Stock Annex: Cod (Gadus morhua) in NAFO area 1, West Greenland Offshore Spawning Cod

Stock: West Greenland Offshore spawning cod (*Gadus morhua*, NAFO subarea) (Cod.21.1.osc)

Working Group: North-Western Working Group (NWWG)

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A. General

A.1. Stock definition

ICES advice is given for three separate cod stocks in Greenland waters:

1) West Greenland Offshore Spawning Cod (hereafter called WOSC)
2) East Greenland and Iceland Offshore Spawning Cod (hereafter called EGIOSC)
3) West Greenland Inshore Spawning Cod (hereafter called WISC)

Extensive mixing occurs in West Greenland especially in the inshore area (Buch et al. 2023). Genetic and tagging data (Stor-Paulsen *et al*. 2003, Hedeholm 2018) combined with survey data show that the EGIOSC stock typically migrate eastwards out of West Greenland waters at onset of spawning at age 5-6 yrs. The WOSC stock has its spawning sites on the offshore banks in West Greenland but do migrate inshore both as juveniles and adults. The WISC stock will to a large extent stay inshore. The inshore area is therefore a mixing area of all three stocks whereas the offshore area is primarily a mixing site for the WOSC and the EGIOSC stocks (figure A.1.1).

The assessment for the WOSC stock does not distinct between the offshore and inshore area but covers both areas in West Greenland.

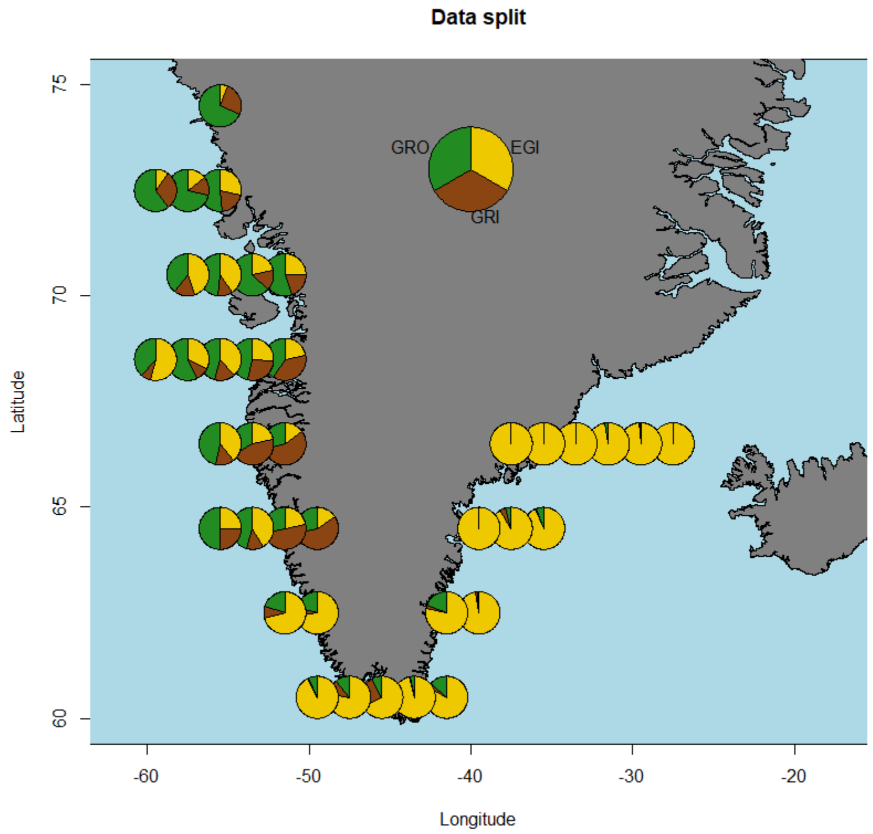

Figure A.1.1. Map of Greenland with piecharts showing the proportion of each of the three cod stocks based on the individual cod sample for genetics from both commercial fisheries and scientific surveys in the period 2000-2021.

A.2. Fishery

A short historical review

The inshore fisheries in West Greenland started in 1911 (figure A.2.1). The fishery has fluctuated through time, with four peaks that reached a maximum of 35,000 – 40,000 tons in the 60ies, the beginning of the 80ies, beginning of the 90ies and lastly in 2016. The peaks were followed by a sharp decline in catches, especially in the 80ies and 90ies, where the catches were below 1,000 tons. This lasted until the beginning of the 00ies where the fishery increased.

The West Greenland offshore fishery in the last century started in 1924 (Figure A.2.1). The fishery rapidly expanded to reach 120,000 t in 1931; a level that remained for a decade (Horsted, 2000). During World War II, landings decreased by 1/3 as only Greenland and Portugal participated in the fishery. From the mid-1950s to 1960, the total annual landings taken offshore averaged about 270,000 tons. In 1962 the offshore landings culminated with landings of 400,000 tons. After this historic high, landings decreased sharply by 90% to 28,000 tons in 1976 and even further down to 15,000 tons in 1980. An annual catch of 50,000 tons have only later been exceeded in 1977–1979 and 1988–1990 due to a few strong year classes. During 1989–1992, the fishery, which almost exclusively depended on one YC (1984 YC), shifted from West to East Greenland.

The fishery in East Greenland (ICES subarea 14b) started in 1954 (Figure A.2.1) and has never reached the same heights as in West Greenland. Landings of 20,000–35,000 tons dominated until the early 1970s, followed by a decrease to 10,000–30,000 tons until the early 1990s, supported by the large year classes in 1973 and 1984. The entire fishery in East Greenland completely collapsed in 1991, and cod was only caught as bycatch in the redfish and Greenland halibut fishery in East Greenland until the mid-2000s.

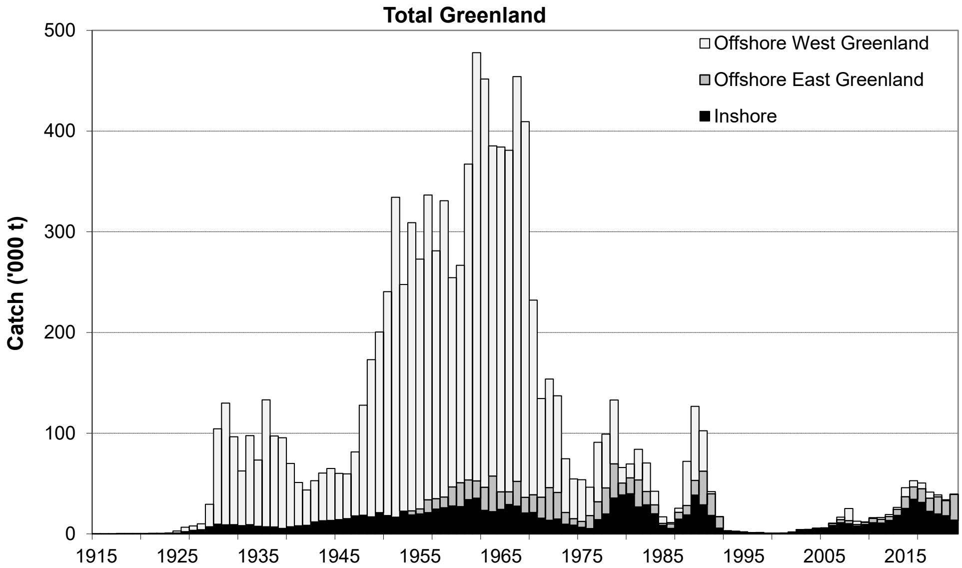

Figure A.2.1. Landings in Greenland divided into 3 areas; Offshore West Greenland, Offshore East Greenland and Inshore West Greenland.

The present fishery

The catches in West Greenland (both offshore and inshore) have been split into the three stocks, WOSC, WISC and EGIOSC from 2000. The split is based on genetic samples and a GAM model (see section B4). Here is described the catch of the WOSC stock.

