1.1 Stock Annex: Cod (*Gadus morhua*) in ICES Subarea 14 and NAFO subarea 1, East Greenland Iceland Offshore Spawning Cod

Stock: East Greenland Iceland Offshore Spawning Cod (*Gadus morhua,* ICES Subarea 14 and NAFO Subarea 1) (Cod.21.27.1.14.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 EGIOSC stock does not distinct between the offshore and inshore area but covers all areas in Greenland both east and west.

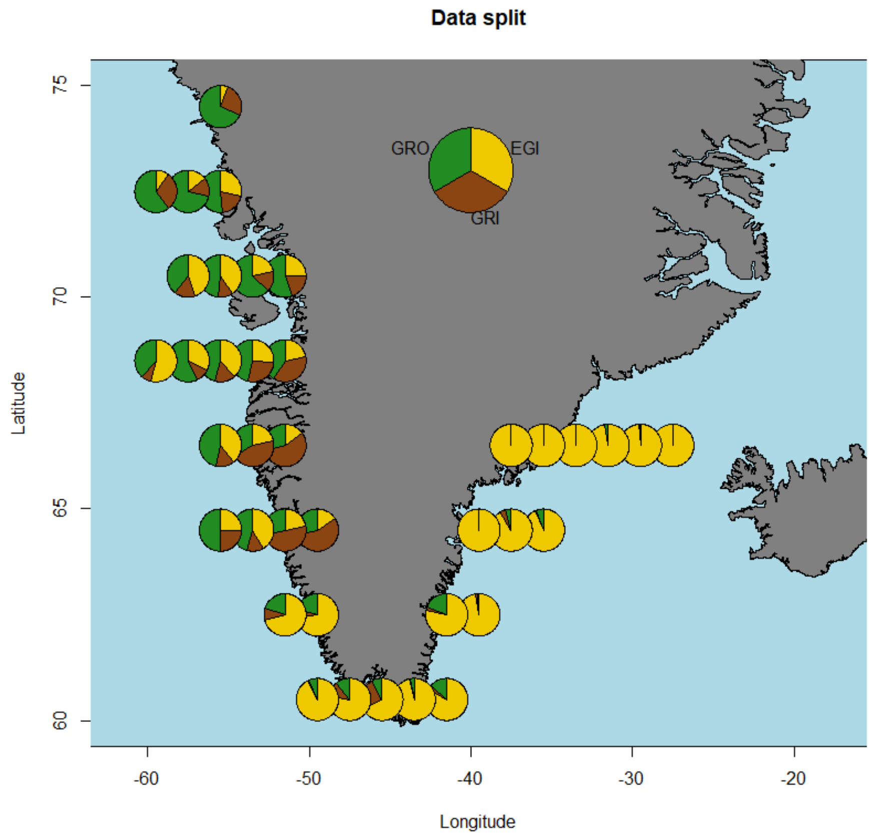

Figure A.1.1. Map of Greenland with piecharts showing the proportion of each of the three cod stocks based on the individual cod sample for genetics from both commercial fisheries and scientific surveys in the period 2000-2021.

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.

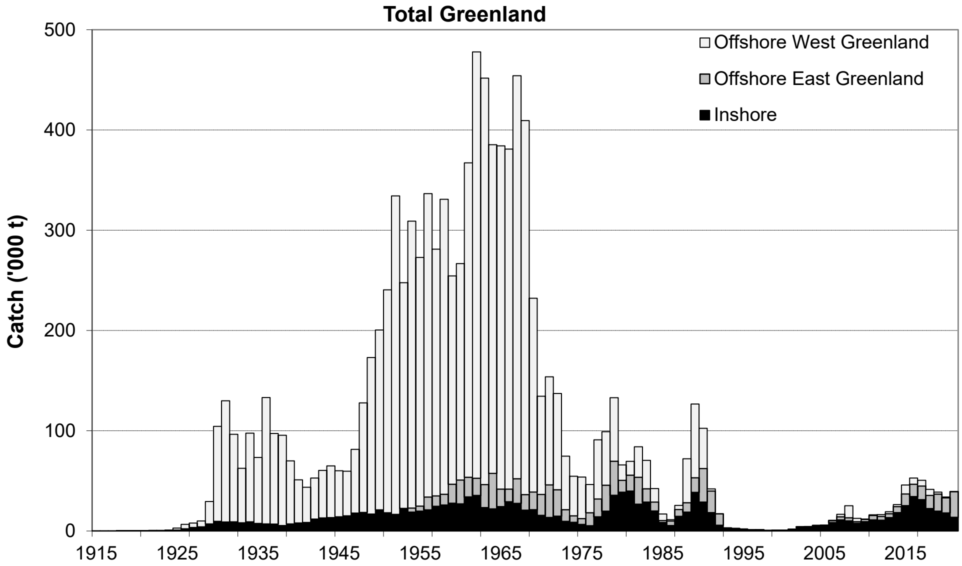

Figure A.2.1. Landings in Greenland divided into 3 areas; Offshore West Greenland, Offshore East Greenland and Inshore West Greenland.

The present fishery

The catches in West Greenland (both offshore and inshore) have been split into the three stocks, WOSC, WISCI 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 EGIOSC stock in all Greenland (East and West).

The catch of the EGIOSC 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 increased to nearly 20,000 tons in 2008, primarily fished in the offshore area in West Greenland (figure A.2.2). The catch hereafter decreased to between 5,000-10,000 tons in the period 2009-2014. In the following years 2015-2020 catches were between 20,000-25,000 tons. In 2021 catches reach highest level of 28,000 tons.

In the beginning of the time series until 2007 catches of the EGIOSC stock was highest in the inshore area averaging 50% of the total catch followed by catches in East Greenland with average 30%. Since 2011 catches of the EGIOSC stock have been higher in East Greenland especially in the latest years.

In West Greenland catches of the EGIOSC stock have generally been larger in the inshore area than in the offshore area except in 2008-2009 and 2015-2018.

