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:	08/02/2018
Timeline of revisions:	Last revised during IPBGCod
Main revisions:	New assessment and Biological Reference Points
Last benchmark:	IPBGCod January 2018

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).

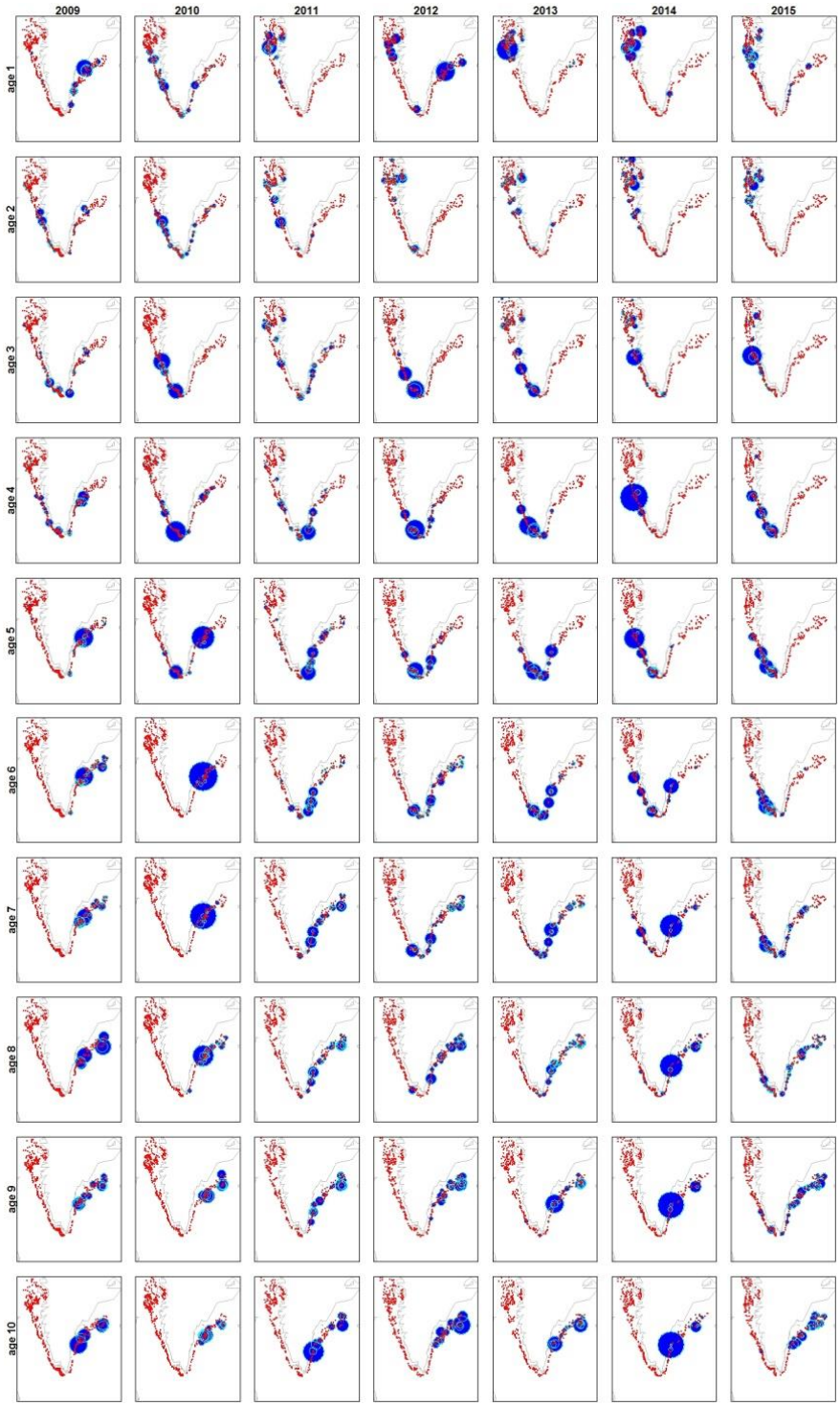

Figure A.1.1. Abundance (%) of ages 1–10 in the years 2009–2015 from the Greenland survey. The size of blue circles denotes the percentage of the cohort in the given year, where each square equals 100%. Red circles are trawl stations.