The catch of the WOSC stock started from almost zero in 2000. In 2001 there were no samples from the fishery and hence no split by stock can be made for this year. The catch steadily increased from below 2,000 tons pr year to a maximum of 13,000 tons in 2016 and 2017 (figure A.2.2). Hereafter the catches have declined.

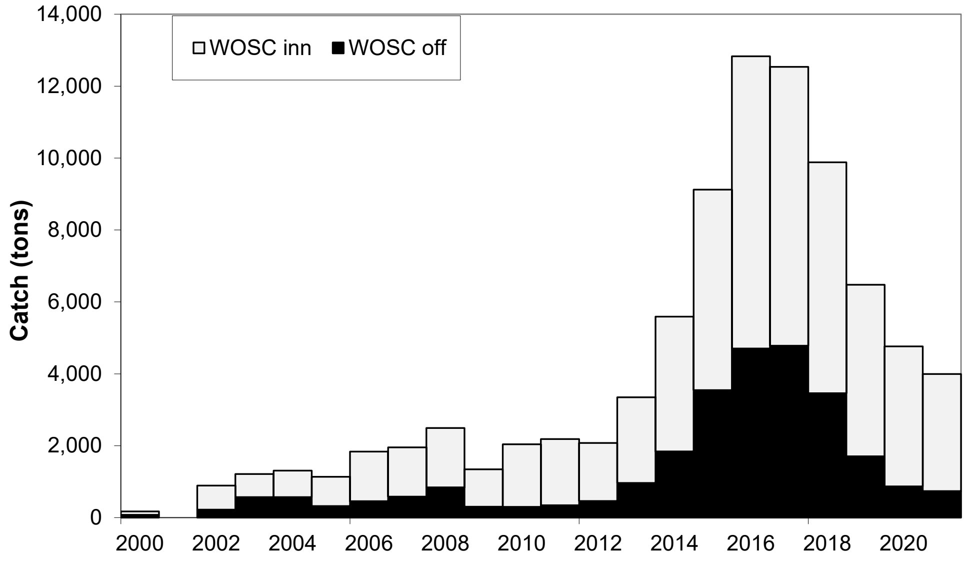

Figure A.2.2. Catch of the Offshore West Greenland cod stock (WOSC) in the inshore and offshore area in West Greenland. No samples from the fishery in 2001.

The WOSC stock is mainly caught in the inshore fishery (average 70%, figure A.2.2). The most important gear in the inshore fishery is pound nets (taking app. 60-80% of the annual catches) anchored at the shore and fishing the upper 20 m. Due to the ice conditions and vertical migration of cod, pound nets are not used during November-April. The inshore fishery uses long-lines, jigs and gillnets in autumn and winter. The catches usually peak in summer and are lowest during late winter or early spring, when the lumpfish fishery dominates. About half of the catches are taken by small dinghies. The other half of the catches are taken by larger vessels (cutters).

The offshore fleet consists of larger vessels where bottom trawl and longline is the main gear used.

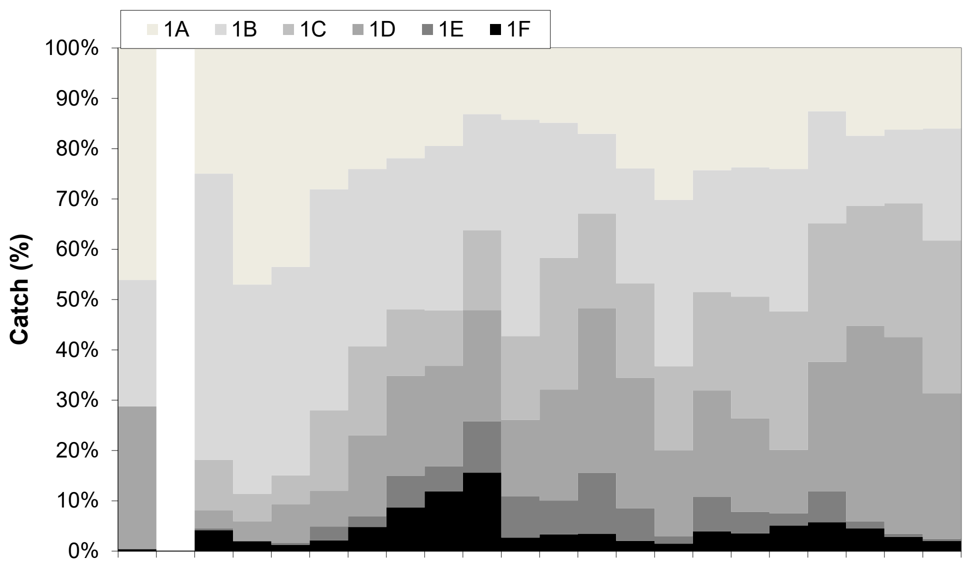

Figure A.2.3. Proportion (%) of catch of the Offshore West Greenland cod stock (WOSC) by NAFO divisions (1A-1F) in West Greenland. NAFO division 1A furthest to the north. No samples from the fishery in 2001.

The WOSC stock is mainly distributed in the mid and northern part of West Greenland corresponding to NAFO divisions 1A-1D where in average 90% of the total catch of WOSC is caught (figure A.2.3).

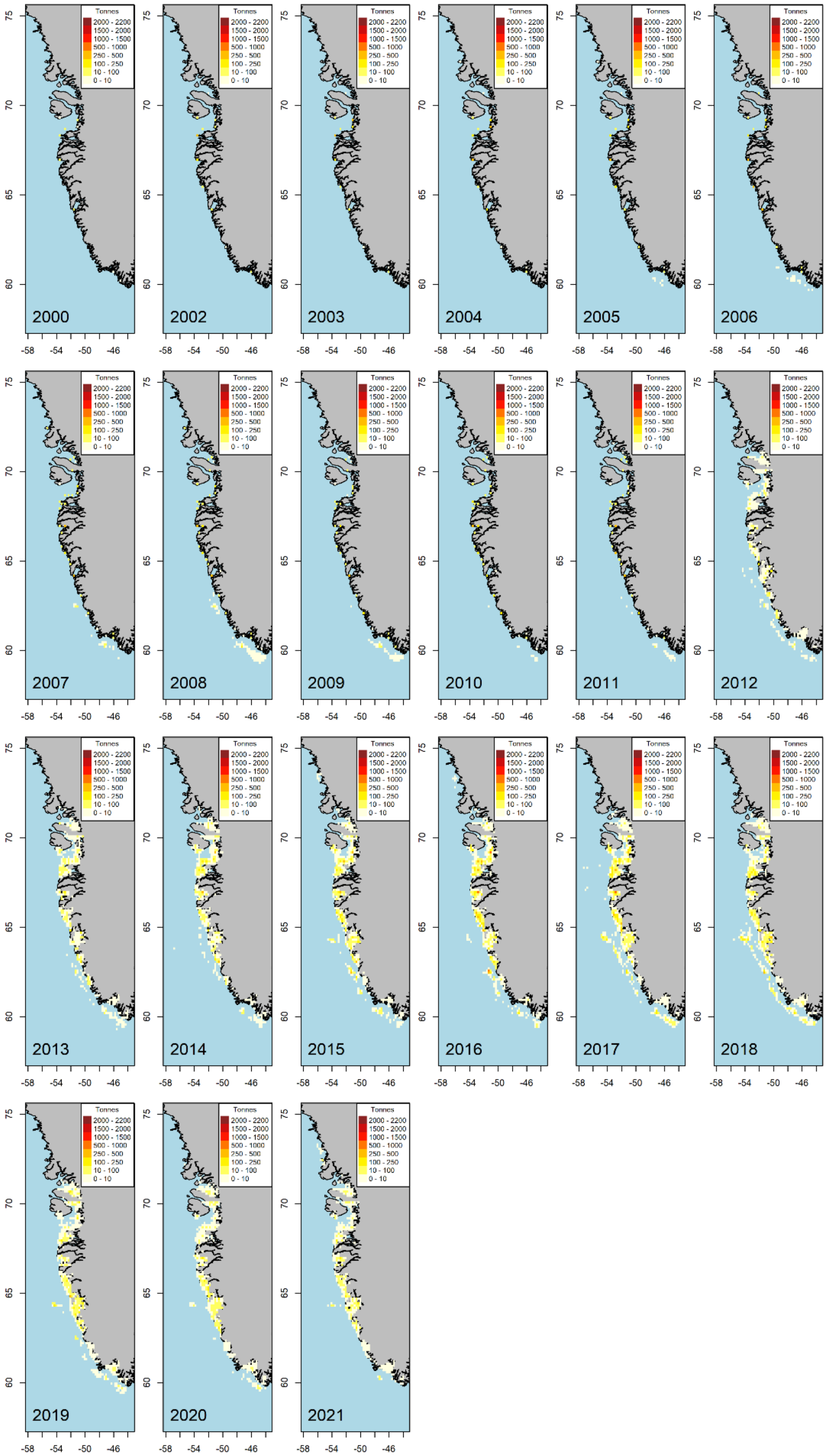

Figure A.2.4: Catch (tons) by field code in West Greenland 2000-2021 for the West Greenland Offshore stock (WOSC).