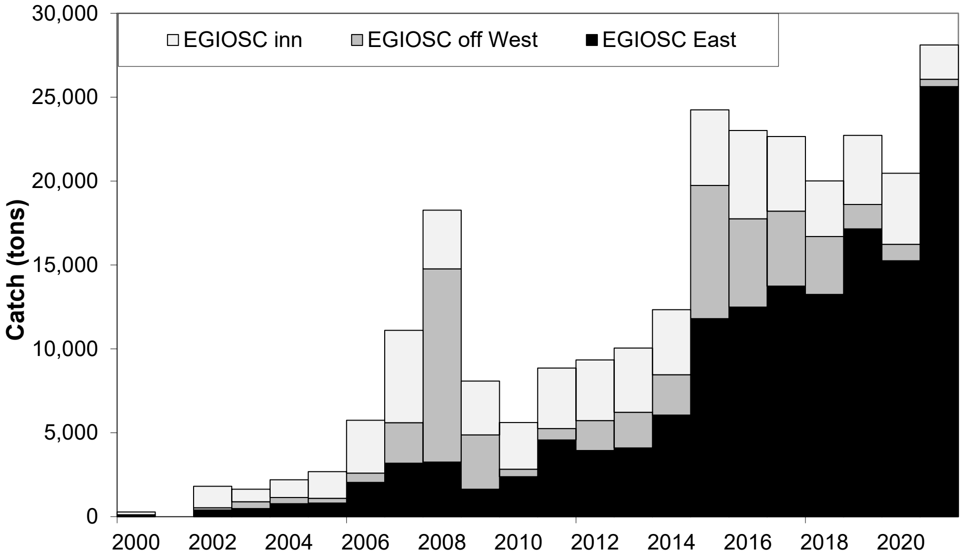

Figure A.2.2. Catch of the East Greenland and Iceland offshore cod stock (EGIOSC) in the inshore and offshore area in West Greenland and East Greenland. No samples from the fishery in 2001.

In West Greenland the EGIOSC stock is caught at different proportions from north to south (figure A.2.3). In general highest proportions are caught in the mid- and southern part covering NAFO divisions 1D, 1E and 1F with average 60%, especially in the years around the high catch in 2008 (2007-2009) where 80% was caught in the southernmost part corresponding to NAFO division 1E and 1F.

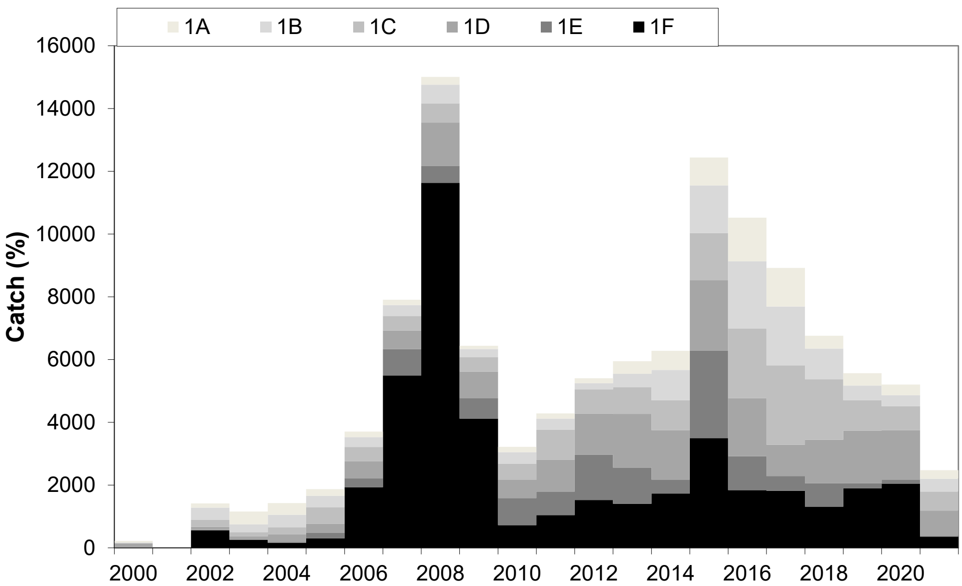

Figure A.2.3. Catch of the East Greenland and Offshore Iceland cod stock (EGIOSC) by NAFO divisions (1A-1F) in West Greenland. NAFO division 1A furthest to the north. No samples from the fishery in 2001.

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.

Since 2012 catches from the commercial fishery in the Dohrn Bank area (Q1-Q2) has constituted a considerable part of the total catch, and this has further increased to above 70% from 2019 (Table A.2.1).

Table A.2.1: Proportion (%) of catch in the Dohrn Bank region in relation to total catch in East Greenland.

	Dohrn Bank (Q1-Q2)	Total East (tons)
2006	5%	2042
2007	0%	3194
2008*	0%	3258
2009*	3%	1642
2010*	5%	2388
2011	2%	4571
2012	40%	3941
2013	52%	4104
2014	43%	6060
2015	46%	11805
2016	31%	12497
2017	43%	13738
2018	40%	13251
2019	71%	17158
2020	69%	15258
2021	77%	25637
2022	74%	26980

The fishery for cod in East Greenland and Iceland is almost a continuum where catches on the southern slope of the Dohrn Bank are close to the Iceland EEZ and the Icelandic fisheries for cod within Icelandic EEZ (Figure A.2.4). Given this distribution of the fishery there is much likely mix over the EEZ border.

