10.1 Greenland Sea ecoregion – Ecosystem overview

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Ecoregion description

The Greenland Sea ecoregion follows the Greenland Exclusive Economic Zone (EEZ) definition and comprises the continental shelf waters and offshore areas. The Denmark Strait between Iceland and Greenland separates the ecoregion into a northern and southern subregion that differ with respect to ice coverage, influence of polar and Atlantic waters, and anthropogenic activity. The ecoregion borders five other ecoregions (Oceanic Northeast Atlantic, Icelandic Waters, Norwegian Sea, Barents Sea, and Arctic Ocean) and also the West Greenland waters (Figure 1).

- The northern subregion: This subregion is characterized by cold and fresh polar waters, a broad continental shelf, year-round sea ice, and little anthropogenic activity.
- The southern subregion: This subregion is characterized by warmer and more saline waters, a narrow continental shelf, seasonal drift ice, and activities of demersal and pelagic fisheries.

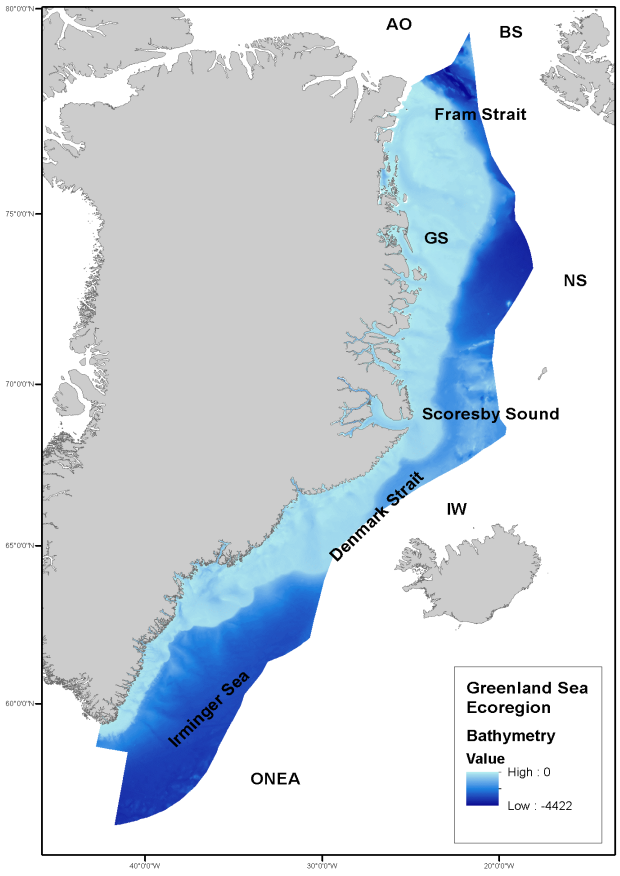

Figure 1 The Greenland Sea ecoregion. The northern ICES ecoregions are outlined in black: AO (Arctic Ocean), GS (Greenland Sea), BS (Barents Sea), NS (Norwegian Sea), IW (Icelandic Waters), ONEA (Oceanic Northeast Atlantic), and West Greenland waters.

Oceanography

The northern subregion is greatly influenced by cold and fresher polar waters from the East Greenland Current (EGC), which originates from the Arctic Ocean and covers a large part of the surface waters of the shelf (Figure 2). In the southern subregion the polar waters are constrained to a narrow coastal region on the shelf, which means that warmer and more saline Atlantic waters, originating from the Subtropical Gyre and transported by the Irminger Current (IC), are more prevalent in this subregion (Figure 2).

The ecoregion is dominated by an inflow of multi-year ice from the Central Arctic Ocean, with maximum coverage in March and minimum in September. The northern subregion has year-round sea ice, with nearly total to partial coverage in winter except for polynyas. In the southern subregion drift ice is seasonal (early spring), transported from the northern subregion in the East Greenland Current.

Much of the waters in the ecoregion are stratified shelf waters, with cold and fresher polar waters overlaying warmer and more saline Atlantic waters.

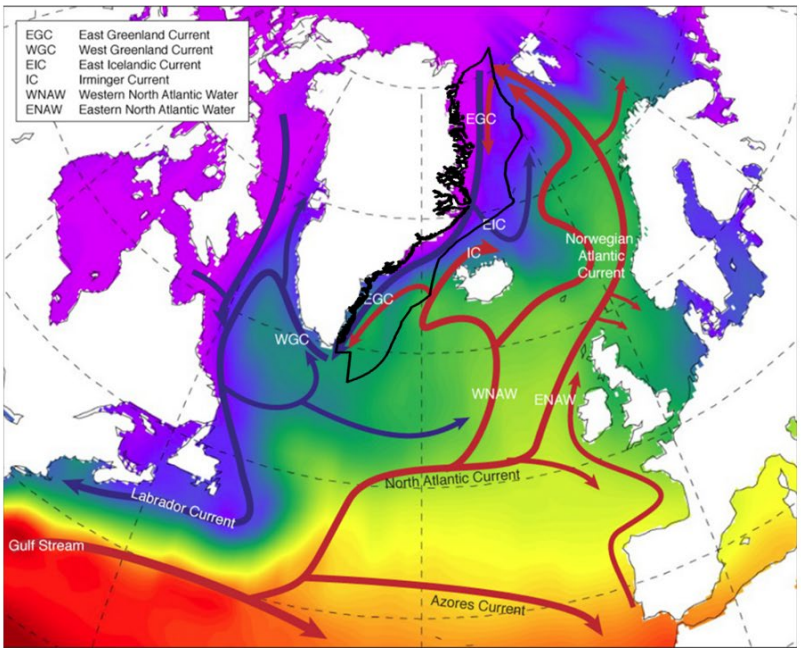

Figure 2 General pattern of surface ocean circulation in the ecoregion (0–1000 m). Blue arrows represent cold currents from the polar region and red arrows warm currents from the Subtropical Gyre (Gonzalez-Pola *et al.*, 2019).

