13 Overview on ecosystem, fisheries and their management in Greenland waters

13.1 Ecosystem considerations

The marine ecosystem around Greenland is located from arctic to Subarctic regions. The water masses in East Greenland are composed of the polar *East Greenland Current* and the warm and saline *Irminger Current* of Atlantic origin. As the currents round Cape Farewell at Southernmost Greenland the saline, warm Irminger water subducts the colder polar water and forms the relatively warm *West Greenland Current*. This flows along the West Greenland coast mixing extensively as it flows north. This current is of importance in the transport of larval and juvenile fish along the coast for important species such as cod and Greenland halibut. Additionally, cod from Icelandic waters spawning south and west of Iceland occasionally enters Greenland waters via the Irminger current and is distributed along both the Greenland East and West coast (Figure 1).

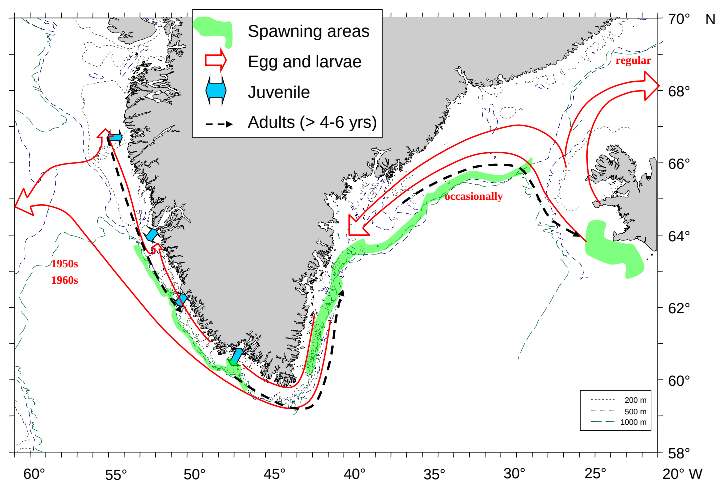

Figure 1. Spawning areas, egg and larval transport of Atlantic cod (*Gadus morhus*) in Greenlandic and Icelandic waters.

Depending of the relative strength of the two East Greenland currents, the Polar Current and the Irminger Current, the marine environment experience extensive variability with respect to the hydrographical properties of the West Greenland Current. The general effects of such changes have been increased production during warm periods as compared to cold periods, and resulted in extensive distribution and productivity changes of many commercial stocks. Historically, cod is the most prominent example of such a change (Hovgård and Wieland, 2008).

In recent years, temperature have increased significantly in Greenland waters. In West Greenland the sea temperature have increased particularly compared to the years in 1970s–mid1990s and historical highs was registered in 2005 for the time-series 1880–2012 (Figure 2).

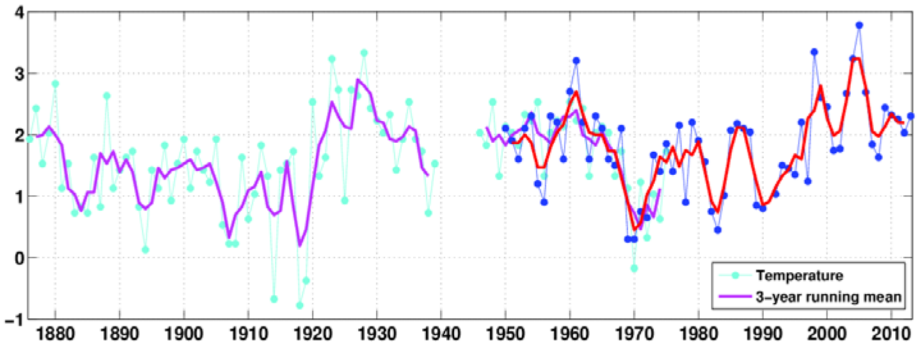

Figure 2. Mean temperature on top of Fylla Bank (located outside Nuuk Fjord, 0–40 m depth) in the middle of June for the period 1950–2013. The curves are 3 year running mean values. The magenta/purple line is extended back to 1876 using Smed-data for area A1. From Ribergaard (2014).

