas are therefore unlikely to be distinct local stocks. Over the past decades, a remarkable recovery has been observed for North Atlantic fin and humpback whales almost to pre whaling levels, while blue whales have shown a much slower recovery (Pike *el al.*, 2020).

4.5 Effects of physical and biological environmental changes

Reduction in the spatial and seasonal ice extent in the Greenland Sea affects all the marine mammals in the area. For the pack ice breeding seals, ice has so far always been available during the breeding and moulting period (e.g. Strong 2012, ICES 2019), but the historically preferred whelping location "Odden" to the North of Jan Mayen has almost ceased to form over the past decades (Wilkinson and Wadhams, 2005). In this area, sea ice was primarily formed in situ and movement was mainly wind-driven (Wilkinsson, 2006). Frequently changing wind directions as well as the physical barrier of the island Jan Mayen appears to have maintained individual ice floes in the area for several weeks during the spring breeding period (Wilkinson, 2006). With the ice edge now generally situated in the East Greenland current, southward drift and melting is likely to be faster, forcing the seals to work harder to maintain their position on a stable platform. This could be a problem both during lactation, moulting and the period of first independent feeding of weaned pups. For Greenland Sea harp seals, the general retreat of the summer ice edge, also increases the distance to previously known feeding areas along the ice edge around Svalbard and eastwards (Folkow *el al.* 2004).

Hooded seals are less ice associated during the feeding period than harp seals, but increased energetic costs during breeding and moulting in a more unstable ice habitat could have contributed to the lack of recovery for the Greenland Sea population (Øigård *el al.* 2014). In addition, reduced ice extent appears to have increased their exposure to polar bear predation (McKinney *el al.* 2013).

Narwhals and bowhead whales are also likely to be negatively affected by a warming climate (Kovacs *el al.* 2020, Louis *el al.*2020). Both species show high affinity to ice and appear to select waters <2 °C (Kovacs *el al.* 2020, Louis *el al.*2020), possibly due to problems with overheating of highly blubber insulated bodies (e.g. Kovacs *el al.* 2020, Louis *el al.*2020). Studies from the northwest Atlantic furthermore show that avoidance of killer whales can be a strong driver of habitat selection in both narwhals (Breed *el al.* 2016) and bowheads (Matthews *el al.* 2020). Northwest Atlantic bowhead whales are more likely to seek dense sea ice concentrations and remain closer to shore, when killer whales are near (Matthews *et al.* 2020). There are no similar studies in the Northeast Atlantic, but data from several tracked animals suggest a very high affinity to ice covered areas (Kovacs *el al.* 2020). There are, however, no reports of killer whale attacks on bowheads in the Northeast Atlantic. It cannot be excluded that some of the bowhead whales recently observed in the Northeast Atlantic have immigrated from adjacent ocean basins (Foote *el al.* 2013b). Weak genetic substructuring among bowhead aggregations across the circumpolar area suggest a high level of gene flow (Foote *el al.* 2013b), which has likely been facilitated by periods of reduced ice cover in the central arctic ocean such as the early Holocene and the past decades (Polyak *el al.* 2010).

Narwhals are generally expected to occur in cold but ice-free waters during summer (Heide-Jørgensen *el al.* 2015). However, recent surveys have shown that at least ~800 narwhals inhabit

the pack ice in Nansen basin of the Central Arctic Ocean during summer (Vacquie-Garcia *el al.* 2017b). Passive acoustic monitoring has also shown narwhal year-round presence in the ice covered western Fram strait (Ahonen *el al.* 2019). The genetic affiliation of these ice associated narwhale groups is not known. Mitogenetic analyses of narwhals summering in coastal areas of East Greenland show significant differences with most samples from the Northwest Atlantic as well as Svalbard (Louis *el al.* 2020). Overall, narwhals are characterized by very low genetic diversity, which has likely been maintained over long periods of their evolutionary history (Westbury *el al.*2019). A threefold increase in effective population size is, however, estimated to have occurred at the start of the Holocene in response to deglaciation (Louis *el al.*2020). According to Polyak *el al.* (2010) ice conditions around Greenland during this period were similar to conditions in recent decades. Future climate scenarios are, however, predicted to reduce suitable narwhal habitat by 25 % (Louis *el al.* 2020). The ability of narwhals to reach the present global abundance of about 170,000 individuals (Lowry *el al.* 2017) despite of very low genetic diversity suggests that deleterious mutations have largely been purged (Louis *el al.* 2020). Low genetic diversity may, however, limit the scope for future adaptability (Westbury *el al.* 2019).

