BENCHMARK WORKSHOP ON GREENLAND COD STOCKS (WKBGREENCOD)

VOLUME 5 | ISSUE 42

ICES SCIENTIFIC REPORTS

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ISSN number: 2618-1371

ICES Scientific Reports

Volume 5 | Issue 42

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Recommended format for purpose of citation:

ICES. 2023. Benchmark workshop on Greenland cod stocks (WKBGREENCOD).
ICES Scientific Reports. 5:42. 287 pp. https://doi.org/10.17895/ices.pub.22683151

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Contents

i Executive summary

Available fisheries, scientific survey and biological data (including genetic data) was evaluated for their appropriateness to assess three Greenland cod stocks during a data evaluation workshop in December 2022. The main objective of the data evaluation workshop was to decide on assigning all available data to three stocks based on genetic analysis, and subsequently assess whether the resulting data is of sufficient quality to have age-based assessments (category 1 stocks) of all three stocks.

Genetic analysis of data was based on survey and commercial fisheries samples collected since 2000. This work was presented before the data evaluation workshop during a meeting at DTU Aqua in September 2022. The number of samples between years and areas varied, and subsequently genetic information was grouped by year classes.

The underlying assumption, based on genetic work, is that cod caught on the western and eastern Greenland shelf belong to a mix of three cod stocks: the East Greenland, West Greenland inshore and West Greenland offshore stock. This genetic classification, based on data collected from commercial catches and during scientific surveys, is the bases for the subsequent stock assessment and setting reference points.

Three separate tuning series were previously used for assessment purposes. The West Greenland gillnet survey, the Greenland shrimp survey, and the German survey. An additional survey, the Greenland halibut survey, was presented at the data evaluation workshop as an additional data source and was included in an initial attempt to combine the survey data from the latter three surveys in a statistical model (INLA) to produce a single survey index. Subsequent model runs however revealed that this particular survey introduced more uncertainty in the survey estimate and it was thus excluded in the calculation of a tuning series for the SAM assessments.

Based on the genetically split data SAM assessments were produced for initially three stocks. However, the West Greenland GRI, which was assessed by using a combined gillnet survey time series, after several configuration changes, produced an assessment which was not ideal based on the retrospective SSB pattern. It was subsequently recommended to assess the stock as two separate units – GRI south and GRI north. This decision was supported by available scientific-, survey- and fisheries data. Tagging data suggests that movement of fish between the main areas within each area, i.e. Nuuk and Sisimiut, is very limited, while treating survey data separately improves internal consistencies between ages. Furthermore, fisheries catches as well as survey indices show opposite trends in recent years, suggesting independent biological processes taking place. Separate assessments were therefore also run for the northern and southern part of the stock, and the final assessments for each of the areas was sufficiently good to be accepted as final. In this report the recommended split assessments are presented.

The estimation of references points for all three stocks proved to be challenging, given the limited length of the time series. The estimation of B_{lim} for all three stocks was problematic, since all stocks produced relatively high recruitment at fairly low SSBs.

Estimated B_{lims} are resultantly relatively low. This was highlighted by one of the external reviewers after the benchmark, and an alternative for calculating $B_{trigger}$ was presented.

ii Expert group information

Expert group name	Benchmark workshop on Greenland cod stocks (WKBGREENCOD)
Expert group cycle	Annual
Year cycle started	2022
Reporting year in cycle	1/1
Chairs	Arved Staby, Norway
	Rick Rideout, Canada
Reviewers	Helen Dobby, Scotland
	Johan Lövgren, Sweden
Meeting venues and dates	Data Evaluation Workshop: 12–14 December 2022, Copenhagen, Denmark (8 participants in person and 4 participants online)
	Intersessional meeting: 25 January (Online meeting, 10 participants)
	Benchmark Workshop: 7–10 February 2023, Copenhagen, Denmark (13 participants)

1 Stock name and codes

Prior to the 2023 WKGREENCOD the Greenlandic cod stocks were assessed based on geographical boundaries. At the benchmark this was changed based on genetic analysis, such that the Greenlandic cod stocks were assessed as separate genetic stocks. ICES advice is thus recommended to be given for three separate cod stocks in Greenland waters:

West Greenland Offshore Spawning Cod (hereafter called WOSC)

East Greenland and Iceland Offshore Spawning Cod (hereafter called EGIOSC)

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 1.1).

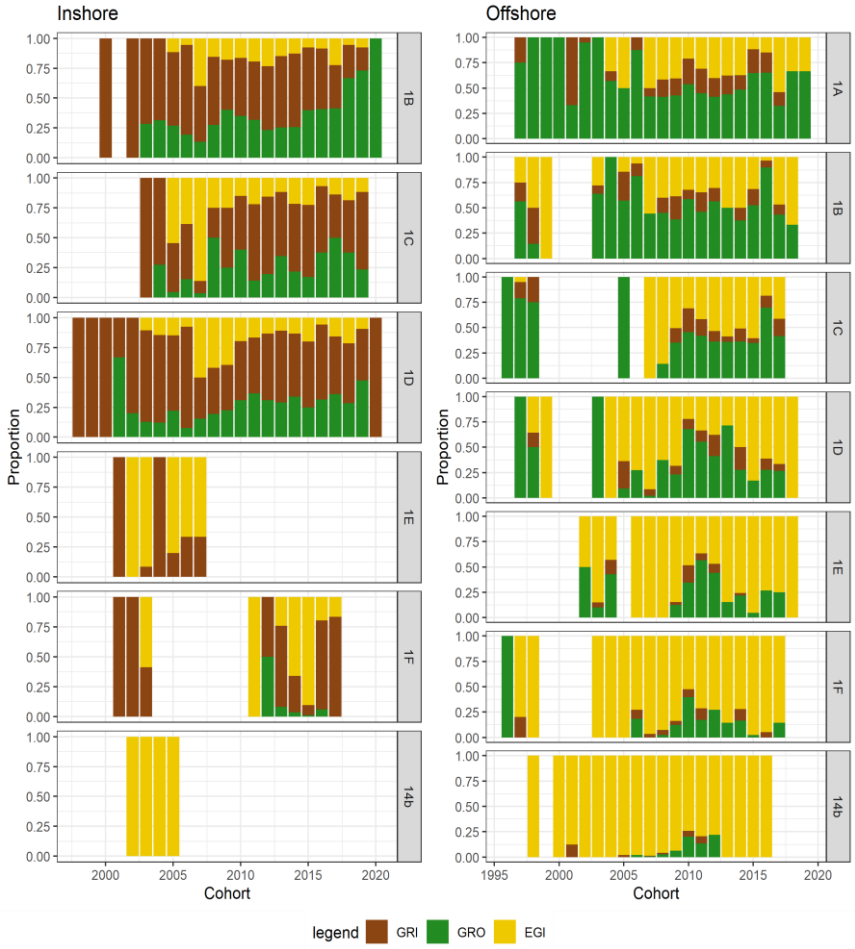

Figure 1.1: Proportion of individuals assigned to each of the three stocks in inshore and offshore areas based on samples, by area and cohort. Divided into NAFO areas 1A-1F (West Greenland) and ICES area 14b (East Greenland). Cohort bars with only one colour are likely due to few samples.

The assessment of the WISC stock was split into two, one for the northern area, NAFO subareas 1A-C (hereafter called N-WISC) and one for the southern area, NAFO subarea 1D-F (hereafter called S-WISC). Details on this are given in Section 3.

It was decided that the stock codes and descriptions should be updated to capture the change. The table below gives the details:

Current Code	Current Description	New definition	New Code	New Description
Cod.21.1.a-e	Cod (Gadus morhua) in NAFO divisions 1.A-E, offshore (West Greenland)	Covers offshore spawning genotype from all of west Greenland.	Cod.21.1.osc	WOSC (West Greenland Offshore Spawning Cod (*Gadus morhua*, NAFO Subarea 1).
Cod.2127.1f.14	Cod (Gadus morhua) in ICES Subarea 14 and NAFO Division 1.F (East Greenland, South Greenland)	Covers East Greenland-Iceland offshore spawning genotype from both East Greenland and West Greenland, excluding some of the migrants of the same genotype to/from areas outside Greenland. Not comparable with the obsolete 'Cod.2127.1f.14'.	Cod.21.27.1.14.osc	EGIOSC (East Greenland Iceland Offshore Spawning Cod (*Gadus morhua*, NAFO Subarea 1 and ICES Subarea 14).
Cod.21.1	Cod (Gadus morhua) in NAFO Subarea 1, inshore (West Greenland cod)	Covers inshore spawning genotype from northern west Greenland (1a-1c). Not comparable with the obsolete 'Cod.21.1'.	Cod.21.1a-c.isc	N-WISC (Northern West Greenland Inshore Spawning Cod (*Gadus morhua*, NAFO Subarea 1a-c).
Cod.21.1	Cod (Gadus morhua) in NAFO Subarea 1, inshore (West Greenland cod)	Covers inshore spawning genotype from southern west Greenland (1d-1f). Not comparable with the obsolete 'Cod.21.1'.	Cod.21.1d-f.isc	S-WISC (Southern West Greenland Inshore Spawning Cod (*Gadus morhua*, NAFO Subarea 1d-f,).

The updated stock names were implemented after the benchmark. The new stock names are used in the stock annex and in the report. For the WDs and figures in the report the old acronyms for the stocks were used. They are given below:

Stock	acronym	Old acronym
West Greenland Offshore Spawning Cod (*Gadus morhua*, NAFO Subarea 1	WOSC	GRO
East Greenland Iceland Offshore Spawning Cod (*Gadus morhua*, NAFO Subarea 1 and ICES Subarea 14	EGIOSC	EGI
West Greenland Inshore Spawning Cod (*Gadus morhua*, NAFO Subarea 1a-f).	WISC	GRI
Northern West Greenland Inshore Spawning Cod (*Gadus morhua*, NAFO Subarea 1a-c	N-WISC	GRI North (GRI_N)
Southern West Greenland Inshore Spawning Cod (*Gadus morhua* , NAFO Subarea 1d-f,	S-WISC	GRI South (GRI_S)

2 West Greenland Offshore Spawning Cod (*Gadus morhua*, NAFO Subarea 1)

2.1 Summary

Genetic studies have shown that the stock known as the West Greenland offshore stock, hereafter named West Greenland Offshore Spawning Cod (WOSC), is heavily fished in the inshore fishery (se stock annex). Previously, only data from the geographical area corresponding to the offshore area of NAFO division 1A-1E have been used in the assessment, and the assessment was based on survey trends (Category 3) with an advice of no fishing. At this benchmark the commercial data has been split into three stocks which results in a complete dataset for the WOSC stock fished in all areas in West Greenland, both in- and off-shore. In addition, data from the West Greenland offshore bottom trawl surveys and the inshore gillnet survey are also split into stocks and used in the assessment. As a result, the assessment is upgraded to a category 1 assessment based on the state-space model (SAM).

2.2 Stock Identity

Genomic analysis of contemporary and historical samples identified the distinct stock identity West Greenland Offshore Spawning Cod (WOSC) (Therkildsen *et al*. 2013).

2.3 Data Quality

Due to low genetic sampling before year 2000, the assessment year starts at 2000.

2.4 Commercial Catch Data

Commercial catch data are set up as catch in numbers at age and weight at age on field-code level which are squares of 7.5 min and 15 min per Lat and Lon, respectively. The catch in numbers at age are split into the three stocks (WD1; WD2).

For further description see stock annex.

2.5 Fishery-independent Data

Demersal trawl surveys (G2064 and G3244)

Abundance indices in the summer-autumn was derived from a geostatistical model fitted to catch data from bottom trawl surveys conducted during summer and autumn in Greenlandic waters. Catch data were split by stock based on genetics (WD1; WD2). A complete description of the data and model can be found in WD5 and WD03 respectively, as well as in the stock annex.

The data were compiled from two bottom trawl surveys. Namely "SF" (G2064) conducted between May –October from 2005—2020 by the Greenlandic Institute of Natural Resources, and "GGS" (G3244) conducted between September –November from 2000—2020 by the Thünen Institute for Sea Fisheries.

All surveys sample the fish community on the continental shelf and upper shelf slope.

Trawl operations have largely been standardized on each of the surveys but differ substantially between the two. A survey effect was therefore included in the model in addition to the effect of effort (swept area in nmi^2).

In 2018 only West Greenland was covered, and no surveys were conducted 2021. These years were excluded accordingly.

Figure 2.1 provides an overview of the distribution and number of samples.

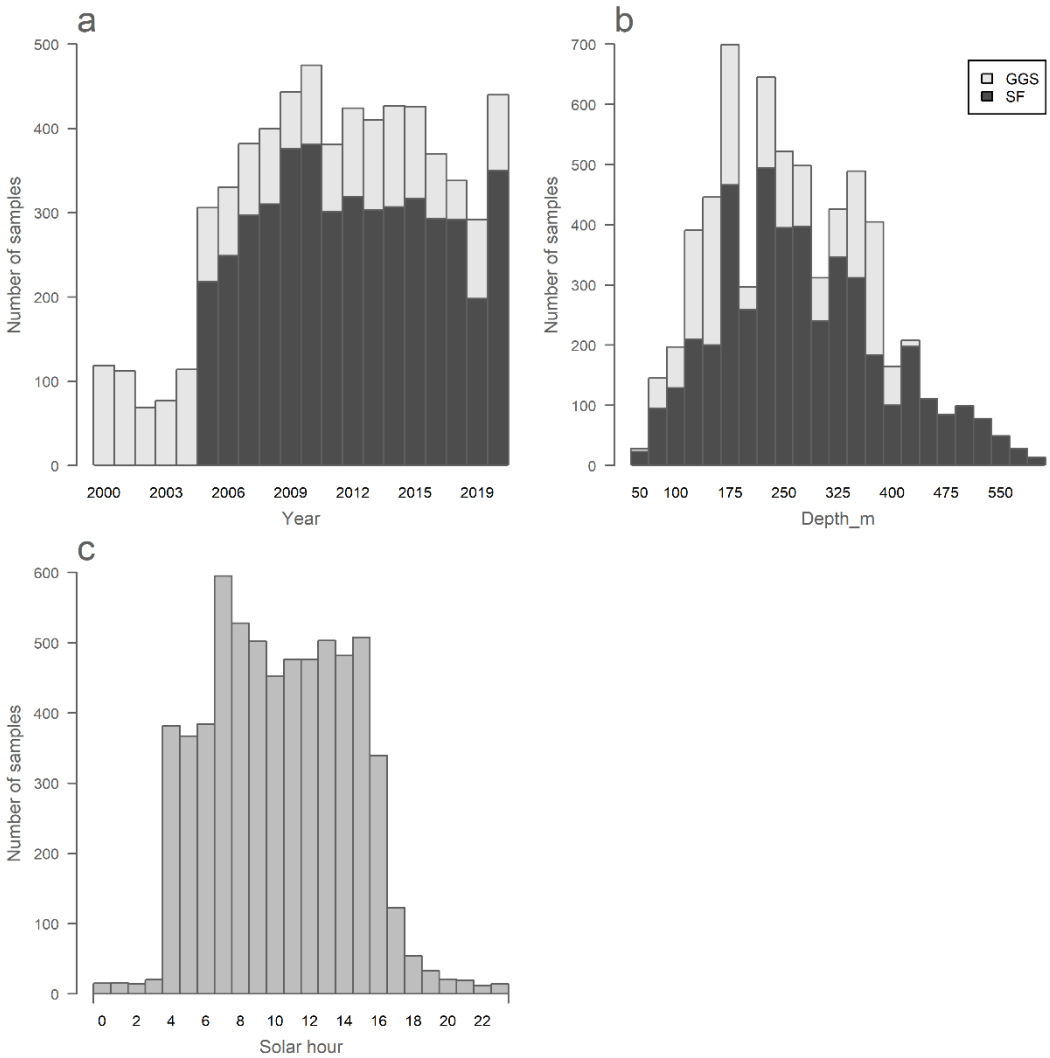

Figure 2.1: Number of trawl stations by year, survey, depth and solar hour from the SF (G2064) and GGS (G3244) survey.

INLA (Integrated Nested Laplace Approximation) was used to fit a spatially explicit statistical model. INLA is a Bayesian statistical method for fast fitting of complex statistical models such as generalized additive models (GAM) with spatial correlations (Lindgren *et al*., 2015; Rue *et al*., 2009). Based on simulations with the model, spatial distributions and time series for each age and stock was estimated. Model diagnostics are presented in WD3.

Results from the model runs were used to map the spatial distributions of mean density indices by age in Figure 2.2. The time series of spatially integrated density indices that

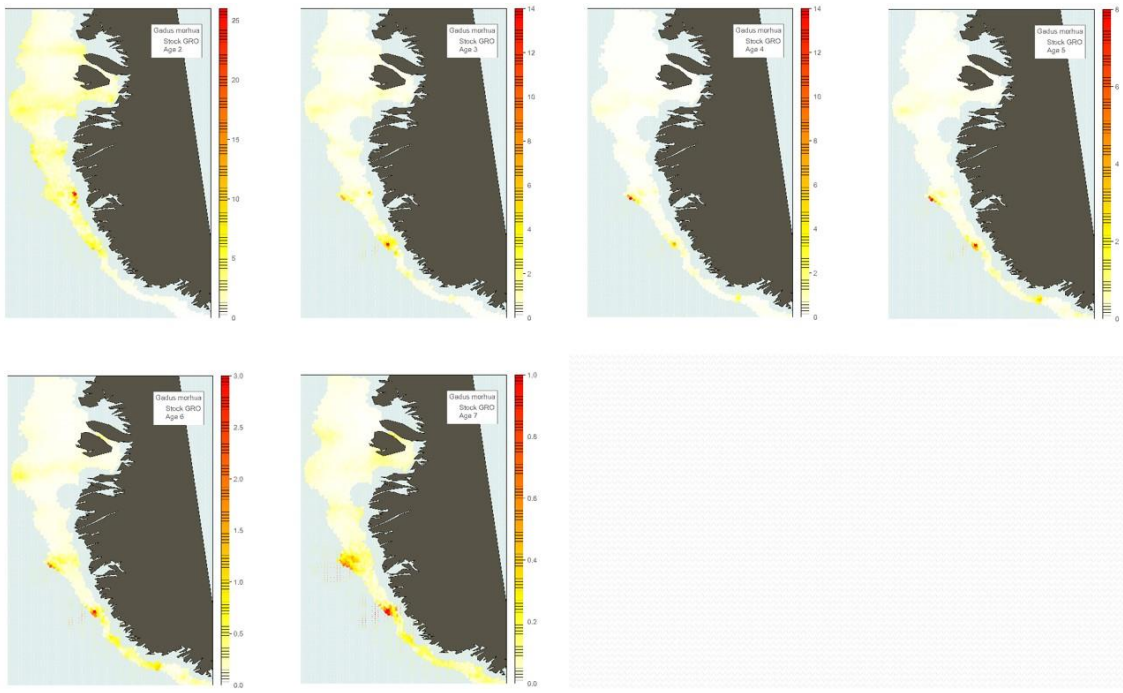

Figure 2.2: Spatial distribution of mean densities by age based on INLA for GRO (WOSC).

Figure 2.3: Relative abundance estimates of cod for GRO (WOSC).

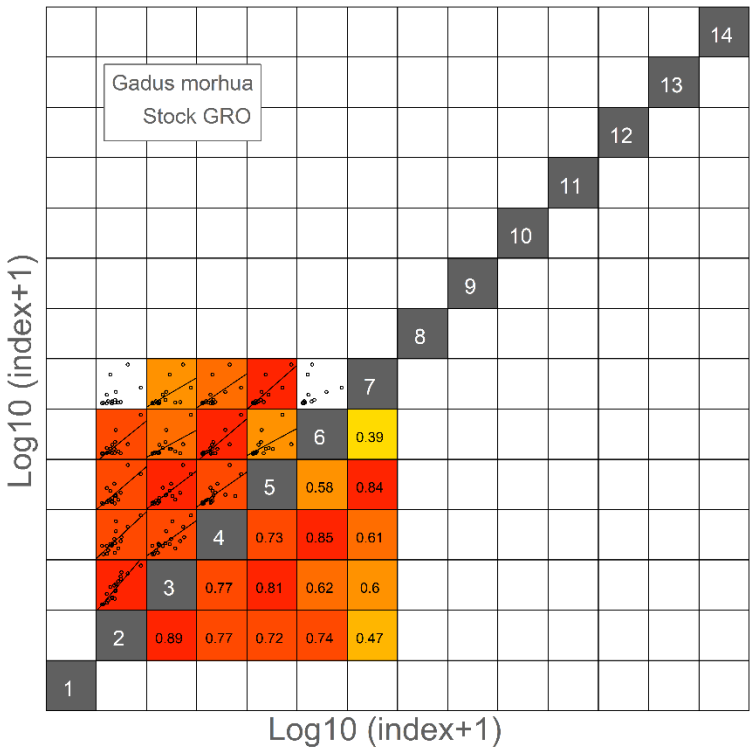

Figure 2.4: Internal consistency plot for GRO (WOSC).

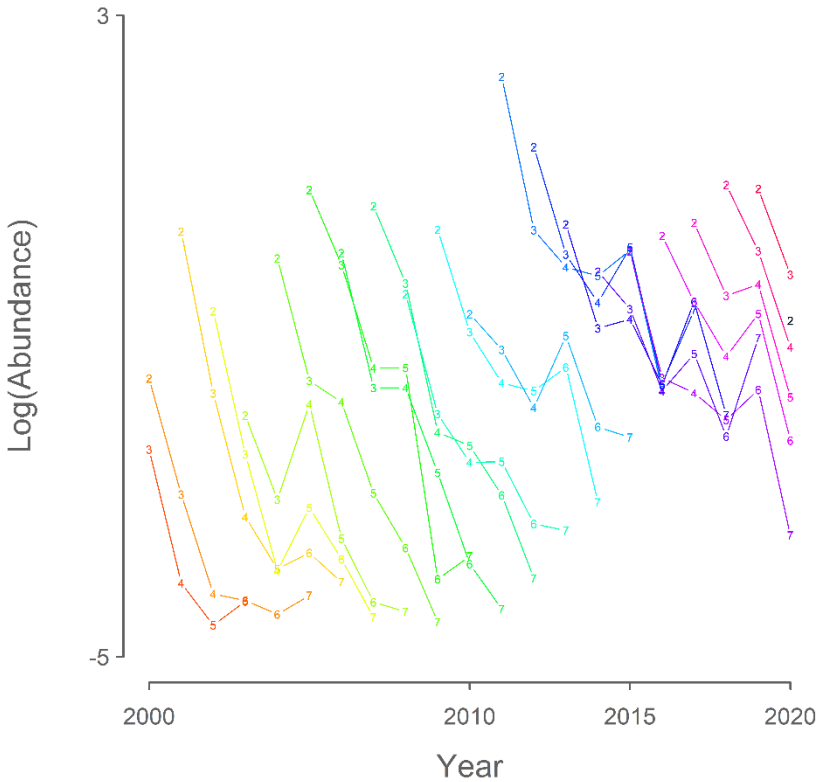

Figure 2.5: Catch curve for GRO (WOSC).

Were used in the assessment as relative abundance indices of cod at age (Figures 2.3.) were found to have good internal consistency (Figure 2.4 and 2.5).

In 2022 the GGS survey was not conducted. From 2023, the Thünen institute will change the timing of the GGS survey from autumn to summer. This must initially be considered as a new survey. The model will need more than one year of data to estimate the new survey effect. It must therefore be expected that only SF will be used by NWWG in 2023 and 2024.

Inshore gillnet survey (N6619)

A gillnet survey covers the inshore area in two NAFO divisions 1B and 1D. The survey is a multi-meshed gillnet survey designed to target juvenile cod (age 2) and 3 year-old cod 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. Therefore, gillnet catches of older fish ages 2–6 were included in the data set. The abundance index used in the survey is defined as 100*(# caught/net*hour).

For further description see stock annex.

2.6 Maturity

Ogives are calculated for cod that were genetically assigned (WD01) and from spawning months (March, April, May and June). Due to low sampling size and no yearly genetic analysis in spawning season, the proportion of mature fish by age is left unchanged from year to year.

For further description see stock annex.

2.7 Recruitment

Recruitment is det at age 2.

2.8 Stock Weight

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 2.6). 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.

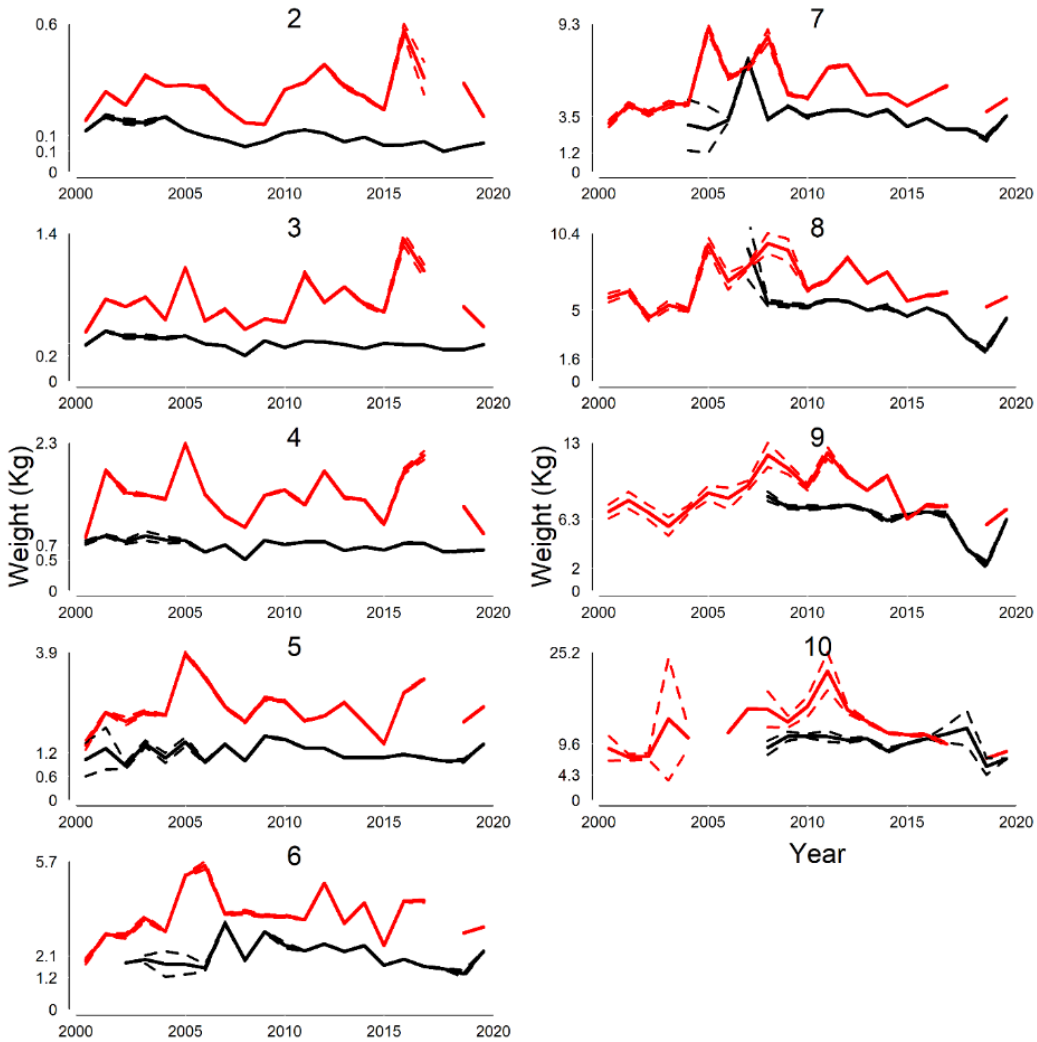

Figure 2.6: Weight at age (2-10) in the Greenland (SF, black) and German survey (GGS, red). Dashed lines are 95% CI.

2.9 Natural Mortality

Natural mortality is differentiated by age but fixed at 0.2 for all ages. For further description see stock annex.

2.10 Final Model Settings

The stock is assessed using the state-space model SAM (Nielsen and Berg, 2014). The final model is described below, details on other configurations tested during the benchmark are given in WD07.

Attempts were made to use SpiCT for this stock, but these were not successful.

Data used to fit the assessment model

Table 2.1: Input data for the SAM model for the West Greenland Offshore stock (WOSC/GRO).

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 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
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	

Due to poor sampling no commercial data (Canum) was available for 2001.

Two tuning series were used for this assessment. The first is a survey index by age for ages 2-7 estimated using INLA, where input data for INLA were two offshore trawl surveys. The second tuning series 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.

Model Configurations

Catch mean weight-at-age are calculated from commercial samples and used as observations for the catch weight process within SAM (figure 2.7). Stock mean weight-at-age are calculated from the offshore Greenlandic survey and used as observations for the stock weight process within SAM (figure 2.8). 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, which is supported by changes in the selectivity pattern during the assessment period. The Fbar range was set to ages 4-7 as these ages constitute 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.

Figure 2.7: Catch weight at age (in kilograms) for the West Greenland Offshore stock (WOSC/GRO). Numbers are input values by age and the line give the estimates from the model.

Figure 2.8: Stock weight at age (in kilograms) for the West Greenland Offshore stock (WOSC/GRO). Numbers are input values by age, the line give the estimates from the model.

It is believed that no discarding has taken place.

The natural mortality was set 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 and 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.

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

The survey catchability parameters are estimated individually for each age for the INLA index, which 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.

Details are given in WD07.

Model diagnostics

For the most recent years with high catches the model tended to underestimate catch (Figure 2.9).

There are some patterns in the residuals (Figure 2.10). For the catch residuals there is a block of positive residuals, showing that the model underestimates catches in these years. There is also a block of negative residuals for the INLA survey residuals early in the timeseries.

In order to test the robustness of the assessment a 5-year retrospective analysis (Figures 2.11-13) were conducted. For F all peels, except one, are within the confidence intervals and fluctuate around the current estimate (Mohn's rho=0.087; Figure 2.11). Similarly, all estimates for SSB are within confidence intervals and fluctuate around the current estimate, i.e. no consistent over- or underestimation (Mohn's rho= -0.002, Figure 2.12). For recruitment the two most recent estimates are within the confidence limits, all estimates except for the most recent show a tendency to underestimate recruitment (Mohn's rho=-0.253; Figure 2.13).

Assessment results

The estimated SSB, Fbar and recruitment from the model are given in figures 2.14, 2.15 and 2.16. Assessment name of stockassessment.org is 'WKGREENCOD_GRO'.

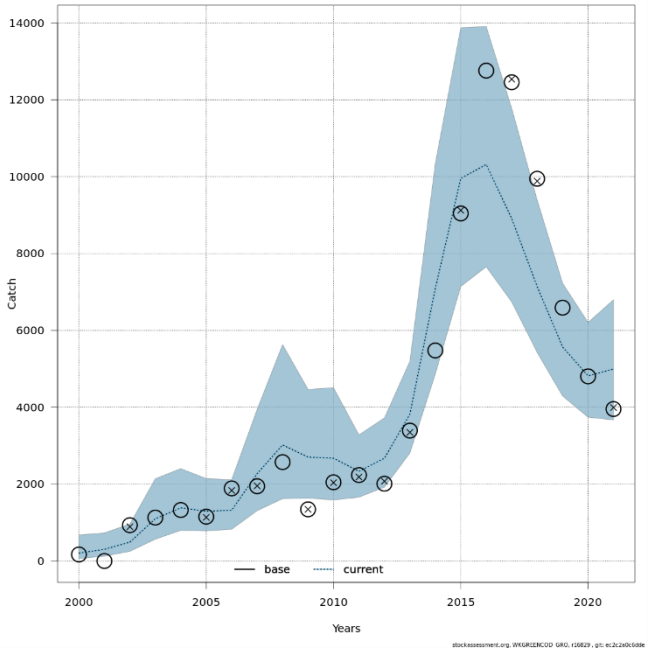

Figure 2.9: Estimated (line), observed catches (x), and catches based on smoothed catch weights (o) for the West Greenland Offshore stock (WOSC/GRO). Estimated catch is shown with 95% confidence intervals.

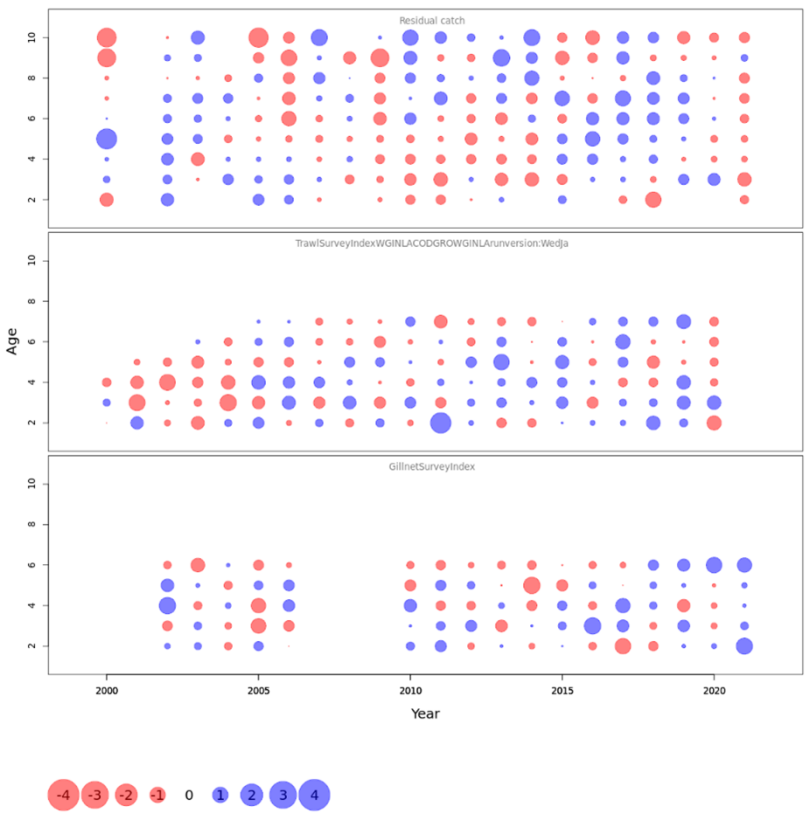

Figure 2.10: Normalized residuals derived from SAM for the West Greenland Offshore stock (WOSC/GRO). Blue indicates positive residuals (observation larger than predicted) and red circles indicated negative residuals.

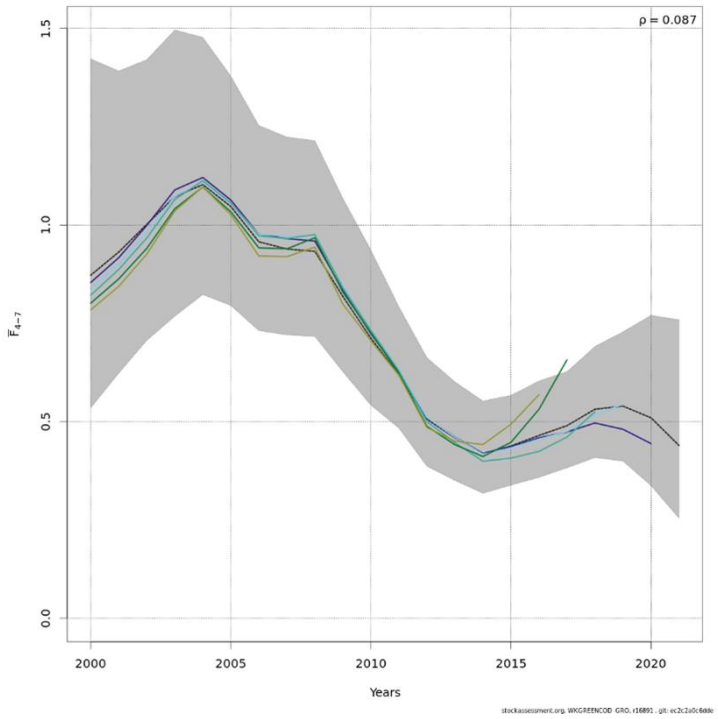

Figure 2.11: Retrospective plots of Fbar (5 years) for the West Greenland Offshore stock (WOSC/GRO). Mohn's rho is given in the upper right corner.

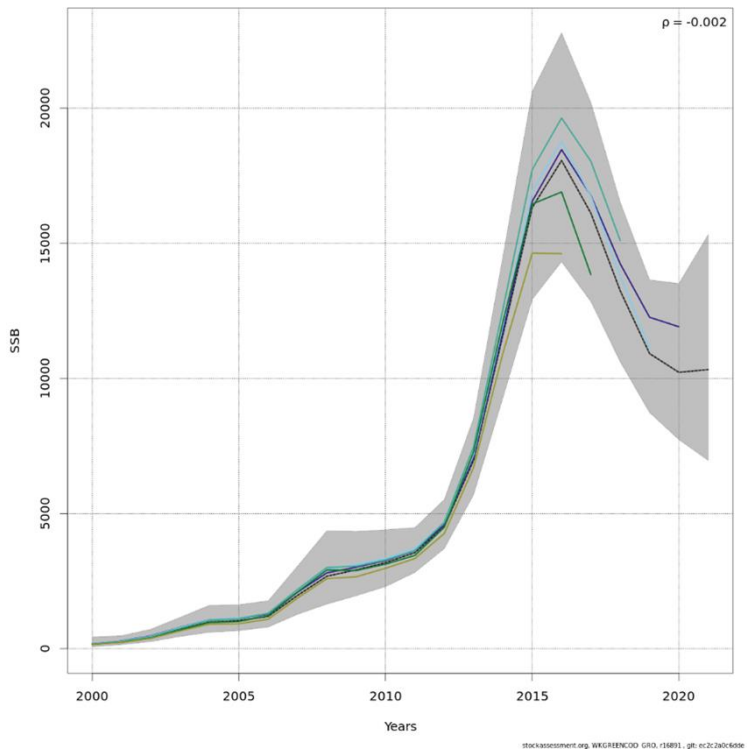

Figure 2.12: Retrospective plots of SSB (5 years) for the West Greenland Offshore stock (WOSC/GRO). Mohn's rho is given in the upper right corner.

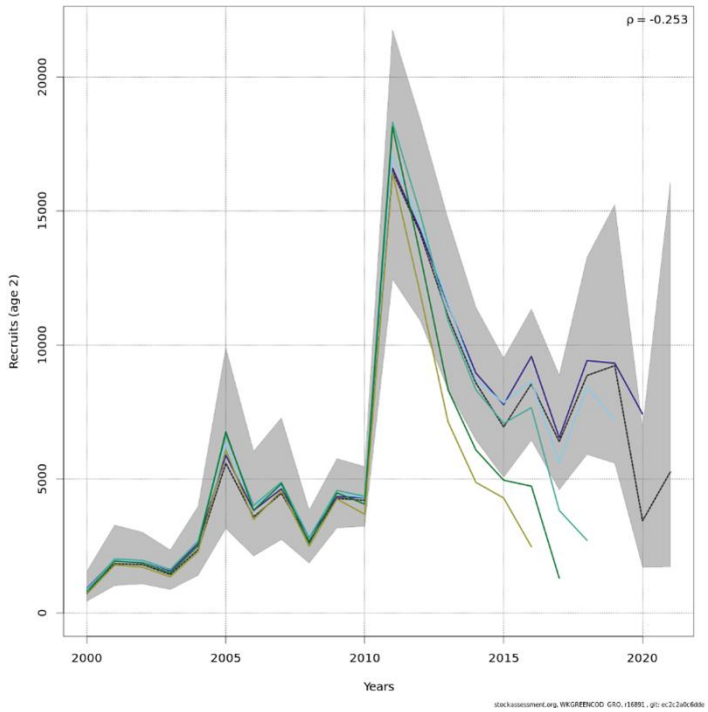

Figure 2.13: Retrospective plots of age 2 recruitment (5 years) for the West Greenland Offshore stock (WOSC/GRO). Mohn's rho is given in the upper right corner.

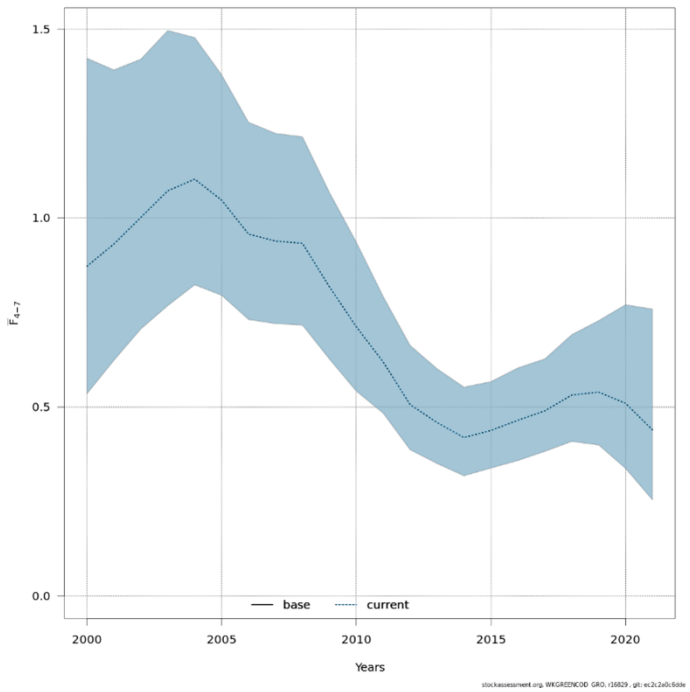

Figure 2.14: Estimated historical pattern of fishing mortality (Fbar4-7) for the West Greenland Offshore stock (WOSC/GRO). The shaded area is 95% confidence intervals.

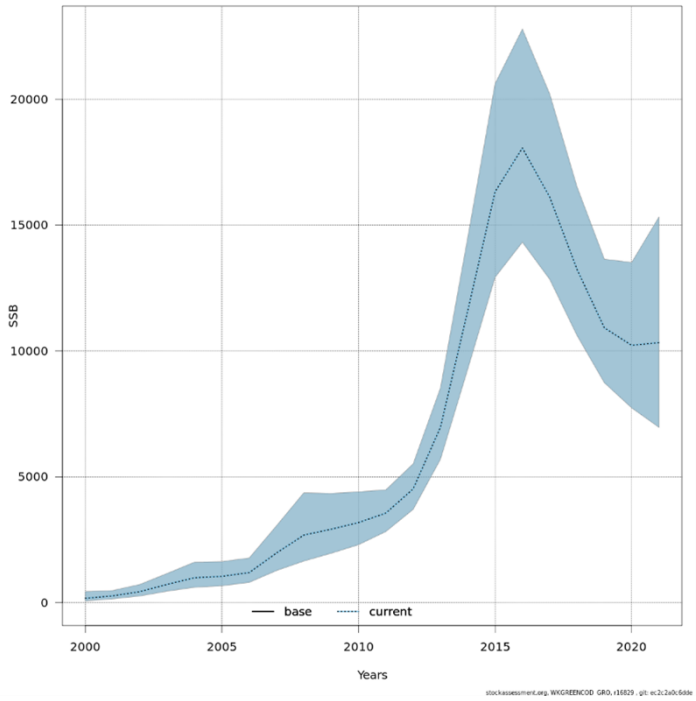

Figure 2.15: Estimated historical patterns of spawning stock biomass (SSB) for the West Greenland Offshore stock (WOSC/GRO). The shaded area is 95% confidence intervals.

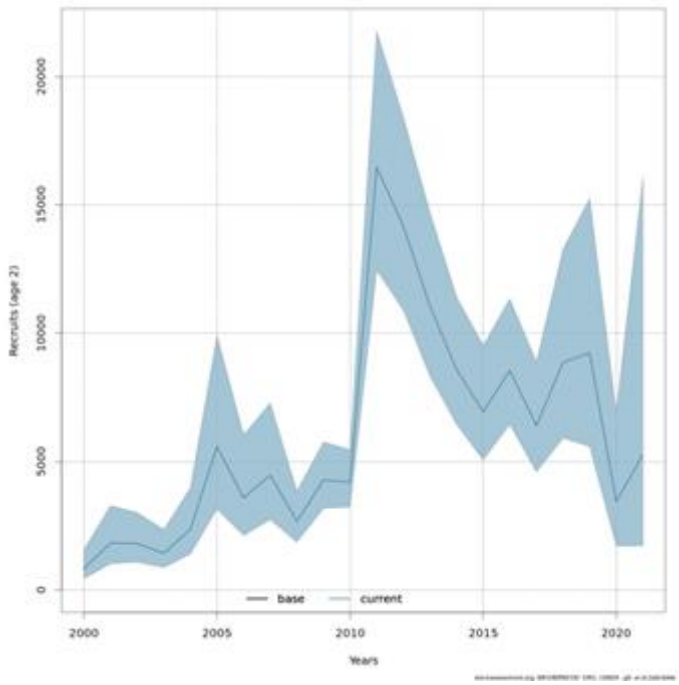

Figure 2.16: Estimated historical patterns of age 2 recruitment for the West Greenland Offshore stock (WOSC/GRO). The shaded area is 95% confidence intervals.

2.11 Short term forecasts

Table 2.2: Settings for the short-term forecast set up in SAM for the West Greenland Offshore stock (WOSC/GRO).

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.

2.12 Reference Points

For estimating B_{lim} a categorization of the stock-recruitment relationship into type is required (ICES, 2021a). The group agreed to use the average SSB of the three years with highest recruitment (Figure 2.17). This gave a B_{lim} of 3219t.

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

Table 2.3: Estimated reference points for the West Greenland Offshore stock (WOSC/GRO).

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

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.. Due to very high estimate of F_{lim}, it was decided to not report on this value. See Figure 2.18.

Details can be found in WD 07.

It is recommended that Reference points are revised when more data are available.

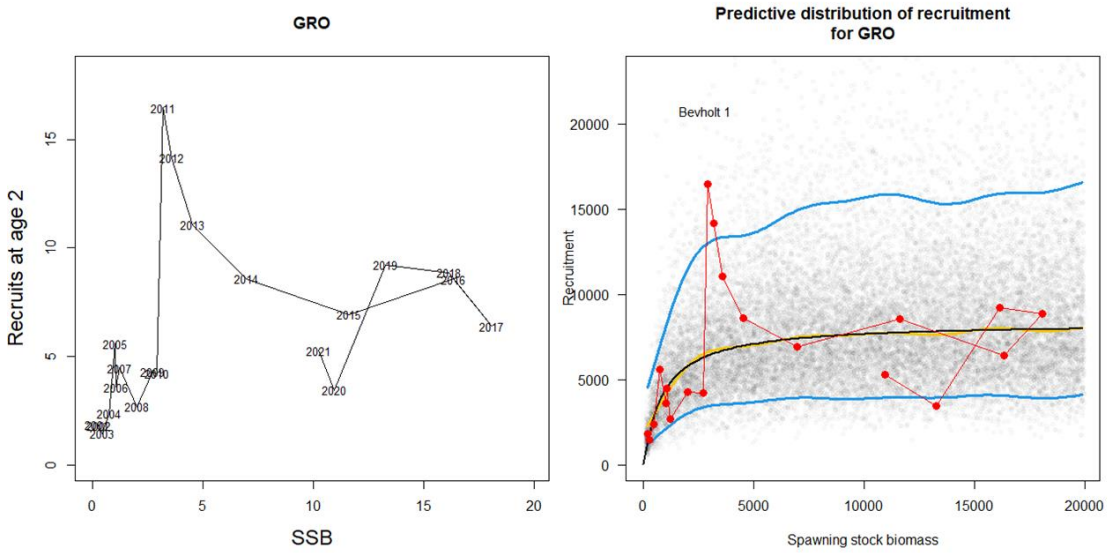

Figure 2.17 Left: SSB-recruitment relationship, labels indicate recruitment year. Right: SSB-recruitment relationship estimated by simulation using EqSim with fitted SSB-recruitment relationships. The solid line gives the fitted model and the blue lines indicated the interval in which 95% of the simulations falls.

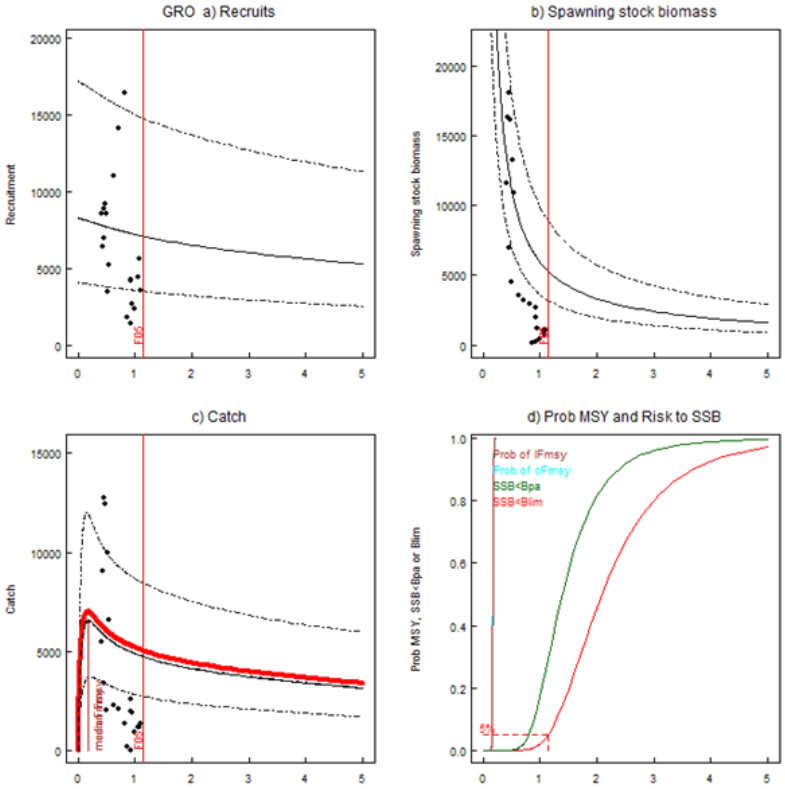

Figure 2.18: EqSim plots of recruitment, SSB, catch and probability of SSB falling below Bpa and Blim. F is on the x-axis.

3 West Greenland Inshore Spawning Cod (*Gadus morhua,* NAFO subarea 1)

In West Greenland, inshore spawning cod are genetically distinct from the offshore spawning stocks (Therkildsen *et al*., 2013). Differentiation between fjords or by distance along the coast remains to be studied.

Substantial isolation between major fjords along the coast appears likely, as this is indicated by tagging experiments, age distributions, recruitment patterns as well as trend in survey indices and commercial catches (Stor-Paulsen *et al*. 2003). Furthermore, spawning areas are present at the inner parts of the fjords (only information from the major fjords is available), so the cod do not have to migrate between fjords to spawn.

Tagging studies between 2003-2016 showed that only one cod out of 250 cod that was tagged and recaptured after more than 100 days at liberty migrated between Nuuk and Sisimiut, while only two migrated between Nuuk and South Greenland (Figure 3.1) /South Greenland (Hedeholm 2018). Four fish migrated to East Greenland / Iceland. None of the tagged specimens were genetically analysed, so it has likely been a mixture of inshore and offshore spawners, which would explain why some migrated to East Greenland / Iceland.

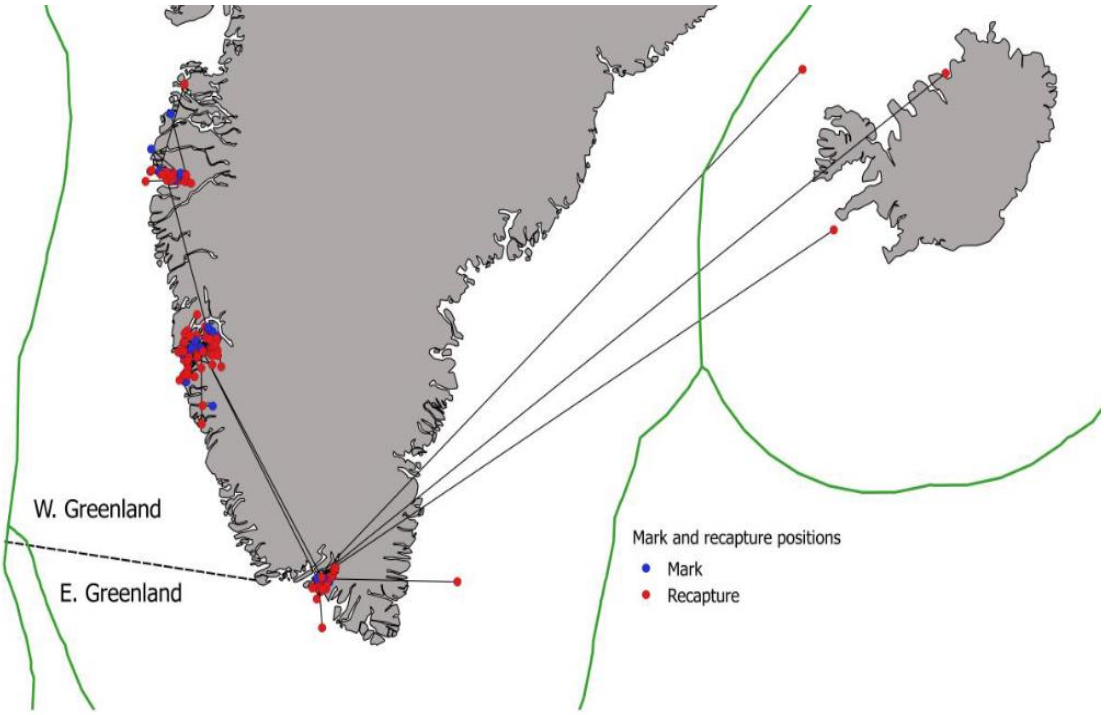

Figure 3.1: Mark and recapture positions of all recaptured cod tagged in West Greenland (from Hedeholm, 2018).

CPUE indices from the gillnet surveys in Nuuk and Sisimiut in the last decades suggested different recruitment histories (see age 2) and development in the older part of the populations (age 4-7; figure 3.2). The latter is also reflected in the commercial catches (Figure 3.3).

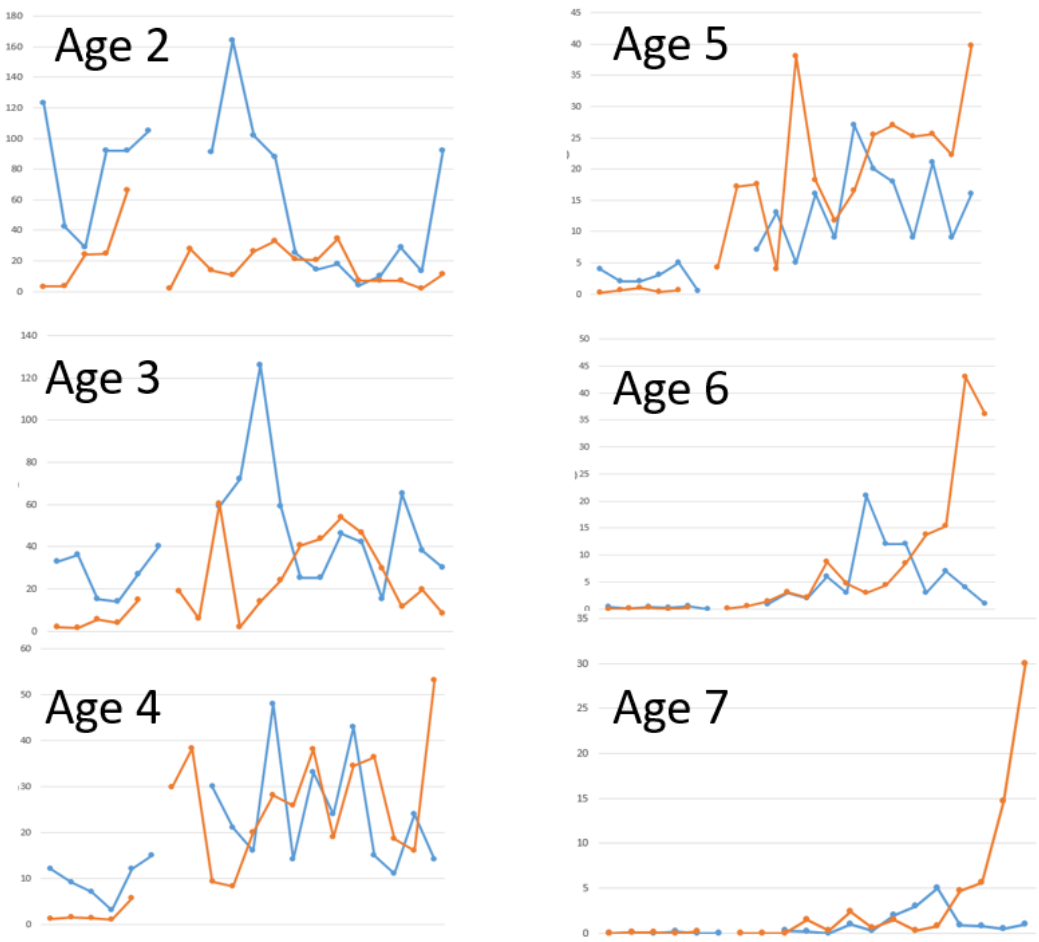

Figure 3.2: Survey CPUE of inshore spawning cod by age from gillnet survey in Nuuk (orange) and Sisimiut (blue).

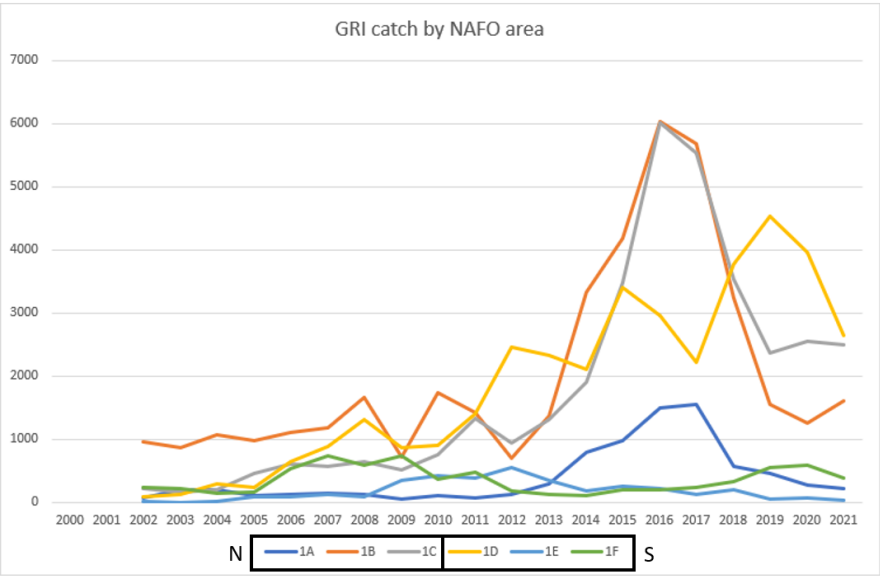

Figure 3.3: Commercial catches in West Greenland by NAFO area.

Genetic differences on this scale takes thousands of years to develop. Separation on shorter time scales are also relevant for stock assessments, because the models follow the cohorts through their lifespans, which is less than 25 years. Short term forecasting projects these cohorts up to 3 years ahead, so for assessment, advice and management purposes, it is the biological population that is relevant. Multiple biological populations may mix on a low level, but enough to ensure genetic mixing on an evolutionary time scale, but less than what is numerically relevant for quantitative cohort tracking.

For this reason, and because we find it most likely, based on the abovementioned information from tagging, surveys and commercial catches, that the inshore spawning cod consists of multiple populations with their own dynamics on the time scale relevant for providing short term fisheries advice. With the data presently available in ICES, it is practically possible to split the inshore spawners into two stocks, and it appears reasonable to draw a line between NAFO areas 1ABC and 1 DEF. One gillnet survey is conducted in each area and the commercial catch data reflects the recent decrease in the northern survey in the catches from 1C and northwards. There are 22nsufficient information and data available from south Greenland to consider a separation from the major driver in this area – the fjord system around Nuuk in 1D.

The group therefore decided to assess these two stocks:

Cod.21.1a-c.isc (N-WISC: Northern West Greenland Inshore Spawning Cod (Gadus morhua, NAFO Subarea 1a-c).

Cod.21.1d-f.isc (S-WISC: Southern West Greenland Inshore Spawning Cod (*Gadus morhua* , NAFO Subarea 1d-f,).

That improved the internal consistency of the surveys (especially in the south, figure 3.4) and the retrospective patterns in the assemssment models. The group therefore decided to implement this, to be used from NWWG 2023 onwards. [Note: Post-benchmark, this was presented to managers and the reaction was positive, and it appears feasible to set quotas on managements areas according to the advice given on spawning stocks. A tool has been developed for this process, but that is outside the ICES process).

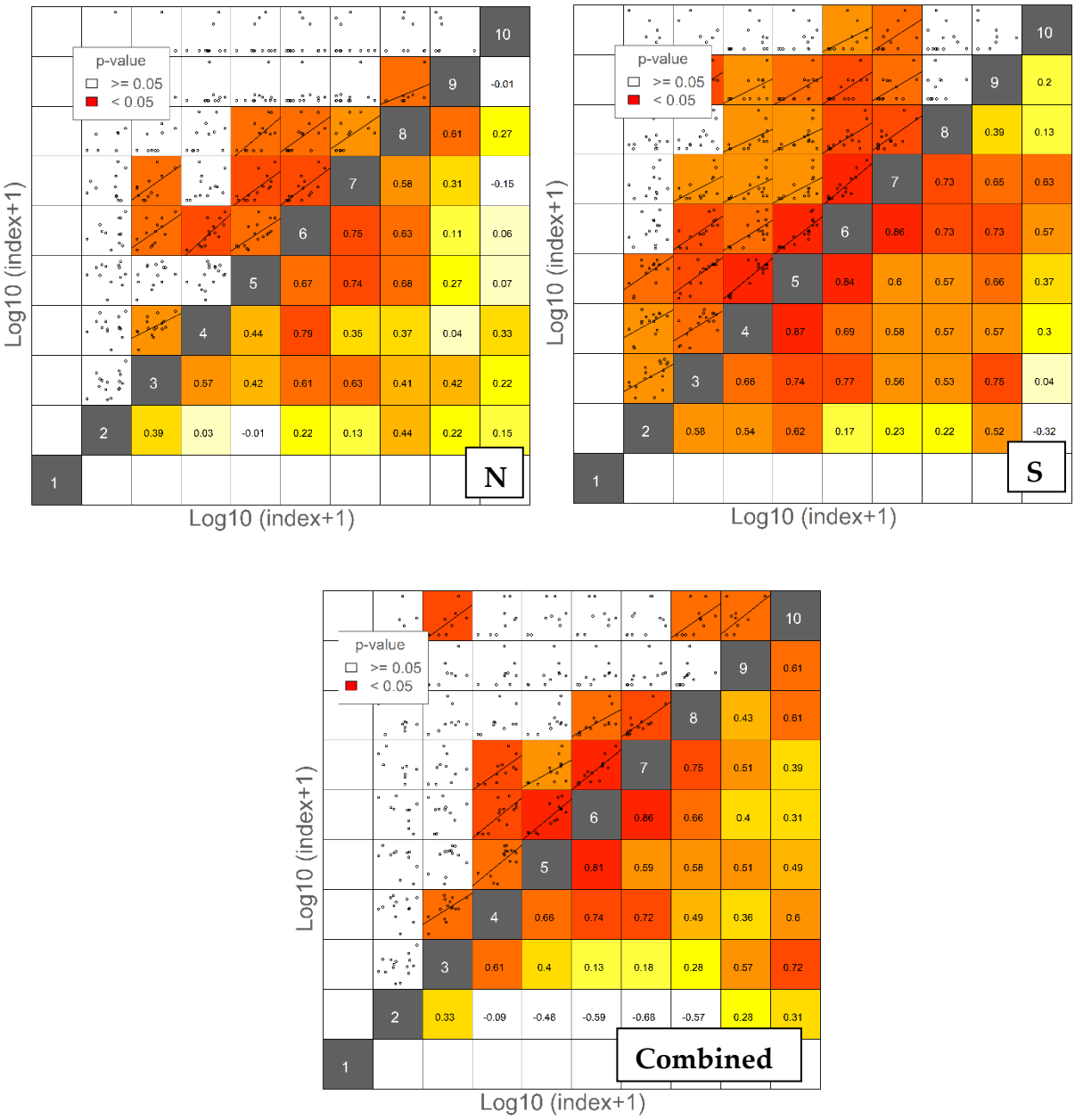

Figure 3.4: Internal consistency of the gillnet survey (S = Nuuk survey, N = Sisimiut survey).

3.1 Assessment Model and Reference Points

Attempts were made to assess the entire WISC stock using the state-space model SAM (Nielsen and Berg, 2014). The best model is described in WD09 and can be found on stockassessment.org names 'WKGREENCOD_GRO'. Issues remained with this assessment, including some patterns in the residuals and some concerns regarding the retrospective analysis.

Attempts were made to use SpiCT for this stock, this was not successful.

Attempts were made to estimate reference point based on the SAM assessment using EqSim, details are given in WD09. It was not possible to estimate reference points that could be accepted.

4 Northern West Greenland Inshore Spawning Cod (*Gadus morhua*, NAFO subarea 1A-C)

4.1 Summary

Genetic studies have shown that the fishery in the inshore area in West Greenland consist of more stocks than the West Greenland inshore stock. Previously only data from the geographical area corresponding to the inshore area of NAFO division 1A-1F have been used in the assessment. At this benchmark the commercial data has been split into three stocks which results in a complete dataset for the inshore stock fished in all areas in West Greenland, both in- and offshore. In addition, data from the West Greenland inshore gillnet survey is also split into stocks and used in the assessment. As there are different regimes and trends between fjord systems the assessment is split into two areas representing two stock units, the geographical area for the Northern West Greenland Inshore Spawning Cod (N-WISC) is corresponding to NAFO divisions 1A-1C. The assessment is a category 1 assessment based on the state-space model (SAM).

4.2 Stock Identity

Genomic analysis of contemporary and historical samples identified the distinct stock identity West Greenland Inshore Spawning Cod (WISC) (Therkildsen *et al*., 2013).

4.3 Data Quality

Due to low genetic sampling before year 2000, the assessment year starts at 2000.

4.4 Commercial Catch Data

Commercial catch data are set up as catch in numbers at age and weight at age on field-code level which are squares of 7.5 min and 15 min per Lat Lon, respectively. The catch in numbers at age are split into the three stocks (WD1; WD2).

For further description see stock annex.

4.5 Fishery-independent Data

A Gillnet survey (N6619) covers the inshore area in two NAFO divisions 1B and 1D. The survey in division 1B is used in the assessment of N-WISC.

The survey is a multi-meshed gillnet survey designed to target juvenile cod (age 2) and 3 year-old cod 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. Therefore, gillnet catches of older fish ages 2–8 were included in the data set. The abundance index used in the survey is defined as 100*(# caught/net*hour).

For further description see stock annex.

4.6 Maturity

Ogives were calculated for cod that has been genetically assigned (WD01) and from spawning month (March, April, May and June). Due to low sampling size and no yearly genetic analysis in spawning season, the proportion of mature fish by age is left unchanged from year to year.

For further description see stock annex.

