

1.1 Stock Annex: Cod (*Gadus morhua*) in ICES Subarea 14 and NAFO Division 1.F (East Greenland, South Greenland)

Stock specific documentation of standard assessment procedures used by ICES.

Stock:	Cod
Working Group:	North Western Working Group (NWWG)
Last revised:	18/08/2021
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Main revisions:	Change in assessment settings and revised Biological Reference Points
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A. General

A.1. Stock definition

Cod found in Greenland is a mixture of four separate “stocks” that are defined by their spawning areas: i) offshore West Greenland waters; ii) West Greenland fiords cod iii) offshore East Greenland and offshore Icelandic waters and iv) inshore Icelandic waters (Therkildsen *et 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 irregular (Buch *et al.*, 1994; Schopka, 1994) and of varying intensity.

Tagging information and recent studies clearly demonstrate this spawning migration (Storr-Paulsen *et al.*, 2004; Bonanomi *et 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 (Figure A.1.1).

Before 2016 cod in East Greenland was considered part of a larger offshore stock complex with West Greenland. Hence, advice was given for the whole area. Since 2016 the assessment area of the East Greenland cod is defined as the area comprising NAFO Division 1F in SouthWest Greenland and ICES Subarea 14 (East Greenland, Figure A.1.2).

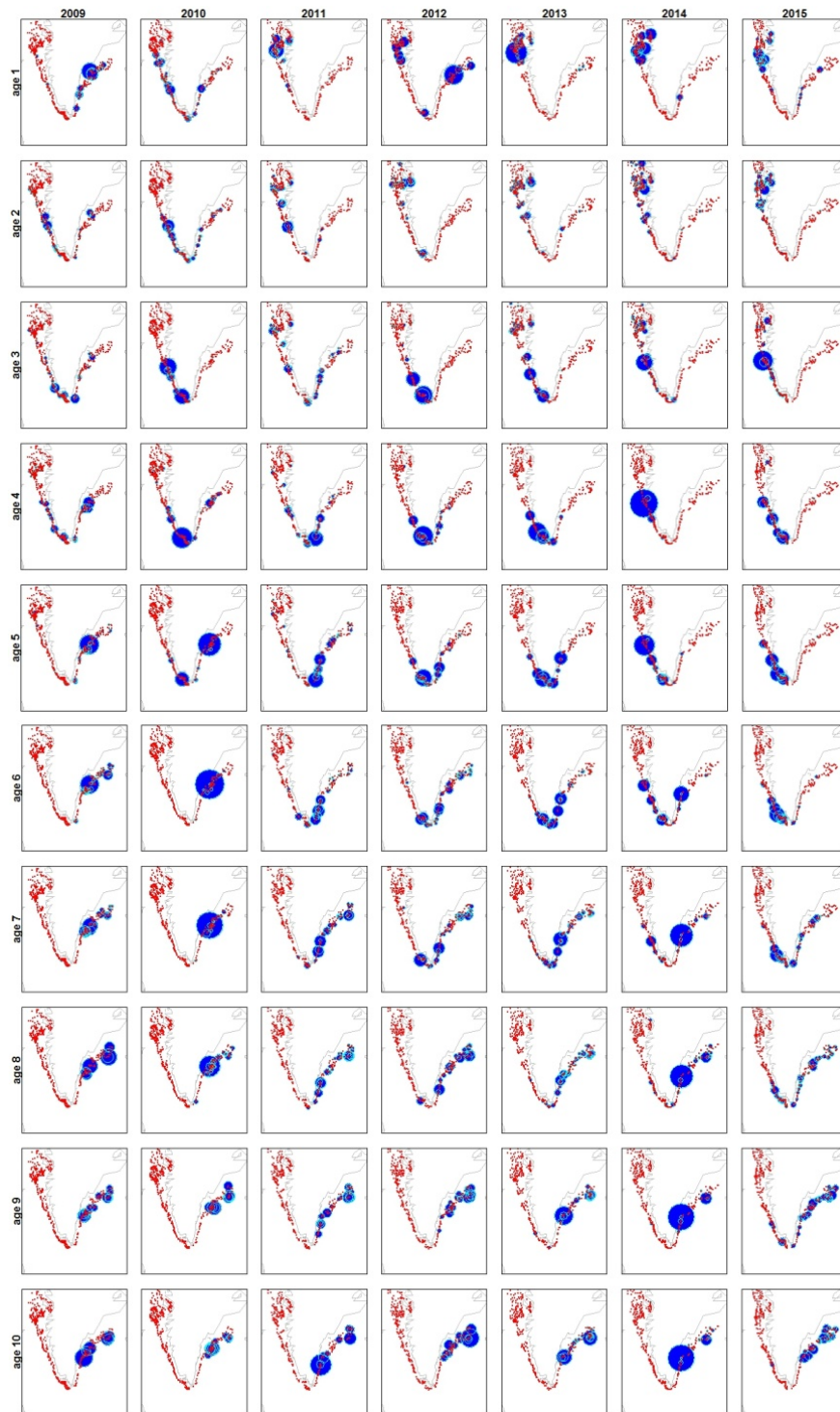


Figure A.1.1. Abundance (%) of ages 1–10 in the years 2009–2015 from the Greenland survey. The size of blue circles denotes the percentage of the cohort in the given year, where each square equals 100%. Red circles are trawl stations.

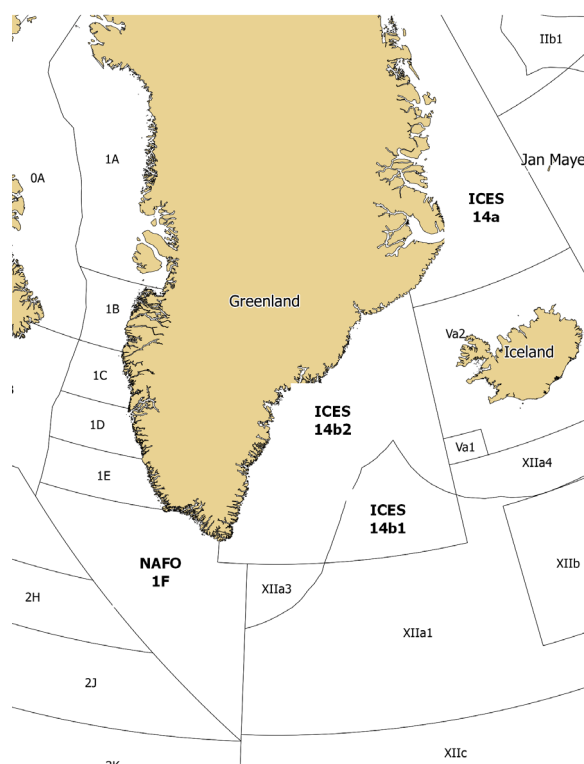