Temperature in the centre of the Irminger Sea, in the depth interval 200–400 m, shows no such clear long-term trend (ICES, 2013c). However, Rudels *et al.* (2012) finds that between 1998–2010, the salinity and temperature of the deep water in the Greenland Sea increased. Furthermore, increasing temperatures in the Atlantic Water entering the Arctic in the Fram Strait has increased throughout the period 1996–2012, though with the highest observation in 2006 (ICES, 2013c). Such environmental changes might well propagate to different trophic levels. Accordingly, shrimp biomass fluctuations in Greenland waters as a result of environmental changes could affect fish predators such as cod (Hvingel and Kingsley, 2006) and the other way around.

The primary production period in Greenland is timely displaced along the coast due to increasing sea ice cover and a shorter summer period moving north (Blicher *et al.*, 2007), but the main primary production takes place in May–June (Figure 3). The large latitudinal gradient spanned by Greenland, the ecosystem structure shifts moving north. For instance, the secondary producer assembly (e.g. mainly copepods) shifts from being dominated by smaller Atlantic species (*Calanus finmarchicus* and *Calanus glacialis*) to being increasingly dominated by the (sub)arctic species *Calanus hyperboreus*.

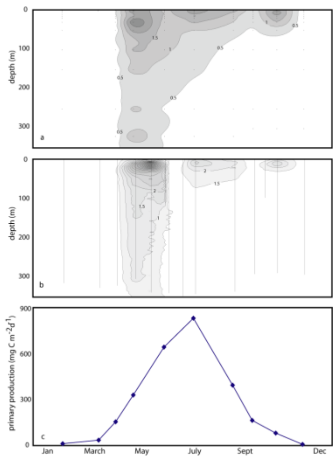

Figure 3. Annual variation in algal biomass and productivity at the inlet of Nuuk Fjord.
a: chlorophyll (µg l^{-1}), b: fluorescence, c: primary production (mg C m^{-2} d^{-1}). Dots represent sampling points. From Mikkelsen *et al.* (2008).

Recently, the distribution of commercial species such as cod and shrimp has shifted considerably in the north. Such shifts have previously been associated with temperature, and may very well be linked to the observed increase in temperature. Additionally, changes in growth of fish may also increase as a result of temperature changes as seen for both Greenland halibut (Sünksen *et al.*, 2010) and cod (Hovgård and Wieland, 2008).

In recent years, more southerly distributed species not normally seen in Greenland waters such as pearlside (*Maurolicus muelleri*), whiting (*Merlangius merlangus*), blackbelly rosefish (*Helicolenus dactylopterus*), angler (*Lophius piscatorius*) and snake pipefish (*Entelurus aequoreus*) have been observed in surveys in offshore West and East Greenland and inshore West Greenland and their presence is possibly linked to increases in temperature (Møller *et al.*, 2010).

In 2011, a mackerel (*Scomber scombrus)* fishery was initiated in East Greenland waters. Previous to this, no catches had ever been reported for this area and in 2013 mackerel was for the first time documented along the West Greenland coast. The reason(s) for the increased abundance of mackerel in Greenlandic waters has not been clarified, however factors such as changes in the regime for their usual food resources, a density-dependent effect and increased temperatures have been proposed (ICES, 2013a). The effects of increased pelagic fish abundance and their distributional shifts on demersal fish are unknown.

13.1.1 Atmospheric conditions

Cod and possibly other species recruitment in Greenland waters is significantly influenced by environmental factors such as sea surface temperatures in the important Dohrn Bank region during spawning and hence by air temperatures together with the meridional wind in the region between Iceland and Greenland (Stein and Borovkov, 2004). The effect of the meridional wind component in the region off South Greenland on the first winter of the offspring appears to play a vital role for the cod recruitment process. For instance, during 2003, when the strong 2003 YC was born, negative anomalies were more than -2.0 m/sec, and that particular YC was large in East Greenland waters. In general, it seems that during anomalous east wind conditions during summer months, anomalous numbers of 0-group cod are also found in Greenland waters.