4.7 Recruitment

Recruitment is set at age 2.

4.8 Stock Weight

Stock weights are taken from the gillnet surveys.

4.9 Natural Mortality

Natural mortality is differentiated by age but fixed at 0.2 for all ages. Tagging data showed, 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 WISC stock and natural mortality is by default set to value of 0.2.

4.10 Final Model Settings

The stock is assessed using the state-space model SAM (Nielsen and Berg, 2014). The final model is described below, details on other configurations tested during the benchmark are given in WD10.

Data used to fit the assessment model

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

The model is tuned with one survey. It is a CPUE index by age for ages 2-8 for the inshore gillnet survey in NAFO areas 1B.

Table 4. 1: Input data for the SAM model for the Northern West Greenland Inshore stock (N-WISC /GRI_N).

Type	Name	Year range	Age range	Variable from year to year
Canum	Catch-at-age in numbers	2000–present Except 2001	3–10+	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
Tuning fleet 1	CPUE index (gillnet survey 1B) Except	2002–present 2008, 2009	2–8	

Model Configurations

Catch mean weight-at-age are calculated from commercial samples, and used as observations for the catch weight process within SAM (Figure 4.1). Stock mean weight-at-age are calculated from the inshore gillnet survey, and used as observations for the stock weight process within SAM (Figure 4.2). Both the catch and stock weight process are included as GMRF with cohort and within age correlations.

Fishing mortality is estimated individually for ages 3-8, and for age 9 and 10 assumed to be the same, while age 2 is set to -1 and therefore not used. 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 3 and they are coupled for ages 4-10. Age to is set to -1 and not used.

The covariance structure for catch is assumed to be independent.

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.

Discarding is believed to have not taken place.

The natural mortality was set at 0.2 for all ages.

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.

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.

Figure 4.1: Catch weight at age (in kilograms) for the Northern West Greenland Inshore stock (N-WISC /GRI_N). Numbers give the input values by age, the line give the estimates from the model.

Figure 4.2: Stock weight at age (in kilograms) for the Northern West Greenland Inshore stock (N-WISC /GRI_N). Numbers give the input values by age, the line give the estimates from the model.

The survey catchability parameters are estimated individually for age 2, 3 and 4. Ages 5 and 6 and coupled and ages 7 and 8 are coupled.

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

For the survey the covariance structure is assumed to follow an AR(1) structure. This was done because there was evidence of year effects in the observation residuals for the survey.

Details are given in WD10.

Model diagnostics

For the most recent years with high catches the model tends to underestimate catch (Figure 4.3).

Observation residuals for both catches and survey shows some tendency for larger residuals early in the time series (Figure 4.4). There is a block of negative residuals for the survey residuals early in the timeseries. For the catch residuals there are a block of positive residuals, showing that the model underestimate catches in these years.

In order to test the robustness of the assessment a 5-year retrospective analysis (Figures 4.5 - 7) were conducted. For F all peels are within the confidence intervals. With some peels above and some below the current estimate (Mohn's rho=-0.011) (Figure 4.5). All peels for SSB, except the oldest, are within confidence intervals. The oldest peel underestimate SSB and remaining fluctuate around the current estimate (Mohn's rho= -0.051) (Figure 4.6). For recruitment the three most recent peels are within the confidence limits (Mohn's rho=0.047) (Figure 4.7).

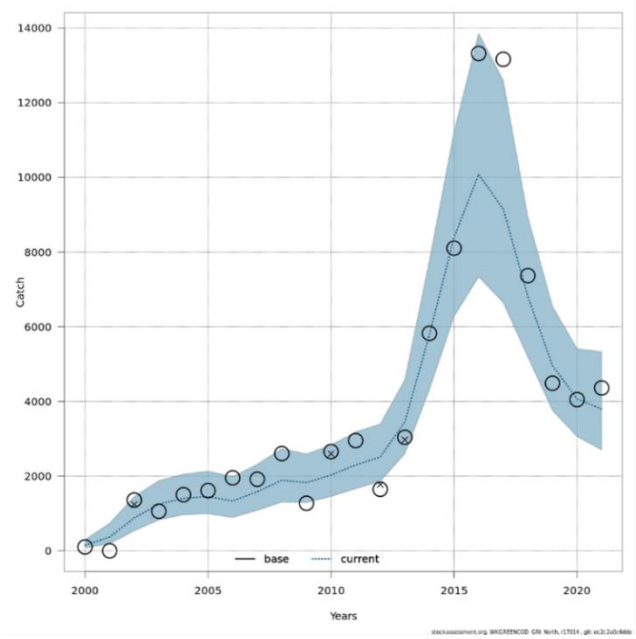

Figure 4.3: Estimated (line), observed catches (x), and catches based on smoothed catch weights (o) for the Northern West Greenland Inshore stock (N-WISC /GRI_N). Estimated catch is shown with 95% confidence intervals.

Figure 4.4: Normalized residuals derived from SAM for the Northern West Greenland Inshore stock (N-WISC /GRI_N). Blue indicates positive residuals (observation larger than predicted) and red circles indicated negative residuals.

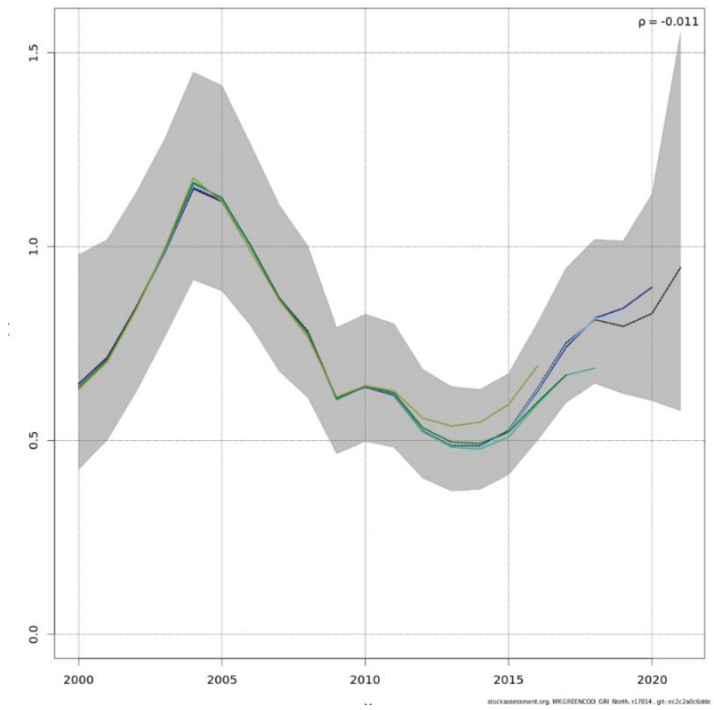

Figure 4.5: Retrospective plots of Fbar (5 years) for the Northern West Greenland Inshore stock (N-WISC /GRI_N). Mohn's rho is given in the upper right corner.

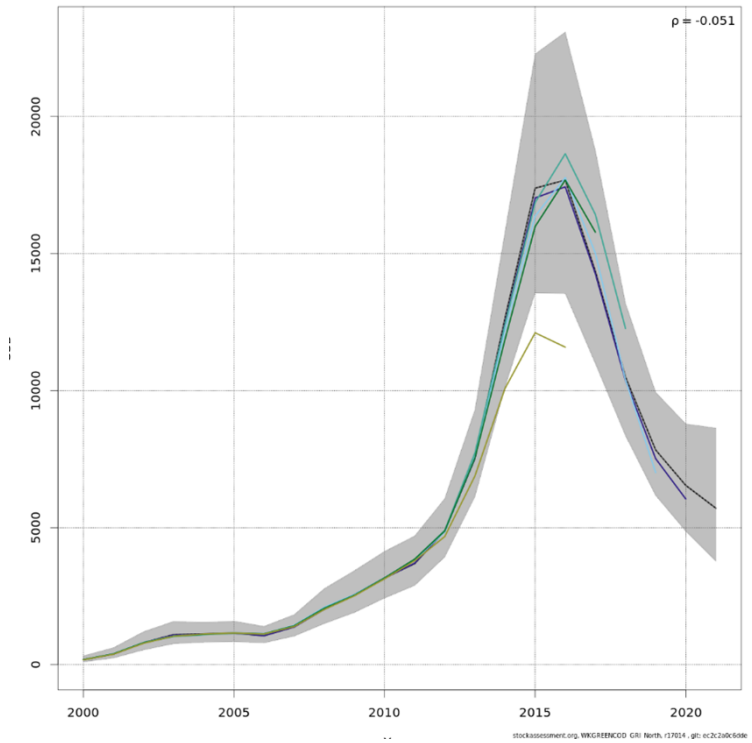

Figure 4.6: Retrospective plots of SSB (5 years) for the Northern West Greenland Inshore stock (N-WISC /GRI_N). Mohn's rho is given in the upper right corner.

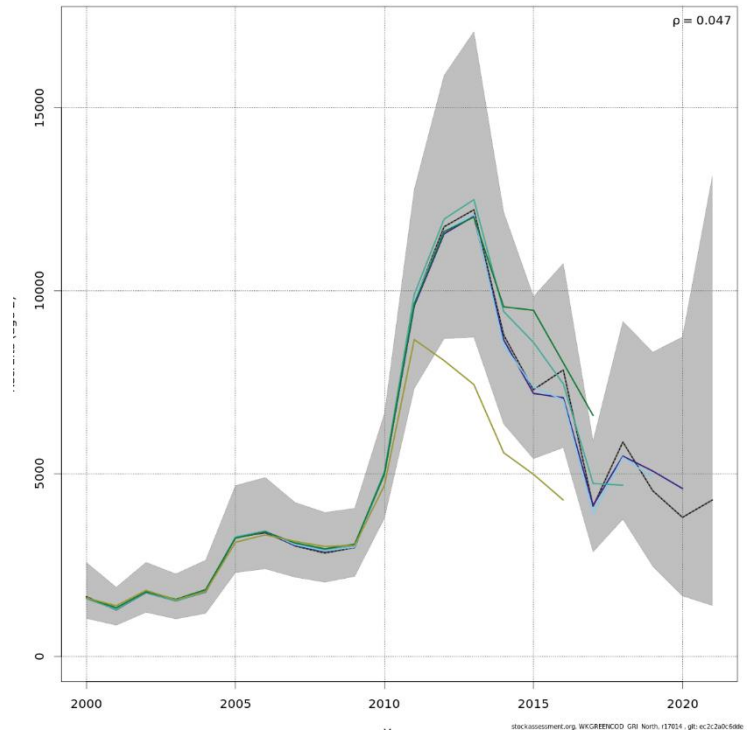

Figure 4.7: Retrospective plots of age 2 recruitment (5 years) for the Northern West Greenland Inshore stock (N-WISC /GRI_N). Mohn's rho is given in the upper right corner.

Assessment results

The estimated SSB, Fbar and recruitment from the model are given in figures 4.8, 4.9 and 4.10. Assessment name on stockassessment.org is 'WKGREENCOD_GRI_North'.

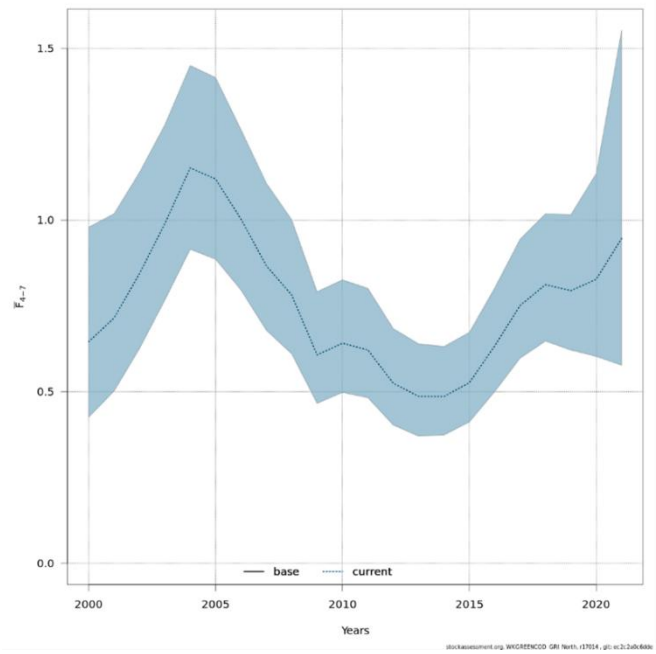

Figure 4.8 Estimated historical pattern of fishing mortality (Fbar4-7) for the Northern West Greenland Inshore stock (N-WISC /GRI_N).. The shaded area is 95% confidence intervals.

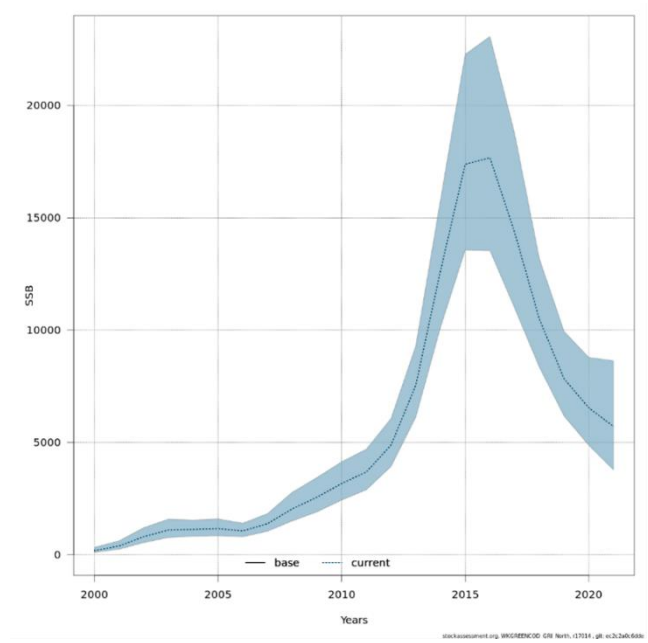

Figure 4.9: Estimated historical patterns of spawning stock biomass (SSB)) for the Northern West Greenland Inshore stock (N-WISC /GRI_N). The shaded area is 95% confidence intervals.

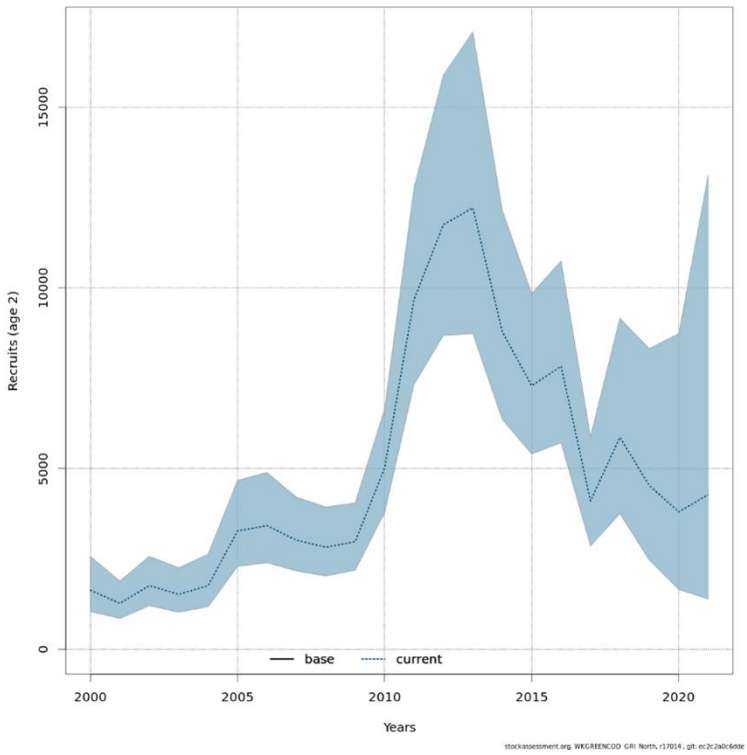

Figure 4.10: Estimated historical patterns of age 2 recruitment) for the Northern West Greenland Inshore stock (N-WISC /GRI_N). The shaded area is 95% confidence intervals.

4.11 Short term forecasts

Table 4.2: Settings for the short-term forecast set up in SAM for the Northern West Greenland Inshore stock (N-WISC /GRI_N).

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.

Short term forecast should always be based on the range of F_{msy} values specified in the reference point sections, and not just on the average value.

4.12 Reference Points

For estimating B_{lim} a categorization of the stock-recruitment relationship into type is required (ICES, 2021a). At the benchmark it was agreed that the Type 2- S-R relationship corresponded best to the stock-recruitment relationship with a wide dynamic range of SSB and evidence that recruitment is or has been impaired. According to this SR type B_{lim} is based on the breakpoint in a segmented regression (Figure 4.11). This gave a B_{lim} of 2 147 t.

It was not possible to estimate reference points for this stock using EqSim. It was decided to look at the two stocks most similar to this, WOSC and S-WISC. The benchmark group therefore gives F_{msy} at the average of the two other stock and also suggest carrying out forecast covering the range of F_{msy}. Similarly, F_{pa} is given as a range based on the other two stocks and using the average as the actual F_{pa} value. B_{lim} and thus B_{pa} is based on B_{lim} from the segmented regression. Table 4.3 shows the final reference points.

Table 4.3: Estimated reference points for the Northern West Greenland Inshore stock (N-WISC /GRI_N).

Framework	Reference point	Value	Technical basis	Source
MSY approach	MSY $B_{trigger}$	3 017 t	B_{pa}	WKGREENCOD 2023
	F_{MSY}	0.24 (0.18-0.29)	Based on the average of F_{MSY} from the GRO (F_{MSY} =0.18) and GRI south (F_{MSY} =0.29) stock	WKGREENCOD 2023
Precautionary approach	B_{lim}	2 147 t	From segmented regression breakpoint	WKGREENCOD 2023
	B_{pa}	3 015 t	B_{lim}*exp(sigmaSSB*1.645), sigmaSSB=0.207	WKGREENCOD 2023
	F_{lim}	NA	Equilibrium F, which will maintain the stock above Blim with a 50% probability.	
	F_{pa}	2.63 (1.34-3.92)	Based on the average of Fpa from the GRO (Fpa=1.34) and GRI south (Fpa=3.92) stock	WKGREENCOD 2023

Details can be found in WD 10.

It is recommended that Reference points are revised when more data are available.

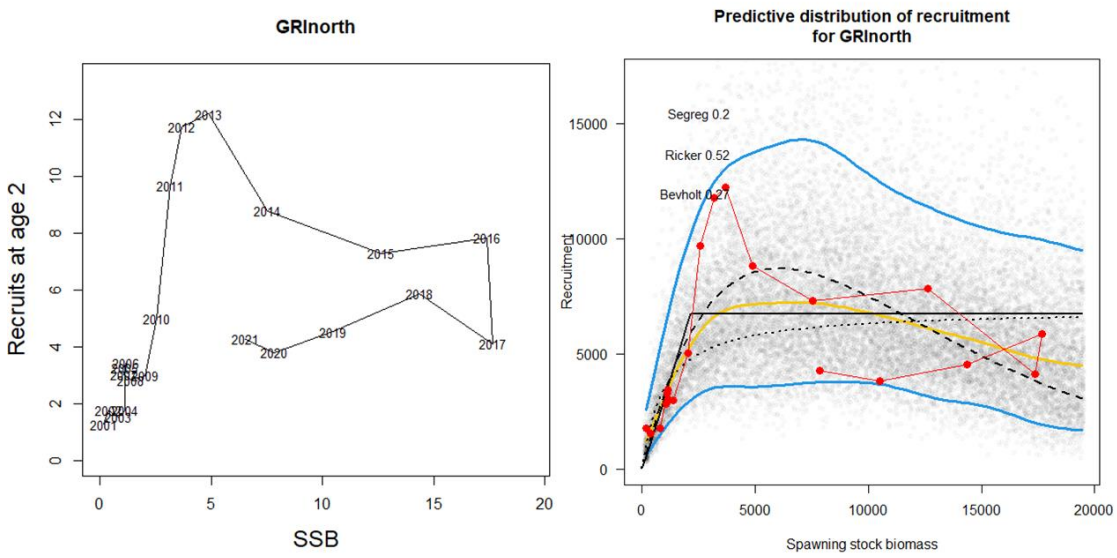

Figure 4.11: left - SSB-recruitment relationship, labels indicate recruitment year. Right - SSB-recruitment relationship estimated by simulation using EqSim with fitted SSB-recruitment relationships. The solid line gives the fitted model and the blue lines indicated the interval in which 95% of the simulations falls.

5 Southern West Greenland Inshore Spawning Cod (*Gadus morhua*, NAFO subarea 1D-F)

5.1 Summary

Genetic studies have shown that the fishery in the inshore area in West Greenland consist of more stocks than the West Greenland inshore stock. Previously only data from the geographical area corresponding to the inshore area of NAFO division 1A-1F have been used in the assessment. At this benchmark the commercial data has been split into three stocks which results in a complete dataset for the inshore stock fished in all areas in West Greenland, both in- and offshore. In addition, data from the West Greenland inshore gillnet survey is also split into stocks and used in the assessment. As there are different regimes and trends between fjord systems the assessment is split into two areas representing two stock units, the geographical area for the Southern West Greenland Inshore Spawning Cod (S-WISC) is corresponding to NAFO divisions 1D-1F. The assessment is a category 1 assessment based on the state-space model (SAM).

5.2 Stock Identity

Genomic analysis of contemporary and historical samples identified the distinct stock identity West Greenland Inshore Spawning Cod (WISC) (Therkildsen *et al*., 2013).

5.3 Data Quality

Due to low genetic sampling before year 2000, the assessment year starts at 2000.

5.4 Commercial Catch Data

Commercial catch data are set up as catch in numbers at age and weight at age on field-code level which are squares of 7.5 min and 15 min per Lat Lon, respectively. The catch in numbers at age are split into the three stocks (WD1; WD2).

For further description see stock annex.

5.5 Fishery-independent Data

A Gillnet survey (N6619) covers the inshore area in two NAFO divisions 1B and 1D. The survey in division 1D is used in the assessment of S-WISC.

The survey is a multi-meshed gillnet survey designed to target juvenile cod (age 2) and 3 year-old cod 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. Therefore, gillnet catches of older fish ages 2–8 were included in the data set. The abundance index used in the survey is defined as 100*(# caught/net*hour).

For further description see stock annex.

5.6 Maturity

Ogives are calculated for cod that were genetically assigned (WD01) and from spawning month (March, April, May and June). Due to low sampling size and no yearly genetic analysis in spawning season, the proportion of mature fish by age is left unchanged from year to year.

For further description see stock annex.

5.7 Recruitment

Recruitment is set at age 2.

5.8 Stock Weight

Stock weights are taken from the gillnet surveys.

5.9 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 WISC stock and natural mortality is by default set to value of 0.2.

5.10 Final Model Settings

The stock is assessed using the state-space model SAM (Nielsen and Berg, 2014). The final model is described below, details on other configurations tested during the benchmark are given in WD11.

Attempts were made to use SPiCT for this stock, this was not successful.

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

The model is tuned with one survey. It is a CPUE index by age for ages 2-8 for the inshore gillnet survey in NAFO areas 1D.

Data used to fit the assessment model

Table 5.1: Input data for the SAM model for the Southern West Greenland Inshore stock (S-WISC /GRI_S).

Type	Name	Year range	Age range	Variable from year to year
Canum	Catch-at-age in numbers	2000–present Except 2001	3–10+	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
Tuning fleet 1	CPUE index (gillnet survey 1D) Except	2002–present 2007	2–8	

Model Configurations

Catch mean weight-at-age are calculated from commercial samples, and used as observations for the catch weight process within SAM (figure 5.1). Stock mean weight-at-age are calculated from the inshore gillnet survey, and used as observations for the stock weight process within SAM (see figure 5.2). Both the catch and stock weight process are included as GMRF with cohort and within age correlations.

Fishing mortality is estimated individually for ages 3-8, age 9 and 10 are assumed to be the same, age 2 is set to -1 and therefore not used. 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 3 and they are coupled for ages 4-10. Age to is set to -1 and not used.

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.

The covariance structure for catch is assumed to be independent.

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

No discarding is believed to take place.

The natural mortality is set at 0.2 for all ages.

Figure 5.1: Catch weight at age (in kilograms) Southern West Greenland Inshore stock (S-WISC /GRI_S). Numbers give the input values by age, the line give the estimates from the model.

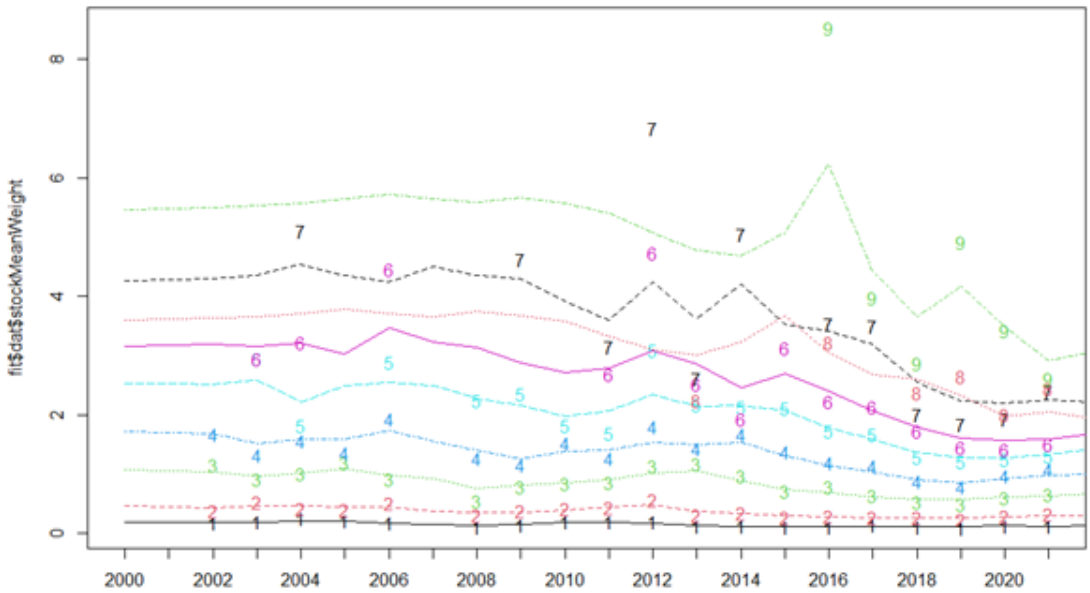

Figure 5.2: Stock weight at age (in kilograms) for the Southern West Greenland Inshore stock (S-WISC /GRI_S). Numbers gives the input values by age, the line give the estimates from the model.

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.

The survey catchability parameters are estimated individually for ages, 2, 3 and 4. They are coupled for ages 5 and 6 and for ages 7 and 8.

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

For the survey the covariance structure is assumed to follow an AR(1) structure.

Details are given in WD11.

Model diagnostics

The estimated catches are in line with observed catches (Figure 5.3).

Observation residuals for both catches and survey shows some tendency for larger residuals early in the time series (Figure 5.4). There is a block of negative residuals for the survey residuals early in the timeseries and a block of positive residuals in the most recent years. For the catch residuals there is a block of positive residuals, showing that the model underestimate catches in these years. The most recent year has negative residuals for all ages.

In order to test the robustness of the assessment a 5-year retrospective analysis (Figures 5.5 - 7) were conducted. For F all peels, except one, are within the confidence intervals. The oldest peels show a tendency to overestimate F, whereas the three most recent peels show some tendency to underestimate F (Mohn's rho=0.119) (Figure 5.5). All peels for SSB, except the two oldest, are within confidence intervals. The oldest peels show a tendency to underestimate SSB and the three most recent peels shows a tendency to overestimate SSB (Mohn's rho= 0.001) (Figure 5.6). For recruitment the three most recent peels are within the confidence limits (Mohn's rho=0.004) (Figure 5.7).

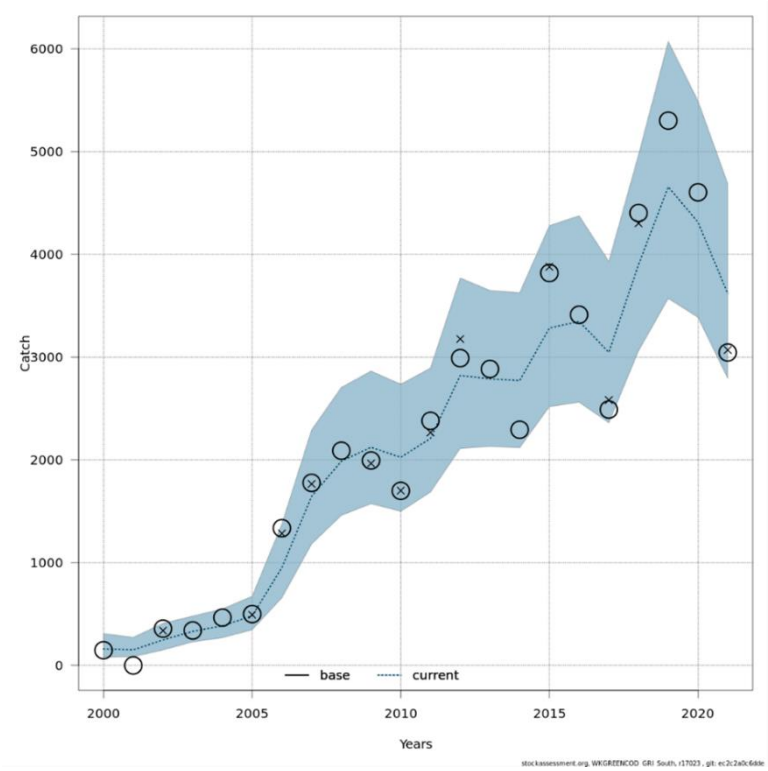

Figure 5.3: Estimated (line), observed catches (x), and catches based on smoothed catch weights (o) for the Southern West Greenland Inshore stock (S-WISC /GRI_S). Estimated catch is shown with 95% confidence intervals.

Figure 5.4: Normalized residuals derived from SAM for the Southern West Greenland Inshore stock (S-WISC /GRI_S). Blue indicates positive residuals (observation larger than predicted) and red circles indicated negative residuals.

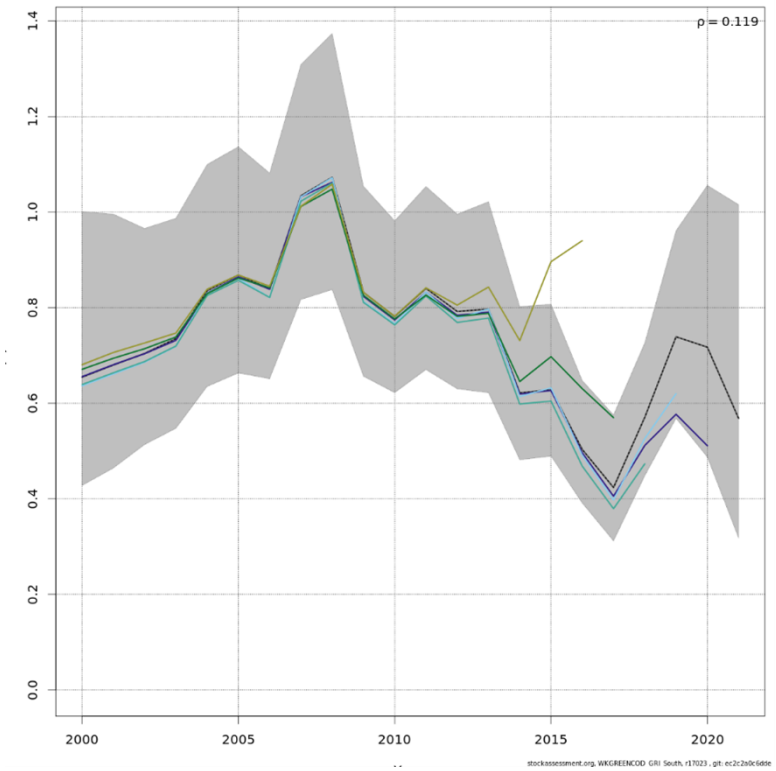

Figure 5.5: Retrospective plots of Fbar (5 years) for the Southern West Greenland Inshore stock (S-WISC /GRI_S). Mohn's rho is given in the upper right corner.

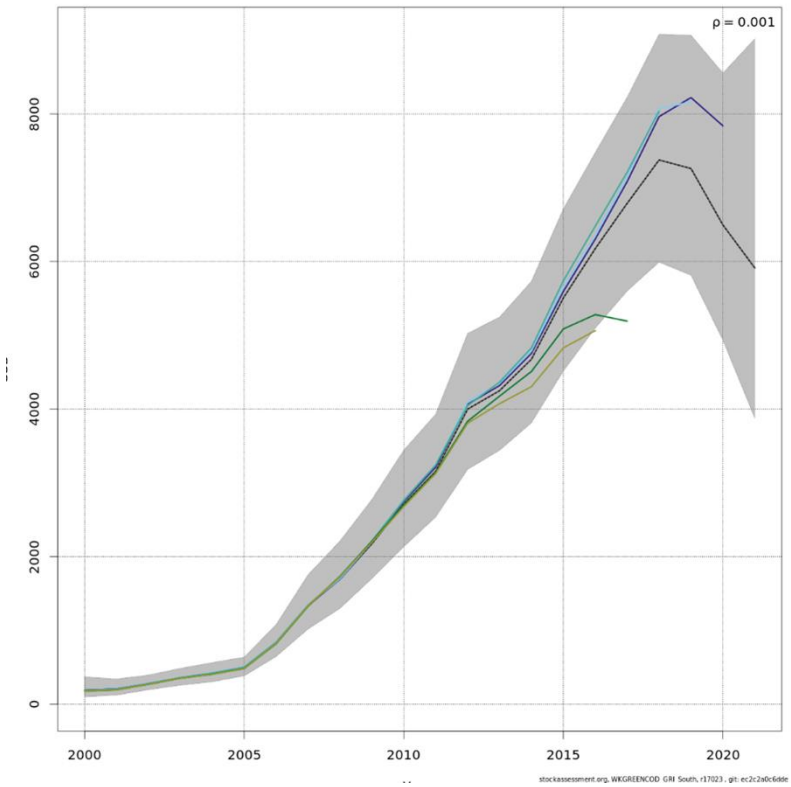

Figure 5.6: Retrospective plots of SSB (5 years) for the Southern West Greenland Inshore stock (S-WISC /GRI_S). Mohn's rho is given in the upper right corner.

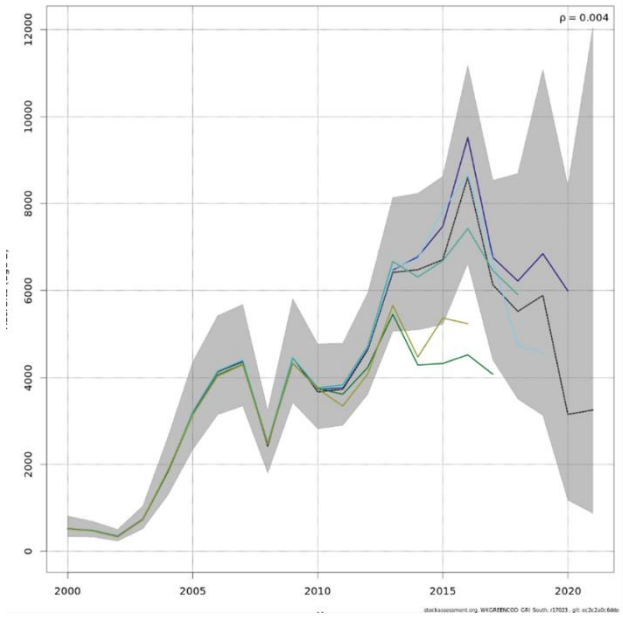

Figure 5.7: Retrospective plots of age 2 recruitment (5 years peel) for the Southern West Greenland Inshore stock (S-WISC /GRI_S). Mohn's rho is given in the upper right corner.

Assessment results

The estimated SSB, Fbar and recruitment from the model are given in figures 5.8, 5.9 and 5.10. Assessment name on stockassessment.org is 'WKGREENCOD_GRI_South'.

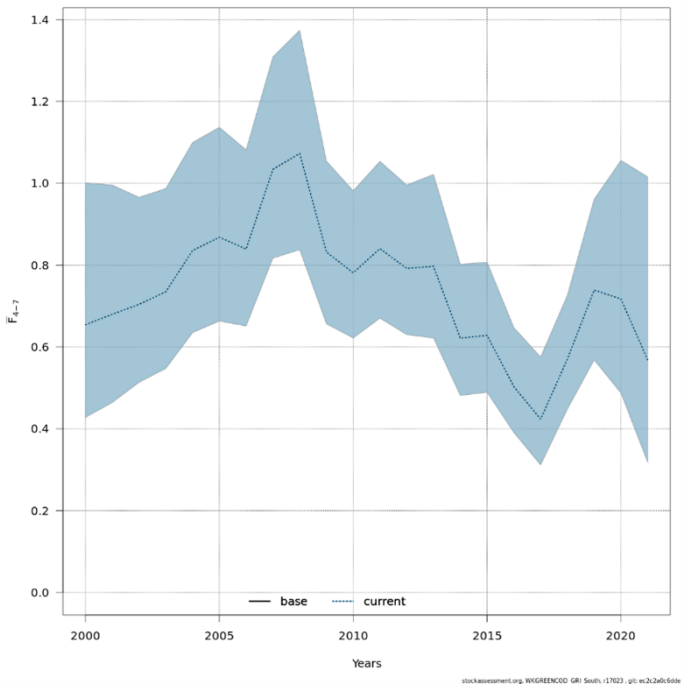

Figure 5.8: Estimated historical pattern of fishing mortality (Fbar4-7) for the Southern West Greenland Inshore stock (S-WISC /GRI_S). The shaded area is 95% confidence intervals.

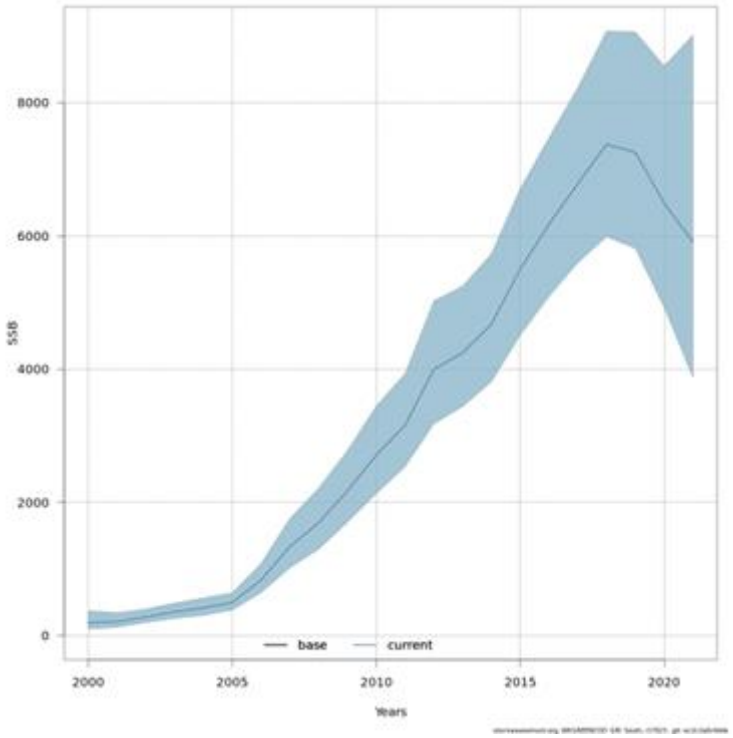

Figure 5.9: Estimated historical patterns of spawning stock biomass (SSB) for the Southern West Greenland Inshore stock (S-WISC /GRI_S). The shaded area is 95% confidence intervals.

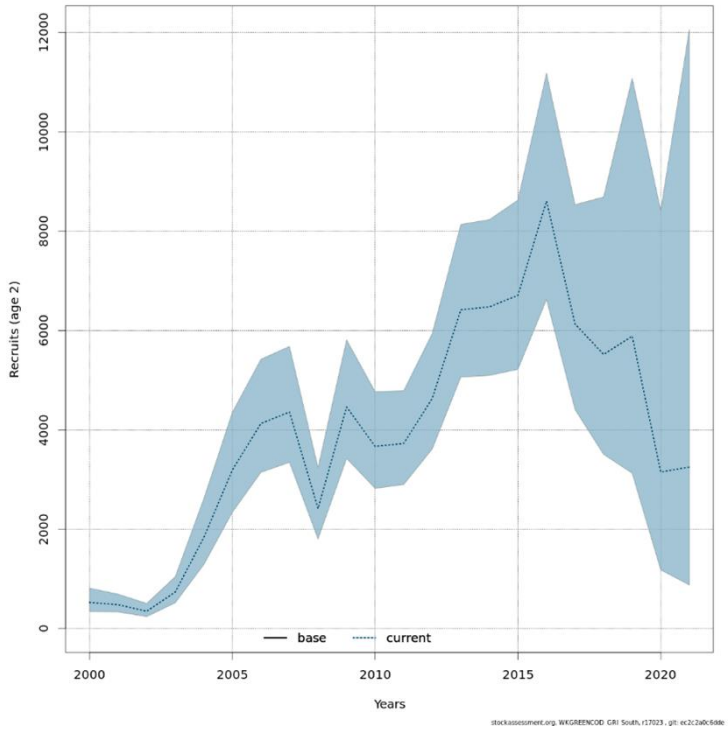

Figure 5.10: Estimated historical patterns of age 2 recruitment for the Southern West Greenland Inshore stock (S-WISC /GRI_S). The shaded area is 95% confidence intervals.

5.11 Short term forecasts

Table 5.2: Settings for the short-term forecast set up in SAM for the Southern West Greenland Inshore stock (S-WISC /GRI_S).

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.

5.12 Reference Points

For estimating B_{lim} a categorization of the stock-recruitment relationship into type is required (ICES, 2021a). The group agreed that the Type 2- S-R relationship corresponded best to the stock-recruitment relationship with a wide dynamic range of SSB and evidence that recruitment is or has been impaired. According to this SR type B_{lim} is based on the breakpoint in a segmented regression (Figure 5.11). This gave a B_{lim} of 1 067 t.

The simulation settings for the stock-recruitment relationship were as follows. The number of simulations were set to 1500. The years 2018 and 2019 (recruitment in 2020 and 2021) were excluded. For assessment error sigmaF was set to default of 0.2 and sigmaSSB was 0.211 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 5 years were used. For selectivity the last 5 years were used. The estimated reference points are given in the table 5.3 (see also figure 5.12).

Details can be found in WD 11.

It is recommended that Reference points are revised when more data are available.

Table 5.3: Estimated reference points for the Southern West Greenland Inshore stock (S-WISC /GRI_S).

Framework	Reference point	Value	Technical basis	Source
MSY approach	MSY $B_{trigger}$	1 510 t	B_{pa}	WKGREENCOD 2023
	F_{MSY}	0.29	EQSim analysis based on the recruitment period 2000–2021.	WKGREENCOD 2023
Precautionary approach	B_{lim}	1 067 t	From segmented regression breakpoint	WKGREENCOD 2023
	B_{pa}	1 510 t	B_{lim}*exp(sigmaSSB*1.645), sigmaSSB=0.211	WKGREENCOD 2023
	F_{lim}	NA	Equilibrium F, which will maintain the stock above Blim with a 50% probability.	
	F_{pa}	3.9	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

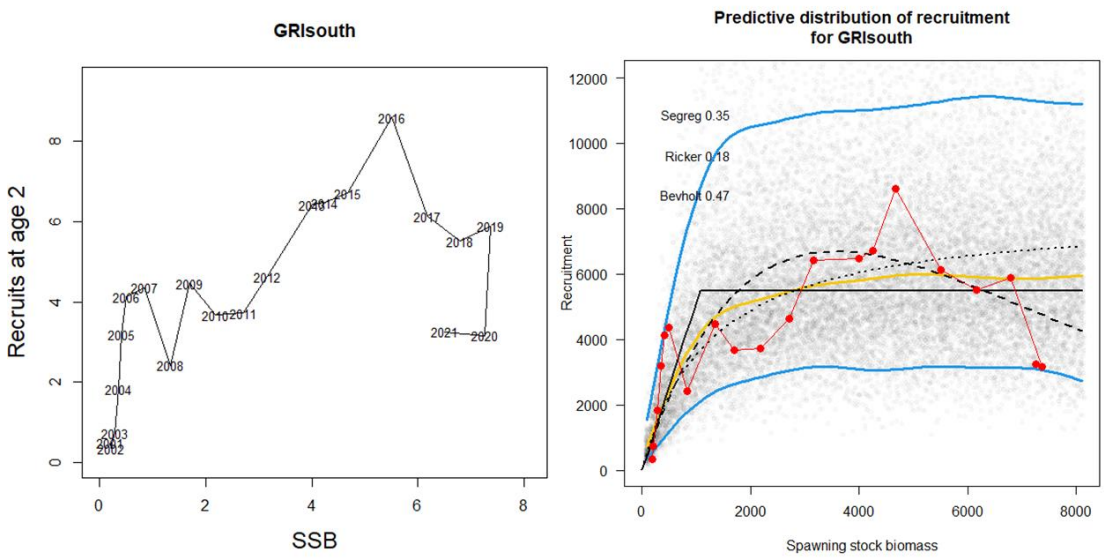

Figure 5.11: left: SSB-recruitment relationship, labels indicate recruitment year. right: SSB-recruitment relationship estimated by simulation using EqSim with fitted SSB-recruitment relationships. The solid line gives the fitted model and the blue lines indicated the interval in which 95% of the simulations falls.

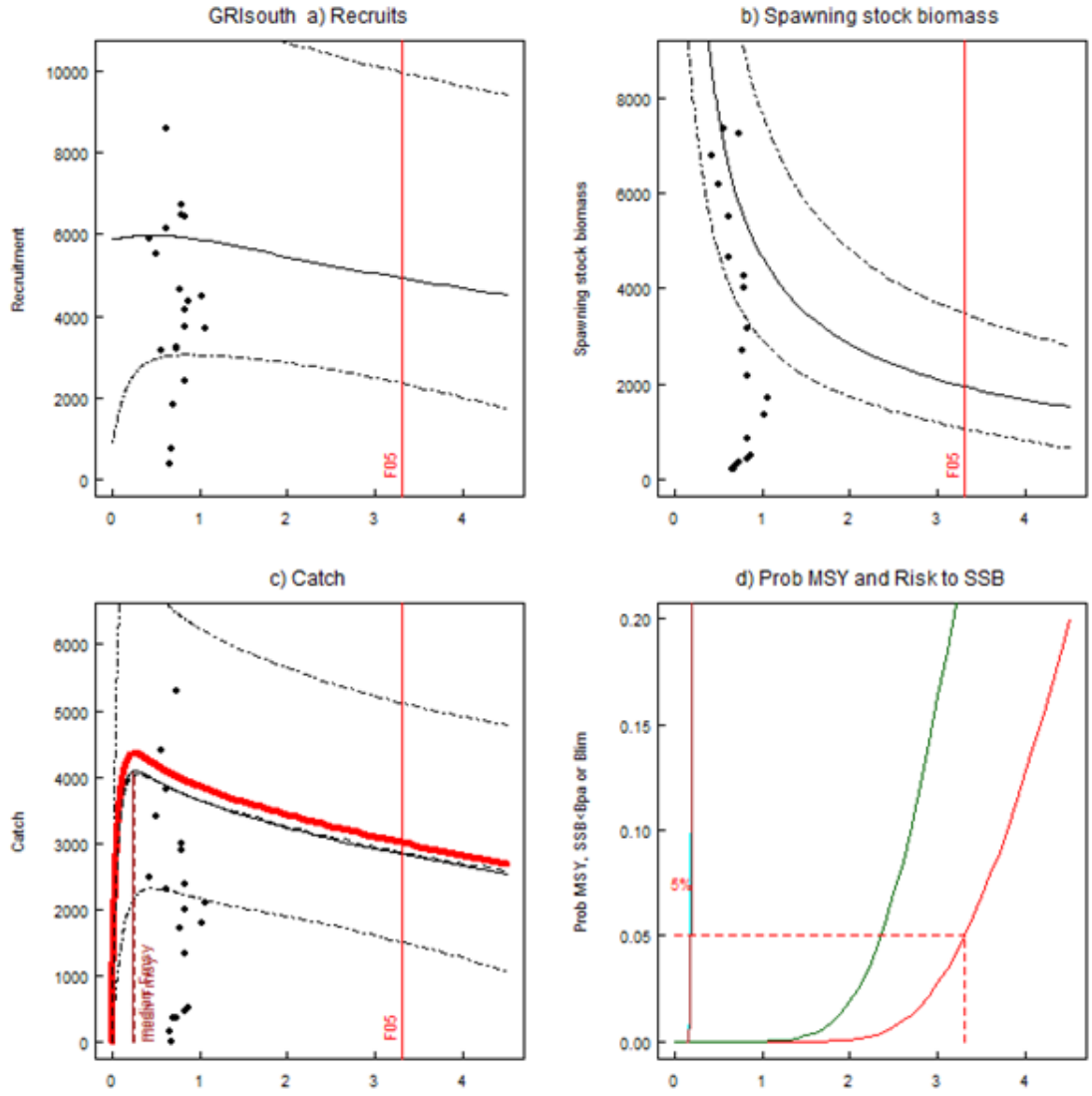

Figure 5.12: EqSim plots of recruitment, SSB, catch and probability of SSB falling below Bpa and Blim. F is on the x-axis.

6 East Greenland Iceland Offshore Spawning Cod (*Gadus morhua*, NAFO subarea 1 and ICES subarea 14)

6.1 Summary

Genetic studies have shown that the stock known as the East Greenland and offshore Iceland stock, hereafter named East Greenland Iceland Offshore Spawning Cod (EGIOSC), is also fished in the inshore and offshore fishery in West Greenland (se stock annex). Previously only data from the geographical area corresponding to the offshore area of NAFO division 1F and East Greenland have been used in the assessment. At this benchmark the commercial data from all of West Greenland, both in- and off-shore has been split into three stocks which results in a complete dataset for the EGIOSC stock. In addition, data from the West Greenland offshore bottom trawl surveys are also split into stocks and used in the assessment. The assessment is a category 1 assessment based on the state-space model (SAM).

6.2 Stock Identity

Genomic analysis of contemporary and historical samples identified the distinct stock identity East Greenland Iceland Offshore Spawning Cod (EGIOSC) (Therkildsen *et al*. 2013).

6.3 Data Quality

Due to low genetic sampling before year 2000, the assessment year starts at 2000.

6.4 Commercial Catch Data

In West Greenland commercial catch data are set up as catch in numbers at age and weight at age on field-code level which are squares of 7.5 min and 15 min per Lat Lon, respectively. The catch in numbers at age are split into the three stocks (WD1; WD2).

For further description see stock annex.

6.5 Fishery-independent Data

Demersal trawl surveys (G2064 and G3244)

Abundance indices in the summer-autumn were derived from a geostatistical model fitted to catch data from bottom trawl surveys conducted during summer and autumn in Greenlandic waters. Catch data were split by stock based on genetics (WD1; WD2). A complete description of the data and model can be found in WD5 and WD03 respectively, as well as in the stock annex.

The data were compiled from two bottom trawl surveys. Namely "SF" (G2064) conducted between 28 May – 4 October from 2005—2020 by the Greenlandic Institute of Natural Ressources, and "GGS" (G3244) conducted between 22 September – 15 November from 2000—2020 by the Thünen Institute for Sea Fisheries.

All surveys sample the fish community on the continental shelf and upper shelf slope.

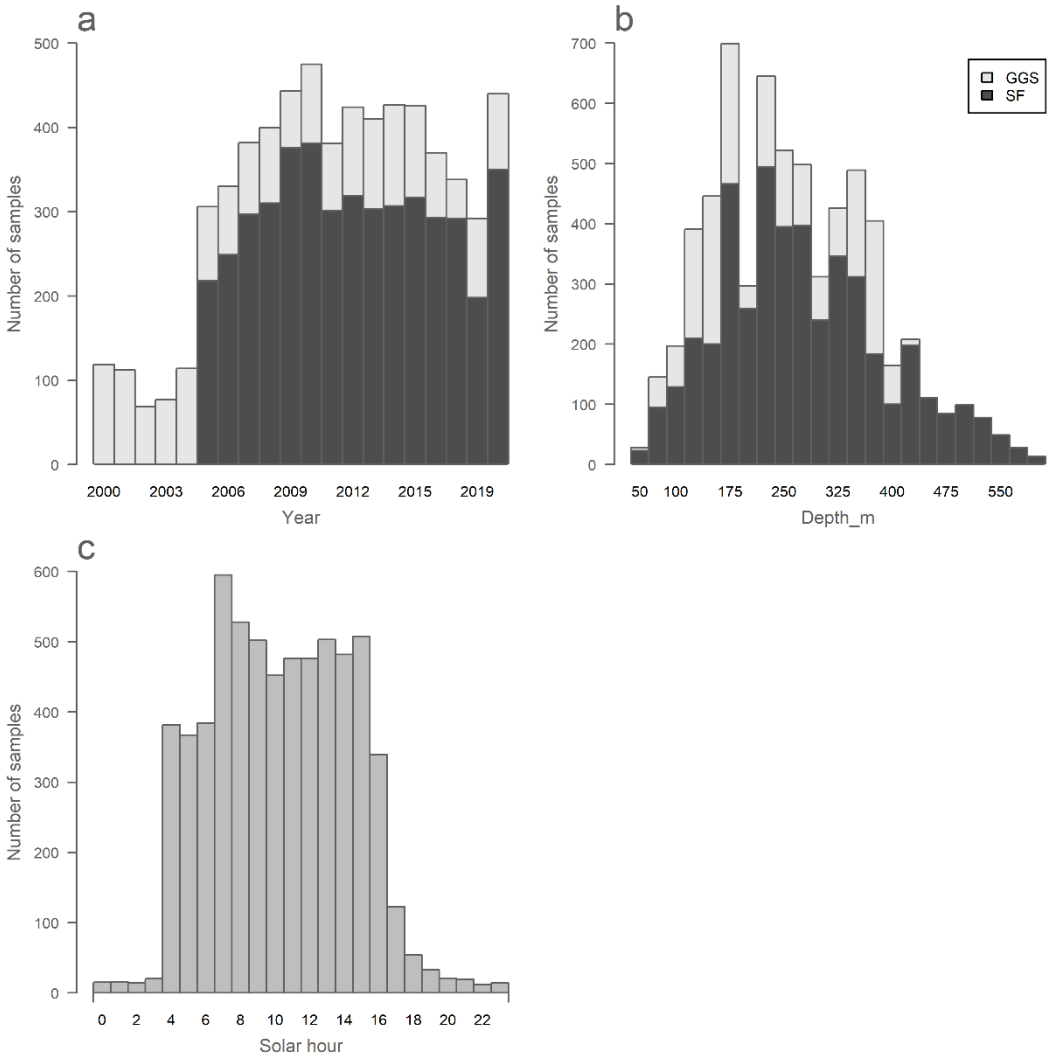

Figure 6.1: Number of trawl stations by year, survey, depth and solar hour from the SF (G2064) and GGS (G3244) survey.

Trawl operations have largely been standardized for each of the surveys, but differ substantially between the two. A survey effect was therefore included in the model in addition to the effect of effort (swept area in nmi^2).

In 2018 only West Greenland was covered and no surveys were conducted 2021. These years were excluded accordingly.

Figure 6.1 provides an overview of the distribution and number of samples.

INLA (Integrated Nested Laplace Approximation) was used to fit a spatially explicit statistical model. INLA is a Bayesian statistical method for fast fitting of complex statistical models such as generalized additive models (GAM) with spatial correlations (Lindgren *et al.*, 2015; Rue *et al.*, 2009). Based on simulations with the model, spatial distributions and time series for each age and stock was estimated. Model diagnostics are presented in WD3.

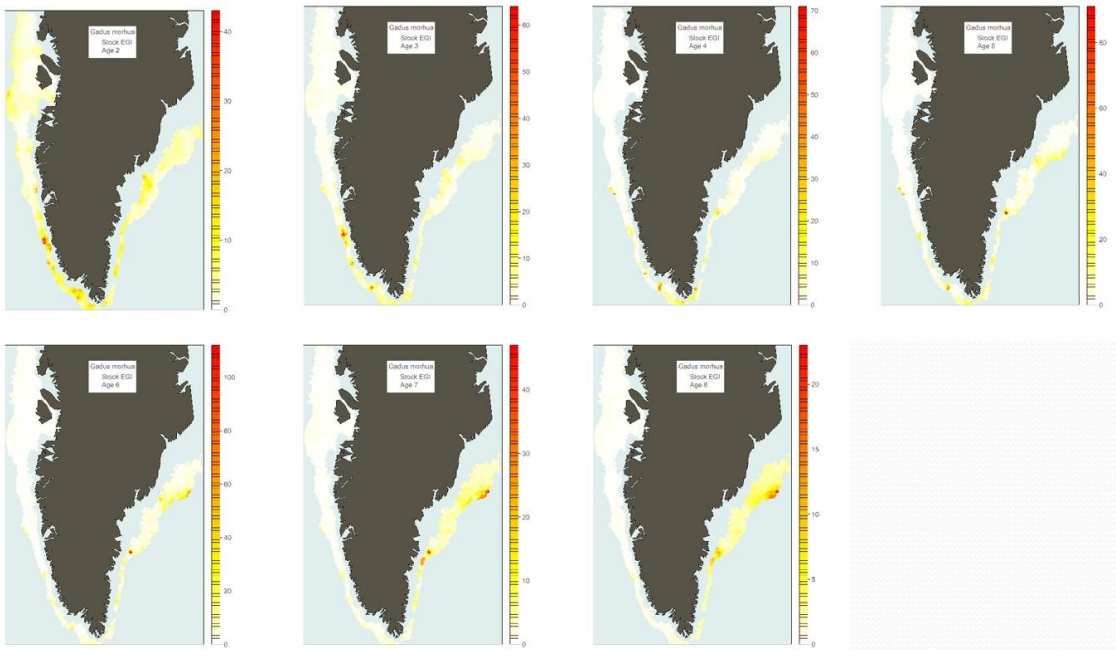

Figure 6.2: Spatial distribution of mean densities by age based on INLA for EGI (EGIOSC).

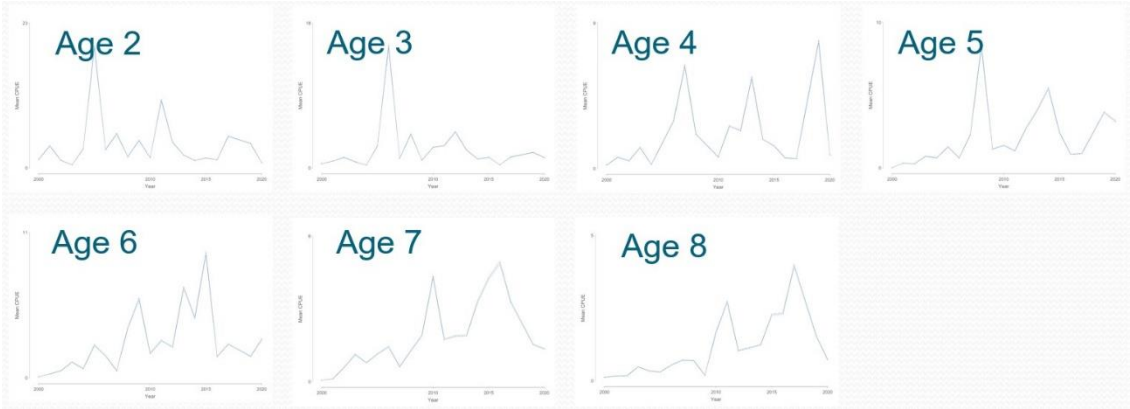

Figure 6.3: Relative abundance estimates of cod for EGI (EGIOSC).

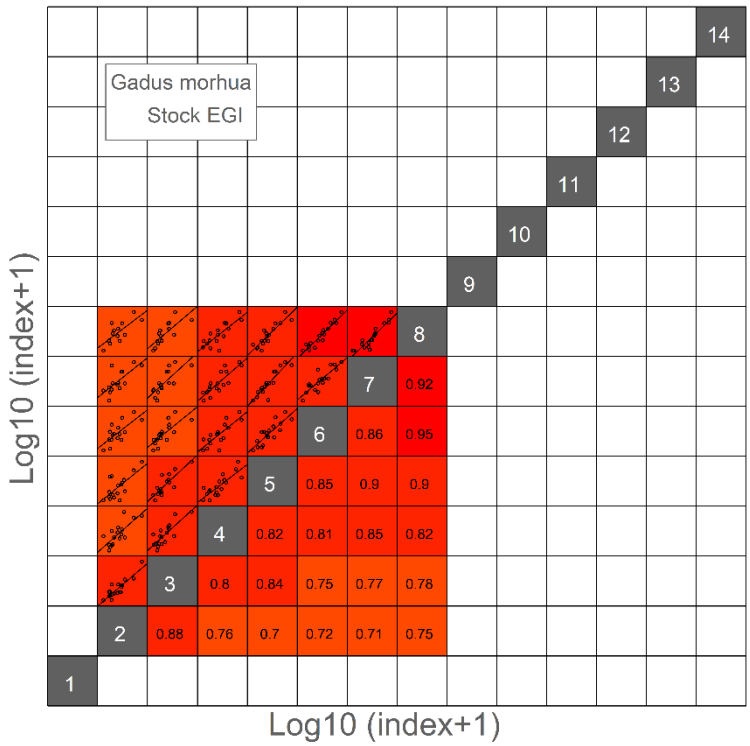

Figure 6.4: Internal consistency plot for EGI (EGIOSC).

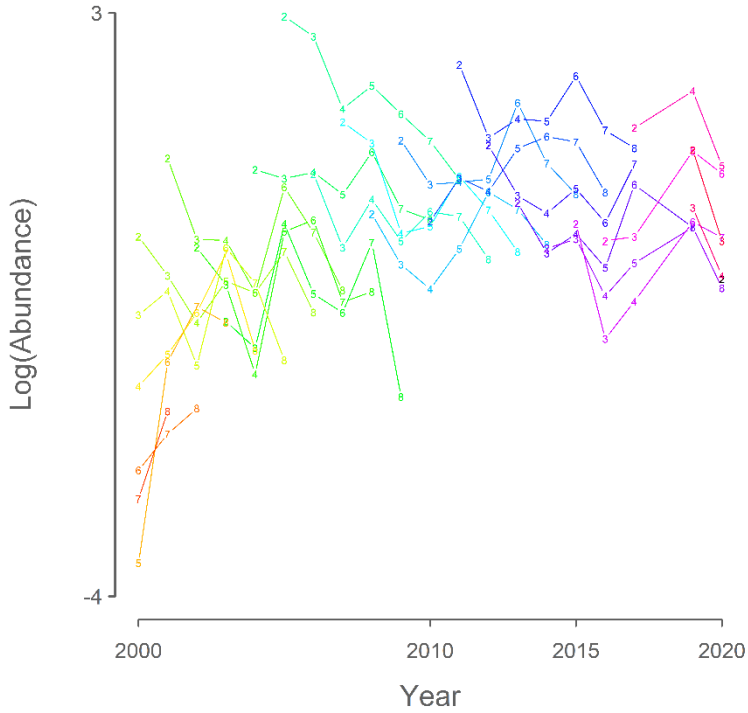

Figure 6.5: Catch curve for EGI (EGIOSC).

The spatial distributions of mean density indices were mapped by age in Figure 6.2. The time series of spatially integrated density indices that were used in the assessment as relative abundance indices of cod at age (Figures 6.3.) were found to have good internal consistency (Figure 6.4 and 6.5).

In 2022 the GGS survey was not conducted. From 2023 the Thünen institute will change the timing of the GGS survey from autumn to summer. This must initially be considered as a new survey. The model will need more than one year of data to estimate the new survey effect. It must therefore be expected that only SF will be used by NWWG in 2023 and 2024.

6.6 Maturity

Maturity ogive from East Greenland is used for the EGIOSC stock as East Greenland 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. Hence, the proportion of mature fish by age are left unchanged in two periods from 2000–2017 and 2018-present.

For further description see stock annex.

6.7 Recruitment

Recruitment is set at age 2.

6.8 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 6.). 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.

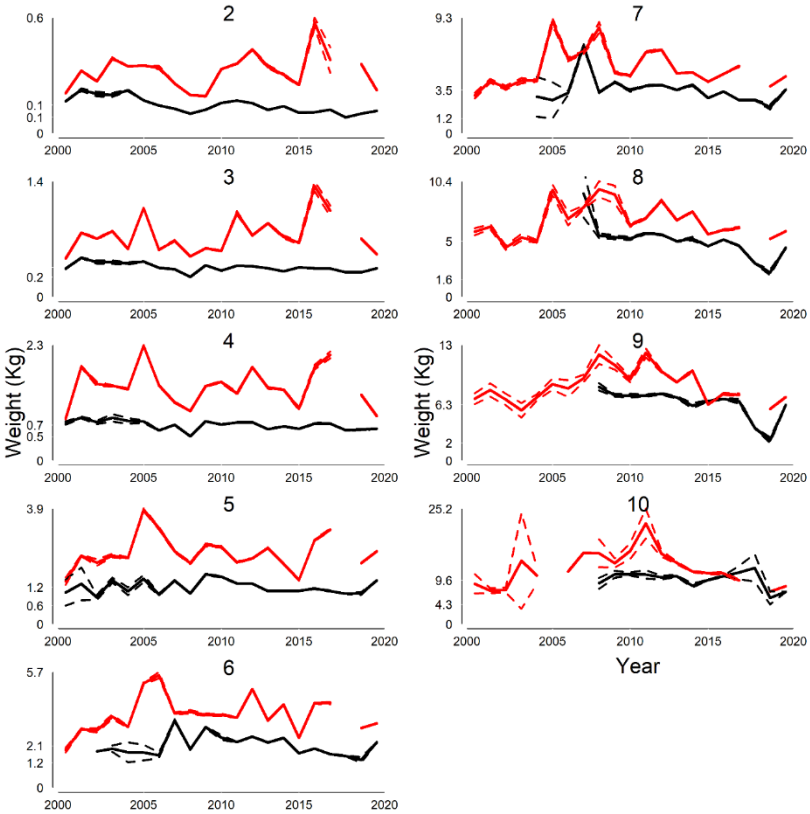

Figure 6.6: Weight at age (2-10) in the Greenland (black) and German survey (red) in East and West Greenland combined. Dashed lines are 95% CI.

6.9 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 2021b). Natural mortality for the EGIOSC stock is by default set to value of 0.2.

6.10 Final Model Settings

The stock is assessed using the state-space model SAM (Nielsen and Berg, 2014). The final model is described below, details on other configurations tested during the benchmark are given in WD09.

Attempts were made to use SPiCT for this stock, this was not successful.

Data used to fit the assessment model

The available data are listed in the table 6.1.

Table 6.1: Input data for the SAM model for the East Greenland Iceland Offshore stock (EGIOSC / EGI).