Regulation of human activities

As the ecoregion is within the Greenland EEZ, the management of marine resources are under Greenlandic authority. Fisheries targeting widely-distributed fish stocks (e.g. herring (*Clupea harengus*), mackerel (*Scomber scombrus*), and capelin (*Mallotus villosus*)) are managed by NEAFC or coastal state agreements. The International Whaling Commission (IWC) has regulations for the conservation and harvesting of whales. Other mammals are covered by the North Atlantic Marine Mammal Commission (NAMMCO). International shipping is managed under the International Maritime Organization (IMO). The Greenland Government and the commissions that manage fish stocks and the environment obtain advice from ICES and OSPAR.

Key signals within the environment and the ecosystem

Climate change affects the entire ecoregion while fisheries remain the most important, direct pressure for the ecosystem. Sea ice coverage in the ecoregion has been diminishing in the several past decades, including a decrease in winter maximum sea ice extent since the start of satellite records in 1979, and a weak decline in summer minimum ice coverage since 2006.

There is evidence of changing surface water temperature and salinity throughout the ecoregion. Surface water temperature has increased by 1–2°C on the narrow southeastern Greenland shelf and in the northern subregion, while it has cooled by up to 2°C in the southeastern part of the ecoregion (relative to mean conditions for 1981–2010). Surface water salinity has been increasing in open waters of the ecoregion and decreasing in the East Greenland shelf waters and Irminger Sea.

Several taxa have shown distributional changes recently. These include:

- Inmigration of bluefin tuna (*Thunnus thynnus*), mackerel, and Norwegian spring-spawning herring have become regular visitors in the ecoregion in summer (June–September) during the last decade.
- There has been a westward distributional shift of capelin nursery and feeding grounds since the late 1990s into the ecoregion.
- At least two bird species have immigrated to the southern subregion during recent decades: great cormorant (*Phalacrocorax carbo*) and lesser black-backed gull (*Larus fuscus*).
- Expansion of the breeding areas of common eider (*Somateria mollissima*) over 200 km northwards.
- With the retreat of sea ice, recent years have shown an increase in sightings of cosmopolitan whale species, such as fin whales (*Balaenoptera physalus*) and humpback whales (*Megaptera novaeangliae*) on the shelf areas of the ecoregion.

Pressures

The remote location of the Greenland Sea ecoregion and its low population density allows for few human activities and associated pressures. Human activity occurs mostly in the southern subregion, linked to coastal and offshore fishing, and hunting in the coastal area. The most important pressures in the ecoregion are the selective extraction of species, abrasion, and introduction of contaminant compounds (Figure 3). Other pressures have very limited impact in this ecoregion, although data gaps exist because of limited research effort. Similarly, even for the most important pressures in the ecoregion, there is limited evidence of direct impacts of human activity on ecosystem state components such as productivity and plankton, though such impacts are known to occur elsewhere. The main pressures described below are defined in the ICES Technical Guidelines.

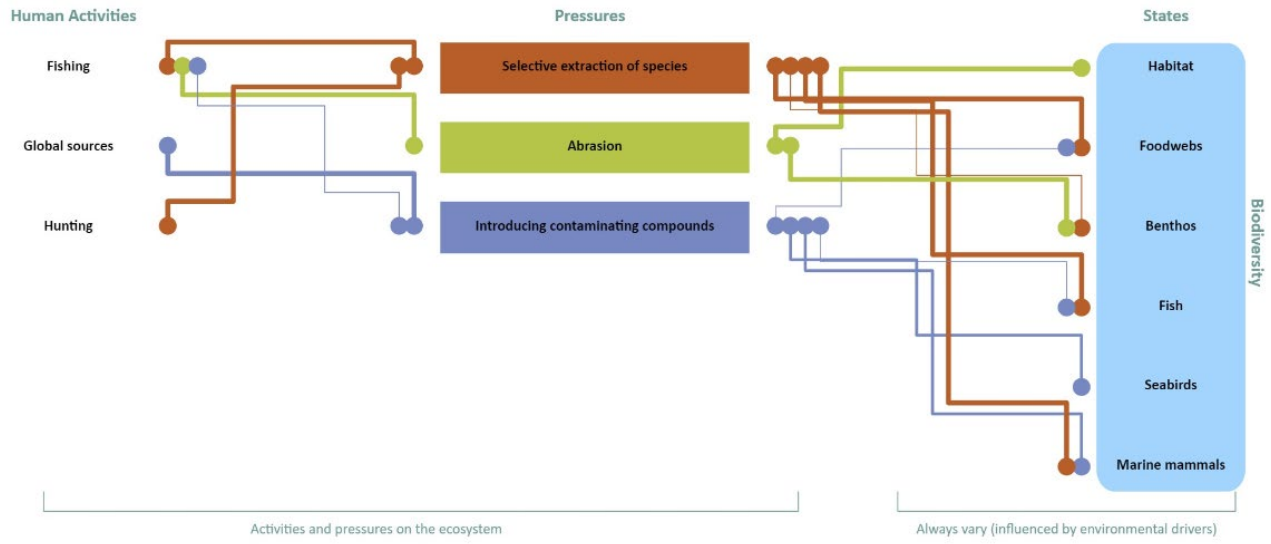

Figure 3 Greenland Sea ecoregion overview with the major regional pressures, human activities, and state of the ecosystem components. The width of lines indicates the relative importance of individual links (the scaled strength of pressures should be understood as a relevant strength between the human activities listed and not as an assessment of the actual pressure on the ecosystem). Climate change affects human activities, the intensity of the pressures, and some aspects of state, as well as the links between these.