Figure A.1.2 NAFO divisions and ICES subareas around Greenland.

A.2. Fishery

A.2.1 General description

A short historical review

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. 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 present fishery

Landings in East and South Greenland increased from 1 000 tonnes in 2005 to 15 000 tonnes in 2008. The landings in 2008 were primarily fished in SouthWest Greenland (NAFO Division 1F), as East Greenland was closed (see 'fishery management regulations' below). In the following years landings dropped to 2 500 tonnes in 2010. Since then catches have increased to average of 15 000 tonnes in the period 2015 - 2020. The distribution of the fishery has changed since 2010 from SouthWest Greenland to East Greenland where the majority of the catches since 2019 have been fished on the southern slope of the Dohrn Bank region close to the EEZ to Iceland.

The cod fishery in East Greenland has traditionally been a bottom trawl fishery, but in recent years 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 (>75%), with EU, Norway and the Faroe Islands landing minor quantumts.

Since discards are not taking place landings are equivalent to catches.

A.2.2. Fishery management regulations

In the offshore fisheries vessels are above 75BT/120BT and restricted to an area more than 3 nm off the baseline. The vessels require a licence that stipulates a unique vessel quota. Trawl and longlines are the main fishing gears. 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. Comparison of length measurement of cod caught in the trawl fishery and longline fishery show similar length distributions

No directed offshore fishery was allowed for the period 1993–2005, except for some minor allocations to Norway and the Færoe Islands.