Type	Name	Year range	Age range	Variable from year to year
Canum	Catch-at-age in numbers	2000–present	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
Tuning fleet 1	INLA index (based on Greenland GRL-GFS and German G3244 DTS (GFS))	2000–present Except 2019, 2021	2-8	

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

Model Configurations

Catch mean weight-at-age are calculated from commercial samples, and used as observations for the catch weight process within SAM (see figure 6.7). Stock mean weight-at-age are calculated from the offshore Greenlandic survey, and used as observations for the stock weight process within SAM (see figure 6.8). 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.

Table 6.2 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).

Table 6.2: Catches of cod in the period 2006–2022 in East Greenland and the proportion of that catch taken in the Dohrn bank area.

Year	Dohrn Bank (Q1-Q2) Percentage of total catch	Total (tonnes)
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 table 6.2 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 have taken 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.

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).

Details are given in WD09.

Figure 6.7: Catch weight at age (in kilograms) for the East Greenland Iceland Offshore stock (EGIOSC / EGI). Numbers indicate the input values by age, the line shows the estimate from the model.

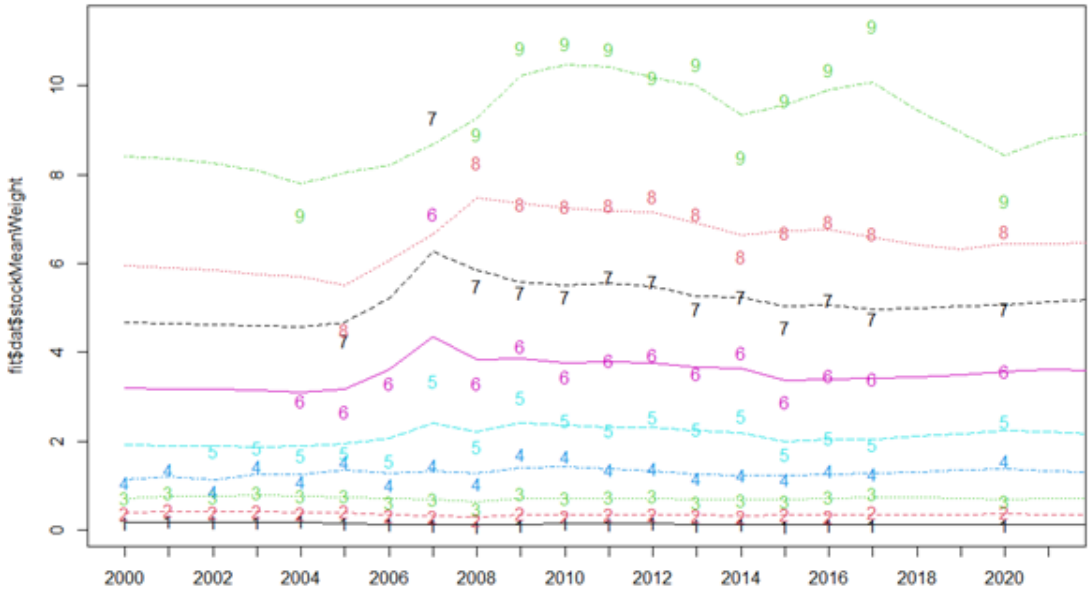

Figure 6.8: Stock weight at age (in kilograms) for the East Greenland Iceland Offshore stock (EGIOSC / EGI). Numbers indicate the input values by age, the line shows the estimate from the model.

Model diagnostics

The estimated catches, when accounting for the part of the catch estimated by the model to be from a different stock, are in line with observed catches (Figure 6.9).

Observation residuals for both catches and survey shows some tendency for larger residuals early in the time series (Figure 6.10). For the catches there is a group of positive residuals early in the timeseries. For the survey there are groups of both positive and negative residuals.

To test the robustness of the assessment a 5-year retrospective analysis (Figures 6.11 - 13) were conducted. For F all peels except one are within the confidence intervals and show tendency to overestimate F (Mohn's rho=0.131) (Figure 6.11). For SSB all peels except one are within confidence intervals and tend underestimate SSB (Mohn's rho= -0.015) (Figure 6.12). For recruitment most of the peels follow the current estimates OK (Mohn's rho=0.377) (Figure 6.13). It appears that the retros are impacted by the choice of groupings for the catch scaling, i.e., the first peel are in the second period for the catch scaling show a different trajectory.

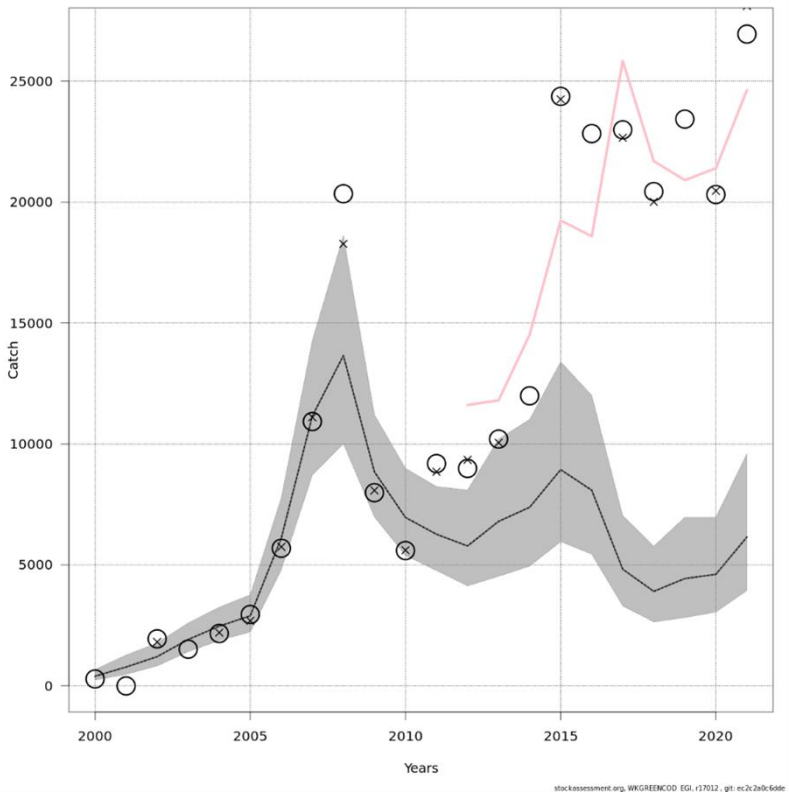

Figure 6.9: Estimated (line), observed catches (x), and catches based on smoothed catch weights (o) for the East Greenland Iceland Offshore stock (EGIOSC / EGI). Estimated catch is shown with 95% confidence intervals. The red line covers the period where catch scaling was applied and gives the estimated catch combined with the scaled catch.

Figure 6.10: Normalized residuals derived from SAM for the East Greenland Iceland Offshore stock (EGIOSC / EGI). Blue indicates positive residuals (observation larger than predicted) and red circles indicated negative residuals.

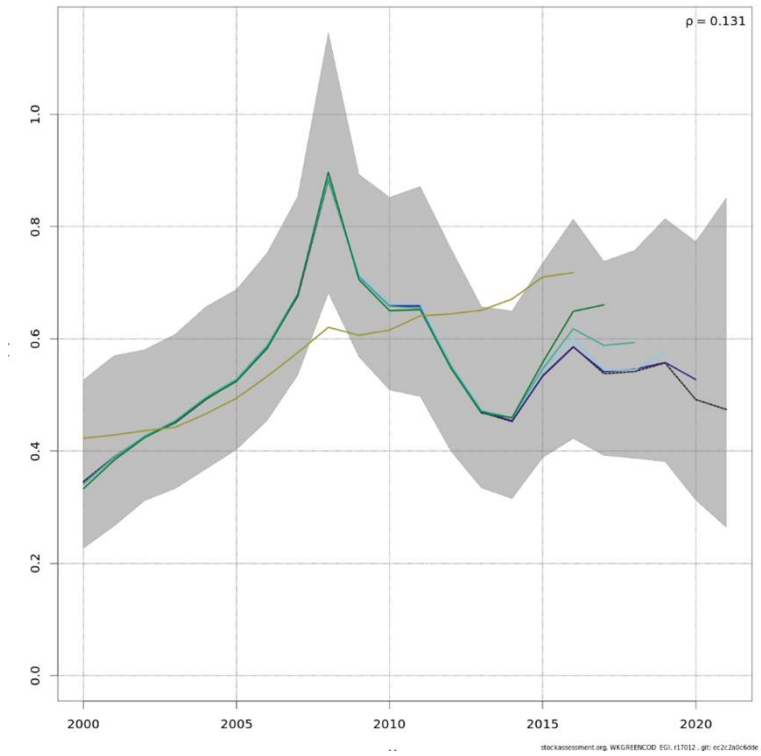

Figure 6.11: Retrospective plots of Fbar (5 years peel) for the East Greenland Iceland Offshore stock (EGIOSC / EGI). Mohn's rho is given in the upper right corner.

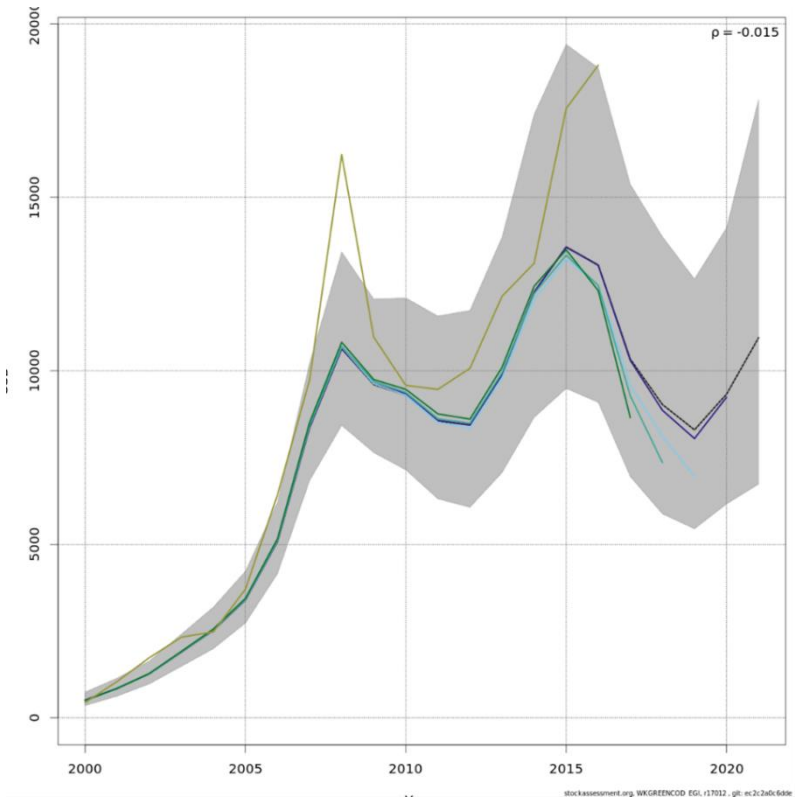

Figure 6.12: Retrospective plots of SSB (5 years) for the East Greenland Iceland Offshore stock (EGIOSC / EGI). Mohn's rho is given in the upper right corner.

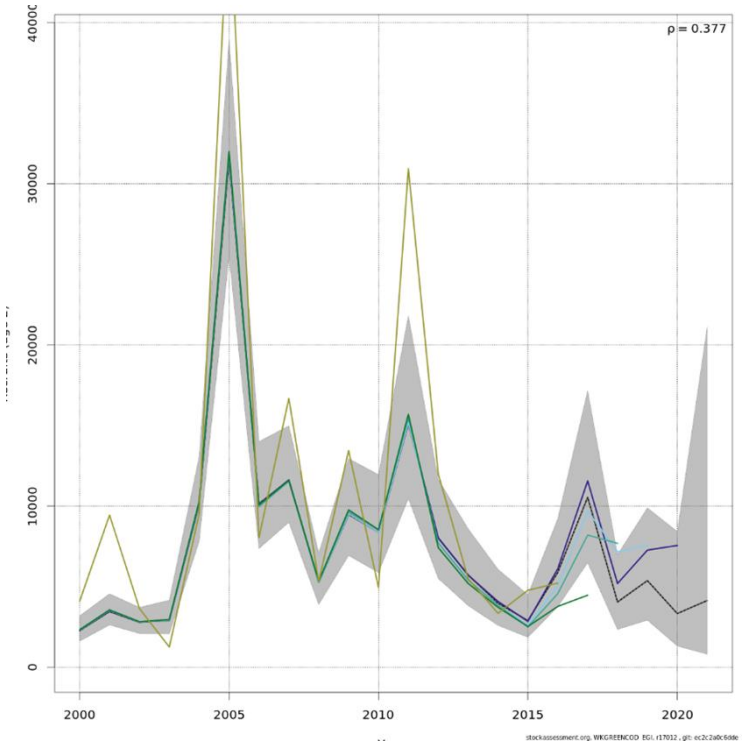

Figure 6.13: Retrospective plots of age 2 recruitment (5 years) for the East Greenland Iceland Offshore stock (EGIOSC / EGI). Mohn's rho is given in the upper right corner.

Assessment results

The estimated SSB, Fbar and recruitment from the model are given in figures 6.14, 6.15 and 6.16. Assessment name on stockassessment.org is 'WKGREENCOD_EGI'.

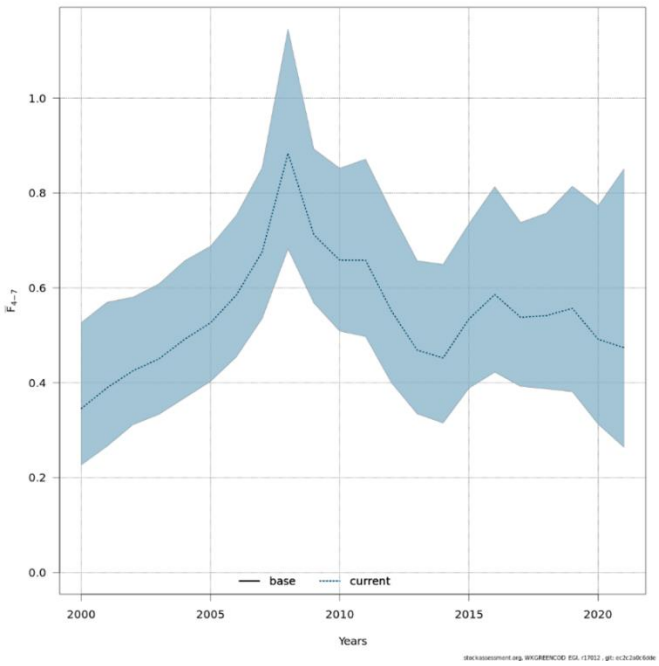

Figure 6.14: Estimated historical pattern of fishing mortality (Fbar4-7) for the East Greenland Iceland Offshore stock (EGI-OSC / EGI). The shaded area is 95% confidence intervals.

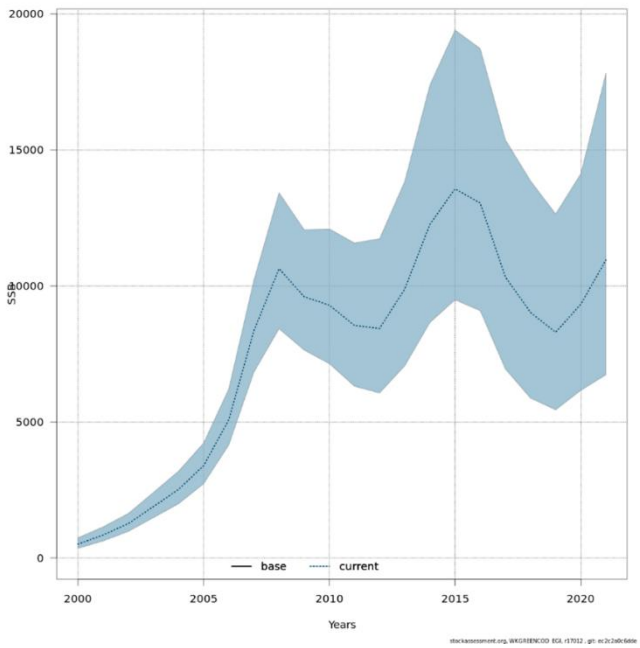

Figure 6.15: Estimated historical patterns of spawning stock biomass (SSB) for the East Greenland Iceland Offshore stock (EGIOSC / EGI). The shaded area is 95% confidence intervals.

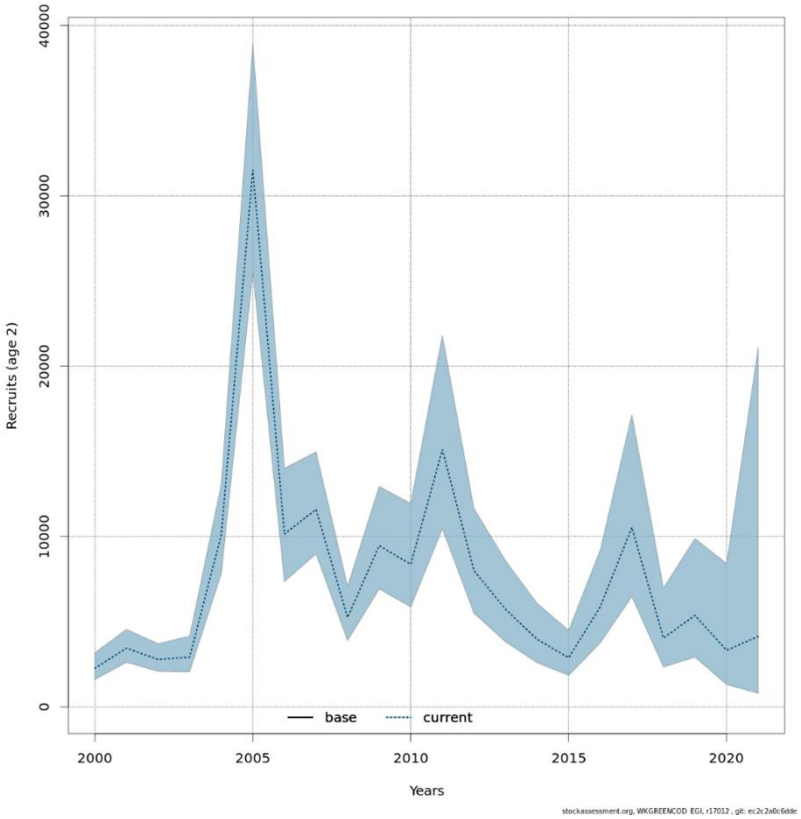

Figure 6.16: Estimated historical patterns of age 2 recruitment for the East Greenland Iceland Offshore stock (EGIOSC / EGI). The shaded area is 95% confidence intervals.

6.11 Short term forecasts

Table 6.3: Settings for the short-term forecast set up in SAM for the East Greenland Iceland Offshore stock (EGIOSC / EGI).

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.

6.12 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 (Figure 6.17). 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 table 6.4 (see also Figure 6.18.).

Due to very high estimate of F_{lim}, it was decided to not report on this value.

Table 6.4: Estimated reference points for the East Greenland Iceland Offshore stock (EGIOSC / EGI).

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

Details can be found in WD 09.

It is recommended that Reference points are revised when more data are available.

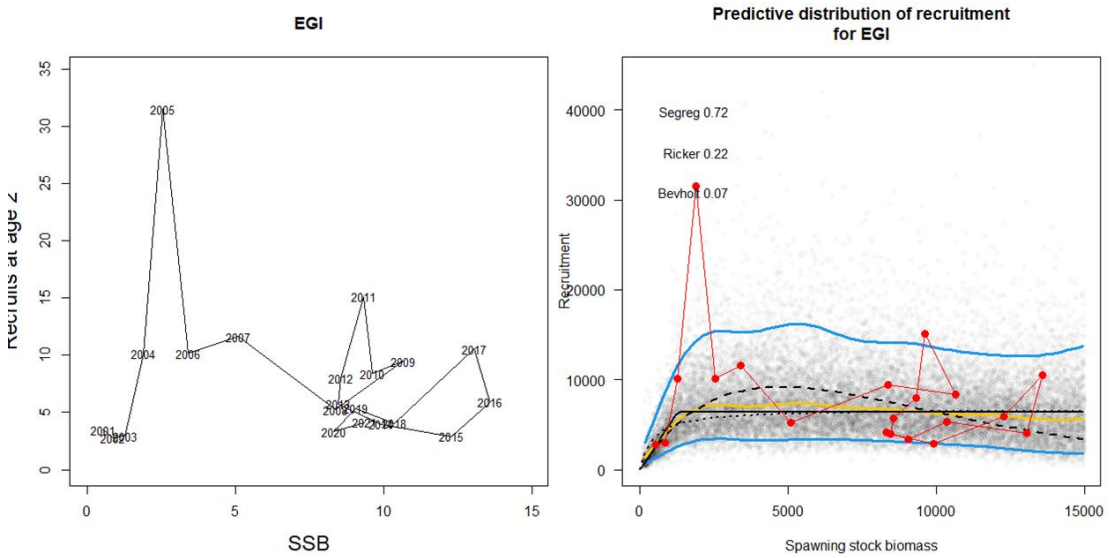

Figure 6.17: left: SSB-recruitment relationship, labels indicate recruitment year. right: SSB-recruitment relationship estimated by simulation using EqSim with fitted SSB-recruitment relationships. The solid line shows the fitted model and the blue lines indicated the interval in which 95% of the simulations falls.

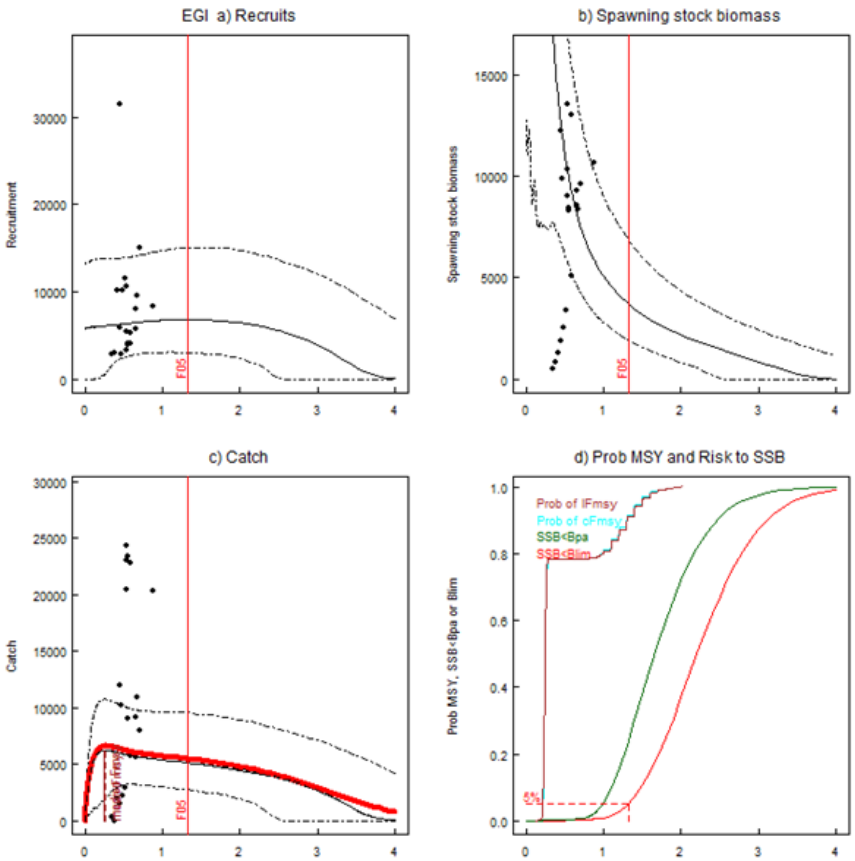

Figure 6.18: EqSim plots of recruitment, SSB, catch and probability of SSB falling below Bpa and Blim. F is on the x-axis.

7 Recommendations from the benchmark

It is recommended that the splitting of the West Greenland inshore stock into two separate stock units, based on available biological (tagging), catch trends and survey trends, is reviewed by the ICES Stock Identification Methods Working Group as soon as possible.

Due to the uncertainty regarding the reference point simulations for all assessed stocks as well as a short time series it is recommended to estimate these at the NWWG meeting in 2024.

In recent years the cod catches on Dohrn Bank in the north-eastern area close to the Icelandic EEZ have visibly increased, and it is assumed, based on the modelling made during the benchmark, that a large proportion of these cod originate from another stock outside the Greenland EEZ. To better understand the dynamics occurring in this area it is recommended to have tagging and otolith chemistry studies based on samples from Greenland and Icelandic catches.

The NWWG should consider including the abovementioned unallocated catches in the assessment of the Cod5a stock. This would be in line with the current procedure of adding the large migrating year classes at age 6, i.e. 1984 and 2003, in the assessment where interactions with the East Greenland area are accounted for.

Since the assignment of catch and biological data to either of the three cod stocks is based on genetic analysis, it is also recommended that sufficient number of samples from both fisheries dependent and fisheries independent catches area collected.

Issue list for next benchmark

- Revisit the Greenland halibut survey (WD3)
- Attempt to estimate M
- Consider the inclusion of gillnet survey in 1c and large-mesh gillnet survey in 1c and 1d
- Consider the inclusion of acoustic survey in 1d
- Revision of maturity ogives

8 External Reviewers Report

8.1 Overview

The management scenarios for cod stocks around Greenland have changed over the years as more information has become available with respect to stock connectivity and fish movement patterns. The stock complex has variously been assessed as a single stock, two stocks, and more recently three stocks using data split on a geographical basis. Many of the difficulties associated with the quality of the previous assessments have been deemed to be associated with inappropriate assumptions about stock structure, including not accounting for stock mixing. Advances in genomics and the application of spatial modelling suggest a substantial amount of spatial overlap (i.e. mixing) among Greenland cod stocks, raising questions about previous assessment methods that were based on geographic boundaries. The primary objective of the benchmark meeting was to develop separate assessments based on fish being genetically assigned to a stock rather than assigned based on geographic location. The new approach based on genetic assignment marks a step forward in the consideration of biological 'realism' in these assessments, and should represent a marked improvement over the previous method for defining stocks.

Other advances applied in this benchmark include the use of a spatial model (via INLA) that combines multiple surveys with partial coverage of the stock area(s) into a more informative single survey index. Previously, indices were derived from the individual surveys which (separately) do not have full coverage of the stocks – a modelled approach, combining the data, was therefore considered likely to give a better representation of the stocks (better coverage) and also to be able to account for variations in catch rate not associated with trends in stock size but associated with covariates such as location, depth and gear.

8.2 Data Review

The data compilation workshop focused on the same three stocks as the previous benchmark: Western Greenland Inshore (GRI), Western Greenland Offshore (GRO), and Eastern Greenland-Iceland (EGI). However, the current data workshop and benchmark focused on genetic splitting of stocks rather than stocks based on geographic boundaries. The approach used a GAM fitted to the available genetic data to subsequently split both the catch and survey data according to genetic origin (i.e. stock). The reviewers considered that the GAM fit the data adequately with no worrying residual patterns. The genetically-split survey indices had substantially better diagnostics (e.g. internal consistency) relative to the geographically-split indices, supporting the move to stock assessments based on the genetically split data.

The switch from geographically to genetically-defined stocks represents a major change in the assessment methodology. Hence, much of the workshop was taken up with reviewing the methods used to estimate the relative proportions of the genetic stocks across the area and the subsequent production of genetically-split assessment input data. The task of splitting the data according to genetic stock was clearly a significant and complex undertaking. While the stock assessors were able to provide a thorough explanation of the process during the data compilation meeting, the enormity of this task meant that relatively limited time was devoted to other biological input parameters typically reviewed during the benchmark process – even after the addition of a second (virtual) data review meeting. For example, although stock mean weights (derived from survey data) were presented and discussed, there was almost no discussion of maturity ogives other than to say that 'the previous approach' would be followed. The inherent expectation that

the reviewers were familiar with all aspects of previous assessments was at times problematic for the reviewers.

Another very important consideration not fully explored during the data review workshop was the suitability of the values used for natural mortality. Given the amount of work to be explored and presented during this benchmark, it is perhaps not surprising that the decision was made to assume that M=0.2 for all age-year combinations for all three stocks. The reviewers highlighted that, although the assumption of M=0.2 is historically common in stock assessments, methods are being used elsewhere to estimate M (e.g. life history approaches, estimates based on fish condition, estimates from multispecies models which account for predation mortality) and that estimates of M for nearby northwest Atlantic cod stocks in recent years can be much higher than 0.2. It is strongly recommended that consideration is given as to how best to estimate M for these stocks ahead of the next benchmark, as inappropriate assumptions of constant M (for example) can have significant implications for assessment model outputs.

There is apparent cohort-related variability in the degree to which the genetic stocks overlap. However, there is insufficient genetic data to treat cohorts individually in the model. Therefore cohorts were grouped according to similar year class strength, based on evidence that similar strength cohorts show similar spatial distributions. The rationale for cohort groupings was not initially well-documented by the stock assessors. The reviewers were concerned about the potential impact that poor/patchy genetic sampling in the future could have on cohort groupings and the overall suitability of the assessment going forward. As a result, a more explicit and less subjective approach to grouping cohorts was provided, which should be able to objectively account for any poorly sampled future cohorts.

While the genetic stock splitting appears to be an advancement over previous assessments, it has a major limitation in that there are no equivalent genetic data prior to the year 2000 and therefore those years are not included in the assessments. Concern was expressed regarding the reduced assessment period (2000-2021) relative to previous assessments and the fact that the assessments would be losing potentially important information from the historical stock perspective. A major methodological modification was not possible during the framework but it is suggested that future work could explore the use of a modelling approach (e.g. 'multiSAM') that allows for the inclusion of both recent genetically-split data as well as data from years that are not genetically split as a means to include the historical stock context. It is possible that the loss of data from the historic period, when stocks may have been at a much higher level and were perhaps more productive, could also largely influence the establishment of limit reference points (see below).

8.3 Benchmark

The data review meeting ended with the recommendation to go forward with three genetic stocks for the Benchmark meeting. Base assessment model runs were presented early on in the assessment meeting for each of the genetic stocks but all showed serious issues with respect to model fit. For all stocks, initial model runs showed residual patterns with a tendency for greater residuals in the early period. This was resolved by either i) allowing for greater observation error in this period (likely due to lower genetic sampling levels) or ii) allowing for the model to estimate the relationship between observation variance and prediction. In some cases, there was evidence (from the residuals) of survey year effects and in these cases the survey covariance structure was assumed to follow an AR(1) process. The resulting final assessments have, in general, a reasonable fit to the data and adequate diagnostics in terms of Mohn's rho (on SSB and F), although in all cases the assessments show substantial uncertainty.

It proved difficult to get a sufficiently robust assessment of the GRI stock (e.g. very poor retrospective patterns). As a result, the decision was made early in the Benchmark meeting to split

the stock into two stocks: GRI North and GRI South, which seemed to improve the issue. The reviewers questioned (1) whether the improved retrospective pattern was sufficient evidence to support the splitting of a stock, and (2) whether the Benchmark was the proper venue for decisions regarding stock splitting. In response, the assessors provided evidence of very limited or a lack of fish movement between the northern and southern fjords and other biological data supporting the stock splitting. However, the available genetic data did not necessarily provide any evidence of separate north and south inshore stocks (an interesting point considering that the entire stock definitions for this benchmark were based on genetics). It was noted that biological (e.g. growth) differences can exist between components of the same stock, but ultimately the Benchmark moved forward with the plan to treat GRI North and GRI South as separate stocks. Although there had been some discussion of the potential lack of connectivity between these inshore components during the data compilation meeting, this proposal came at rather a late stage of the benchmark process. In response to the reviewers' concerns about process, the ICES Professional Officer suggested that the group recommend evidence in support of splitting the inshore stock into two stocks be reviewed by SIMWG via correspondence at the earliest opportunity. This would normally have been done in advance of a benchmark workshop. A contingency plan of also preparing an annex for the combined inshore stock was proposed.

In the EGI assessment, the model had an extremely poor fit to the catch data during the recent period. Evidence was provided which showed that the distribution of fishing effort for this stock has changed significantly over time. In recent years an increased proportion of the landings have come from an area where fish are very likely to have belonged to the Icelandic stock rather than EGI genetic stock. Allowing the model to estimate a catch scaling factor to account for this appeared to be more appropriate than attempting to modify estimates of natural mortality. On the whole the changes made to the model configurations appeared sensible and were well justified.

Some concern was expressed as to how catch limits based on genetically separated stocks could be effectively assigned and regulated for these mixed stocks. Although it was suggested that a decision-making tool (e.g. spreadsheet) could be provided to managers to help with these decisions, this was ultimately not a topic to be addressed during the Benchmark.

8.4 Reference Points

The reference point estimation process was extremely difficult. As far as possible, the ICES guidelines were followed in the derivation of reference points but the stock-recruit plots were highly variable and didn't necessarily fit well to traditional SR curves. As in many stocks, the main difficulty in calculating reference points for these stocks was the choice of the derivation of Blim. These stocks appear to be in a recovery phase and within the time series of the benchmark assessments, have generated high recruitment from very low SSB. As a result, following the ICES guidelines in the choice of stock type and subsequent calculation of Blim results in the estimate of the latter being towards the lower end of the SSB estimates. The subsequent estimation of MSY reference points proved particularly difficult for the GFI_N stock. The fitted stock recruitment relationship gave significant weighting to a Ricker with a peak at low stock size resulting in a very flat topped yield curve and high FMSY (compared to other cod stocks). The stock assessors considered this to be unrealistic and proposed to take an average of neighbouring cod stocks. While it seems reasonable to expect a similar FMSY value between stocks of the same species in a similar location, at least one reviewer felt that it might have been more appropriate to use the estimates of FMSY from the EqSim analysis with the Ricker model excluded.

It is worth noting that in all these stocks the time series of SSB and R estimates is very short (data prior to 2000 could not be genetically split and therefore were not included in the assessments) and therefore individual data points can potentially have substantial influence on the estimated

stock recruitment relationship. Furthermore, substantial retrospective revisions are made to the estimates of recruitment and hence the values of the stock recruit pairs are likely to change substantially with additional years of data. For this reason it was advised that the reference points should be revisited in a few years (or sooner) if there are substantial changes to the stock recruitment data (or if the assessments change so as to be able to include data prior to 2000 – see above).

Subsequent to the benchmark, one of the reviewers expressed strong concern regarding the impact that the short time series (2000-2020) used for the new proposed assessments could have on the suitability of the suggested reference points (see appended WP). The concern is that by examining only a period where the stocks are considered to be recovering, and excluding the historical period when stock size was much larger, there is a strong potential for limit reference points to be set too low relative to the carrying capacity of the stocks and the biomass that is able to produce MSY (i.e. BMSY). If reference points are set too low, they may contribute to preventing stocks from growing/recovering to historical levels. The proposal in the reviewers' working paper is to not reopen discussions surrounding Blim at this time, but rather to set Btrigger at 50% BMSY instead of the typical practice of setting Btrigger as Blim*1.4. It is argued that this would at least bring Btrigger in line with the dynamics of the stocks and would ensure appropriate changes to F in response to changes in stock size. These suggestions were not tabled and discussed during the benchmark but are provided here to convey the full review of the assessments. These comments again reiterate the need in the next benchmark to consider the potential for extending the time series for the assessments to include pre-2000 data.

8.5 Conclusion

A significant amount of time and effort had been put into preparation for the benchmark by a team of scientists, and the amount of work presented was commendable. The presentations and WDs provided a thorough investigation of most of the issues relevant to the Terms of Reference (the exception being biological parameters) and the experts were well prepared to answer questions and address the reviewers' issues.

The reviewers consider the assessments based on the genetic splitting of stocks to be an improvement over previous assessments that were based on firm stock geographic boundaries. Consideration will be needed with respect to the implications/complications for assigning quota but those concerns are beyond the scope of the benchmark. The reference points have (with some exceptions) been derived following the ICES guidelines. The reviewers consider the quality of the assessments appropriate to be used as the basis for advice.

It is noted that following the benchmark meeting, suggestions were made during report drafting to change the names of the four proposed stocks. Those proposed stock name changes are not reflected in this reviewer report.

9 References

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10 Working documents

WD 01 - DNA split of Atlantic cod (*Gadus morhua*) stocks in Greenland waters. An overview of data.

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Abstract

The assessment of the three major Atlantic cod (*Gadus morhua*) stocks in Greenland waters are currently based on geographical boundaries which were implemented based on genetic studies. Here the genetic data from previous studies are combined with newly available genetic data from sampling on scientific survey and of the commercial catches in Greenlandic waters. The updated dataset shows extensive mixing of the three stocks which is more complex than currently assumed in the assessment. There is a north to south gradient with the Greenland offshore stock dominating in the northern areas of West Greenland, both inshore and offshore. The Inshore stock is dominating in the inshore areas in Mid-West Greenland. And the East Greenland – Icelandic offshore stock is dominating in South (both inshore and offshore) and East Greenland. The assessment should therefore not be based on the current geographical boundaries but rather take the genetic split with latitude/longitude into account. This document presents the genetic data available for Greenlandic cod and the final dataset (n=7662) used to fit a GAM model to split survey and commercial data into the three stocks.

Introduction

Genetic assignment of Atlantic cod (*Gadus morhua*) in Greenland waters started with the publication "Spatiotemporal SNP analysis reveals pronounced biocomplexity at the northern range margin of Atlantic cod *Gadus morhua*" by Therkildsen *et al*. in 2013. The publication identifies four genetically distinct groups (se also figure 1):

Iceland-inshore (hereafter named ISI) is characterized as having their spawning area nearshore Iceland. The proportion of this stock compared to the other stocks in Greenland is limited.
Nuuk (hereafter named GRI) is characterized as having their main distribution and spawning in the inshore area in West Greenland, especially between Sisimiut and Nuuk corresponding to NAFO subdivisions 1B, 1C and 1D.
West (hereafter named GRO) is characterized as being mainly distributed in West Greenland and spawning on the offshore banks of West Greenland.
East (hereafter named EGI) is characterized as having their spawning grounds on the offshore banks of East Greenland and Iceland.

Due to ocean currents eggs and larvae are transported from East to West. The transportation, however, is highly irregular, especially from the spawning grounds in Iceland. Cod belonging to the EGI-stock will home for spawning (Bonanomi *et al*. 2016) leading to fluctuating entities of cod from this stock in West Greenland.

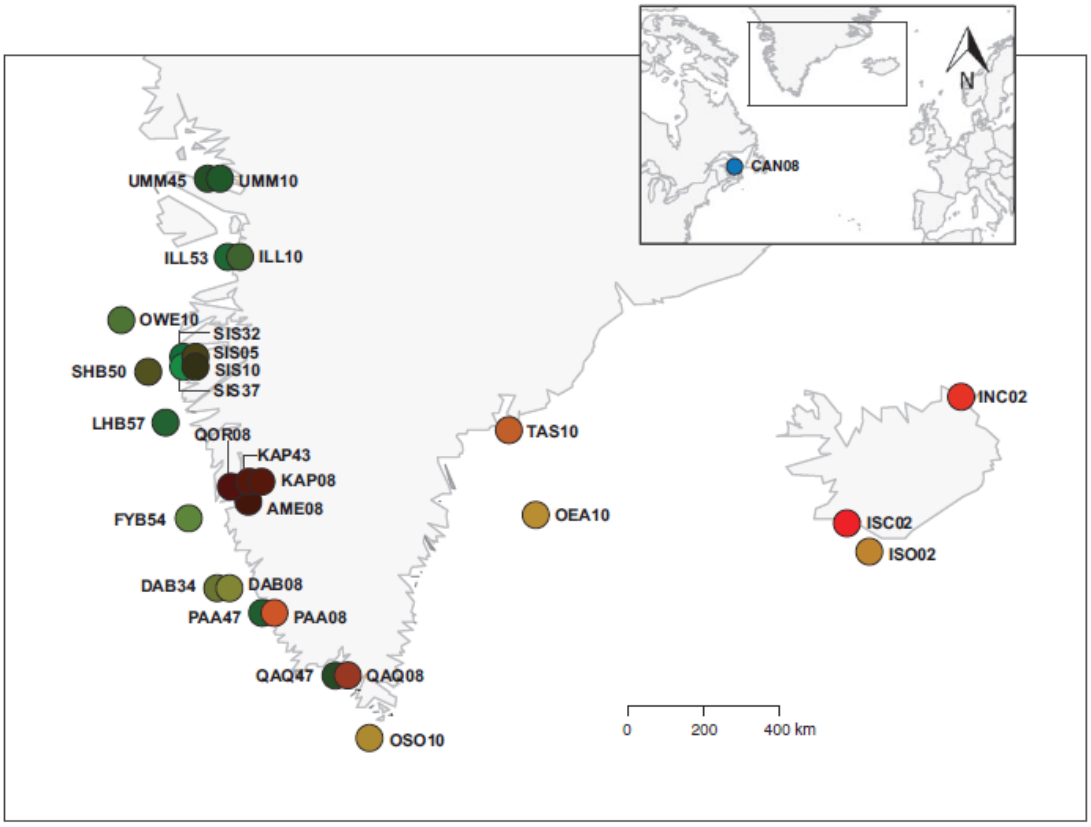

Figure 1. (from Therkildsen *et al*. 2013). Approximate sampling locations in Greenland and Iceland (main map) shown in relation to the reference sample from Canada (blue dot on the inset map). Dots shifted left represent historical samples while dots shifted right represent contemporary samples. Samples are named by three-letter codes to indicate location followed by two digits to indicate the sampling year (see Table 1 in Therkildsen *et al*. 2013). The colors of dots represent the blends of stocks: red: ISI, brown: GRI, green: GRO and yellow: EGI (previously called ISO).

The cod fishery in Greenland collapsed in the 1990s. With the distinction of several cod stocks and investigations of their resilience to fisheries and climate change (Bonanomi *et al* 2015) it became clear that the GRO-stock was dominating the combined biomass in the early 1950s when catches were at 300.000 tons (figure 2). The catches then peaked at 400.000 tons in the 1960s while the biomass declined, and it was the GRO-stock that was disappearing from the biomass. From 1970 to the collapse in 1990 the primary stock in the fishery was the EGI-stock.

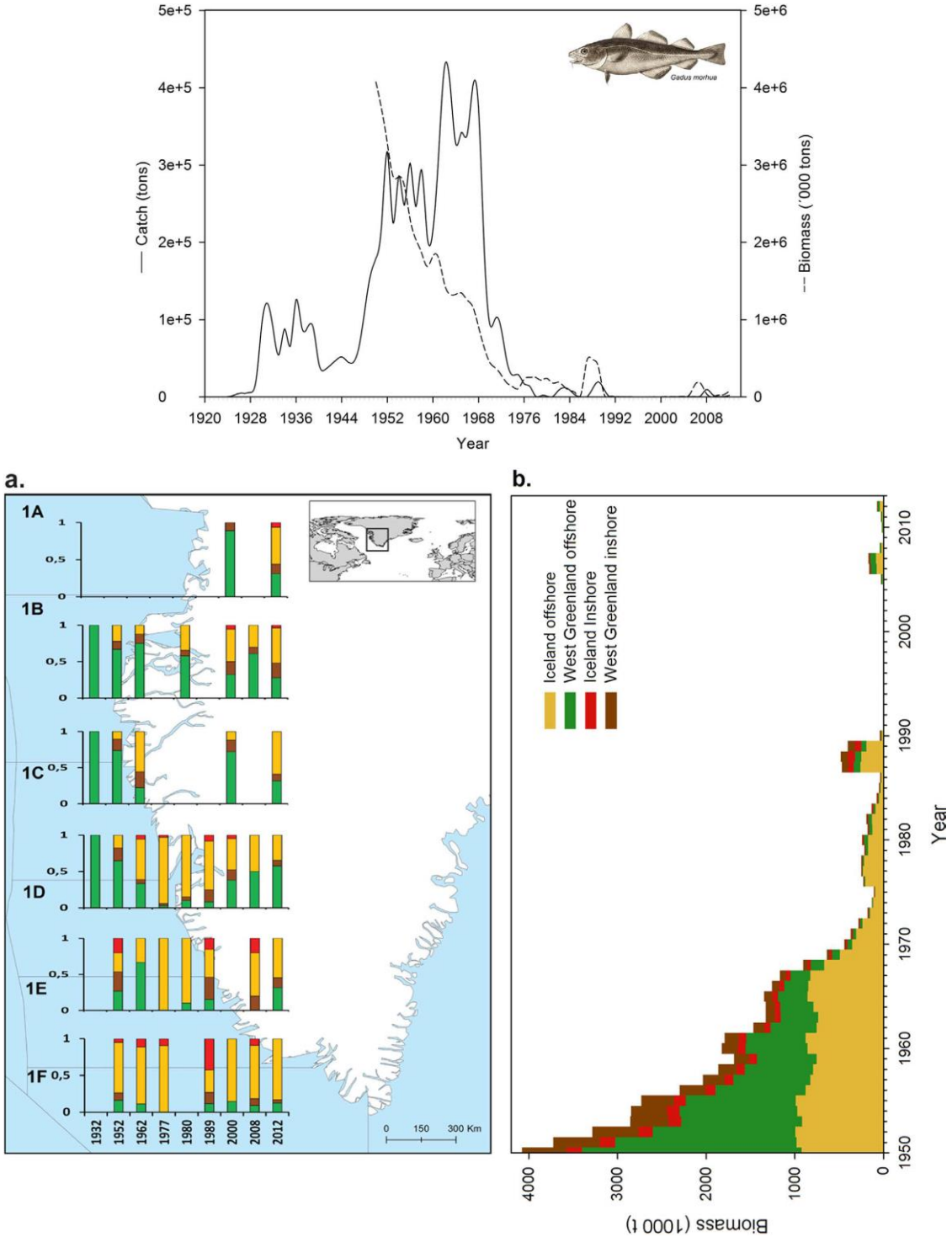

Figure 2. (from Bonanomi *et al* 2015) **Top**. Historical Atlantic cod biomass (dotted line) and commercial catch (solid line) in West Greenland. **Bottom** (**a**) Spatiotemporal development in the proportions of different Atlantic cod stocks in the historical West Greenland fishery (NAFO divisions from 1A to 1F): Colors represents each stock: Green: GRO, Brown: GRI, Yellow: EGI (previously called ISO) and Red: ISI. (**b**) Estimated stock biomass composition of cod along West Greenland 1950–2012 (NAFO divisions 1A–1F). Biomass is estimated based on catch proportions (se supplementary Figure 1 in Bonanomi *et al*. 2015) and the biomass of 3+ years old cod in the stock.

The advice for the fisheries has until 2012 been given as one advice for all of Greenland. Based on the genetic findings that several cod stocks, with distinct spawning sites, exist in Greenland, advice was first divided into separate advice for the inshore area in West Greenland corresponding to NAFO subdivisions 1A-1F in 2012 and the offshore area in Greenland (East + West) (ICES 2012). In 2015 the offshore area was divided into West Greenland corresponding to NAFO subdivisions 1A-1E and East Greenland corresponding to NAFO subdivision 1F and ICES 14 (figure 3). The delineation between NAFO 1E and 1F was based on the findings in Therkildsen *et al*. 2013 that showed that spawning cod in NAFO 1E and northwards primarily belonged to the GRO stock (figure 1) (ICES 2014).

Figure 3. Current assessment areas for cod in Greenland.

For the area West Greenland Inshore (representing the GRI-stock) and East Greenland (representing the EGI-stock) a stage-based model (SAM) is used to generate advice (Rigét *et al*., 2022 and Buch *et al*., 2022). The input data for both areas are therefore based on data from all cod in the corresponding area. However, there is extensive mixing of the stocks in especially the inshore area (Christensen 2019) and the data for the model is therefore from a mix of stocks and does not reflect the actual dynamics of the inshore stock. This is evident especially in the reference point B_{lim} which is calculated based on the output from the model (ICES 2018). B_{lim} is very low and is caused by high recruitment from an almost non-existing spawning population. This can be caused by transportation of high numbers of eggs, larvae and young cod from another stock into the area.

This working document gives an overview of the genetic data available for the cod stocks found in Greenland waters. It also shows what additional information is available for the samples and any gaps in the dataset.

Material and Methods

GINR collect biological information (e.g. length and age) for cod during scientific surveys and for commercial catches. In addition to standard sampling fin clippings have been collected in order to carry out genetic analysis and assign fish to one of the four cod stocks in Greenlandic waters. Background on the four stocks and assignment methods can be found in Therkildsen *et al*. 2013 and Bonanomi *et al* 2016.

There are data available from two previous studies (Therkildsen *et al*. 2013 and Bonanomi *et al* 2015), these covers the years 1932-2012 and are from West and East Greenland as well as from Icelandic waters. Therkildsen *et al*. 2013 collected fin clippings from 13 known spawning areas in Greenland during spawning season in 2008-2010, these were matched with historic samples from GINR otolith archive that matched location and time of year. Further reference samples from spawning components in Iceland from 2002 and a single population sample collected during the feeding season in 2005 were included in the study. The samples were used to define four stocks. The analysis used were DAPC. Bonanomi *et al* 2015 used the otolith archive at GINR to gather samples representing years with large total catches. Samples were from both surveys, commercial sampling and cod tagging. Samples were all from late June to January. These samples were assigned to one of the four stocks defined in Therkildsen *et al* 2013 using the method Geneclass.

From 2011 to 2021 fin clippings have been collected from cod during scientific surveys and for commercial sampling (Table 1). Table 1 gives an overview of the number of samples analysed, when and where they were collected and a referenced for the published data. Generally, for the survey data there are information on position, length, and age, for commercial sampling there are often lengths, but in some cases position and age information are missing. All the samples in Table 1 from 2011-2021 used GeneClass for assigning to stock.

Table 1. Overview of collected data.

Main reference	Sample source	Years	Samples	Area	Method
Therkildsen *et al* 2013	Spawning samples (March to May) from 2008-2012 from finclippings and Historic samples from otolitharchive.	1932, 1934, 1937, 1943, 1945, 1947, 1950, 1952-1954, 1957, 2002, 2005, 2008, 2010	847	All areas, including iceland	DAPC
Bonanomi *et al* 2015	Both commercial fisheries, surveys and tagging. Late June to July. Focus on years important to the fisheries (large catches). from finclippings and Historic samples from otolitharchive.	1932, 1952, 1962, 1977, 1980, 1989, 2000, 2008, 2012	874	West Offshore	GeneClass/DAPC
Analysed 2022	Survey, fin clippings	2011	668	West inshore and offshore, 14b	GeneClass
Analysed 2022	Survey, fin clippings	2012	104	1B-1D ishore and offshore	GeneClass
Henriksen 2015	From master study, commercial samples. Fin clippings	2013	220	Inshore 1B and 1D	GC/DAPC Rounded assignment 0.5 and up
Analysed 2022	Survey, fin clippings	2013	1248	Offshore west and 14b	GeneClass
New data 2014	Commercial, finclippings	2014	100	1C (not used in model – position uncertain)	GeneClass
Bonanomi *et al* 2016	Genetics/ tagging			Not used in model	GeneClass/DAPC
New data from 2016	Survey, fin clippings.	2016	358	1AX and ishore 1B and 1D	GC/DAPC Rounded assignment 0.5 and up
Analysed 2022	Survey, fin clippings	2016	404	Offshore west	Geneclass
PIFT 2017	Commercial west Greenland inshore. Jan-Dec.In kommection with PIFT project.	2017	2708	Inshore 1B (Sisimiut) and 1D (Nuuk).	GeneClass
		2018	64		
2018 survey and commercial	Survey, finclippings. From tagging og	2018	51	1C indenskærs survey (Maniitsoq survey)	Geneclass

	spawning individuals.				
	Commercial fin clippings	2018	118	1C inshore	Geneclass
	Survey, fin clippings. Tagging of spawning fish.	2018	107	1C Offshore survey (tovqussaq banke survey)	Geneclass
	Commercial trial fisheries, fin clippings. Spawning period	2018	200	East Greenland trial fisheries.	Geneclass
New data from 2018 and 2019	Ccommercial fishery in spawning time. Fin clippings. April-May.	2018	187	1C and 1D offshore	Geneclass
	commercial fishery indshore West-Greenland (may-novemebr). Fin clippings	2019	402	inshore 1B-sisimiut, 1B-Kangatsiaq, 1C, 1D, 1F	Geneclass
New data 2019	Survey indshore offshore westgreenland. April-july	2019	1387	Offshore: 1A-1F Inshore: 1AX, 1B (Sisimiut and Kangatsiaq), 1C and 1D	GeneClass
WH 2019	Survey Walther Herwig. Oct. Fi clippings	2019	101 90	Offshore:1E+1F 14b	GeneClass
2020 commercial data	Commercial, fin clippings	2020	55	1F	GeneClass
Survey and commercial 2021	Survey fin clippings	2021	614	Survey inshore and pelagic. 1AUP, 1AUM, 1AX, 1B, 1C, 1D Inshore OK / trip 1 and 3 SAnna not in model dataset	GeneClass
	Commercial fin clippings	2021	132	1F inshore	GeneClass

The separate datasets from Table 1 were combined to one large dataset using R, and formatting were standardized. This combined dataset was then used for preliminary analysis.

Data overview

There are data from 30 different years covering 1932-2021. The samples are from 73 different cohorts. Samples have been collected on both scientific survey and for commercial fisheries. And covers the NAFO areas 1A- 1F (West Greenland) and ICES area 14b (East Greenland), both inshore and offshore.

Individual assignment probability

Individuals assigned to a stock with a probability lower than 0.7 was excluded from the dataset. Previous work found that the choice of cut off for assignment value did not impact proportions assigned to each stock (see figure 4, and Henriksen 2015). Using only individual assignments of 0.7 and above removes 531 samples once all other data subsets had been applied.

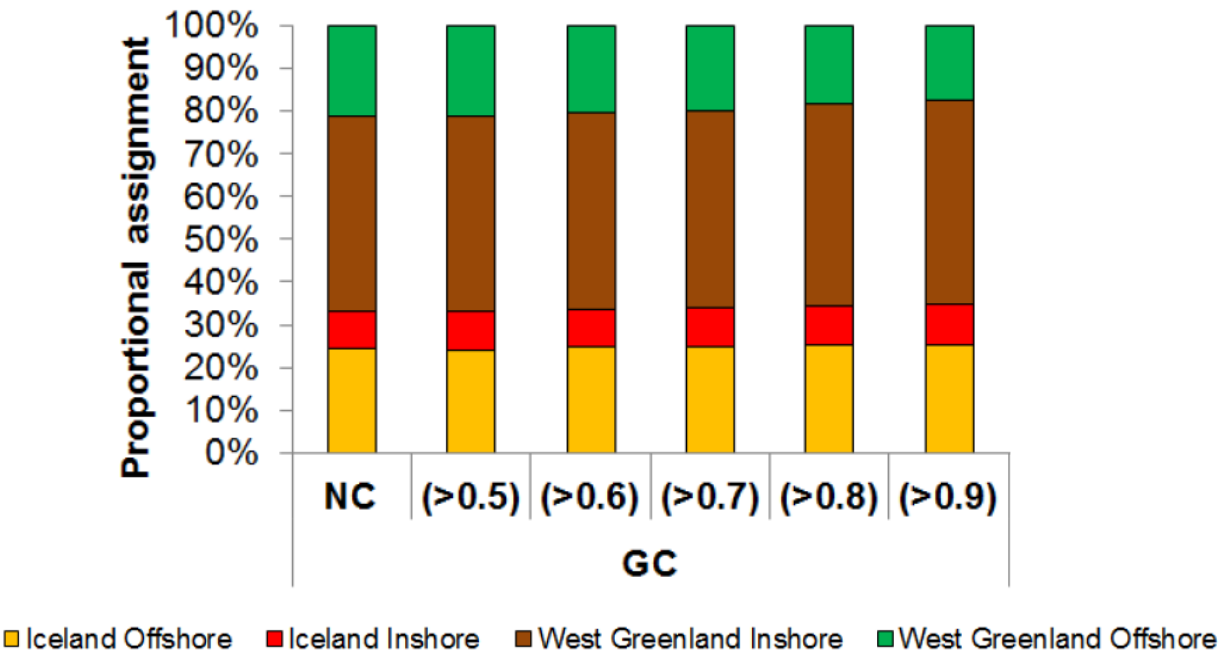

Figure 4. Figure showing impact of cut off values for individual assignment to stock, plot and figure text taken from Henriksen 2015. ' Individual assignment of Atlantic cod (*Gadus morhua*) from West Greenland based on GeneGlass2 (GC) approach. Stacked columns show the proportional assignment of individuals that are correctly assigned to one of the four populations for different set criteria cutoffs.

Survey and commercial samples

Individual cod have been sampled from both the commercial fisheries and on scientific surveys. In 2019 individuals were sampled from both the inshore fisheries and the scientific survey in NAFO areas 1B-1D. Figure 5 shows a proportion of each of the four stocks in the commercial and survey samples. Figure 6 shows proportion of each stock in the samples from NAFO area 1D in 2019 by year class. Overall Figure 5 and 6 show that there is no difference in the composition of stocks when comparing commercial samples and survey samples. Therefore, samples from both the commercial fisheries and the scientific surveys are included in the final dataset.

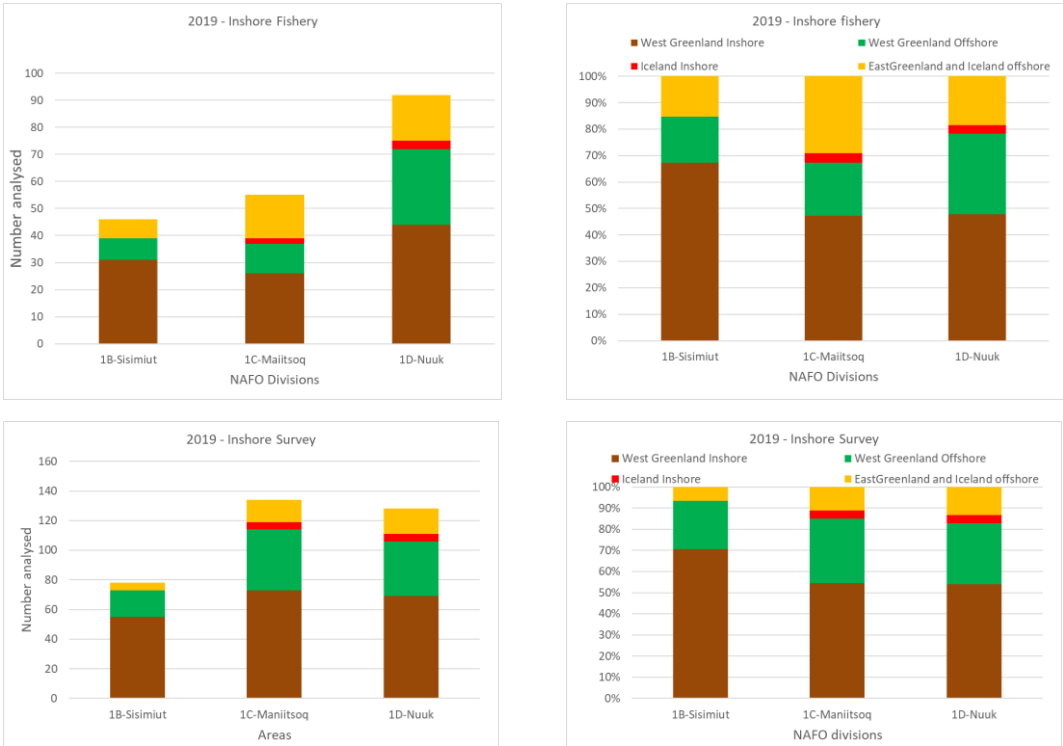

Figure 5 comparison of genetic split for samples collected in 2019 from the inshore survey (1B-1D) and from the commercial fisheries in the same area.

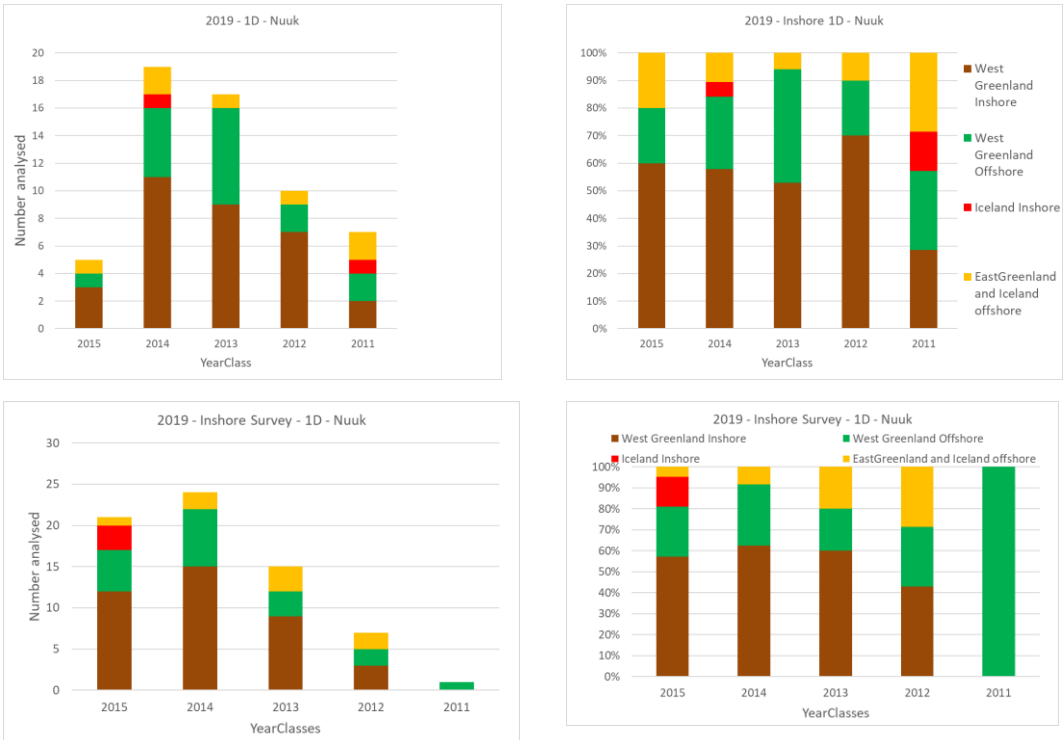

Figure 6 Genetic split in 1D in 2019 by year class from the commercial fisheries (top panel) and from the inshore survey (bottom panel).

Position of samples

Many of the samples in the dataset were collected on scientific surveys and the exact position of the hauls from which the samples were taken are therefore available. For samples taken from the commercial fisheries usually the resolution is by fieldcode (0.125 degrees latitude*0.25 degrees longitude) or NAFO area. When fieldcode were available, the centre point of the fieldcode was used to give the position. If it was not possible to assign samples to fieldcode or in cases where there has been uncertainty about position of samples, the samples were excluded from further analysis.

Temporal coverage

Figure A1 and A2 gives an overview of for which cohorts there are genetic data available. For the inshore area there are no samples from the mid-1950s to 2000, whereas for the offshore area, samples are more spread out. Given the sporadic coverage early in the timeseries, it was decided to focus on data collected between 2000-2021.

Area coverage

Areas 5a (Iceland) and 0A (Canadian area) were removed from the dataset because the final model will not be applied to catches from these areas. The Split model will not be used on data from the east coast of Greenland because it is assumed that most individuals here belong to the EGI stock. Figure A1 and A2 shows some individuals of GRO and GRI origin in 14b in 2001 and 2005-2013 cohorts. These are mostly from the same sampling event in 2018 (58 individuals out of 64 in total of GRI and GRO origin in 14b) and are therefore not believe to be representative of the entire area. Genetic sampling in the future will continue to cover 14b, and if it is found that there is a mix of stocks in the area it can be accounted for.

Icelandic inshore stock (ISI)

Individuals assigned to the ISI (Icelandic inshore stock) were removed from the model dataset. There are several reasons for doing this. We are not seeing any consistent patterns in ISI cohorts in Greenlandic waters, individuals are found throughout the region (figure 7) and at different ages. Historically (i.e. prior to 2000, see figures A1 and A2) we have very limited occurrences of ISI individuals, since 2000 they have been found in the samples, representing 5-10% of the individuals in some cohorts. In 1E, and to some extent 1F, inshore areas some cohorts appear to consist of larger proportions of ISI individuals, these are all from samples collected in 2008. We are not currently providing advice for the ISI stock in Greenlandic waters, and it is not present at such large numbers that it may have a large impact when they migrate in and out of the region. Future sampling will allow monitoring of ISI individuals and it will be possible to include it at a later benchmark if more starts appearing in Greenlandic waters.

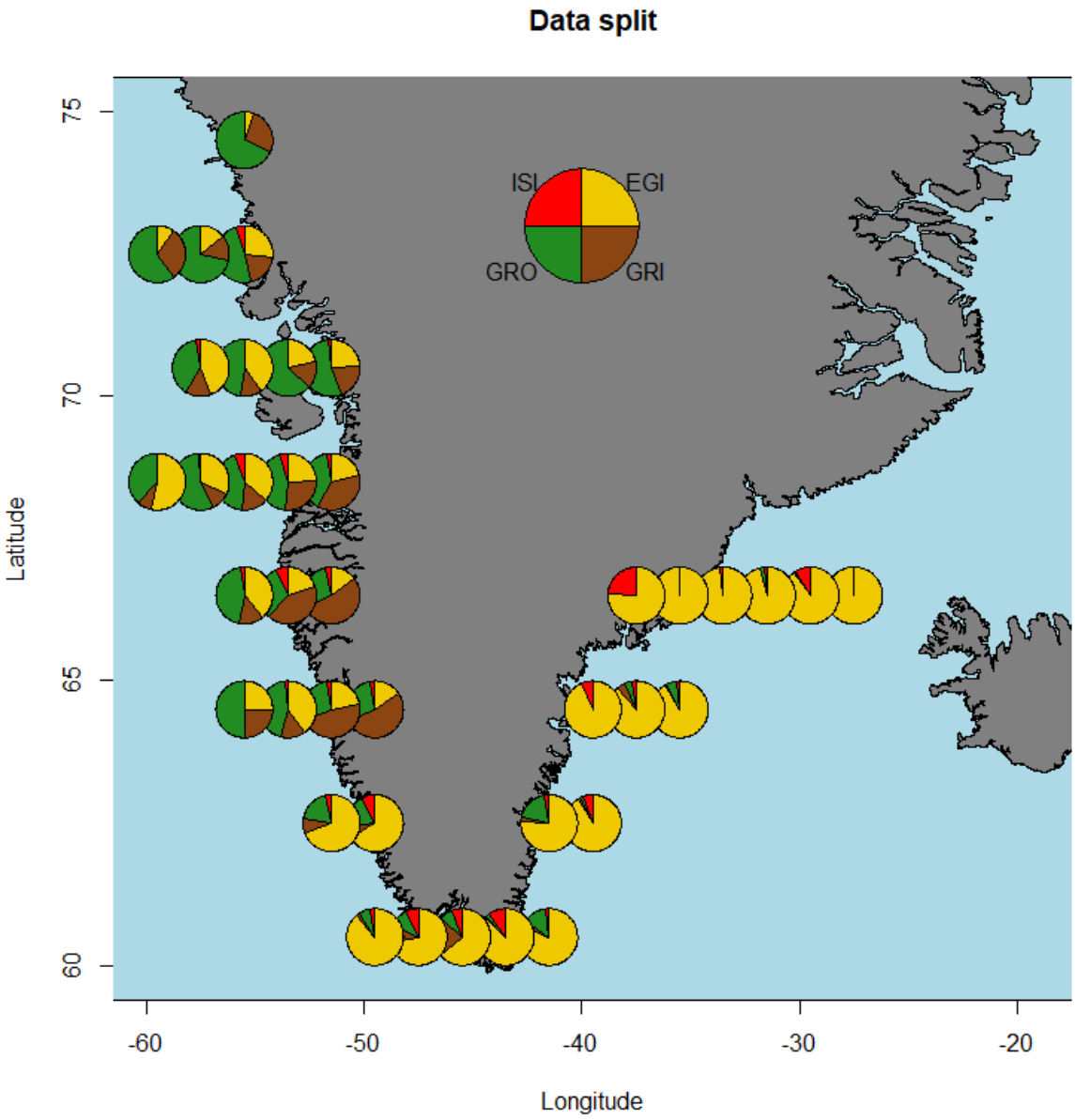

Figure 7. Map of Greenland with piecharts showing the proportion of each of the four cod stocks based on the individual cod sample for genetics from both commercial fisheries and scientific surveys in the period 2000-2021.