In the northern part of West Greenland (north of NAFO division 1C) the WOSC stock is exclusively fished in the inshore area (figure A.2.4).

Fishery management regulations

The coastal fisheries did not require a license until 2009 and have historically not been constrained from catch ceilings. In 2009 a TAC of 10,000 tons was introduced, and since, yearly TAC has been used. In general, however, when the TAC is fished, additional tons are added, increasing the TAC over the year. This situation happened in 2010-2011 and 2014-2016. From 2016 to 2019 it was allowed to fish offshore both in West and East Greenland on the inshore quota, but limited amount (less than 500 tons) was fished. Trawling is not allowed within 3 nm off the baseline (figure A.2.5), and vessels above 75BRT/120BT are not allowed to fish within the 3 nm-line off the baseline.

Vessels in the offshore fisheries are vessels above 75BT/120BTand restricted to the area more than 3 nm off the baseline. The vessels require a license that stipulates a unique vessel quota. No directed offshore fishery was allowed for the period 1993–2005. Since 2005 the offshore area in West Greenland has been subjected to partial closures leaving the southern part (corresponding to NAFO division 1F) open to fishery.

Figure A.2.5: Map of Greenland with NAFO divisions in West and Q division in East. 3 NM line of the baseline, the EEZ and depth curves are indicated.

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.

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). Sales slips document inshore catches, but logbooks have been mandatory since 2008 for vessels larger than 30 ft. The main fishing gear of these vessels is pound nets that catch live fish until the nets are saturated. Information on CPUE from this type of fishing gear is therefore questionable. Information from vessels smaller than 30 ft is only from sale slips. Until 2011, these were of poor quality, meaning that catches were compiled using landing data from the factories with no information on the effort, gear type or field code of the actual catch. Since 2012, the quality of sale slips has improved and includes information on the effort, gear type and field code (7.5 min and 15 min per Lat Lon, respectively, figure A.2.4) of each catch that is landed at a factory.

Sampling of length frequencies and information on age from the inshore catches, weights and maturities are collected and compiled by the Greenland Institute of Natural Resources. A well-balanced sampling of the Greenland inshore catches has always been impeded by the geographical conditions, i.e., the existence of many small landing sites separated along the over 1,000 km coast. Except for the Nuuk area in NAFO division 1D (Figure A.2.5), which is easily covered, sampling relies on dedicated sampling trips supplemented with ad hoc samplings when ports are called through other institute activities.

The offshore information is available on the haul-by-haul scale provided by logbooks. The ship crew collect individual measurements (length, weight, and gutted weight) and biological samples, such as otoliths, from randomly selected cod in the catches. This has been a part of the license requirements since 2011. From these collections, length and age frequencies are constructed.

Catch and weight at age are compiled on NAFO division (Figure A.2.5) in West Greenland for the inshore and offshore areas separately. When there are no samples from a NAFO division, samples from the neighboring area is used. Length samples are weighted by gear and quarter of the year to catch when sampling allows it.

Collection of otoliths is often more complicated to archive than length measurements of the commercial catch, especially for the inshore area, as cod is often landed at the factory without a head. In years with poor sampling from the commercial fishery, information from otoliths collected from surveys in the area is used.

An overview of sampling from the fishery in the period used in the assessment (from 2000) is seen in tables B.1.1 and B.1.2.

Table B.1.1: Sampling of the Inshore fishery.

Year	Length Samples	N fish measured	Otolith samples from surveys	Otolith samples from fishery

2000	1	375	145	-
2001	No samples			
2002	21	10157	220	209
2003	22	4402	303	322
2004	4	1585	633	222
2005	9	1820	480	197
2006	34	9496	368	-
2007	69	19297	199	767
2008	41	8366	297	1226
2009	47	11541	425	1429
2010	50	11590	378	2332
2011	63	9572	1202	914
2012	79	13503	710	317
2013	68	11406	729	470
2014	49	6446	730	407
2015	115	21854	740	218
2016	110	21816	893	179
2017	110	15402	1407	-
2018	44	7168	1274	246
2019	98	17711	1212	297
2020	50	10192	891	84
2021	57	10082	1112	298

Table B.1.2: Sampling of the Offshore fishery in West Greenland.

Year	Length Samples	N fish measured	Otolith samples from surveys	Otolith samples from fishery
2004	No samples			
2005	8	1800	445	47
2006	No samples		988	35
2007	22	3081	793	83
2008	8	1277	1117	106
2009	40	7329	641	247
2010	25	4523	922	575
2011	46	5985	831	1199
2012	41	5601	750	671
2013	70	9045	980	437
2014	64	4727	898	748
2015	132	10312	1082	531
2016	67	3652	785	83
2017	234	32176	1071	1712
2018	157	21379	878	971
2019	65	9167	1317	642
2020	6	900	908	-

2021	No samples	-	-

The genetic composition of the three cod stocks in West Greenland (Buch et al. 2023) changes from south to north and inshore to offshore. Therefore, to calculate the catch of each stock, catch- and weight at age are compiled on field code level instead of the larger NAFO areas (Retzel et al. 2023). Field codes are squares of 7.5 minutes (0.125 degrees) latitude (North) and 15 minutes (0.25 degrees) longitude (West) (Figure B.1.1).

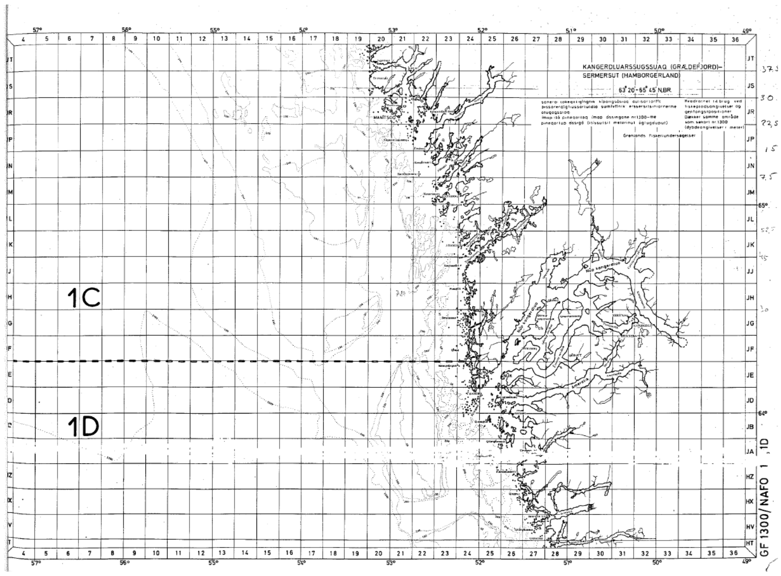

Figure B.1.1: Example of Field codes in the Nuuk area (NAFO division 1C and 1D).

For the inshore area, since 2012 and onwards, catch positions have been available by field code levels. From 2000-2011, catch areas are only known from factory locations. Nevertheless, as fishermen only sail short distances, we find it reasonable to assume that the catch landed at a factory is caught in a nearby area. Therefore, the field code of where the factory is situated is used as the catch field code for the period 2000-2011 (figure A.2.4).