After an experimental fishery in East Greenland in 2007, when dense concentrations of large spawning cod were found, the area was subject to several area closures. In 2008 fishing was not allowed north of N63°00' in order to protect the potential spawning segments, especially on Kleine Banke. In 2009–2010 the delinitation was at N62°00' and additionally NAFO Division 1F was closed in 2010, primarily to protect the relatively strong incoming year classes.

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). However fishing for cod in East Greenland (ICES Subarea 14) was closed from 1 January to 30 June.

The management plan was updated in 2014 where the distinction between the inshore and two offshore stocks was implemented. The two offshore stocks are defined in the regions: West Greenland offshore stock (NAFO divisions 1A-1E) and East Greenland offshore stock (ICES division 14b and NAFO division 1F). The management plan from 2014 has been modified during the years with TAC being distributed between management areas within the region South and East Greenland (NAFO 1F and ICES 14b). The number of management areas within this region has varied between two to four. In 2020 the government operated with three management areas which was reduced to two in 2021. The area around the spawning grounds of Kleine Bank is closed for fishery from 1st of March – 31st of May.

A.3. Ecosystem aspects

There are few studies on cod from this area. A recent study shows that fish is the dominant prey group and that cannibalism is limited to the largest cod (Hedeholm *et 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.

In Greenland cod live near the distributional limit as the cold polar water sets the limit for the northern distribution range, and will therefore be susceptible to especially temperature variations to colder environment. Hence, the emergence of the cod stocks in Greenland during the first half of the 20th century, and the rapid decline in the last part of the 20th century coincide respectively with a warm and cold period, (Hovgård and Wieland 2008). This renders the stock vulnerable to overfishing in colder periods. The recent increase in cod in Greenland in general can also be positively correlated to ocean warming, as can the general increase in the appearance of warm-water species (Møller *et al.*, 2010)

B. Data

B.1. Commercial catch

The information on landings in weight are compiled and processed by the Greenland Fisheries License Control (GFLK). The offshore information is available through logbooks on a haul-by-haul basis.

Offshore sampling is laborious, as most vessels produce frozen fillets that are commonly landed outside Greenland. Since 2011 sampling of length frequencies and information on age, weights and maturities are collected by the vessels and compiled by the Greenland Institute of Natural Resources.

To facilitate the ICES procedure, catches are raised and reported in a catch-at-age matrix.

B.1.2. Discards estimates

There is a discard ban in Greenland waters and there is no reason to suspect that discarding takes place.

B.1.3 Recreational catches

There are no recreational catches in East Greenland as it is inaccessible to small vessels.

B.2. Biological sampling

B.2.1 Maturity

Due to lack of data it is not possible to generate a year specific maturity ogive (Table B.2.1.1). Hence, the proportion of mature fish by age are left unchanged from year to year from 1973–2017 (Table B.2.1.2). The maturity ogive is based on 1557 samples with maturity information on collections made in the spawning season april and may. No data on maturity in the spawning season exist before 2005. The majority of the maturity information is based on a survey in 2009 and on extensive sampling from commercial experimental fishery in 2007. The maturity ogive was estimated by a general linear model (GLM) with binomial errors. L50 was estimated to 5.19 years (SE = 0.07). Since 2018 a separate ogive was estimated based on cod sampled from an experimental fishery in the same spawning area as in 2007 (GINR, 2018). The two maturity ogives were similar.

Table B.2.1.1: Number of samples with information on maturity and age in april and may by year used in maturity ogive.

Year	Number	Origin
2007	435	commercial
2008	62	commercial
2009	751	survey
2010	193	commercial
2011	116	commercial
Total	1557	
2018	165	Experimental fishery

Table B.2.1.2: Maturity ogive by age

Age group	Proportion mature 2073-2017	Proportion mature 2018-present
1	0.020	0
2	0.049	0.001
3	0.116	0.011
4	0.249	0.081
5	0.456	0.410
6	0.679	0.847
7	0.843	0.978
8	0.931	0.997
9	0.972	0.999
10	0.989	0.999