Age data

For further analysis, the input into the model requires age (or cohort) for each sample. Having ages makes it possible to follow specific cohorts and to explore the contribution of different stock to the cohorts important in the fisheries. The input data used in the current SAM assessment model are age-aggregated and in order to split catches stock composition will be needed by age. Therefore, only individuals with associated age are used.

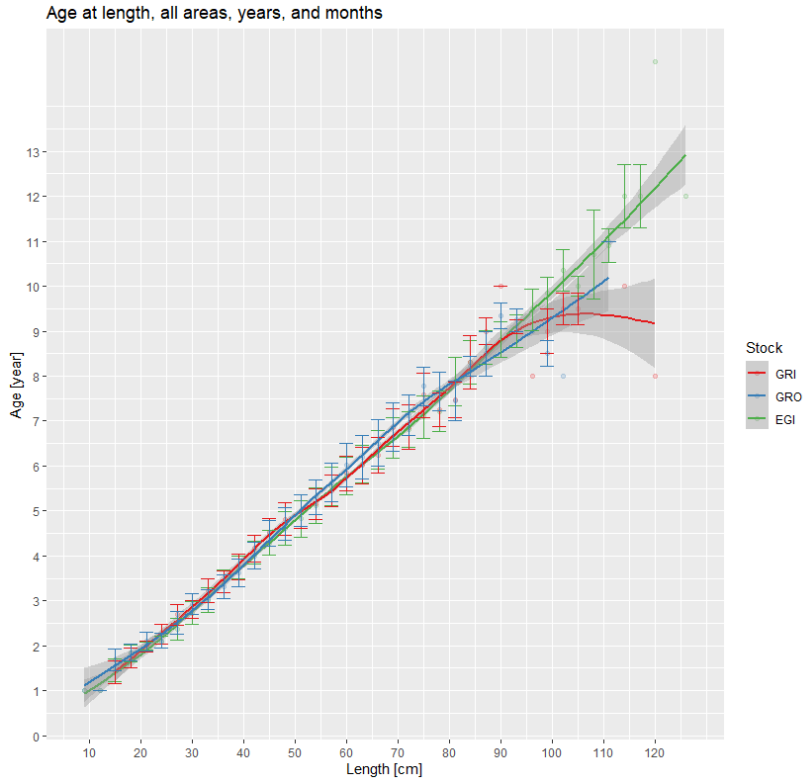

Figure 8. Age-length relationship for each of the three cod stocks GRI, GRO and EGI. From Bjare 2022 updated with more genetics samples.

There are a number of samples without associated ages, and many of these have length data. Analysis in Bjare (2022) showed that based on the genetics data there are no differences in age-length relationships in the three stocks (see figure 8, note that above 100 cm there are few samples). Therefore, available age and length data were used to estimate ages for some of the samples with lengths but no ages. This was done be area and year, and only when representative age-length data were available.

Table 2. Overview of number of individuals for which ages have been estimated based on available length data.

Year	Type	Area	Number of individuals
2013	Commercial	Nuuk	11
	Commercial	Sisimiut	27
2017	Commercial	Nuuk	1 897
	Commercial	Sisimiut	1 378
2018	Survey	Tovqussaq banke	103
2019	Commercial	Nuuk	36
	Commercial	Maniitsoq	47
	Commercial	Sisimiut	46
	Commercial	Kangaatsiaq	76

Inshore/offshore
All samples are defined as either inshore or offshore in the dataset. This variable will be used in the split model. Inshore (I) samples are those taken in one of the inshore fjord systems south of Disko Bay. The remaining samples are defined as offshore.

Within year stability

In 2017 catches from the commercial fisheries in Sisimiut (1B) and Nuuk (1D) were sampled for genetics throughout the year. From this data, Christensen *et al* (2022) found no significant difference in proportion of the three different stocks, between months, areas, and distance to fjord mouth.

Future data availability

Fin clippings have been collected on the 2022 inshore and offshore surveys, and it is expected that the inshore samples will be ready for the assessment in 2023. It is expected that sampling for DNA will take place every second year on the inshore and offshore surveys, this will allow update of the split model with data for incoming cohorts.

Results

Final dataset for the model
From 2000-2021 there is a fairly good coverage for all areas and the initial modelling will therefore be based on this subset of the dataset, see Table 3 and Figures A3 and A4 for data overview for 2000-2021.

Table 3. Number of Samples per area for the years 2000-2021: Inshore and Offshore. Area gives the NAFO area. Samples gives the number of samples with age and position in the final dataset. Cohorts gives the number of cohorts represented in the samples.

InOff	Area	Samples	cohorts
I	1B	1884	20
I	1C	500	17
I	1D	1892	23
I	1E	34	7
I	1F	256	10
O	1A	669	23
O	1B	394	19
O	1C	699	15
O	1D	473	19
O	1E	381	16
O	1F	480	18
Total	**All**	**7662**	**25**

Sample coverage

Samples from the commercial fisheries have mainly been taken inshore in west Greenland and on east due to the limited fisheries offshore in west Greenland in recent years. Samples from the

surveys cover the entire area. There are samples covering January to November, but most samples have been collected from April to August which is the survey season.

Figure 9 shows sample location for the samples with position information for both West and east Greenland. Only samples collected on west are used in the Split model.

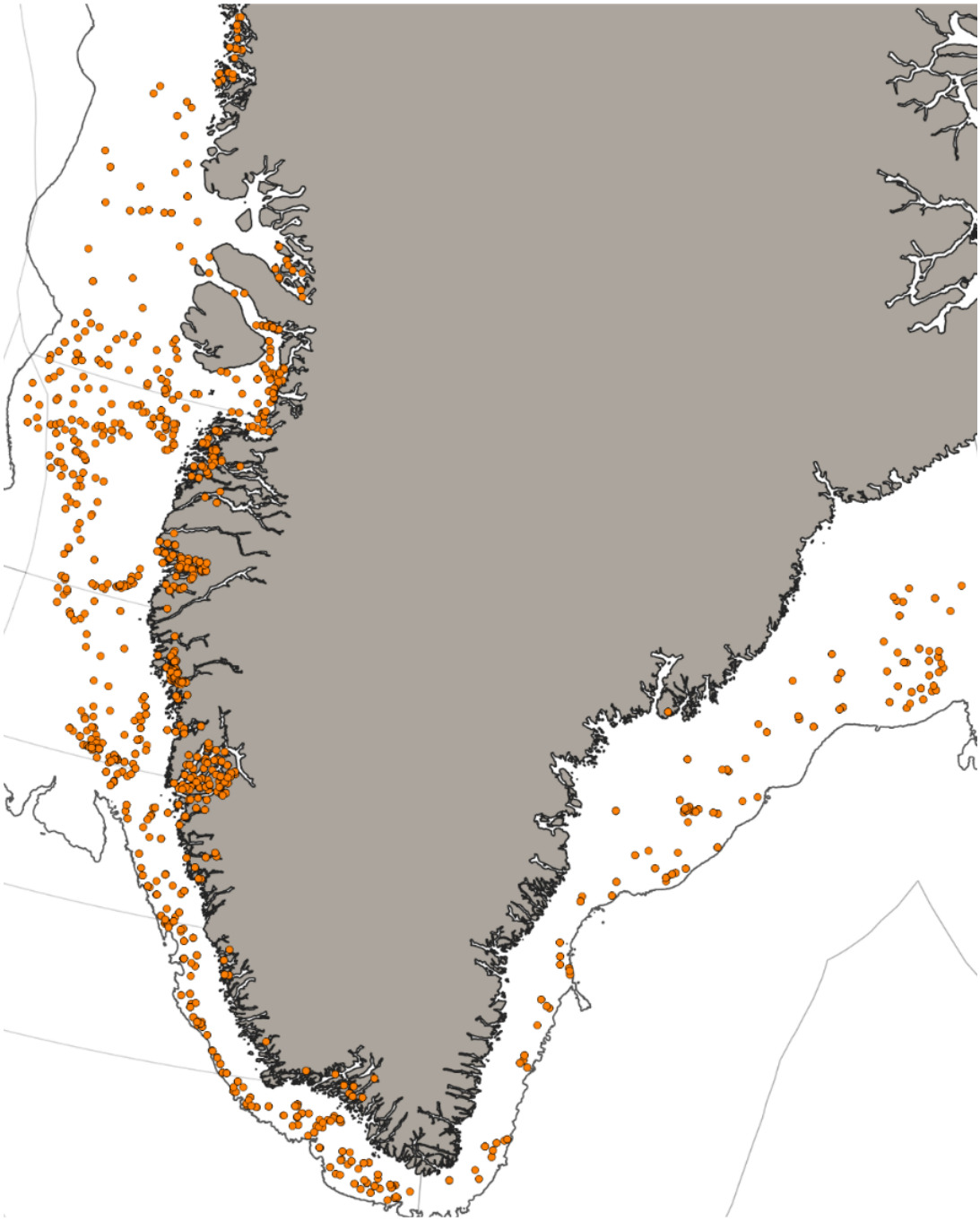

Figure 9. Overview of location of samples collected around Greenland (red marks) in 2000-2021. Assignment >=0.7. Only samples with position information or fieldcode are on the map.

Discussion

Benchmark

The data presented here shows that the stock composition in Greenland waters is more complex than previously assumed and that a split based on NAFO and ICES area (as it is now) do not account for this. It should therefore be a priority to improve this in the upcoming benchmark.

The data presented in this document can be used to develop a model which can provide a way for splitting the commercial and survey data currently being used to assess the three Greenlandic cod stocks (see WD 02). The good spatial resolution of the dataset means that it can be used in a spatial model which can estimate stock composition at a higher spatial resolution than NAFO/ICES areas. Thus, making it possible to improve the way that data are split into stocks and to run assessment models for each stock and thereby accounting for stock specific dynamics.

Conclusion

The findings of mixing of stocks to a larger extent than previously assumed warrants for a new way to split stocks than the geographical delineation assessment is based on today. In order to provide advice which gives an accurate stock status for each of the three Greenland cod stocks it is necessary to account for the complex mixing, the upcoming benchmark will be able to facilitate the improvement in stock splitting based on the data presented here.

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Appendix

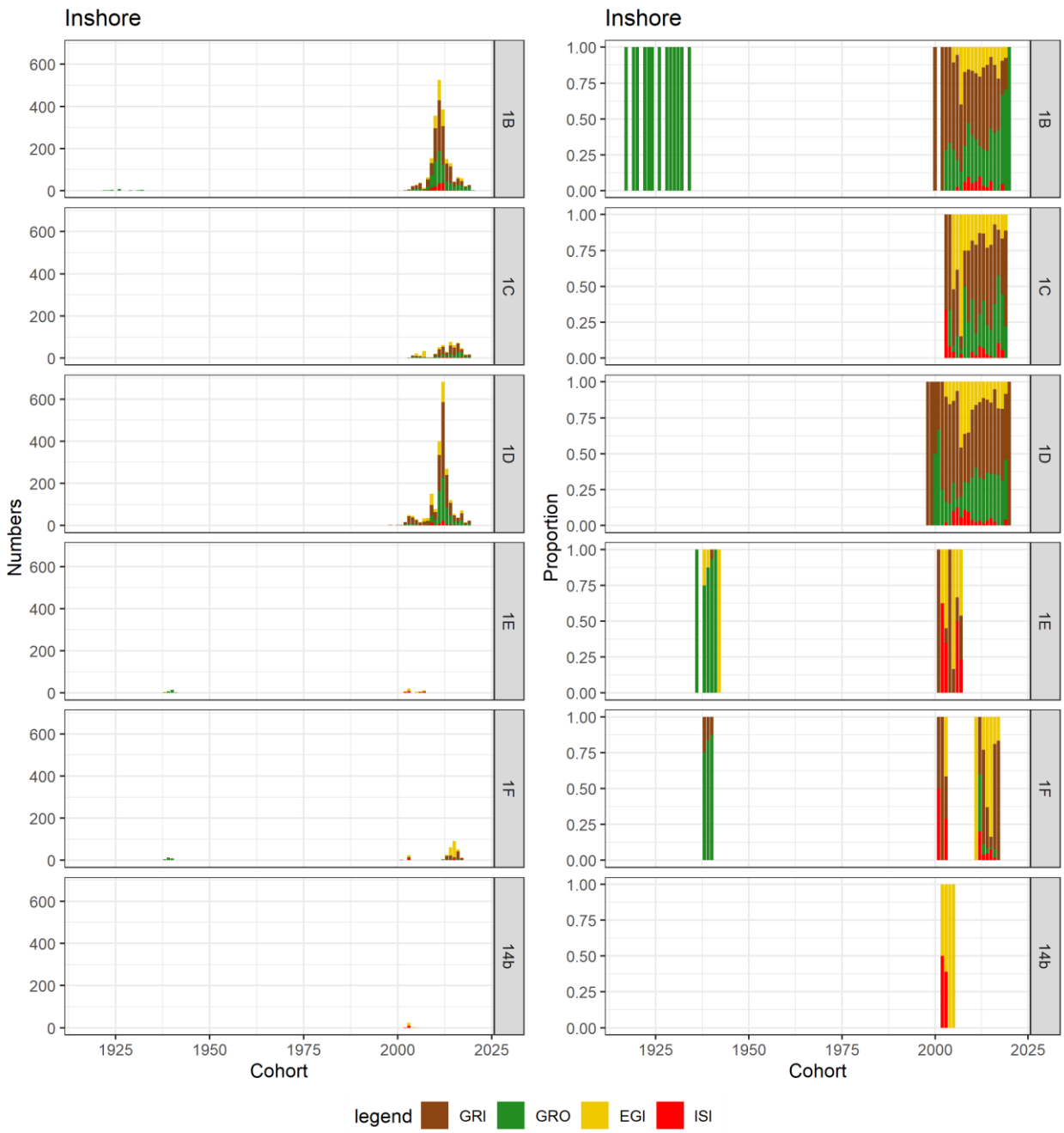

Figure A1 Overview of inshore samples by area and cohort, all samples with assignment 0.7 or above. On the left is the number of samples by cohort, area, and stock. On the right is the proportion of each stock by cohort and area based on the samples.

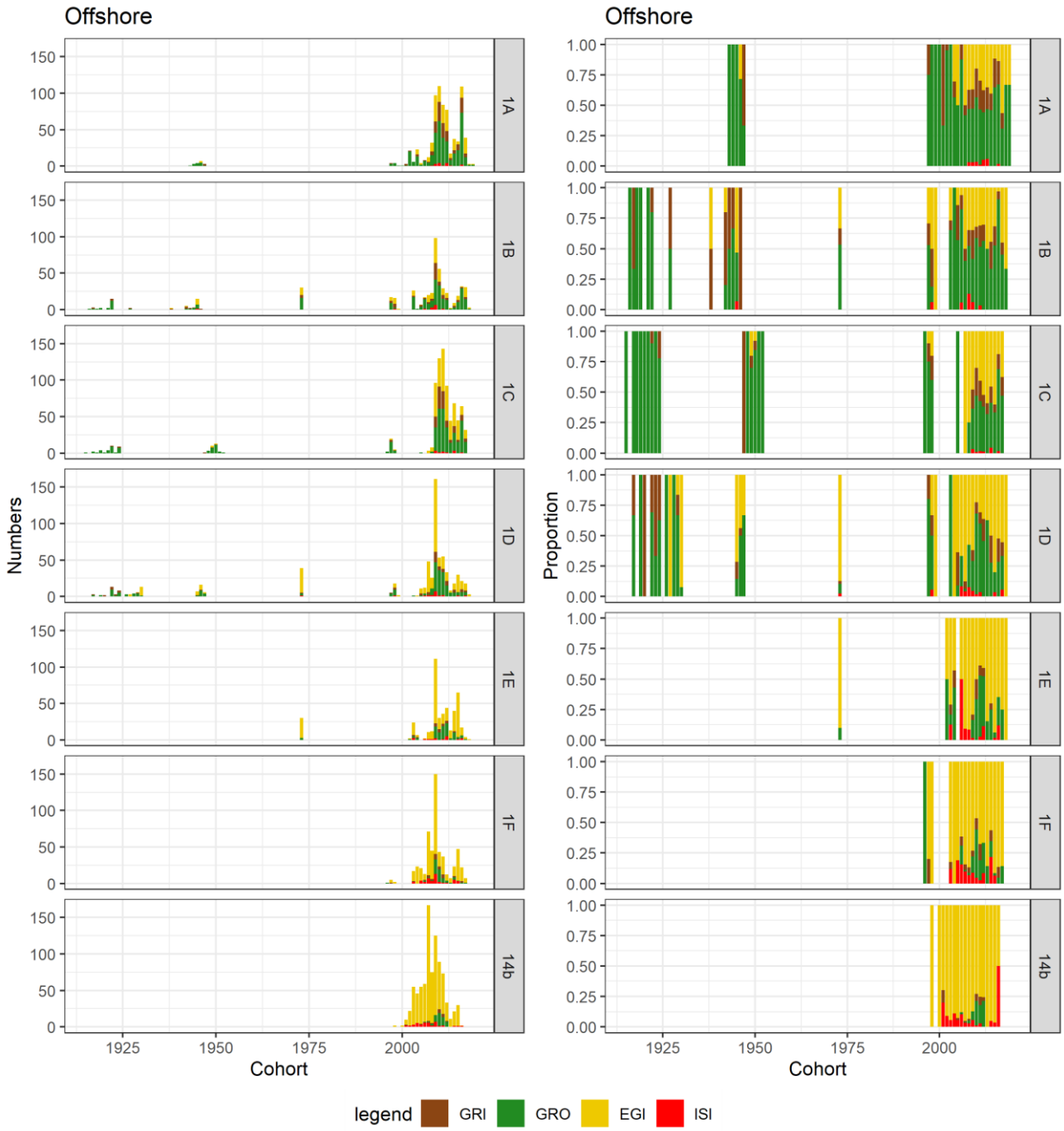

Figure A2 Overview of offshore samples by area and cohort, all samples with assignment 0.7 or above. On the left is the number of samples by cohort, area, and stock. On the right is the proportion of each stock by cohort and area based on the samples.

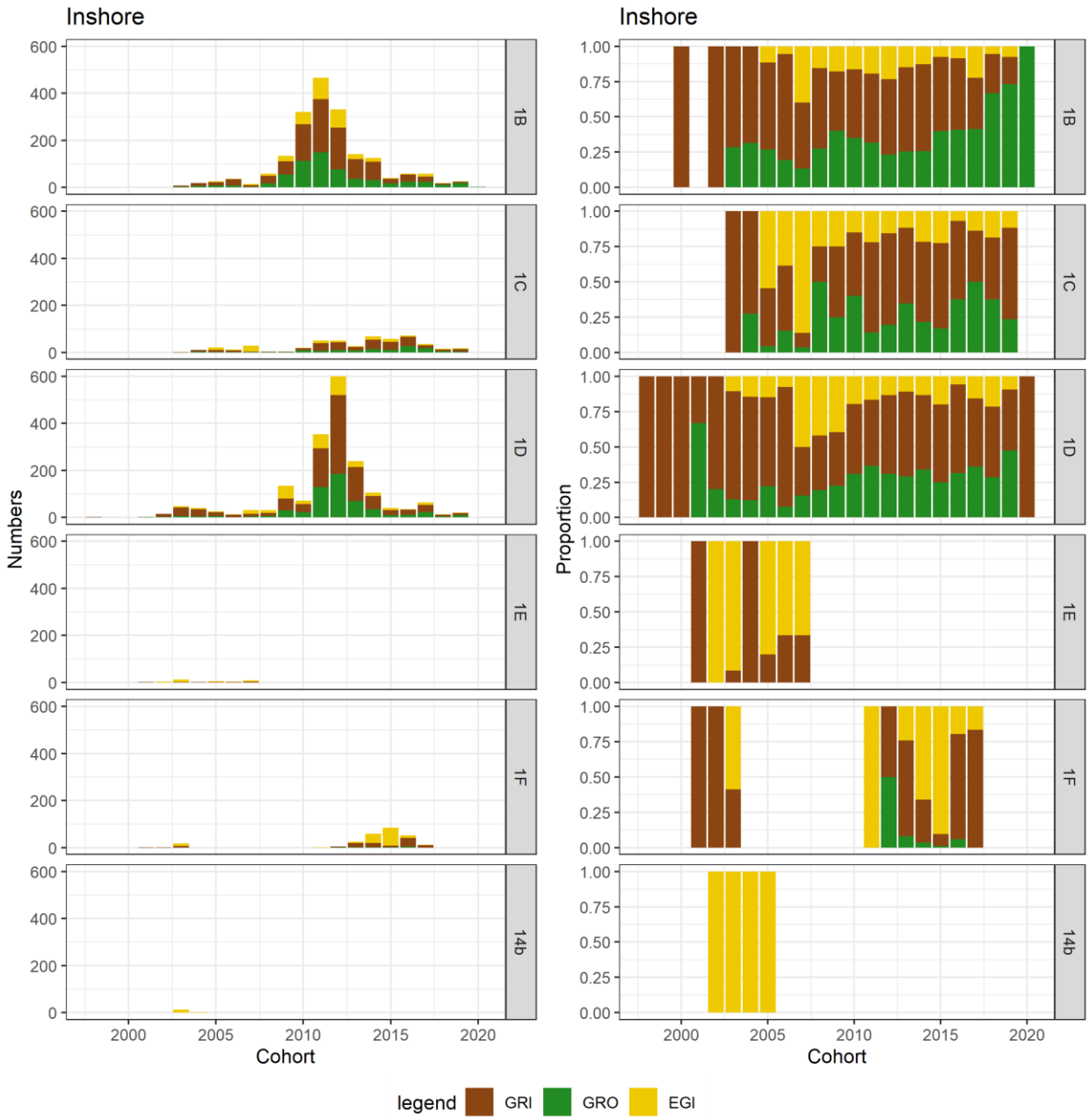

Figure A3 Overview of inshore samples collected in 2000-2021 by area and cohort, all samples with assignment 0.7 or above. Individuals assigned to ISI stock have been removed.

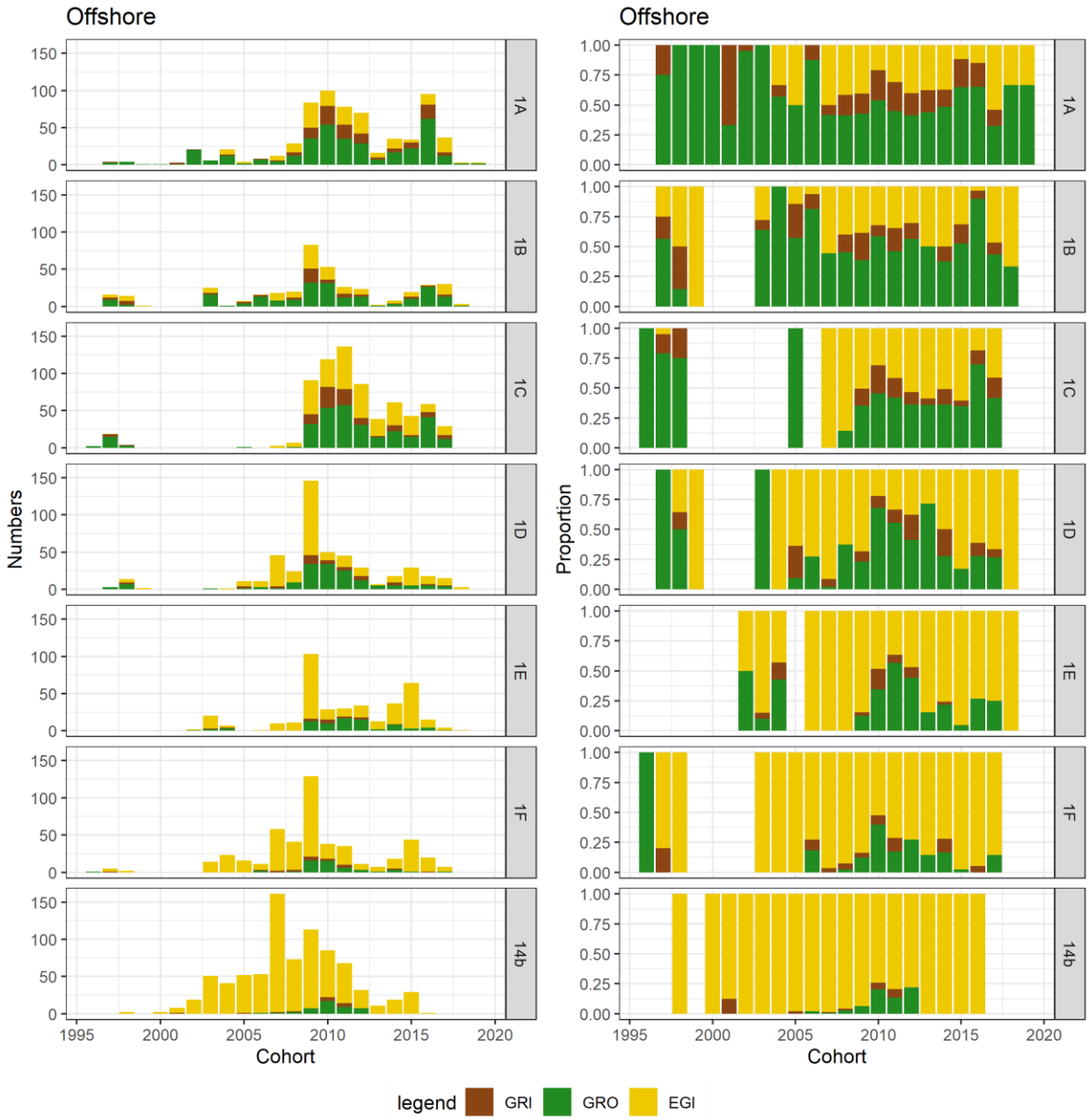

Figure A4 Overview of offshore samples collected in 2000-2021 by area and cohort, all samples with assignment 0.7 or above. Individuals assigned to ISI stock have been removed.

WD 02 - GAM modeling of genetic stock composition of Atlantic cod (Gadus morhua) in West Greenland

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Introduction

A model was developed for splitting commercial and survey catches of Atlantic cod (*Gadus morhua*) into the three major genetically distinct cod stocks in Greenland.

A multinomial Generalized Additive Model (GAM) with random effects was applied to account for possible nonlinear correlations between the response variable and covariates.

The final model showed a good fit to the observations with no worrying trends in the diagnostics.

Methods

Data selection

For an introduction to the stock structure and genetic data used in the model, see WD01. WD05 provides an overview of the commercial catches and survey data.

Based on catch curves and internal consistency plots on the surveys, it was decided to omit 0 and 1 year old's from the final stock assessment model (SAM). A further support to leaving out these ages is that the surveys occasionally confuse juvenile Atlantic cod with polar cod (*Boreogadus saida*) (and the other way around). Hence, we did not model the proportions of age 0 and 1 year old fish.

Only samples from West Greenland were included in the GAM (with Cape Farewell - tip of South Greenland as the cutoff), as all individuals in East were regarded as being mainly EGI.

Based on the data filter described in WD01, input data consisted of genetic observations from 7598 cod.

Using an Information-Theoretic Approach, we set up a list of possible models with combinations of potential variables (including smoothers and interactions) that were thought relevant. This led to a test of 127 models in total ("WD02_Appendix1_Model_results_AIC.csv"). Some models were computationally heavy to run (+10 hours**)**, especially those including random effects, and not all converged.

The tested parameters can be seen in table 1.

Table 1: Overview of parameters tested in the model.

Parameter	**Description**
Lat	Latitude in decimal degree
Lon	Longitude in decimal degree
GeoAxis	Point assigned to a line following the coastline (based on nearest distance)
GeoAxisDist	Shortest distance to GeoAxis (in Km)
InOff	In- or Offshore
Age	Age of fish
fAgeGr	Age as factor with multiple ages grouped (2-3, 4-6 &+7)
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

A more detailed description of the parameters and the rationale for being used is provided in the following sections.

Age

It is evident from the offshore surveys that age groups are not uniformly distributed along West Greenland. Young cod are typically distributed further to the north in West Greenland. As they get older, they move further south and to East Greenland (Fig. 1). Based on this distribution pattern, age was implemented as a parameter in the model, both as numeric in a smoother and as a factor. In the latter, ages of 'similar' spatial distribution patterns were grouped to higher the number of samples within each group. Based on distribution plots, e.g. Fig. 1, and the number of samples, ages 2-3, 4-6 and fish above seven were grouped.

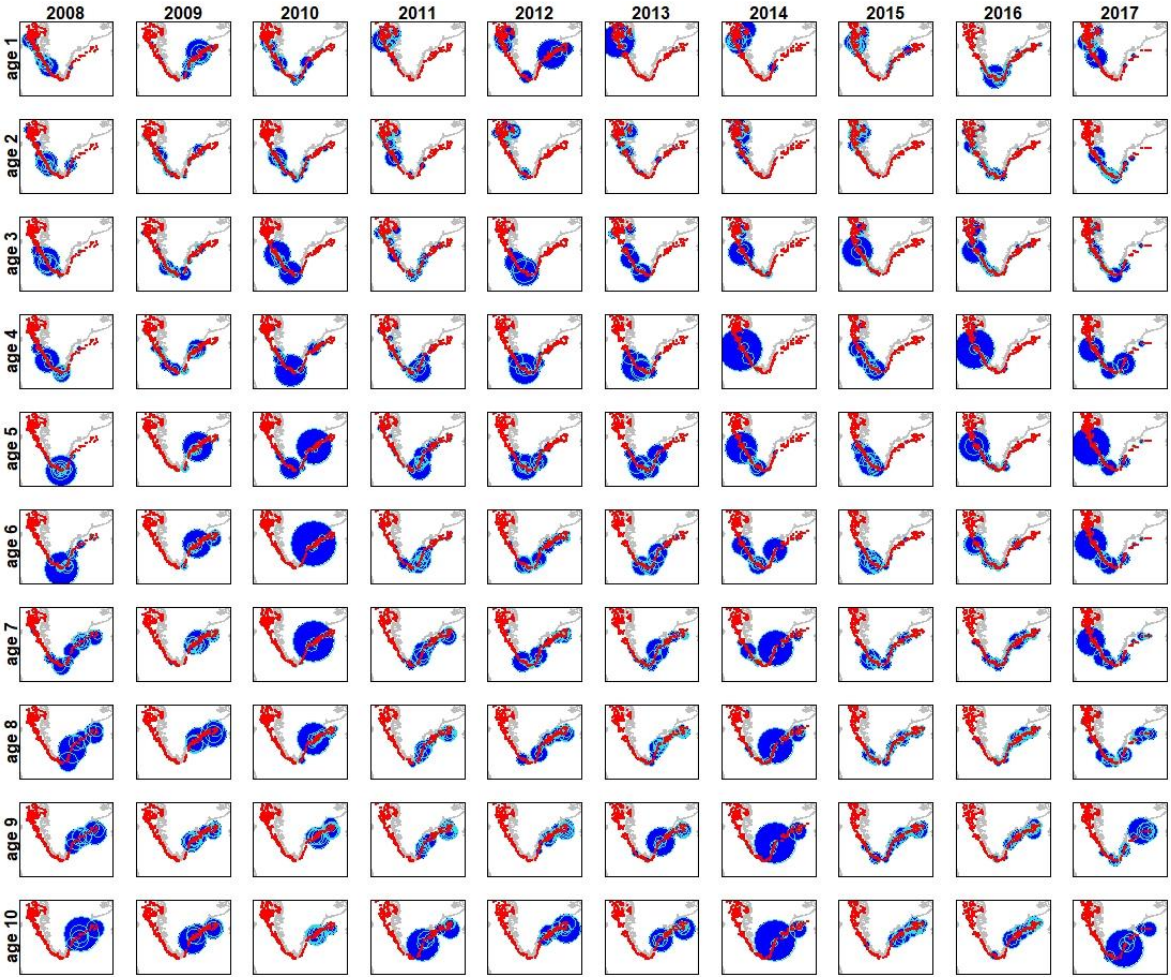

Figure 1: Map of age distribution. Abundance (%) of ages 1–10 in the years 2008–2017 from the Greenland survey. The size of blue circles denotes the percentage of the age in the given year, where each square equals 100%. Red circles are trawl stations.

Cohort grouping

The strength of cohorts is highly variable, as is the distribution range along the coast (how far north in West Greenland). As the geographical distribution varies between cohorts, we aimed to model the distribution by cohort and age. However, the genetic samples do not have proper coverage for all cohorts throughout the region; therefore, we grouped those showing similar distribution patterns. To identify "similar" strong cohorts, mean CPUE by cohort for all stations in the Greenland offshore bottom trawl survey (SF) for ages 3, 4 and 5 was calculated (Fig. 2). Values were normalized (divided by max). Strong cohorts were then defined as those above the 75% quantile. In addition, mean center of distribution by age (Fig. 3) was performed on these strong cohorts to identify a difference in the distribution range. Furthermore, the genetic split of the strong cohorts by NAFO region was investigated to find out if there was a difference in the proportions across regions (Fig. A1-A6). Finally, cohorts showing similar distribution patterns were grouped and used as categorical factors in the GAM model.

Based on the above, the following grouping was decided:

Cohorts before 2009 that leave West Greenland at age ~5 (1996,1998, 1999, 2000, 2001, 2002, 2004, 2005, 2006, 2007,2008)

Strong cohorts distributed further south, primarily of East origin (2003, 2014 and 2015): however, as too low sampling in the age group 2-3, it was decided to include the 1997 YC in this group as it has similar genetic split in the age group 2-3 as the 2003+2014 and 2015 YC at age group 4-6 (Fig. A1-A6).
A single strong cohort primarily of East origin (2009 YC) reaching far north.
Strong and medium cohorts primarily of Offshore West Greenland origin (2010,2011,2012 YC). 2010 is a strong cohort, but due to low sampling inshore at ages 4-6, it was decided to group it with 2011 and 2012. These 3 YC were fished at high levels in the inshore fishery at ages 4-6 and had a similar genetic composition, Fig.A1-A6).
Other cohorts after 2009 staying in West Greenland at older ages +5 (2013, 2016, 2017,2018 and 2019).

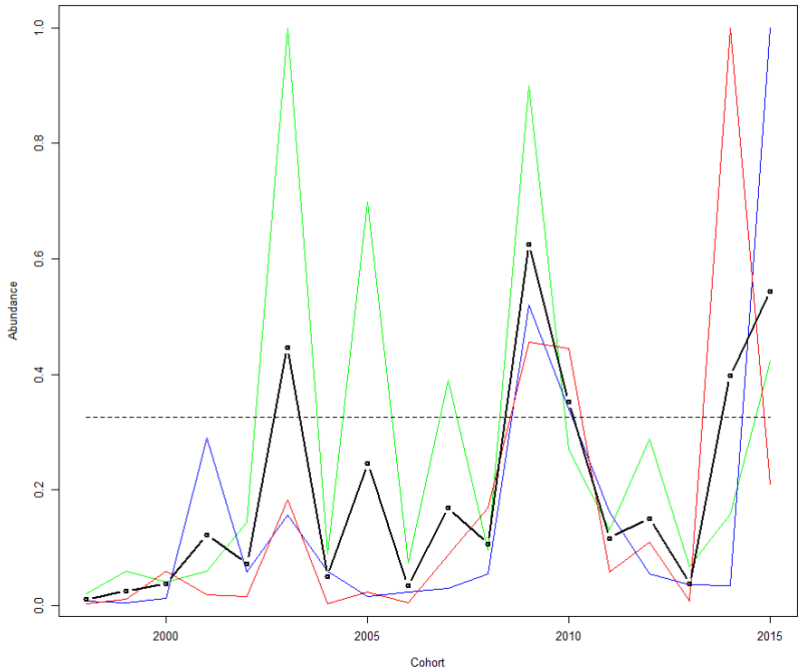

Figure 2: Normalized CPUE (black) with 75% quantile (dashed) of ages 3 (green), 4 (blue) and 5 (red) in the Greenland bottom trawl survey.

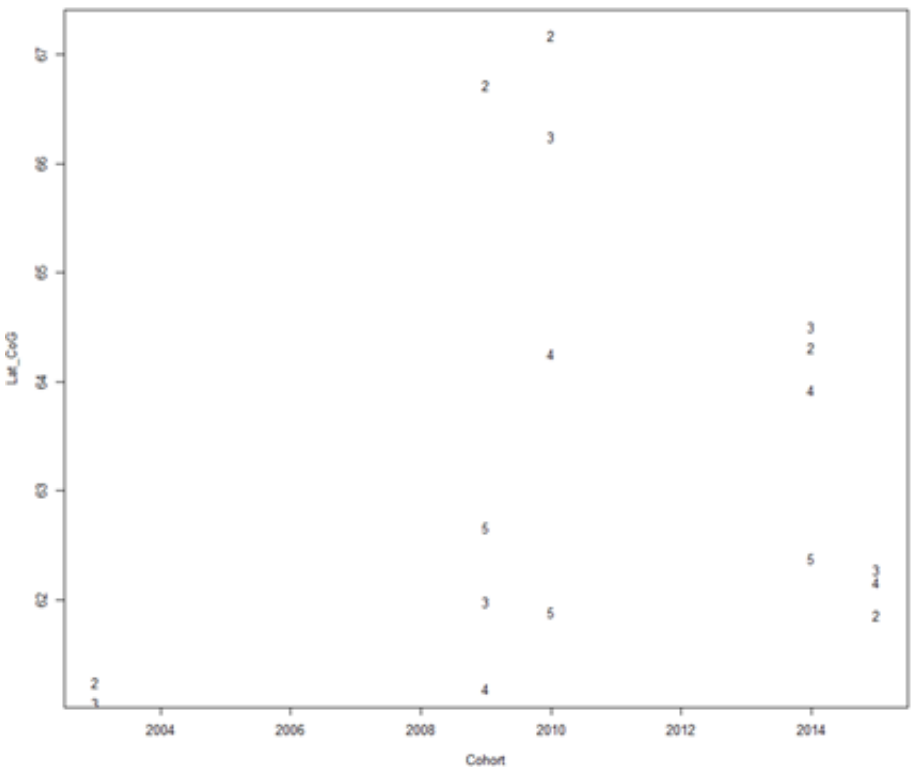

Figure 3: Mean center of distribution by age of cohort 2003, 2009, 2010, 2014 and 2015. Y axis is latitude.

Incoming cohorts will then be treated as follow:

When a new cohort enters the model at age 2, compare the genetic composition of the cohort with age 2 in the cohort-groups used in the model by in- offshore area and NAFO division. Grouping it with the cohort-group having similar genetic composition.

As genetic analysis will be implemented on a yearly basis the aim is to treat each new cohort independently in the model.
Suppose there are not enough genetic samples to have a cohort separately. In that case, the genetic composition is followed as it ages and compared continuously to see which cohort group it should be reallocated to.

Inshore-Offshore area definition

The inshore area is defined as samples taken from the fjords, and the delineation is the baseline which is a line that connects the outermost coastline from Island to Island (Fig. 4).

As results from the genetics analysis revealed that a higher ratio of GRO is present in samples from the inshore area from Disco Bay and northwards (compared to fjords further south), it was decided to regard these as Offshore. The delineation is north of 68.6°N.

GeoAxis and GeoAxisDist

“GeoAxis” represents a one-dimensional spatial distribution along the West coast of Greenland (Fig. 6). It is created as an axis (~1800 km) following the coast and samples are

projected onto the nearest point on this axis (Fig. 4). To capture gradual differences from coast to offshore we tested a parameter called "GeoAxisDist", which is the shortest distance to the coast (GeoAxis, in Km).

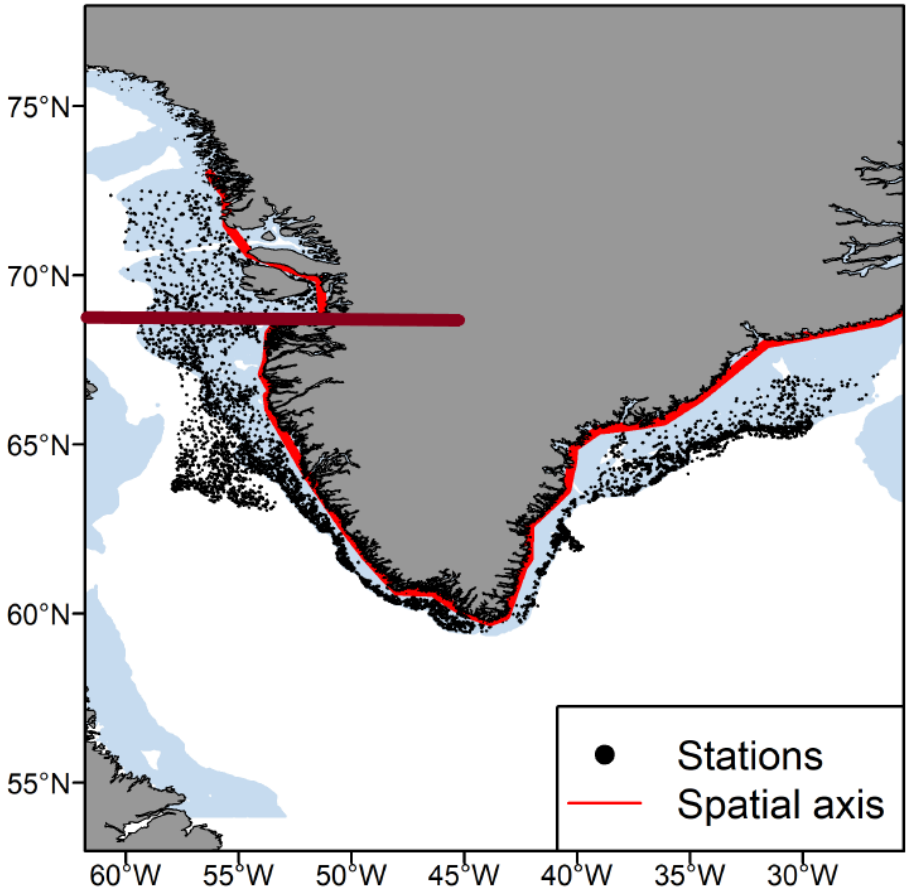

Figure 4: Coastline of West Greenland with baseline ending at 68.6°N. North of 68.6, every sample is assigned as offshore. Black dots are SF, GHL and GGS stations.

Model setup and selection

The GAM was fitted in R v.4.2.1 using the *mgcv* packages v.1.8.40 (Wood 2001, 2011; R Core Team 2022). As the response variable could be either GRI, GRO or EGI, we used a multinomial distribution family. In practice, the family is set as follows: Family=multinom(K=2), where the response is assigned to a value of 0, 1, or 2, representing GRI, GRO or EGI, respectively.

Based on an information theoretic approach, we set up a list of possible models with combinations of potential variables (including smoothers and random effects) that were thought relevant. This led to a test of 127 models in total (Table "WD02_1_model_results_AIC.csv").

The final model was selected using Akaike's Information Criteria (AIC) by choosing the model with lowest AIC. The model with the lowest AIC was model 19, with the following structure:

Let the ith observation,X_i, be a three dimensional vector such that $X_i = (1,0,0)^T$ for an individual assigned as GRI, $X_i = (0,1,0)^T$ for an individual assigned as GRO , and $X_i = (0,0,1)^T$ for an individual assigned as EGI . Then X_i is assumed to follow a multinomial distribution,$X_i \sim Multinom(1, p_i)$.

The stock composition probabilities are parameterized such that

$$p_{i,GRI} = \frac{1}{1 + exp(\eta_{i,GRO}) + exp(\eta_{i,EGI})}$$
$$p_{i,GRO} = \frac{exp(\eta_{i,GRO})}{1 + exp(\eta_{i,GRO}) + exp(\eta_{i,EGI})}$$
$$p_{i,i,EGI} = \frac{exp(\eta_{i,EGI})}{1 + exp(\eta_{i,GRO}) + exp(\eta_{i,EGI})}$$

where

$$\eta_{GRO} = \beta_{1,GRO} + \beta_{2,GRO} 1_{i,\text{Offshore}}$$
$$+\beta_{3,GRO} 1_{i,\text{Cohort=LargeYC\_EG\_FarWest\_2009}} + \beta_{4,GRO} 1_{i,\text{Cohort=LargeYC\_EG\_NotFarWest}}$$
$$+\beta_{5,GRO} 1_{i,\text{Cohort=LowMediumYC\_After2012}} + \beta_{6,GRO} 1_{i,\text{Cohort=LowMediumYC\_Before2009}}$$
$$+S_{GRO,CohortGroup(i)}(Lat_i, Lon_i, Age_i) + U_{GRO,SampleID(i)}$$

and

$$\eta_{EGI} = \beta_{1,EGI} + \beta_{2,EGI} 1_{i,\text{Offshore}}$$
$$+\beta_{3,EGI} 1_{i,\text{Cohort=LargeYC\_EG\_FarWest\_2009}} + \beta_{4,EGI} 1_{i,\text{Cohort=LargeYC\_EG\_NotFarWest}}$$
$$+\beta_{5,EGI} 1_{i,Cohort=\text{LowMediumYC\_After2012}} + \beta_{6,EGI} 1_{i,Cohort=\text{LowMediumYC\_Before2009}}$$
$$+S_{EGI,CohortGroup(i)}(Lat_i, Lon_i, Age_i) + U_{EGI,SampleID(i)}$$

In both formulas above, βs are fixed effect parameters, $1_{i,\text{Offshore}}$ is an indicator function which is one if the individual was captured offshore, $1_{i,\text{Cohort=x}}$s are indicator functions which are one if the individual belongs to cohort group “x”, S are thin plate regression splines on latitude, longitude, and age where the parameters depend on cohort group. Finally, U are random effects on sample ID.