For the offshore area, information on catches is on a haul-by-haul basis in logbooks with precise gps positions. These are compiled as catch by field code.

Discards estimates

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

Recreational catches

Recreational catches are considered low.

B.2. Biological

B.2.1 Maturity

Maturity stage of Atlantic cod in Greenland is classified after Tomkiewicz et al. (2002) from stage 1-9; 1-2 are juveniles, 3-4 is ripening, 5-7 is spawning and 8-9 is spent. For maturity ogive calculation stages 1-2 are juveniles and stages 3-9 are adult. Ogives are calculated on cod that has been genetically assigned (Buch et al 2023) and from spawning month (March, April, May and June) as there can be errors in classification between stage 2 and 9 outside spawning season. Due to low sampling size and no yearly genetic analysis in spawning season (table B.2.1.1), the proportion of mature fish by age is left unchanged from year to year (table B.2.1.2). The maturity ogives for WOSC was estimated by a general linear model (GLM) with binomial errors (using the glm function from 'The R Stats Package' version 4.0.5). Estimated A_{50} is 4.45 for WOSC.

Table B.2.1.1: Number of samples with information on maturity, age and genetic composition in March, April, May and June by year used in maturity ogive for the West Greenland offshore stock (WOSC).

Year	WOSC
2008	20
2010	66
2011	89
2012	53
2013	108
2016	154
2017	360
2018	148
2019	332
2021	128
Total	**1458**

Table B.2.1.2: Maturity ogive by age for the West Greenland offshore stock (WOSC).

Age group	WOSC
1	0.008
2	0.032
3	0.117
4	0.349
5	0.685
6	0.898
7	0.973
8	0.993
9	0.998
10	1.000

B 2.2 Natural mortality

Natural mortality is differentiated by age but fixed at 0.2 for all ages. Tagging data shows, that there is migration from the coastal area to offshore regions and further to East Greenland and

Iceland (Storr-Paulsen et al. 2004, Hedeholm, 2018). Genetic investigations have shown that the migration is limited to the East Greenland-Iceland offshore stock EGIOSC (Bonanomi *et al.* 2016) and has therefore no effect on the WOSC stock and natural mortality is by default set to value of 0.2.

B.3. Surveys

B 3.1 Trawl survey by Greenland (Greenland Shrimp and Fish survey (G2064)

Since 1992, GINR has conducted an annual stratified random bottom-trawl survey at West Greenland. The survey is designed to target shrimp and ground fish such as cod. Stations covers depths from 50-600 m and are annually allocated by a random stratified buffer method (Kingsley et al. 2004). The number of strata in West Greenland is 70 (figure B.3.1.1)

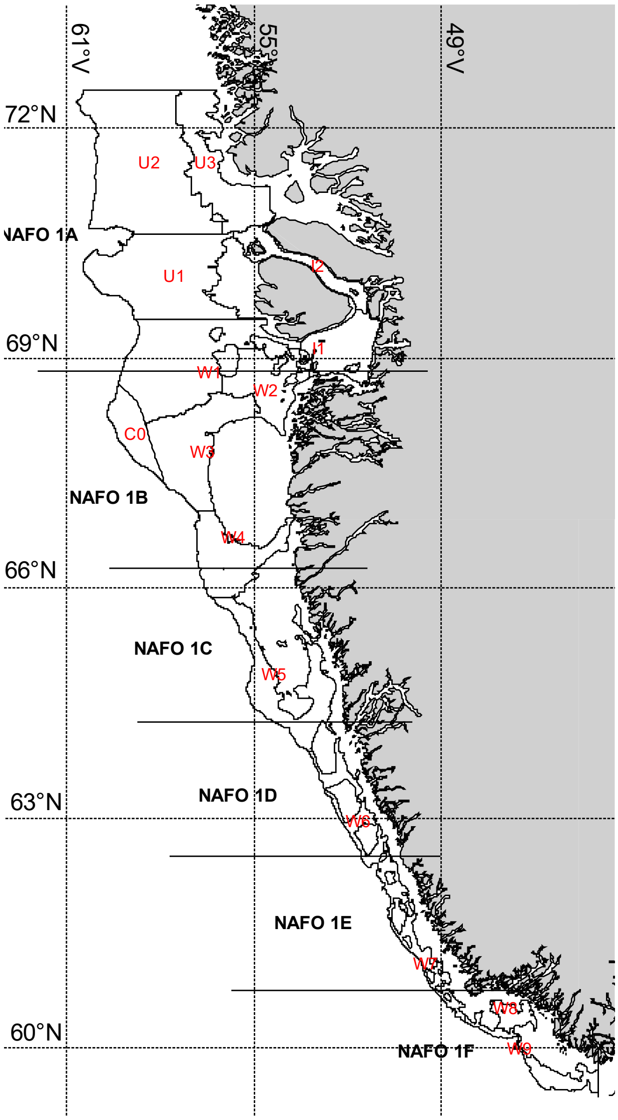

Figure B.3.1.1 The stratification areas used in the Greenland shrimp and fish survey. In West Greenland each strata is divided in depth strata of 150–200 m, 200–300 m, 300–400 m and 400–600 m. “Shallow” water strata of 50–100 m and 100–150 m are delimited by the 50 m depth contour towards the coast and the NAFO divisions.

The trawl gear was changed in 2005 (Table B.3.1.1), and therefore we only included data from 2005 onwards. Number of stations varies between years but are on average 230 in West Greenland (Table B.3.1.2). The survey season is typically June-July. Vast majority of stations have been conducted between 8-20 UTC (figure B.3.1.1). However, since 2019 stations have been taken throughout the whole daily cycle. Haul duration is standardized to 15 min but stations occasionally last longer or shorter.

Table B.3.1.1: Details of trawl surveys used for modelling.

Survey	Ship	Trawl gear	Haul speed (knots)	Towing time (min) Avg. and range	Wing spread (m)	Door spread (m)	Vertical opening	From	To
Greenland fish and shellfish * (G2064)	RV Paamiut Sjurdarberg (2018) Helga Maria(2019,2020)	Cosmos trouser	2.4	15 7-31	35	48	12	2005	2020
German Greenland ground fish** (G3244)	RV Walther Herwig III	Bottom trawl	4.5	28 9-60	22	60	4	2000	2020

References: *(Burmeister et al. 2022), **(Fock, 2016)

Table B.3.1.2: Number of Stations by year and NAFO divisions in the Greenland survey used in the assessment. No survey in 2021.

Year	C0	1A	1B	1C	1D	1E	1F	Total
2005	6	65	56	26	19	23	23	218
2006	5	86	60	26	20	21	31	249
2007	8	73	58	26	27	31	39	262
2008	6	69	61	28	23	25	47	259
2009	8	74	75	28	22	24	48	279
2010	10	95	76	30	23	25	40	299
2011	0	73	64	24	18	12	25	216
2012	0	73	64	21	18	18	26	220
2013	4	73	52	20	13	21	28	211
2014	0	78	57	19	17	23	32	226
2015	0	70	49	24	22	21	36	222
2016	0	59	38	26	14	19	36	192
2017	3	99	52	25	18	25	35	257
2018	0	78	42	26	23	20	36	225
2019	0	86	36	20	18	14	25	199
2020	0	84	51	29	21	23	43	251
2021	-	-	-	-	-	-	-	-

All fish from survey stations are length measured and total weight is recorded. Otoliths and DNA are taken from 5 fish per cm group in each NAFO division.

A length-age key was made by NAFO division. The length-age key within each area was used on the cod caught at stations in their respective areas. The weight at age was also taken from the length-age key, e.g., a cod at 38 cm being 4 years old has the mean weight of the 4 year olds at length 38 cm in the respective area of catch.