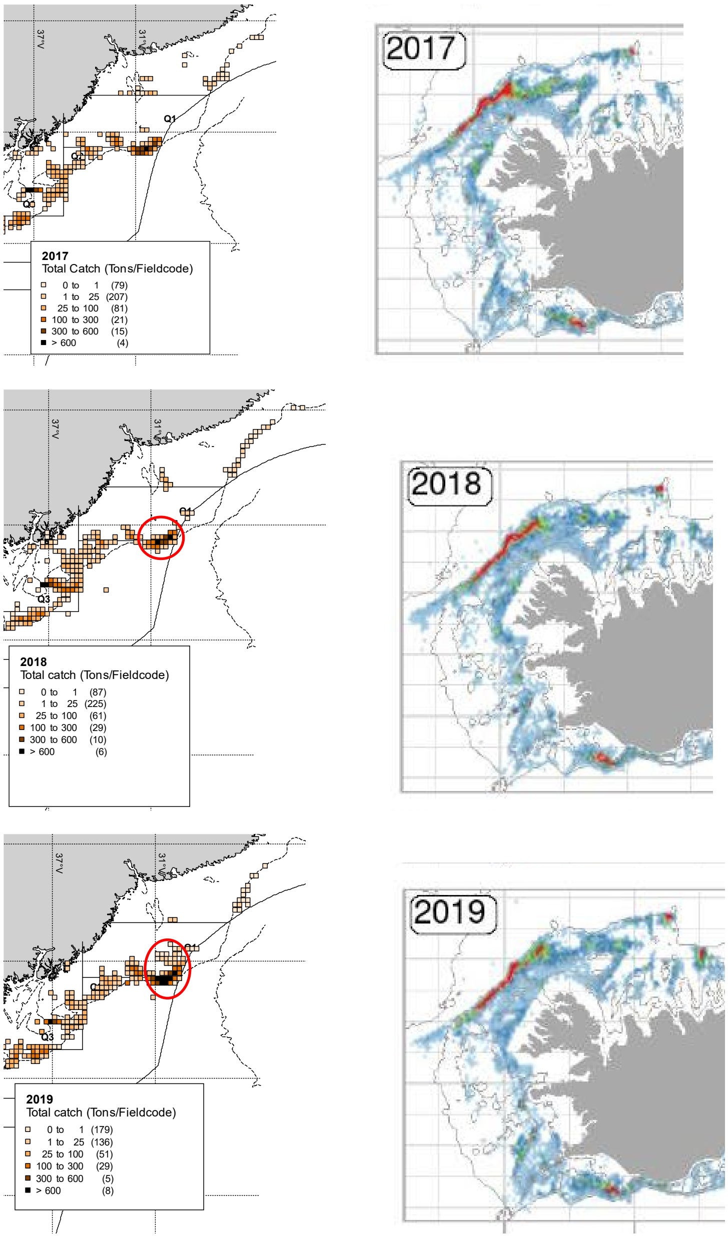

Figure A.2.4. Total catch distribution of cod in recent years from the northeastern part of Greenland and the western part of Iceland.

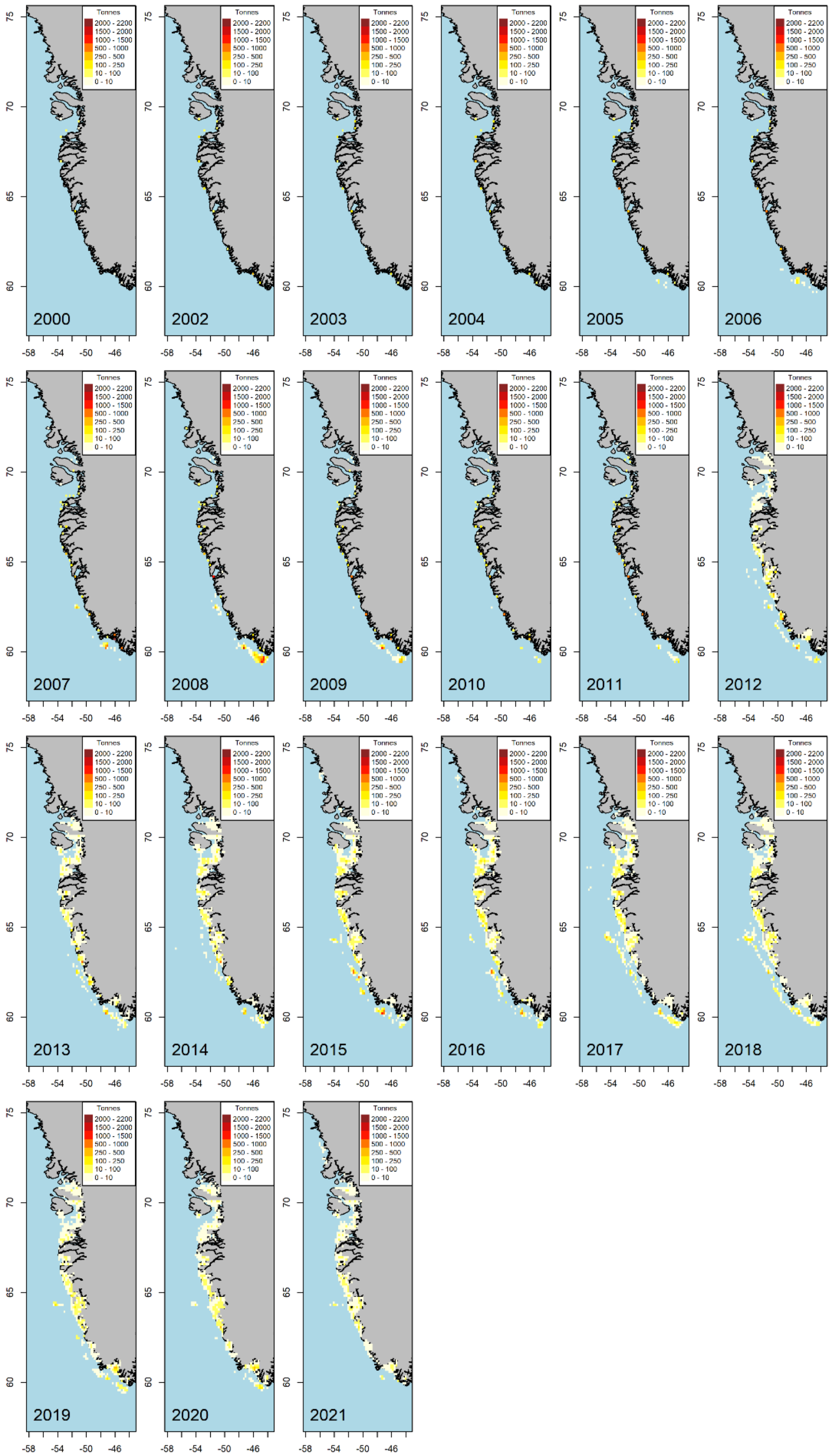

Figure A.2.5: Catch (tons) by field code in West Greenland 2000-2021 for the East Greenland Iceland Offshore stock (EGIOSC).