Selective extraction of species (including non-target catch)

A multinational fishery currently operates in the ecoregion, using various fishing gears and targeting several species. Demersal fishing by Greenland and multinational fleets takes place mainly in the southern subregion. Most of this fishery is bottom trawling and only a minor part is longlining. The number of fishing vessels has declined over the past many decades, while the sizes of the vessels are increasing. The demersal fishery mainly operates on the slope at depths between 400 m and 100 m, and target species are northern shrimp (*Pandalus borealis*), golden redfish (*Sebastes norvegicus*) and beaked redfish (*Sebastes mentella*), cod (*Gadus morhua*), and Greenland halibut (*Reinhardtius hippoglossoides*) (Figure 6). Pelagic fisheries targeting mackerel, herring, and capelin are performed using mid-waters trawl or purse seining and are widespread in a north–south direction across the ecoregion. Mackerel is fished mainly in the southern subregion while herring and capelin are fished further north (Figure 4).

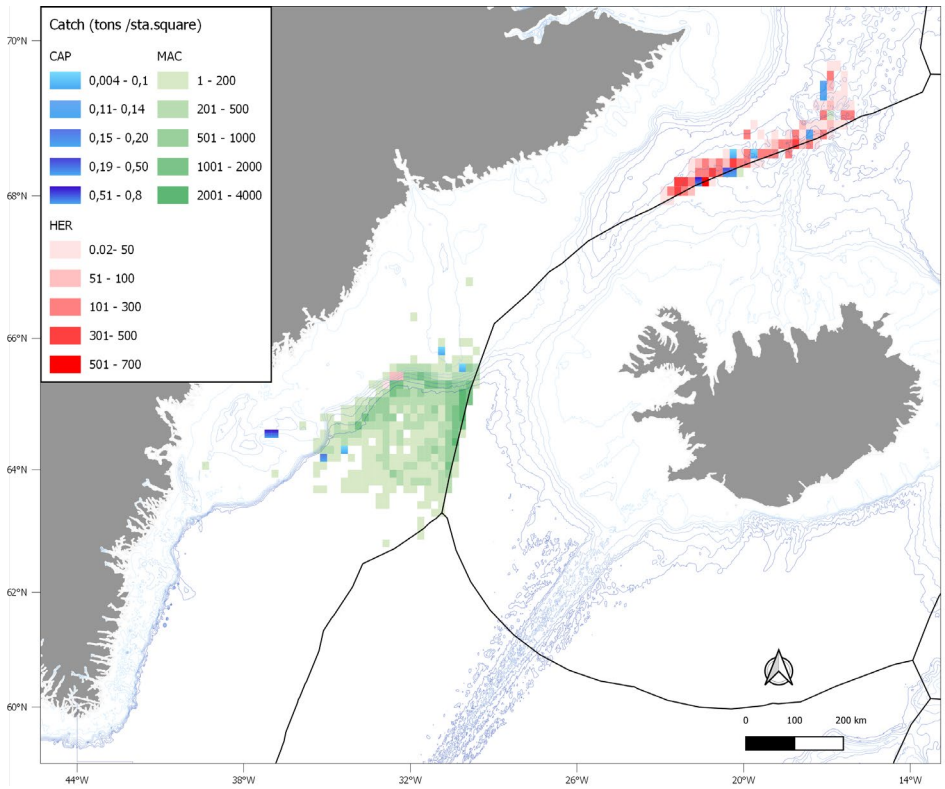

Figure 4 Fishing footprint of pelagic fisheries in 2017–2019 for capelin (CAP), mackerel (MAC), and herring (HER) within the Greenland Sea ecoregion.

The total annual catch in the ecoregion has varied between 67 000 tonnes to 203 000 tonnes in the last ten years, taken from the stocks of Northeast Atlantic (NEA) mackerel, Norwegian spring-spawning herring, cod, Greenland halibut, redfish (*Sebastes* spp.), northern shrimp, and capelin. The majority of these catches are pelagic species (68%). Fishing pressure for Greenland halibut and golden redfish has gradually decreased to a sustainable level around F_{MSY} (Figure 5). After a period around the 2000s with virtually no cod in the ecoregion, the stock was slowly rebuilt and in recent years the fishing pressure has increased to about F_{MSY}. Northern shrimp is of little commercial importance and catches are very low.

NEA mackerel and Atlanto-Scandian herring are mainly distributed in the Northeast Atlantic along the European continental shelf. Parts of these stocks migrate seasonally to the Greenland Sea ecoregion for feeding. Fishing pressure on these stocks has decreased in the last decade; however, for mackerel the harvest is still above sustainable levels (Figure 5).

Since the 1990s sorting grids have been mandatory in the shrimp fishery to avoid bycatch of juvenile fish and shrimp as well as bycatch of larger fish, sharks, and cetaceans. Areas closed to trawling have been in place to protect spawning concentrations of cod in order to rebuild the stock.

Sailray (*Rajella lintea*), common skate (*Dipturus batis*), leafscale gulper shark (*Centrophorus squamosus*), Portuguese dogfish (*Centroscymnus coelolepis*), and starry ray (*Amblyraja radiate*) have been bycaught in bottom-trawl fisheries in the ecoregion.