For both narwhals and bowheads, avoidance of prey competition with more cosmopolitan baleen whales could also drive habitat selection (e.g. Laidre and Heide-Jørgensen 2012, Heide-Jørgensen *el al.* 2020 in prep.). Narwhals are known to feed primarily in winter, but even then, humpback whales are present in considerable numbers in the Denmark Strait area. The collapse of the Icelandic capelin population and increased competition with other species could therefore have played a role in the recent decline in narwhal numbers in southeast Greenland. There is as yet no indication of a recent decline in the abundance of bowhead whales in the Northeast Atlantic (Vacquie-Garcia *el al.* 2017b, De Boer *el al.* 2019). It has been argued that some degree of warming may have had a positive impact on population growth of bowhead whales due to increased access to shelf areas and increased upwelling and primary productivity (Foote *el al.* 2013b, Falch-Petersen *el al.* 2015, George *el al.* 2015). However, modelling of future climate scenarios has suggested a significant reduction in suitable bowhead habitat of about 50% by 2100 (Kovacs *el al.* 2020).

Reduction of ice cover along the East Greenland coast, has opened new habitats to several cosmopolitan species (e.g. Hansen *el al.* 2018, Heide-Jørgensen *el al.* 2020 in prep.), but in the case of humpback whales and minke whales, the overall occurrence of these species in the central Atlantic appears to have declined in recent years (Pike *el al.* 2019). The reason for this is unknown, but it could be related to the reduction in abundance of Icelandic capelin. In contrast, the fin whale population may have increased (Pike *el al.* 2019), possibly related to increased strength of the subpolar gyre, pumping up nutrients to the Irminger Sea primary producers and hence increasing the food base for krill (Hatun *el al.*2016, Hatun *el al.* 2017). Mackerel in the same area feed mainly on copepods and are therefore not likely to compete strongly with fin whales (Kvåvik *el al.* 2019). Ice independent species like killer whales, white-beaked dolphins, harbour porpoises and harbour seals may respond positively to warming due to increased feeding habitat and primary production. This effect may, however, to some extent be countered by increased hunting mortality (Figure 22c) due to closer contact with settlements. Although not reflected in Figure 22c, this appears to have been the case for harbour seals (Rosing-Asvid *el al.* 2010) and concern has also been raised regarding huntning of killer whales in East Greenland settlements (Jourdain *el al.* 2019).

4.6 Effects of contaminants

Toothed whales are particularly prone to accumulation of high levels of chemical pollutants due to their high trophic level and low capacity for contaminant metabolization (Boon *el al.* 1997). In spite of a ban on PCB since the 1980s, PCB levels are still above threshold levels for immunological effects (9 mg/kg lipid) and reproductive effects (41 mg/kg lipid) in several odontocetes in the North Atlantic and elsewhere (e.g. Jepson *el al.* 2016, Desforges *el al.* 2018, Dietz *el al.* 2019). Based on observed PCB values of up to around 100 mg/Kg lipid weight, Desforges *el al.* (2018) argued that the East Greenland killer whales like several other killer whale populations are likely to go extinct within 100 years. Other studies have disputed this and argue that the chosen baseline population growth rates are set too low (e.g. Witting, 2018).

There are no data on PCBs for East Greenland narwhals, but levels in Svalbard are well below standard threshold levels for reproductive effects (Wolkers *el al.* 2006, Dietz *el al.* 2019). Mercury levels in East Greenland narwhals exceed the threshold for potential neurological effects and mild liver and kidney pathologies in some animals (Dietz *el al.*, 2019). Overall, however, mercury levels in East Greenland narwhals are lower than in the Northwest Atlantic, where the species is doing very well (Dietz *el al.* 2019). Contaminants are not thought to play a major role in the observed decline in narwhal occurrence in East Greenland (NAMMCO, 2019).

While levels of PCB in East Greenland polar bears have decreased over the last 30 years, levels of brominated pollutants have increased (Mckinney *el al.*, 2013). Several studies suggest that the recent levels of persistent organic pollutants and mercury are contributing to subclinical reproductive and immune related health effects in East Greenland polar bears (Sonne 2010, Dietz *el al.* 2018).