The model can be expressed in R-code 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=df_kystW,family=
multinom(K=2))
```

Model validation was subsequently performed on this model. Quantile residuals were calculated following Trijoulet *et al*. (2023). See “WD02_Appendix2_Validation_GAM_Model19.pdf” for various metrics. The prediction ratio of the three stocks and coefficient of variation can be seen in “WD02_Appendix3_Prediction_and_Validation_GAM_Model_19.pdf”. A comparison of the observed with the modelled stock ratio was also made for the inshore areas Nafo 1B and 1D (where the gillnet survey is conducted). Here stock proportions were compared between observed and modelled at three positions from the outer to the inner part of the fjord (Fig. A7-A8).

Overall, there are no strong worrying trends in the diagnostics, and the predictions are in line with the observations.

Therefore, this model was used to split commercial and survey catches used in the further assessment work, i.e. INLA and SAM. Results of the split in the inshore surveys can be seen in WD06 and INLA in WD03.

Results of split of commercial data

The West Greenland inshore stock (GRI) is mainly fished in Mid Greenland in NAFO division 1B, 1C and 1D and to some extent in the northernmost region (NAFO 1A) in the period with high catches (2015-2017, figure 5, A9). Very little is caught in the south region of this stock (NAFO 1E and 1F).

The West Greenland offshore stock (GRO) is mainly caught in the northern area (NAFO divisions 1A, 1B and 1C) where catches start to increase in 2013 and peak in 2016 and 2017 (figure 5, table 2, A10).

The East Greenland and Iceland offshore stock (EGI) is concentrated in the catches in south Greenland especially in 2008 where the 2003 yearclass was fished in NAFO division 1F (figure 5, A11).

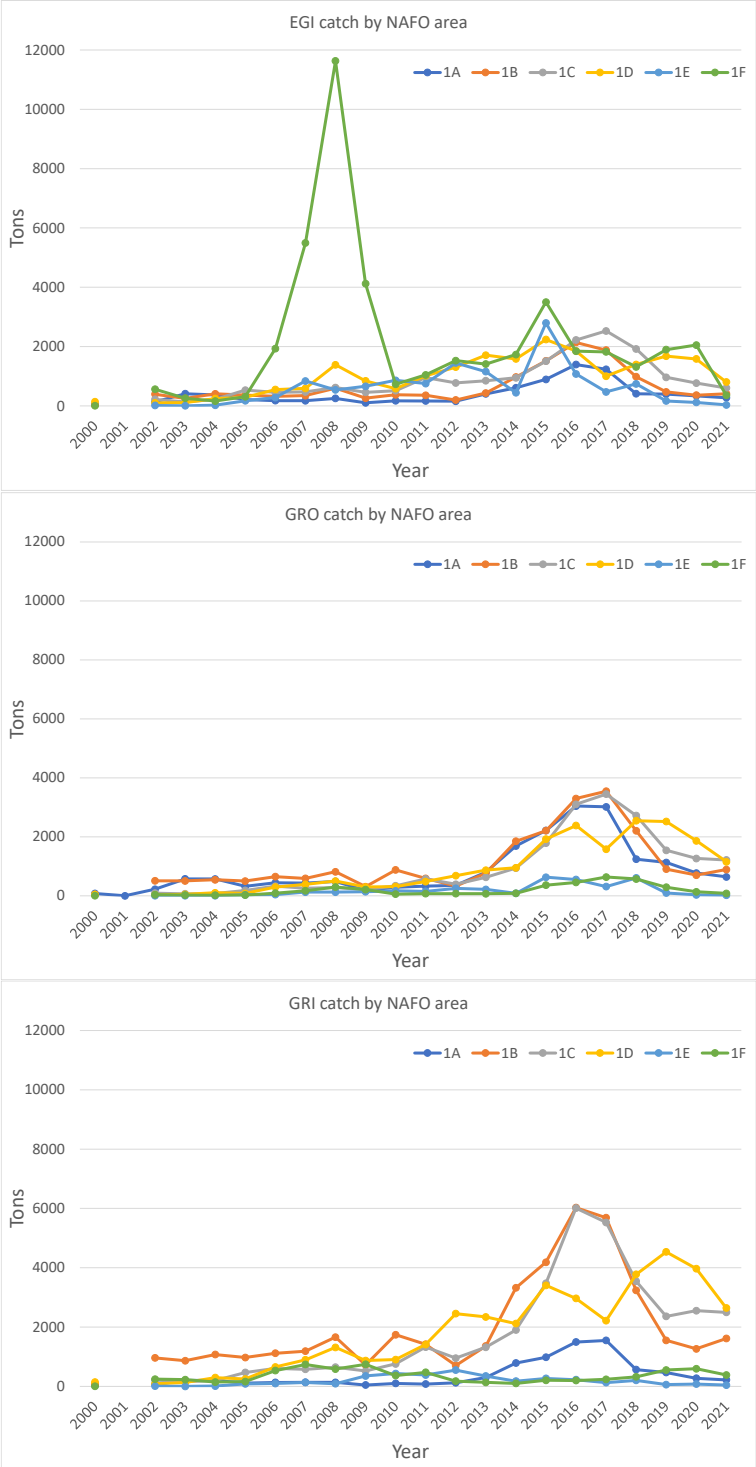

Figure 5. Total catch (tons) of the three stocks; top: EastGreenland and Iceland offshore (EGI), middle: WestGreenland offshore (GRO), bottom: WestGreenland inshore (GRI) by NAFO divisions. 1A furthest to the north and 1F furthest to the south.

Table 2: Commercial catches (tons) by year and stock. No samples in 2001 hence split cannot be made.

Year/NAFO	GRI	GRO	EGI-West	EGI-East	EGI TOT	Total Greenland
2000	253	171	224	63	286	**711**
2001						
2002	1581	891	1419	398	1817	**4289**
2003	1584	1214	1158	485	1643	**4441**
2004	1920	1306	1427	778	2205	**5431**
2005	2043	1136	1871	819	2690	**5869**
2006	3140	1836	3706	2042	5748	**10724**
2007	3667	1955	7910	3194	11105	**16726**
2008	4426	2493	15012	3258	18270	**25189**
2009	3248	1344	6438	1642	8081	**12672**
2010	4302	2039	3220	2388	5608	**11949**
2011	5089	2185	4283	4571	8854	**16128**
2012	4951	2075	5405	3941	9346	**16372**
2013	5799	3348	5951	4104	10055	**19202**
2014	8405	5592	6282	6060	12342	**26339**
2015	12520	9124	12443	11805	24248	**45892**
2016	16924	12830	10524	12497	23021	**52775**
2017	15345	12536	8924	13738	22662	**50543**
2018	11647	9883	6759	13251	20011	**41540**
2019	9522	6475	5566	17158	22724	**38721**
2020	8732	4764	5207	15258	20466	**33961**
2021	7399	3993	2475	25637	28112	**39504**

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Appendix

Genetic split in three age groups (2-3, 4-6 and 7+) by cohorts for inshore and offshore. Figures A1-A6

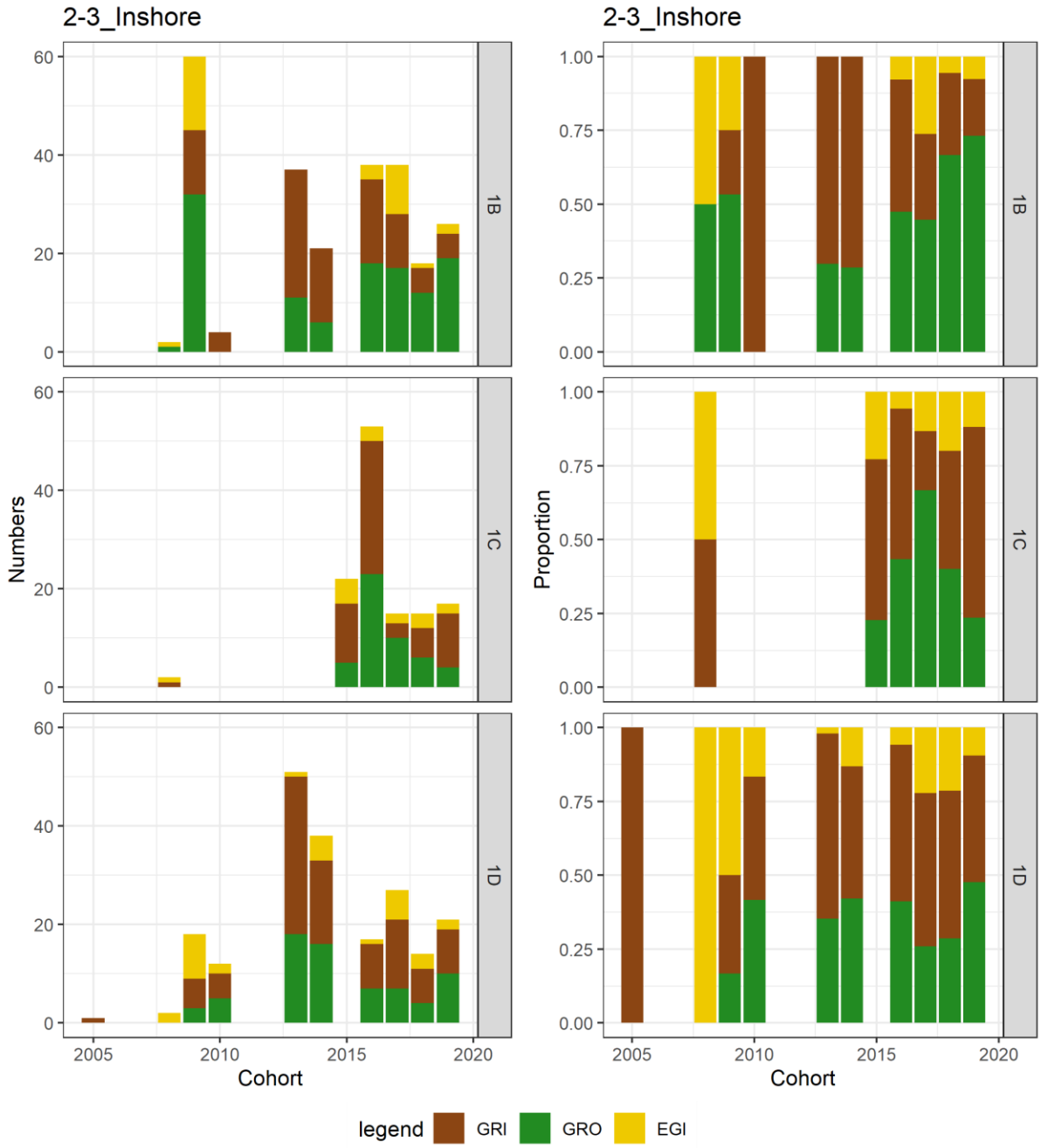

Figure A1. Genetic split in age group 2-3 inshore by cohorts.

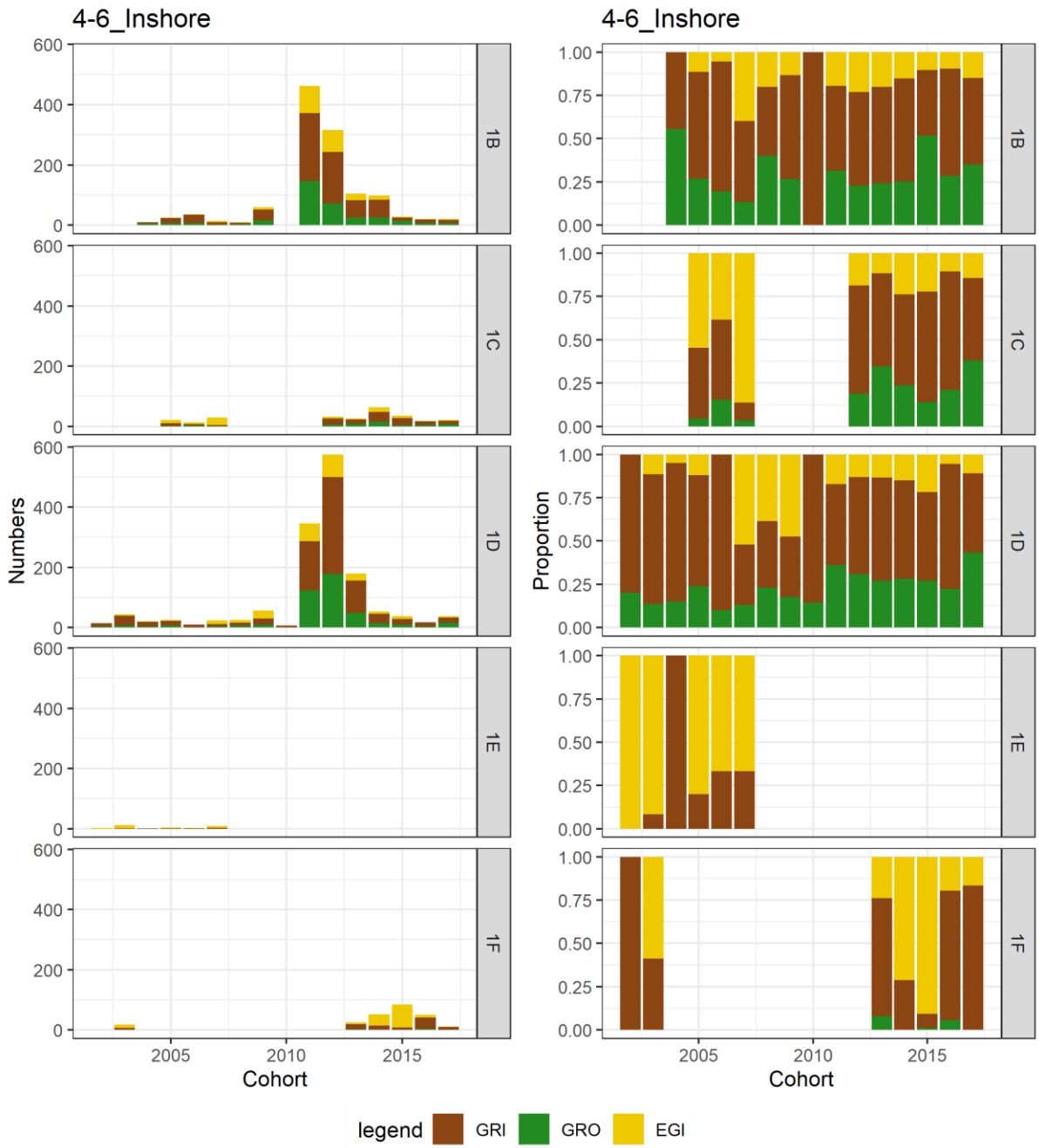

Figure A2. Genetic split in age group 4-6 inshore by cohorts.

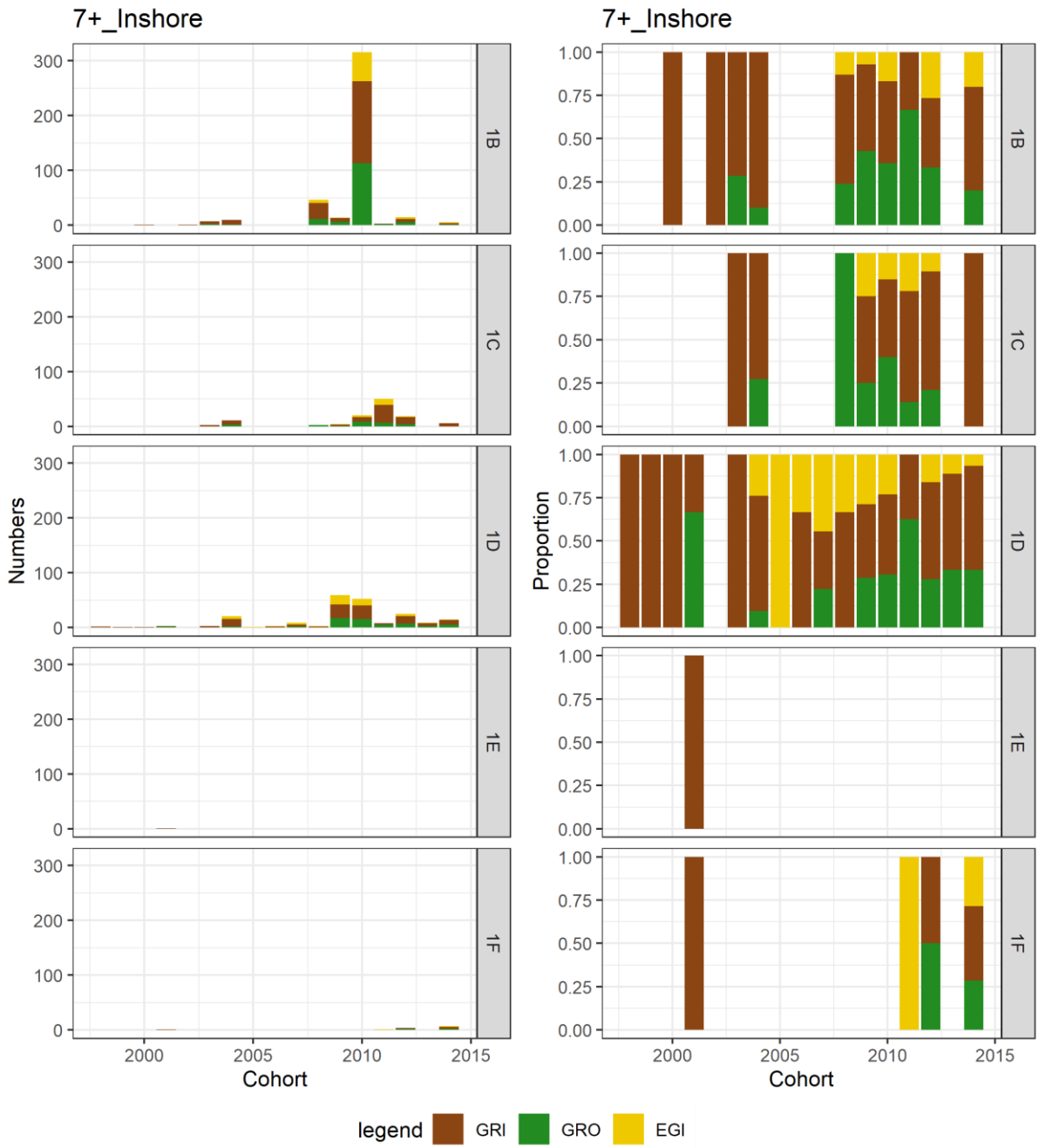

Figure A3. Genetic split in age group 7+ inshore by cohorts.

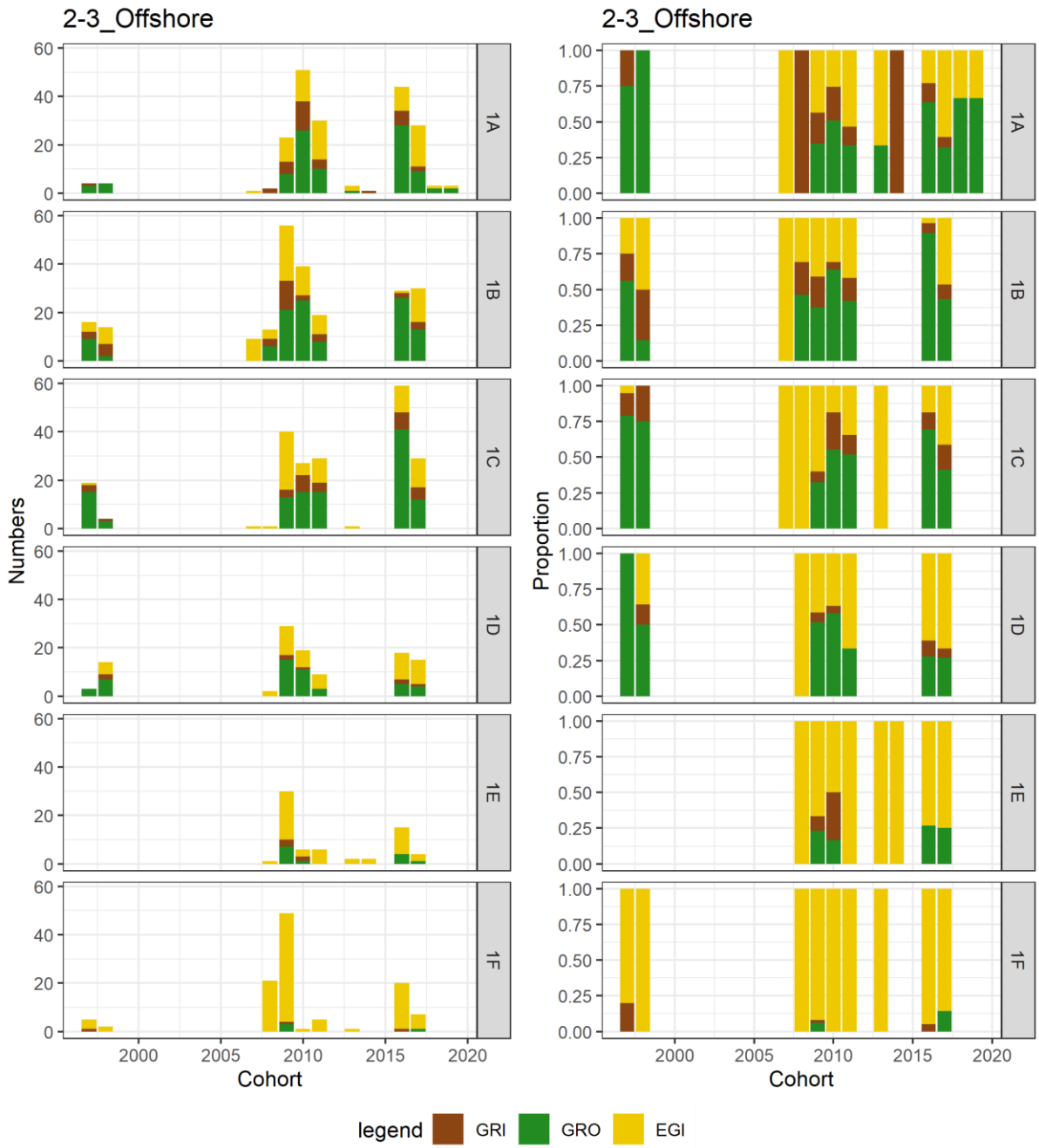

Figure A4. Genetic split in age group 2-3 offshore by cohorts.

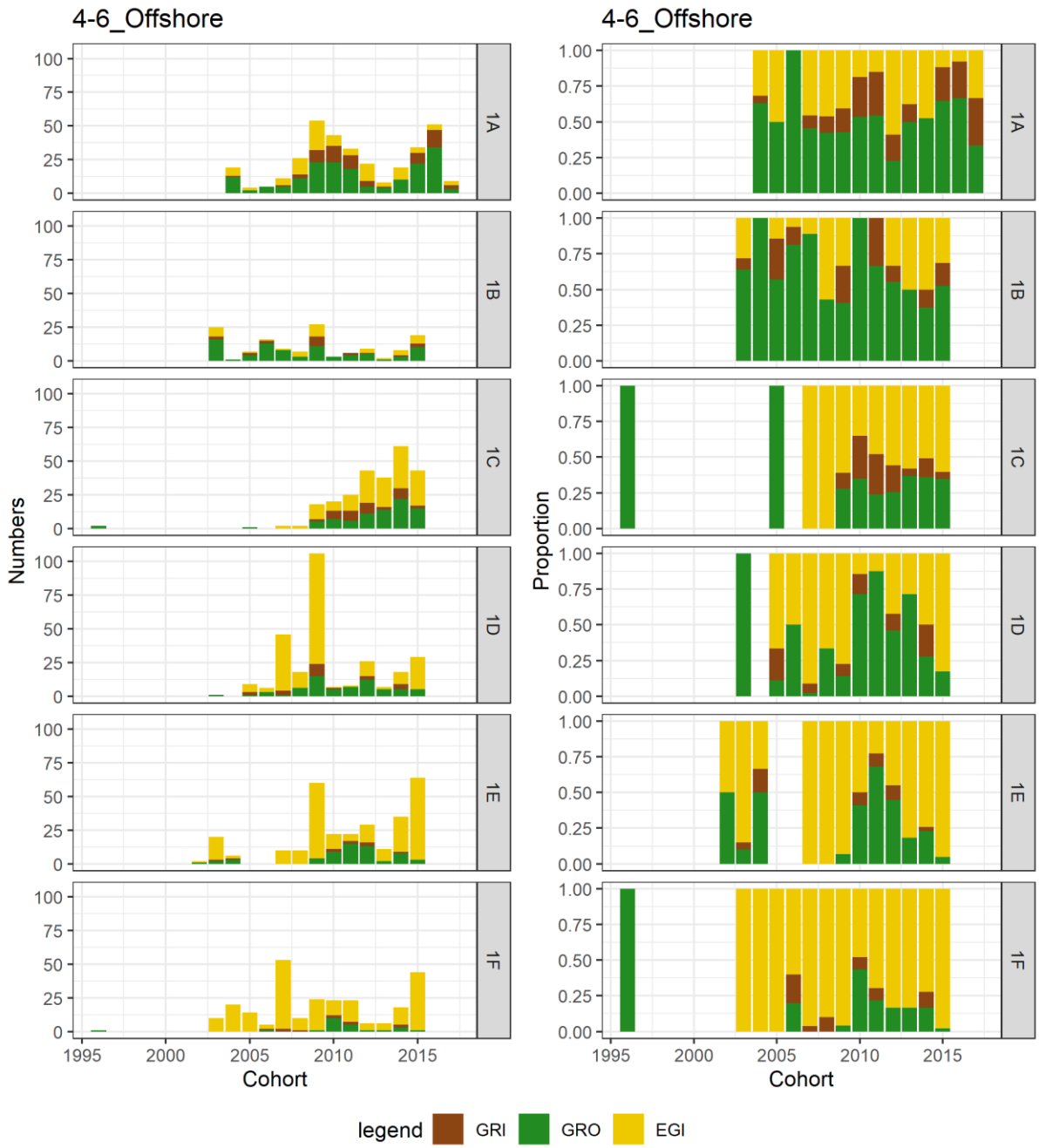

Figure A5. Genetic split in age group 4-6 offshore by cohorts.

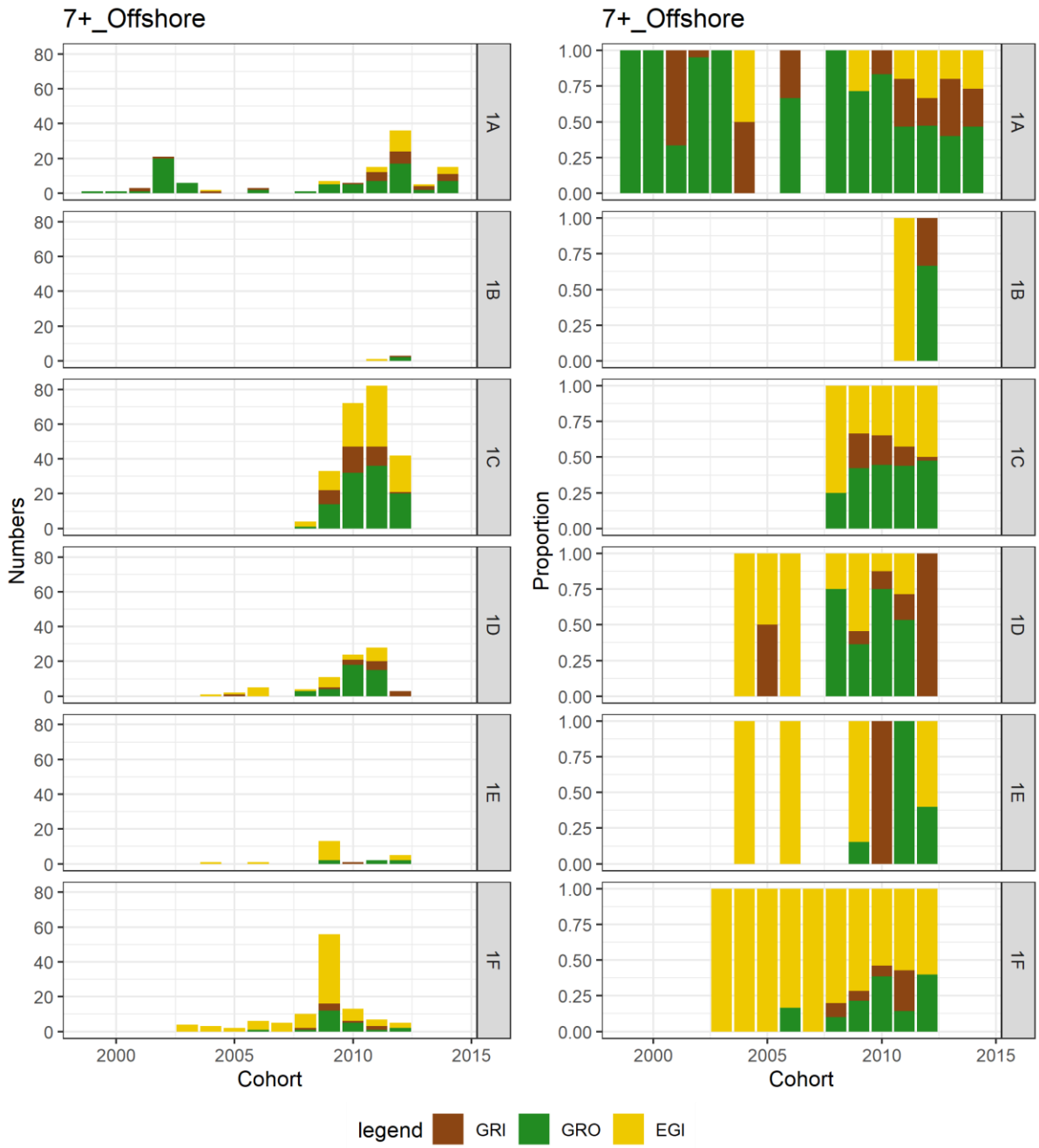

Figure A6. Genetic split in age group 7+ offshore by cohorts.

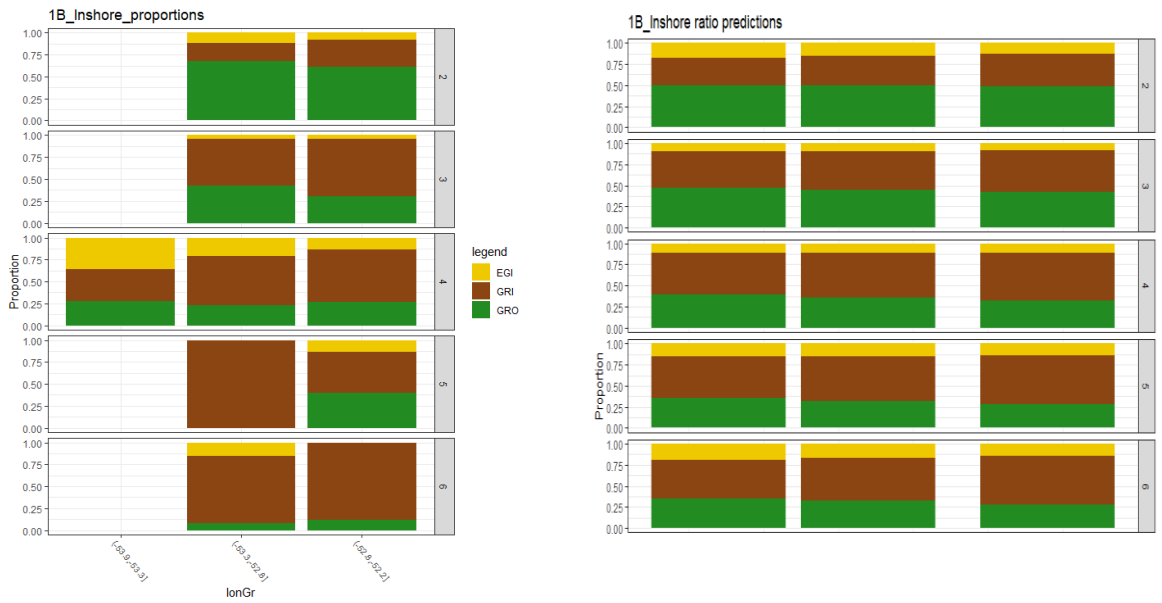

Figure A7: Gradient of stock composition by age based on the genetics data used in the split model (left-hand plot) and predicted from the split model (right-hand plot) for 1B (both for cohort group 'LowMediumYC_After12'). Both x-axes go from outer part of fjord to inner part of fjord.

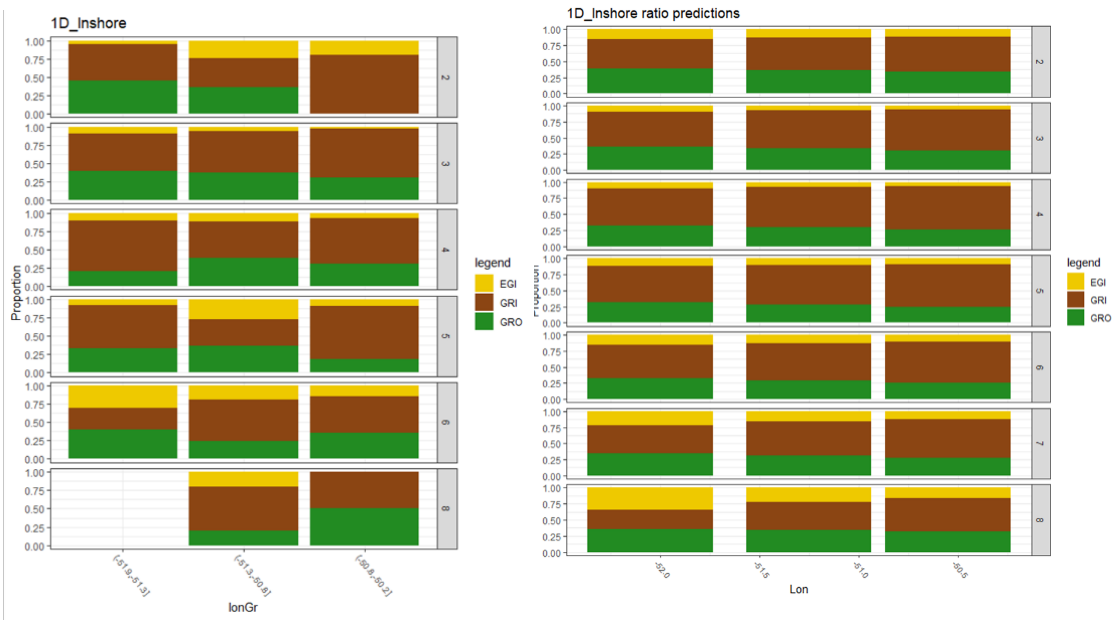

Figure A8: Gradient of stock composition by age based on the genetics data used in the split model (left-hand plot) and predicted from the split model (right-hand plot) for 1D (both for cohort group 'LowMediumYC_After12'). Both x-axes go from outer part of fjord to inner part of fjord.

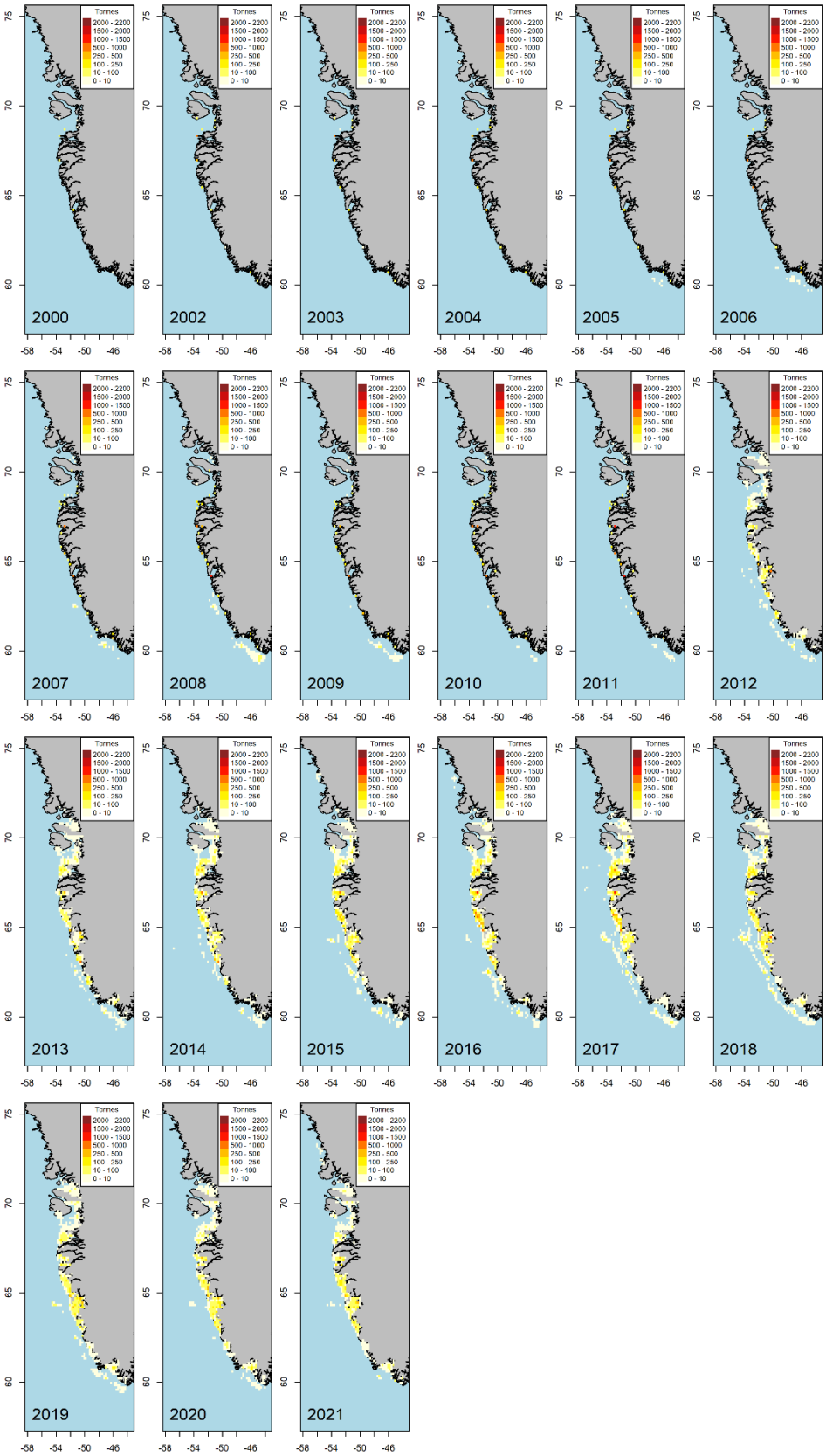

Figure A9: Catch (tons) by field code in West Greenland 2000-2021 for the West Greenland Inshore stock (GRI).

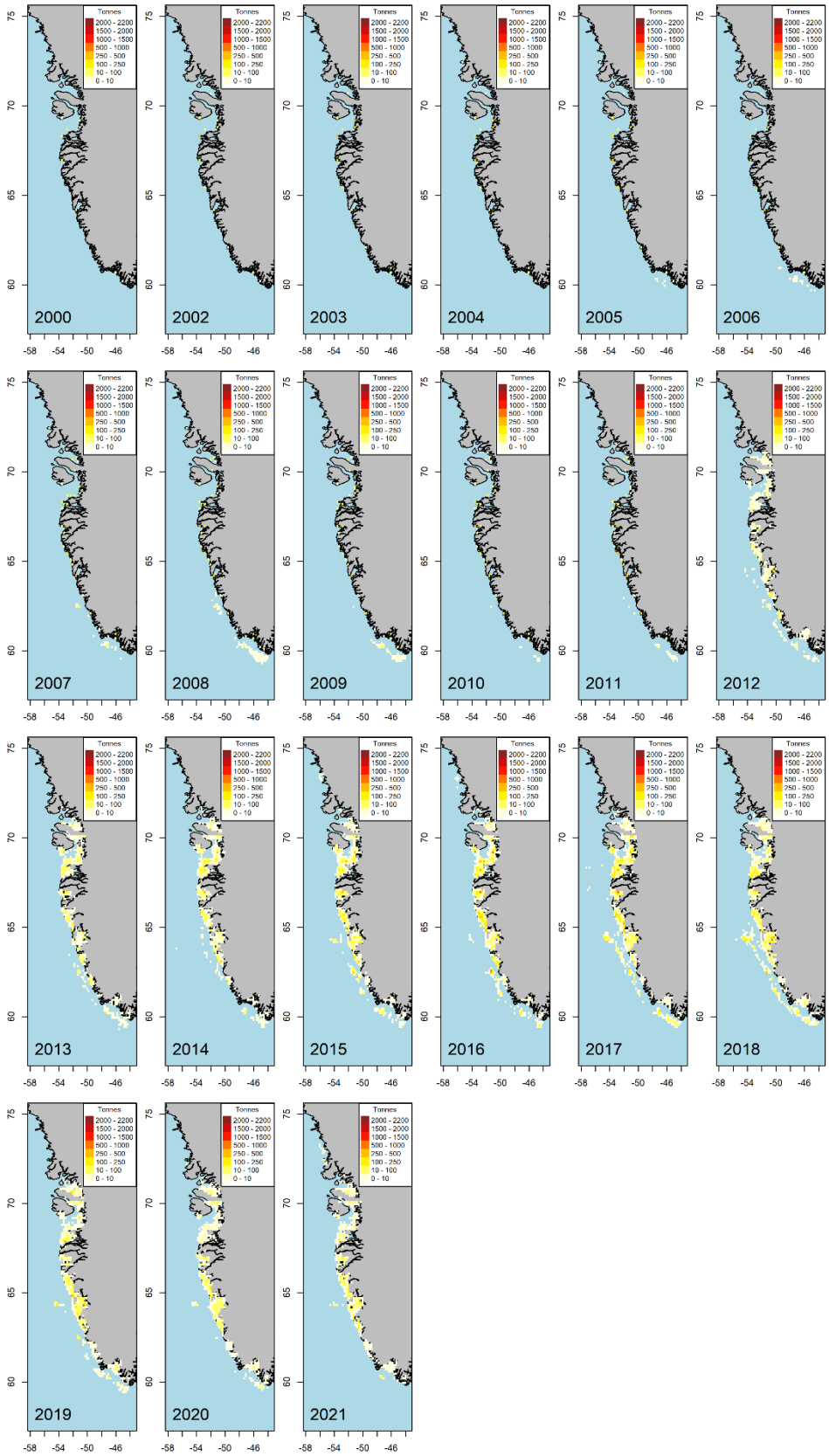

Figure A10: Catch (tons) by field code in West Greenland 2000-2021 for the West Greenland Offshore stock (GRO).

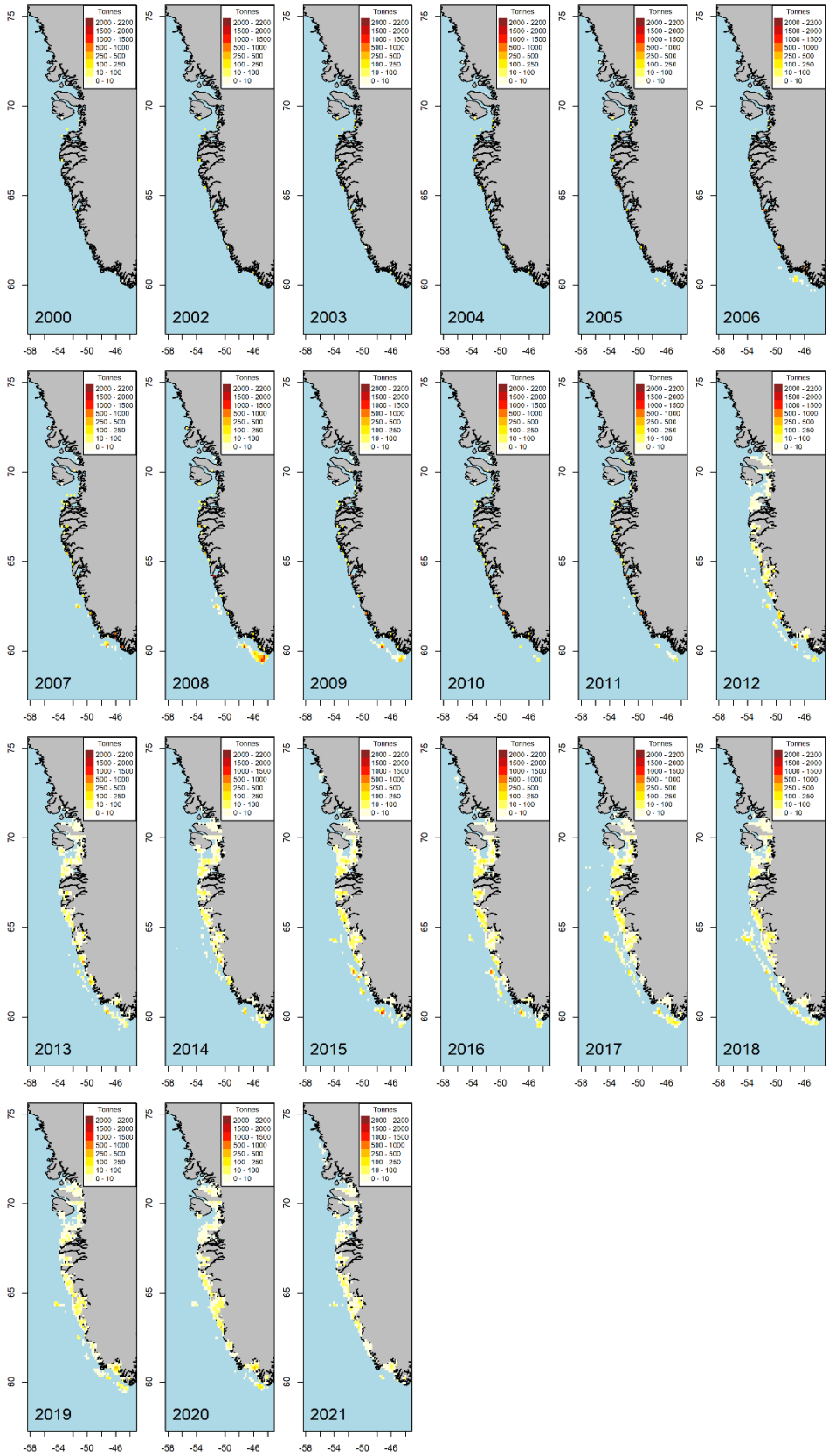

Figure A11: Catch (tons) by field code in West Greenland 2000-2021 for the East Greenland Iceland Offshore stock (EGI).

Table A1: Data used for left-hand plot in figure A7 (a), and figure A8 (b). Both for cohort group 'LowMediumYC_After12'. lonGr gives grouping along the longitudinal gradient (from coast towards inner parts of the fjords). 1B samples are without samples from area 1B-kan.

1B inshore genetic samples				1D inshore genetic samples			
	lonGr				**lonGr**		
Age	(-53.9,-53.3]	(-53.3,-52.8]	(-52.8,-52.2]	**Age**	(-51.9,-51.3]	(-51.3,-50.8]	(-50.8,-50.2]
2	0	25	13	2	18	25	5
3	0	47	23	3	33	16	33
4	11	48	15	4	68	44	29
5	0	6	15	5	27	11	11
6	0	13	17	6	10	21	14
				8	0	5	4

WD 03 Spatial statistical modelling of demersal trawl survey catches of Atlantic cod (*Gadus morhua*) in Greenland using INLA

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Introduction

Demersal trawl survey data are fundamental for the ICES assessment and catch advice for the Atlantic cod (*Gadus morhua*) around Greenland. Three surveys are conducted each year, namely the ShrimpFish Survey (SF), the Greenland Halibut Survey (GHL) and the German Groundfish Survey (GGS). The catch data from the SF and GGS surveys have previously been aggregated into two separate catch rate indices (by year and age) and used in the assessments as proxies for abundance of the entire stock. However, when treated in isolation, these surveys are not covering the entire stock distribution (Christensen *et al*. 2022). Furthermore, the surveys are partly separated by depth. The indices were calculated as stratified means which are sensitive to single large catches that are common in demersal trawl surveys due to the patchy distribution of fish. Furthermore, the applied method involves subjective choices for strata definitions and interpolation when strata are not sampled. As a result, internal consistencies of the surveys have been poor (REF).

In this paper, we present a new approach to derive catch rate indices for the cod assessments, based on the new dataset where survey catches have been split into the three major genetically distinct populations (WKGREENCOD WD 01, WD 02). Firstly, we i) combine all three surveys into one dataset, and ii) split the data by age because of the age-specific difference in geographical distribution due to ontogenetic migration. Secondly, a statistical model is fitted to each stock-age-specific subset of the data.

Catches in fish trawl surveys are typically correlated in space and with covariates such as effort (swept area), gear, year, time of day and depth. Some of these relations can be non-linear. Given this complexity and a moderately high number of observations (7691 trawl stations with 230 868 cod), we used INLA (Integrated Nested Laplace Approximation). INLA is a Bayesian statistical method for fast fitting of complex statistical models such as generalized additive models (GAM) with spatial correlations (Lindgren *et al*., 2015; Rue *et al*., 2009). INLA uses Markov chain Monte Carlo (MCMC) sampling to estimate the posterior distribution of the model parameters (Rue *et al*., 2009).

Based on simulations with the model, we calculate spatial distributions and time series for each age and stock. Model diagnostics and data consistency (cohort tracking signal/noise) are presented.

Methods

Data

The three bottom trawl surveys, SF, GHL and GGS covering the offshore areas of Greenland were used for creating age specific survey indices for the GRO and EGI stocks (Table 1). However, the GHL survey was omitted for all three stocks due to parameter estimation problems likely because of collinearity (this survey trawl for shorter times and in deeper locations). See WD05 for a description of the surveys and WD02 for how catches were split into specific stocks prior modelling.

Below is a short description of the data filter used for modelling the survey indices. The first survey (GGS) started in 1981, but due to the available DNA samples for performing the stock split by station in the surveys (WD1 and WD2), we included data from 2000-2020 (no survey was conducted in 2021). SF changed gear in 2005 and, hence, this was the start year for this survey. Based on poor internal consistency of age 0 and 1 and uncertainty in catches of these (WD02), it was decided to model catches of age group 2 to 10 plus. This was done for the two stocks separately. The offshore bottom trawl survey was not used for the inshore stock (GRI) and therefore only calculated for exploratory purposes (GRI is included in some figures, but will not be further presented herein).

Table 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** (SF)	RV Paamiut Sjurdarberg (2018) Helga Maria(2019,2020)	Cosmos trouser	2.4	15 7-31	35	48	12	2005	2020
Greenland halibut*** (GHL)	RV Paamiut Sjurdarberg (2018) Helga Maria(2019,2020)	Alfredo	2.8	28 8-60	34	137	5.5	2000	2020
German Greenland ground fish* (GGS)	RV Walther Herwig III	Bottom trawl	4.5	28 9-60	22	60	4	2000	2020

References: *(Fock, 2016), **(Retzel, 2017a, 2017b), ***(Jørgensen, 2017)

GRO (West Greenland offshore stock):

As very few old fish were caught in the early period, the model did not converge when including the entire period for these ages. Therefore, for age 5, 6, 7, 8, data were excluded before 2001, 2002, 2004 and 2007, respectively.

Model

Two error-distributions for continuous and zero-inflated response variables were considered, namely the Tweedie distribution and the ZAG (Zero-altered gamma) distribution. The ZAG is a Hurdle model consisting of two components: A Bernuolli model and a Gamma model. The fitted value of the ZAG equals the multiplied fitted values of the two components.

```
AP_i ~ Bernoulli(Pi_i)
E[AP_i] = Pi_i
var[AP_i] = Pi_i * (1 - Pi)
logit(Pi_i) = Intercept + Dis
```