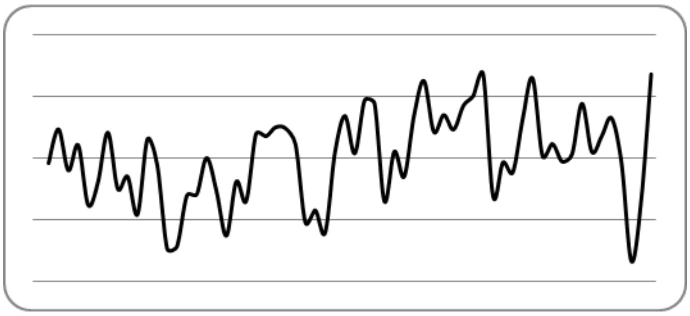

Figure 4. NAO Index (Dec–Feb) 1950–2012.

The NAO index

The NAO index, as given for 1950–2012 (Figure 4), shows negative values for winter (December–February) 2008/2009, 2009/2010 and 2010/2011. The 2009/2010 index is the strongest negative index (-1.64), encountered since 1950.

During the second half of the last century the 1960s were generally “low-index” years while the 1990s were “high-index” years. A major exception to this pattern occurred between the winter preceding 1995 and 1996, when the index flipped from being one of its most positive (1.36) values to a negative value (-0.62). The direct influence of NAO on Nuuk winter mean air temperatures is as follows: A “low-index” year corresponds to warmer-than-normal years. Colder-than-normal temperature conditions at Nuuk are linked to “high-index” years and hence indicate a negative correlation of Nuuk winter air temperatures with the NAO. Correlation between both time-series is significant ($r = -0.73$, $p \ll 0.001$; Stein, 2004). This is seen for instance in 2009, 2010 and 2011 where air temperature anomalies at Nuuk (1.0K, 4.8K and 2.9K) where associated with low

NAO values (Figure 5). The 2010 air temperature anomaly (4.0K) was the highest recorded, and was associated with the largest negative NAO anomaly (see Figure 6).

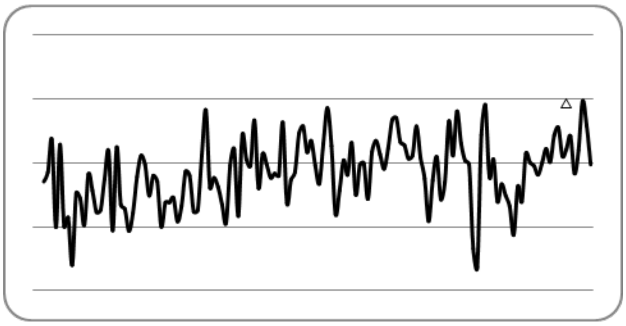

Figure 5. Time-series of annual mean winter (DEC–FEB) air temperature anomalies (K) at Nuuk (1876–2012, rel. 1961–1990)

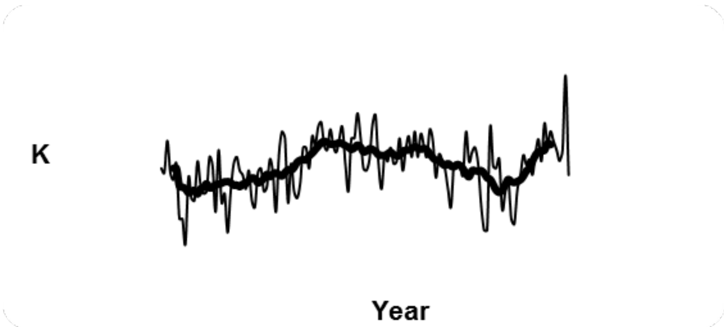

Figure 6. Time-series of annual mean air temperature anomalies (K) at Nuuk (1876–2011, rel. 1961–1990), and 13 year running mean.

Zonal wind components

A negative anomaly of zonal wind components for the Northwest Atlantic is associated with atmospheric conditions in the Iceland-Greenland region enclosing strong easterly winds (Figure 7, top left panel). These winds favour surface water transports from Iceland to East Greenland and was particularly strong in 2009, while it was completely different during the same months in 2010 (Figure 7). During May–August in 2011, the cells of negative anomalies were seen to the east of Newfoundland (anomalies < 3.0 m/sec), and to the east of Iceland.