B.2.2. Natural mortality

Natural mortality is differentiated by age. Tagging data clearly illustrate a migration from East Greenland to Iceland (Storr-Paulsen *et al.*, 2004, ICES 2018). Because this migration hinges on the onset of spawning and appears to be consistent across year-classes, natural mortality is estimated at 0.2 for ages 1–4, 0.3 for age 5, 0.4 for age 6 and 0.5 for older in the period 1973–2015. In the period 2016–present natural mortality was changed to 0.2 for all years (table B2.2.1). The reason for this change is that the assumption on migration may not be valid for the older cod found in the Dohrn Bank area which in recent years have been an increasing part of the total numbers in the catch at age for the commercial fishery. The older cod might possibly migrate back and forth across the EEZ border between Greenland and Iceland waters as indicated by the continuum of catches across this border and a recapture of a large cod in East Greenland waters tagged in Iceland waters.

Table B2.2.1: Settings of natural mortality (M) in the period 1973-2015 and 2016-present.

M	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	Age 10+
1973-2015	0.2	0.2	0.2	0.2	0.3	0.4	0.5	0.5	0.5	0.5
2016-present	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2

There are no data to estimate the predation pressure on cod of various sizes and how this may alter M between years.

B.2.3. Weight-at-age

Mean stock weight-at-age is provided from the Greenland shrimp and fish survey in the period 2008–2016 (GRL-GFS). The mean weight at age for this period are applied to the years before. Mean catch weight-at-age is calculated from annually sampled commercial catches. There are no sampling from the fishery in the period 1996–2004 and the weight-at-age applied in these years is an average of weight-at-age in the period 1973–1995 and 2005–2016. Mean stock weights are also available from the German survey. However, the weight-at-age patterns in the two surveys differ, with higher weight-at-age in the German survey than the Greenland survey especially for older age groups.

Work to identify the reason for the discrepancy is ongoing, but as approximately 80% of the fishery takes place from January–August, the German survey takes place outside the main part of the fishery season and is therefore most likely not representative of the fishable biomass. Therefore the assessment is based on the weight-at-age from the Greenland survey. The survey started in 2008, and for the 1973–2007 period an average of the weight-at-age from 2008–2016 was used.

B.2.4. Recruitment

In addition to the recruitment from cod spawning in East Greenland there is substantial recruitment from spawning in Iceland waters (Bonanomi *et al.*, 2016). It is not possible to distinguish between these sources of recruitment, but from age 2 the surveys in the region document the size of each yearclass. Often the recruits are found in West Greenland, and do not show up in East Greenland before age 4–5.

B.3. Surveys

Two survey series are available for this assessment (Figure B.3.1 and B.3.2):

- A Greenland mid-year bottom trawl survey (GRL-GFS) which covers the entire area in August–September each year from 0–600 m. It has been undertaken since 2008, except 2018 and 2019, and has approximately 130 stations per year.

The survey uses a 2600/20-mesh “Cosmos” 2000 trouser bottom trawl equipped with ‘rock-hopper’ ground gear comprising steel bobbins and rubber disks. Trawl doors are 7.5 m² weighing 2 800 kg. Towing speed is 2.5 knots with each haul being 15 minutes.

Survey abundance and biomass is based on swept area estimates raised to survey stratum area, *i.e.* wingspread x towed distance, where wingspread is inferred from Scanmar recordings and the towed distance is measured by GPS.

- The German groundfish survey commenced in 1982 and was designed for the assessment of cod and covers 0–400 m. The survey includes approximately 80–100 stations per year. In 2013, the survey was re-stratified and now has 5 strata in East Greenland in the depth intervals 0–200 m and 200–400 m. Biomass indices for the time-series were accordingly recalculated. For further information about the restratification see WD 25, ICES 2013. The survey was carried out by the research vessel (R/V) WALTHER HERWIG II 1982–1993 (except in 1984 where R/V ANTON DOHRN was used) and since 1994 by R/V WALTHER HERWIG III. The fishing gear used is a standardized 140-feet wide bottom trawl, composed of a net frame rigged with heavy ground gear due to the rough nature of the fishing grounds. A small mesh liner (10 mm) was used inside the cod end. The horizontal distance between wing-ends was 25 m and the vertical net opening being 4 m at 300 m depth. In 1994 smaller Polyvalent doors (4.5 m², 1 500 kg) were used for the first time in order to reduce net damages due to overspread caused by bigger doors (6 m², 1 700 kg), which have been used earlier.