Levels of PCB and several other persistent organic pollutants samples from Greenland Sea hooded seals collected in 2008 were below threshold levels for reproductive and immune effects (Villanger *el al.*, 2013), but caused some concern for pup health (Villanger *el al.*, 2013). Contaminant loads in harp and ringed seals from the Greenland Sea are significantly lower than for hooded seals (Espeland *el al.*, 1997, Soulen *el al.* 2018).

No data on contaminant levels are available for East Greenland bowhead whales, but studies from other areas show that contaminant levels in baleen whales feeding on lower trophic levels are generally too low to cause concern for significant health effects to these animals (O'Shea and Brownell. 1994, O'Hara *el al.* 1999, Bolton *el al.* 2020, Tartu *el al.* 2020). However, due to large body size and late age at maturity in bowhead whales, maternal off-loading of contaminants to the first calf could potentially be of concern, but there is currently no available data on this (O'Shea and Brownell. 1994, Elfes *el al.* 2010).

4.7 Anthropogenic noise

Passive acoustic monitoring data for the Fram Strait are available over the period 2008-2014 and suggest a rather pristine acoustic environment except for some noise from shipping and (distant) seismic airgun noise in summer (Ahonen *el al.* 2017, Hiemer *el al.* 2020). These low frequency sounds may mask the vocalizations of baleen whales, but the seasonal occurrence in the Fram Strait is out of phase with the main baleen whale vocal activity in the area, which occurs during winter. The western Fram Strait in particular, seems to be a favoured area for bowhead singing displays and likely mating during the period November to March (Ahonen *el al.* 2017). Fin whale singing is also heard in this area and humpback whale singing is heard closer to Iceland (Magnusdottir *el al.* 2014). Baleen whales exposed to seismic airgun noise during the mating season

have been found to avoid ensonified areas (e.g. Castellote *el al.* 2012) or to modify vocalizations with respect to one or more characteristics like call rate, frequency and sound levels (e.g. Blackwell *el al.* 2015, Castellote *el al.* 2012, Di Iorio and Clark 2009, Fouda *el al.* 2018). Blue whales are the only baleen whales vocalizing during summer in the Fram Strait (Ahonen *el al.* 2017). In the Saint Lawrence estuary, blue whales exposed to seismic airgun noise have been found to increase the calling rate to overcome the masking effect (Di Iorio and Clark, 2009), suggesting high importance of vocalizations in feeding aggregations of blue whales. Exposure to low frequency anthropogenic noise has also been shown to increase the levels of stress hormones in baleen whales even in the absence of clear behavioural responses (e.g. Rolland *el al.* 2012).

Seals and walruses also have good low frequency hearing and parts of their vocalization repertoire falls below 1 kHz and may thus be masked by low frequency anthropogenic noise (Southall *el al.* 2019). Bearded seal calls were recorded by hydrophones in the Fram Strait from March to June coinciding with the mating period (Ahonen *el al.* 2017). Underwater vocal displays are also part of the mating displays by harp, ringed and harbor seals (Perry and Terhune 1999, Van Parijs *el al.* 1999, Van Parijs *el al.* 2006). Arctic pinnipeds are mainly found to vocalize during the ice-covered season with a peak in the breeding season, which is generally in spring (e.g. Stirling *el al.* 1983, Jones *el al.* 2014).

Toothed whales produce sound both for orientation and communication, but in a higher frequency range, which is not subject to direct masking by low frequency anthropogenic noise. They do, however, often respond behaviourally to this type of noise. Hence, Kavanagh *el al.* (2019) found that toothed whales off western Ireland increased submersion times at changed distribution in response to seismic operations. Several cases of distribution shifts in narwhals and belugas have also been linked with exposure to seismic airgun noise (Heide-Jørgensen *el al.* 2013, Harwood and Kingsley 2013, Ahonen *el al.* 2019, Kyhn *el al.* 2019) as well as much weaker sound exposures from icebreakers and seem to particularly sensitive (Finley *el al.* 1990) to acoustic disturbance. Narwhals general choice of coastal summering habitats may to some extent protect them from anthropogenic noise due to attenuation in shallow waters and deflection by skerries and islands (Blackwell *el al.* 2018, Kyhn *el al.* 2019). However, narwhals in the Fram Strait and adjacent Nansen basin area spend the entire year in deep offshore waters and may thus be more vulnerable to far travelling low frequency noise (Ahonen *el al.* 2019). Ongoing research in northeast Greenland aims to increase understanding of the sensitivity of this species to anthropogenic noise including planned seismic explorations off Northeast Greenland.