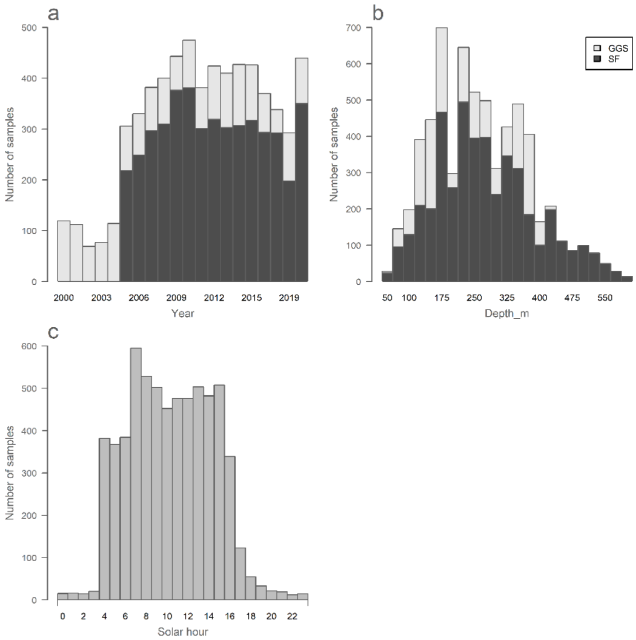

Figure B.3.1.2. Number of trawl stations by year, depth, and solar hour for the Greenland (SF, G2064) and German surveys (GGS,G3244) in both East and West Greenland.

B 3.2 Trawl survey by Germany (German Greenland groundfish survey (G3244)

The German survey was initiated in 1981 and was primarily designed for cod assessment (Fock, 2016). RV Walther Herwig II carried out the surveys until 1993, except for 1984, where RV Anton Dohrn was used. In 1994 the new RV Walther Herwig III took over and has carried out the survey since. October and November were chosen as survey season because of low ice conditions and to avoid spawning concentrations (Fock 2016). The survey area covers depths from 0-400 m and covers areas along the slope and partly on the shelf. Stations are fixed. Number of strata in West Greenland is 8 (figure B.3.2.1).

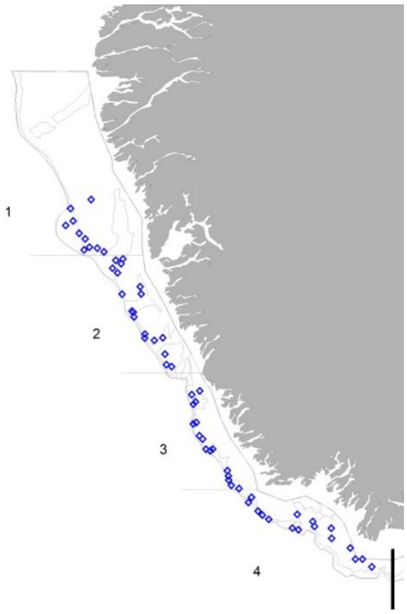

Figure B.3.2.1: The Stratification areas used in the German Greenland groundfish survey in West Greenland. Each stratum is divided into two depth zones, 0–200 m and 201–400 m. Stratum 1= southern part of NAFO div 1B and 1C, Stratum 2=NAFO div 1D, stratum 3= NAFO div 1E, Stratum 4= NAFO div 1F.

The survey has on average 46 stations in West Greenland (table B.3.2.1). Because of technical problems there was no survey in 2018, 2021 and 2022.

The coverage of the Greenland and the German surveys are different in especially West Greenland. The German survey has since 2016 been covering less in the West Greenland area and never as far North as NAFO division 1A and 1B (table B.3.2.1).

The trawl gear consists of a standardized 140-feet bottom trawl, with a net frame rigged with heavy ground gear. Inside the cod end, a small mesh liner of 10mm is used. The horizontal net opening is approximately 22 m whereas the vertical opening is 4 m (table B.3.1.1). Trawling speed is standardized to 4.5 knots, i.e. much faster than Greenland survey. Haul duration is 30 min, with occasional deviations. Trawling has mostly been done between sunrise and sunset.

Table B.3.2.1: Number of Stations by year and area in the German GGS survey. No survey was performed in 2018, 2021 and 2022. Survey coverage was low in 2017 due to technical problems with the ship and bad weather conditions.

Year	1B	1C	1D	1E	1F	Total
2000	4	15	21	19	14	73
2001			22	20	17	59
2002			9	11	12	32
2003			13	14	12	39
2004	2	14	20	15	14	65
2005			16	14	11	41
2006	5	6	12	14	13	50
2007		10	12	12	13	47
2008		5	14	17	14	50
2009		2	10	12	10	34
2010		10	15	16	16	57

2011			10	10	13	33
2012		10	18	16	16	60
2013		10	16	17	15	58
2014		10	18	17	16	61
2015	4	10	11	10	14	49
2016				5	18	23
2017					7	7
2018						
2019				16	23	39
2020	6	9	16	6	6	43
2021						

B 3.3 Inshore gillnet survey (N6619)

A Gillnet survey covers the inshore area in two NAFO divisions 1B and 1D (Figure B.3.3.1). The survey is a multi-meshed gillnet survey designed to target juvenile cod age 2 and 3 yrs old in the inshore area in West Greenland. 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 (Figure B.3.3.2). Therefore, gillnet catches of older fish ages 2–6 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). The nets are set annually during late spring/early summer. They 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). An average of 117 stations have been taken in the assessment period (2000-2021, table B.3.3.1).

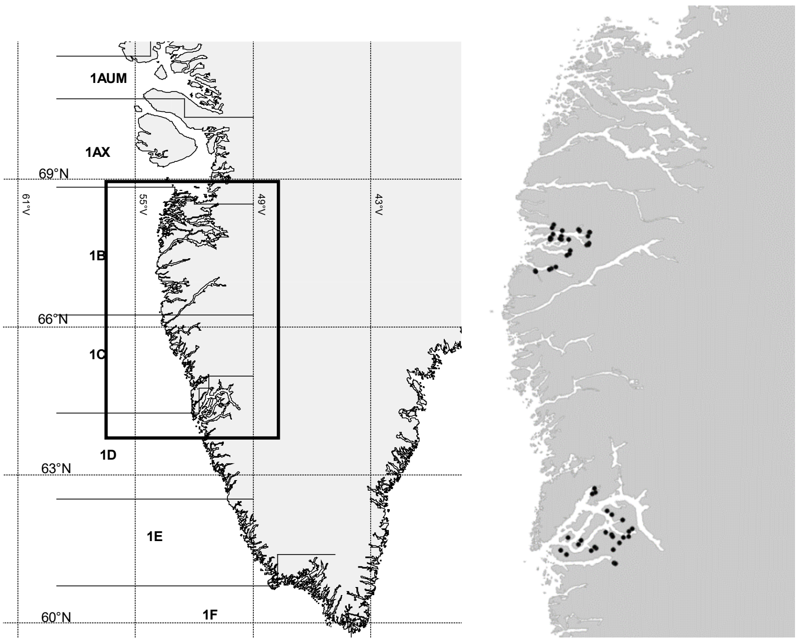

Figure B.3.3.1: Stations in the Gillnet survey.

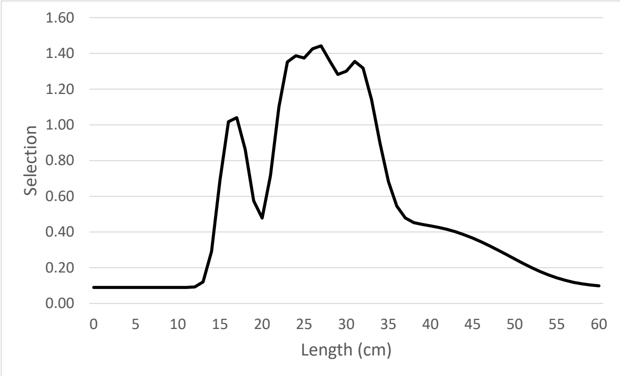

Figure B.3.3.2: Combined selection curve for all mesh sizes (16.5, 18, 24, 28 and 33 mm, ½ mesh).