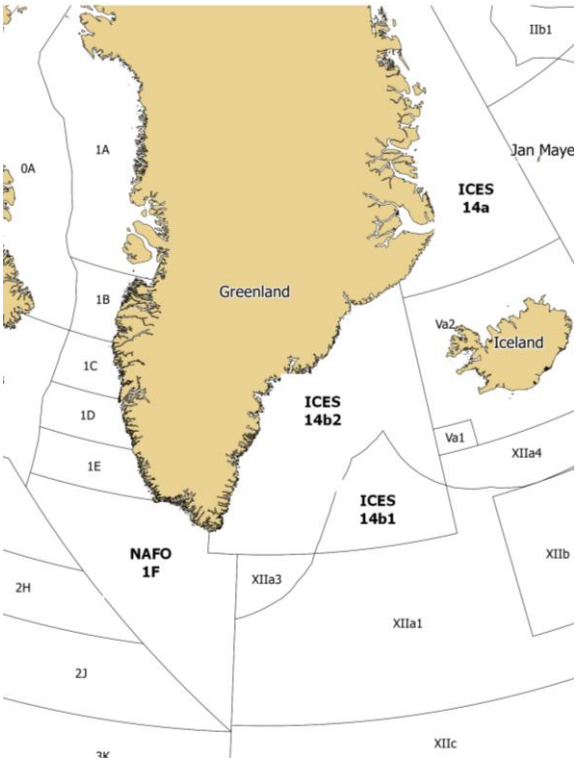

Figure A.1.2 NAFO divisions and ICES subareas around Greenland.

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 15 000 tonnes in 2015 and 2016.

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, amouting 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 quantums.

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 areawas 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.

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. The plan also outlined a number of management areas between which the TAC should be divided. This was done to ensure spreading of the fishery. The TAC limitation and area division were only followed in 2014. TAC was increased to 18 000 tonnes in 2015 due to an increase in survey biomass, but was only reduced to 16 000 tonnes in 2016 and 2017, despite decreasing survey biomass.

Since 2014 the area north of N62º30′ is closed in the period 1 April to 31 May.

A.3. Ecosystem aspects

There are few studies on cod from this area. A recent study shows that fish is the dominatent 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 therefor 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. Sampling of length frequencies and information on age, weights and maturities are collected and compiled by the Greenland Institute of Natural Resources.

Offshore sampling is laborious, as most vessels produce frozen fillets that are commonly landed outside Greenland. When it is done, it is by GFLK observers or in some cases skippers that organize the length measuring of random samples and/or to freeze individual cod for later analysis at the laboratory.

In 2011, 2012 and 2013 the offshore fishery was defined as an experimental fishery. This meant that the vessels themselves took length measurement and biological sampling of the catches but since 2014 this has not been the case.

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–present (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).

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	

Table B.2.1.2: Maturity ogive by age

Age group	Proportion mature
1	0.020
2	0.049
3	0.116
4	0.249
5	0.456
6	0.679
7	0.843
8	0.931
9	0.972
10	0.989

B.2.2. Natural mortality

Natural mortalty is differentiated by age. Tagging data clearly illustrate a migration from East Greenland to Iceland (Storr-Paulsen *et al.*, 2004, IBPGCod WD#03). Because this migration hinges on the onset of spawning and appears to be consistent acorss 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. 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. The catch-at-

age pattern in the two surveys does not indicate an age reading issue, the weight-at-age in the fishery corresponds overall to the weight-at-age in the Greenland survey. 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. Therefor 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 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 m^2 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 were 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 m^2, 1 500 kg) were used for the first time in order to reduce net damages due to overspread caused by bigger doors (6 m^2, 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.