In contrast to cetaceans, pinnipeds do not appear to increase submersion times in the vicinity of seismic operations (Harris *el al.* 2001). This has been interpreted as tolerance to noise, but Kvadsheim *el al.* (2010) suggest another possibility. Captive hooded seals exposed to midfrequency sonar initially responded with a clear stress reaction including increased heart rate and swimming away from the sound with the head out of the water. Upon later exposures, the main response was to stay at the surface with the head out of the water. This may be interpreted as a lack of negative effects effect but could imply reduced foraging success of the seals. It is of high importance to determine whether the general high visibility of seals in the vicinity of seismic surveys is due to tolerance or stress (Kyhn *el al.* 2019).

Effects of military midfrequency sonars on cetaceans have been investigated over the past decade in the Northeast Atlantic (Kvadsheim *el al.* 2020). Analyses of movement patterns before, during and after experimental exposures in the Norwegian sea area have shown particularly low

threshold levels in northern Bottlenose whales (Wensveen *el al.* 2019), minke whales (Kvadsheim *el al.* 2017), killer whales (Miller *el al.* 2012) and harbor porpoises (Tougård *el al.* 2015), while pilot whales, humpback whales and sperm whales were less sensitive (Antunes *el al.* 2014, Miller *el al.* 2012, Sivle *el al.* 2015). In contrast to responses to seismic airgun noise, the general response to military sonars was to stay close to the surface while moving away from the sound source, as also observed for hooded seals. In longfinned pilot whales, evasive behavior lasted only for as long as the exposure itself (Antunes *el al.*, 2014), while other species avoided the exposed habitat for several hours after the end of exposure – up to more than 24 hours in bottlenose whales, during which time the animals did not appear to feed (Miller *el al.*, 2015). The reaction in bottlenose whales also differed from the other species by involving abrupt and very deep escape dives, which may increase the risk of symptoms similar to "the bends" (Kvadsheim *el al.*, 2012). A similar strong panic reaction has been observed in narwhals after handling during tagging (Williams *el al.* 2017), but no data are available on dive patterns during exposure to sonar or other types of anthropogenic noise.

Generally, cetaceans appear to be more tolerant of anthropogenic noise, when they are feeding (e.g. Koski *el al.*2009) than when they are travelling (Richardsson *el al.* 1999). Studies in the Pacific have, however, suggested that exposure to military sonars and artificial low frequency noise may reduce lunge feeding rates in large baleen whales (Goldbogen *el al.* 2013, Friedlaender *el al.* 2016). More recent studies, have not found any change in lunge feeding rates in fin and blue whales in response to sonar exposure (Harris *el al.* 2019). These discrepancies could be due to modifying effects of environmental cofactors (Friedlaender *el al.* 2016) or to habituation. Sivle *et al.* (2016) reported likely habituation of rorquals to military sonars (e.g. Sivle *el al.* 2016). This may also have affected the reported behavior of blue and fin whales by Harris *el al.* (2019), since all were studied within a naval exercise area.

Table 2. Estimated consumption in the Greenland Sea by seals.

Species	**Period** **Numbers** **(Trend)**	**Consumption/day** **Consumption/yr.** **(Consumption as % of total)**	**Main prey species**	**Consumption divided by species** N. C. S. = Non commercial species V. F. S. = Valuable fish species
Harp seal	Mar-Jul (80%) ***340.000	** ~1.5 kg 80.000 ton	*Themisto sp. 50 % *Gonatus fabricii) 20 % *Ammodytes sp 10 % * Polar cod 10 % * Others 10 %	*Themisto sp. 40.000 ton *Gonatus fabricii) 16.000 ton *Ammodytes sp 8.000 ton *Polar cod 8.000 ton * Others 8.000 ton
Harp seal	Aug-Feb (20%) ***85.000	** ~3.5 kg 60.000 ton	unknown	Others 60.000 ton