In the northern part of West Greenland (north of NAFO division 1C) the EGIOSC stock is exclusively fished in the inshore area (figure A.2.5).

Fishery management regulations

The coastal fisheries did not require a licence 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.2.6), 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.2.6: 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.

Several management plans have been implemented and modified. The current management plan for East Greenland, implemented in 2021, operates with two management areas in South and East Greenland (corresponding to NAFO division 1F and ICES 14b, Figure A.2.7). It takes scientific advice, migration to Iceland, and protection of spawning grounds into account. For the management area “Dohrn Bank”, a yearly TAC of 20,000 tons is set, whereas for the management area “SouthWest- and SouthEast Greenland”, TAC is set according to scientific advice. The area around the spawning grounds of Kleine Bank is closed for fishery from 1st of March – 31st of May.

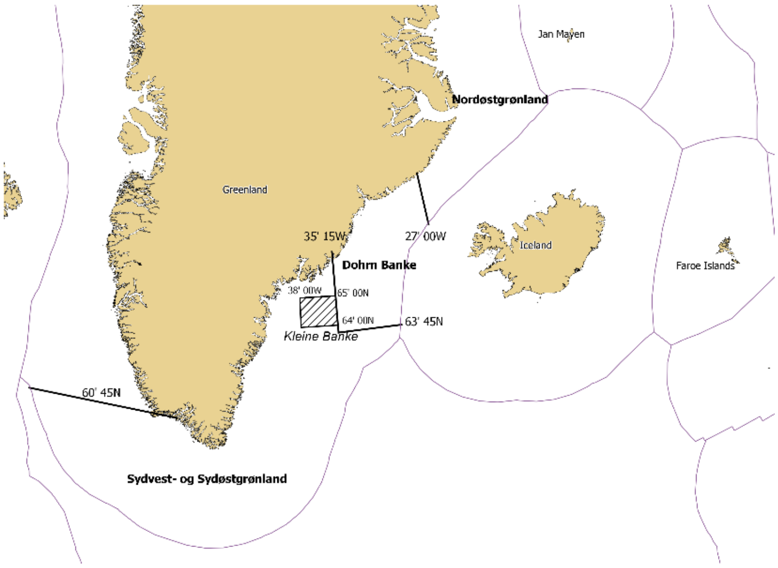

Figure A.2.7: Management area of the South and East Greenland. Square is closed for fishery from 1st of March to 31st of May.

A.3. Ecosystem aspects

There are few studies on cod from this area. A recent study shows that fish is the dominant prey group and that cannibalism is limited to the largest cod (Hedeholm *et al.*, 2016). Cod off Iceland and West Greenland rely heavily on capelin as prey, which was not evident for East Greenland cod, possibly because of timing issue. As the stock appears to be highly influenced by stock dynamics in the adjacent Icelandic area (Wieland and Hovgård, 2002), ecosystem variability will propagate to Greenland through variable inflow of larvae. These inflow events are significantly influenced by environmental factors like air and sea surface temperatures in the Dohrn Bank region during spawning, the zonal wind component in the region between Iceland and Greenland during the first summer (Stein and Borokov, 2004), as well as the size of the Iceland cod stock.

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

B. Data

B.1. Commercial catch

The information on landings in weight are compiled and processed by the Greenland Fisheries License Control (GFLK). 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. In East Greenland, the area levels are Q1Q2, Q3Q4 and Q5Q6. When there are no samples from a NAFO or Q area, 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, B.1.2 and B.1.3.

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		-	-

Table B.1.3: Sampling of the Offshore fishery in East Greenland.

Year	Catch (tons)	Length Samples	N fish measured	Otolith samples from Greenland surveys	Otolith samples from fishery
2000	63	No samples*			
2001	125	No samples			
2002	398	No samples*			
2003	485	No samples*			
2004	778	No samples*			
2005	819	18	2350	69	20
2006	2042	14	3554	45	50
2007	3194	94	16405	396	868
2008	3258	3	486	488	62
2009	1642	5	1952	866	594
2010	2388	2	8647	689	1441
2011	4571	115	16104	828	1114
2012	3941	56	8724	680	1707
2013	4104	111	13404	833	1492
2014	6060	153	10259	534	746
2015	11805	102	4915	647	676
2016	12497	117	11466	610	868
2017	13738	121	13525	543	781
2018	13251	176	22486	-	788
2019	17158	320	35564	-	900

2020	15258	222	26725	718	396
2021	25637	224	32221	-	1533

*Length distribution for commercial catch calculated based on Length distributions in the German survey (see chapter 'East Greenland catch and weight at age 2000-2004')

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).