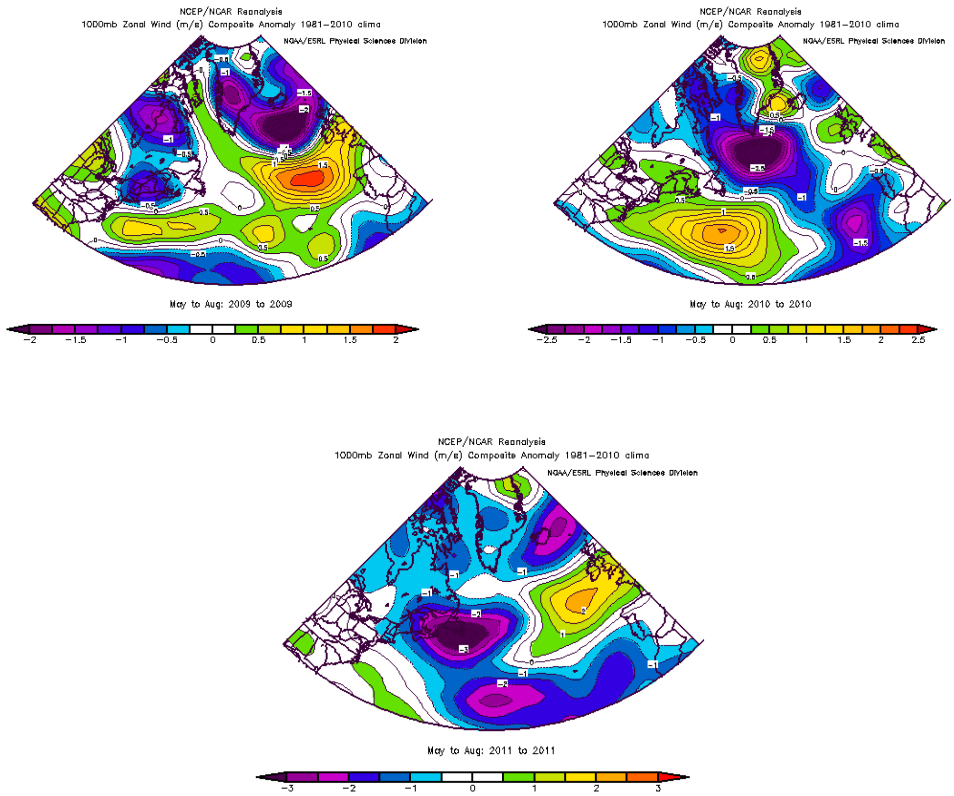

Figure 7. Zonal wind components for the North Atlantic (May–Aug), anomalies from 1981–2010.Top left: 2009; top right: 2010; bottom: 2011.

Meridional wind components

As discussed in Stein and Borovkov (2004), the meridional wind component (Dec–Jan) from the Southwest Greenland region correlated positively with the trend in Greenland cod recruitment time-series (first winter of age-0 cod). During winter 2009/2010, positive meridional wind anomalies were observed Southwest Greenland (Figure 8, top left panel). During winter 2010/2011, the center of positive meridional wind anomalies had moved to the Davis Strait region (Figure 5, top right panel), and during winter 2011/2012, positive meridional wind anomalies had moved to the Northeast off Newfoundland (bottom panel in Figure 8).