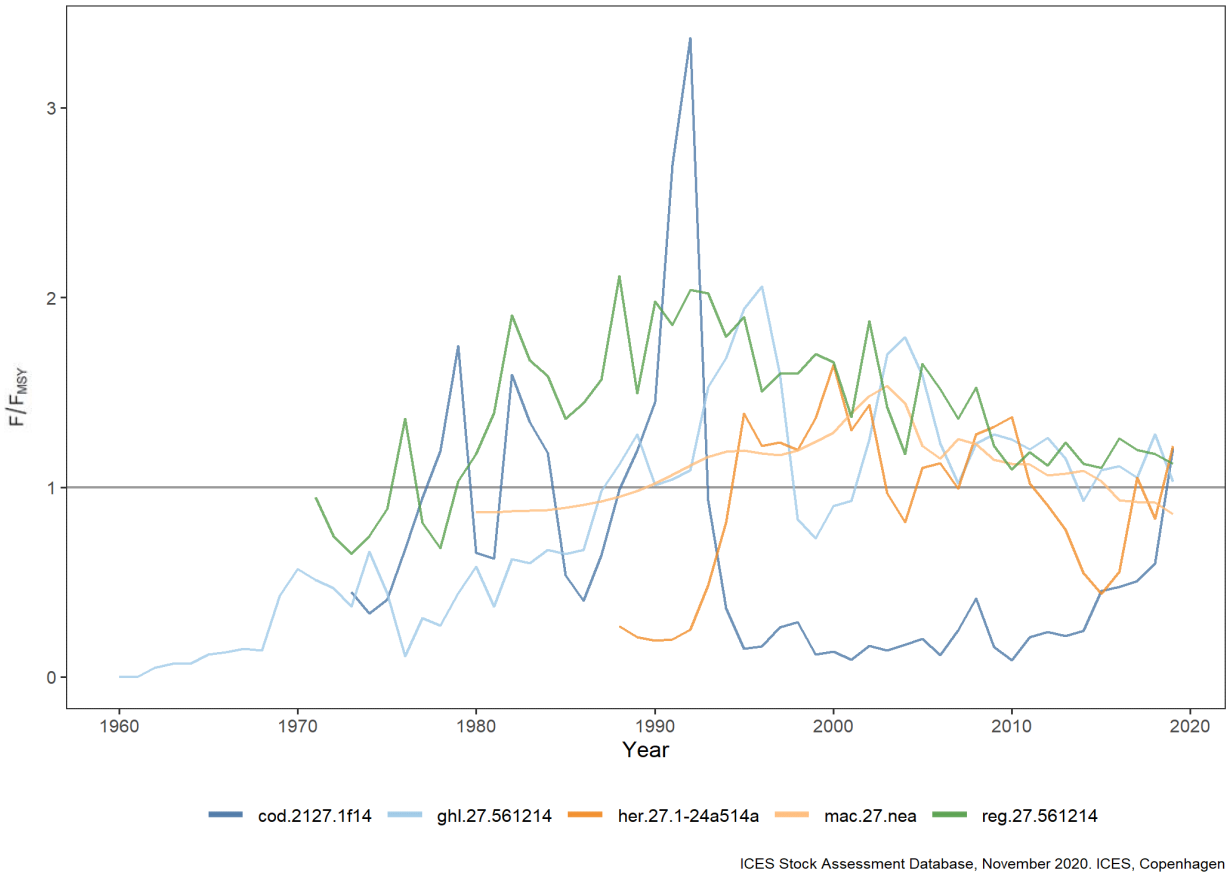

Figure 5 Time-series of relative fishing mortality (F to F_{MSY} ratio) for the main demersal fish species: cod (cod.2127.1f14), Greenland halibut (ghl.27.561214), golden redfish (reg.27.561214) and for the main pelagic fish species: NEA mackerel (mac.27.new) and Atlanto-Scandian herring (her.27.1-24a514a). . Table A1 in the Annex details Stocks with analytical assessments and guilds in the Greenland Sea ecoregion.

International commercial hunting of marine mammals before the 1960s had an extensive influence on populations, leading to drastic reductions in abundances. Based on current data, the hunting of seabirds and mammals is for local consumption and only occurs near the few settlements in East Greenland in the southern subregion. A small Norwegian commercial hunting for harp seals (*Pagophilus groenlandicus*) is still ongoing in the pack ice breeding areas off East Greenland (Greenland Sea and Norwegian Sea ecoregions). The area north of Scoresby Sound is a national park where hunting is prohibited.

Abrasion

Most demersal fisheries in the ecoregion are bottom-trawl fisheries. Abrasion by towed bottom-contacting gear causes damage and loss of potentially important benthic habitat. Figure 6 maps the effort by bottom trawlers in the recent decade (2009–2019) for the main targeted species. Mapping of benthic habitats is currently limited. Preliminary data indicate a high degree of overlap between the trawl footprint for cod and redfish and the habitats of corals and sponges (Figure 7).