The survey has been conducted since 1982 and 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. In 2017 NAFO division 1C was added as a survey area, but due to short timeseries the survey in this area is not included as a tuning fleet.

The survey indices of the two areas NAFO 1B and 1D are combined and used as a tuning fleet for the years 2002-2021 except the period 2007-2009 where no survey in either one of the areas was conducted.

Table B.3.3.1: Number of Stations by year and NAFO area in the inshore Gillnet survey.

Year	1B	1D	Total 1B+1D
2000	-	-	
2001	-	-	
2002	63	63	126
2003	99	81	180
2004	80	90	170
2005	84	73	157
2006	43	51	94
2007	55	-	
2008	-	58	
2009	-	58	
2010	66	52	118
2011	57	44	101
2012	54	52	106
2013	58	52	110
2014	60	41	101
2015	59	44	103
2016	58	40	98
2017	57	46	103
2018	58	52	110
2019	48	54	102
2020	53	50	103
2021	54	53	107

B 3.4 Survey Weight at age (Stock weights)

As the offshore surveys have more stations and cover more areas it was decided to use the weight from the offshore surveys as Stock weight.

Weight and length at age differs between the Greenland survey and the German survey with weight and length at age from the German survey being significantly larger. Furthermore, the weight at age from the German survey variates more between years than the Greenland survey (Figure B.3.4.1). The cause for the difference has been explored (Bjare, 2022) and the conclusions drawn where that seasonal effects (summer versus fall) and catch efficiency (difference in gears and towing speed) could potentially cause the difference. Based on the lower coverage of the German survey, especially in West Greenland, the weights from the Greenland survey are used in the stock mean weight for the assessment.

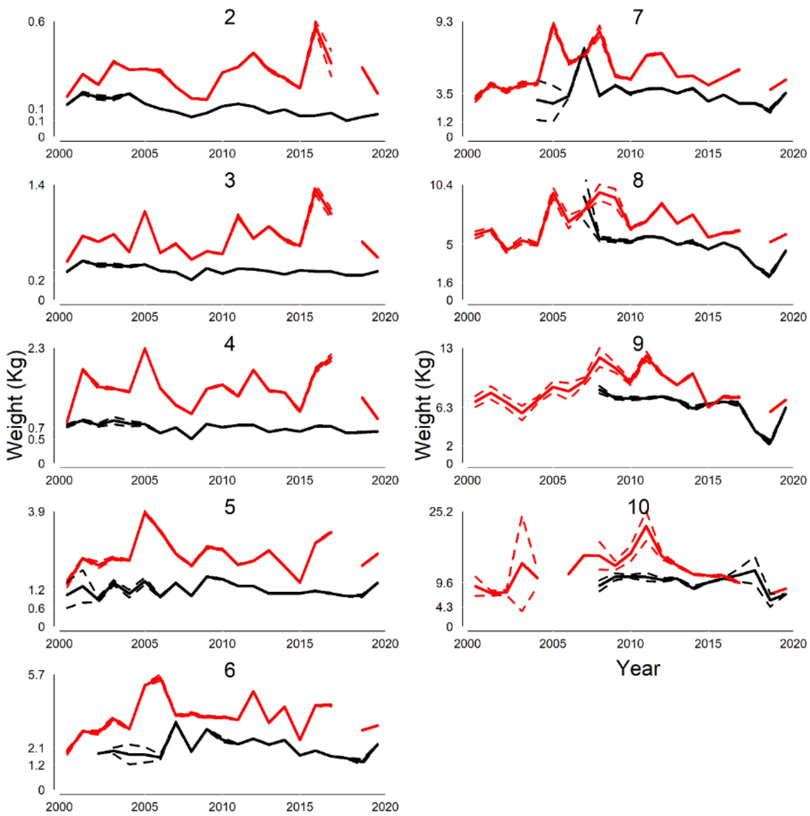

Figure B.3.4.1: Weight at age (2-10) in the Greenland (black) and German survey (red) in East and West Greenland combined. Dashed lines are 95% CI.

B.4. Stock split model

Commercial and survey catch data are split into separate spawning stock units using a Generalized Additive Model (GAM). This is done for the three genetically distinct spawning stock units advised in Greenland waters. Below is a condensed description of the model, while Post *et al.* (2023) provides a more thorough description, including model selection and validation.

The model was a multinomial distribution model providing a ratio of the three individual stocks. In total, 8576 genetically assigned cod from the period 2000-2022 was used as data input. Explanatory parameters were:

PARAMETER	DESCRIPTION
Lat	Latitude in decimal degree
Lon	Longitude in decimal degree
InOff	In- or Offshore, coastal base line
Age	Age of fish
fCohortGr	Birth year as factor with multiple cohorts grouped
s(SampleID, bs='re')	A random effect of the sampling station to account for a possible grouping/schooling effect

In R terms, the model can be noted as:

```
gam(list(Stock~InOff+fCohortGr+s(Lat,Lon,Age,by=fCohortGr)+s(SampleID,bs="re"),
~InOff+fCohortGr+s(Lat,Lon,Age,by=fCohortGr)+s(SampleID,bs="re")),data,family=multinom(
K=2))
```

This model was then used to split all catches by cohort, age, and area.

B.5. INLA

Abundance indices are calculated for each stock (Cod.21.1.osc and Cod.21.27.1.14.osc) and age using INLA. INLA is a Bayesian statistical method for fast fitting of complex statistical models such as generalized additive models (GAM) with spatial correlations. The data used for the index calculations are from the demersal trawl surveys SF and GGS that have been split into stocks by the abovementioned GAM model. Technical details of the INLA scripts are presented in Jansen and Post (2023).

C. Assessment: data and method

C.1 Choice of stock assessment model

This stock has not previously been subject to a full analytical assessment. However, following the work done in connection to WKGREENCOD and splitting data into stocks using a model based on genetics data it is now possible to conduct an 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

Due to poor sampling no commercial data are available for 2001.

The available data are listed in the table below.

TYPE	NAME	YEAR RANGE	AGE RANGE	VARIABLE FROM YEAR TO
Canum	Catch-at-age in numbers	2000– present Except 2001	2–10+	Yes

Weca and West	Weight-at-age in the commercial catch and stock	2000–present	2–10+	Yes
Mprop	Proportion of natural mortality before spawning	2000–present	2–10+	No, set at 0.
Fprop	Proportion of fishing mortality before spawning	2000–present	2–10+	No, set at 0.
Matprop	Proportion mature at age	2000–present	2–10+	No
Natmor	Natural mortality	2000–present	2–10+	No, set to 0.2

Catch mean weight-at-age are calculated from commercial samples, and used as observations for the catch weight process within SAM. Stock mean weight-at-age are calculated from the offshore Greenlandic survey, and used as observations for the stock weight process within SAM. Both the catch and stock weight process are included as GMRF with cohort and within age correlations.

Fishing mortality is estimated individually for ages 2-8, age 9 and 10 are assumed to be the same. It is assumed that there are no correlations across ages, this is supported by changes in the selectivity pattern during the assessment period. The Fbar range was set to 4-7 years old as these ages constitutes the main part of the catches.

The variance parameters for the catch are separate for age 2 and 3, and they are coupled for ages 4-10.

The covariance structure for the catches is assumed to be independent for the catches.

No discarding is believed to take place.

The natural mortality is estimated at 0.2 for all ages.

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 plain random walk process.

For age 2 the coupling of the recruitment and survival process variance parameters for the log(N)-process are different from the other ages. In the model.R script the following was added: par$logSdLogN<-c(0,-5), which sets the process variance of N to a very low value. This was needed due to the short assessment time series.

Additional uncertainty was added for catches ad the tuning series for the early period, 2000-2010. All years and ages were couple for each fleet, such that there was one parameter for each fleet.

Tuning data

Two tuning series are used for this assessment. The first is a survey index by age for ages 2-7 estimated using INLA, input data for INLA is two offshore trawl surveys. The second is a CPUE index by age for ages 2-6 for the inshore gillnet survey in NAFO areas 1B and 1D combined into one index.