Hooded seal	Average all year ***20.000	** 4kg/day 30.000 ton	*Gonatus fabricii) 50 % * Polar cod 30 % *Themisto sp. 10 % *Ammodytes sp 10 %	*Gonatus fabricii) 15.000 ton * Polar cod 9.000 ton *Themisto sp. 3.000 ton *Ammodytes sp 3.000 ton
Ringed seal	All year *100-200.000	** ~ 2 kg/day 80-160.000 ton	***Polar cod 50 % ***Themisto) 30 % * N.C.S. 20 % (ex. Stichaeidae sp Liparis sp. Thysanoessa inermis	Polar cod 40-80.000 ton Themisto 25-50.000 ton N.C.S. 15-30.000 ton
Bearded seal	All year *10-20.000	** ~ 5 kg/day 20-40.000 ton	*Polar cod 50 % *Various inverte-brates and fish 50 %	Polar cod 10-20.000 ton Others 10-20.000 ton
Total		270-370.000 ton		Ammodytes sp 11.000 ton Gonatus fabricii) 31.000 ton Others 78-88.000 ton Themisto sp. 68-93.000 ton Polar cod 67-117.000 ton

Data quality: **** = Good *** = Fair **= Estimate * = Very uncertain estimate

5 Marine birds

5.1 Breeding seabirds

All the seabird species depends on open water for foraging and for some species also for protection during breeding, why ice cover is a limiting factor. For many species breeding is concentrated near the polynyas while other species are dispersed along the coasts, especially where there is early tidal driven open water. A few species have extremely long foraging ranges (ivory gull and fulmar) and can breed far from open water.

A status of knowledge on breeding colonial seabirds in East Greenland was published recently (Boertmann *el al.* 2020a). This was based on aerial surveys (Merkel *el al.* 2010, Boertmann & Nielsen 2009, Boertmann *el al.* 2010) on ship based surveys (Boertmann & Rosing-Asvid 2014, 2017) and the efforts of the French GREA-expeditions 2004-2015. The conclusion was that in total 799 breeding sites for seventeen colonial seabird species are known (Table 3).

The most significant polynya with regards to breeding seabirds is at the mouth of Scoresby Sound, where millions of little auk breed and where the only colonies (n = 2) with thick-billed murres are found. The Northeast Water Polynya have much less seabirds (Falk *el al.* 1997), with species such as northern fulmar, common eider, black-legged kittiwake, ivory gull and Sabines gull.

Species breeding widespread along the coasts include glaucous gull, Arctic tern, common eider and black guillemot, the latter only in Southeast Greenland.

Seabirds breeding solitary or species utilizing the marine environment for feeding, while breeding inland include mallard, king eider, long-tailed duck, red-breasted merganser, red-throated diver and great northern diver.

In recent decades two birdspecies have immigrated to Southeast Greenland: great cormorant and lesser black-backed gull, and at least common eider have expanded the breeding range more than 200 km towards north, indicating climate change impacts on the breeding populations of seabirds in East Greenland.

5.2 Non-breeding coastal seabirds

Non-breeding seabirds in summer comprise mainly moulting seaducks such as common eider, king eider and long-tailed duck. Moulting seaducks were surveyed from aircraft in 2008 (Boertmann *el al.* 2009, Merkel *el al.* 2010) and in 2009 (Boertmann & Nielsen 2010). No large moulting concentrations were located, but moulting common eiders were found scattered along most of the coasts, while long-tailed ducks were more located. Moulting king eiders were only found at a single site on the Blosseville Coast.

In spring, high concentrations of common eiders have been recorded along the coasts of the larger polynyas, while large numbers of king eiders were found in the Northeast Water (Boertmann *el al.* 2009).

In winter, common eiders, glaucous gulls and black guillemots are known to occur in open waters along the coast in Southeast Greenland, while very few, if any, are present further north (Boertmann 1994).

5.3 Seabirds-at-sea

Mehlum (1989) surveyed the waters between Svalbard and Greenland in summer. In the early 1990s extensive studies were carried out in the Northeast Water Polynya, including bird studies (Falk *el al.* 1997, Joiris *el al.* 1997), and Joiris have published observations from several expeditions with RV Polarstern, e.g. Joiris (2016). However, reports from the migration periods and the winter are very few (e.g. Hjort 1976, Brown 1984, Petersen 1995, Byrkjedal & Madsen 2008). This lack of knowledge was addressed in August/September 2017 when several bird studies were carried out in the assessment area as a part of the *Strategic Environmental Study Program for Northeast Greenland* carried out in 2016-2019. Seabird abundance off Northeast Greenland was then surveyed both from ship and aircraft in autumn 2017 (Boertmann *el al.* 2019, 2020b, Møller *el al.* 2019).