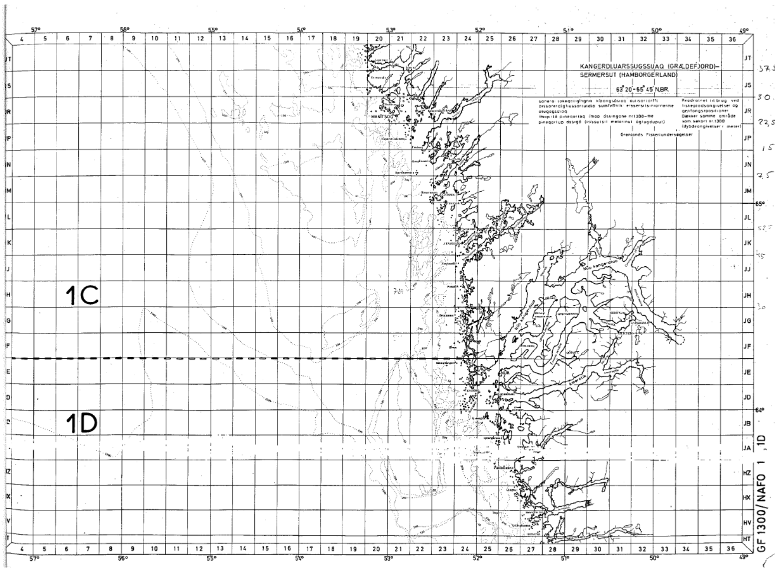

Figure B.1.1: Example of Field codes in the Nuuk area (NAFO division 1C and 1D).

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.2.5).

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 in West Greenland.

In the years 2000, 2002-2004, biological samples covered the fishery in West Greenland, and the proportion of the EGIOSC can be calculated in this fishery. However, the age distribution in the East Greenland part, which comprise app. 20 % of the catches in this period (figure A.2.2), is unknown as the fishery was unsampled (table B.1.3). We decided to lengthen the catch and weight at age time series back to 2000 by using length and age information from the German survey in the same area as the fishery in East Greenland (Retzel et al. 2023). Length frequencies were constructed by estimating retention probabilities from a trawl with a codend of 135 mm mesh size (a standard codend for the fishery, Werner 2020).

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

B.2. Biological sampling

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. For the East Greenland-Iceland offshore stock (EGIOSC) the maturity ogive from East Greenland is used as this is the main spawning area for this stock in Greenland. 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 2000–2017 (Table B.2.1.2). The maturity ogive is based on 1557 samples with maturity information on collections made in the spawning season April and May. No data on maturity in the spawning season exist before 2005. The majority of the maturity information is based on a survey in 2009 and on extensive sampling from commercial experimental fishery in 2007. The maturity ogive was estimated by a general linear model (GLM) with binomial errors. L50 was estimated to 5.19 years (SE = 0.07). Since 2018 a separate ogive was estimated based on cod sampled from an experimental fishery in the same spawning area as in 2007 (GINR, 2018). The two maturity ogives were similar.

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

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

Table B.2.1.2: Maturity ogive by age

Age group	Proportion mature 2000-2017	Proportion mature 2018-present
1	0.020	0
2	0.049	0.001
3	0.116	0.011

4	0.249	0.081
5	0.456	0.410
6	0.679	0.847
7	0.843	0.978
8	0.931	0.997
9	0.972	0.999
10	0.989	0.999

B.2.2. Natural mortality

Natural mortality is differentiated by age 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).

To account for migration from Greenland to Iceland natural mortality has in previous assessment been increased with age. However, the model turned out highly unstable by using this approach and constantly underestimated SSB (ICES 2021). Natural mortality for the EGIOSC stock is by default set to value of 0.2.

B.3. Surveys

GINR has conducted an annual stratified random bottom-trawl survey at West Greenland since 1992 and at East Greenland since 2008. 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 and 18 in East Greenland (figure B.3.1.1)