```
Y[i]      ~ Gamma(mu[i], r)
E(Y[i])   = mu[i]
var(Y[i]) = mu[i]^2 / r
mu[i]     = exp(eta[i])
eta[i]    = Covariates
```

Pi_i = exp(Intercept+Covariates)/(1+exp(Intercept+Covariates))

Predictors (covariates) were limited to parameters describing the space, time and trawl effort and catchability [Eq.1].

Effort was expressed as swept area (in nmi^2) of the seabed (= speed x duration x trawl width). Catchability was expected to differ between surveys (factorial *Survey* parameter) and scale with dynamics of the demersal-pelagic behavior of the cod. Diel-vertical migration of fish moving from the bottom and up into the water column at night may reduce catchability of the demersal trawls because the fish are above the trawl opening. Time of the day (*SolarHour* parameter in decimal hours) was therefore included in the model. Solar hour is 12 when the sun is at the highest position above the horizon and thereby radiating the most during that day. Solar hour was calculated from time and position using the astrocalc4r()-function in the *fishmethods*-package (Jacobsen *et al.* 2011).

Depth, *SolarHour* and *SweptArea* were assumed to have non-linear effects and were consequently modelled as smoothers in the GAM.

Spatial parameters were Depth in meters and the positions (latitude and longitude projected to UTM as *Xkm* and *Ykm* in kilometers). Positions were used to generate a grid using the 'constrained refined Delaunay triangulation' method in the INLA package. The grid for Greenland (EGI stock) had 1750 nodes, while the grid for West Greenland (GRI and GRO stocks) had 655 nodes (Figure 1).

$$ResponseVar \sim (Intercept) + fYear + fSurvey + s(Depth, 3) + s(SolarHour, 6)) + SweptArea\_std \quad \text{[Eq.1]}$$

s(,k) indicates a cubic-regression spline smoother with k knots. This was set to be cyclic for the *SolarHour* parameter. The "*f*"-prefix indicates a factorial parameter and the "_std"-postfix indicates that the parameter has been standardized.

Spatial autocorrelation was handled in the model by the Matérn covariate function. The spatial autocorrelation was evaluated by mapping the correlation distance on a map of the study region.

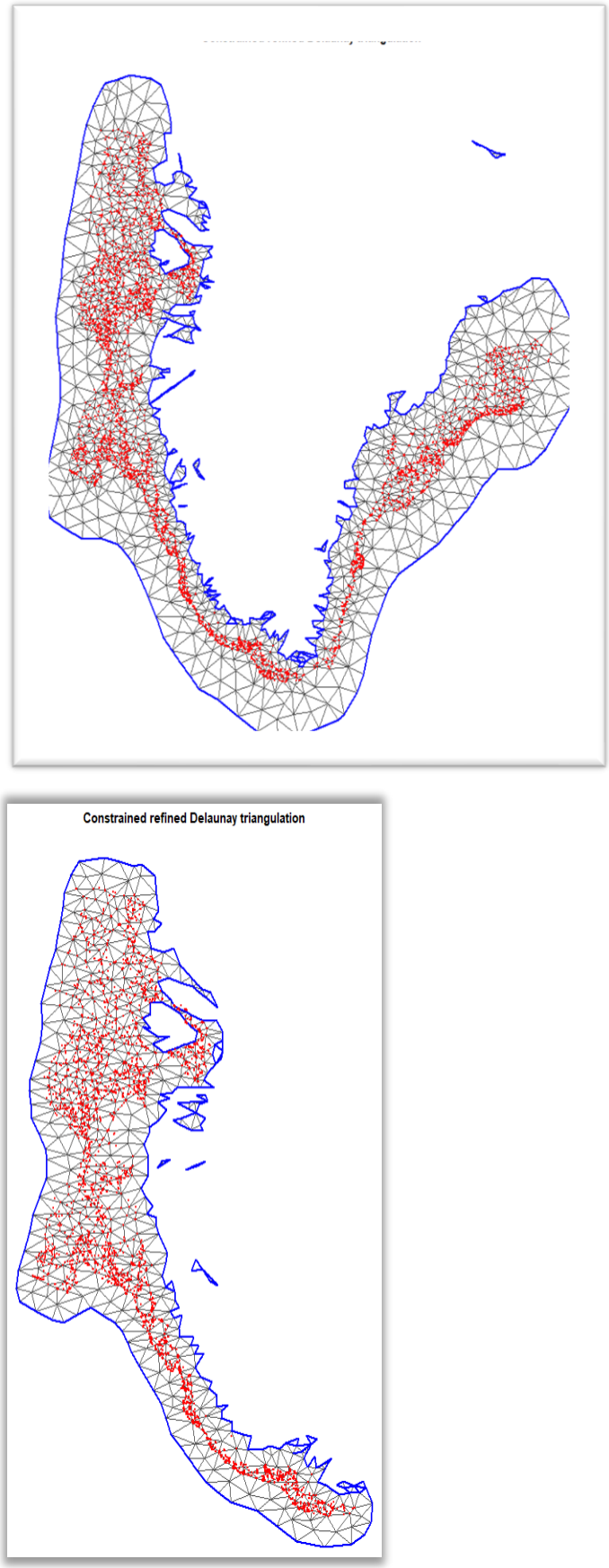

Figure 1. Spatial grids in blue and trawl station positions in red. Greenland (left) and West Greenland (right).

To assess the fit of the models, we can use various diagnostic plots and goodness-of-fit tests (Rue *et al*., 2009). These can help us to determine whether the model is a good fit for the data and whether the assumptions of the model are reasonable (Lindgren *et al*., 2015).

Model structure could be altered by removing parameters that were non-significant in most/all models. However, only one model structure would be selected as the final model for all stock-age combinations, and for both the Bernoulli- and Gamma-parts.

For each model fit (i.e. stock/age combination), 1000 specific model realizations were generated (simulated) from the estimates of parameters and parameter uncertainties. Each model was used to predict for a range of covariate combitions.

Predictions were calculated for a mean effort (*SweptArea* = 0 because it is standardized, effectively removing it from the calculation), at the lightest time of the day (12:00 *SolarHour*) for a standard *Survey* (SF), at a grid of equal distant (10 km) distributed positions within the sampled region (a polygon shrinked to fit around all observations using the ahull()-method in the 'alphahull' package (Edelsbrunner *et al.*, 1983; Rodriguez-Casal 2007). On the shape of a set of points in the plane. IEEE Transactions on Information Theory, 29(4), pp.551-559.). Depths were set to the depth measured at the nearest trawl station. This was done for each year in the time series 2000-2020.

Time series of overall mean density by year were calculated for each stock-age combination. First the mean density for a given position and year were calculated as the mean of all simulations for that position. Second, the mean of all positions was calculated by year, giving one density value per year, i.e. a time series of density for an area that is kept constant. Combining this output from each age-specific model for a stock gives the abundance index time series by age and year provided as a candidate for the stock assessment.

Spatial distribution maps were based on similar aggregated data, but where the second aggregation step is to calculate the mean by position across all years, instead of the opposite (as described above).

Results

In the final dataset used for modelling, years were fairly equally covered from 2005 to 2020 (Figure 2a). Before this SF was missing. Sampling depths ranged from 45 to 996 m with the most (88%) samples being taken at 80-650 m (Figure 2b). Trawling was done at all times of the diel cycle, but with the most during day (89%) between 04:00 and 17:00 solar hour (Figure 2c).

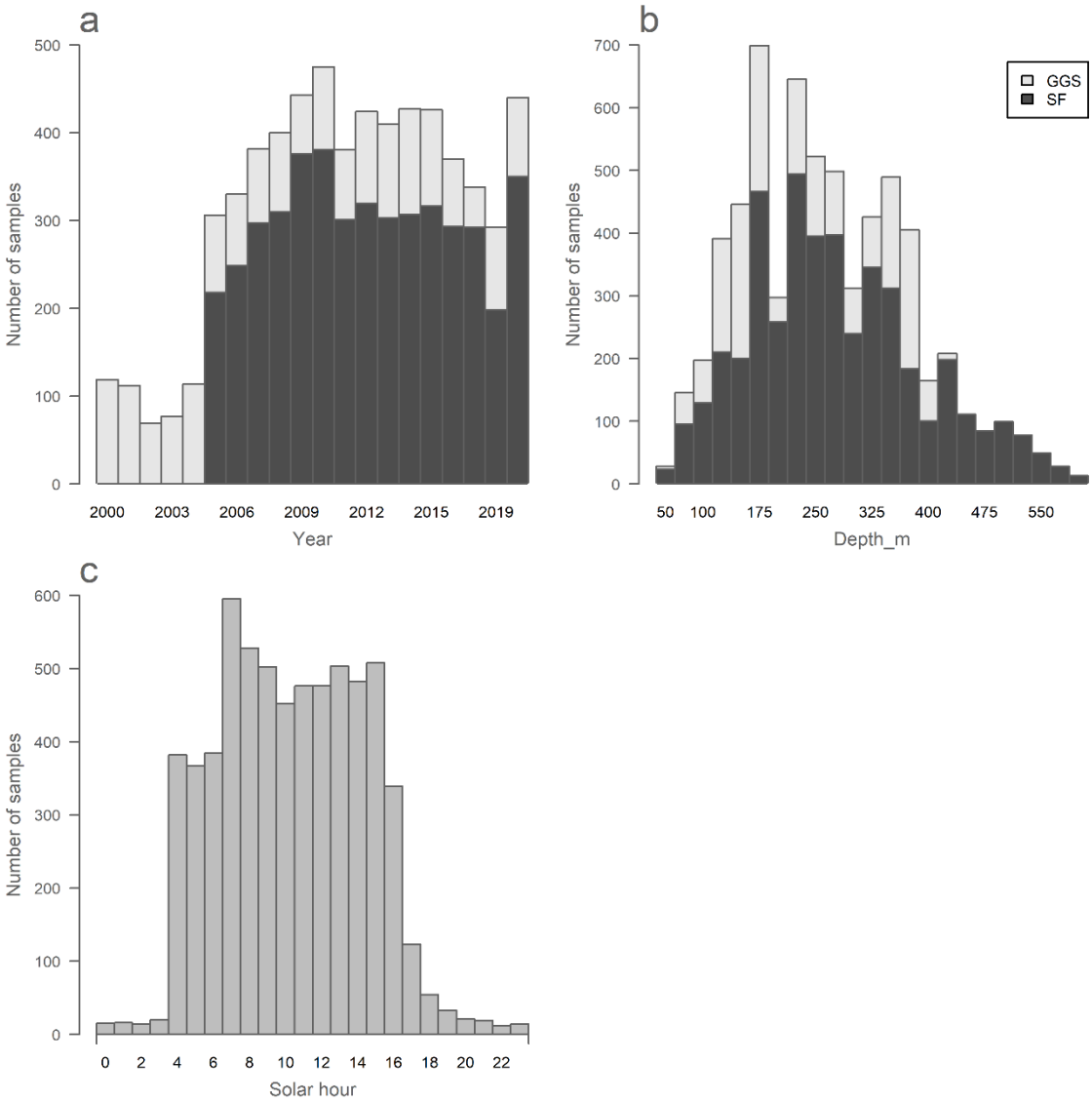

Figure. 2. Number of trawl stations by year, survey, depth and solar hour.

For ages above 7 (GRI and GRO) and 8 (EGI) the low number of observations made model fitting difficult/impossible, so the maximum ages were set accordingly. 19 model were therefore fitted to the data. This and the simulations took around 2 hours for all 19 models. A RData file was saved for each of the model runs and saved in the data repository.

Model fits using the Tweedie distribution were less optimal than their ZAG counterparts in all 19 models judged by DIC (appendix 1). This is often the case when the presence/absence-signal is more important than the signal in the presents (Zuur, pers.comm, 2021). Further work was therefore solely done on ZAG models.

Predicted values are plotted vs. Pearsons residuals and observed values in appendix 2. The model ability to simulate zero stations (no catch of the given age and stock) were moderate (appendix 3). The observed percentage of zero-stations ranges between approximately 50 and 90 %. In only 6 of the 19 models, this was with in the 95% credibility range (appendix 3), but the remaining 13 model were close.

The *depth* parameter was generally significant (appendix 4). The Gamma model sometimes moderates the effect from the Bernoulli (e.g. GRO age 6), but this was always with a lower effect (parameter estimate). Maximum catch rates were between 200 and 300 meters. In some cases, also high at shallower depths, but always decreasing sharply towards the largest depts.

The *Solar hour* parameter was mostly non-significant (appendix 4), but in several cases it predicts significantly lower catches at night compared to the day. This is in accordance with the diel vertical migration, where cod are migrating away from the bottom at night, which would reduce catch rates. The present dataset includes relatively few samples at night, which possibly is parts of the reason for the non-significance. The parameter was retained in the final model because future sampling plans include more sampling at night and because it appeared significant in some models.

Spatial correlations distances were sufficiently long and strong to affect neighboring sampling locations and beyond, but not on a large regional scale (appendix 5). The spatial random fields were (appendix 6) and the prediction-based mapping of cod distribution were mapped by age and stock (appendix 7 and 8). Visual inspection of distribution maps overlayed with observations (appendix 8) indicated that the spatial fits were generally good.

Time series by age and stock (appendix 9) were compiled by stock and the signal-to-noise ratio in cohort-strength tracking was illustrated (appendix 10 and 11). Comparison with time series based on stratified means (old method, appendix 12) suggests a substantially improved signal in the data. The internal consistency plots generally demonstrate relatively strong correlations between relative cohort abundance from one year to the next, however, this type of plot may mask trends in mortality over time which is problematic for stocks assessment models. Log ratios were therefore plotted (appendix 13). No indications of substantial temporal bias were found when inspecting these plots.

Time did not allow for a full investigation of method stability (retro plots) as suggested by the reviewers at the data meeting. However, two peels were briefly explored and were not found to lead to revised perceptions of the stock sizes. All models converged except age 7 (GRO only).

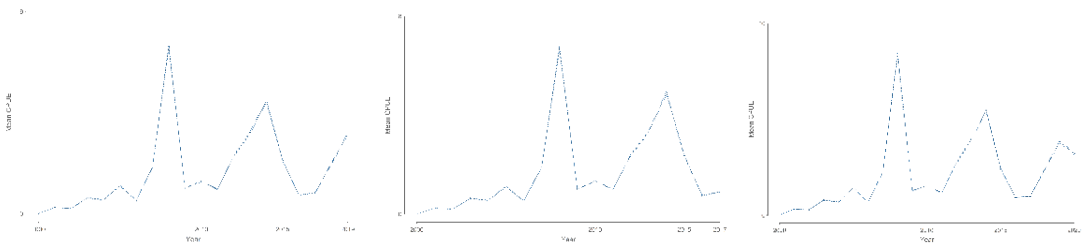

Figure 3. Retrospective performance exemplified by age 5 EGI. Full time series (left), excluding the last year of data (mid), excluding the two last years of data (right).

Discussion and conclusion

The time series of abundance index is recommended to be used in assessment of GRO and EGI.

Recommendations for future work:

- If more cod appears in deeper waters (> 600 m), then it should be reconsidered to utilize the information from the GHL for the older cod. Perhaps by expanding the SF/GGS surveys spatially and increasing the depth coverage. Such overlap with GHL may lead to an estimation of the survey effect and thereby allow for inclusion of GHL data in the model.

Acknowledgements

Thanks to Alain Zuur and Elena Ieno (Highland Statistics) for an inspiring course about INLA.

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WD 05 - Compilation of Commercial and Survey data for the GAM, INLA and SAM models

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Commercial catch

Coastal/Inshore fishery

The coastal fisheries started in 1911. 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 (Figure 1, table A1).

The most important gear is pound-net (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 where the dominating gear is jigs followed by gillnet. The other half of the catches are taken by larger vessels (cutters) where the dominating gear is pound nets.

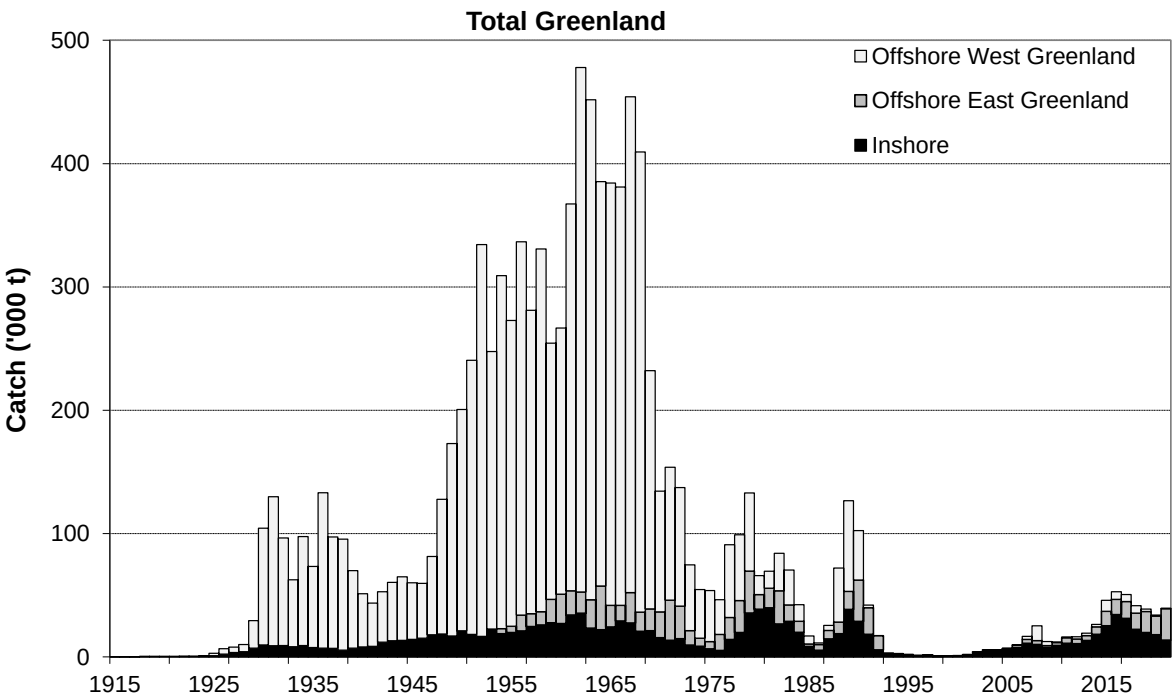

Figure 1: Total catches divided into Offshore West Greenland (NAFO divisions 1A-1F), Offshore East Greenland (ICES division 14b) and inshore (NAFO divisions 1A-1F) areas.

Management of coastal fishery

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 it was allowed to fish offshore in West Greenland on the inshore quota.

Trawling is not allowed within 3 nm off the baseline (Fig. 2), and vessels above 75BRT/120BT are not allowed to fish within the 3 nm-line off the baseline.

Figure 2: 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.

Offshore fishery

The offshore fishery in the last century started in 1924 when Norwegian fishers discovered dense concentrations of cod on Fylla Bank in West Greenland (NAFO Division 1D, Fig. 1 and 2, table A1). The West Greenland offshore 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 (Fig. 1, table A2) 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 offshore fishery completely collapsed in 1991 (Fig. 1), and cod was only caught as bycatch in the redfish fishery in East Greenland until the mid-2000s. The main fishery in the recent period is in East Greenland, where Trawlers and Longliners constitute the fishing fleet.

Management of offshore fishery

Offshore vessels in Greenland EEZ are defined as vessels above 75BRT/120BT restricted to areas more than 3nm off the baseline. The offshore vessels require a license that stipulates the vessel quota.

No directed offshore fishery was allowed for the period 1993–2005. Since 2005 several area closures have been implemented in East and West Greenland. Especially spawning grounds have been closed through the spawning season March-May.

Several management plans have been implemented and modified. The current management plan for the East Greenland stock, implemented in 2021, operates with two management areas in South and East Greenland (corresponding to NAFO division 1F and ICES 14b, Fig. 3). 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.

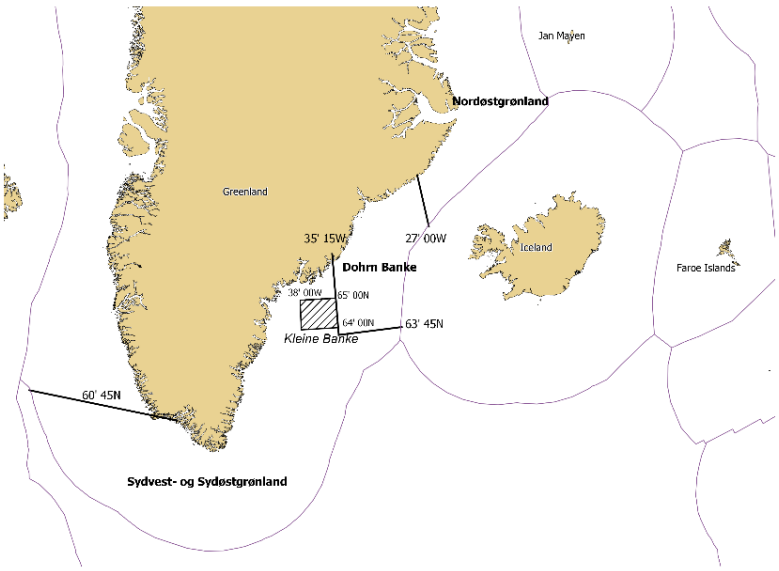

Figure 3: Management area of the South and East Greenland. Square is closed for fishery from 1st of March to 31st of May.

Catch in tons

Coastal/Inshore

The information on landings in weight is 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 (4 and 8 per Lat Lon, respectively) of each catch that is landed at a factory. The preferred gear used by small dinghies is jigs, and CPUE from this type of fishing gear is also questionable.

Offshore fishery

The information from the offshore fishery on landings in weight is compiled and processed by the Greenland Fisheries License Control (GFLK). It is available on haul-by-haul provided by log-books.

Samples from catch

Coastal/Inshore

A sampling of length frequencies and information on age from the coastal fleet, weights and maturities are collected and compiled by the Greenland Institute of Natural Resources. A well-balanced sampling of the Greenland inshore fleet 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 1D (Fig. 2), which is easily covered, sampling relies on dedicated sampling trips supplemented with ad hoc samplings when ports are called through other institute activities.

An overview of sampling from the fishery in the period used in the assessment (from 2000) is seen in table 3.

Table 3: Sampling of the coastal/Inshore fishery.

Year	Catch (tons)	Length Samples	N fish measured	Otolith samples from surveys	Otolith samples from fishery
2000	647	1	375	145	-
2001	1684	No samples			
2002	3891	21	10157	220	209
2003	3957	22	4402	303	322
2004	4653	4	1585	633	222
2005	4979	9	1820	480	197
2006	8267	34	9496	368	-
2007	11055	69	19297	199	767
2008	10003	41	8366	297	1226
2009	7671	47	11541	425	1429
2010	9268	50	11590	378	2332
2011	11007	63	9572	1202	914
2012	10617	79	13503	710	317
2013	13201	68	11406	729	470
2014	18330	49	6446	730	407
2015	25272	115	21854	740	218
2016	34203	110	21816	893	179
2017	31220	110	15402	1407	-
2018	22289	44	7168	1274	246
2019	19750	98	17711	1212	297
2020	17926	50	10192	891	84
2021	13580	57	10082	1112	298

Offshore fishery

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.

An overview of sampling from the fishery in the period used in the assessment (from 2000) is seen in table 4 and 5.

Table 4: Sampling of the Offshore fishery in West Greenland.

Year	Catch (tons)	Length Samples	N fish measured	Otolith samples from surveys	Otolith samples from fishery
2004	9	No samples			
2005	72	8	1800	445	47
2006	414	No samples		988	35
2007	2477	22	3081	793	83
2008	11927	8	1277	1117	106
2009	3360	40	7329	641	247
2010	290	25	4523	922	575
2011	550	46	5985	831	1199
2012	1814	41	5601	750	671
2013	1897	70	9045	980	437
2014	1949	64	4727	898	748
2015	8814	132	10312	1082	531
2016	6075	67	3652	785	83
2017	5585	234	32176	1071	1712
2018	6001	157	21379	878	971
2019	1813	65	9167	1317	642
2020	777	6	900	908	-
2021	288	No samples		-	-

Table 5: 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')

Catch and weight at age

Catch and weight at age are compiled on NAFO areas (Fig. 2) 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.

East Greenland catch and weight at age 2000-2004

In the years 2000, 2002-2004, biological samples covered the fishery in West Greenland, and the proportion of the EGI 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 (see table 2 in WD02), is unknown as the fishery was unsampled (table 5). 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. This approach has previously been done by Werner (2020). Following this method, length frequencies used for calculating age distributions were constructed by estimating retention probabilities from a trawl with a codend of 135 mm mesh size (a standard codend for the fishery). After the retention corrections, the calculated length distribution increased the survey catches' length estimates (Fig. 4).

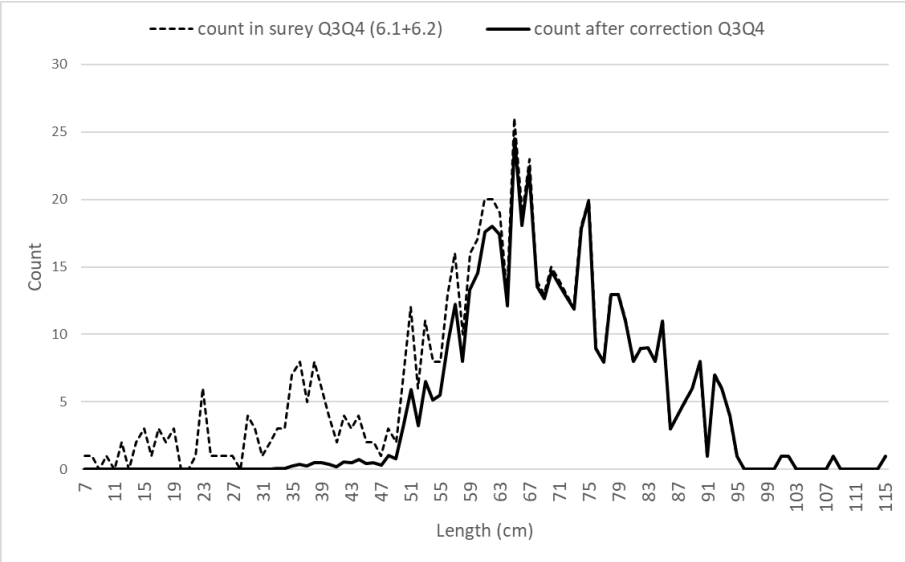

Figure 4. Length distribution from the German survey 2004 before and after correction with retention probability.

From 2000-2004, cod in East Greenland were primarily caught as bycatch in the redfish and Greenland halibut fishery, which usually takes place at greater depths than the survey. Therefore, to judge if the approach was reasonable, we compared known length distribution with this method for samples in 2005 (Fig. 5). Length samples from the fishery are from June, whereas the survey samples are from October. In the comparison the method does not include the small cod length 40-50 cm which were in the commercial sample. However, as the catch of cod in the fishery in the period 2000-2004 are probably with different gear the comparison is difficult. As the major part of the catches on the EGI stock in the period 2000-2004 is from the inshore fishery in West Greenland we concluded that we use the method.

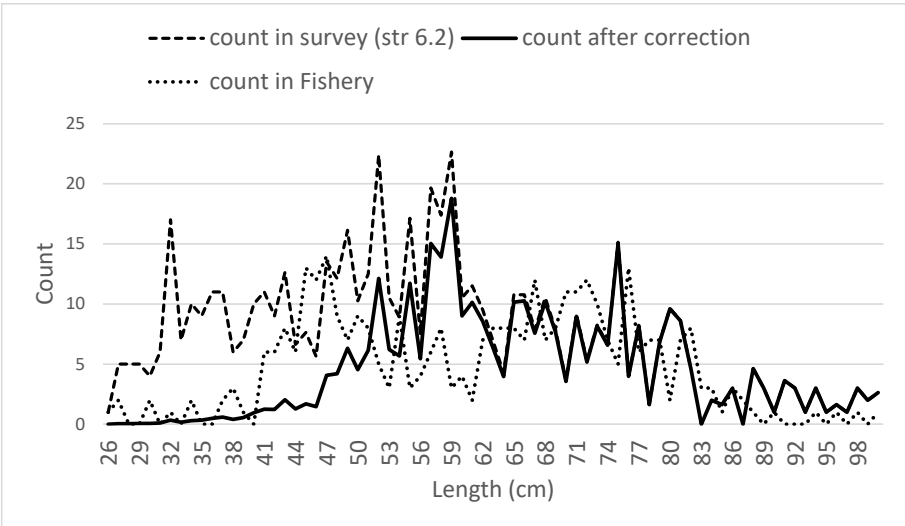

Figure 5. Length distribution from the German survey 2005 before and after correction with retention probability and known from samples from the fishery.

Catch and weight at age by Field code

The genetic composition of the three cod stocks in West Greenland (see WD02) 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. Field codes area squares of 7.5 minutes (0.125 degrees) latitude (North) and 15 minutes (0.25 degrees) longitude (West) (Fig. 6).

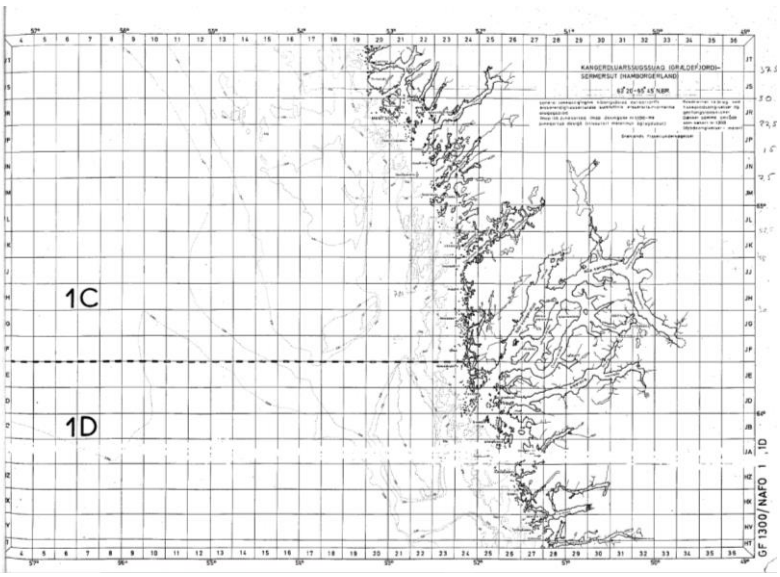

Figure 6: Example of Field codes in the Nuuk area (NAFO division 1C and 1D).

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 (Fig. 7).

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 (Fig. 7).

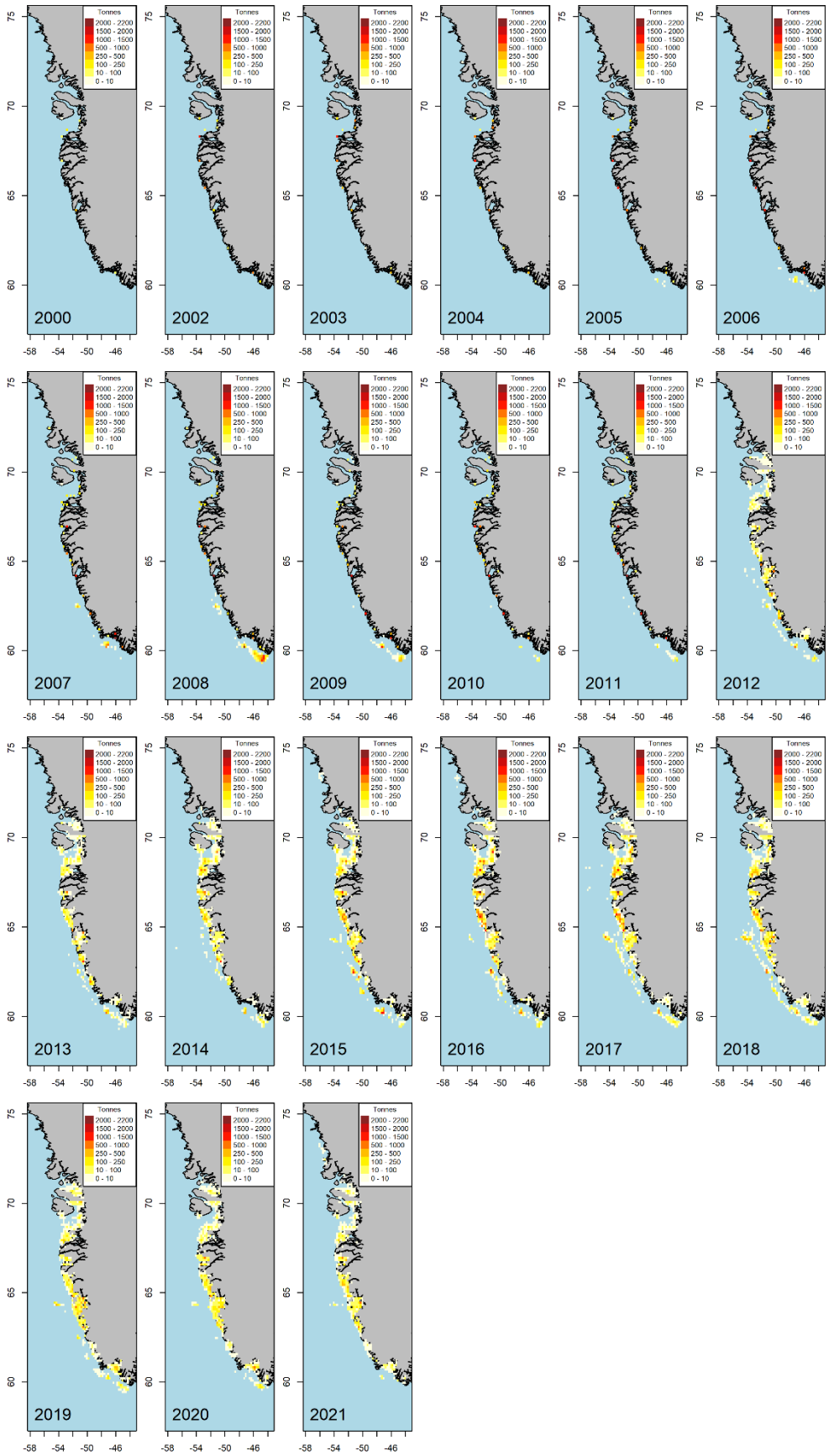

Figure 7: Catch (tons) by field code in West Greenland 2000-2021.

To convert catch at age (CAA) and weight at age (WAA) by NAFO area to field code levels, the following procedure was used, with 2015 as an example:

year	division	Number_Age3	Number_Age4	Number_Age5	Number_Age6	Number_Age7	Number_Age8	Number_Age9	Number_Age10	Total tons
2015	1C	1	12	68	112	15	5	2	1	341
2015	1D	2	14	113	176	56	38	11	3	954
2015	1E	3	41	321	773	169	115	32	13	3564
2015	1F	2	53	338	991	305	136	17	10	3984
		weight_Age3	weight_Age4	weight_Age5	weight_Age6	weight_Age7	weight_Age8	weight_Age9	weight_Age10	
2015	1C	0.356	0.658	1.191	1.580	2.579	4.733	6.087	7.392	
2015	1D	0.470	0.728	1.262	1.895	3.111	5.166	6.760	8.100	
2015	1E	0.508	0.758	1.361	2.061	3.264	5.016	7.362	10.899	
2015	1F	0.503	0.837	1.384	1.847	2.942	4.036	6.839	7.716	

Example: Calculate CAA and WAA of a field code catch of 1050 tons within NAFO 1F.

N_by_FK_age3 = Catch_FC * (N_Age3_Nafo/Total_Catch_Nafo) => 1050 * (2/3984) = 0.527
W_age3 = 0.503

Where K_age3 is the number of age 3 in that particular field code. The number of age 3 in this field code is hereafter split into three stocks components according to the proportion of every stock given by the split model (GAM, see WD02).

WAA of the catch in each field code within NAFO 1F are regarded as the same within each age-group and stock.

WAA for the entire catch by year (used for SAM) was calculated such that the weight at age for every field code was weighted with the amount of catch within the field code in relation to the total catch. This was done as follow, with age 3 again as an example:

For every field code, calculate Weight_Age3_FK_Weighted

Weight_Age3_FK_Weighted = Weight_Age3_FK*(N_Age3_FC/Total_N_Age3_Year) => 0.503*(0.1/8)

then

Weight_Age3_Total = sum(Weight_Age3_FK_Weighted, for all field codes).

Survey

Offshore

Three bottom trawl surveys are conducted annually in the offshore waters of Greenland, the ShrimpFish Survey (SF), the Greenland Halibut Survey (GHL), and the German Groundfish Survey (GGS). Below is a short description of the three surveys. All surveys started before 2000, but due to the available DNA samples for performing the stock split by station in the surveys (WD1 and WD2), we only include data from 2000 in the rest of the stock assessment calculations. Fig. 8 shows the spatial distribution of the surveys, while Fig. 9 shows the number of stations by

year, depths and time of day (in solar time) for the SF and GGS survey used in the final SAM trials.

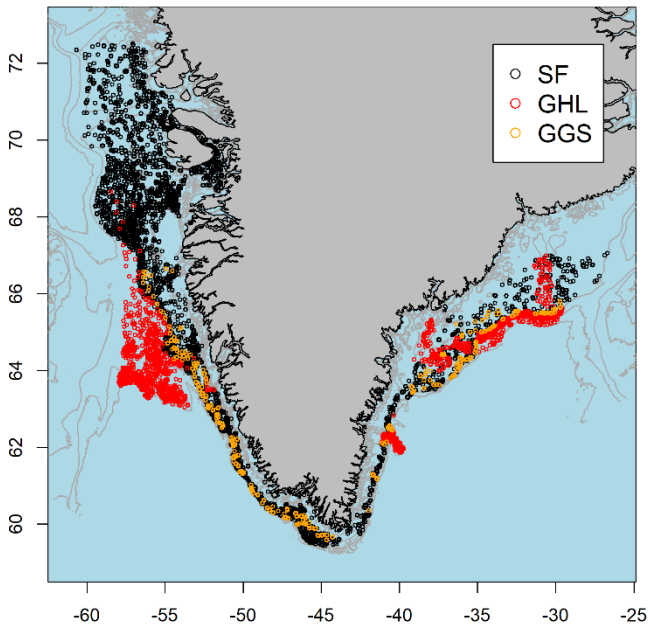

Fig 8. Map showing the geographical locations of the three surveys from 2000-2020. Grey lines are depth contours ranging from 100-1500m.

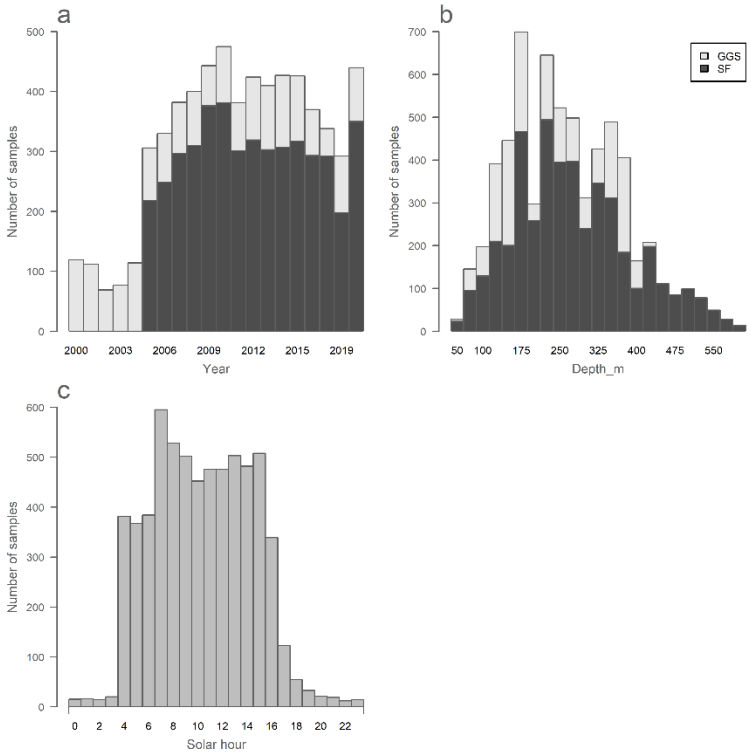

Figure. 9. Number of trawl stations by year, depth, and solar hour for the SF and GGS surveys.

<u>ShrimpFish (SF) survey</u>:

The SF survey is designed to target shrimp and ground fish such as cod and is conducted both in East and West Greenland. Stations covers depths from 50-600m and are annually allocated by a random stratified buffer method (Kingsley *et al*. 2004). The trawl gear was changed in 2005 (Table 6), and therefore we only included data from 2005 onwards. Number of stations varies between years but are on average 280 (Fig. 9, table 7). The survey season is typically June-September. Vast majority of stations have been conducted between 8-20 UTC. 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.

In most years the research vessel (RV) Paamiut have been used, but due to vessel failure, chartered vessels were used in 2018-2020. In 2018-2019, the survey coverage was limited to West Greenland because of vessel break-down and financial issues. No survey was conducted in 2021. In 2022, the new RV Tarajoq has taken over and is expected to conduct the surveys in the coming years. The data from 2022 will not be available for WKGREENCOD, but they will be included at NWWG 2023. The same gear and trawling practice were applied on the chartered vessels and currently applied on the new RV vessel (table 6).

Table 6: 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* (SF)	RV Paamiut Sjurdarberg (2018) Helga Maria(2019,2020)	Cosmos trouser	2.4	15 7-31	35	48	12	2005	2020
Greenland halibut** (GHL)	RV Paamiut Sjurdarberg (2018) Helga Maria(2019,2020)	Alfredo	2.8	28 8-60	34	137	5.5	2000	2020
German Greenland ground fish*** (GGS)	RV Walther Herwig III	Bottom trawl	4.5	28 9-60	22	60	4	2000	2020

References: *(Burmeister *et al*. 2022), **(Jørgensen, 2017), ***(Fock, 2016)

Table 6: Number of Stations by year and area in the Greenland SF survey used in the assessment.

		West Greenland						East Greenland						
Year	C0	1A	1B	1C	1D	1E	1F	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	11	7	7	12	6	8	310
2009	8	74	75	28	22	24	48	13	6	20	25	11	22	376
2010	10	95	76	30	23	25	40	10	6	9	24	14	19	381
2011	0	73	64	24	18	12	25	14	7	12	21	11	20	301
2012	0	73	64	21	18	18	26	15	7	13	28	16	20	319
2013	4	73	52	20	13	21	28	14	5	14	22	12	25	303
2014	0	78	57	19	17	23	32	16	8	9	12	14	22	307
2015	0	70	49	24	22	21	36	14	8	12	24	11	26	317
2016	0	59	38	26	14	19	36	16	7	13	26	10	29	293
2017	3	99	52	25	18	25	35	11	6	6	7	4	2	293
2018	0	78	42	26	23	20	36							189
2019	0	86	36	20	18	14	25							174
2020	0	84	51	29	21	23	43	16	7	13	27	13	23	350
2021														

Greenland Halibut Survey (GHL):

The GHL survey is more restricted along the shelf edge compared to SF and covers both East and West Greenland. The same vessels have been used as the SF, but with a different trawl (table 4). The trawling speed is on average 2.8 knots, which is slightly faster than SF. Haul duration is typically 30 min but have occasionally been shorter or longer.

Depths covers 400-1500 m. Initial screening of catches showed that no cod were caught below 1000 m, except for a single individual, which we suspect to be a misreporting as it had the exact same size as an individual from the previous station on ~400 m. Therefore, we only include stations less than 1000 m.

The method for station allocations have been different from East and West. In West, a random stratified buffer method has been used, while in East, a combination of random stratified buffer method and fixed stations. Number of stations are provided in table 7. From 2022 the method for East is changed to be solely fixed stations (internal GINR report – but can be made available). This is primarily due to the difficulties in finding suitable trawlable bottom.

The GHL survey is more restricted along the shelf edge compared to SF and covers both East and West Greenland. However, in West Greenland, the spatial coverage is restricted to a small area at ~ 63-66 N latitudes and only have very few catches of cod. Therefore, we did not include data from the GHL survey in West Greenland.

Season of survey typically July-September and trawling happens at all hours during the day.

Trawling gear changed in 2022 to a Bacalao trawl. Preliminary data exploration suggests a difference and catch species composition and may therefore also have a different catchability of cod than the Alfredo. It is therefore suggested to treat this as a new 'survey'.

Table 7: Number of stations by year and area in the Greenland GHL survey. No survey in 2018, 2020 and 2021.

	West Greenland		East Greenland					
Year	1C	1D	Q1	Q2	Q3	Q4	Q5	Total
2000	9	22	15	14	15		11	
2001	17	29						
2002	10	25	12	13	4		11	
2003	12	23	13	14	8		5	75
2004	18	33	2	20	13		17	103
2005	22	39		21	11		15	108
2006	19	42		27	4		12	104
2007	16	33	2	20	8		16	96
2008	21	49	4	20	10		13	117
2009	24	44	4	23	18		19	132
2010	20	46	2	22	14		12	116
2011	22	45	8	20	18		20	133
2012	18	35	7	29	15		16	120
2013		27	10	22	24		24	107
2014	20	38	7	26	24	1	20	136
2015	23	44	11	27	23		23	151
2016	26	44	12	29	31		28	170
2017	15	38					10	63
2018								
2019	27	43						70

German Groundfish Survey (GGS):

The GGS 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 on the shelf. The survey has the objective to carry out 80-110 stations per year, dependent on weather conditions and/or technical issues with the vessel. Because of such technical problems there was no survey in 2018, 2021 and 2022 and because of bad weather conditions and technical issues survey coverage was poor in 2017. The coverage of the SF and the GGS surveys are different in especially West Greenland. The German GGS survey has in recent years been covering less in the West Greenland area and never as far North as NAFO regions 1A and 1B (table 6 and 8). For abundance calculation purposes the survey area is divided into 14 strata and it is each years's target to cover at least 5 stations in each stratum. Not each year the same stations are covered due to logistic reasons and weather conditions but all covered stations are within a set of trawl tracks, which are repeatedly used and where net damage is known to be minimal.

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. Trawling speed is standardized to 4.5 knots, i.e. much faster than SF and GHL. Haul duration is 30 min, with occasional deviations. Trawling has mostly been done between sunrise and sunset.

Table 8: 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	Q5Q6	Q3Q4	Q1Q2	Total
2000	4	15	21	19	14	8	25	13	119
2001			22	20	17	10	26	17	112
2002			9	11	12	10	15	12	69
2003			13	14	12	9	13	16	77
2004	2	14	20	15	14	12	21	16	114
2005			16	14	11	11	20	16	88
2006	5	6	12	14	13	2	15	14	81
2007		10	12	12	13	7	16	15	85
2008		5	14	17	14	10	16	14	90
2009		2	10	12	10	5	16	12	67
2010		10	15	16	16	3	19	15	94
2011			10	10	13	10	20	17	80
2012		10	18	16	16	10	21	14	105
2013		10	16	17	15	11	20	18	107
2014		10	18	17	16	10	28	21	120
2015	4	10	11	10	14	11	27	22	109
2016				5	18	11	26	17	77
2017					7	4	19	16	46
2018									
2019				16	23	8	28	19	94
2020	6	9	16	6	6	9	22	16	90
2021									

Inshore

A Gillnet survey is covering the inshore area in three NAFO divisions 1B, 1C and 1D (table 9, Fig. 2) (ICES, 2018). 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. Therefore, gillnet catches of older fish ages 2–8 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).

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.

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

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

NAFO Division 1D, survey index for the period 1987–2016 except in 2002 and 2007 where no survey was conducted.

Table 9: Number of Stations by year and NAFO area in the inshore Gillnet survey.

Year	1B	1C	1D	1F	Total 1B+1D
2000	-	-	81	61	
2001	-	-	-	-	
2002	63	-	63	-	126
2003	99	-	81	-	180
2004	80	-	90	-	170
2005	84	-	73	-	157
2006	43	-	51	-	94
2007	55	-	-	39	
2008	-	-	58	60	
2009	-	-	58	18	
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	59	46	-	103
2018	58	61	52	-	110
2019	48	47	54	-	102
2020	53	50	50	-	103
2021	54	51	53	-	107

Sampling

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 area in West Greenland and 3 areas in East Greenland corresponding to area Q1Q2, Q3Q4 and Q5Q6 (Fig. 2).

On the German survey all individuals per station are length measured and total catch weight of cod is recorded. Otoliths are collected and age-read for catches up to a total size of ~ 30 cod individuals. Subsampling takes place above this total catch size. Then it is the goal to collect otoliths for subsequent age-reading for at least one fish per each 1-cm-length class present in the catch.

Catch and weight at age by station

For the offshore bottom trawl surveys (SF, GHL and GGS) a length-age key was made by NAFO region in West Greenland and by 3 areas in East Greenland (Q1Q2, Q3Q4, Q5Q6). 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.

Same procedure is used for the inshore surveys.

Large variation in weights coincides with low sampling which is usually the case for older fish that are in lower numbers in West Greenland. There are regional differences in weight at age between the three areas: West Greenland inshore, West Greenland offshore and East Greenland (Fig. 10). The cod in East Greenland are especially heavier than in West Greenland. This is more likely caused by regional differences rather than genetically induced (see WD01).

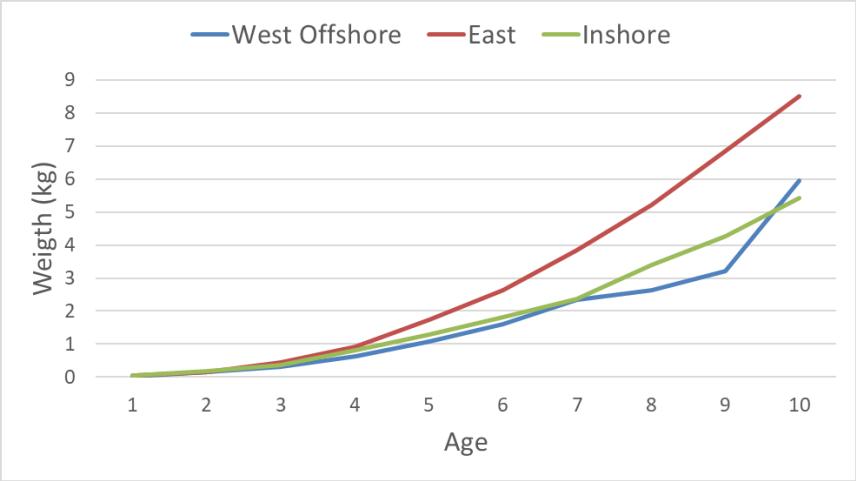

Figure 10: Mean weight at age for cod caught in Greenland SF (offshore) and the CODI (inshore) surveys in three areas (West Greenland Offshore, East Greenland and West Greenland inshore) in the period 2005-2021.

Weight and length at age differs between the Greenland SF survey and the German GGS survey with weight and length at age from the German survey being significantly larger. Furthermore, the weight at age from the German GGS survey variates more between years than the Greenland SF survey (Fig. 11). 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 GGS survey, especially in West Greenland, the weights from the Greenland SF survey are used in the stock mean weight for the assessment.

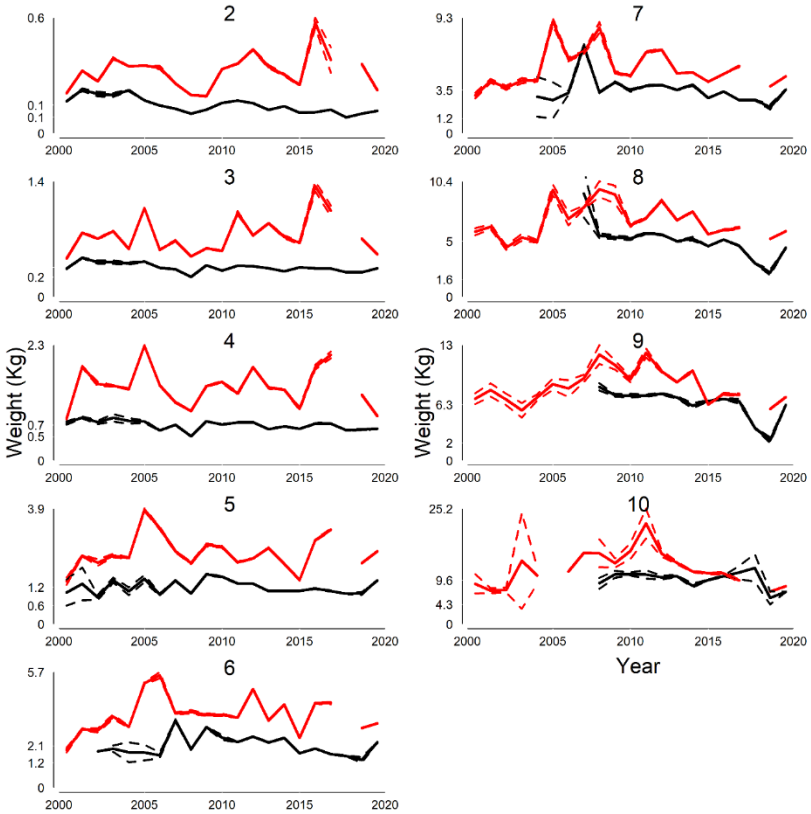

Figure 11: Weight at age (2-10) in the Greenland (SF, black) and German survey (GGS, red). Dashed lines are 95% CI.

To calculate stock mean weight by year for the SAM, all stations were used from SF for GRO and EGI. For GRI, the gillnet stations were used instead (WD06) The method followed largely the approach used for the commercial data but instead of using field codes, every station was included separately and weighted with the amount of catch (in numbers) compared to the total in the entire survey. This was done as follow, with age 3 again as an example:

For every station, calculate Weight_Age3_Station_Weighted

Weight_Age3_Station_Weighted = Weight_Age3_Station*(N_Age_Station/Total_N_Age3_Year)

then

Weight_Age3_StockMeanWeight = sum(Weight_Age3_Station_Weighted, for all stations).

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 (see WD01) 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 10), the proportion of mature fish by age is left unchanged from year to year for the West Greenland inshore stock (GRI) and the West Greenland offshore stock (GRO) (table 11). The maturity ogives for GRI and

GRO were 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} are 4.56 for GRI and 4.45 for GRO.

Table 10: 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 inshore stock (GRI) and the Wes tGreenland offshore stock (GRO).

Year	GRI	GRO
2008	58	20
2010	16	66
2011	162	89
2012	34	53
2013	38	108
2016	214	154
2017	515	360
2018	88	148
2019	299	332
2021	164	128
Total	**1588**	**1458**

Table 11: Maturity ogive by age and stock.

	Proportion Mature			
Age group	**GRI**	**GRO**	**EGI 2000-2017**	**EGI 2018-present**
1	0.004	0.008	0.020	0
2	0.020	0.032	0.049	0.001
3	0.085	0.117	0.116	0.011
4	0.299	0.349	0.249	0.081
5	0.661	0.685	0.456	0.410
6	0.899	0.898	0.679	0.847
7	0.976	0.973	0.843	0.978
8	0.995	0.993	0.931	0.997
9	0.999	0.998	0.972	0.999
10	1.000	1.000	0.989	0.999

Table 12: Number of samples with information on maturity and age in ICES 14b in April and May by year used in maturity ogive for EastGreenland-Iceland offshore stock (EGI).

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

For the East Greenland-Iceland offshore stock (EGI) the maturity ogive from East Greenland is used as this is the main spawning area for this stock in Greenland (Table 12). Due to lack of data proportion of mature fish by age is left unchanged for two periods; 2000-2017 and 2018-present. The maturity ogive for the period 2000-2017 is based on 1557 samples with maturity information on collections made in the spawning season April and May (table 12). 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 are similar. The maturity ogive was estimated by a general linear model (GLM) with binomial errors. A_{50} was estimated to 5.19 years.

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 EGI (Bonanomi *et al.* 2016) and has therefore no effect on the GRO og GRI stock and natural mortality is by default set to value of 0.2.

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 EGI stock is by default set to value of 0.2.

Recommendations

Maturity: Revision of maturity ogive for EGI; analysis of EGI spawners in West Greenland with respect to magnitude and extent of spawning. Compare with data of spawning cod in East Greenland.

Natural mortality: Several approaches should be used (Life-history based methods (overview of methods presented by Masnadi *et al* 2021 and The Barefoot Ecologist's Toolbox (http://barefootecologist.com.au/shiny_m) in order to analyse natural mortality.

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Appendix tables

Table A1: Cod catches (t) divided into NAFO divisions, caught in the inshore fishery (1911-1993: Horsted 2000, 1994-2006: Statistic Greenland, 2007-present: Greenland Fisheries License Control). ICES 14b=inshore East Greenland.

	NAFO divisions								
Year	1A	1B	1C	1D	1E	1F	Unknown NAFO div	Total West-Greenland	ICES 14b
1911				19				19	
1912				5				5	
1913				66				66	
1914				60				60	
1915		47	6	45				98	
1916		66	24	103				193	
1917		67	28	59				154	
1918		106	26	140		169		441	
1919		39	37	140	148	137		501	
1920		117	32	187	23	95		454	
1921		116	92	97	7	196		508	
1922		82	178	144	40	158		602	
1923		120	116	147	0	307		690	
1924		131	223	221	1	267		843	
1925		122	371	318	45	168		1024	
1926		97	785	673	170	499		2224	
1927		282	974	982	305	1027		3570	
1928		426	888	1153	497	1199		4163	
1929		1479	1572	1335	642	2052		7080	
1930	137	2208	2326	1681	994	2312		9658	
1931	315	1905	2026	1520	835	2453		9054	
1932	358	1713	2130	1042	731	3258		9232	
1933	304	1799	1743	1148	948	2296		8238	
1934	451	2080	1473	652	921	3591		9168	
1935	524	1870	1277	769	670	2466		7576	
1936	329	2039	1199	705	717	2185		7174	
1937	135	1982	1433	854	496	2061		6961	
1938	258	1743	1406	703	347	1035		5492	
1939	416	2256	1732	896	431	1430		7161	
1940	482	2478	1600	1061	646	1759		8026	
1941	636	3229	1473	823	593	1868		8622	
1942	879	3831	2249	1332	1003	2733		12027	
1943	1507	5056	2016	1240	1134	2073		13026	
1944	1795	4322	2355	1547	1198	2168		13385	
1945	1585	4987	2844	1207	1474	2192		14289	
1946	1889	5210	2871	1438	1139	2715		15262	
1947	1573	5261	3323	2096	1658	4118		18029	
1948	1130	5660	3756	1657	1652	4820		18675	
1949	1403	4580	3666	2110	2151	3140		17050	
1950	1657	6358	4140	2357	2278	4383		21173	

1951	1277	5322	3324	2571	2101	3605		18200	
1952	646	4443	2906	2437	2216	4078		16726	
1953	1092	5030	3662	5513	3093	4261		22651	
1954	950	6164	3118	3275	1773	3418		18698	
1955	591	5523	3225	4061	2773	3614		19787	
1956	475	5373	3175	5127	3292	3586		21028	
1957	277	6146	3282	5257	4380	5251		24593	
1958	19	6178	3724	5456	3975	6450		25802	
1959	237	6404	5590	5009	3767	6570		27577	
1960	188	6741	6230	3614	3626	6610		27009	
1961	601	6569	6726	4178	6182	9709		33965	
1962	315	7809	6269	3824	5638	11525		35380	
1963	295	4877	3178	2804	3078	9037		23269	
1964	275	3311	2447	8766	2206	4981		21986	
1965	325	5209	4818	6046	2477	5447		24322	
1966	483	8738	5669	7022	2335	4799		29046	
1967	310	5658	6248	6747	2429	6132		27524	
1968	142	1669	2738	6123	2837	7207		20716	
1969	57	1767	4287	7540	2017	5568		21236	
1970	136	1469	2219	3661	2424	5654		15563	
1971	255	1807	2011	3802	1698	3933		13506	
1972	263	1855	3328	3973	1533	3696		14648	
1973	158	1362	1225	3682	1614	1581		9622	
1974	454	926	1449	2588	1628	1593		8638	
1975	216	1038	1930	1269	964	1140		6557	
1976	204	644	1224	904	1367	831		5174	
1977	216	580	2505	2946	3521	4231		13999	
1978	348	1587	3244	2614	4642	7244		19679	
1979	433	1768	2201	6378	9609	15201		35590	
1980	719	2303	2269	7781	10647	14852		38571	
1981	281	2810	3599	6119	7711	11505	7678	39703	
1982	206	2448	3176	7186	4536	3621	5491	26664	
1983	148	2803	3640	7430	5016	2500	7205	28742	
1984	175	3908	1889	5414	1149	1333	6090	19958	
1985	149	2936	957	1976	1178	1245		8441	
1986	76	1038	255	1209	1456	1268		5302	
1987	77	2366	423	6407	3602	1326	403	14604	
1988	333	6294	1342	2992	3346	4484		18791	
1989	634	8491	5671	8212	10845	4676		38529	
1990	476	9857	1482	9826	1917	5241		28799	
1991	876	8641	917	2782	1089	4007		18312	
1992	695	2710	563	1070	239	450		5727	
1993	333	327	168	970	19	109		1926	
1994	202	336	588	745	151	92		2113	72
1995	65	484	704	329	40	86	1	1709	26
1996	54	199	495	133	17	46		944	5
1997	22	438	199	100	13	130		903	32
1998	15	111	80	78	0	38		323	32

1999	6	140	55	336	7	4		548	24
2000	160	143	0	332	0	12		647	20
2001	252	1046	245	54	0	81	6	1684	20
2002	413	1802	505	214	24	813	120	3891	33
2003	1109	1522	334	274	3	479	236	3957	4
2004	902	1600	385	507	30	257	970	4653	1
2005	638	1827	1173	614	284	420	23	4979	0
2006	641	1783	1183	1282	358	1830	1190	8267	1
2007	738	2119	1304	1843	660	4391		11055	42
2008	870	3067	1538	3171	224	1134		10003	6
2009	325	1288	1189	2009	1142	1718		7671	2
2010	559	2990	1607	1795	1458	859		9268	2
2011	567	2364	2850	2905	1274	1047		11007	0
2012	632	1227	2115	4343	2002	299		10617	0.02
2013	1500	2558	2792	4703	1448	200		13201	35
2014	3083	6143	3756	4582	684	82		18330	38
2015	4088	7912	6426	6613	117	115		25272	50
2016	5929	11466	11270	5279	87	173		34203	39
2017	5797	11111	10060	4066	56	131		31220	82
2018	2213	6422	6189	7043	31	390		22289	51
2019	1988	2925	4212	8673	131	1822		19750	143
2020	1382	2324	4482	7412	222	2104		17926	223
2021	1133	2910	4217	4597	93	629		13580	286

Table A2: Offshore catches (t) divided into NAFO divisions in West Greenland and East Greenland (ICES 14b). 1924-1995: Horsted 2000, 1995-2000: ICES Catch Statistics, 2001-present: Greenland Fisheries License Control.

Year	NAFO 1A	NAFO 1B	NAFO 1C	NAFO 1D	NAFO 1E	NAFO 1F	Unknown NAFO div.	Total West Greenland	Total East Greenland ICES 14b
1924							200	200	
1925							1871	1871	
1926							4452	4452	
1927							4427	4427	
1928							5871	5871	
1929							22304	22304	
1930							94722	94722	
1931							120858	120858	
1932							87273	87273	
1933							54351	54351	
1934							88422	88422	
1935							65796	65796	
1936							125972	125972	
1937							90296	90296	
1938							90042	90042	
1939							62807	62807	
1940							43122	43122	
1941							35000	35000	
1942							40814	40814	
1943							47400	47400	
1944							51627	51627	
1945							45800	45800	
1946							44395	44395	
1947							63458	63458	
1948							109058	109058	

1949							156015	156015	
1950							179398	179398	
1951							222340	222340	
1952	0	261	2996	18188	707	37905	257488	317545	
1953	4546	46546	10611	38915	932	25242	98225	225017	
1954	2811	97306	18192	91555	727	15350	60179	286120	4321
1955	773	50106	32829	87327	3753	4655	68488	247931	5135
1956	15	56011	38428	128255	8721	4922	66265	302617	12887
1957	0	58575	32594	62106	29093	16317	47357	246042	10453
1958	168	55626	41074	73067	21624	26765	75795	294119	10915
1959	986	74304	10954	30254	12560	11009	67598	207665	19178
1960	35	58648	18493	35939	16396	9885	76431	215827	23914
1961	503	78018	43351	70881	16031	14618	90224	313626	19690
1962	1017	122388	75380	57972	25336	17289	125896	425278	17315
1963	66	70236	73142	76579	46370	16440	122653	405486	23057
1964	96	49049	49102	82936	33287	13844	99438	327752	35577
1965	385	80931	66817	71036	15594	15002	92630	342395	17497
1966	12	99495	43557	62594	19579	18769	95124	339130	12870
1967	361	58612	78270	122518	34096	12187	95911	401955	24732
1968	881	12333	89636	94820	61591	16362	97390	373013	15701
1969	490	7652	31140	65115	41648	11507	35611	193163	17771
1970	278	3719	13244	23496	23215	15519	18420	97891	20907
1971	39	1621	28839	21188	9088	20515	26384	107674	32616
1972	0	3033	42736	18699	7022	4396	20083	95969	26629
1973	0	2341	17735	18587	10581	2908	1168	53320	11752
1974	36	1430	12452	14747	8701	1374	656	39396	6553
1975	0	49	18258	12494	6880	3124	549	41354	5925
1976	0	442	5418	10704	8446	2873	229	28112	13025
1977	127	301	4472	7943	8506	2175	35477 [1]	23524	18000 [2]
1978	0	0	11856	2638	3715	549	34563 [1]	18758	26000 [2]
1979	0	16	6561	4042	1115	537	51139 [1]	12271	34000 [2]
1980	0	1800	2200	2117	1687	384	7241 [1]	8188	12000 [2]
1981	0	0	4289	4701	4508	255	0	13753	16000 [2]
1982	0	133	6143	10977	11222	692	1174	30341	27000 [2]
1983	0	0	717	6223	16518	4628	293	28379	13378
1984	0	0	0	4921	5453	3083	0	13457	8914
1985	0	0	0	145	1961	1927	2402	6435	2112
1986	0	0	0	2	72	24	1203	1301	4755
1987	0	0	5	815	67	43	3041	3971	6909
1988	0	0	919	17463	10913	6466	8101	43862	9457
1989	0	0	0	11071	48092	14248	2	73413	14669
1990	0	0	2	563	21513	10580	7503	40161	33508
1991	0	0	0	0	104	1942	0	2046	21596
1992	0	0	0	0	0	0	0	0	11349
1993	0	0	0	0	0	0	0	0	1135
1994	0	0	0	0	0	0	0	0	437
1995	0	0	0	0	0	0	0	0	284
1996	0	0	0	0	0	0	0	0	192
1997	0	0	0	0	0	0	0	0	355
1998	0	0	0	0	0	0	0	0	345
1999	0	0	0	0	0	0	0	0	116
2000	0	0	0	0	0	0	0	0	63
2001	0	0	0	0	0	0	0	0	125
2002	0	0	0	0	0	0	0	0	398
2003	0	0	0	0	0	0	0	0	485
2004	0	0	0	5	3	1	0	9	778
2005	0	0	0	0	0	72	0	72	819
2006	0	0	0	0	0.05	414	0	414	2042
2007	0	0	0	31	435	2011	0	2477	3194
2008	0	0	0	23	526	11378	0	11927	3258
2009	0	0	0	0	6	3354	0	3360	1642
2010	0	0	0	0	2	288	0	290	2388
2011	0	0	0	0.1	8	542	0	550	4571

2012	0	0	1	97	243	1473	0	1814	3941
2013	0	0	0	215	270	1412	0	1897	4104
2014	0	0	30	68	18	1833	0	1949	6060
2015	0	0	341	954	3569	3950	0	8814	11805
2016	0	0	67	1924	1764	2320	0	6075	12497
2017	0	0.4	1442	730	852	2561	0	5585	13738
2018	0	0	1994	675	1517	1815	0	6001	13251
2019	0	0	654	57	186	916	0	1813	17158
2020	0	0	101	0	1	675	0	777	15258
2021	0	0	96	0	0	192	0	288	25637

Estimates for assessment include estimates of unreported catches. The total estimated value for West Greenland (inshore + offshore) was 73000 t in 1977 and 1978, 1979: 99000 t, 1980: 54000 t. The value given in the table are these values minus the inshore catches minus known offshore NAFO division catches.
Estimates for assessment include estimates of unreported catches in East Greenland.

WD 06 - West Greenland inshore survey indices for the three cod stocks GRI, GRO, and EGI from 2002-2021

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Summary

Survey catches from the West Greenland inshore gillnet survey in NAFO areas 1B and 1D split for each of the three Greenlandic cod stocks, West Greenland offshore (GRO), West Greenland inshore (GRI) and East Greenland-Iceland (EGI) are presented. For each stock a combined index for the two areas is calculated.

Introduction

An annual multimesh gillnet surveys designed to target cod aged 2 and 3 years old have been conducted in the inshore areas NAFO 1B (Sisimiut) and 1D (Nuuk) since 1987. Full description of the survey is given in WD05. Previously the gillnet surveys were used as two tuning indices (one for 1B and one for 1D) for the SAM model for West Greenland inshore cod stock.

For WKGREENCOD the catches from the gillnet survey are split into the three genetically distinct cod stocks, West Greenland offshore (GRO), West Greenland inshore (GRI) and East-Greenland-Iceland (EGI) based on the methodology described in WD02. For each of the three stocks a new CPUE index combined for areas 1B and 1D were calculated for the years 2002-2021.

A combined index is thought to be more representative of the entire inshore stock than having separate indices for the two areas in the assessment for the full area.

The CPUE index for GRI presented here are used as tuning series for the SAM model for GRI and for SPiCT for GRI (see WD04). The CPUE index for GRO were used as tuning series for one of the SAM model runs for GRO. CPUE indices for areas 1B and 1D individually are presented and used in SAM model runs for each area separately.

Methods

Survey timeseries
The time period for the assessments presented at WKGREENCOD is 2000-2021 (see WD01 for details). For the gillnet survey in 2000 there are uncertainty on the positions from the surveys, in 2001 and 2007-2009 only one of the areas were covered (2007 survey in 1B - Sisimiut, 2008-2009 survey in 1D - Nuuk). These years are not in the final combined index.

Combined index
For each stock a CPUE index by age, for the areas 1B (Sisimiut) and 1D (Nuuk) combined, were calculated as *number of cod caught per 100 hours of fishing* and weighted by the numbers caught in each area. Calculations were done in R v.4.0.5 using 'weighted.mean' function from 'The R Stats package v.4.0.5 and the 'Hmisc' package v.4.5 (R Core Team 2011,2022, Harrell 2021).

Indices for 1B and 1D

For the areas 1B – Sisimiut and 1D – Nuuk separate survey CPUE indices were calculated as number of cod caught per 100 hours of fishing. To get indices by area for each for the three stocks and to identify any difference in stock development between the two areas and for used in SAM runs for each of the areas.

Results

Combined indices

West Greenland inshore stock - GRI

The CPUEindex for GRI are presented in figure 1 and in table A2. It is possible to follow larger cohorts through the years, e.g. cohort 2009 which has a high index value as age 2 in 2011 and as age 3 in 2012. Compare to the other stocks (see figures 1, 3 and 5) the CPUE index for GRI tends to be higher. Very few fish older than age 7 are caught.

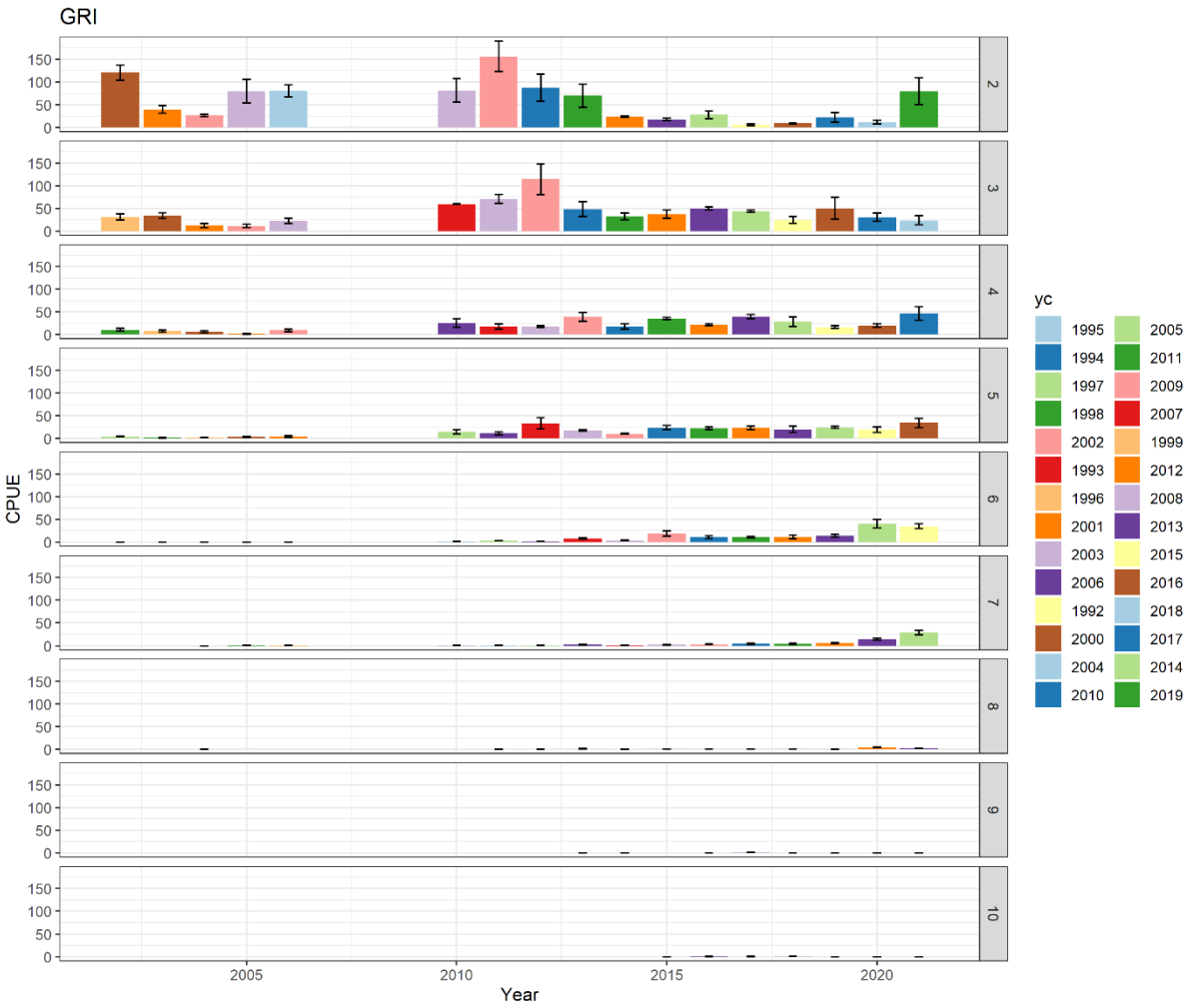

Figure 1 CPUE index (cod caught per 100 hours fishing and weighted by numbers caught for each area) for GRI by age and Year. Colours indicate cohorts.

Lower internal consistency for age 2-3 may give a late indication of stock trends for incoming cohorts (Figure 2). However, there are good internal consistency for ages 3-4, 4-5, 5-6, 6-7 and 7-8. Based on this the final CPUEidex for GRI going into the SAM model will be for ages 2-8.

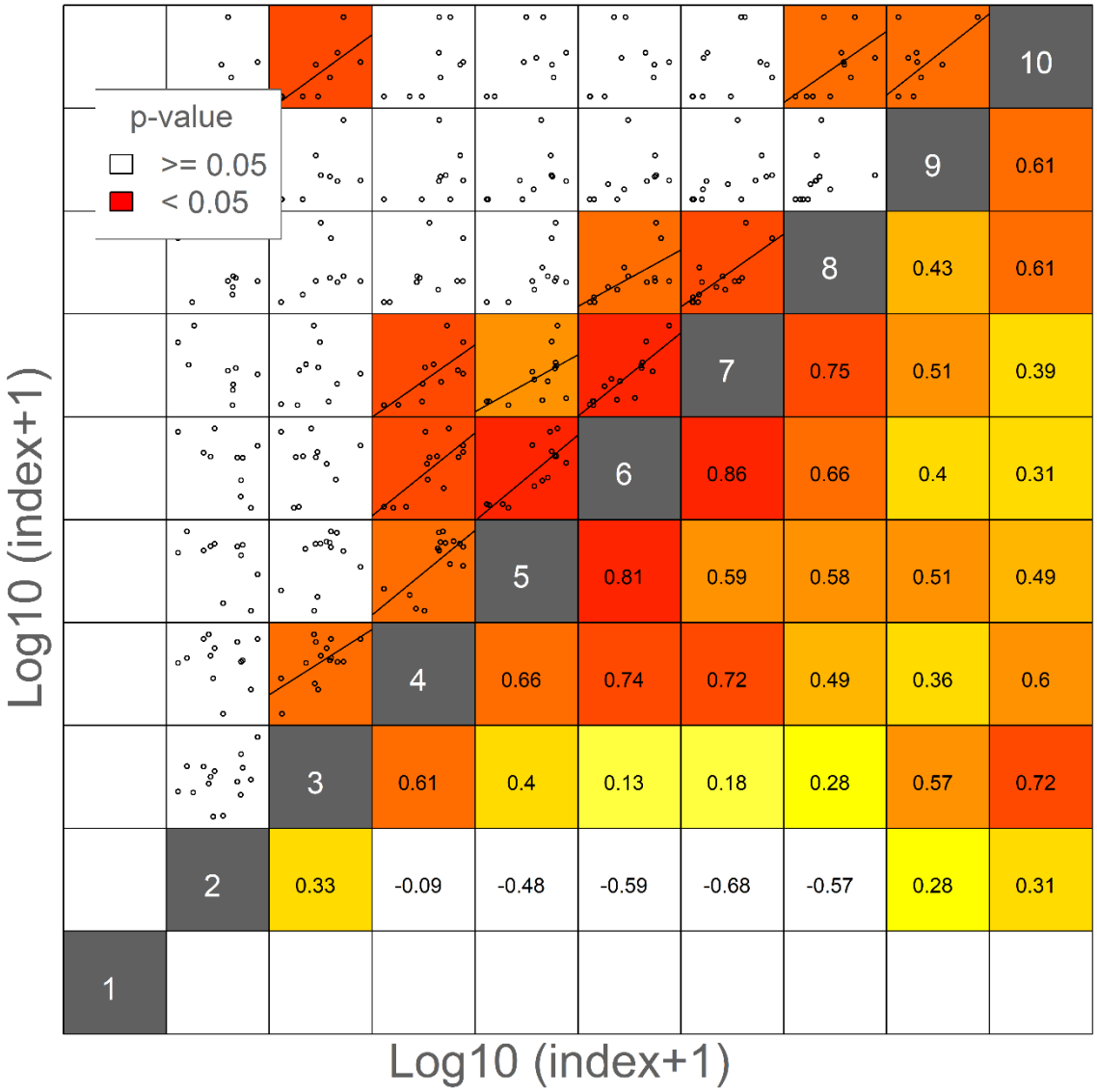

Figure 2 Internal consistencies for the combined CPUE index for GRI for the years 2002-2021.

West Greenland offshore stock - GRO

The CPUE index for GRO are presented in figure 3 and in table A3. It is possible to follow larger cohorts through the years, e.g., cohort 2009 which has a high index value as age 2 in 2011 and as age 3 in 2012. Very few fish older than age 7 are caught. Incoming year class 2019 also show high abundance at age 2.

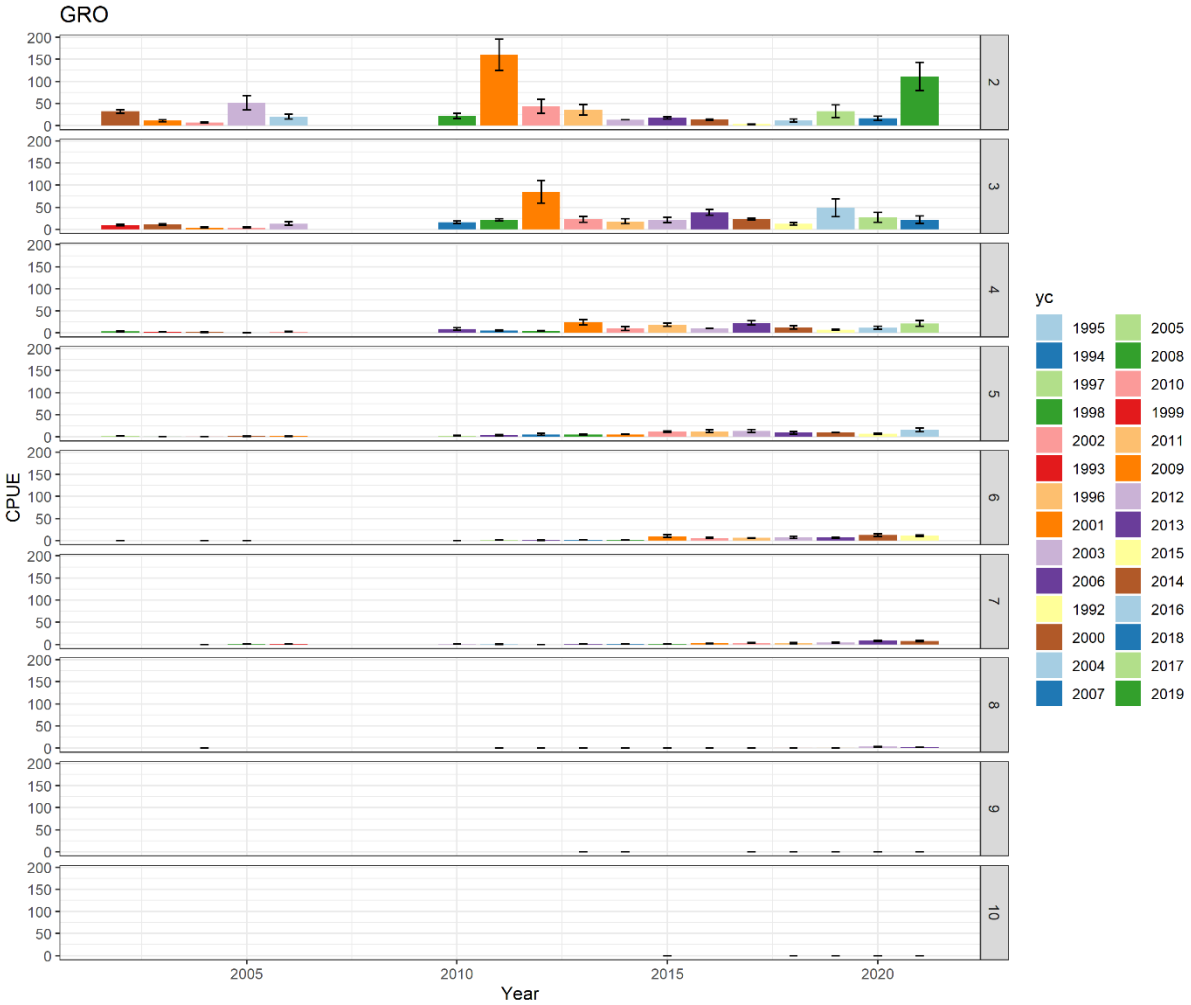

Figure 3 CPUE index (cod caught per 100 hours fishing and weighted by numbers caught for each area) for GRO by age and Year. Colours indicate cohorts.

Good internal consistency between all ages except 8-9 and 9-10 where very few individuals are caught (figure 4).

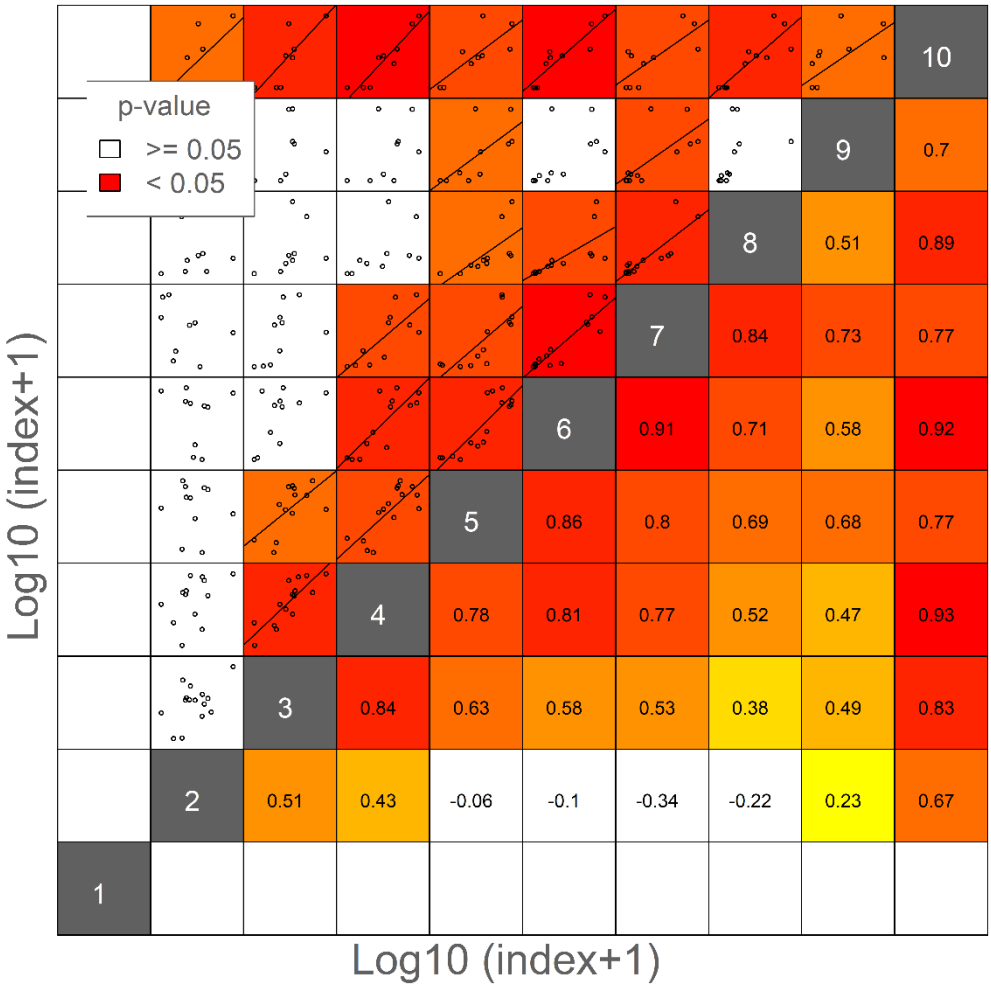

Figure 4. Internal consistencies for the combined CPUE index for GRO for the years 2002-2021.

East Greenland-Iceland stock - EGI

The CPUE index for EGI are presented in figure 5 and in table A4. One cohort of the EGI was found at high abundance in the inshore gillnet survey, that is cohort 2009 at age 2,3 and 4. Very few fish older than age 7 are caught. In general, the CPUE index for EGI is lower than for the two other stocks.

Figure 5 CPUE index (cod caught per 100 hours fishing and weighted by numbers caught for each area) for EGI by age and Year. Colours indicate cohorts.

Good internal consistency for between ages 2-3, 4-5, 5-6, 6-7 and 7-8 (figure 6). Lower internal consistency for ages 3-4.

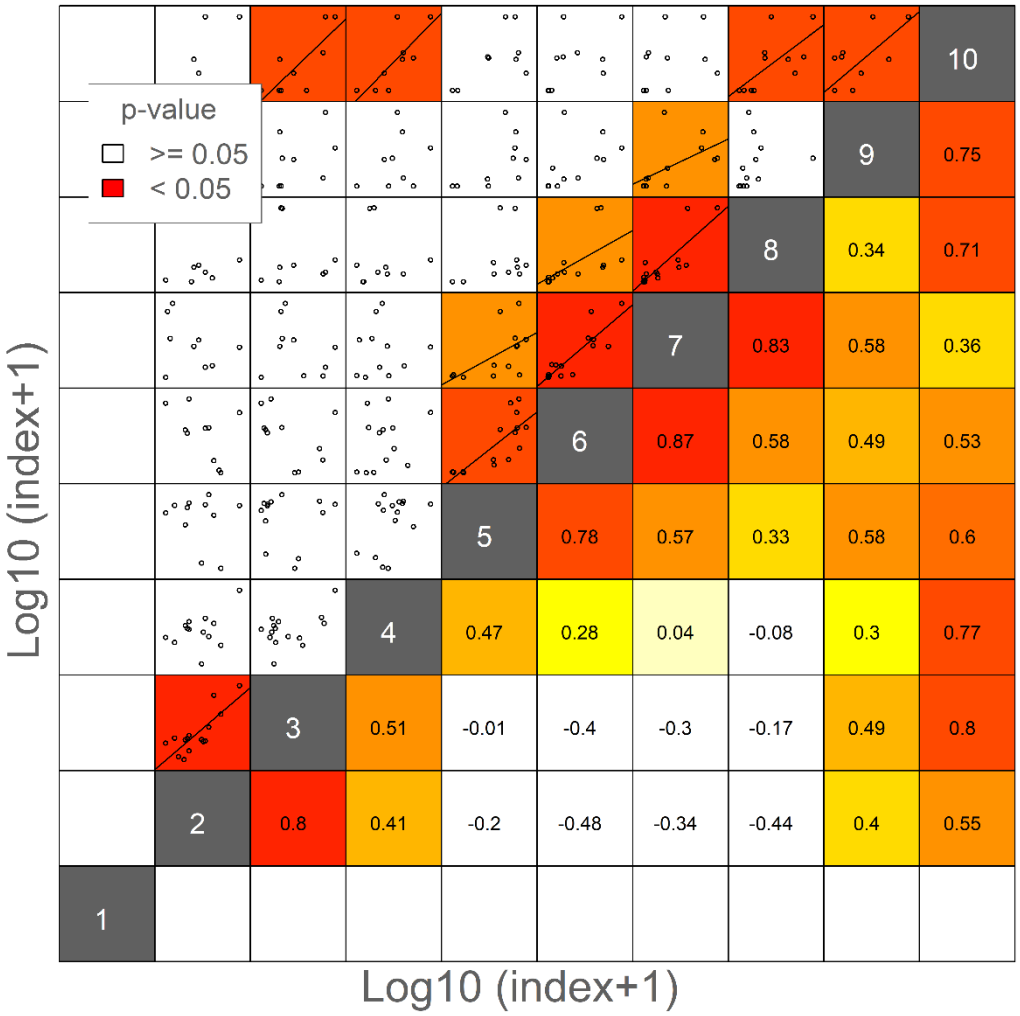

Figure 6. Internal consistencies for the combined CPUE index for EGI for the years 2002-2021.

Comparison of the indices for GRI, GRO and EGI

All three stocks seem to follow similar trends over time (figure 7). In general, the highest CPUE index values are for GRI for all years and ages, with the exception of age 2 in recent years where the GRO index is higher. For the time period 2002- 2014 the CPUE index for ages 6+ were close to zero, older fish caught in the more recent time period has mainly been of the GRI and GRO stocks.

Age 2 (recruitment)

For the period 2002-2018 the highest CPUE has been for GRI, but in recent years CPUE has been higher for GRO, this trend is only apparent for age 2.

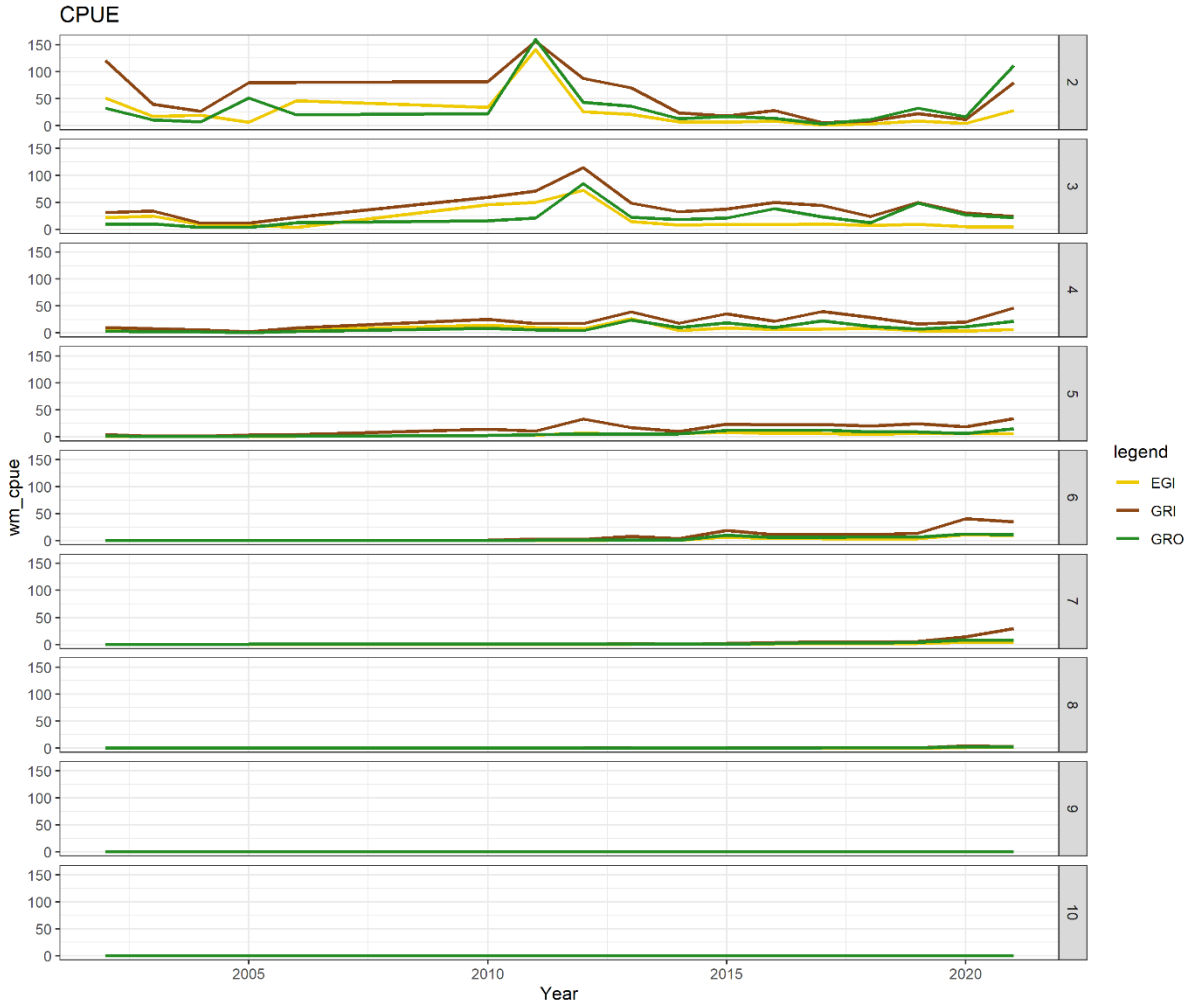

Figure 7. Comparison of CPUE indices (cod caught per 100 hours fishing and weighted by numbers caught for each area) for all three stocks. Y axis at different scales.

CPUE indices for areas 1B and 1D separately

The CPUE indices for 1B (Sisimiut) and 1D (Nuuk) are presented in figure 8. The CPUE index for age 2 for 1B is higher than for 1D, and in Sisimiut the CPUE index for GRO is higher than for GRI. The CPUE indices for age 4 show opposite trends the most recent years.

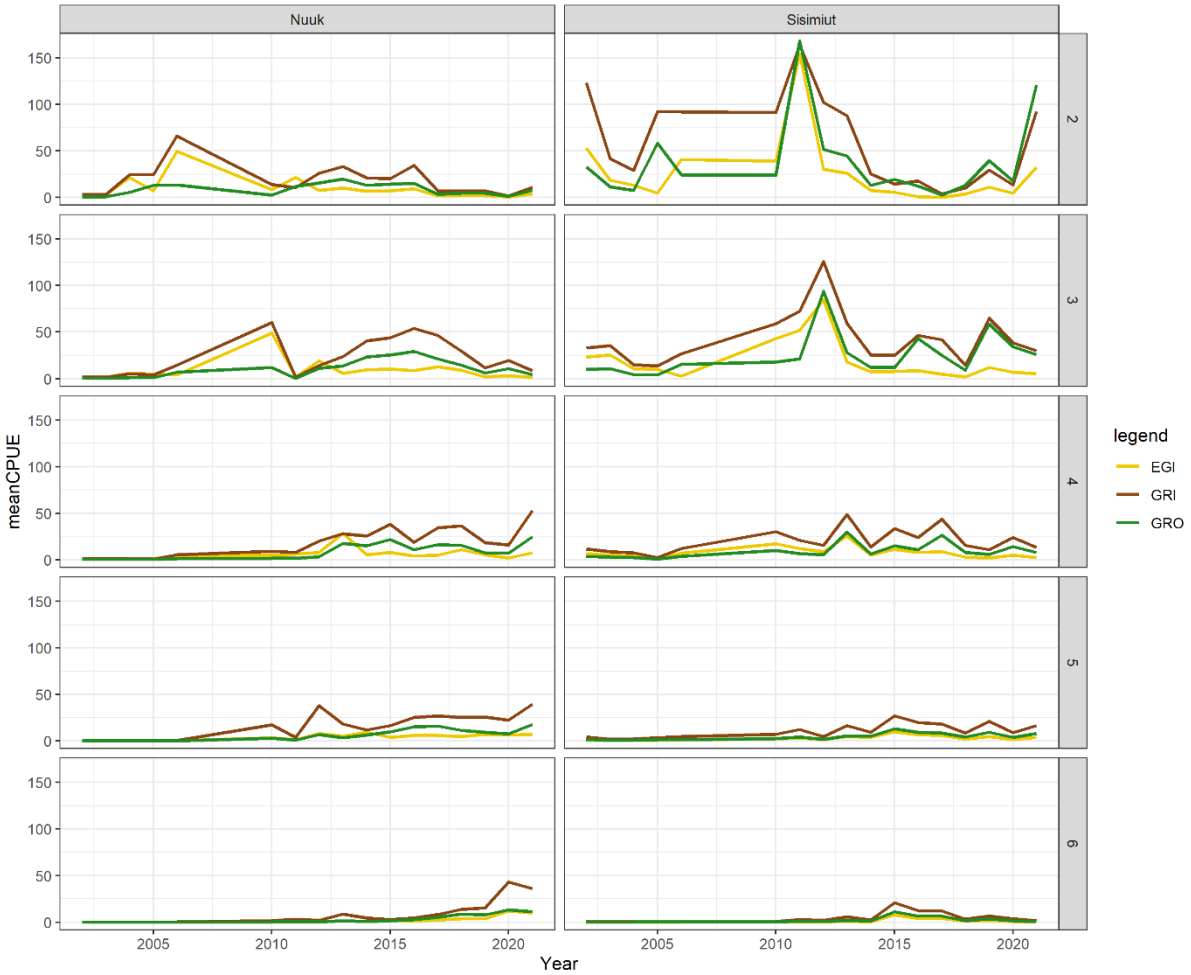

Figure 8. Gillnet survey index (cod caught per 100 hours fishing) for ages 2-6 for areas 1B – Sisimiut and 1D – Nuuk. There are no data included for 2007 to 2009.

Figure 9 shows the CPUE indices for GRI for area 1B and 1D separately. There was no survey in 1B in 2008 and 2009, and for 1D there was no survey in 2007. Figure 10 show the internal consistencies for the CPUE indices for GRI in areas 1B and 1D. The internal consistencies are better for 1D- Nuuk compared to 1B – Sisimiut.

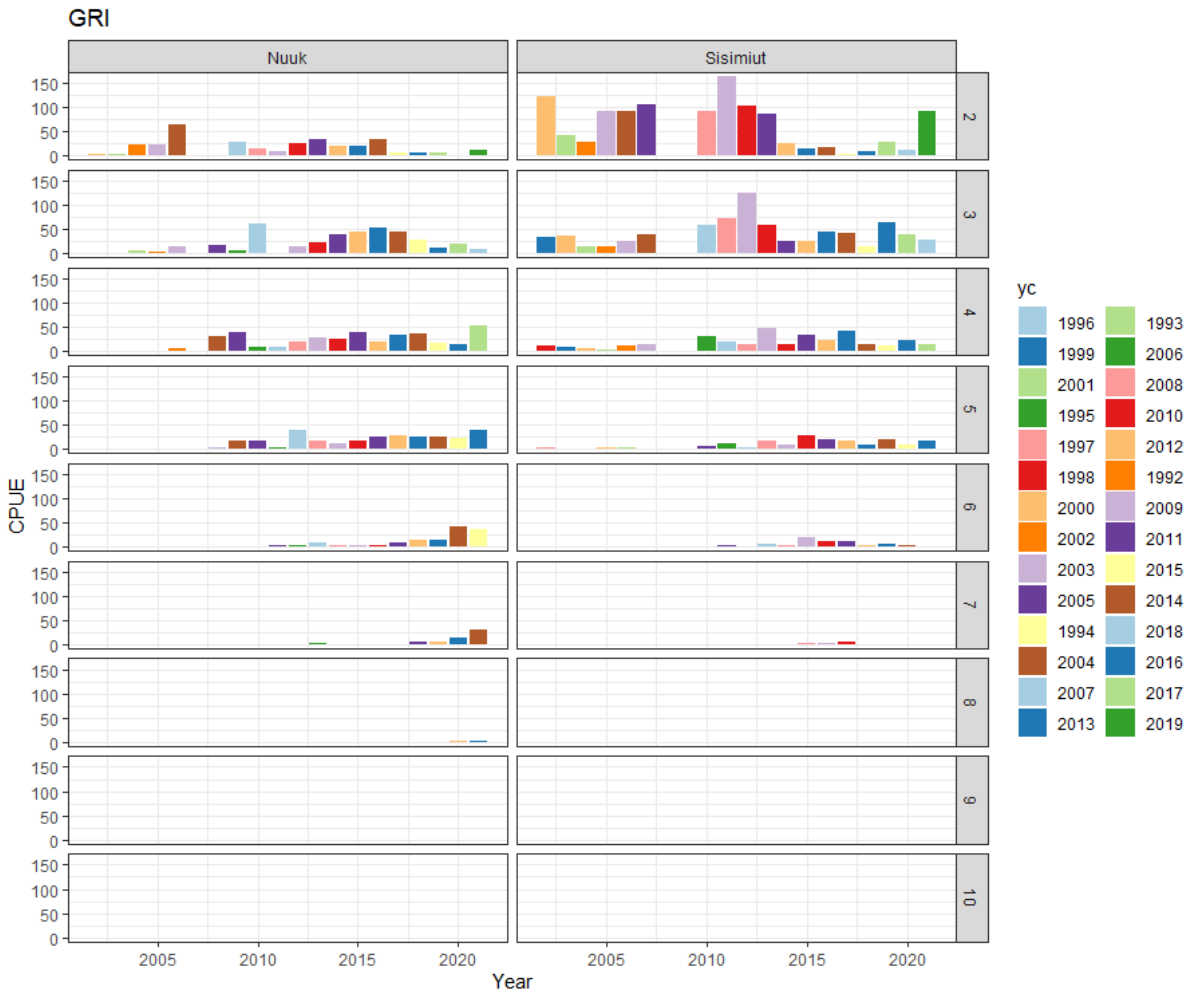

Figure 9. CPUE index (cod caught per 100 hours fishing and weighted by numbers caught for each area) for GRI by age and Year for areas 1B – Sisimiut and 1D - Nuuk. Colours indicate cohorts.

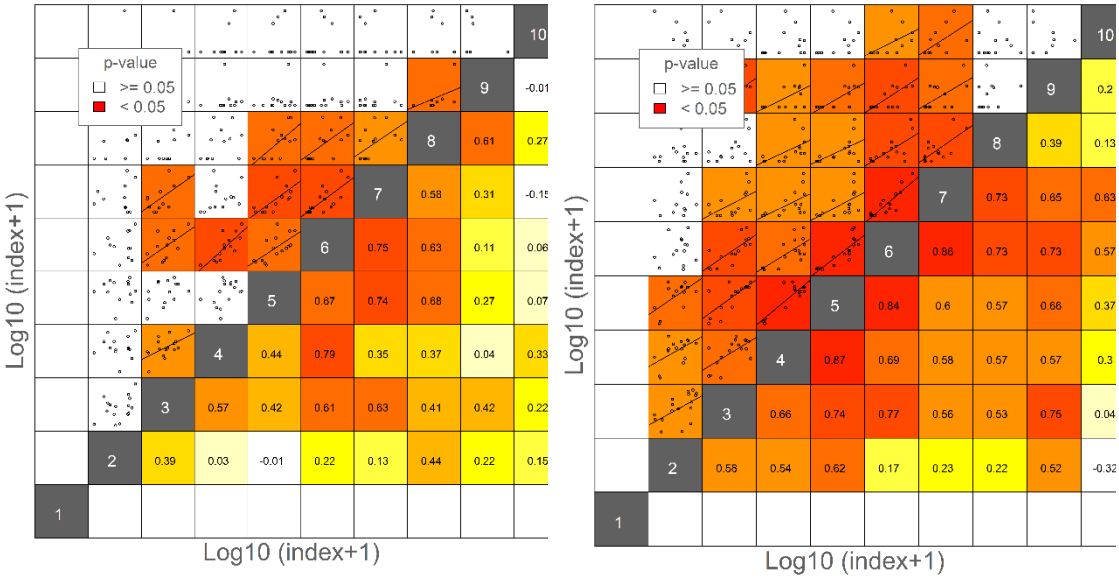

Figure 10. Internal consistencies for the CPUE indices for GRI for the years 2002-2021 in areas 1B – Sisimiut (left) and 1D – Nuuk (right). For 1B there are no data for 2008 to 2009. For 1D there are no data for 2007.

Discussion

The indices for GRI, GRO and EGI follow similar trends for ages 2-6 for most years, this is likely to partly be a result of how the data are split into the three stocks. However, by splitting the data it is possible to see when the dynamics are changing. And to get a better understanding of differences between the three stocks.

There is evidence of an increase in GRO at age 2 in the 2021 survey, without splitting the survey data by stocks it would not have been possible to account for this change.

The CPUE index for EGI has been at a low level since 2014, and follows what is already know, that for most years the proportion of EGI in the inshore area is at a stable low level.

References

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Computing, Vienna, Austria. URL https://www.R-project.org/.RStudio Team. 2022. "RStudio: Integrated Development Environment for R. RStudio, PBC, Boston, MA. URL Http://Www.Rstudio.Com/."

Appendix

Table A1. Number of cod caught in the gillnet survey by year (2002-2021) and ages 2-10 for 1B and 1D combined. For the three stocks GRI, GRO and EGI. For the years 2007-2009 only one area covered so data not included.

GRI									
Year/Age	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
2002	664	183	64	21	1.5	0	0	0	0
2003	464	351	94	20	1.7	0.15	0	0	0
2004	417	154	63	23	4.5	0.34	1.11	0	0
2005	842	122	23	24	2.1	1.25	0	0	0
2006	630	158	67	18	2	0.61	0	0	0
2010	414	582	196	116	11.1	0.63	0	0	0
2011	774	333	126	74	22.2	5.2	0.49	0	0
2012	544	514	116	122	14.3	1.4	0.96	0	0
2013	621	451	377	174	73.2	18	8	0.7	0
2014	233	313	198	118	32	3.47	2.23	0.62	0
2015	156	272	299	186	101	14.02	1.84	0	0.58
2016	228	453	199	205	80.3	20.42	5.57	1.52	1.56
2017	55	424	342	193	93.6	28.36	4.84	4.54	1.24
2018	93	234	264	159	74.7	25.31	5.57	1.39	0.7
2019	170	328	192	287	149.6	47.82	5.39	1.83	0.74
2020	95	388	261	212	330.5	108.11	33.44	3.86	0.43
2021	507	209	496	394	276.9	231	19.79	1.63	0.64
GRO									
Year/Age	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
2002	175	53	21	9.7	0.53	0	0	0	0
2003	124	105	29.5	6.1	0.62	0.048	0	0	0
2004	103	43	20.2	7.4	1.42	0.103	0.35	0	0
2005	514	35	7.5	9	0.81	0.563	0	0	0
2006	150	85	19.3	6.1	0.74	0.169	0	0	0
2010	105	148	61.3	28.2	2.86	0.191	0	0	0
2011	797	98	38.1	24.2	6.86	1.34	0.13	0	0
2012	284	387	30	25.7	4.29	0.217	0.12	0	0
2013	334	227	233.7	45.5	17.7	3.892	1.66	0.11	0
2014	128	162	100.4	64.1	9.94	1.107	1.09	0.26	0
2015	151	147	153.2	97.5	54.4	4.64	0.83	0	0.27
2016	121	335	97.8	109.3	45.75	12.273	1.82	0.3	0.28
2017	31	226	189.1	104	54.87	19.021	3.23	1.98	0.43
2018	100	124	122.5	76	46.57	17.287	4.31	1.21	0.12
2019	189	259	83.7	111.3	75.11	33.225	4.22	1.62	0.81
2020	115	289	140.5	79.7	103.15	63.061	25.89	3.46	0.46
2021	612	159	239.8	180.5	87.22	61.714	15.43	1.44	0.67

EGI									
Year/Age	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
2002	289.7	130	39	5.1	0.24	0	0	0	0
2003	216.4	253	54	5.9	0.43	0.031	0	0	0
2004	286.6	131	38	7.3	0.88	0.06	0.54	0	0
2005	77	100	17	7.8	0.37	0.186	0	0	0
2006	364.1	27	44	5.9	0.37	0.217	0	0	0
2010	190.3	443	109	27.5	1.7	0.089	0	0	0
2011	771.3	244	85	23.6	4.46	1.311	0.048	0	0
2012	161.5	383	57	28.3	2.36	0.19	0.117	0	0
2013	187.2	127	277	48.9	12.24	2.743	1.663	0.19	0
2014	71.9	84	58	63.8	5.46	0.544	0.677	0.11	0
2015	56.9	71	81	59.2	42.17	2.502	0.323	0	0.14
2016	42.2	79	57	60.2	26.55	7.475	0.858	0.18	0.16
2017	9.6	82	62	54.6	30.58	9.611	2.17	0.93	0.33
2018	32.9	55	68	33	21.49	7.815	1.788	0.65	0.18
2019	59.5	57	49	77.5	37.69	14.803	1.702	0.55	0.46

2020	33.3	67	46	56.2	89.89	31.266	10.292	1.15	0.12
2021	175.7	35	74	77.5	75.4	39.88	9.355	0.47	0.18

Table A2. CPUE index (cpueidx, cod caught per 100 hours fishing and weighted by numbers caught for each area), weighted standard deviation (SD) and coefficient of variance (CV) for GRI for years 2002-2021 (except 2007-2009) and for ages 2-10.

Year	Age	CPUE index	SD	CV
2002	2	120.71	16.96	0.14
2002	3	31.29	7.01	0.22
2002	4	10.77	3.07	0.29
2002	5	4.02	0.91	0.23
2002	6	0.31	0.00	0.00
2002	7	0.00	-	-
2002	8	0.00	-	-
2002	9	0.00	-	-
2002	10	0.00	-	-
2003	2	39.72	8.51	0.21
2003	3	34.34	6.39	0.19
2003	4	7.95	2.47	0.31
2003	5	1.47	0.53	0.36
2003	6	0.12	0.05	0.47
2003	7	0.01	-	-
2003	8	0.00	-	-
2003	9	0.00	-	-
2003	10	0.00	-	-
2004	2	26.50	2.31	0.09
2004	3	11.95	4.39	0.37
2004	4	6.29	2.41	0.38
2004	5	1.66	0.53	0.32
2004	6	0.33	0.14	0.41
2004	7	0.03	0.00	0.00
2004	8	0.10	0.00	0.00
2004	9	0.00	-	-
2004	10	0.00	-	-
2005	2	79.73	26.16	0.33
2005	3	11.65	4.08	0.35
2005	4	2.20	0.70	0.32
2005	5	3.20	0.87	0.27
2005	6	0.28	0.00	0.00
2005	7	0.20	0.00	0.00
2005	8	0.00	-	-
2005	9	0.00	-	-
2005	10	0.00	-	-
2006	2	80.28	13.06	0.16
2006	3	22.16	5.93	0.27
2006	4	9.71	3.13	0.32
2006	5	4.16	1.34	0.32
2006	6	0.33	0.18	0.55
2006	7	0.19	0.00	0.00
2006	8	0.00	-	-
2006	9	0.00	-	-
2006	10	0.00	-	-
2010	2	81.44	25.86	0.32
2010	3	59.50	0.65	0.01
2010	4	25.74	8.77	0.34
2010	5	14.42	4.72	0.33
2010	6	1.18	0.32	0.27
2010	7	0.24	0.00	0.00
2010	8	0.00	-	-
2010	9	0.00	-	-
2010	10	0.00	-	-

2011	2	156.25	33.50	0.21
2011	3	70.95	9.60	0.14
2011	4	17.66	5.65	0.32
2011	5	10.85	3.40	0.31
2011	6	2.87	0.24	0.08
2011	7	1.26	0.51	0.40
2011	8	0.17	0.00	0.00
2011	9	0.00	-	-
2011	10	0.00	-	-
2012	2	87.19	30.17	0.35
2012	3	114.17	34.17	0.30
2012	4	17.80	2.22	0.12
2012	5	32.86	12.17	0.37
2012	6	2.01	0.11	0.06
2012	7	0.27	0.00	0.00
2012	8	0.36	0.00	0.00
2012	9	0.00	-	-
2012	10	0.00	-	-
2013	2	70.17	25.49	0.36
2013	3	48.23	16.56	0.34
2013	4	39.61	10.13	0.26
2013	5	17.49	0.88	0.05
2013	6	7.77	1.47	0.19
2013	7	2.07	0.63	0.30
2013	8	1.03	0.33	0.32
2013	9	0.13	0.00	0.00
2013	10	0.00	-	-
2014	2	23.91	1.99	0.08
2014	3	32.45	7.61	0.23
2014	4	18.66	5.85	0.31
2014	5	10.10	1.03	0.10
2014	6	3.44	1.07	0.31
2014	7	0.38	0.18	0.47
2014	8	0.29	0.08	0.28
2014	9	0.08	0.00	0.00
2014	10	0.00	-	-
2015	2	17.84	2.96	0.17
2015	3	37.34	9.01	0.24
2015	4	35.83	2.37	0.07
2015	5	23.41	5.05	0.22
2015	6	18.60	5.81	0.31
2015	7	1.83	0.32	0.17
2015	8	0.51	0.00	0.00
2015	9	0.00	-	-
2015	10	0.10	0.00	0.00
2016	2	27.93	8.15	0.29
2016	3	49.86	3.77	0.08
2016	4	22.14	2.37	0.11
2016	5	22.37	2.78	0.12
2016	6	10.67	3.16	0.30
2016	7	3.26	0.72	0.22
2016	8	0.70	0.17	0.25
2016	9	0.15	0.08	0.54
2016	10	0.22	0.16	0.72
2017	2	5.91	1.71	0.29
2017	3	43.99	2.30	0.05
2017	4	39.93	4.39	0.11
2017	5	22.75	4.40	0.19
2017	6	10.80	1.67	0.16
2017	7	4.48	1.25	0.28
2017	8	0.54	0.16	0.29
2017	9	0.87	0.00	0.00
2017	10	0.12	0.07	0.57

2018	2	8.79	1.50	0.17
2018	3	24.25	7.34	0.30
2018	4	28.95	10.11	0.35
2018	5	20.01	7.69	0.38
2018	6	11.27	4.51	0.40
2018	7	3.92	1.60	0.41
2018	8	0.64	0.26	0.41
2018	9	0.16	0.13	0.81
2018	10	0.22	0.00	0.00
2019	2	21.94	10.54	0.48
2019	3	50.28	23.94	0.48
2019	4	16.99	3.12	0.18
2019	5	24.29	2.09	0.09
2019	6	13.67	3.48	0.25
2019	7	5.23	1.25	0.24
2019	8	0.55	0.23	0.43
2019	9	0.20	0.00	0.00
2019	10	0.09	0.00	0.00
2020	2	11.44	4.31	0.38
2020	3	30.58	9.21	0.30
2020	4	20.31	3.97	0.20
2020	5	18.86	5.77	0.31
2020	6	40.43	9.71	0.24
2020	7	14.33	2.31	0.16
2020	8	4.10	0.95	0.23
2020	9	0.41	0.15	0.36
2020	10	0.05	0.00	0.00
2021	2	79.73	29.31	0.37
2021	3	23.63	9.81	0.42
2021	4	46.87	14.35	0.31
2021	5	34.12	10.00	0.29
2021	6	34.96	5.94	0.17
2021	7	29.01	5.26	0.18
2021	8	2.72	0.00	0.00
2021	9	0.21	0.00	0.00
2021	10	0.08	0.00	0.00

Table A3. CPUE index (cpueidx, cod caught per 100 hours fishing and weighted by numbers caught for each area), weighted standard deviation (SD) and coefficient of variance (CV) for GRO for years 2002-2021 (except 2007-2009) and for ages 2-10.

Year	Age	CPUE index	SD	CV
2002	2	32.09	4.14	0.13
2002	3	9.44	1.78	0.19
2002	4	3.65	0.96	0.26
2002	5	1.82	0.41	0.23
2002	6	0.11	0.00	0.00
2002	7	0.00	-	-
2002	8	0.00	-	-
2002	9	0.00	-	-
2002	10	0.00	-	-
2003	2	10.81	2.12	0.20
2003	3	10.47	1.65	0.16
2003	4	2.73	0.72	0.26
2003	5	0.52	0.20	0.38
2003	6	0.04	-	-
2003	7	0.00	-	-
2003	8	0.00	-	-
2003	9	0.00	-	-
2003	10	0.00	-	-
2004	2	6.65	1.15	0.17
2004	3	3.73	1.46	0.39

2004	4	2.25	0.78	0.35
2004	5	0.62	0.26	0.41
2004	6	0.12	0.09	0.74
2004	7	0.01	0.00	0.00
2004	8	0.03	0.00	0.00
2004	9	0.00	-	-
2004	10	0.00	-	-
2005	2	51.31	16.48	0.32
2005	3	3.65	1.27	0.35
2005	4	0.77	0.27	0.35
2005	5	1.23	0.31	0.25
2005	6	0.11	0.00	0.00
2005	7	0.09	0.00	0.00
2005	8	0.00	-	-
2005	9	0.00	-	-
2005	10	0.00	-	-
2006	2	20.24	5.36	0.26
2006	3	12.65	4.05	0.32
2006	4	3.14	1.20	0.38
2006	5	1.44	0.46	0.32
2006	6	0.17	-	-
2006	7	0.05	0.00	0.00
2006	8	0.00	-	-
2006	9	0.00	-	-
2006	10	0.00	-	-
2010	2	22.04	6.30	0.29
2010	3	15.74	2.85	0.18
2010	4	9.08	2.89	0.32
2010	5	2.91	0.17	0.06
2010	6	0.27	0.03	0.13
2010	7	0.07	0.00	0.00
2010	8	0.00	-	-
2010	9	0.00	-	-
2010	10	0.00	-	-
2011	2	159.67	35.34	0.22
2011	3	21.09	2.57	0.12
2011	4	5.81	2.03	0.35
2011	5	3.87	1.21	0.31
2011	6	0.89	0.15	0.17
2011	7	0.27	0.22	0.82
2011	8	0.04	0.00	0.00
2011	9	0.00	-	-
2011	10	0.00	-	-
2012	2	43.48	15.06	0.35
2012	3	84.91	25.96	0.31
2012	4	4.70	0.92	0.20
2012	5	5.42	2.30	0.42
2012	6	0.68	0.22	0.32
2012	7	0.04	0.00	0.00
2012	8	0.04	0.00	0.00
2012	9	0.00	-	-
2012	10	0.00	-	-
2013	2	35.70	11.82	0.33
2013	3	22.70	6.77	0.30
2013	4	24.51	6.11	0.25
2013	5	4.76	1.02	0.21
2013	6	1.83	0.16	0.09
2013	7	0.40	0.01	0.04
2013	8	0.18	0.04	0.20
2013	9	0.02	0.00	0.00
2013	10	0.00	-	-
2014	2	13.09	0.09	0.01
2014	3	17.91	5.81	0.32

2014	4	10.29	4.28	0.42
2014	5	5.53	0.55	0.10
2014	6	0.93	0.02	0.02
2014	7	0.10	0.02	0.19
2014	8	0.15	0.14	0.91
2014	9	0.03	0.00	0.00
2014	10	0.00	-	-
2015	2	17.18	2.64	0.15
2015	3	21.19	6.12	0.29
2015	4	18.92	3.23	0.17
2015	5	11.86	1.54	0.13
2015	6	10.11	3.12	0.31
2015	7	0.70	0.26	0.37
2015	8	0.23	0.00	0.00
2015	9	0.00	-	-
2015	10	0.05	0.00	0.00
2016	2	13.73	1.44	0.10
2016	3	38.30	6.71	0.18
2016	4	10.79	0.08	0.01
2016	5	12.52	3.04	0.24
2016	6	5.88	1.66	0.28
2016	7	1.97	0.42	0.21
2016	8	0.30	0.13	0.43
2016	9	0.03	-	-
2016	10	0.03	-	-
2017	2	3.08	0.60	0.19
2017	3	23.40	1.71	0.07
2017	4	22.88	4.75	0.21
2017	5	12.96	3.81	0.29
2017	6	6.21	0.58	0.09
2017	7	2.98	0.84	0.28
2017	8	0.35	0.10	0.27
2017	9	0.37	0.00	0.00
2017	10	0.04	-	-
2018	2	11.22	3.69	0.33
2018	3	12.11	2.74	0.23
2018	4	12.57	3.68	0.29
2018	5	9.23	3.38	0.37
2018	6	7.37	2.89	0.39
2018	7	2.71	1.11	0.41
2018	8	0.49	0.20	0.41
2018	9	0.13	0.13	1.00
2018	10	0.04	0.00	0.00
2019	2	32.32	14.01	0.43
2019	3	48.90	20.43	0.42
2019	4	7.22	0.82	0.11
2019	5	9.38	0.09	0.01
2019	6	6.83	1.68	0.25
2019	7	3.68	0.86	0.23
2019	8	0.44	0.20	0.46
2019	9	0.17	0.00	0.00
2019	10	0.10	0.00	0.00
2020	2	16.14	4.74	0.29
2020	3	27.02	10.84	0.40
2020	4	11.68	3.48	0.30
2020	5	6.67	1.75	0.26
2020	6	12.25	3.19	0.26
2020	7	8.28	1.41	0.17
2020	8	3.17	0.75	0.24
2020	9	0.36	0.14	0.38
2020	10	0.05	0.00	0.00
2021	2	111.09	31.80	0.29
2021	3	21.57	8.69	0.40

2021	4	21.68	6.58	0.30
2021	5	15.42	4.35	0.28
2021	6	10.86	1.99	0.18
2021	7	7.65	1.49	0.19
2021	8	2.11	0.00	0.00
2021	9	0.19	0.00	0.00
2021	10	0.09	0.00	0.00

Table A4. CPUE index (cpueidx, cod caught per 100 hours fishing and weighted by numbers caught for each area), weighted standard deviation (SD) and coefficient of variance (CV) for EGI for years 2002-2021 (except 2007-2009) and for ages 2-10.

Year	Age	CPUE index	SD	CV
2002	2	50.94	9.78	0.19
2002	3	21.80	5.30	0.24
2002	4	5.79	1.96	0.34
2002	5	0.91	0.27	0.29
2002	6	0.05	0.00	0.00
2002	7	0.00	-	-
2002	8	0.00	-	-
2002	9	0.00	-	-
2002	10	0.00	-	-
2003	2	17.18	4.58	0.27
2003	3	24.32	5.11	0.21
2003	4	4.65	1.37	0.30
2003	5	0.45	0.16	0.36
2003	6	0.03	-	-
2003	7	0.00	-	-
2003	8	0.00	-	-
2003	9	0.00	-	-
2003	10	0.00	-	-
2004	2	18.99	3.94	0.21
2004	3	8.80	2.18	0.25
2004	4	3.45	1.40	0.41
2004	5	0.49	0.12	0.24
2004	6	0.06	-	-
2004	7	0.01	0.00	0.00
2004	8	0.05	0.00	0.00
2004	9	0.00	-	-
2004	10	0.00	-	-
2005	2	5.96	1.23	0.21
2005	3	8.14	2.28	0.28
2005	4	1.38	0.16	0.12
2005	5	0.90	0.31	0.34
2005	6	0.05	0.00	0.00
2005	7	0.03	0.00	0.00
2005	8	0.00	-	-
2005	9	0.00	-	-
2005	10	0.00	-	-
2006	2	45.82	4.46	0.10
2006	3	3.68	0.72	0.19
2006	4	5.89	1.17	0.20
2006	5	1.13	0.45	0.40
2006	6	0.07	-	-
2006	7	0.07	0.00	0.00
2006	8	0.00	-	-
2006	9	0.00	-	-

2006	10	0.00	-	-
2010	2	34.14	11.57	0.34
2010	3	45.79	3.11	0.07
2010	4	14.87	5.08	0.34
2010	5	3.09	0.78	0.25
2010	6	0.17	0.04	0.26
2010	7	0.03	0.00	0.00
2010	8	0.00	-	-
2010	9	0.00	-	-
2010	10	0.00	-	-
2011	2	140.82	40.07	0.28
2011	3	50.32	8.94	0.18
2011	4	10.33	2.81	0.27
2011	5	3.16	0.98	0.31
2011	6	0.59	0.15	0.26
2011	7	0.37	0.22	0.60
2011	8	0.02	0.00	0.00
2011	9	0.00	-	-
2011	10	0.00	-	-
2012	2	25.84	9.03	0.35
2012	3	72.15	25.75	0.36
2012	4	8.30	0.45	0.05
2012	5	6.95	2.80	0.40
2012	6	0.34	0.00	0.01
2012	7	0.03	0.00	0.00
2012	8	0.04	0.00	0.00
2012	9	0.00	-	-
2012	10	0.00	-	-
2013	2	21.04	7.60	0.36
2013	3	14.65	5.42	0.37
2013	4	27.21	1.43	0.05
2013	5	5.00	0.19	0.04
2013	6	1.35	0.29	0.22
2013	7	0.35	0.13	0.39
2013	8	0.24	0.11	0.46
2013	9	0.04	0.00	0.00
2013	10	0.00	-	-
2014	2	7.36	0.28	0.04
2014	3	8.34	0.96	0.11
2014	4	4.98	0.27	0.05
2014	5	6.39	2.63	0.41
2014	6	0.60	0.23	0.38
2014	7	0.06	-	-
2014	8	0.09	-	-
2014	9	0.01	-	-
2014	10	0.00	-	-
2015	2	6.49	0.83	0.13
2015	3	9.28	1.14	0.12
2015	4	9.97	1.66	0.17
2015	5	8.39	2.72	0.32
2015	6	6.82	2.39	0.35
2015	7	0.31	0.04	0.12
2015	8	0.09	0.00	0.00
2015	9	0.00	-	-
2015	10	0.03	0.00	0.00
2016	2	8.21	2.70	0.33
2016	3	8.74	0.09	0.01
2016	4	6.84	1.68	0.25
2016	5	6.53	0.50	0.08
2016	6	3.74	1.16	0.31
2016	7	1.13	0.31	0.28
2016	8	0.11	-	-
2016	9	0.02	-	-

2016	10	0.02	-	-
2017	2	1.57	0.52	0.33
2017	3	10.45	3.83	0.37
2017	4	7.59	1.80	0.24
2017	5	6.10	0.12	0.02
2017	6	3.66	0.88	0.24
2017	7	1.53	0.42	0.28
2017	8	0.27	0.15	0.53
2017	9	0.17	0.00	0.00
2017	10	0.03	-	-
2018	2	3.17	0.66	0.21
2018	3	7.60	2.78	0.37
2018	4	8.83	3.50	0.40
2018	5	3.87	1.35	0.35
2018	6	2.97	1.19	0.40
2018	7	1.17	0.51	0.43
2018	8	0.20	0.11	0.53
2018	9	0.08	-	-
2018	10	0.06	0.00	0.00
2019	2	8.17	3.96	0.48
2019	3	9.40	4.39	0.47
2019	4	4.79	1.17	0.24
2019	5	6.83	1.10	0.16
2019	6	3.40	0.82	0.24
2019	7	1.61	0.39	0.24
2019	8	0.17	0.11	0.62
2019	9	0.06	0.00	0.00
2019	10	0.06	0.00	0.00
2020	2	4.16	1.54	0.37
2020	3	5.47	1.84	0.34
2020	4	3.89	1.25	0.32
2020	5	5.33	1.75	0.33
2020	6	11.24	2.49	0.22
2020	7	3.99	0.80	0.20
2020	8	1.26	0.31	0.24
2020	9	0.12	0.11	0.88
2020	10	0.01	0.00	0.00
2021	2	28.26	10.26	0.36
2021	3	4.20	1.78	0.42
2021	4	6.60	1.99	0.30
2021	5	6.43	1.68	0.26
2021	6	9.69	1.45	0.15
2021	7	5.08	0.87	0.17
2021	8	1.27	0.00	0.00
2021	9	0.06	0.00	0.00
2021	10	0.02	-	-

WD 07 - A SAM assessment of the West Greenland offshore cod stock (GRO)

Stockassessment.org run name: **WKGREENCOD_GRO**

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Introduction

The Atlantic cod (*Gadus morhua*) in Greenland waters is primarily of three genetically distinct stocks: West Greenland inshore (GRI), West Greenland offshore (GRO), and East Greenland-Iceland (EGI) (see WD01 for details). Previously advice has been provided based on geographical areas. At WKGREENCOD data from the commercial fisheries and scientific surveys in Greenland waters are split into the three stock components (see WD01, WD02, WD05).

This document presents the results of the state-space model (SAM) (Nielsen and Berg, 2014) for the GRO stock and estimation of reference points using EqSim. This document was updated following the discussions during the WKGREENCOD meeting.

Input data

The input data for the SAM assessment model are described in WD05. The assessment covers the period 2000-2021.

Total catches
Total catches were available for the stock GRO from 2000-2021, due to poor sampling in 2001 catch data are not included from that year (see Table 1 for input file). No discarding is believed to take place, landings are assumed to equal catches.

Catch mean weight at age
Catch mean weight at age were estimated for all years. Some age-year combination without sufficient data were left as NA in the input file (see Table 1 for input file). The given catch mean weights were then treated as observation to inform the catch weight process (GMRF with cohort and within-year correlations) ($catchWeightModel, $keyCatchWeightMean and $keyCatchWeightObsVar in Table 2). See figure 1 for catch weights estimated by the model.

Landings mean weights and discard mean weights are set equal to catch mean weight without any smoothing as these are not used.

Stock mean weight at age
The same process as described to Catch mean weights were used for stock mean weights (see Table 1 for input file) ($stockWeightModel, $keyStockWEightMean and $keyStockWeightObsVar in Table 2), see figure 2 for stock weight estimated by the model. The stock weights are calculated from the Greenlandic offshore survey.

Surveys

Two tuning series are used for this assessment. The first is a survey index by age for ages 2-7 estimated using INLA (see Table 1 for input file), for details on survey data see WD05 and for details on INLA see WD03. 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 (see WD05 for information on survey and WD06 for index calculations).

Landings fraction
Set to 1, landings are assumed to equal catches.

Natural mortality
Set to default 0.2 for all years and ages (see Table 1 for input file). See details in WD05.

Maturity
Maturity ogive is based on genetic dataset presented in WD01 (see Table 1 for input file). There are currently not data to produce annual maturity ogives. Details are given in WD05.

F before spawning
The fraction of the fishing mortality rate, which is applied prior to spawning divided into age classes for each year. Set to 0 for all years and ages.

M before spawning
The fraction of the natural mortality rate, which is applied prior to spawning divided into age classes for each year. Set to 0 for all years and ages.

Assessment

Configurations

Recruitment
Recruitment parameters are estimated within the assessment model. The parameter structure is assumed as a plain random walk process ($stockRecruitmentModelCode in Table 2).

Fishing mortality and Fbar
Fishing mortality is estimated individually for ages 2-8, age 9 and 10 are assumed to be the same ($keyLogFsta in Table 2). It is assumed that there are no correlations across ages ($corFlag in Table 2), this is supported by changes in the selectivity pattern during the assessment period, meaning that correlations between ages are unlikely to be consistent throughout the period (Figure 3). The Fbar range was set to 4-7 years old as these ages constitutes the main part of the catches ($fbarRange in Table 2).

Survey
The survey catchability parameters are estimated individually for each age for the INLA index (fleet 2), this is related to the way the index for each age is estimated separately using INLA. For the CPUE index (fleet 3) 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 ($keyLogFpar in Table 2).

Variance parameters
For age 2 the coupling of the recruitment and survival process variance parameters for the log(N)-process are different from the other ages ($keyVarLogN in Table 2). In the model.R script the following was added: par$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.

The variance parameters for the catch are separate for age 2 and 3, and they are coupled for ages 4-10. 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 ($keyVarObs in Table 2). For the CPUE index the variance parameters are separate for age 2 and 3, and ages 4-6 are coupled.

The covariance structure for the catches is assumed to be independent for the catches (fleet 1) ($obsCorStruct in Table 2). For both the tuning series the covariance structures were assumed to be AR(1), with different parameters for fleet 2 and 3. This was done to allow for year effects, it was coupled for all ages within fleet. Meaning that any year effect is assumed for impact all ages. This was done because earlier runs showed indications of year effects in the residuals. This would also account for any effect of vessels change.

Observation variance
Additional uncertainty was added for the early period, 2000-2010 (see $keyXtraSd in Table 2). All years and ages were couple for each fleet, such that there was one parameter for each fleet. The reason for allowing for additional uncertainty in the observations were based on previous SAM runs where the observation residuals showed a tendency for larger residuals early in the period for all fleets. Further look into the background data found that the sampling coverage for the genetic split in this early period were not as good as the most recent period. Additional, for the catches the sampling coverage are better in the most recent period.

Model diagnostics

For both SSB and F the uncertainty surrounding the estimates are reasonable (Figure 7 and 8), although uncertainty for F a bit high early in the period. For the most recent years with high catches the model tends to underestimate catch (Figure 4). Figure 5 shows the relative weight of the different data sources, the model puts high weight on the INLA survey index for age 3, and for catches for age 4-10. Age 2 from the catches is given very low weighting.

Parameter estimation
Parameter estimates are given in Table 3.

Residuals
There are some patterns in the residuals. For the catch residuals there are a block of positive residuals, showing that the model underestimate catches in these years. There is a block of negative residuals for the INLA survey residuals early in the timeseries.

Stock summary

Fishing mortality
Fishing mortality fluctuated between 0.7 and 1.1 early in the timeseries (2000-2010), F dropped in 2012 to 0.5 and has fluctuated around that level since (Figure 7).

SSB
SSB was at a low level at the beginning of the timeseries and increased from 173 in 2000 to 18066 t in 2016. Since the SSB has decreased and shows a small increase in 2021 (Figure 8).

Recruitment
Recruitment has fluctuated during the timeseries with peak in recruitment in the years 2005, 2011 and 2018 (cohorts 2003, 2009 and 2015 respectively) (Figure 9).

Retrospective analysis

In order to test the robustness of the assessment a 5-year retrospective analysis (Figures 10-12) were conducted. For F all peels, except one, are within the confidence intervals and fluctuate around the current estimate (Mohn'r rho=0.087) (Figure 10). Similarly, all peels for SSB are within confidence intervals and fluctuate around the current estimate, i.e. no consistent over- or underestimation (Mohn'r rho= -0.002) (Figure 11). For recruitment the two most recent peels are within the confidence limits, all peels except for the most recent show a tendency to underestimate recruitment (Mohn's rho=-0.253) (Figure 12).

Sensitivity to tuning series (leave one out analysis)

Leave one out plots show the estimates when removing one of the tuning series, the results are in figures 13-15. For Fbar the trends are similar when leaving out one or the other tuning series, in the early years when leaving out the CPUE index the fluctuations are smaller (Figure 13). For SSB there are the same overall trend the main difference is that without the CPUE index the SSB are lower in the final year (Figure 14). For the recruitment leaving out one or the other tuning series has a large impact (Figure 15). For the run without the INLA index the recruitment is smoother and fluctuates less. For the run without the CPUE index the fluctuations are much larger and recruitment is very low in the most recent years.

<u>Alternative settings and configurations</u>

The first SAM model set up for this stock used only the INLA index, it was found that the addition of the CPUE index improved the stability of the model.

An initial run based mainly on default configurations were used as a starting point for setting up the final SAM model. Impact of each change in configuration were evaluated during the process.

An alternative SAM run was tried without data for age 2, since both survey series and catch showed high variability for age 2, this did not improve the model diagnostics.

A sensitivity run was conducted using averages in both catch and stock weight, this resulted in larger weight at age for the most recent years. This in turn impacted the most recent SSB and catches, where the weights are used.

Because the model was not able to estimate the high catches observed in 2016-2018 a sensitivity run was conducted where the variability on F was lowered, meaning that the model put high weight on the catches. This resulted in a very unstable model, with issuers for the retrospective analysis.

The model to not estimated the largest catches well, therefore a run where the parameters used in a prediction-variance link for observations were coupled for age 2-3 and for ages 4-10. This did not have any major impact and was not included in the final model.

Short term forecast

Short term forecasts were set up using mainly default settings for the SAM run on stockassessment.org. Uncertainty on F were taken from the model. Catch ad stock weights were taken from the model used for these, the model is set up to estimate further ahead in time than the assessment run. For maturity and natural mortality average of the last 5 years were used, currently maturity and natural mortality is constant over time so the time period for this would not have any impact. The default for the recruitment is the last 10 years, it was decided at the meeting that this period is appropriate.

Reference points using EqSim

The estimation of reference points follows ICES Reference Points guidance, 2021. The estimation was done using the R-programme EqSim developed by D. C. M. Miller, which works directly on a specified SAM fit. The code for the final run is on the ICES sharepoint for the WKGREENCOD benchmark and named 'WKGREENCOD_GRO_EqSim_feb23_Final.R'. David Miller attended parts of the meeting where reference points were discussed and provided guidance on the ICES procedures and EqSim settings.

Following ICES guidelines the stock-recruitment relationship appears to follow a type 2 stock type, where B_{lim}= segmented regression change point. Due to very low SSB early in the assessment period where the stock was recovering after being at very low SSB the breakpoint from the segmented regression gave a low B_{lim}. As an alternative the approach for spasmodic stocks (type 1) was used, where the lowest SSB with high recruitment is used as B_{lim}. Rather than just using one data point, it was decided to use the average SSB of the three highest recruitments (that being the SSB in 2009-2011), this gave a B_{lim} of 3219.

The simulation settings for the stock-recruitment relationship were as follows. 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, based on figure 16 there has been a reduction in weight-at-age in the assessment period. 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 (Figure 17). Run settings are given in table 4. The estimated reference points are given in table 5. Due to very high estimate of F_{lim}, it was decided to not report on this value.

Due to the currently short timeseries the group recommends that reference point calculations are revisited when two more years of data are available.

Conclusion

The model presented here fit the observation reasonably well, and seem to capture trends in stock size and fishing mortality well.

The assessment model is based on data for the GRO stock, rather than previous geographical data split. The model provides a useful tool for assessing the GRO stock.

References

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

Table 1. Input files to SAM runs (rounded values, unrounded values can be found on stock-assessment.org)

Catch in Numbers (thousands)								
1	2							
2000	2021							
2	10							
1								
0.00	1.45	44.92	78.82	1.90	0.07	0.04	0.00	0.00
-1	-1	-1	-1	-1	-1	-1	-1	-1
0.07	117.81	536.13	175.45	8.77	3.07	0.21	0.08	0.02
0	32.10	102.46	413.66	50.20	6.44	1.32	1.30	0.71
0	169.21	490.47	243.93	50.30	10.21	0.22	0	0
4.06	229.03	430.68	221.64	31.89	4.56	1.36	0.33	0.01
4.47	1192.58	629.43	195.74	10.40	1.20	0.33	0.20	0.00
0.20	401.20	1005.32	197.63	50.06	20.69	6.91	3.83	0.84
0	104.98	972.97	772.23	146.68	23.02	3.07	0.87	0
0.13	89.67	426.70	455.51	68.96	4.47	0.95	0.08	0.27
0.01	22.32	150.28	431.38	393.49	35.01	12.09	7.39	9.19
0.03	14.45	374.25	507.03	312.50	62.17	19.35	2.88	1.69
0.12	168.06	251.20	446.15	195.15	51.22	9.92	6.17	2.07
0.17	41.38	943.46	539.71	275.76	100.11	29.83	24.30	4.82
0	12.04	442.88	1133.61	620.94	105.36	79.87	47.68	21.79
0.16	8.03	615.24	2075.86	1238.79	421.23	75.41	9.32	6.65
0	12.60	631.13	3033.29	2484.30	594.88	86.84	18.76	2.55
0.03	15.51	484.19	1947.30	1948.46	1622.52	318.16	66.66	22.29
0.00	6.50	720.51	1424.78	1579.82	1101.00	626.21	152.77	38.09
0	20.16	375.84	1597.19	1133.88	728.45	311.44	103.73	32.99
0	39.61	479.22	885.36	1016.85	346.39	220.03	69.59	38.33
0.00	1.98	426.20	1123.76	455.21	291.45	84.42	73.66	22.44

Table 1 *continued*

Mean Weight in Catch (kilograms)								
1	3							
2000	2021							
2	10							
1								
NA	0.64	1.12	1.45	2.38	2.62	2.41	NA	NA
NA	NA	NA	NA	NA	NA	NA	NA	NA
0.36	0.71	1.00	1.40	2.32	1.88	2.85	3.56	3.36
NA	1.06	1.43	2.09	2.53	3.65	4.58	4.81	6.85
NA	1.00	1.26	1.54	2.28	2.92	6.13	NA	NA
0.41	0.78	1.10	1.73	2.47	2.69	3.23	6.92	8.30
0.36	0.75	0.96	1.50	2.91	3.74	4.96	7.33	8.13
0.19	0.68	1.04	1.67	2.84	4.23	5.69	6.65	10.17
NA	0.63	0.91	1.45	2.18	3.45	5.59	7.31	NA
0.23	0.63	0.95	1.49	2.49	4.51	5.92	8.53	13.52
0.50	0.67	1.06	1.59	2.21	3.28	4.88	6.92	9.37
0.38	0.70	1.00	1.53	2.15	3.32	5.41	7.91	10.67
0.44	0.79	1.13	1.80	2.75	3.82	5.61	6.65	13.16
0.24	0.77	1.28	1.65	2.27	3.31	3.93	4.45	6.13
NA	0.68	1.21	1.95	2.58	3.50	5.39	5.81	7.32
0.13	0.68	1.10	1.69	2.41	3.45	4.84	7.31	11.98
NA	0.52	1.03	1.46	2.19	3.08	3.97	4.39	9.14
0.16	0.50	0.80	1.29	1.88	2.71	3.47	4.33	7.55
0.09	0.40	0.90	1.13	1.64	2.18	2.99	3.67	5.30
NA	0.72	0.80	1.09	1.42	1.92	2.65	3.82	5.41
NA	0.54	0.90	1.23	1.49	1.96	2.62	3.53	5.22
0.28	0.51	1.02	1.35	1.64	1.92	3.20	4.44	6.09

Table 1 *continued*

Mean Weight in survey (kilograms)								
1	3							
2000	2021							
2	10							
1								
0.15	0.32	0.75	1.06	NA	NA	NA	NA	NA
0.21	0.47	0.85	1.34	NA	NA	NA	NA	NA
0.20	0.40	0.76	0.93	1.79	NA	NA	NA	NA
0.19	0.39	0.84	1.58	1.87	NA	NA	NA	NA
0.21	0.41	0.83	1.14	1.93	2.99	NA	NA	7.11
0.15	0.33	0.74	1.47	1.71	2.75	3.30	4.51	NA
0.14	0.34	0.51	0.80	1.86	2.87	NA	NA	NA
0.13	0.35	0.63	1.39	3.31	6.90	8.35	NA	NA
0.10	0.25	0.49	0.93	1.78	2.84	NA	NA	NA
0.10	0.36	0.66	1.35	2.36	3.82	NA	NA	NA
0.13	0.30	0.69	1.14	1.98	3.01	NA	NA	NA
0.17	0.40	0.72	1.32	2.16	3.52	7.68	NA	NA
0.14	0.38	0.72	1.20	1.87	3.36	4.74	NA	NA
0.11	0.33	0.59	0.79	1.67	2.66	4.12	6.15	NA
0.14	0.30	0.68	0.99	1.75	2.45	3.47	5.29	8.75
0.10	0.35	0.62	1.12	1.64	2.66	4.15	4.93	9.06
0.09	0.35	0.73	1.12	1.77	2.84	4.17	6.27	17.60
0.08	0.26	0.65	1.04	1.48	1.96	3.80	5.92	5.21
0.08	0.26	0.55	0.91	1.52	2.62	2.98	3.64	7.34
0.09	0.29	0.62	1.04	1.35	2.12	2.19	2.29	5.77
0.10	0.27	0.55	1.12	1.56	3.03	3.59	4.72	5.74
NA	NA	NA	NA	NA	NA	NA	NA	NA

Table 1 *continued*

Proportion	Mature	at	Year	Start				
1	6							
2000	2021							
2	10							
1								
0.032	0.117	0.349	0.685	0.898	0.973	0.993	0.998	1
0.032	0.117	0.349	0.685	0.898	0.973	0.993	0.998	1
0.032	0.117	0.349	0.685	0.898	0.973	0.993	0.998	1
0.032	0.117	0.349	0.685	0.898	0.973	0.993	0.998	1
0.032	0.117	0.349	0.685	0.898	0.973	0.993	0.998	1
0.032	0.117	0.349	0.685	0.898	0.973	0.993	0.998	1
0.032	0.117	0.349	0.685	0.898	0.973	0.993	0.998	1
0.032	0.117	0.349	0.685	0.898	0.973	0.993	0.998	1
0.032	0.117	0.349	0.685	0.898	0.973	0.993	0.998	1
0.032	0.117	0.349	0.685	0.898	0.973	0.993	0.998	1
0.032	0.117	0.349	0.685	0.898	0.973	0.993	0.998	1
0.032	0.117	0.349	0.685	0.898	0.973	0.993	0.998	1
0.032	0.117	0.349	0.685	0.898	0.973	0.993	0.998	1
0.032	0.117	0.349	0.685	0.898	0.973	0.993	0.998	1
0.032	0.117	0.349	0.685	0.898	0.973	0.993	0.998	1
0.032	0.117	0.349	0.685	0.898	0.973	0.993	0.998	1
0.032	0.117	0.349	0.685	0.898	0.973	0.993	0.998	1
0.032	0.117	0.349	0.685	0.898	0.973	0.993	0.998	1
0.032	0.117	0.349	0.685	0.898	0.973	0.993	0.998	1
0.032	0.117	0.349	0.685	0.898	0.973	0.993	0.998	1
0.032	0.117	0.349	0.685	0.898	0.973	0.993	0.998	1
0.032	0.117	0.349	0.685	0.898	0.973	0.993	0.998	1

Table 1 *continued*