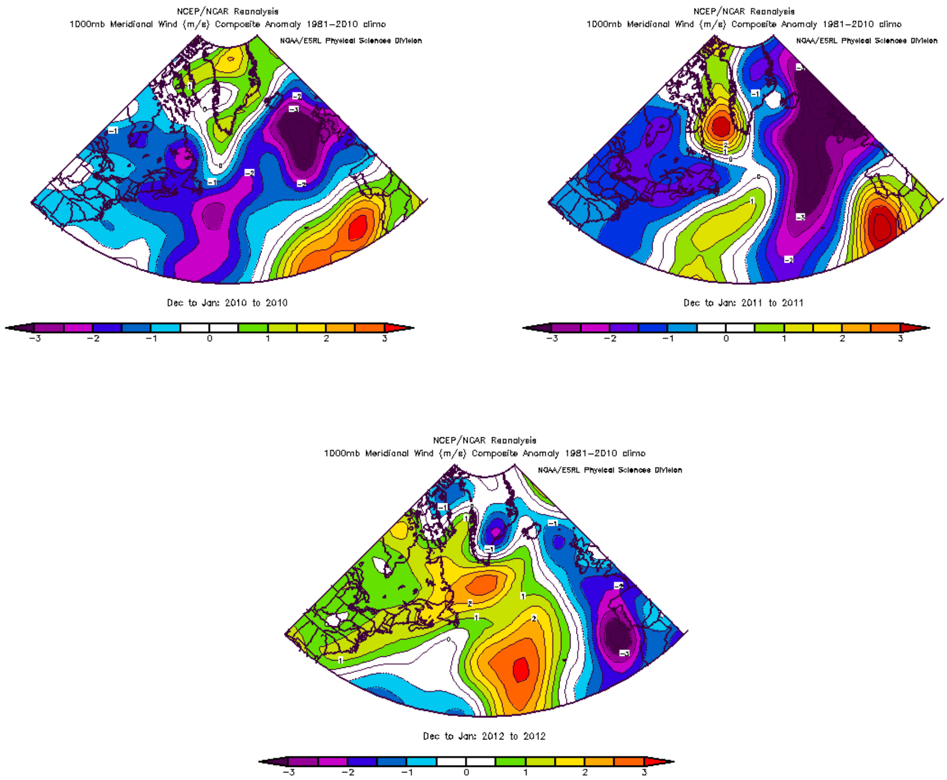

Figure 8. Meridional wind component (Dec–Jan), anomalies from 1981–2010. top left: 2009/2010; top right: 2010/2011; bottom: 2011/2012;

13.1.2 Description of the fisheries

Fisheries targeting marine resources off Greenland can be divided into inshore and offshore fleets. The majority of the Greenland fleet has been built up through the 60s and is today comprised of approx. 450 larger vessels and a big fleet of small boats. It is estimated that around 1700 small boats are dissipating in some sort of artisanal fishery mainly for private use or in the poundnet fishery.

Active fishing fleet reported to Greenland statistic by GRT in 1996 – no later number is available:

All fleet (N)	< 5GRT	6–10GRT	11–20GRT	21–80GRT	> 80GRT
441	31%	34%	2%	9%	6%

There is a large difference between the fleet in the northern and southern part of Greenland. In south, were the cod fishery has historically been important the average vessel age is 22 years, in north only 9 years as it is mostly comprised of smaller boats targeting Greenland halibut using longlines.

13.1.3 Inshore fleets

The fleet is constituted by a variety of different platforms from dog sledges used for ice fishing, to small multipurpose boats engaged in whaling or deploying passive gears such as gillnets, poundnets, traps, dredges and longlines.

In the northern areas from Disko Bay at 72ºN and north to Upernavik at 74º30N, dog sledge are the platforms in winter and small open vessels the units in summer, both fishing with longlines to target Greenland halibut in the ice fjords. The main bycatch from this fishery is redfish, Greenland shark, roughhead grenadier and in recent years, cod in Disko Bay.

The coastal shrimp fisheries are distributed along most of the West coast from 61–72ºN. The main bycatch with the inshore shrimp trawlers is juvenile redfish, cod and Greenland halibut. An inshore shrimp fishery is conducted mainly in Disko Bay. Sorting grid is mandatory for the shrimp fishery; however, several small inshore shrimp trawlers have dispensation for using sorting grid.

Cod is targeted all year, but with a peak in effort in June–July as cod in this period is accessible in shallow waters facilitating the use of the main gear types, pound and gillnets. Bycatches are limited and are mainly Greenland cod (*Gadus ogac*) and wolffish.

In the recent years there has been an increasing exploitation rate for lumpfish. The fishing season is short, with the majority of the catch being caught in May–June. Lumpfish is caught along most of the West coast and is caught using gillnets. In small areas there is a substantial by catch of birds, especially common eiders (*Somateria mollissima*)

The scallop fishery is conducted with dredges at the West coast from 64–72 ºN, with the main landings at 66ºN. Bycatch in this fishery is considered insignificant.

Snow crabs are caught in traps in areas 62–70ºN. Problems with bycatch are at present unknown, but are believed to be insignificant.

Salmon are caught in August–October with drifting nets and gillnets. The fishery is a mix of salmon of European and North American origin.

The coastal fleets fishing for Atlantic cod, snow crab, scallops and shrimp are regulated by licenses, TAC and closed areas. Fishery for salmon and lumpfish are unregulated.