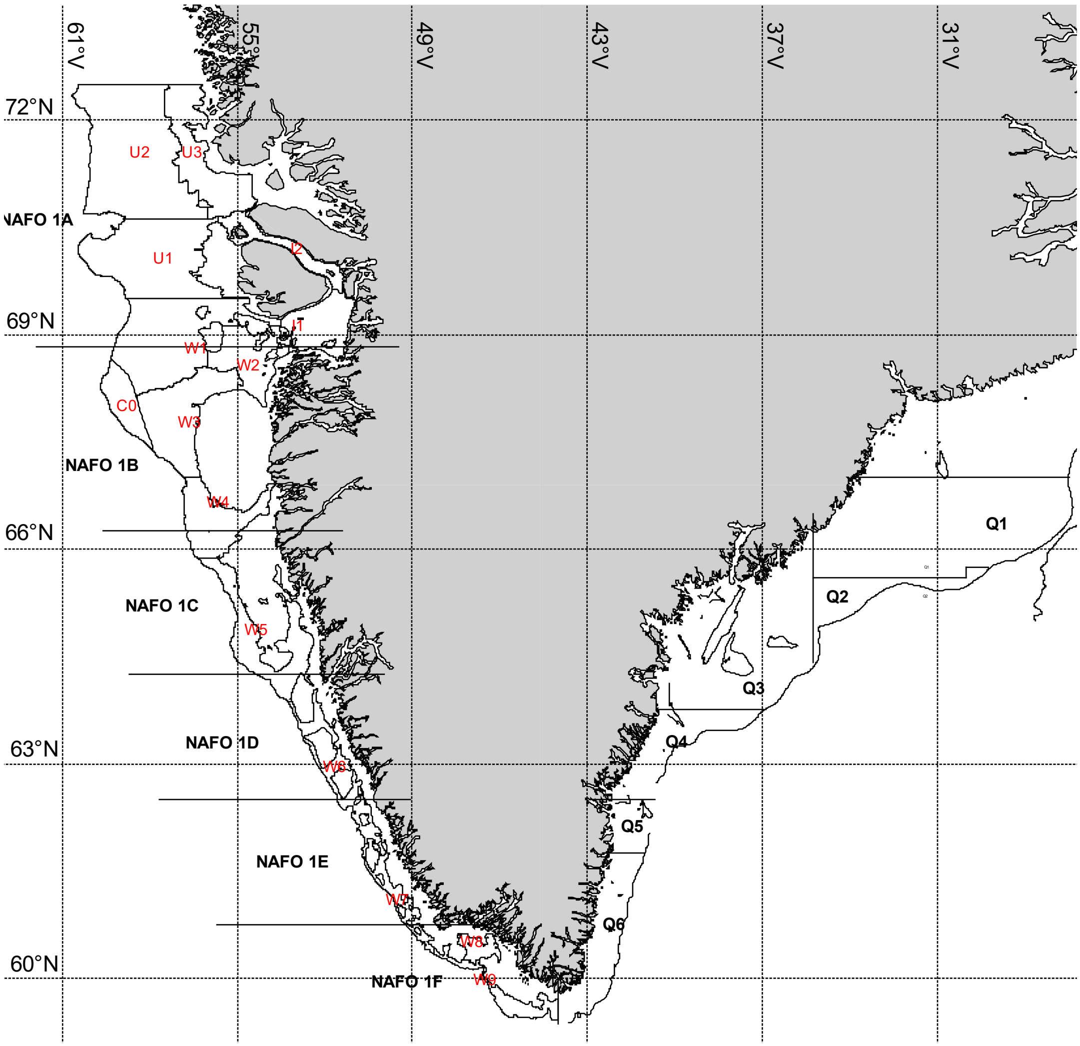

Figure B.3.1. The stratification areas used in the Greenland shrimp and fish survey. In West Greenland each strata is divided in depth strata of 150–200 m, 200–300 m, 300–400 m and 400–600 m. "Shallow" water strata of 50–100 m and 100–150 m are delimited by the 50 m depth contour towards the coast and the NAFO divisions. In East Greenland each strata is divided in depth strata of 0–200 m, 200–400 m and 400–600 m.

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 and 70 in East Greenland (Table B.3.1.2). The survey season is typically June-July in West Greenland and August-September in East Greenland. 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 except in West Greenland in depth strata 150-600 m. 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 (m)	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 / Q divisions in the Greenland survey used in the assessment. No survey in 2021.

	West Greenland								East Greenland						
Year	**C0**	**1A**	**1B**	**1C**	**1D**	**1E**	**1F**	**Total**	**Q6**	**Q5**	**Q4**	**Q3**	**Q2**	**Q1**	**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**	11	7	7	12	6	8	**51**
2009	8	74	75	28	22	24	48	**279**	13	6	20	25	11	22	**97**
2010	10	95	76	30	23	25	40	**299**	10	6	9	24	14	19	**82**
2011	0	73	64	24	18	12	25	**216**	14	7	12	21	11	20	**85**
2012	0	73	64	21	18	18	26	**220**	15	7	13	28	16	20	**99**
2013	4	73	52	20	13	21	28	**211**	14	5	14	22	12	25	**92**
2014	0	78	57	19	17	23	32	**226**	16	8	9	12	14	22	**81**
2015	0	70	49	24	22	21	36	**222**	14	8	12	24	11	26	**95**
2016	0	59	38	26	14	19	36	**192**	16	7	13	26	10	29	**101**
2017	3	99	52	25	18	25	35	**257**	11	6	6	7	4	2	**36**
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**	16	7	13	27	13	23	**99**
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.

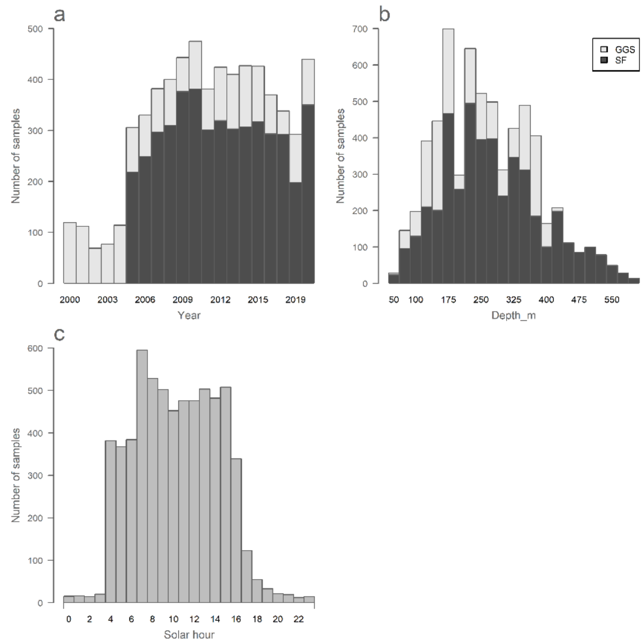

Figure B.3.1.2. Number of trawl stations by year, depth, and solar hour for the Greenland (SF, G2064) and German surveys (GGS,G3244) in both East and West Greenland.

B 3.2 Trawl survey by Germany (German Greenland groundfish survey (Ger(GRL)-GFS-Q4))

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 (Werner et. al. 2021). 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 and 8 in East Greenland (figure B.3.2.1).

