Stock Annex: Stock Annex: Cod (Gadus morhua) in NAFO Subarea 1, inshore (West Greenland cod)

Stock specific documentation of standard assessment procedures used by ICES.

Stock:	Cod
Working Group:	North Western Working Group (NWWG)
Last revised:	26/02/2018
Timeline of revisions:	Last revised during IBPGCod
Main revisions:	New assessment and Biological Reference Points
Last benchmark:	IBPGCod 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).

All stocks to some extent use the inshore area as a nursery ground. Tagging information shows, that cod tagged deep in the fjords tend to stay (i.e. they are inshore cod), whereas cod tagged in the coastal region are a mix of the different cod stocks (Storr-Paulsen *et al.*, 2004). Because of distinct homing behaviour for all stocks, the stock entitites remain genetically unique. Recent genetic studies have continuously demonstrated this stock mixing both in surveys and in the catches (Henriksen, 2015; GINR unpublished data). However, no apparent morphological distinction is possible, although local fishermen are clear in their distinction of morphotypes, but these seem to be related to environment rather than genetics (Hedeholm *et al.*, 2016).

Within the inshore area, spawning takes place in several fjords, with major spawning areas indentified in Nuuk and Sisimiut. These are also the areas with yearly surveys.

Until 2012 cod in the inshore area in West Greenland was considered part of a larger offshore stock complex with West and East Greenland. Hence, advice was given for the whole area. Since 2012 the assessment area of the inshore West Greenland cod is defined as the area inside the baseline comprising NAFO Division 1A-1F (Figure A.1.).

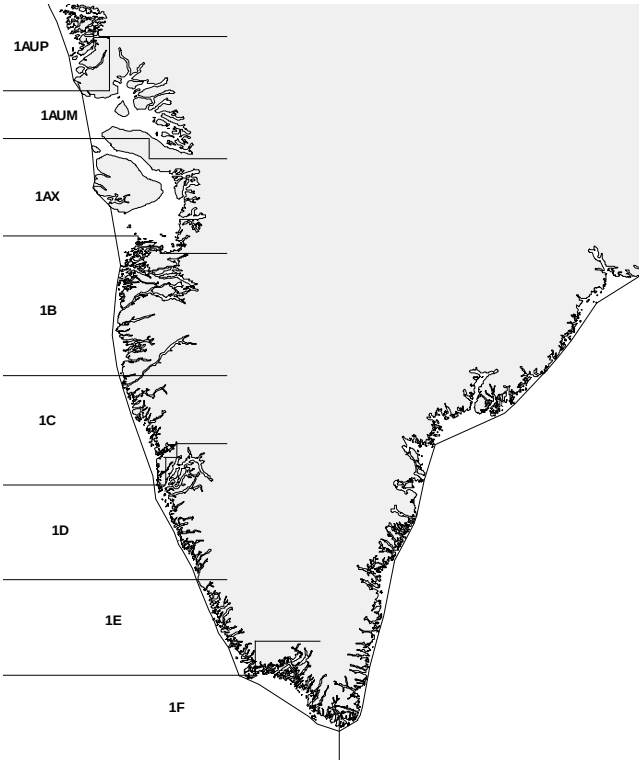

Figure A.1. NAFO divisions in West Greenland with baseline.

A.2. Fishery

A.2.1 General description

The inshore Greenland commercial cod fishery in West Greenland started in 1911 by opening cod trading facilities where cod seemed to occur regularly. The fishery expanded over the next decades with the addition of new trading facilities. Annual catches above 20 000 t have been taken inshore during the period 1955–1969 but declined to around 5 000 t in the 1970s. In the 1980s catches fluctuated between 5 000 and 35 000 t, partly driven by a few strong year classes (1979 and 1984) entering from the offshore stock (Horsted, 2000). From 1993 to 2001 the inshore catches were low, in the range 500–2 000 t. In the 2000s catches have gradually increased and currently exceeds 30 000 t (Figure A.2.1.1).

The most important gear has been pound-net (between 60% and 80% of the annual catches). These are anchored to the shore and fishing the upper 20 m. Due to ice poundnets are replaced by jigs, longlines and gillnets during November-April. Trawling is not allowed within 3 nm off the baseline. The fishery is carried out along the entire coastline of West Greenland from Disko Bay to Cap Farewell, with the majority of the catches being taken in mid-Greenland (NAFO areas 1B-1D).