Up to 2008 strata with less than 5 hauls were excluded in the annual stock calculations. From 2009 all valid hauls have been included and biomass indices for the entire time-series have been corrected. For strata with less than 5 haul samples, GLM and quasi-likelihood estimates have been recalculated based on year and stratum effects from the time-series. In some years (notable 1992 and 1994) several strata were uncovered, implying that the survey estimate implicitly refers to varying geographical areas. The survey was not undertaken in 2018 due to vessel breakdown.

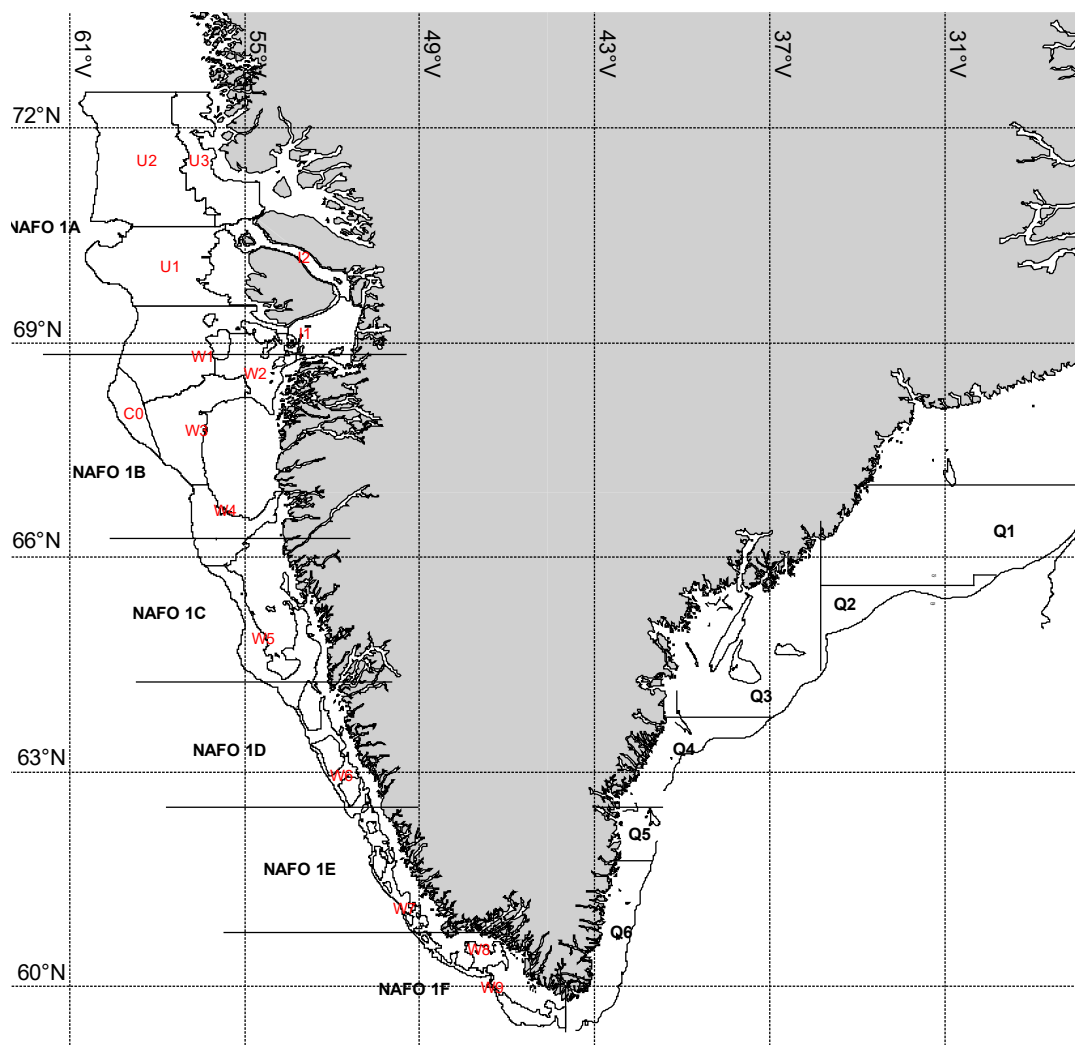


Figure B.3.1. The stratification areas used in the Greenland shrimp and fish survey. In West Greenland each strata is divided in depth strata of 150–200 m, 200–300 m, 300–400 m and 400–600 m. “Shallow” water strata of 0–100 m and 100–150 m are delimited by the 3 nm line (not shown) and the NAFO divisions. In East Greenland each strata is divided in depth strata of 0–200 m, 200–400 m and 400–600 m. “Shallow” water strata of 0–200 m is delimited by the 3 nm line (not shown).