```
Natural Mortality
1 5
2000 2021
2 10
1
0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2
0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2
0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2
0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2
0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2
0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2
0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2
0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2
0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2
0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2
0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2
0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2
0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2
0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2
0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2
0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2
0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2
0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2
0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2
0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2
0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2
0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2
```

Table 1 *continued*

```
Tuning series GRO
   102
TrawlSurveyIndex WG INLA GRO WG INLA run version: Wed Jan 25 09:39:06 2023
  2000        2020
     1           1        0.58        0.65
     2           7
     1    0.207105    0.079475    0.010987          -1          -1          -1
     1    1.346273    0.041142      0.0069    0.002931          -1          -1
     1    0.493022    0.170489    0.004759    1.34E-03          -1          -1
     1    0.126772    0.074254    0.028617    0.003594    0.003464          -1
     1    0.961959    0.037966    0.009657    0.010129    0.001454          -1
     1    2.277263    0.200627    0.147472    0.033324    0.014643    0.004489
     1    1.029026    0.882332    0.151752    0.019407    0.012763    0.007092
     1    1.854506    0.183186    0.237046    0.041817    0.003323     0.00102
     1    0.611825    0.700905    0.183146    0.237727    0.016215    0.001825
     1    1.379845    0.129253    0.100926     0.05709    0.007765    0.000393
     1    0.474945    0.377464    0.066311    0.083756    0.011462    0.013615
     1    9.357454    0.300439    0.195314    0.066779    0.040553    0.002218
     1    3.891438    1.374566    0.140934    0.175895    0.025385    0.007941
     1    1.475258    1.008686    0.859167    0.358936    0.239376     0.02251
     1    0.815139    0.395648    0.549301    0.769695    0.108445     0.03636
     1    1.046341    0.505421    0.445286    1.103181    1.065704    0.094178
     1    1.277586    0.208273    0.175748    0.189971    0.192858    0.177976
     1    1.505417    0.552788    0.171214    0.285676    0.555242    0.500175
     1    2.421591    0.598853    0.275268    0.119314    0.095341    0.127214
     1    2.303369     1.05415    0.692326    0.476296    0.178611    0.350005
     1     0.43685    0.780865    0.310607    0.161614    0.090188    0.020667
```

GillnetSurveyIndex

2002	2021				
1	1	0.5	0.6		
2	6				
1	32.09038	9.438202	3.648234	1.8229	0.112536
1	10.81176	10.46875	2.725995	0.52028	0.04358
1	6.651614	3.730037	2.245078	0.623386	0.119833
1	51.30584	3.648065	0.77218	1.234244	0.107987
1	20.24053	12.65301	3.138397	1.443122	0.174862
1	-1	-1	-1	-1	-1
1	-1	-1	-1	-1	-1
1	-1	-1	-1	-1	-1
1	22.04239	15.74423	9.082689	2.909125	0.269459
1	159.6708	21.08542	5.810838	3.867302	0.891728
1	43.48302	84.90728	4.702534	5.415372	0.680279
1	35.69835	22.70113	24.50877	4.757546	1.825251
1	13.08554	17.90735	10.28771	5.525285	0.932306
1	17.18419	21.18738	18.91574	11.85788	10.11144
1	13.73128	38.29884	10.79203	12.52488	5.88219
1	3.081926	23.39647	22.88057	12.96125	6.208067
1	11.22121	12.10852	12.57412	9.231894	7.37477
1	32.3187	48.90307	7.216479	9.383809	6.830387
1	16.1368	27.01823	11.68391	6.666883	12.25405
1	111.0928	21.57428	21.6806	15.41652	10.85895

Table 2. SAM configurations for WKGREENCOD_GRO

```
# 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
1	2009	8	0
1	2010	8	0
1	2000	9	0
1	2001	9	0
1	2002	9	0
1	2003	9	0
1	2004	9	0
1	2005	9	0
1	2006	9	0
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
2	2004	2	1
2	2005	2	1
2	2006	2	1
2	2007	2	1
2	2008	2	1
2	2009	2	1
2	2010	2	1
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2	2001	3	1
2	2002	3	1
2	2003	3	1
2	2004	3	1
2	2005	3	1
2	2006	3	1

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

3	2004	3	2
3	2005	3	2
3	2006	3	2
3	2007	3	2
3	2008	3	2
3	2009	3	2
3	2010	3	2
3	2000	4	2
3	2001	4	2
3	2002	4	2
3	2003	4	2
3	2004	4	2
3	2005	4	2
3	2006	4	2
3	2007	4	2
3	2008	4	2
3	2009	4	2
3	2010	4	2
3	2000	5	2
3	2001	5	2
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3	2003	5	2
3	2004	5	2
3	2005	5	2
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

Table 3. Table of SAM model parameters.

Parameter name	par	sd(par)	exp(par)	Low	High
logFpar_0	-8.308	0.167	0.000	0.000	0.000
logFpar_1	-9.269	0.143	0.000	0.000	0.000
logFpar_2	-9.637	0.157	0.000	0.000	0.000
logFpar_3	-9.168	0.159	0.000	0.000	0.000
logFpar_4	-8.871	0.181	0.000	0.000	0.000
logFpar_5	-8.781	0.266	0.000	0.000	0.000
logFpar_6	-5.428	0.159	0.004	0.003	0.006
logFpar_7	-5.882	0.163	0.003	0.002	0.004
logFpar_8	-5.602	0.151	0.004	0.003	0.005
logSdLogFsta_0	-1.079	0.221	0.340	0.219	0.529
logSdLogN_0	-0.562	0.204	0.570	0.379	0.857
logSdLogObs_0	0.391	0.231	1.479	0.933	2.346
logSdLogObs_1	-0.456	0.230	0.634	0.400	1.004

logSdLogObs_2	-0.749	0.133	0.473	0.362	0.618
logSdLogObs_3	-0.631	0.201	0.532	0.356	0.795
logSdLogObs_4	-0.810	0.205	0.445	0.295	0.670
logSdLogObs_5	-0.678	0.163	0.508	0.366	0.704
logSdLogObs_6	-0.519	0.174	0.595	0.421	0.843
logSdLogObs_7	-0.106	0.130	0.899	0.693	1.166
logSdLogObs_8	-0.667	0.195	0.513	0.347	0.759
logSdLogObs_9	-0.585	0.150	0.557	0.413	0.753
transfIRARdist_0	-0.176	0.282	0.839	0.478	1.474
transfIRARdist_1	0.077	0.348	1.080	0.538	2.167
logPhiSW_0	4.251	1.610	70.172	2.805	1755.190
logPhiSW_1	4.541	1.639	93.757	3.538	2484.376
logSdProcLogSW_0	0.506	0.720	1.659	0.393	7.000
meanLogSW_0	-2.078	0.122	0.125	0.098	0.160
meanLogSW_1	-1.133	0.119	0.322	0.254	0.408
meanLogSW_2	-0.452	0.117	0.636	0.503	0.804
meanLogSW_3	0.057	0.116	1.059	0.839	1.336
meanLogSW_4	0.546	0.118	1.727	1.365	2.185
meanLogSW_5	1.021	0.121	2.777	2.182	3.534
meanLogSW_6	1.390	0.128	4.013	3.109	5.181
meanLogSW_7	1.547	0.138	4.696	3.566	6.185
meanLogSW_8	2.016	0.147	7.509	5.598	10.073
logSdLogSW_0	-1.786	0.107	0.168	0.135	0.208
logPhiCW_0	3.681	1.243	39.693	3.303	477.010
logPhiCW_1	4.268	1.232	71.380	6.071	839.221
logSdProcLogCW_0	0.705	0.577	2.025	0.638	6.422
meanLogCW_0	-1.390	0.150	0.249	0.184	0.336
meanLogCW_1	-0.420	0.141	0.657	0.496	0.871
meanLogCW_2	0.006	0.137	1.006	0.765	1.324
meanLogCW_3	0.378	0.136	1.460	1.113	1.915
meanLogCW_4	0.735	0.136	2.085	1.590	2.735
meanLogCW_5	1.017	0.137	2.766	2.101	3.640
meanLogCW_6	1.351	0.141	3.860	2.913	5.114
meanLogCW_7	1.609	0.146	4.999	3.733	6.695
meanLogCW_8	1.981	0.153	7.248	5.333	9.850
logSdLogCW_0	-2.489	0.354	0.083	0.041	0.168
logXtraSd_0	0.957	0.158	2.604	1.898	3.573
logXtraSd_1	0.450	0.166	1.568	1.125	2.185
logXtraSd_2	0.214	0.191	1.238	0.845	1.814

Table 4. Run setting for EqSim

From R scripts	description	Value
stockName	Name of the stock	GRO
SAOAssessment	Name of assessment on stockassessmet.org	WKGREENCOD_GRO
sigmaF	From SAM assessment	0.206485
sigmaSSB	Default value of 0.2	0.2
noSims	Recommended minimum 1000	1500
SRused	Models used in the simulations (usually segmented regression, Ricker, beverton-holt). Weight given to the model in the simulation given in brackets.	Beverton-Holt (100%)
SRyears_min	Same as assessment	2000
SRyears_max	Same as assessment	2020
rhoRec	Autocorrelation in recruitment	F (default)
numAvgYrsB	Years used for the average Weight at age	5
numAvgYrsS	Years used for the average selectivity	10
cvF	Forecast error F	Default = 0.212
phiF	Forecast error F	Default = 0.423
cvSSB	Forecast error SSB	Default = 0
phiSSB	Forecast error SSB	Default = 0
SSB05	5th percentile of SSB in the final year of the assessment, used in MSY Btrigger calculation. If set at 0, ignored.	Set to 0
rmSRRYrs	Which years (SSB years, not recruitment years) to exclude from the SRR fits	None

Table 5. Reference points estimated from EqSim. Flim not reported.

Framework	Reference point	Value	Technical basis
Precautionary approach	B_{lim}	3219	Segmented regression, lower biomass where high recruitment has been observed, visual judgement.
	B_{pa}	4473	Bpa = Blim × exp(1.645 × σ), σ=0.245
	F_{lim}	NA	The fishing mortality rate (F) that in stochastic equilibrium will result in median (SSB) = Blim (i.e. 50% probability of SSB being above or below Blim).
	Fpa	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).
MSY approach	F_{MSY}	0.18	F that provides maximum yield
	MSY $B_{trigger}$	4473	MSY Btrigger = maximum (Bpa, the 5th percentile of the distribution of SSB when fishing at FMSY)

Figure 1. Catch weight at age (in kilograms).. Numbers give the input values by age, the line give the estimates from the model

Figure 2. Stock weight at age (in kilograms). Numbers gives the input values by age, the line give the estimates from the model.

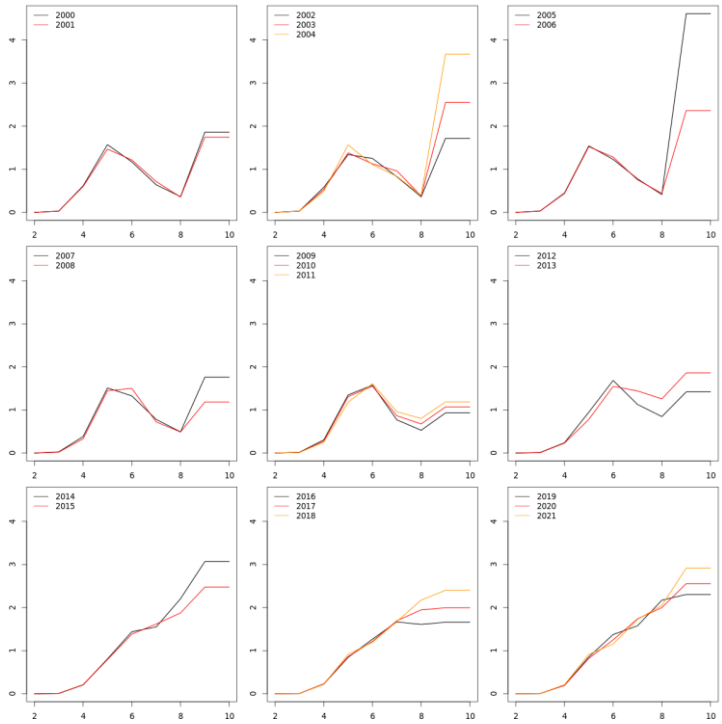

Figure 3. Selection pattern (F_{age}/Fbar) from the SAM model.

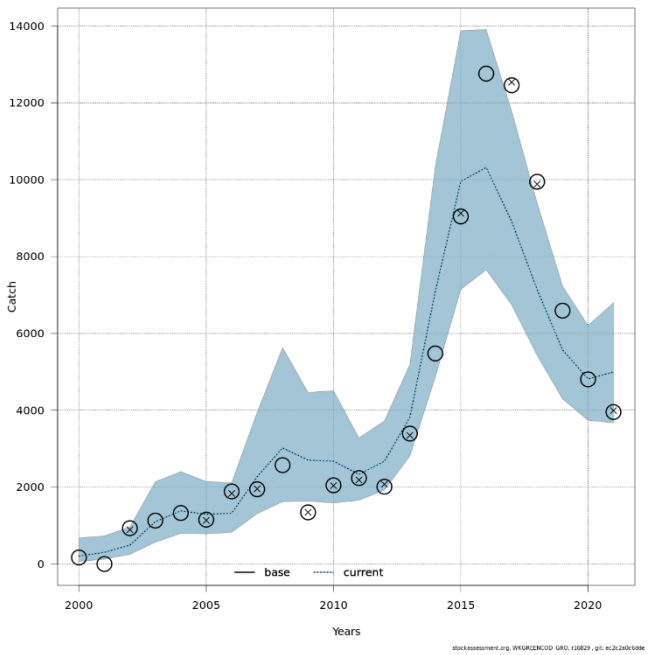

Figure 4. Estimated (line), observed catches (x), and catches based on smoothed catch weights (o). Estimated catch is shown with 95% confidence intervals.

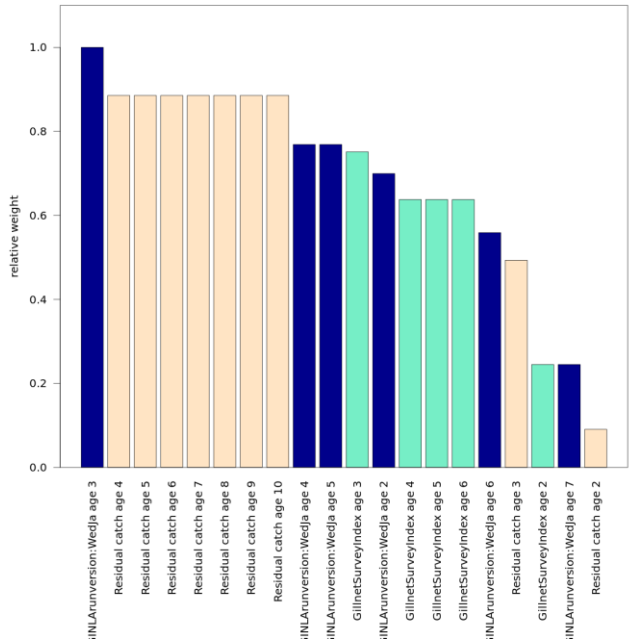

Figure 5. Relative weighting of input data.

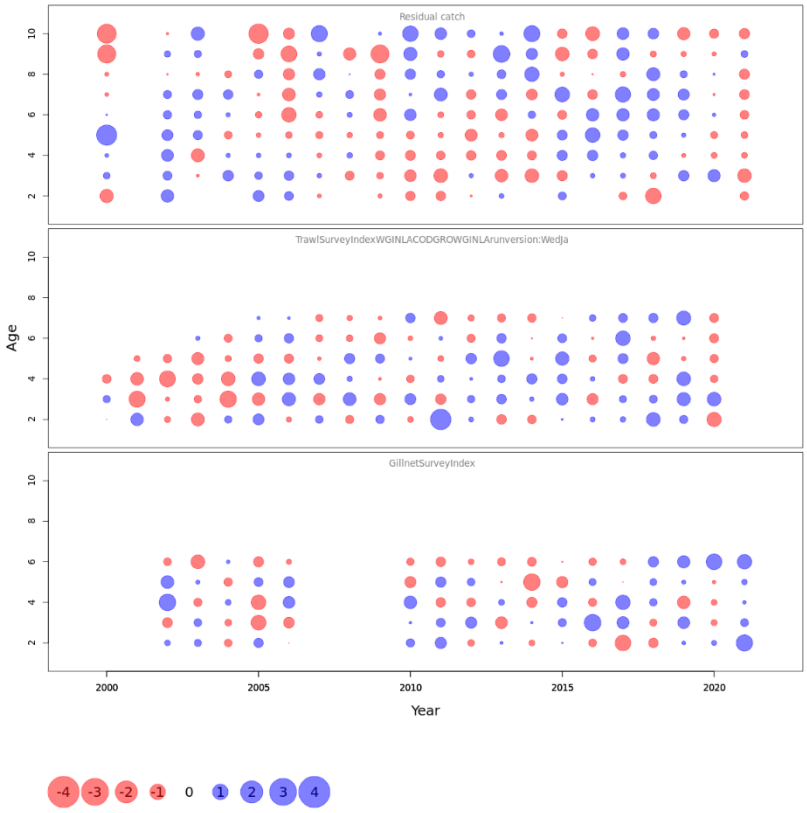

Figure 6. Normalized residuals derived from SAM. Blue indicate positive residuals (observation larger than predicted) and red circles indicated negative residuals.

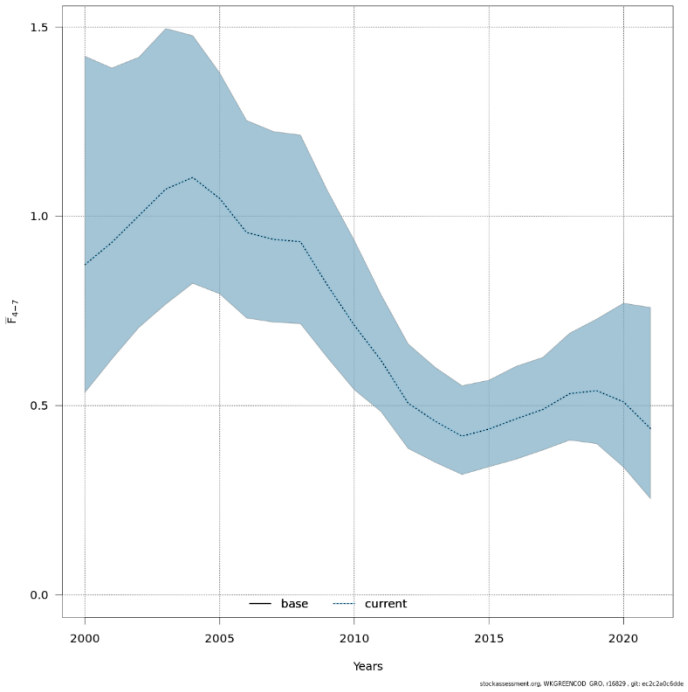

Figure 7. Estimated historical pattern of fishing mortality (Fbar4-7). The shaded area is 95% confidence intervals.

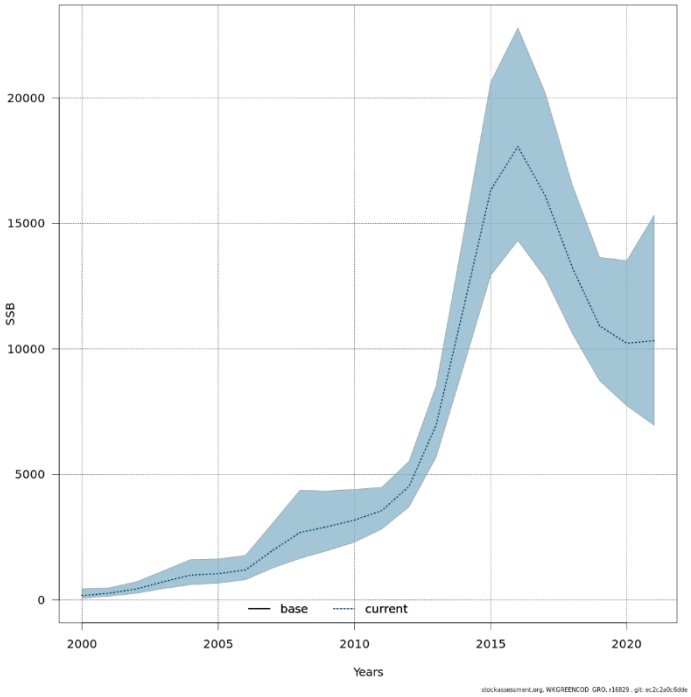

Figure 8. Estimated historical patterns of spawning stock biomass (SSB). The shaded area is 95% confidence intervals.

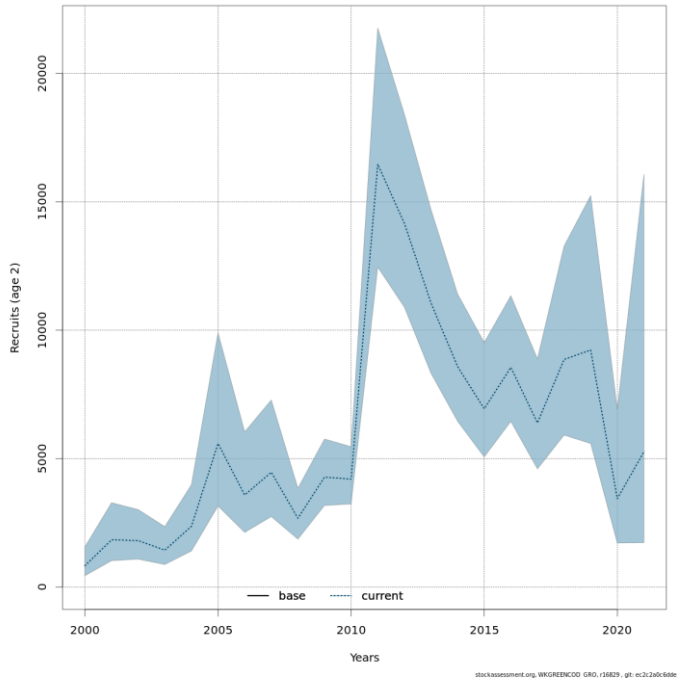

Figure 9. Estimated historical patterns of age 2 recruitment. The shaded area is 95% confidence intervals.