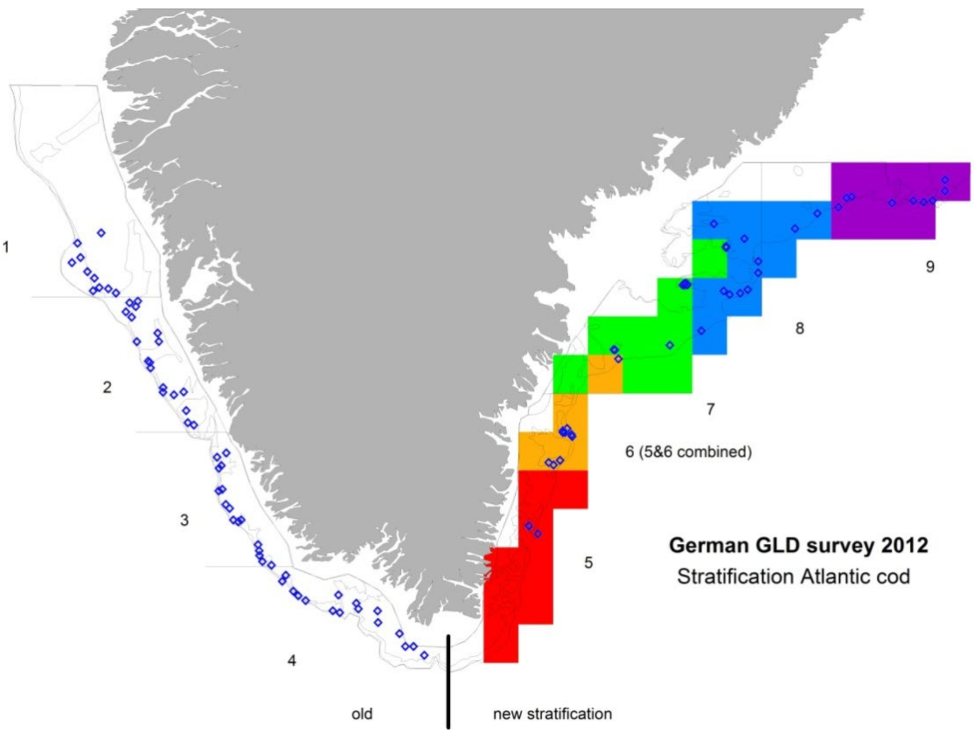

Figure B.3.2.1. The Stratification areas used in the German Greenland groundfish survey. Each stratum is divided into two depth zones, 0–200 m and 201–400 m. Stratum 1= southern part of NAFO div 1B and 1C, Stratum 2=NAFO div 1D, stratum 3= NAFO div 1E, Stratum 4= NAFO div 1F.

The survey has on average 46 stations in West Greenland and 43 in East 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.

	West Greenland						East Greenland			
Year	**1B**	**1C**	**1D**	**1E**	**1F**	**Total**	**Q5Q6 Str 5**	**Q3Q4 Str 6+7**	**Q1Q2 Str 8+9**	**Total**

2000	4	15	21	19	14	**73**	8	25	13	**46**
2001			22	20	17	**59**	10	26	17	**53**
2002			9	11	12	**32**	10	15	12	**37**
2003			13	14	12	**39**	9	13	16	**38**
2004	2	14	20	15	14	**65**	12	21	16	**49**
2005			16	14	11	**41**	11	20	16	**47**
2006	5	6	12	14	13	**50**	2	15	14	**31**
2007		10	12	12	13	**47**	7	16	15	**38**
2008		5	14	17	14	**50**	10	16	14	**40**
2009		2	10	12	10	**34**	5	16	12	**33**
2010		10	15	16	16	**57**	3	19	15	**37**
2011			10	10	13	**33**	10	20	17	**47**
2012		10	18	16	16	**60**	10	21	14	**45**
2013		10	16	17	15	**58**	11	20	18	**49**
2014		10	18	17	16	**61**	10	28	21	**59**
2015	4	10	11	10	14	**49**	11	27	22	**60**
2016				5	18	**23**	11	26	17	**54**
2017					7	**7**	4	19	16	**39**
2018										**0**
2019				16	23	**39**	8	28	19	**55**
2020	6	9	16	6	6	**43**	9	22	16	**47**
2021										

B 3.4 Survey Weight at age (Stock weights)

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.

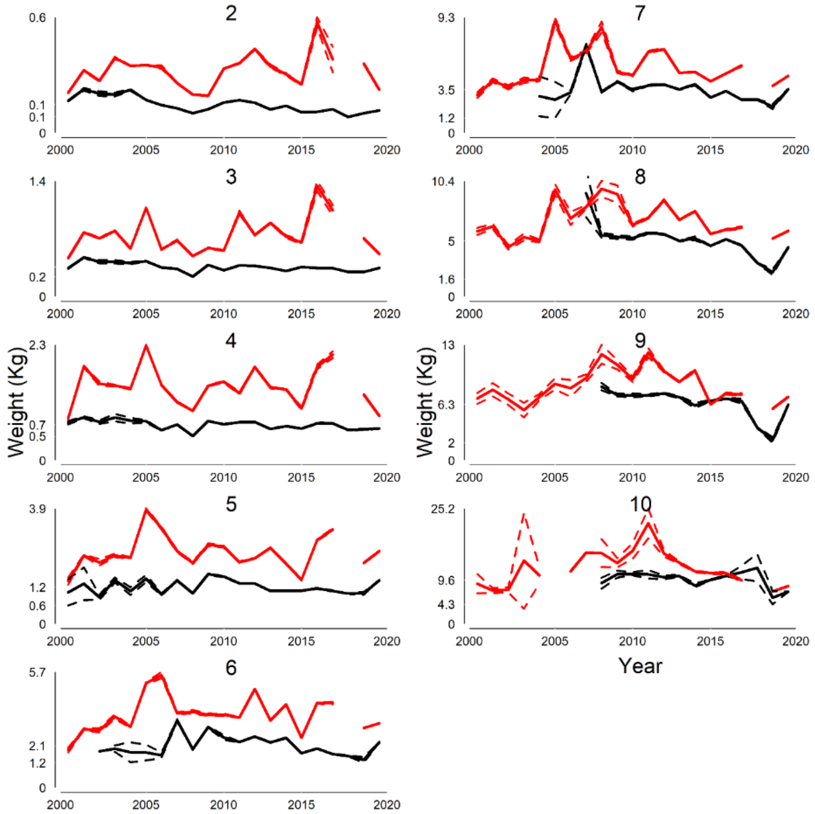

Figure B.3.4.1: Weight at age (2-10) in the Greenland (black) and German survey (red) in East and West Greenland combined. Dashed lines are 95% CI.

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 method and settings

C.1 Choice of stock assessment model

Based on availability of age disaggregated data from two surveys and commercial catches in combination with a good understanding of migration this stock has since 2018 been subject to a full analytical assessment. This is the first time the full analytical assessment has been for the genetic East Greenland-Iceland stock.