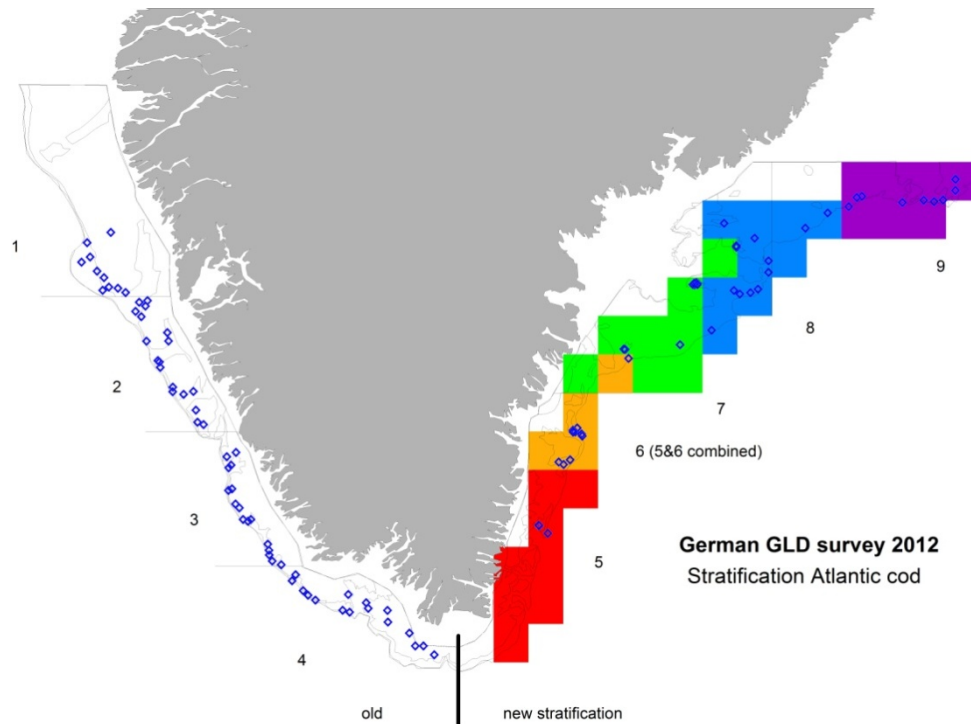


Figure B.3.2. The Stratification areas used in the German Greenland groundfish survey. Each stratum is divided into two depth zones, 0–200 m and 201–400 m.

B.4. Commercial CPUE

Commercial CPUE data are available. However, due to the limited time-series they are not used in the assessment.

B.5. Other relevant data

Both the Greenland and the German surveys also cover the West Greenland area (NAFO 1A-1E). Because this area is a nursery ground for the East Greenland stock, the abundance of especially pre-spawning individuals is an indicator of the level of immigration expected in the East Greenland area in the next couple of years.

C. Assessment method and settings

C.1 Choice of stock assessment model

Based on availability of age disaggregated data from two surveys and commercial catches in combination with a good understanding of migration this stock has since 2018 been subject to a full analytical assessment.