In recent years the fishery has expanded north, and catches in this area are to a large extent caught as bycatch in the Greenland halibut fishery.

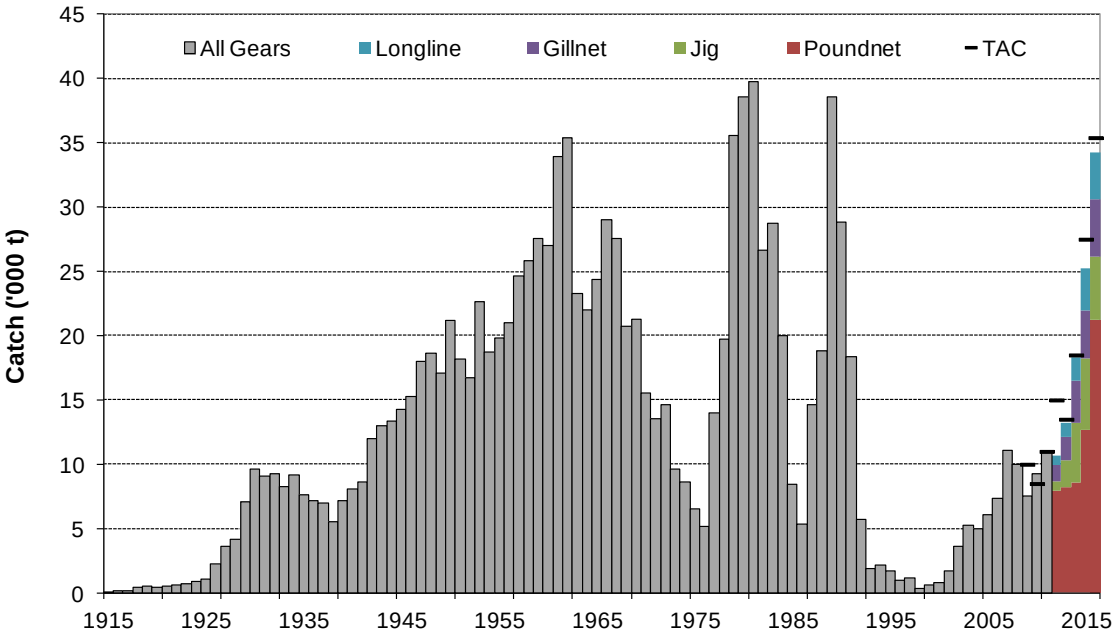

Figure A.2.1.1: Total cod catches in the inshore fishery. From 2012 divided into gears.

A.2.2. Fishery management regulations

Coastal vessels in the inshore fishery are defined as vessels below 75BT/120BT. No licence was required until 2009 and the fishery has historically not been constrained by a TAC. From 2009–present there has been a TAC, but this is often increased during the fishing year when the quota limit is reached. A minimum landing size of 40 cm has been enforced for decades. All landings are reported, no discarding is assumed to take place and the data quality is considered high. There are no season or area closures.

Information on landings in weight are compiled and processed by the Greenland Fisheries Licence Control (GFLK). Inshore catches are in addition documented by sale slips and from logbooks which have been mandatory since 2008 for vessels larger than 30 ft.

A.3. Ecosystem aspects

There is little bycatch in the poundnet or jig fishery. Additionally, fish below the minimum size are easily released from the poundnets and are believed to survive. Poundnet selectivity means that fish ages six and older are not caught in proportion to the stock composition.

Cod in the inshore region feed on a several prey items, but the summer spawning of capelin in shallow water seems to be linked to intense feeding from cod (GINR unpublished data). There is no quantification of the predatory impact of cod, but as capelin in the inshore area are not commercially exploited there are no possible regulations.

B. Data

B.1. Commercial catch

The main fishing gear of these vessels are pound nets that catch live fish until the nets are saturated and information on CPUE from this type of fishing gear is therefore questionable. Information from vessels smaller than 30 ft are only from sale slips, and until 2011 these where of poor quality, meaning that catches where compiled using landing data from the factories with no information on effort, gear type or fieldcode of actual catch. From 2012 the quality of sale slips has improved and includs information on effort, gear type and fieldcode of each catch that is landed to a factory. The preferred gear used by small dinghies is jigs and CPUE from this type of fishing gear is questionable.