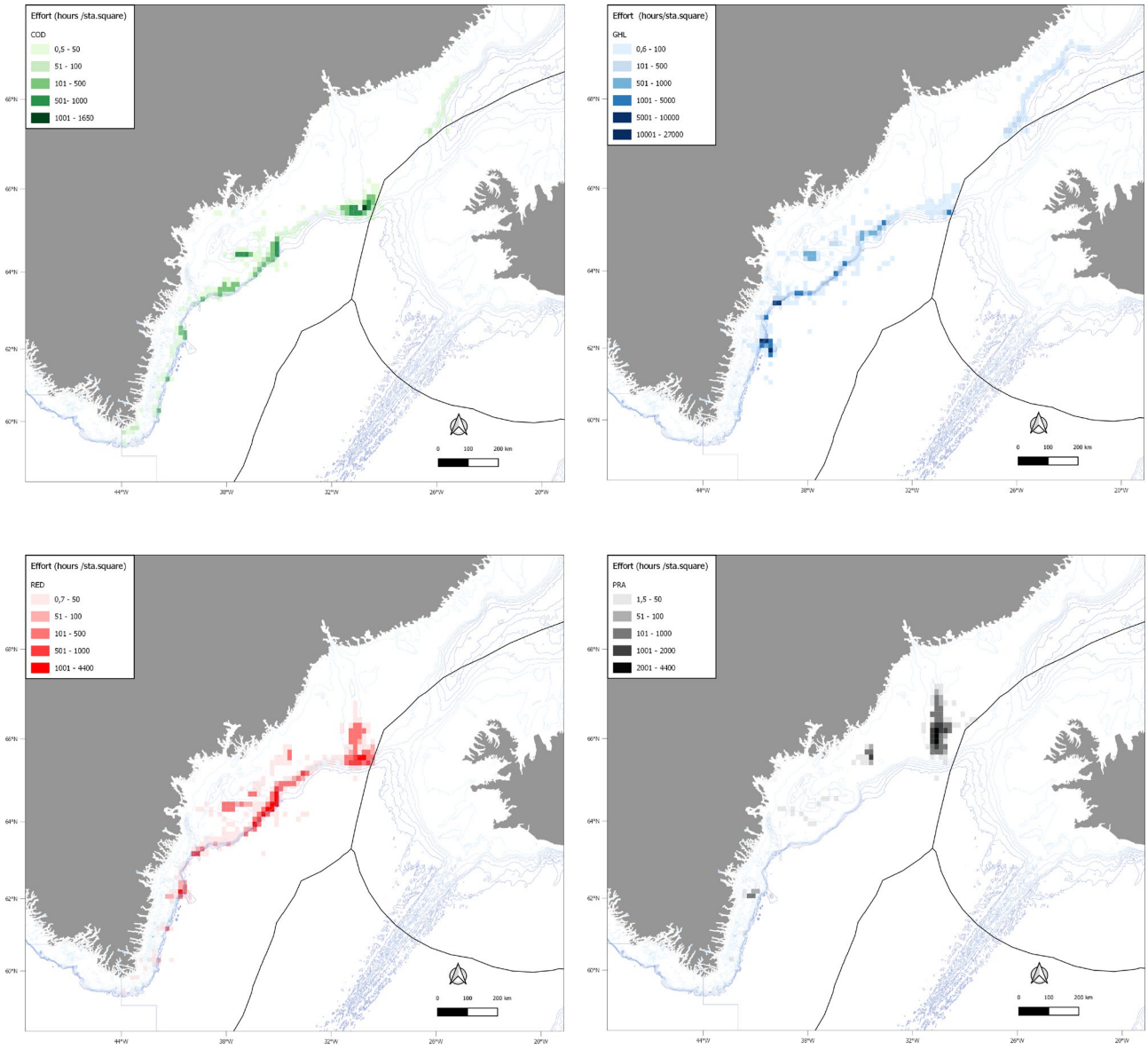

Figure 6 Bottom-trawling effort distribution in the last decade (2009–2019) for four demersal species. Upper panels: cod and Greenland halibut (GHL). Lower panels: redfish spp. (RED) and northern shrimp (PRA). The Greenland and Iceland EEZ borders are shown.

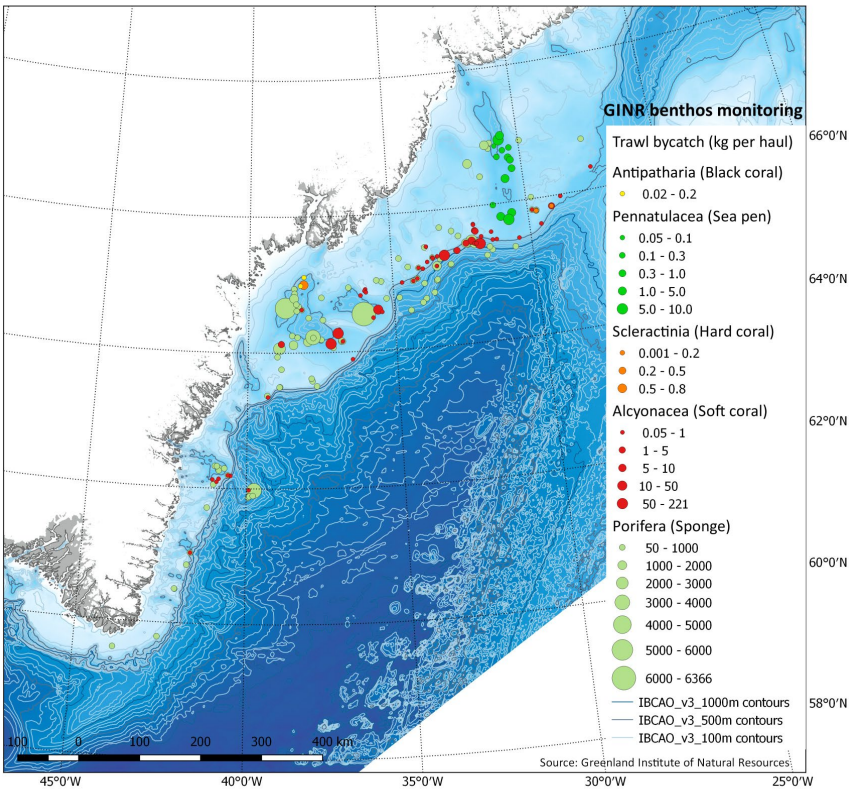

Figure 7 Overview of observations of corals and sponges collected as trawl bycatch on research surveys conducted by the Greenland Institute of Natural Resources (GINR) in East Greenland. Species-level information is stored in GINR's benthos database. Modified from Blicher and Hammeken Arboe (2017).

Introduction of contaminating compounds

Limited data on pollution is available in the ecoregion because pollution monitoring in the region is sporadic and not comprehensive across trophic levels and types of contaminants. However, pollution is considered an important pressure although it is relatively low compared to other ecoregions because of the remoteness and the small resident human population of this ecoregion. The available evidence suggests that the main source of pollution is from afar, which limits the list of contaminants to those that can be transported over long distances and accumulate in the food chain. Arctic waters flowing through the ecoregion continue to have higher mercury concentrations compared to Atlantic waters. Mercury levels in marine mammals in the European Arctic and in this ecoregion have generally decreased. The mercury content in polar bears is monitored in the ecoregion and has decreased notably since the 1960s.

Climate change impacts

The water in the northern area of the ecoregion has warmed and become more saline over the last two decades. Surface waters on the narrow southeastern Greenland shelf and in the area north of Denmark Strait are 1–2°C warmer than the mean conditions for 1981–2010 for much of the year (Figure 8). In contrast, surface waters in the southeastern reaches of the region have cooled by up to 2°C. Surface salinity has increased in the open waters of the ecoregion, but decreased in the East Greenland shelf waters and Irminger Sea surface waters.