C.2 Model used as basis for advice

The stock is assessed using the state-space model SAM (Nielsen and Berg, 2014)

C.3 Assessment model configuration

Two survey indices are used with commercial catch-at-age data. No commercial fleets with effort information are used. The available data are listed in table 3.1

Table 3.1: Input data

TYPE	NAME	YEAR RANGE	AGE RANGE	VARIABLE FROM YEAR TO YEAR
Caton	Catch in tonnes	1973–present	1–10+	Yes
Canum	Catch-at-age in numbers	1973–present	1–10+	Yes
Weca	Weight-at-age in the commercial catch	1973–present	1–10+	Yes
West	Weight-at-age in the stock	1973–2007 2008–present	1–10+ 1–10+	Mean 2008–2016 Yes
Mprop	Proportion of natural mortality before spawning	1973–present	1–10+	No
Fprop	Proportion of fishing mortality before spawning	1973–present	1–10+	No
Matprop	Proportion mature at age	1973–2017 2017–present	1–10+ 1–10+	No No
Natmor	Natural mortality	1973–2015 2016–present	1–10+ 1–10+	No, but differentiated by age. No

In the period 1996 to 2004 no age aggregated catch-at-age data existed because of the very limited fishery. The annual total weight of catch for this period was included in the model configuration as a “third survey”. This “technical” solution was preferred instead having missing information.

No discarding is believed to take place.

Mean weight-at-age in the stock for the period 2008–2016 derive from the Greenland survey (GRL-GFS). The average mean weight-at-age for this period was applied for the 1973–2007 period.

The natural mortality is estimated at 0.2 for ages 1–4, 0.3 for age 5, 0.4 for age 6 and 0.5 for age 7 and older in order to mimic the emigration to the Icelandic area in the period 1973–2015. In the period 2016–present natural mortality was changed to 0.2 for all ages as a consequence of the changed pattern in the fishery with higher proportion of old cod dominating the commercial catches.

Estimation of recruitment is an integrated part of the model. Recruitment parameters are estimated within the assessment model. The parameter structure is assumed as a random walk process.

The correlation of fishing mortalities across ages is set to no correlation (independent) as fishing mortalities in recent years seem to be different across ages. As a consequence the model fit better for the recent years of the time series at the expense of the earlier part.

The model is tuned with two surveys (Table below)

Tuning data:

TYPE	NAME	YEAR RANGE	AGE RANGE
Tuning fleet 1	Greenland GRL-GFS	2008–present	1–9+
Tuning fleet 2	German G3244 DTS (GFS)	1982–present	1–9+

D. Short-Term Projection

Table D.1. Forecast assumptions. [Note that the values that appear in the catch options table of the advice sheet are medians from the distributions that result from the stochastic forecast.]

Initial stock size	Starting populations are simulated from the estimated distribution at the start of the intermediate year (including co-variances).
Maturity	Maturity is fixed until new information becomes available.
Natural mortality	Natural mortality is fixed between years.
F and M before spawning	Both taken as zero.
Weight at age in the catch	Average of final three years of assessment data.
Weight at age in the stock	Based on the latest GRL-GFS survey
Exploitation pattern	Catch set according to most recent TAC
Intermediate year assumptions	NA
Stock recruitment model used	Recruitment for the intermediate (the year the WG meets) is taken from the SAM assessment and assumes a random walk.

E. Medium-Term Projections

Medium-term projections are not carried out for this stock.

F. Long-Term Projections

Long-term projections are not carried out for this stock.

G. Biological Reference Points

The updated reference points and their technical bases are as follows.

Framework	Reference point	Value	Technical basis	Source
MSY approach	MSY $B_{trigger}$	18 146 t	The default option of B_{pa} .	ICES advice technical guidelines
	F_{MSY}	0.29	F_{MSY} simulated should be lower than $F_{05} = 0.65$	ICES advice technical guidelines
Precautionary approach	B_{lim}	11 738 t	Mean of three lowest SSB given large recruitment	IBPGCod2 2021
	B_{pa}	18 146 t	$B_{lim} * \exp(1.645 * \sigma)$, $\sigma = 0.23$	IBPGCod2 2021
	F_{lim}	1.98	F_{50} deterministic simulated	
	F_{pa}	0.65	$F_{0.05}$	IBPGCod2 2021

H. Other Issues

There are no other issues.

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