13.1.4 Offshore fleets

Apart from the Greenland fleet, the marine resources in Greenland waters are exploited by several nations, mainly EU, Iceland and Norway using bottom and pelagic trawls as well as longlines.

The demersal offshore fishery is comprised of vessels primarily fishing Greenland halibut, shrimp, redfish and cod. Greenland halibut and redfish have been targeted since 1985 using demersal otter board trawls with a minimum mesh size of 140 mm. A cod fishery has previously been conducted since 1920s in West Greenland offshore waters but was absent from 1992–2000s. In 2010, the cod fishery was closed off West Greenland and catches has been insignificant since. The Greenland offshore shrimp fleet consist of 15 freezer trawlers. They exclusively target shrimp stocks off West and East Greenland with landings slightly below 100 000 tonnes. The shrimp fleet is close to or above 80 BT and 75% of the fleet process the shrimp on board. Shrimp trawls are used with a minimum mesh size of 44 mm and a mandatory sorting grid (22 mm) to avoid bycatch of juvenile fish. The three most economically important fish species in Greenland: Greenland halibut, redfish and cod are found in relatively small proportions in the bycatch. However, when juvenile fish are caught, even small biomasses can correspond to relatively large numbers.

Longliners are operating on both the East and West coast with Greenland halibut and cod as targeted species. Bycatches include roundnose grenadier, roughhead grenadier, tusk, Atlantic halibut and Greenland shark (Gordon *et al.*, 2003).

The pelagic fishery in Greenland waters is conducted in East Greenland and currently targeted species are mackerel and pelagic redfish. A relatively small fishery after herring is carried out in the border area between Greenland, Iceland and Jan Mayen. A capelin fishery has previously been done but as the Greenland share of the TAC is taken in other waters. Generally, the pelagic fishery in Greenland is very clean, with small amounts of bycatch seen.

The demersal and pelagic offshore fishing, together with longlines are managed by TAC, minimum landing sizes, gear specifications and irregularly closed areas.

13.2 Overview of resources

In the last century, the main target species of the various fisheries in Greenland waters have changed. A large international fleet in the 1950s and 1960s landed large catches of cod reaching historic high in 1962 with about 450 000 tonnes. The offshore stock collapsed in the late 1960s–early 1970s due to heavy exploitation and possibly due to environmental conditions. Since then the stock has been low, with occasional larger YC being transported from Iceland (i.e. 1984 and 2003). Since 2010, the cod biomass has been concentrated in the spawning grounds off East Greenland. Following the cod collapse, the offshore shrimp fishery started in 1969 and has been increasing up to 2003 reaching a catch level close to 150 000 tonnes. The stock decreased thereafter and is now at the low 1990 level with an advised TAC for 2015 of 60 000 tonnes. The advised TAC for 2016 increased to 90 000 tonnes.

13.2.1 Shrimp

The shrimp (*Pandalus borealis)* stock in Greenland waters has been declining since 2003. The stock in East Greenland is at a low level based on available information. The 2003 West Greenland shrimp biomass was at the highest in the time-series, but it has since decreased.

13.2.2 Snow crab

The biomass of snow crab (*Chionoecetes opilio*) in West Greenland waters has decreased substantially since 2001. Snow crab has been exploited inshore since the mid-1990s and offshore since 1999. Total landings have since 2010 been reported at around 2000 tonnes a decrease from a high level in 2001 at 15 000 tonnes. After several years of decreasing CPUE it now appears to have stabilized at low levels in the majority of areas.

13.2.3 Scallops

The status of scallops in Greenland is unknown. From the mid-1980s to the start 1990s landings were between 4–600 tonnes yearly, increased to around 2000 tonnes in late 1990s. Catches decreased again and is below 600 tonnes in 2014. The fishery is based on license and is exclusively at the west coast between 20–60 m. The growth rate is considered very low reaching the minimum landing size on 65 mm in 10 years.

13.2.4 Squids

The status of squids in Greenland waters are unknown.