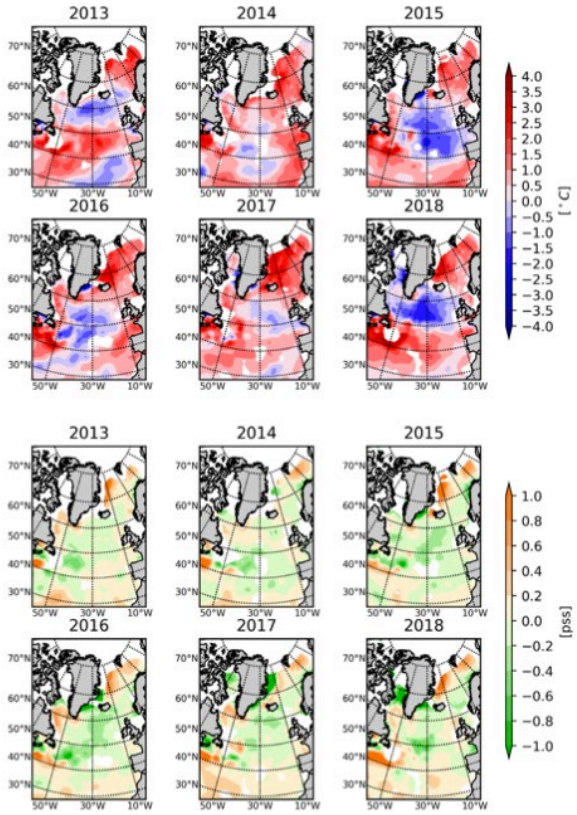

Figure 8 Temperature and salinity anomalies for surface waters of the North Atlantic region reported by ICES Working Group on Oceanic Hydrography. Anomalies are calculated as differences between monthly means (Argo data) and World Ocean Atlas 2005 climatology. Top maps (red and blue): temperature; bottom maps (brown and green): salinity (Gonzalez-Pola *et al.*, 2019).

The sea ice coverage in the ecoregion has been diminishing over several decades (Figure 9). The winter maximum sea ice extent has generally decreased since satellite records began in 1979, while a small decline in summer minimum ice coverage has been seen from 2006 onwards. Retreating sea ice has been linked to the increasing occurrence of migratory whale species such as finwhales and humpback whales on the East Greenland shelf.

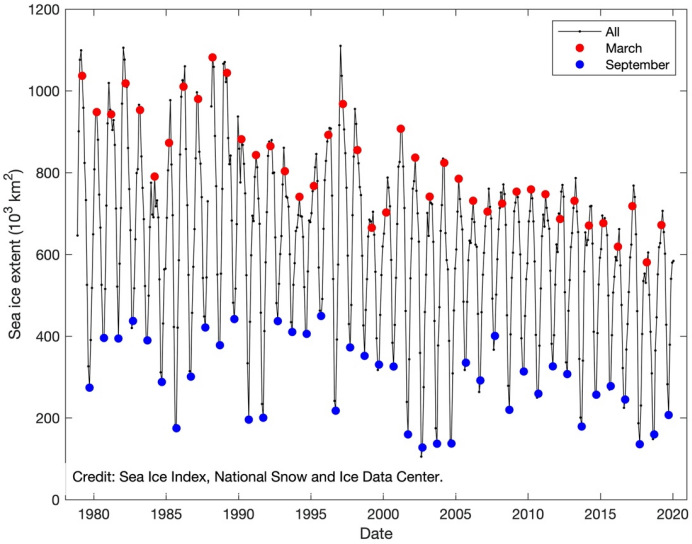

Figure 9 Monthly average sea ice extent for the Greenland region (Meier *et al.*, 2007), which corresponds to an area covering the Greenland Sea, Icelandic Waters, and the western part of the Norwegian Sea ICES ecoregions.

Bluefin tuna has been observed in the ecoregion since 2012. The seasonal occurrence of bluefin tuna is associated with warming sea surface temperatures in the southern subregion and associated increase in prey availability, namely Atlantic mackerel immigration to the area.

There is evidence of northward shifts in some breeding populations of seabirds in East Greenland, including the immigration of at least two bird species to the southeastern part of the ecoregion in recent decades: great cormorant and lesser black-backed gull. The breeding areas of common eider have also expanded more than 200 km northwards.

Climate model comparison studies indicate that from 2000 to 2050, the maximum fish catch potential in the region will increase by 25% under both low (RCP [Representative Concentration Pathway] 2.6) and high (RCP 8.5) CO_2 emission scenarios. This is globally unique and in strong contrast to maximum fish catch potential at lower latitudes (south of approximately 60°N), which are expected to show the opposite trend.

There has been a persistent westward shift in capelin distribution since the late 1990s and early 2000s, from the Icelandic Waters and Norwegian Sea ecoregions to the Greenland Sea ecoregion. Most of the nursery grounds for juveniles have moved to the southern subregion. The summer feeding grounds for adult capelin are now mainly located in the northern subregion. In addition, several boreal species such as Atlantic cod, beaked redfish and deep-sea shrimp recently found on the Northeast Greenland shelf originate from the Barents Sea. These changes are thought to be a response to large-scale ocean climate changes as a result of global warming.

State of the ecosystem

Benthic habitats (substratum)

There is currently limited information available on the benthic habitats in the ecoregion. Bottom habitats south of 69°N latitude (southern subregion) are affected by abrasion from bottom trawling, and the fishing areas are limited to the outer shelf and the slopes at approximately 400–1000 m depth (Figure 6).

Benthos

The benthic community on the shelf is poorly mapped. In 2015, the Greenland Institute of Natural Resources initiated a long-term monitoring programme of marine bottom-living invertebrate fauna in the southern subregion. The available data indicate a species-rich and structurally complex benthic community with high biomasses of large sessile species. These include several vulnerable marine ecosystem (VME) indicator taxa, such as corals and sponges; such taxa are particularly vulnerable to bottom-contacting fishing activity (Figure 7). In general, benthic communities in the ecoregion are impacted by bottom trawling, which mainly occurs in the southern subregion (Figure 6).

Productivity (phytoplankton and zooplankton)

Plankton production in the ecoregion reflects a stratified ocean circulation and sea ice coverage that controls nutrient and light availability. The cold and fresher surface polar waters are nutrient depleted during summer; therefore, much of the phytoplankton production is associated with warmer and more saline subsurface Atlantic layers.