Sampling of length frequencies and information on age, weight and maturity is collected and compiled by the Greenland Institute of Natural Resources. A well-balanced sampling of the Greenland coastal fleets catches has always been impeded by the geographical conditions, i.e. the existence of many small landing sites separated along the over 1000 km coast. Except for the Nuuk area that is easily covered sampling relies on dedicated sampling trips supplemented with ad hoc sampling. The sampling coverage was especially poor in the late 1990s when catches were very low (<1 000 t annually) and length frequencies are missing in 1998 and 2001. The sampling coverage has improved since around 2004 through a formal cooperation with GFLK observers. Currently, sampling is considered adequate to reliably describe the age composition of the catches.

To facilitate the ICES procedure, cathes 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 some recreational catches, but these are considered negligible.

B.2. Biological sampling

B.2.1 Maturity

Due to large variation between years iregarding number of maturity samples - some years with little or no sampling - it is not possible to generate a year specific maturity ogive (Table B.2.1.1). Maturity information prior to 2000 is only available for November in 1987 (n = 484). From a more recent period maturity information is available from the spawning season (April and May) since 2007, especially in 2010 and 2011 where dedicated sampling of maturity data was conducted. The maturity ogive for the two periods (1987 versus 2007–2016) was estimated by a general linear model (GLM) with binomial errors. The ogives for the two periods are estimated to be different. L_{50} from 1987 was 5.07 years (SE = 0.18), and for 2007–2016 L_{50} was 4.32 years (SE = 0.04). It was decided to use the years with very low catches (600–800 tonnes) as transition years between the two maturity ogives. The maturity ogive for the period 1976–2006 was set

constant to the estimated 1987 ogive. For the remaining period (2007–2016) the maturity ogive was fixed at the 2007–2016 estimates.

Even though the maturity ogive for the period 1976–1999 is based on few fish caught outside spawning season it was decided to use this as this maturity ogive is supported by earlier maturity ogives from the 1930'ies that have a similar L_{50} (Hansen, 1949).

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

Year	Number	Year	Number
1987	484	2007	102
		2008	485
		2009	386
		2010	828
		2011	882
		2012	207
		2013	204
		2014	305
		2015	8
		2016	296
		Total	3326

Table B.2.1.2: Maturity ogive by age

Age group	Proportion mature 1976-2006	Proportion mature 2007-present
1	0.000	0.000
2	0.011	0.077
3	0.045	0.196
4	0.171	0.415
5	0.475	0.674
6	0.799	0.858
7	0.946	0.946
8	0.987	0.981
9	0.997	0.993
10	0.999	0.998

B.2.2. Natural mortality

Natural mortalty is differentiated by age, but fixed at 0.2 for all ages. Tagging data show, that there is migration from the coastal area to offshore regions (ICES, 2018). However, cod tagged in the deeper parts of the fjord are to a very large extent stationary. Hence, natural mortality for the inshore cod is set at the default value of 0.2 except for the 1984 yearclass. This yearclass disappears vey rapidly from the catches and anecdotal information also suggests that the cod apparently disappeared "over night". Since this migration is driven by homing to spawning grounds in offshore areas, the natural mortality was set at 0.2 for age groups 1–5 and 0.4 for older age groups for this yearclass.

B.2.3. Weight–at–age

Mean stock weight-at-age data are based on the Greenland inshore gill net survey. The data are collected every year.

The catch mean weights are set equal to the stock mean weights. There is insufficient data available from the commercial fishery to estimate the weights in the catches. However, the survey and main gear (poundnet) are in the same area and depth, and should be targeting the same fish.

B.2.4. Recruitment

The West Greenland inshore gill net survey is a recruitment survey, primarily targeting ages 2 and 3. Due to the inflow of cod from other stocks to the area, the survey will catch cod that eventually recruit to other areas. However, recent studies show, that the fish caught in the survey are primarily inshore cod, and therefor the survey is considered a reliable indicator of inshore recruitment. The reason for this is probably, that the stations contributing most to the index values, are located in the inner parts of the fjords and these are apparently "clean" inshore cod areas.

B.3. Surveys

A multi meshed gillnet survey designed to target juvenile cod age 2 and 3 yrs old in the inshore area in West Greenland has been conducted annually since 1987. The objective of the survey is to assess the abundance and distribution of recruiting cod. However, given the different ways of being caught in a gillnet other than being gilled the selectivity is not entirely dome shaped but elongated towards larger fish. Therefore, gillnet catches of older fish ages 1–5 were included in the data set.