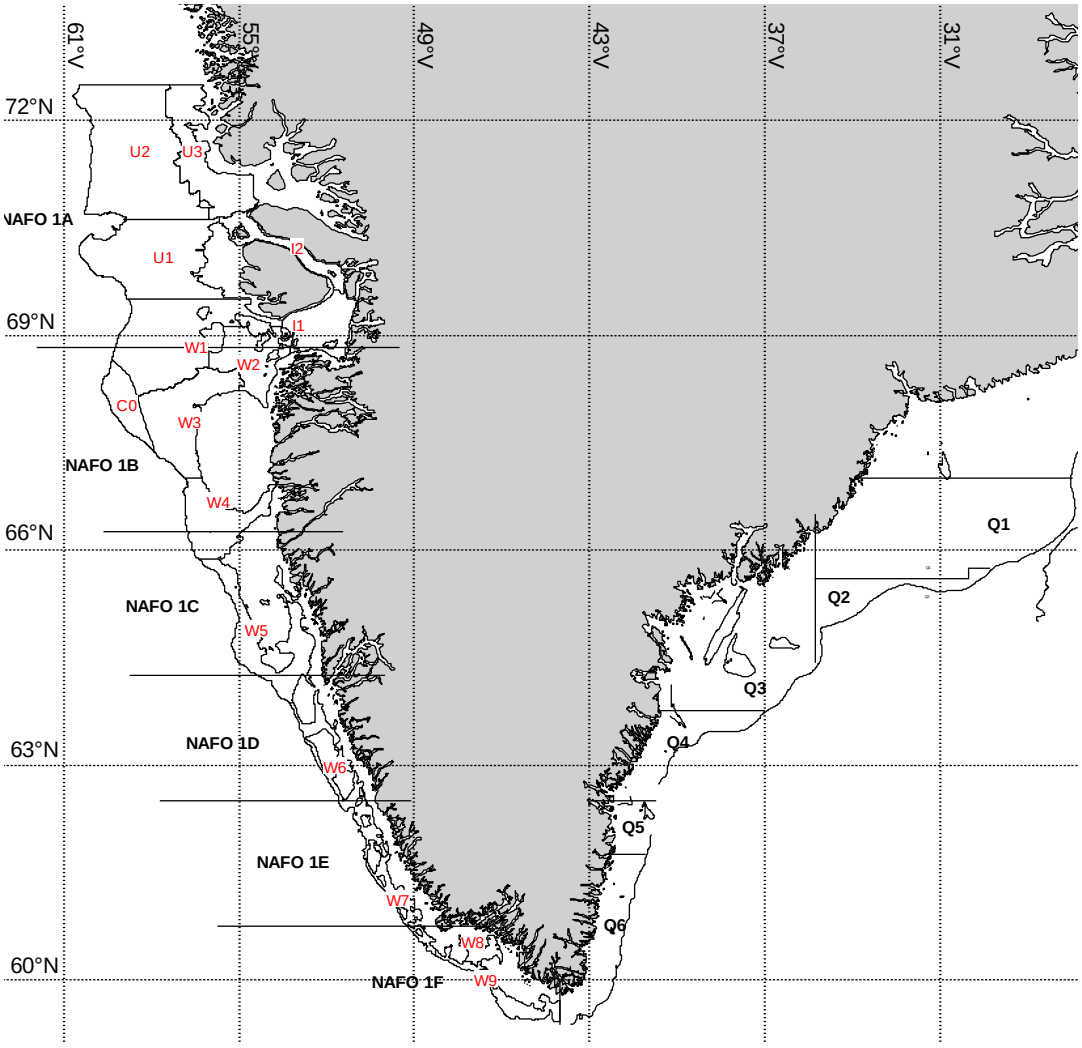

Figure B.3.1. The stratification areas used in the Greenland shrimp and fish survey. In West Greenland each strata is divided in depth strata of 150–200 m, 200–300 m, 300–400 m and 400–600 m. "Shallow" water strata of 0–100 m and 100–150 m are delimited by the 3 nm line (not shown) and the NAFO divisions.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