None of the times-series measurements of phytoplankton abundances are representative of the entire ecoregion. Based on remote sensing data, the increase in phytoplankton abundance is due to increased light availability and vertical mixing from the retreating ice coverage in neighboring Arctic regions such as the Barents Sea, but no clear trends have been observed for the Greenland Sea ecoregion. However, estimates from remote sensing products fail to capture the persistent deep chlorophyll maxima in these stratified waters during the summer months.

The zooplankton community composition is driven by the regional ocean circulation, with differences in dominant copepod species between Atlantic and polar waters. Copepods dominate the mesozooplankton biomass, and their biomass is generally highest along the shelf break area.

Fish

The main commercial demersal species in this ecoregion are Greenland halibut, cod, beaked redfish, and golden redfish. The abundance of Greenland halibut has been relatively stable over the past decade and is at full reproductive capacity. While stock status for cod has been variable, it is presently at full reproductive capacity. Stock status for golden redfish has been at full reproductive capacity for more than a decade. The status for beaked redfish is unknown.

Changing distributions of pelagic fish species are linked to increased abundance of mackerel, herring, and capelin in the ecoregion during the feeding season (June to September). Since 2012, bycatch of bluefin tuna has occurred in mackerel fisheries. These regional changes are impacting the fish community structure.

The NEA mackerel stock is only abundant in the third quarter in the ecoregion during feeding migrations. The stock was previously at a low level but started to increase in the mid-2000s and is currently at full reproductive capacity. The Norwegian spring-spawning herring stock is also a seasonal guest in the third quarter; the stock size has been declining since 2009, but is still at full reproductive capacity.

Capelin stock size is highly variable because of the short life span of the species and its dependence on recruitment. Presently the stock size is very low and below the biomass reference point B_{lim}.

Information on community composition, non-commercial species, and the main bycatch species in the ecoregion are available from surveys and could be compiled in the future.

Seabirds

Seabirds are dependent on open (ice-free) water for feeding and are therefore distributed either in the southern subregion or in the proximity of large polynyas, such as that off Scoresby Sound, Young Sound, and in the Fram Strait (Figure 1). Seventeen seabird species are known to breed in the ecoregion. The majority of these are colonial breeders, and 799 breeding sites have been located.

The little auk (*Alle alle*) is by far the most abundant with an estimated population of 3.5 million. The common eider, Arctic tern *Sterna paradisaea*, and black guillemot (*Cepphus grylle*) are the next most abundant species with populations between 10 000 and 16 000 individuals. Each of the remaining species populations are estimated to be less than 5000 individuals. The common eider and Arctic tern breed across the ecoregion, while the black guillemot only breeds in the part of the ecoregion that extends from Scoresby Sound and southwards.

Seabird densities within the ecoregion are higher in coastal than in offshore areas. Black-legged kittiwake (*Rissa tridactyla)* and northern fulmar (*Fulmarus glacialis*) as the most numereous species in offshore areas.

Marine mammals

The abundant and diverse fauna of marine mammals in the ecoregion includes at least 13 species of whales, seven pinnipeds (six species of seals and one walrus (*Odobenus rosmarus*)), and the polar bear (*Ursus maritimus*). Recent abundance estimates for the most common species are shown in Figure 10.

Ice dependent cetaceans such as narwhals (*Monodon Monoceros*) and bowhead whales (*Balaena mysticetus*) are believed to calve in the Greenland Sea ecoregion. Narwhals form a genetically distinct population in the ecoregion. Hunting has led to a decline in the abundance of narwhals over the last 50 years; consequently, hunting quotas have been reduced and are continuing to decrease. The ecoregion is also an important summering and nursing ground for bowhead whales that belong to a larger stock distributed from East Greenland to Franz Josef Land.

Highly migratory species like fin whales, humpback whales, and minke whales (*Rorcual minke*) feed in the ecoregion during summer. Migratory whales and bowhead whales are increasingly observed in coastal areas of the ecoregion as the summer pack ice recedes. Historically, most whale species have been severely depleted by hunting. It is unclear whether increased sightings are due to population recovery or immigration favoured by changing environmental conditions, or both.

The three most abundant seal species in the ecoregion are the hooded seal (*Cystophora cristata*), the harp sea, and the ringed seal (*Pusa hispida*). The Greenland Sea hooded seal population remains at a historically low level (less than 10% of the 1946 baseline) despite no hunting since 2007. Estimated pup production of the Greenland Sea harp seal population has declined by approximately 50% from 2007 to 2018. There is no information on trends in abundance for ringed seals in the ecoregion, except a single-point estimate of 28 000 individuals in the King Oscars Fjord area in 1984.

Polar bears in East Greenland are considered a separate subpopulation according to data on movement of tagged animals. Interviews with local hunters suggest that the occurrence of polar bears near settlements has increased in recent years; the underlying reasons remain to be investigated.