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

The available data are listed in table 3.1

Table 3.1: Input data

Type	Name	Year range	Age range	Variable from year to year
Canum	Catch-at-age in numbers	2000–present Except 2001	2–10+	Yes
Weca	Weight-at-age in the commercial catch	2000–present	2–10+	Yes
West	Weight-at-age in the stock	2000–present	2–10+	Yes
Mprop	Proportion of natural mortality before spawning	2000–present	2–10+	No

Fprop	Proportion of fishing mortality before spawning	2000–present	2–10+	No
Matprop	Proportion mature at age	2000–2017 2017-present	2–10+	No No
Natmor	Natural mortality	2000–present	2–10+	No, default of 0.2

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

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.

For the catches the variation around the mean were allowed to vary additionally, parameters were coupled for ages 2-3 and for ages 4-10.

The covariance structure for catches is assumed to be independent.

Catch scaling

Initial SAM run showed that the model couldn't estimate the high catches in recent years, this combined with knowledge that there has been a shift in the fisheries indicates that some of the catches are taken from another stock. The table below shows the catch of cod in East Greenland and the proportion of that catch taken in the Dohrn bank area (Northeastern part of the area):

Year	Dohrn Bank (Q1-Q2) Percentage of total catch	Total (tons)
2006	4%	2456
2007	0%	5205
2008*	0%	14628
2009*	1%	4965
2010*	4%	2669
2011	2%	5113
2012	29%	5411
2013	39%	5511
2014	33%	7893
2015	34%	15755
2016	26%	14818
2017	37%	16224
2018	35%	14980
2019	67%	18030
2020	66%	15917
2021	76%	25829

2022	74%	26952

* Closed for fishery north of 62ºN in East Greenland

The fishery on Dohrn bank takes place close to Iceland and it is believed that the fishery in this area mainly targets old fish from the Icelandic cod stock. There is no quantitative data indicating the scale of this.

The years in the catch scaling are 2012-present. Based on the table above the following years were grouped: 2012-2016 and 2017-present. The first period is the first increase in the percentage taken in the Dohrn bank area, and the second period showed a large rise in the percentage taken in the Dohrn bank areas. Further ages were groups for 2-4, 5-7 and 8-10 for each time period. This gave a total of 6 scaling parameters. If there are any major shifts in the fisheries the groupings should be re-evaluated.

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.

No discarding is believed to take place.

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.

Tuning data:

The model is tuned with one survey index which is based on two surveys (Table below)

Type	Name	Year range	Age range
Tuning fleet 1	INLA index (based on Greenland GRL-GFS and German G3244 DTS (GFS))	2000–present Except 2019, 2021	2-8

The survey catchability parameters are estimated individually for each age.

The variance parameters for the survey are separate for age 2 and 3, ages 4-6 are coupled and ages 7 and 8 are separate.

For the tuning series the covariance structure was assumed to be AR(1).

Assessment

The additional of catch scaling to the model configuration allows the model to account to the total observed catches. However, it is important to note that the model represent the stock which is also covered by the surveys and not neighboring stock where some of the catches are coming from.

Retrospective analysis show some tendency to underestimate SSB and overestimate F, it also shows that the groupings for the catch scaling have an impact of the estimates.

C 3.1. Model Options chosen:

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

```
# Configuration saved: Wed Jan 11 15:33:05 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

$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

$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  6 -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

$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

$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  5  6  7  -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"

$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  0  -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.
 10

$keyScaledYears
# A vector of the years where catch scaling is applied.
2012 2013 2014 2015 2016 2017 2018 2019 2020 2021

$keyParScaledYA
# A matrix specifying the couplings of scale parameters (nrow = no scaled years, ncols = no ages).
0 0 0 1 1 1 2 2 2
0 0 0 1 1 1 2 2 2
0 0 0 1 1 1 2 2 2
0 0 0 1 1 1 2 2 2
0 0 0 1 1 1 2 2 2
3 3 3 4 4 4 5 5 5
3 3 3 4 4 4 5 5 5
```

3 3 3 4 4 4 5 5 5
3 3 3 4 4 4 5 5 5
3 3 3 4 4 4 5 5 5

$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

$obsLikelihoodFlag
Option for observational likelihood | Possible values are: "LN" "ALN"
"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

$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.
0 0 1 1 1 1 1 1 1
-1 -1 -1 -1 -1 -1 -1 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

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

Following ICES guidelines the stock-recruitment relationship appears to follow a type 1 stock type, where B_{lim} is based on the lowest SSB, where large recruitment is observed. It was found that the lowest observed SSBs would likely impair recruitment and therefore and average of the SSB from the three lowest SSBs following the low values were chosen as basis for Blim. The average of SSB in 2002-2004 gave a Blim of 1894.

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 simulation settings for the stock-recruitment relationship were as follows. The number of simulations were set to 1500. SSB in 2003 (recruitment in 2005) were omitted, looking at the overall stock structure and migration it is believed that this recruitment is mostly from Icelandic spawning grounds. For assessment error sigmaF was 0.226 from the SAM model and sigmaSSB was 0.243 from the SAM model. 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 10 years were used, based on figure 16. For selectivity the last 10 years were used, there appear to have been a change in selectivity early in the assessment period, but selectivity was stable in the last 10 years.

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.

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

Framework	Reference point	Value	Technical basis	Source
MSY approach	MSY $B_{trigger}$	2 826 t	B_{pa}	WKGREENCOD 2023
	F_{MSY}	0.26	EQSim analysis based on the recruitment period 2000–2021.	WKGREENCOD 2023
Precautionary approach	B_{lim}	1 894 t	Average SSB of the three years with low SSB and high recruitmet	WKGREENCOD 2023
	B_{pa}	2 826 t	B_{lim}*exp(sigmaSSB*1.645), sigmaSSB=0.243	WKGREENCOD 2023
	F_{lim}	NA	Equilibrium F, which will maintain the stock above Blim with a 50% probability.	

F_{pa}	1.55	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

H. Other Issues

There are no other issues.

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