13.2.5 Cod

Since 2015, assessment and advice for cod in Greenland water take into account that three different stocks, based on spawning areas and genetics, are the basis for the cod fishery and the following management is therefore recommended for different three areas: a) inshore in Western Greenland (NAFO Subdivision 1A–1F), b) offshore Western Greenland (NAFO Subdivision 1A–1E) and offshore Eastern and South Greenland (ICES Subarea 14.b and NAFO Subdivision 1F). Current landings for inshore cod are 35 000 tonnes, and have steadily increased since 2009 where landings were 7000 tonnes. Landing from offshore Western Greenland was minor (less than 500 tonnes since 2006) until 2015 where catches increased to 4600 tonnes. From offshore Eastern Greenland area 2015 landing was 15 800 tonnes, an increase from the 2011–2013 level at 5000 tonnes.

Catches are high compared to the last three decades; however, they are only a fraction of the landings caught in the 1950s and 1960s. Recruitment has been negligible since the 1984- and 1985-year classes, though it has improved in the last decade, especially inshore, where the 2009 YC is the best seen in the time-series since 1982. In 2007 and 2009, dense concentrations of unusually large cod were documented to be actively spawning off East Greenland, and management actions have been taken to protect these spawning aggregations. The inshore fishery has been regulated since 2009 and the offshore fishery is managed with license and minimum size (40 cm). As a response to the favourable environmental conditions (large shrimp stock, high temperatures) there is a possibility that the offshore cod will rebuild to historical levels if managed with this objective. A management plan with the objective of achieving this goal has been implemented for the fishing seasons 2014–2016. Several YC are present in the inshore fishery, and with the stable recruitment in recent years and widespread fishery there are several indications that the stock is experiencing favourable conditions and that recruitment is not impaired despite an increased fishing effort in later years. However, in 2015 signs of increasing fishing pressure is seen as the biomass index in the inshore survey is stable and recruitment is low.

13.2.6 Redfish

Redfish (*Sebastes mentella* and *Sebastes norvegicus*) are primarily caught of East Greenland. Catches have been small since 1994, but recently large year classes have given rise to a significant fishery with catches in 2010–16 being around 8000 tonnes. This includes both redfish species. The majority (e.g. ~70%) has earlier been identified as *S. mentella*. However, recent East Greenland survey estimates indicate a decline in *S. mentella* while *S. norvegicus* is increasing, and based on samples from the fishery the proportion of *S. norvegicus* exceeded *S. mentella* in 2016 for the first time.

13.2.7 Greenland halibut

Greenland halibut in the Greenland area consist of at least two stocks and several components; the status of the inshore component is not known, but it has sustained catches of 15–20 000 tonnes annually, taken primarily in the northern area (north of 68°N). The offshore stock component in West Greenland (NAFO SA 0+1) is a part of a shared stock between Greenland and Canada. The stock has remained stable in the last decade, sustaining a fishery of about 30 000 tonnes annually (15 000 tonnes in Greenland water). The East Greenland stock is a part of a stock complex extending from Greenland to the Barents Sea. The stock size is currently estimated as being at a historical low. In 2015, catches were around 9400 tonnes.

13.2.8 Lumpfish

The status of the lumpfish is unknown. The landing of lumpfish has increased dramatically in the last decades with catches being close to 13 000 tonnes in 2013. Catches are highest in the southern-mid section of the Greenland west coast. There are no indications of the impact on the stock. A management plan was implemented in 2014 regulating the fishery with TAC and number of fishing days.

13.2.9 Capelin

On the Greenland East coast an offshore pelagic fleet have been conducting a fishery on capelin (2500 tonnes (summer/autumn) landed in 2015 by Greenland, EU, Norway and Iceland). The capelin has shifted distribution more west and north in recent years, and are believed to spend a substantial amount of time in Greenland waters. The west Greenland capelin stock is not fished and its size is unknown.

13.2.10 Mackerel

A mackerel fishery in Greenland waters initiated in 2011 with catches of 162 tonnes and increased to more than 32 000 tonnes in 2015. Mackerel is known to feed on various species, including fish larvae, and it competes with others pelagic species, such as herring, for resources (Langøy *et al.*, 2012). Thus, it might/can have a key role on the ecosystem of many commercial important species in Greenland.

13.2.11 Herring

A fishery for Norwegian spring-spawning herring in Greenland water has increased in recent years and in 2014 catches increased to 9000 tonnes. The herring has shifted distribution more west in recent years.

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