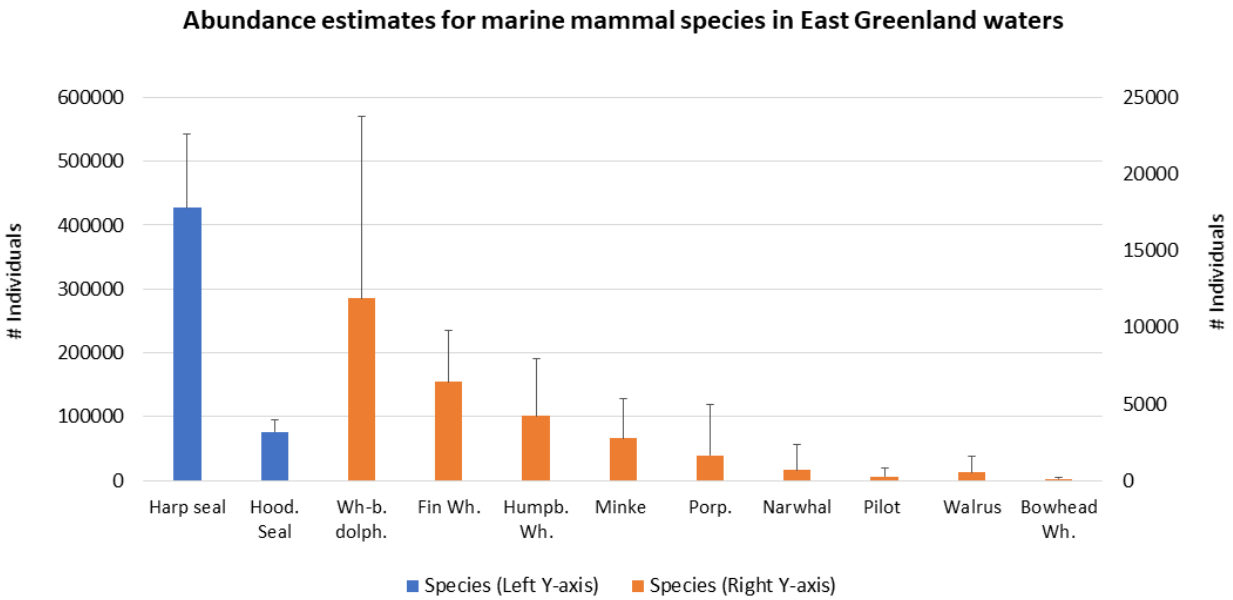

Figure 10 Abundance estimates for 11 marine mammal species in East Greenland Sea (NAMMCO, 2018). With the exception of walruses, error bars show approximate upper 95% confidence limit, either according to an original reference or calculated as 2 × standard deviation based on reported coefficients of variation (CVs) or standard deviations. For walruses the error bar shows an upper 90% confidence limit. Abbreviations: Hood. Seal = Hooded seal; Wh-b. dolph = White-beaked dolphin (*Lagenorhynchus albirostris*); Fin Wh. = Fin whale; Humpb Wh = Humpback whale; Porp = Harbour porpoise *Phocoena phocoena*; Bowhead Wh = Bowhead whale.

Non-indigenous species

No non-indigenous species have been reported in the Greenland Sea ecoregion, but this is likely confounded by limited search effort.

Threatened and declining species in the Greenland Sea ecoregion

Table 1 OSPAR-listed threatened and declining species that occur in the Greenland Sea ecoregion.

Scientific name	Common name
Seabirds	
Larus fuscus fuscus	Lesser black-backed gull
Pagophila eburnea	Ivory gull
Polysticta stelleri	Steller's eider
Rissa tridactyla	Black-legged kittiwake
Uria lomvia	Thick-billed murre

Fish	
Anguilla anguilla	European eel
Centroscymnus coelolepis	Portuguese dogfish
Centrophorus squamosus	Leafscale gulper shark
Cetorhinus maximus	Basking shark
Dipturus batis (synonym: *Raja batis*)	Common Skate
Hoplostethus atlanticus	Orange roughy
Lamna nasus	Porbeagle
Petromyzon marinus	Sea lamprey
Salmo salar	Salmon
Squalus acanthias	[Northeast Atlantic] spurdog
Mammals	
Balaena mysticetus	Bowhead whale
Balaenoptera musculus	Blue whale
Eubalaena glacialis	Northern right whale

Threatened and declining habitats in the Greenland Sea ecoregion

Table 2 Threatened and declining habitats in the Greenland Sea ecoregion according to OSPAR.

Habitats
Coral gardens
Deep-sea sponge aggregations
Intertidal mudflats
Lophelia pertusa reefs
Modiolus modiolus beds
Seamounts

Sources and acknowledgments

The content for the ICES regional ecosystem overviews is based on information and knowledge generated by the following ICES processes: Workshop on Benchmarking Integrated Ecosystem Assessment (WKBEMIA) 2012, ACOM/SCICOM Workshop on Ecosystem Overviews (WKECOVER) 2013, Workshop to draft advice on Ecosystem Overviews (WKDECOVER) 2013, and the Advice Drafting Group to finalize draft Ecosystem Overviews (ADGECO) 2020, which provided the theoretical framework and final layout of the documents.

The ICES Working Group on the Integrated Ecosystem Assessment of the East Greenland Sea (WGIEAGS) contributed to the main sections of this overview, together with contributions from the Greenland Institute of Natural Resources (GINR) for various sections.

The maps and GIS products have been produced by the ICES Secretariat, WGIEAWG, or as indicated in the figure caption. Data used stems from:

1. Exclusive Economic Zones. *Marineregions.org (VLIZ)*
2. Depth Contours. *General Bathymetric Chart of the Oceans (GEBCO)*
3. Ecoregions. *International Council for the Exploration of the Sea (ICES)*
4. ICES Areas. *International Council for the Exploration of the Sea (ICES)*

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Annex A

Table A1 Stocks with analytical assessments and guilds. Detailed information on the fisheries of the Greenland Sea is provided on the Greenland Sea ecoregion Fisheries Overviews.

Stock Code	StocK Name	Fishery Guild
cod.2127.1f14	Cod (*Gadus morhua*) in ICES Subarea 14 and NAFO Division 1.F (East Greenland, South Greenland)	Demersal
ghl.27.561214	Greenland halibut (*Reinhardtius hippoglossoides*) in subareas 5, 6, 12, and 14 (Iceland and Faroes grounds, West of Scotland, North of Azores, East of Greenland)	Demersal
usk.27.5a14	Tusk (*Brosme brosme*) in Subarea 14 and Division 5.a (East Greenland, and Iceland grounds)	Demersal
her.27.1-24a514a	Herring (*Clupea harengus*) in subareas 1, 2, 5 and divisions 4.a and 14.a, Norwegian spring-spawning herring (the Northeast Atlantic and Arctic Ocean)	Pelagic
mac.27.nea	Mackerel (*Scomber scombrus*) in subareas 1-8 and 14 and division 9.a (the Northeast Atlantic and adjacent waters)	Pelagic
reg.27.561214	Beaked redfish (*Sebastes mentella*) in Subarea 14 and Division 5.a, Icelandic slope stock (East of Greenland, Iceland grounds)	Pelagic