Tuning series given in the table below.

Type	Name	Year range	Age range
Tuning fleet 1	INLA index (offshore surveys) Except	2000-present 2021	2-7
Tuning fleet 2	CPUE index (inshore Gillnet survey 1B and 1D) Except	2002–present 2007-2009	2-6

For the two tuning series each of the covariance structure were assumed to follow AR(1) structure across all ages.

The survey catchability parameters are estimated individually for each age for the INLA index, this is related to the way the index for each age is estimated separately using INLA. For the CPUE index survey catchability parameters are coupled for ages 2-3, separate for age 4 and coupled age 5-6, this coupling was based on parameter estimates from a run with separate parameters for each age.

The variance parameters are separate for the two surveys. For the INLA index the variance parameters are separate for age 2 and 3, ages 4-6 are coupled and ages 7-8 are coupled. For the CPUE index the variance parameters are separate for age 2 and 3, and ages 4-6 are coupled.

Assessment

The model output shows that the model are not able to capture the high catches in some years, but estimated catches follows the trends of the observed catches well. Retrospective analysis showed that the model is stable when adding data.

C 3.1. Model Options chosen:

A configuration file is used to set up the model run once the data files.

```
# Configuration saved: Mon Jan  9 14:29:49 2023
#
# Where a matrix is specified rows corresponds to fleets and columns to ages.
# Same number indicates same parameter used
# Numbers (integers) starts from zero and must be consecutive
# Negative numbers indicate that the parameter is not included in the model
#
$minAge
# The minimium age class in the assessment
 2

$maxAge
# The maximum age class in the assessment
 10

$maxAgePlusGroup
# Is last age group considered a plus group for each fleet (1 yes, or 0 no).
 1 0 0

$keyLogFsta
# Coupling of the fishing mortality states processes for each age (normally only
# the first row (= fleet) is used).
# Sequential numbers indicate that the fishing mortality is estimated individually
# for those ages; if the same number is used for two or more ages, F is bound for
# those ages (assumed to be the same). Binding fully selected ages will result in a
# flat selection pattern for those ages.
   0   1   2   3   4   5   6   7   7
  -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,
# 2 AR(1), 3 separable AR(1).
# 0: independent means there is no correlation between F across age
# 1: compound symmetry means that all ages are equally correlated;
# 2: AR(1) first order autoregressive - similar ages are more highly correlated than
# ages that are further apart, so similar ages have similar F patterns over time.
# if the estimated correlation is high, then the F pattern over time for each age
# varies in a similar way. E.g if almost one, then they are parallel (like a
# separable model) and if almost zero then they are independent.
# 3: Separable AR - Included for historic reasons . . .  more later
 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
   0   1   2   3   4   5  -1  -1  -1
   6   6  7   8   8  -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

$keyVarF
# Coupling of process variance parameters for log(F)-process (Fishing mortality
# normally applies to the first (fishing) fleet; therefore only first row is used)
   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

$keyVarLogN
# Coupling of the recruitment and survival process variance parameters for the
# log(N)-process at the different ages. It is advisable to have at least the first age
# class (recruitment) separate, because recruitment is a different process than
```

```
# survival.
 0 1 1 1 1 1 1 1 1

$keyVarObs
# Coupling of the variance parameters for the observations.
# First row refers to the coupling of the variance parameters for the catch data
# observations by age
# Second and further rows refers to coupling of the variance parameters for the
# index data observations by age
   0   1   2   2   2   2   2   2   2
   3   4   5   5   6   7  -1  -1  -1
   7  8   9   9   9   -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" "AR"  "AR"

$keyCorObs
# Coupling of correlation parameters can only be specified if the AR(1) structure is chosen above.
# NA's indicate where correlation parameters can be specified (-1 where they cannot).
#2-3 3-4 4-5 5-6 6-7 7-8 8-9 9-10
  NA  NA  NA  NA  NA  NA  NA  NA
   0   0   0   0   0  -1  -1  -1
   1   1   1   1 -1   -1   -1  -1

$stockRecruitmentModelCode
# Stock recruitment code (0 for plain random walk, 1 for Ricker, 2 for Beverton-Holt, 3 piece-wise constant, 61
for segmented regression/hockey stick, 62 for AR(1), 63 for bent hyperbola / smooth hockey stick, 64 for
power function with degree < 1, 65 for power function with degree > 1, 66 for
Shepher, 67 for Deriso, 68 for Saila-Lorda, 69 for sigmoidal Beverton-Holt, 90 for CMP spline, 91 for more
flexible spline, and 92 for most flexible spline).
 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 7

$keyBiomassTreat
# To be defined only if a biomass survey is used (0 SSB index, 1 catch index, 2 FSB index, 3 total catch, 4 total
landings and 5 TSB 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

$fracMixF
# The fraction of t(3) distribution used in logF increment distribution
 0

$fracMixN
# The fraction of t(3) distribution used in logN increment distribution (for each age group)
 0 0 0 0 0 0 0 0 0
```

$fracMixObs
A vector with same length as number of fleets, where each element is the fraction of t(3) distribution used in the distribution of that fleet
0 0 0

$constRecBreaks
Vector of break years between which recruitment is at constant level. The break year is included in the left interval. (This option is only used in combination with stock-recruitment code 3)

$predVarObsLink
Coupling of parameters used in a prediction-variance link for observations.
-1 -1 -1 -1 -1 -1 -1 -1 -1
-1 -1 -1 -1 -1 -1 NA NA NA
-1 -1 -1 -1 -1 NA NA NA NA

$hockeyStickCurve
#
20

$stockWeightModel
Integer code describing the treatment of stock weights in the model (0 use as known, 1 use as observations to inform stock weight process (GMRF with cohort and within year correlations))
1

$keyStockWeightMean
Coupling of stock-weight process mean parameters (not used if stockWeightModel==0)
0 1 2 3 4 5 6 7 8

$keyStockWeightObsVar
Coupling of stock-weight observation variance parameters (not used if stockWeightModel==0)
0 0 0 0 0 0 0 0 0

$catchWeightModel
Integer code describing the treatment of catch weights in the model (0 use as known, 1 use as observations to inform catch weight process (GMRF with cohort and within year correlations))
1

$keyCatchWeightMean
Coupling of catch-weight process mean parameters (not used if catchWeightModel==0)
0 1 2 3 4 5 6 7 8

$keyCatchWeightObsVar
Coupling of catch-weight observation variance parameters (not used if catchWeightModel==0)
0 0 0 0 0 0 0 0 0

$matureModel
Integer code describing the treatment of proportion mature in the model (0 use as known, 1 use as observations to inform proportion mature process (GMRF with cohort and within year correlations on logit(proportion mature)))
0

$keyMatureMean
Coupling of mature process mean parameters (not used if matureModel==0)
NA NA NA NA NA NA NA NA NA

$mortalityModel
Integer code describing the treatment of natural mortality in the model (0 use as known, 1 use as observations to inform natural mortality process (GMRF with cohort and within year correlations))
0

$keyMortalityMean
#
NA NA NA NA NA NA NA NA NA

$keyMortalityObsVar
Coupling of natural mortality observation variance parameters (not used if mortalityModel==0)
NA NA NA NA NA NA NA NA NA

$keyXtraSd

An integer matrix with 4 columns (fleet year age coupling), which allows additional uncertainty to be estimated for the specified observations