The general picture is that the offshore densities of seabirds are low, with black-legged kittiwake and northern fulmar as the most numereous species. There are however high density areas for example near the large breeding colonies at Scoresby Sound.

The surveys in autumn 2017 revealed that thick-billed murres from Svalbard migrated east of the shelf break, a pattern which is consistent with the tracking results of murres from Svalbard (http://www.seapop.no/en/seatrack/).

The surveys also showed that little auks were distributed throughout the Northeast Greenland shelf in low densities, and that here were high density areas at the shelfbreak. Mosbech *el al.* 2012 tracked little auks from breeding sites at the Scoresby Sound Polynya to these areas and supposed that the birds at these sites were performing post-breeding moult.

The Norwegian Seatrack data (http://www.seapop.no/en/seatrack/) also indicate that little auks, northern fulmars and black-legged kittiwakes from Svalbard and Bjørnøya occur in these areas in autumn.

The results of the 2017 surveys indicate that at least parts of the shelf break off Northeast Greenland is important to seabirds during the migration time and probably also to non-breeding seabirds in summer.

There is very little information available on offshore abundance of seabirds off Southeast Greenland. A survey in October 2013 indicated that there were very few seabirds in the cold polar water of the East Greenland Current, while the warmer Atlantic water closer to the coast may hold more birds in the autumn migration period (Boertmann 2014).

There is almost no information on seabird abundance off East Greenland in winter. The only survey published is Brown (1984), but this took place mainly outside the Greenland EEZ. But the Norwegian SEATRACK-data indicate the several species winter off Southeast Greenland (http://www.seapop.no/en/seatrack/), and tracking of ivory gulls have revealed that they have an important winter area there (Gilg *el al.* 2010).

Table 3. Population status of colonial seabird species breeding in East Greenland (Boertmann *el al.* 2020).

Species	North and East
Northern Fulmar	2000
Great Cormorant	30
Common Eider	16 000
Arctic Skua	200
Sabine's Gull	500
Lesser Black-Backed Gull	60
Iceland Gull	1000
Glaucous Gull	3020
Great Black-backed Gull	20
Ross's Gull	1
Black-legged Kittiwake	4800
Ivory Gull	2000
Arctic Tern	12 000
Thick-billed Murre	4300
Black Guillemot	10 000
Little Auk	3 500 000
Atlantic Puffin	5
Total number	3 555 936

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Annex 1: List of participants and observers

Name	Institute	Country (of institute)	E-mail
Colin Stedmon	Technical University of Denmark, DTU AQua	Denmark	cost@aqua.dtu.dk
Jesper Boje	Technical University of Denmark, DTU AQua	Denmark	jbo@aqua.dtu.dk
Helle Torp Christensen	Greenland Institute of Natural Resources	Greenland	htch@natur.gl
Adriana Nogueira	Greenland Institute of Natural Resources	Greenland	adno@natur.gl
Mie S Winding	Greenland Institute of Natural Resources	Greenland	miwi@natur.gl
Steingrimur Jónsson	University of Akureyri	Iceland	steing@unak.is
Eva Friis Møller	University of Aarhus	Denmark	hiroko.solvang@hi.no
Mikael Sejr	University of Aarhus	Denmark	cecilieb@hi.no
Anders Mosbech	University of Aarhus	Denmark	amo@bios.au.dk
Søren Post	Greenland Institute of Natural Resources	Greenland	Sopo@natur.gl
Peter Munk	Technical University of Denmark, DTU AQua	Denmark	pm@aqua.dtu.dk
Margrete Emblemsvåg	Møreforsking	Norway	margrete.emblemsvag@moreforsk.no
Jørgen Schou Christiansen	University of Tromsø	Norway	jorgen.s.christiansen@uit.no
Anne Kirstine Frie*	Institute of Marine Research	Norway	Anne.kirstine@hi.no
Aqqalu Asvid-Rosing*	Greenland Institute of Natural Resources	Greenland	aqro@natur.gl
Thomas Juul Pedersen*	Greenland Institute of Natural Resources	Greenland	thpe@natur.gl
Martin Blicher*	Greenland Institute of Natural Resources	Greenland	mabl@natur.gl

*Participated by correspondence