The survey uses gangs of gillnets with different mesh sizes (16.5, 18, 24, 28 and 33 mm, ½ mesh). 100–150 nets are set annually and are set parallel to the coast in order to keep the depth constant. The survey effort is allocated evenly between the depth zones of 0–5 m, 5–10 m, 10–15 m and 15–20 m. The abundance index used in the survey is defined as 100*(# caught/net*hour).

Historically three areas were covered: north west (Sisimiut, NAFO Division 1B), mid west (Nuuk, NAFO Division 1D) and south west (Qaqortoq, NAFO Division 1F). South Greenland has only been covered in the period 1987–1995, 1998, 2000 and 2007–2009 and due to very scarce data from this survey this area is not included as a tuning fleet.

Due to local stock dynamics for each fjord complex the survey is split into two survey indices as follows:

- NAFO Division 1B, survey index for the period 1987–1998, 2002–2007 and 2010–2016. In 1999–2001 and 2008–2009 no survey was conducted.
- NAFO Division 1D, survey index for the period 1987–2016 except in 2002 and 2007 where no survey was conducted.

There is generally little agreement in cohort tracking between the two areas. This might be due to different population dynamics in NAFO Division 1B (Sisimiut area) and 1D (Nuuk area).

Genetic investigations of the cod caught in the survey in 2016 showed a clear dominance of fish from the West Greenland inshore stock component (>70%). The West Greenland offshore component is the only other stock with a contribution above 10% (GINR, unpublished data). The survey indices are therefore primarily an expression of the status of the inshore cod stock than the fishable stock which is more a mix of the different cod stocks.

B.4. Commercial CPUE

Commercial CPUE data are not available.

B.5. Other relevant data

None

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 a survey 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 multi meshed gillnet survey indices designed to target juvenile cod in the inshore area in West Greenland; one covering north west (Sisimiut, NAFO division 1B) and one covering mid west (Nuuk, NAFO division 1D). No commercial fleets with effort information are used. The available data are listed in the table below.

TYPE	NAME	YEAR RANGE	AGE RANGE	VARIABLE FROM YEAR TO YEAR
Caton	Catch in tonnes	1976–present	1–10+	Yes
Canum	Catch-at-age in numbers	1976–present	1–10+	Yes

Weca and West	Weight-at-age in the commercial catch and stock	1976–present	1–10+	Yes
Mprop	Proportion of natural mortality before spawning	1976–present	1–10+	No, set at 0.
Fprop	Proportion of fishing mortality before spawning	1976–present	1–10+	No, set at 0.
Matprop	Proportion mature at age	1976–2006 2007–present	1–10+	No, but with two periods.
Natmor	Natural mortality	1976–present	1–10+	No, but 1984 YC set to 0.4 for ages 6 and older. Else 0.2.

Mean weight-at-age in the stock are primarily calculated from survey sampling. Due to insufficient sampling from the fishery mean weigth-at-age in catch is set equal to stock mean weight-at-age. No data were available for 1998 and 2001. In these years mean values of the previous period have been used. Missing values in the mean weigth at catch matrix were replaced by mean values of the previos nearest period.

No discarding is belived to take place.

The natural mortality is estimated at 0.2 for all ages. However, to account for the observed emigration of the big 1984 year class, a value of 0.2 was added to M for ages 6 and older.

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.

An independent correlation structure of fishing mortalities across ages was applied.

The model is tuned with two surveys (see table below)

Tuning data:

TYPE	NAME	YEAR RANGE	AGE RANGE
Tuning fleet 1	1B	1987–present	1–5
	Except	1999–2001, 2008–2009	
Tuning fleet 2	1D	1987–present	1–5
	Except	2001, 2007	

Since the years with missing data differ between areas, it was not possible to combine the surveys without estimating the missing values in the catch-at-age matrix. Therefore the surveys are used as separate input. Because of the survey selectivity, only ages 1-5 are used. Based on the catches, there is information in all these age groups. Within this age range, the surveys show good internal consistency (Figure C.3.1.)