1	2000	2	0
1	2001	2	0
1	2002	2	0
1	2003	2	0
1	2004	2	0
1	2005	2	0
1	2006	2	0
1	2007	2	0
1	2008	2	0
1	2009	2	0
1	2010	2	0
1	2000	3	0
1	2001	3	0
1	2002	3	0
1	2003	3	0
1	2004	3	0
1	2005	3	0
1	2006	3	0
1	2007	3	0
1	2008	3	0
1	2009	3	0
1	2010	3	0
1	2000	4	0
1	2001	4	0
1	2002	4	0
1	2003	4	0
1	2004	4	0
1	2005	4	0
1	2006	4	0
1	2007	4	0
1	2008	4	0
1	2009	4	0
1	2010	4	0
1	2000	5	0
1	2001	5	0
1	2002	5	0
1	2003	5	0
1	2004	5	0
1	2005	5	0
1	2006	5	0
1	2007	5	0
1	2008	5	0
1	2009	5	0
1	2010	5	0
1	2000	6	0
1	2001	6	0
1	2002	6	0
1	2003	6	0
1	2004	6	0
1	2005	6	0
1	2006	6	0
1	2007	6	0
1	2008	6	0
1	2009	6	0
1	2010	6	0
1	2000	7	0
1	2001	7	0
1	2002	7	0
1	2003	7	0
1	2004	7	0
1	2005	7	0
1	2006	7	0
1	2007	7	0
1	2008	7	0
1	2009	7	0
1	2010	7	0
1	2000	8	0
1	2001	8	0
1	2002	8	0

1	2003	8	0
1	2004	8	0
1	2005	8	0
1	2006	8	0
1	2007	8	0
1	2008	8	0
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1	2010	8	0
1	2000	9	0
1	2001	9	0
1	2002	9	0
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1	2004	9	0
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1	2007	9	0
1	2008	9	0
1	2009	9	0
1	2010	9	0
1	2000	10	0
1	2001	10	0
1	2002	10	0
1	2003	10	0
1	2004	10	0
1	2005	10	0
1	2006	10	0
1	2007	10	0
1	2008	10	0
1	2009	10	0
1	2010	10	0
2	2000	2	1
2	2001	2	1
2	2002	2	1
2	2003	2	1
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2	2009	4	1
2	2010	4	1
2	2000	5	1
2	2001	5	1
2	2002	5	1
2	2003	5	1
2	2004	5	1
2	2005	5	1
2	2006	5	1
2	2007	5	1

2	2008	5	1
2	2009	5	1
2	2010	5	1
2	2000	6	1
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2	2000	7	1
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3	2010	4	2
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3	2006	5	2
3	2007	5	2
3	2008	5	2
3	2009	5	2
3	2010	5	2
3	2000	6	2
3	2001	6	2

3	2002	6	2
3	2003	6	2
3	2004	6	2
3	2005	6	2
3	2006	6	2
3	2007	6	2
3	2008	6	2
3	2009	6	2
3	2010	6	2

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	Use average of last 5 years. Maturity is the same for all years.
Natural mortality	Use average of last 5 years. 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	Taken from the stock weight process
Weight-at-age in the stock	Taken from the catch weight process
Exploitation pattern	Several F options explored, including F_{MSY}. Selection pattern based on last five year average.
Intermediate year assumptions	Based on TAC and fishing patterns for intermediate year
Stock recruitment model used	Recruitment for the intermediate is taken from the last 10 years 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, 2021). The group agreed to use the average SSB of the three years with highest recruitment. This gave a B_{lim} of 3 219t.

Data from the SAM assessment agreed at WKGREENCOD (ICES, 2023) were used for the simulations. The Eqsim software was used to define PA and MSY reference points.

The number of simulations were set to 1500. No years were omitted. For assessment error sigmaF was 0.206 from the SAM model and sigmaSSB was set to the default value of 0.2. The default values were used for forecast errors: cvF=0.212, phiF=0.423, cvSSB=0 and phiSSB=0. For weight at age the last 5 years were used. For selectivity the last 10 years were used. The estimated reference points are given in the table below. Due to very high estimate of F_{lim}, it was decided to not report on this value.

Framework	Reference point	Value	Technical basis	Source
MSY approach	MSY $B_{trigger}$	4 473 t	B_{pa}	WKGREENCOD 2023
	F_{MSY}	0.18	EQSim analysis based on the recruitment period 2000–2021.	WKGREENCOD 2023
Precautionary approach	B_{lim}	3 219 t	Average SSB of the three years with low SSB and high recruitmet	WKGREENCOD 2023
	B_{pa}	4 473 t	B_{lim}*exp(sigmaSSB*1.645), sigmaSSB=0.2	WKGREENCOD 2023
	F_{lim}	NA	Equilibrium F, which will maintain the stock above Blim with a 50% probability.	
	F_{pa}	1.33	The fishing mortality including the advice rule that, if applied as a target in the ICES MSY advice rule (AR) would lead to SSB ≥ Blim with a 95% probability (also known as Fp05).	WKGREENCOD 2023

I. References

Bjare, F. 2022. Mean length at age comparison for cod caught in German and Greenlandic surveys. ICES North Western Working Group, WD11.

Bonanomi. S., Therkildsen, N.O., Retzel, A., Hedeholm, R.B., Pedersen, M.W., Meldrup, D., Pampoulie, C., Hemmer-Hanse, J., Grønkjær P.,Nielsen, E.E. 2016. Historical DNA documents long-distance natal homing in marine fish. Molecular Ecology. doi: 10.1111/mec.13580.

Buch, T.B., Retzel, A., Riget, F., Jansen, T., Post, S.L., Boje, J., Berg, C., Bjare, F. 2023. DNA split of Atlantic cod (*Gadus morhua*) stocks in Greenland waters. An overview of data. Report of the Workshop on three Greenland cod stocks (WKGREENCOD) WD 01.

Burmeister, A., Riget, F.F., Buch, T. 2022. The West Greenland trawl survey for *Pandalus borealis*, 2022, with reference to earlier results. NAFO SCR Doc. 022/045

Fock, H., 2016. Update of Groundfish Survey Results for the Atlantic Cod Greenland Offshore Component After Re-Stratification of the Survey 1982-2015. ICES C 2016/ NWWG 2016 WD22 1–30.

Hedeholm, R.B., Mikkelsen, J., Svendsen, S.M., Carl, J., Jensen, K.T. 2016. Atlantic cod (*Gadus morhua*) diet and the interaction with northern shrimp (*Pandalus borealis*) in Greenland waters. Polar Biology 40: 1335-1346.

Hedeholm, R. 2018. Analysis of 2003-2016 tagging data from Greenland waters as it relates to assessment of the East Greenland offshore stock and the West Greenland inshore stock. Report of the InterBenchmark Protocol on Greenland Cod (IBPGCod). ICES CM 2018/ACOM:30. WD03.

Horsted, S.A. 2000. A review of the cod fisheries at Greenland, 1910–1995. J. Northw. Atl. Fish. Sci. 28: 1–112.

Hovgård, H. and K. Wieland. 2008. Fishery and environmental aspects relevant for the emergence and decline of Atlantic cod (*Gadus morhua*) in West Greenland waters. In: Resiliency of gadid stocks to fishing and climate change, p 89–110 (Ed.: G.H. Kruse, K Drinkwater , J.N. Ianelle, J.S. Link, D.L. Stram, V. Wepestad and D. Woodby). Anchorage, Alaska, 2008.

Jansen, T., Post, S. 2023. Spatial statistical modelling of demersal trawl survey catches of Atlantic cod (Gadus morhua) in Greenland using INLA. Report of the Workshop on three Greenland cod stocks (WKGREENCOD) WD 03.

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

Møller, P.R. et al. 2010. A checklist of the fish fauna of Greenland waters. Zootaxa 2378: 1-84.

Kingsley, M.C.S., Kannewoff, P., Carlsson, D.M. 2004. Buffered random sampling: a sequential inhibited spatial point process applied to sampling in a trawl survey for northern shrimp *Pandalus borealis* in West Greenland waters. ICES Journal of Marine Science, 61: 12e24. 2004. doi:10.1016/j.icesjms.2003.11.001

Retzel, A., Post, S., Werner K. 2023. Compilation of Commercial and Survey data for the GAM, INLA and SAM models. Report of the Workshop on three Greenland cod stocks (WKGREENCOD) WD 05.

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.

Tomkiewicz, J, Tybjerg,L, Hom, N, Hansen, A, Broberg, C and Hansen E. 2002. Manual to determined gonadal maturity of Baltic cod. DFU rapport 116-02, Charlottenlund. Danish Institute of Fisheries Research. 49 p.