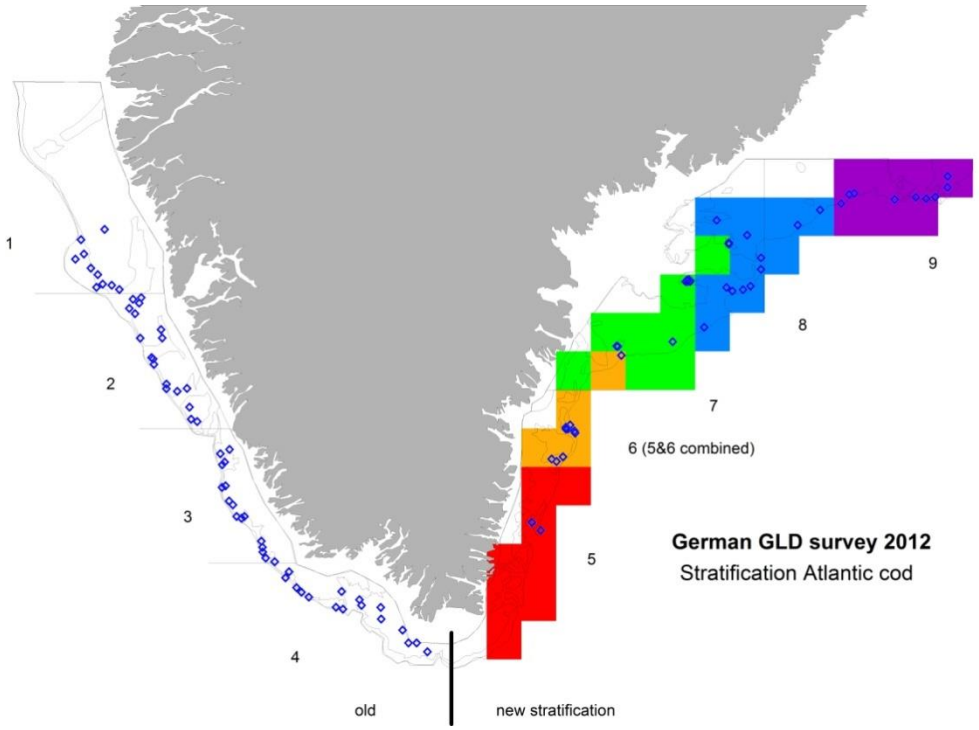

Figure B.3.2. The Stratification areas used in the German Greenland groundfish survey. Each stratum is divided into two depth zones, 0–200 m and 201–400 m.

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

This stock has not previously been subject to a full analytical assessment. However, as age disaggregated data are available from two surveys and commercial catches in combination with a good understanding of migration, recruitment and general biological information an assessement model should be feasible. Prior to the 2018 benchmark (IBPGCod) the state-space model SAM (Nielsen and Berg, 2014) was explored as an assessment model. Early results were compared to SPiCT model runs and both approaches produced comparable results. SAM was explored further as it provides an age disaggrated approach.

C.2 Model used as basis for advice

The stock is assessed using the SAM model.

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 XX

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	1–10+	Mean 2008–2016
		2008–present	1–10+	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–present	1–10+	No
Natmor	Natural mortality	1973–present	1–10+	No, but differentiated by age.

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 belived 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.

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 have autocorrelation structure of order 1 (AR1) to mimic some degree of parallel time-series of fishing mortalities in different age groups. Applying this greatly improved the model in terms of AIC compared to an independent structure.

The model is tuned with two surveys (Table below)

Tuning data:

TYPE	NAME	YEAR RANGE	AGE RANGE
Tuning fleet 1	GRL-GFS	2008–present	1–9+
Tuning fleet 2	GERMAN NAME	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 asummes 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 $B_{trigger}$	14 803 t	The default option of B_{pa}.	ICES advice technical guidelines
	F_{MSY}	0.46	EQSim analysis based on recruitment period 1973–2014	ICES advice technical guidelines
Precautionary approach	B_{lim}	10 354 t	Type 1 S-R relationship	IBPGCod 2018
	B_{pa}	14 803 t	B_{lim} * exp(1.645 * σ), σ = SD of ln(SSB) estiamted by SAM for 2016	IBPGCod 2018
	F_{lim}	2.34	EQSim analysis based on recruitment period 1998–2014	
	F_{pa}	1.33	F_{lim} * exp(-1.654 * σ), σ = SD of ln((F) estimated by SAM for 2016 for 2016	IBPGCod 2018

H. Other Issues

There are no other issues.

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