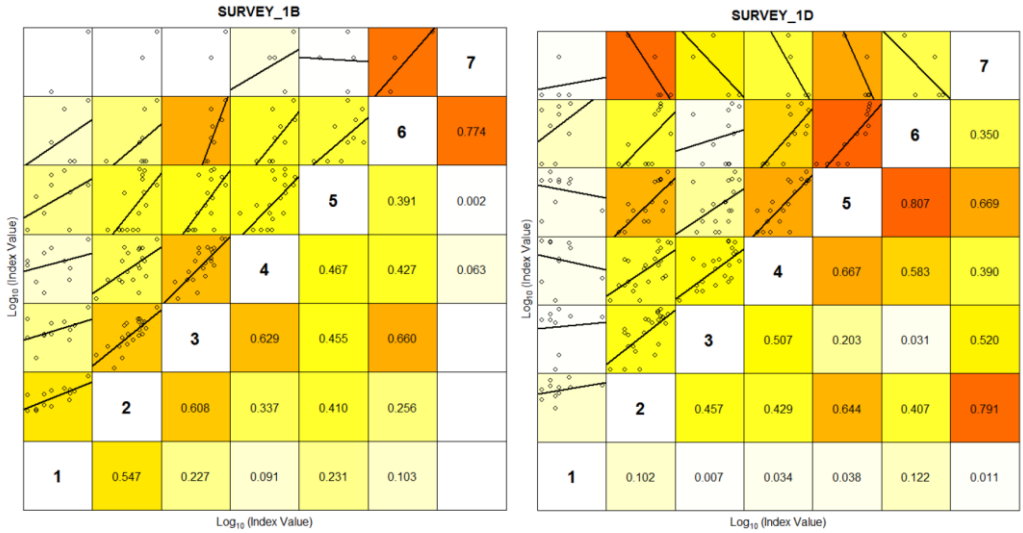

Figure C.3.1: Internal consistency plots for the West Greenland inshore gill net survey. Left: Sisimiut. Right: Nuuk

The model output shows that single years with relative high catches were outside the modelled confidence limits of the catch. SAM appeared not to "believe" in these high catches although catches in general are considered relative precise for this stock. Instead these single high catch years are most likely a result of a net immigration of cod from the offshore area in some years. Hence, the gill net survey, being primarily a recruitment index, does not catch these fish and based on genetics, the survey also appears to be driven by the inshore stock. It was partly possible to reduce this discrepancy by assuming an autocorrelation structure of the fishing mortality across ages or restrict the catch variance in recent years. At IBPGCod (ICES, 2018) it was decided to accept that SAM did not mirror these single years catches because the objective of the assessment is to be a stock assessment and not an area assessment.

C 3.1. Model Options chosen:

A configuration file is used to set up the model run once the data files, in the usual Lowestoft format, have been prepared. The file has the following form:

```
# Configuration saved: Mon Sep  4 10:38:33 2017
$minAge
# The minimium age class in the assessment
 1
$maxAge
# The maximum age class in the assessment
 10
$maxAgePlusGroup
# Is last age group considered a plus group (1 yes, or 0 no).
 1
$keyLogFsta
# Coupling of the fishing mortality states (nomally only first row is used).
 -1 -1  0  1  2  3  4  5  6  6
 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
$corFlag
# Correlation of fishing mortality across ages (0 independent, 1 compound symmetry, or 2 AR(1)
 0
$keyLogFpar
# Coupling of the survey catchability parameters (nomally first row is not used, as that is covered by fishing
mortality).
 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
  0  1  2  3  4  5 -1 -1 -1 -1
  6  7  8  9  10 11 -1 -1 -1 -1
$keyQpow
# Density dependent catchability power parameters (if any).
 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
$keyVarF
# Coupling of process variance parameters for log(F)-process (nomally only first row is used)
  0  0  0  0  0  0  0  0  0  0
 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
$keyVarLogN
# Coupling of process variance parameters for log(N)-process
 0 1 1 1 1 1 1 1 1 1
$keyVarObs
# Coupling of the variance parameters for the observations.
 0 0 0 0 0 0 0  0  0  0
 1 1 1 1 1 1 -1 -1 -1 -1
 2 2 2 2 2 2 -1 -1 -1 -1
$obsCorStruct
# Covariance structure for each fleet ("ID" independent, "AR" AR(1), or "US" for unstructured). | Possible values
are: "ID" "AR" "US"
 "ID" "ID" "ID"
$keyCorObs
# Coupling of correlation parameters must be specified if the AR(1) structure is chosen above.
 NA NA NA NA NA NA NA NA NA
 NA NA NA NA NA -1 -1 -1 -1
 NA NA NA NA NA -1 -1 -1 -1
$stockRecruitmentModelCode
# Stock recruitment code (0 for plain random walk, 1 for Ricker, and 2 for Beverton-Holt).
 0
$noScaledYears
# Number of years where catch scaling is applied.
 0
$keyScaledYears
```

```
# A vector of the years where catch scaling is applied.
$keyParScaledYA
# A matrix specifying the couplings of scale parameters (nrow = no scaled years, ncols = no ages).
$fbarRange
# lowest and higest age included in Fbar
 4 8
$keyBiomassTreat
# To be defined only if a biomass survey is used (0 SSB index, 1 catch index, and 2 FSB index).
 -1 -1 -1
$obsLikelihoodFlag
# Option for observational likelihood | Possible values are: "LN" "ALN"
 "LN" "LN" "LN"
$fixVarToWeight
# If weight attribute is supplied for observations this option sets the treatment (0 relative weight, 1 fix variance
to weight).
 0
```

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 in two periods; before and after 2007. Projections will use the "new" ogive.
Natural mortality	Natural mortality is fixed at 0.2 for all ages.
F and M before spawning	Both taken as zero.
Weight-at-age in the catch	Average of final twenty years of assessment data.
Weight-at-age in the stock	Average of final twenty years of assessment data
Exploitation pattern	F pattern rescaled to catch assumption in the intermediate year. Several F options explored, including F_{MSY}. Selection pattern based on last five year average.
Intermediate year assumptions	Catch set according to the TAC.
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

For estimating B_{lim} a categorization of the stock-recruitment relationship into type is required (ICES, 2017). The group agreed that the Type 2- S-R relationship corresponded best to the stock- recruitment relationship with a wide dynamic range of SSB and evidence that recruitment is or has been impaired. According to this SR type B_{lim} is based on the breakpoint in a segmented regression. This gave a B_{lim} of 4 346 t.

Data from the SAM assessment agreed at IBPGCod (ICES, 2018) were used for the simulations. The Eqsim software was used to define PA and MSY reference points. The text table below provides the simulation settings and the justification. The number of simulations was set to 2000, scanning F from 0 to 5 divided into 101 intervals.

Framework	Reference point	Value	Technical basis	Source
MSY approach	MSY $B_{trigger}$	5 984 t	B_{pa}	ICES advice technical guidelines
	F_{MSY}	0.27	EQSim analysis based on the recruitment period 1973–2016.	ICES advice technical guidelines
Precautionary approach	B_{lim}	4 346 t	Breaking point in segmented regression using the period 1973-2016.	IBPGCod 2018
	B_{pa}	5 983 t	B_{lim}*exp(sigmaSSB*1.645), sigmaSSB=0.194	IBPGCod 2018
	F_{lim}	3.61	Equilibrium F, which will maintain the stock above Blim with a 50% probability.	
	F_{pa}	2.39	F_{lim}*exp(-sigmaF*1.645), sigmaF=0.252	IBPGCod 2018

H. Other Issues

There are no other issues.

I. References

Hansen, P.M. (1949). Studies on the Biology of the Cod in Greenland Waters. B. Luno.

Hedeholm, R.B., Jacobsen, R.B., Nielsen, E.E. 2016. Learning from 'apparent consensus' in TAC disputes: Exploring knowledge overlaps in LEK and genetic categorization of Atlantic cod. Marine Policy 69: 114-120.

Henriksen, O. 2015. Genetic insights into the population composition of two regional inshore mixed stocks of Atlantic cod (*Gadus morhua*) in West Greenland. Master thesis. Technical University of Denmark, Silkeborg, Denmark. 82 pp.

Horsted, S.A. (2000). A review of the cod fisheries at Greenland, 1910-1995. Journal of Northwest Atlantic Fishery Science 28: 1-109.

ICES 2017. ICES fisheries management reference points for category 1 and 2 stocks. DOI: 10.17895/ices.pub.3036

ICES. 2018. Report of the Working Group on Inter-benchmark Protocol on Greenland cod (2018), 8-9 Januar, Copenhagen, Denmark. ICES CM 2018/ACOM:xx. 22 pp.

Nielsen A, Berg CW. 2014. Estimation of time-varying selectivity in stock assessments using state-space models. Fisheries Research. 158: 96-101.

Storr-Paulsen, M., Wieland, K., Hovgård, H., and Rätz, H. J. 2004. Stock structure of Atlantic cod (Gadus morhua) in West Greenland waters: Implications of transport and migration. ICES Journal of Marine Science, 61: 972–982.

Therkildsen N. et al. 2013. Spatiotemporal SNP analysis reveals pronounced biocomplexity at the northern range margin of Atlantic cod *Gadus morhua*. Evolutionary Applications. Doi: 10.1111/eva.12055