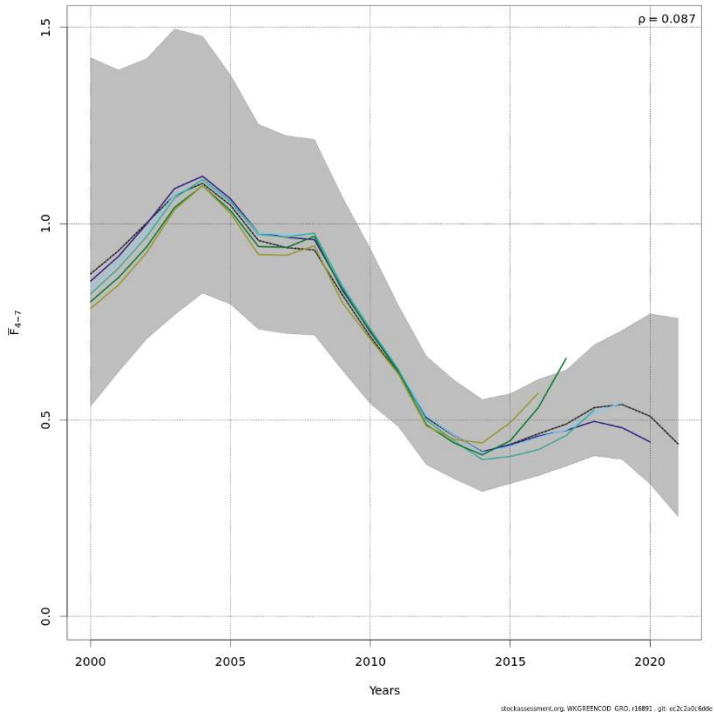

Figure 10. Retrospective plots of Fbar (5 years peel). Mohn's rho is given in the upper right corner.

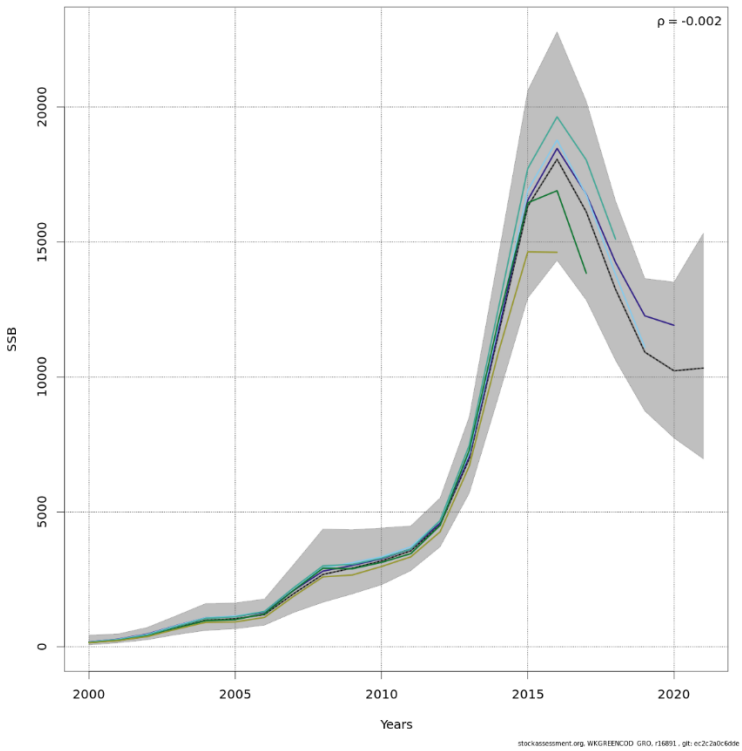

Figure 11. Retrospective plots of SSB (5 years peel). Mohn's rho is given in the upper right corner.

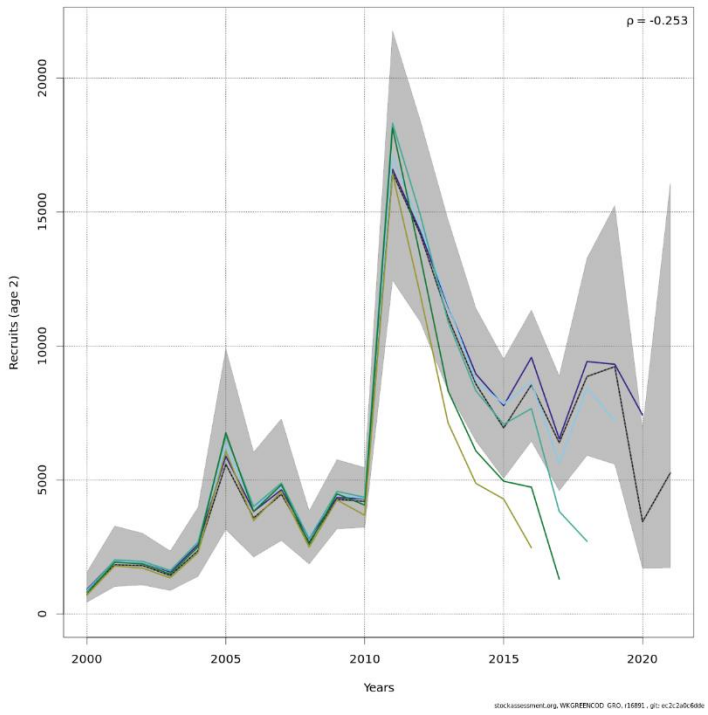

Figure 12. Retrospective plots of age 2 recruitment (5 years peel). Mohn's rho is given in the upper right corner.

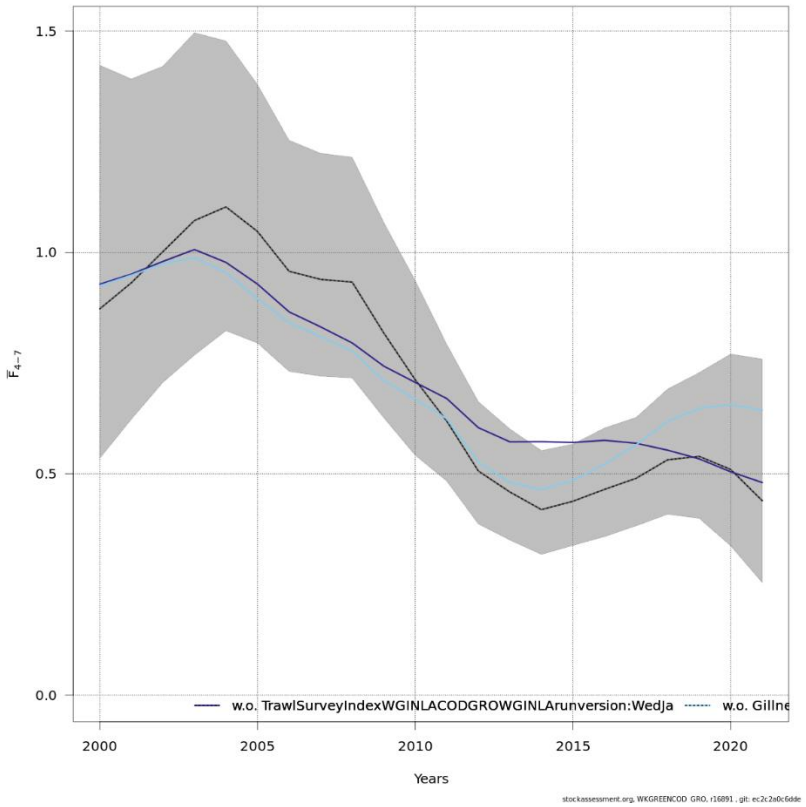

Figure 13. Leave one out plot for Fbar. Black line is with all data. Dark blue line without the INLA survey index. Light blue line without the CPUE index.

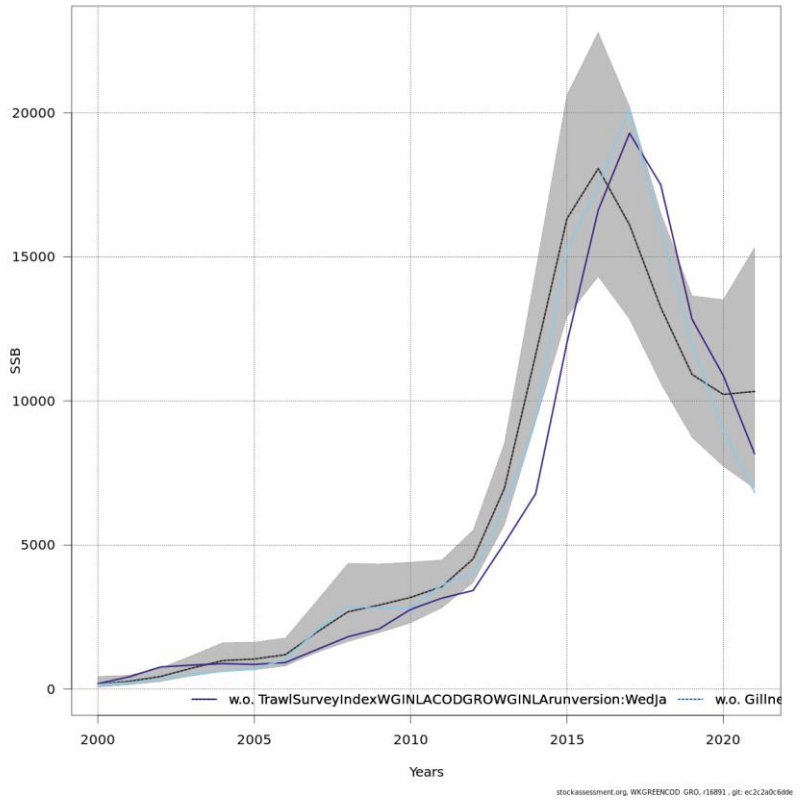

Figure 14. Leave one out for SSB Black line is with all data. Dark blue line without the INLA survey index. Light blue line without the CPUE index.

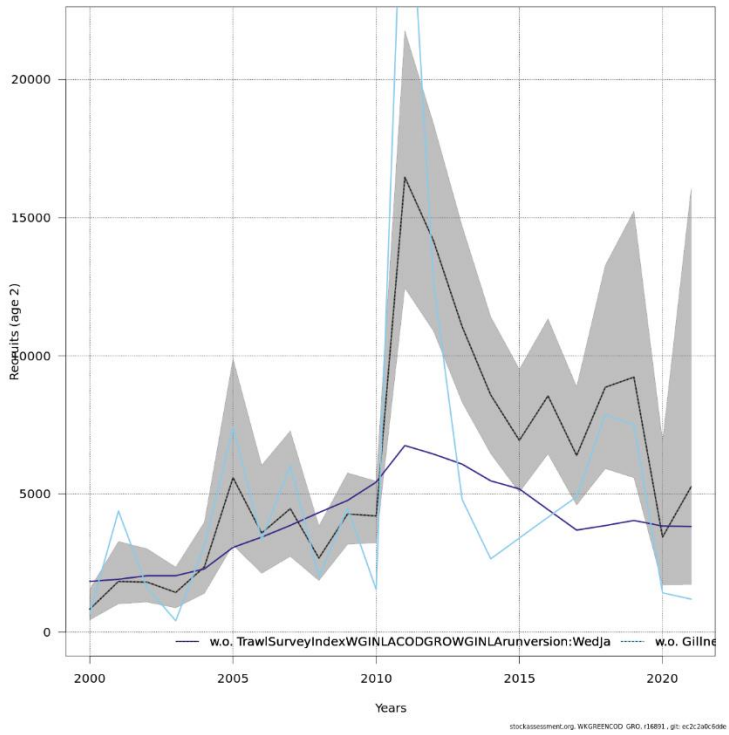

Figure 15. Leave one out for recruitment Black line is with all data. Dark blue line without the INLA survey index. Light blue line without the CPUE index.

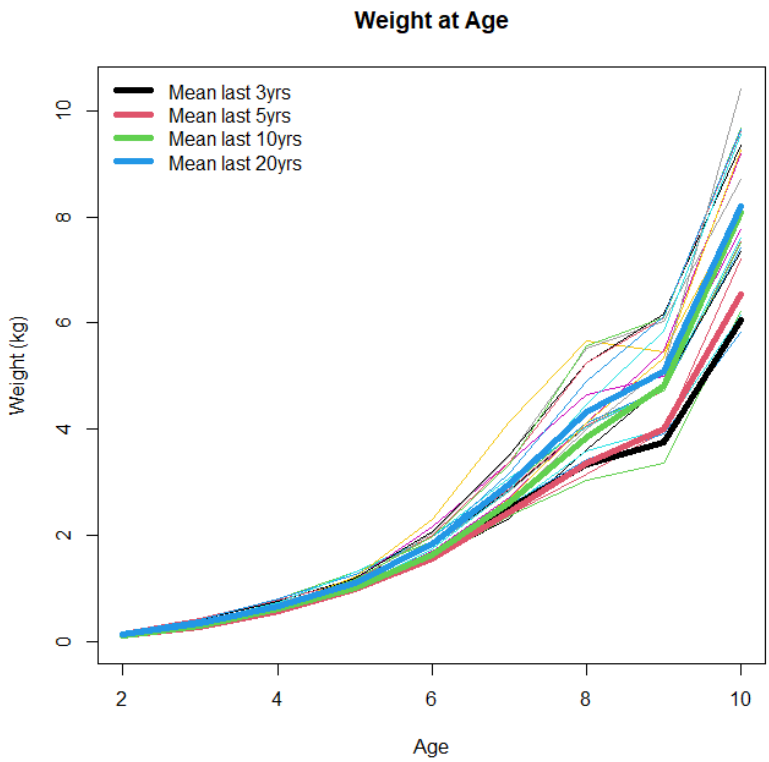

Figure 16. Stock weight at age for all years, bold line show means.

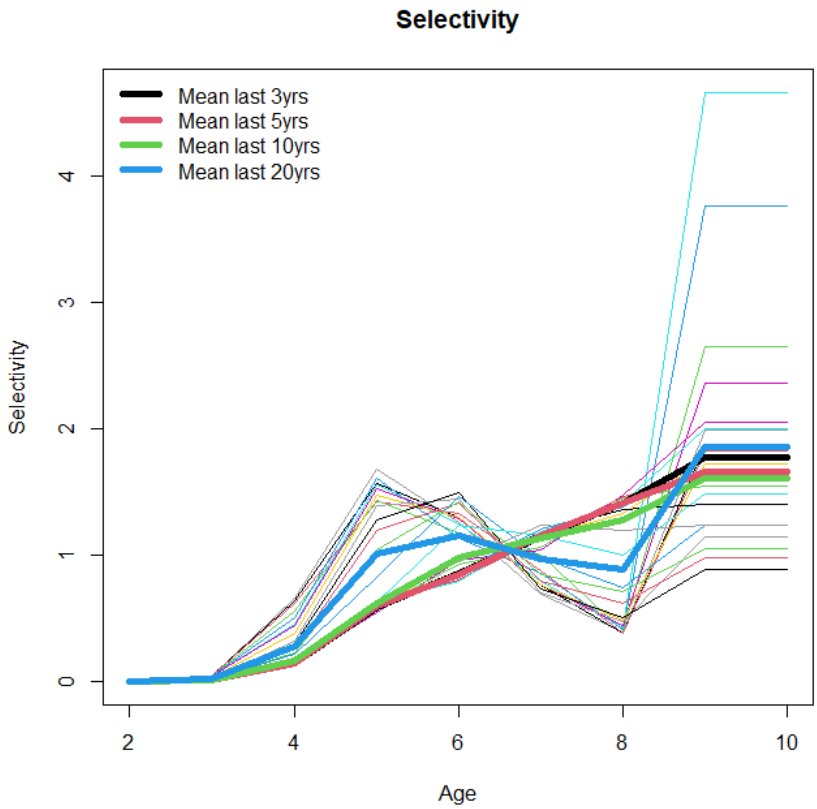

Figure 17. Selectivity at age for all years, bold line show means.

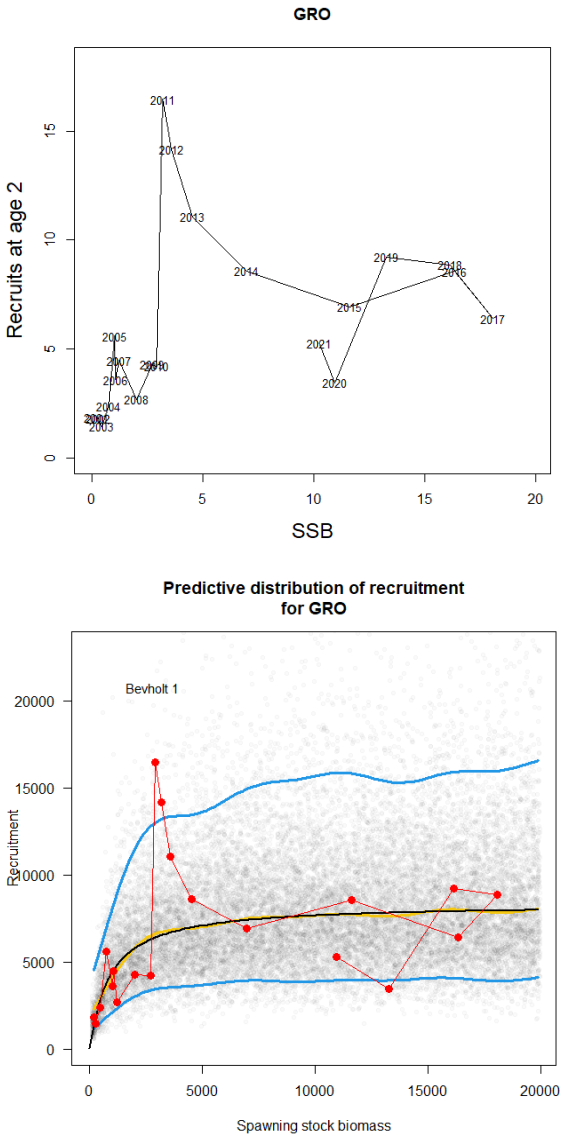

Figure 18. left: SSB-recruitment relationship, labels indicate recruitment year. right: SSB-recruitment relationship estimated by simulation using EqSim with fitted SSB-recruitment relationships. The solid line gives the fitted model and the blue lines indicated the interval in which 95% of the simulations falls.

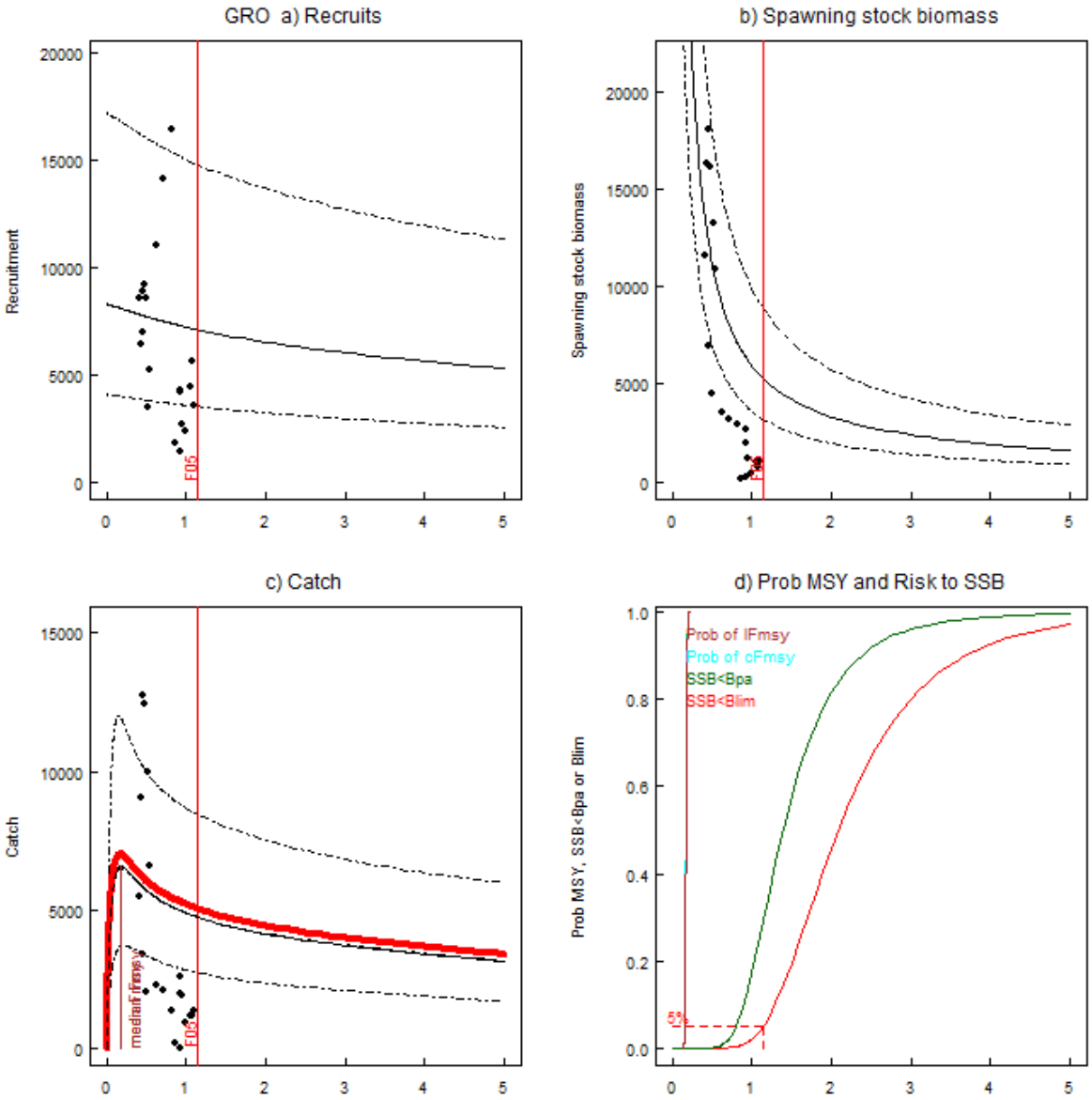

Figure 19. EqSim plots of recruitment, SSB, catch and probability of SSB falling below Bpa and Blim. F is on the x-axis.

WD 08 - A SAM assessment of the West Greenland inshore cod stock (GRI)

Stockassessment.org run name: **WKGREEENCOD_GRI**

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Introduction

The Atlantic cod (*Gadus morhua*) in Greenland waters is primarily of three genetically distinct stocks: West Greenland inshore (GRI), West Greenland offshore (GRO), and East Greenland-Iceland (EGI) (see WD01 for details). Previously advice has been provided based on geographical areas. At WKGREENCOD data from the commercial fisheries and scientific surveys in Greenland waters are split into the three stock components (see WD01, WD02, WD05).

This document presents the results of the state-space model (SAM) (Nielsen and Berg, 2014) for the GRI stock and attempts at estimating reference points using EqSim. It was not possible to do a EqSim run that could be accepted. This document was updated following the discussions during the WKGREENCOD meeting.

Input data

The input data for the SAM assessment model are described in WD05. The Assessment covers the period 2000-2021.

Total catches
Total catches were available for the stock GRI from 2000-2021, due to poor sampling in 2001 catch data are not included from that year (see Table 1 for input file). No discarding is believed to take place, landings are assumed to equal catches.

Catch mean weight at age
Catch mean weight at age were estimated for all years. Some age-year combination without sufficient data were left as NA in the input file (see Table 1 for input file). The given catch mean weights were then treated as observation to inform the catch weight process (GMRF with cohort and within year correlations) ($catchWeightModel, $keyCatchWeightMean and $keyCatchWeightObsVar in Table 2). See figure 1 for catch weights estimated by the model.

Landings mean weights and discard mean weights are set equal to catch mean weight without any smoothing as these are not used.

Stock mean weight at age
The same process as described to Catch mean weights were used for stock mean weights (see Table 1 for input file) ($stockWeightModel, $keyStockWEightMean and $keyStockWeightObsVar in Table 2), see figure 2 for stock weight estimated by the model.

Surveys
Survey CPUE index by age for ages 2-8 estimated from inshore gillnet survey combined for two inshore areas (see Table 1 for input file), for details on survey data see WD05 and for details on index calculations see WD06.

Landings fraction
Set to 1, landings are assumed to equal catches.

Natural mortality
Set to default 0.2 for all years and ages (see Table 1 for input file). See details in WD05.

Maturity
Maturity ogive is based on genetic dataset presented in WD01 (see Table 1 for input file). Not enough data to produce annual maturity ogives. Details are given in WD05.

F before spawning
The fraction of the fishing mortality rate, which is applied prior to spawning divided into age classes for each year. Set to 0 for all years and ages.

M before spawning
The fraction of the natural mortality rate, which is applied prior to spawning divided into age classes for each year. Set to 0 for all years and ages.

Assessment

Configurations

Recruitment
Recruitment parameters are estimated within the assessment model. The parameter structure is assumed as a plain random walk process ($stockRecruitmentModelCode in Table 2).

Fishing mortality and Fbar
Fishing mortality is estimated individually for ages 2-8, age 9 and 10 are assumed to be the same ($keyLogFsta in Table 2). It is assumed that there are no correlations across ages ($corFlag in Table 2), this is supported by changes in the selectivity pattern during the assessment period, meaning that correlations between ages are unlikely to be consistent throughout the period (Figure 3). The Fbar range was set to 4-7 years old as these ages constitutes the main part of the catches ($fbarRange in Table 2).

Survey
The survey catchability parameters are estimated individually for each age ($keyLogFpar in Table 2).

Variance parameters
For age 2 the coupling of the recruitment and survival process variance parameters for the log(N)-process are different from the other ages ($keyVarLogN in Table 2). In the model.R script the following was added: par$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.

The variance parameters for the catch are separate for age 2, 3 and 4, and they are coupled for ages 5-10. The variance parameters for the survey are separate for age 2 and 3, ages 4-8 are coupled ($keyVarObs in Table 2).

The covariance structure for each fleet is assumed to be independent ($obsCorStruct in Table 2). There was no clear evidence of year effects.

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 (see $predVarObsLink in Table 2) (see Breivik *et al* 2021).

Model diagnostics

Uncertainty surrounding the SSB and F estimates appears reasonable (Figure 7 and 8), although high on F for the first couple of years in the time series. The estimated catches are in line with the observed catches (Figure 4).

Parameter estimation
Parameter estimates are given in Table 3.

Residuals
Observation residuals for both catches and survey shows some tendency for larger residuals early in the time series (Figure 5). There is a block of negative residuals for the survey residuals early in the timeseries and a block of positive residuals in the most recent years. For the catch residuals there are a block of positive residuals, showing that the model underestimate catches in these years.

Stock summary

Fishing mortality
Fishing mortality peaked in 2004 at 1.084 and has since been decreasing to the lowest level in the assessment period at 0.559 (Figure 6).

SSB
SSB was at a low level at the beginning of the timeseries and increased from 436 in 2000 to 25459 t in 2016. Since the SSB has since decreased but remain at a high level (Figure 7).

Recruitment
Recruitment was at a low level at the beginning of the assessment period, it increased and had a peak in 2013 (cohort 2011). There was another peak in recruitment in 2016 (cohort 2014). Recruitment has been going down since. The two most recent years have had low recruitment, although these estimates were associated with very large confidence intervals (Figure 8).

Retrospective analysis
In order to test the robustness of the assessment a 5-year retrospective analysis (Figures 9-11) were conducted. For F all peels are within the confidence intervals and show some tendency to overestimate F (Mohn'r rho=0.118) (Figure 9). All peels for SSB, except one, are within confidence intervals, but show a tendency to underestimate SSB (Mohn'r rho= -0.169) (Figure 10). For recruitment only the most recent peel is within the confidence limits, all peels show a tendency to underestimate recruitment (Mohn's rho=-0.393) (Figure 11).

Alternative settings and configurations
An initial run based mainly on default configurations were used as a starting point for setting up the final SAM model. Impact of each change in configuration were evaluated during the process.

A run with additional uncertainty for the early period (2000-2010) for both catches and CPUE index, did not improve the model.
An alternative SAM run was tried without data for age 2, since both survey series and catch showed high variability for age 2, this did not improve the model diagnostics.

Short term forecast

Due to issues with estimating the reference points, short term forecasts were not explored.

Reference points

The estimation of reference points follows ICES Reference Points guidance, 2021. The estimation was done using the R-programme EqSim developed by D. C. M. Miller, which works directly on a specified SAM fit. The code for the final run is on the ICES sharepoint for the WKGREENCOD benchmark and named 'WKGREENCOD_GRI_EqSim_feb23.R'. David Miller attended parts of the meeting where reference points were discussed and provided guidance on the ICES procedures and EqSim settings. It was not possible to find an acceptable

Following ICES guidelines the stock-recruitment relationship appears to follow a type 2 stock type, where B_{lim}= segmented regression change point. This gives a B_{lim} of 3427.

The simulation settings for the initial EqSim run were as follows. The number of simulations were set to 1500. No years were omitted. 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, based on figure 13 there has been a reduction in weight-at-age in the assessment period. 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 (Figure 13). Table 4 gives the run settings for the initial runs and Table 5 and figures 14 and 15 gives the results. This run was not accepted, alternative runs were conducted. One run with only segmented regression and beverton-holt were tried, but the arguments for removing the ricker model was not strong. This run was therefore rejected. A run without the two most recent years of recruitment (with high uncertainty) were tried, this did not improve the EqSim run.

It was not possible to estimate acceptable reference points using the EqSim.

Conclusion

The model presented here fit the observation reasonably well, however retrospective analysis indicates some instability. It was not possible to get acceptable reference points based on this assessment using EqSim.

The assessment model is based on data for the GRI stock, rather than previous geographical data split.

References

Breivik, O. N., Nielsen, A., Berg, C. W. 2021. Prediction-variance relation in a state-space fish stock assessment model. ICES Journal of Marine Science. 78 (10): 3650-3657.
Nielsen A, Berg CW. 2014. Estimation of time-varying selectivity in stock assessments using state-space models. Fisheries research. 158: 96-101.

Table 1. Input files to SAM runs (rounded values, unrounded values can be found on stock-assessment.org)

Catch in Numbers (thousands)

1	2							
2000	2021							
2	10							
1								
0.00	1.54	65.70	117.78	2.73	0.09	0.05	0.00	0.00
-1	-1	-1	-1	-1	-1	-1	-1	-1
0.14	215.51	971.39	294.39	15.32	5.14	0.35	0.14	0.04
0	38.11	145.25	488.78	76.84	16.57	5.28	5.18	3.95
0	210.67	645.52	411.39	90.61	18.57	0.90	0	0
4.06	426.81	772.83	360.17	69.49	12.86	4.81	1.45	0.04
9.45	1511.88	1439.42	380.10	15.49	1.01	0.36	0.23	0.00
0.08	799.93	1975.18	489.15	61.43	19.87	6.90	4.17	3.56
0	270.03	2043.83	1233.31	223.75	36.04	3.73	0.90	0
0.10	171.64	1314.00	1079.10	117.53	8.79	1.95	0.21	2.70
0.04	75.92	392.64	1045.67	779.56	87.43	16.24	10.72	14.45
0.02	39.07	1033.90	1175.76	736.03	130.75	63.77	5.73	3.41
0.09	205.02	708.37	1274.11	421.32	92.72	11.04	10.12	8.07
0.24	64.53	1254.95	1132.02	577.64	194.59	61.64	31.97	6.22
0.00	20.60	683.54	1712.45	1148.99	168.13	69.33	43.52	24.44
0.05	11.69	1089.45	2924.32	1432.29	664.56	63.97	5.75	4.42
0	14.80	1126.10	5023.71	2802.86	535.11	121.31	28.35	4.00
0.01	22.55	762.80	3340.96	2557.28	1598.58	273.75	101.98	27.79
0.00	10.14	1137.27	2300.88	2179.06	1214.87	440.52	96.50	45.25
0	20.90	737.97	3399.92	1918.15	890.99	275.39	57.81	16.07
0	60.00	969.36	2028.72	2444.76	419.56	233.05	52.71	21.49
0.00	1.77	806.33	2108.89	1133.74	862.72	67.61	38.63	11.08

Table 1 *continued*

Mean Weight in Catch (kilograms)

1	3							
2000	2021							
2	10							
1								
NA	0.64	1.12	1.45	2.38	2.62	2.41	NA	NA
NA	NA	NA	NA	NA	NA	NA	NA	NA
0.36	0.71	1.00	1.40	2.32	1.88	2.85	3.56	3.36
NA	1.05	1.40	2.08	2.55	3.33	4.02	5.08	6.96
NA	0.99	1.25	1.57	2.19	3.05	6.13	NA	NA
0.41	0.79	1.10	1.73	2.42	2.65	2.92	6.95	7.47
0.36	0.75	0.95	1.53	3.01	3.75	5.12	7.45	8.13
0.19	0.71	1.02	1.54	2.59	4.09	5.29	6.58	10.32
NA	0.63	0.89	1.46	2.18	3.36	5.15	7.23	NA
0.25	0.64	0.90	1.46	2.43	4.29	5.77	8.52	14.12
0.50	0.66	1.00	1.55	2.15	3.17	4.88	6.92	9.53
0.38	0.67	0.94	1.48	2.04	3.30	5.34	7.58	10.25
0.46	0.79	1.10	1.81	2.68	3.51	5.89	6.88	13.70
0.24	0.77	1.29	1.63	2.27	2.98	3.56	4.02	7.66
NA	0.69	1.23	1.93	2.51	3.39	5.26	5.68	7.94
0.13	0.77	1.13	1.74	2.49	3.34	4.95	7.67	11.95
NA	0.49	1.04	1.47	2.20	3.03	3.67	3.90	8.99
0.17	0.52	0.79	1.27	1.86	2.62	3.42	4.13	7.04
0.09	0.38	0.88	1.12	1.64	2.18	2.90	3.50	5.22
NA	0.76	0.79	1.08	1.41	1.79	2.38	3.60	4.78
NA	0.53	0.93	1.24	1.48	1.91	2.52	3.31	4.93
0.28	0.55	1.03	1.36	1.52	1.80	2.98	4.08	5.92

Table 1 *continued*

Mean Weight in survey (kilograms)

1	3							
2000	2021							
2	10							
1								
NA	NA	NA	NA	NA	NA	NA	NA	NA
NA	NA	NA	NA	NA	NA	NA	NA	NA
0.19	0.32	0.99	1.51	2.13	NA	NA	NA	NA
0.22	0.62	0.99	1.77	2.91	2.94	NA	NA	NA
0.24	0.57	1.07	1.57	2.23	3.23	5.10	NA	NA
0.21	0.44	1.16	1.80	2.10	2.79	NA	NA	NA
0.19	0.57	0.88	1.31	3.16	4.46	NA	NA	NA
NA	NA	NA	NA	NA	NA	NA	NA	NA
NA	NA	NA	NA	NA	NA	NA	NA	NA
NA	NA	NA	NA	NA	NA	NA	NA	NA
0.22	0.46	0.98	1.54	1.97	4.05	NA	NA	NA
0.19	0.33	0.96	1.47	1.88	2.63	3.14	NA	NA
0.18	0.52	1.11	1.84	2.78	4.74	6.84	NA	NA
0.14	0.38	1.10	1.47	2.14	2.68	2.74	2.25	NA
0.14	0.38	1.03	1.73	2.40	2.99	5.35	4.46	NA
0.12	0.33	0.88	1.69	2.61	3.73	5.52	NA	16.10
0.11	0.29	0.79	1.30	2.08	3.01	4.18	3.36	9.85
0.12	0.25	0.58	1.16	1.75	2.58	3.48	4.70	7.50
0.09	0.26	0.54	0.97	1.40	1.96	2.72	3.66	2.88
0.09	0.27	0.54	0.88	1.29	1.54	2.60	2.65	4.91
0.12	0.32	0.67	1.06	1.31	1.44	1.98	2.16	3.42
0.13	0.28	0.70	1.15	1.31	1.54	2.39	2.45	2.61

Table 1 *continued*

Proportion Mature at Year Start

1	6							
2000	2021							
2	10							
1								
0.020	0.085	0.299	0.661	0.899	0.976	0.995	0.999	1.000
0.020	0.085	0.299	0.661	0.899	0.976	0.995	0.999	1.000
0.020	0.085	0.299	0.661	0.899	0.976	0.995	0.999	1.000
0.020	0.085	0.299	0.661	0.899	0.976	0.995	0.999	1.000
0.020	0.085	0.299	0.661	0.899	0.976	0.995	0.999	1.000
0.020	0.085	0.299	0.661	0.899	0.976	0.995	0.999	1.000
0.020	0.085	0.299	0.661	0.899	0.976	0.995	0.999	1.000
0.020	0.085	0.299	0.661	0.899	0.976	0.995	0.999	1.000
0.020	0.085	0.299	0.661	0.899	0.976	0.995	0.999	1.000
0.020	0.085	0.299	0.661	0.899	0.976	0.995	0.999	1.000
0.020	0.085	0.299	0.661	0.899	0.976	0.995	0.999	1.000
0.020	0.085	0.299	0.661	0.899	0.976	0.995	0.999	1.000
0.020	0.085	0.299	0.661	0.899	0.976	0.995	0.999	1.000
0.020	0.085	0.299	0.661	0.899	0.976	0.995	0.999	1.000
0.020	0.085	0.299	0.661	0.899	0.976	0.995	0.999	1.000
0.020	0.085	0.299	0.661	0.899	0.976	0.995	0.999	1.000
0.020	0.085	0.299	0.661	0.899	0.976	0.995	0.999	1.000
0.020	0.085	0.299	0.661	0.899	0.976	0.995	0.999	1.000
0.020	0.085	0.299	0.661	0.899	0.976	0.995	0.999	1.000
0.020	0.085	0.299	0.661	0.899	0.976	0.995	0.999	1.000
0.020	0.085	0.299	0.661	0.899	0.976	0.995	0.999	1.000
0.020	0.085	0.299	0.661	0.899	0.976	0.995	0.999	1.000

Table 1 *continued*

```
Natural Mortality
1 5
2000 2021
2 10
1
0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2
0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2
0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2
0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2
0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2
0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2
0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2
0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2
0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2
0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2
0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2
0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2
0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2
0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2
0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2
0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2
0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2
0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2
0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2
0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2
0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2
0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2
```

Table 1 *continued*

```
   Inshore Gillnet (1B 1D) CPUE GRI
   102
 GillnetSurveyIndex
 2002 2021
     1         1       0.5       0.6
     2         8
     1    120.71     31.29     10.77      4.02      0.31      0.00      0.00
     1     39.72     34.34      7.95      1.47      0.12      0.01      0.00
     1     26.50     11.95      6.29      1.66      0.33      0.03      0.10
     1     79.73     11.65      2.20      3.20      0.28      0.20      0.00
     1     80.28     22.16      9.71      4.16      0.33      0.19      0.00
     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     81.44     59.50     25.74     14.42      1.18      0.24      0.00
     1    156.25     70.95     17.66     10.85      2.87      1.26      0.17
     1     87.19    114.17     17.80     32.86      2.01      0.27      0.36
     1     70.17     48.23     39.61     17.49      7.77      2.07      1.03
     1     23.91     32.45     18.66     10.10      3.44      0.38      0.29
     1     17.84     37.34     35.83     23.41     18.60      1.83      0.51
     1     27.93     49.86     22.14     22.37     10.67      3.26      0.70
     1      5.91     43.99     39.93     22.75     10.80      4.48      0.54
     1      8.79     24.25     28.95     20.01     11.27      3.92      0.64
     1     21.94     50.28     16.99     24.29     13.67      5.23      0.55
     1     11.44     30.58     20.31     18.86     40.43     14.33      4.10
     1     79.73     23.63     46.87     34.12     34.96     29.01      2.72
```

Table 2. SAM configurations for WKGREENCOD_GRI

```
# Configuration saved: Mon Jan 16 14:23:05 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  3  3  3  3  3  3
  4  5  6  6  6 6 6 -1  -1

$obsCorStruct
# Covariance structure for each fleet ("ID" independent, "AR" AR(1), or "US" for unstructured). | Possible values are:
"ID" "AR" "US"
 "ID" "ID"

$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
  NA  NA  NA  NA  NA  NA  -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

$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  -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

Table 3. Table of SAM model parameters.

Parameter name	par	sd(par)	exp(par)	Low	High
logFpar_0	-5.342	0.306	0.005	0.003	0.009
logFpar_1	-5.131	0.177	0.006	0.004	0.008
logFpar_2	-5.397	0.181	0.005	0.003	0.007
logFpar_3	-4.975	0.184	0.007	0.005	0.010
logFpar_4	-5.037	0.193	0.006	0.004	0.010
logFpar_5	-5.111	0.214	0.006	0.004	0.009
logFpar_6	-4.893	0.268	0.007	0.004	0.013
logSdLogFsta_0	-1.368	0.194	0.255	0.173	0.375
logSdLogN_0	-1.177	0.206	0.308	0.204	0.466
logSdLogObs_0	4.857	3.512	128.648	0.115	144451.740
logSdLogObs_1	3.240	4.063	25.524	0.008	86359.427
logSdLogObs_2	4.240	1.091	69.399	7.829	615.218
logSdLogObs_3	3.208	0.683	24.729	6.315	96.835
logSdLogObs_4	0.206	0.175	1.229	0.866	1.745
logSdLogObs_5	-0.361	0.183	0.697	0.483	1.005
logSdLogObs_6	-0.325	0.093	0.723	0.600	0.871
predVarObs_0	-0.383	1.366	0.682	0.044	10.481
predVarObs_1	-2.223	1.398	0.108	0.007	1.774
logPhiSW_0	4.975	1.528	144.691	6.809	3074.631
logPhiSW_1	5.996	1.604	401.759	16.234	9942.729
logSdProcLogSW_0	1.205	0.707	3.338	0.811	13.730
meanLogSW_0	-1.867	0.213	0.155	0.101	0.237
meanLogSW_1	-0.985	0.211	0.373	0.245	0.569
meanLogSW_2	-0.172	0.209	0.842	0.554	1.280
meanLogSW_3	0.289	0.209	1.335	0.879	2.028
meanLogSW_4	0.633	0.209	1.884	1.239	2.863
meanLogSW_5	0.919	0.211	2.506	1.644	3.820
meanLogSW_6	1.197	0.216	3.312	2.152	5.097
meanLogSW_7	1.080	0.225	2.946	1.879	4.619
meanLogSW_8	1.586	0.234	4.886	3.058	7.808
logSdLogSW_0	-1.788	0.128	0.167	0.129	0.216
logPhiCW_0	3.745	1.262	42.321	3.394	527.645

logPhiCW_1	4.288	1.245	72.853	6.037	879.106
logSdProcLogCW_0	0.730	0.584	2.075	0.645	6.672
meanLogCW_0	-1.370	0.154	0.254	0.187	0.345
meanLogCW_1	-0.409	0.144	0.664	0.498	0.886
meanLogCW_2	-0.002	0.141	0.998	0.753	1.322
meanLogCW_3	0.374	0.139	1.454	1.101	1.919
meanLogCW_4	0.720	0.139	2.055	1.556	2.714
meanLogCW_5	0.983	0.141	2.672	2.016	3.541
meanLogCW_6	1.309	0.144	3.701	2.774	4.938
meanLogCW_7	1.577	0.150	4.840	3.588	6.528
meanLogCW_8	1.970	0.157	7.169	5.236	9.816
logSdLogCW_0	-2.332	0.274	0.097	0.056	0.168

Table 4. Run setting for EqSim

From R scripts	description	Value
stockName	Name of the stock	GRI
SAOAssessment	Name of assessment on stockassessmet.org	WKGREENCOD_GRI
sigmaF	From SAM assessment	0.13
sigmaSSB	From SAM assessment	0.15
noSims	Recommended minimum 1000	1500
SRused	Models used in the simulations (usually segmented regression, Ricker, beverton-holt). Weight given to the model in the simulation given in brackets.	Segmented regression (9%) Ricker (76%) Beverton-Holt (15%)
SRyears_min	Same as assessment	2000
SRyears_max	Same as assessment	2020
rhoRec	Autocorrelation in recruitment	F (default)
numAvgYrsB	Years used for the average Weight at age	5
numAvgYrsS	Years used for the average selectivity	10
cvF	Forecast error F	Default = 0.212
phiF	Forecast error F	Default = 0.423
cvSSB	Forecast error SSB	Default = 0
phiSSB	Forecast error SSB	Default = 0
SSB05	5th percentile of SSB in the final year of the assessment, used in MSY Btrigger calculation. If set at 0, ignored.	Set to 0
rmSRRYrs	Which years (SSB years, not recruitment years) to exclude from the SRR fits	None

Table 5. Reference points estimated from EqSim. These were not accepted.

Framework	Reference point	Value	Technical basis
Precautionary approach	B_{lim}	3427	Segmented regression.
	B_{pa}	4388	Bpa = Blim × exp(1.645 × σ), σ=0.15
	F_{lim}	NA	The fishing mortality rate (F) that in stochastic equilibrium will result in median (SSB) = Blim (i.e. 50% probability of SSB being above or below Blim).
	Fpa	2.35	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).
MSY approach	F_{MSY}	0.98	F that provides maximum yield
	MSY $B_{trigger}$	4388	MSY Btrigger = maximum (Bpa, the 5th percentile of the distribution of SSB when fishing at FMSY)

Figure 1. Catch weight at age (in kilograms). Numbers give the input values by age, the line give the estimates from the model

Figure 2. Stock weight at age (in kilograms). Numbers gives the input values by age, the line give the estimates from the model.

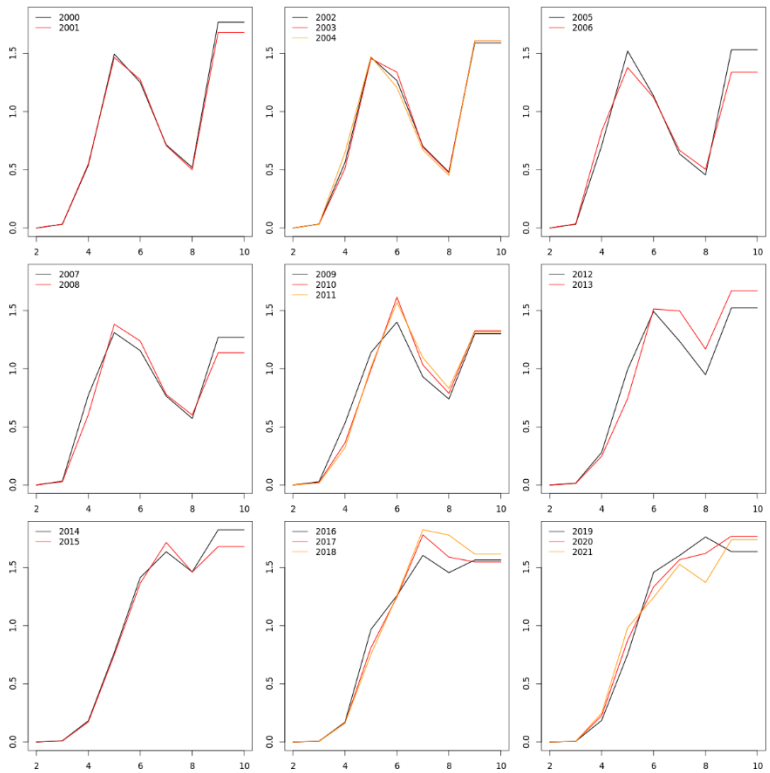

Figure 3. Selection pattern (F_{age}/Fbar) from the SAM model.

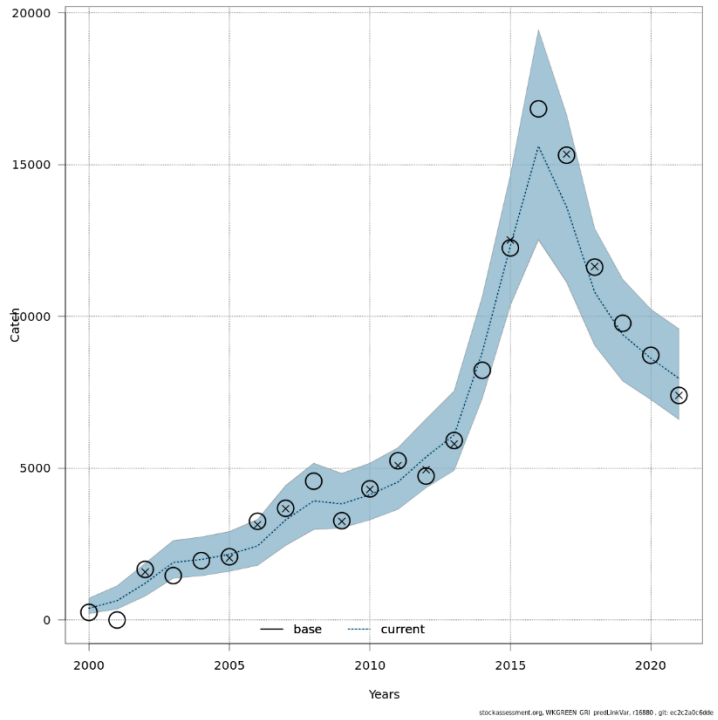

Figure 4. Estimated (line), observed catches (x), and catches based on smoothed catch weights (o). Estimated catch is shown with 95% confidence intervals.

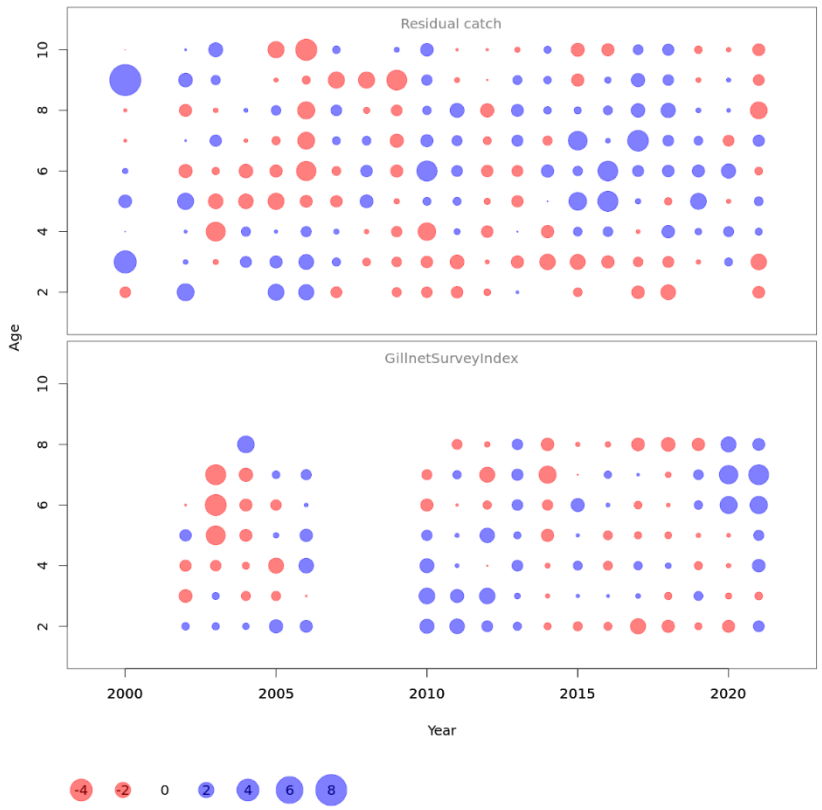

Figure 5. Normalized residuals derived from SAM. Blue indicate positive residuals (observation larger than predicted) and red circles indicated negative residuals.

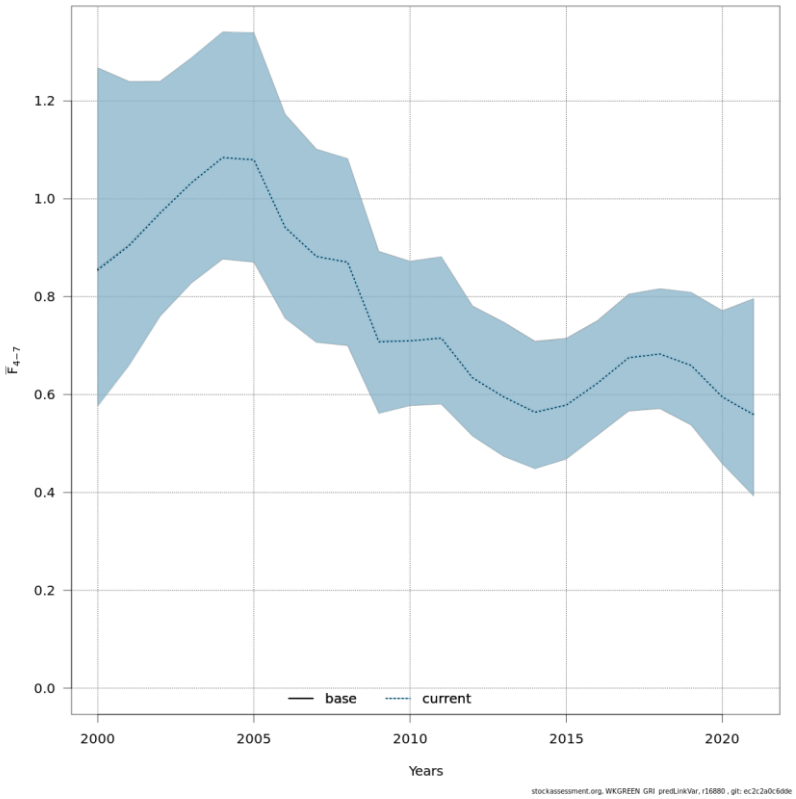

Figure 6. Estimated historical pattern of fishing mortality (Fbar4-7). The shaded area is 95% confidence intervals.

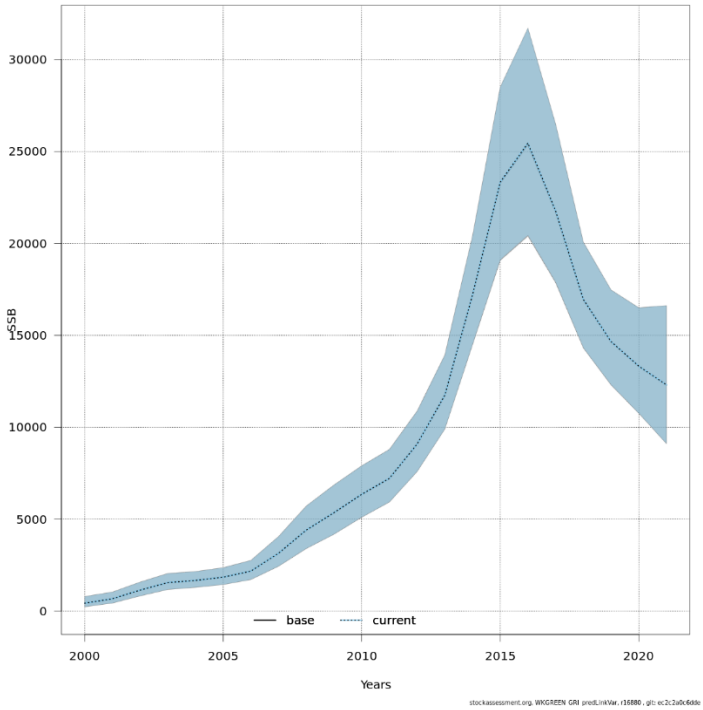

Figure 7. Estimated historical patterns of spawning stock biomass (SSB). The shaded area is 95% confidence intervals.

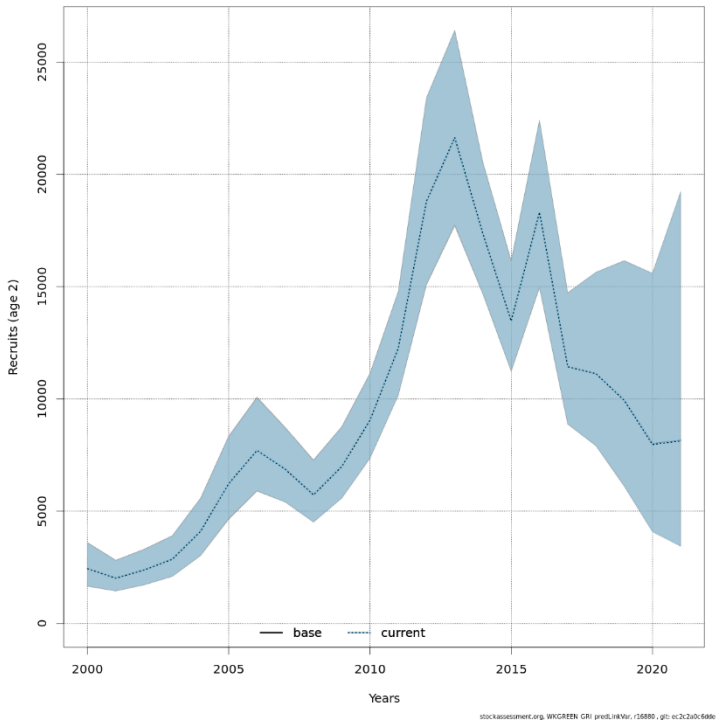

Figure 8. Estimated historical patterns of age 2 recruitment. The shaded area is 95% confidence intervals.

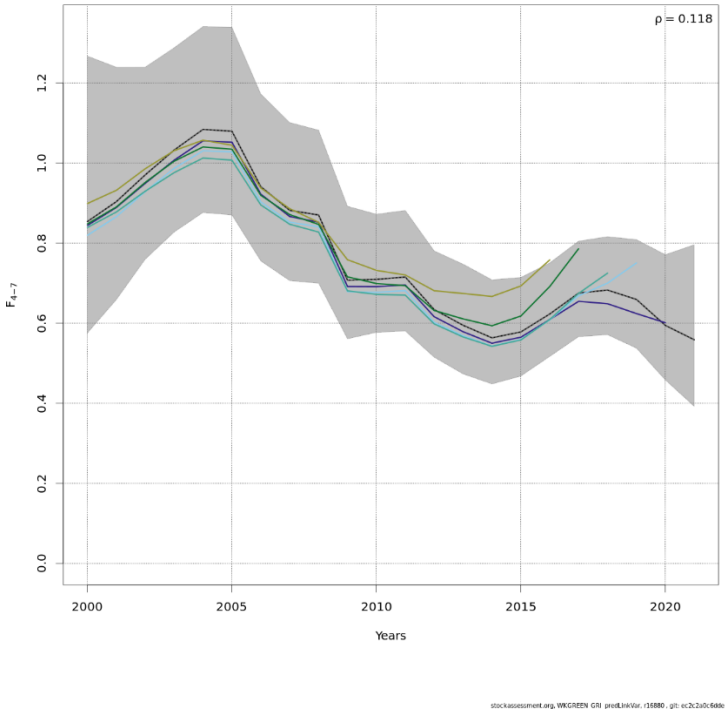

Figure 9. Retrospective plots of Fbar (5 years peel). Mohn's rho is given in the upper right corner.

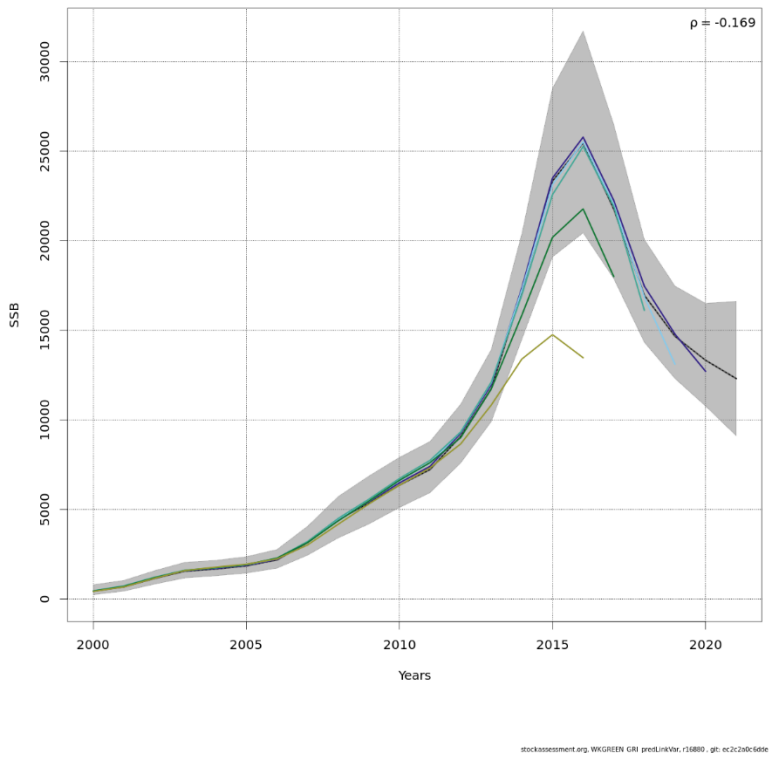

Figure 10. Retrospective plots of SSB (5 years peel). Mohn's rho is given in the upper right corner.

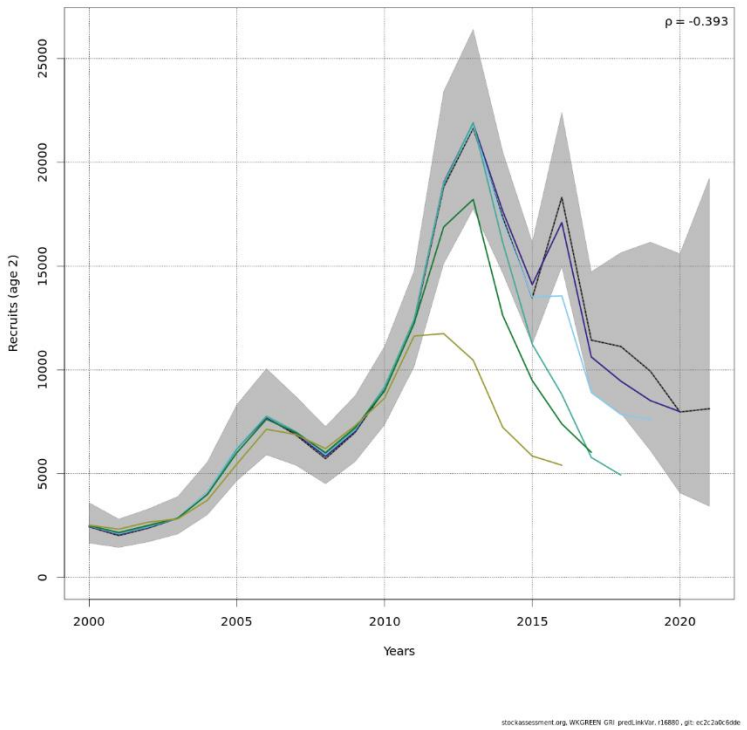

Figure 11. Retrospective plots of age 2 recruitment (5 years peel). Mohn's rho is given in the upper right corner.

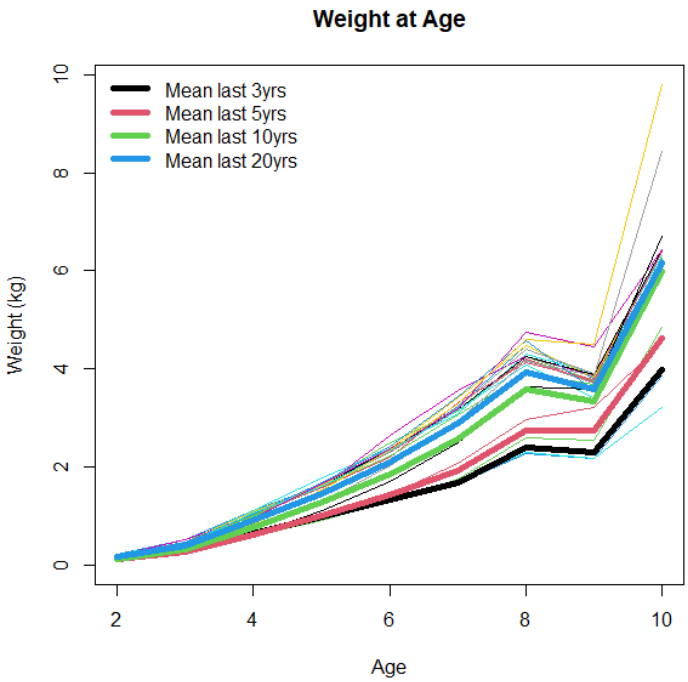

Figure 12. Stock weight at age for all years, bold line show means.

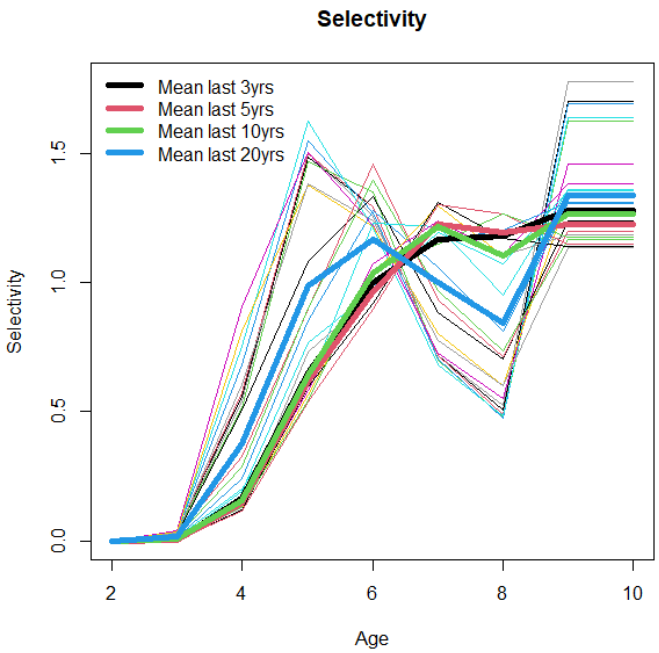

Figure 13. Selectivity at age for all years, bold line show means.

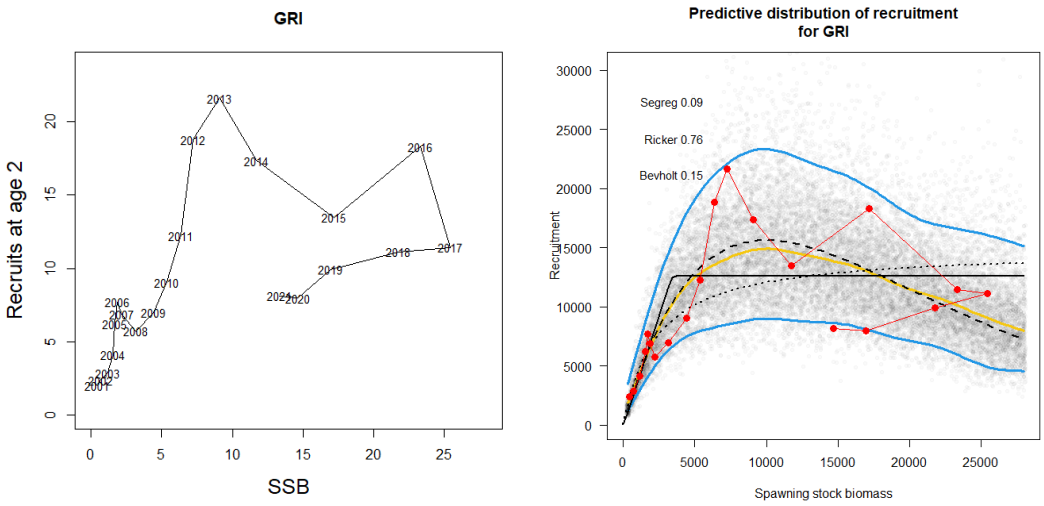

Figure 14. left: SSB-recruitment relationship, labels indicate recruitment year. right: SSB-recruitment relationship estimated by simulation using EqSim with fitted SSB-recruitment relationships. Dashed: Ricker curve. Dotted: Beverton-Holt curve. Solid: Segmented regression. The curve fits are indicated.

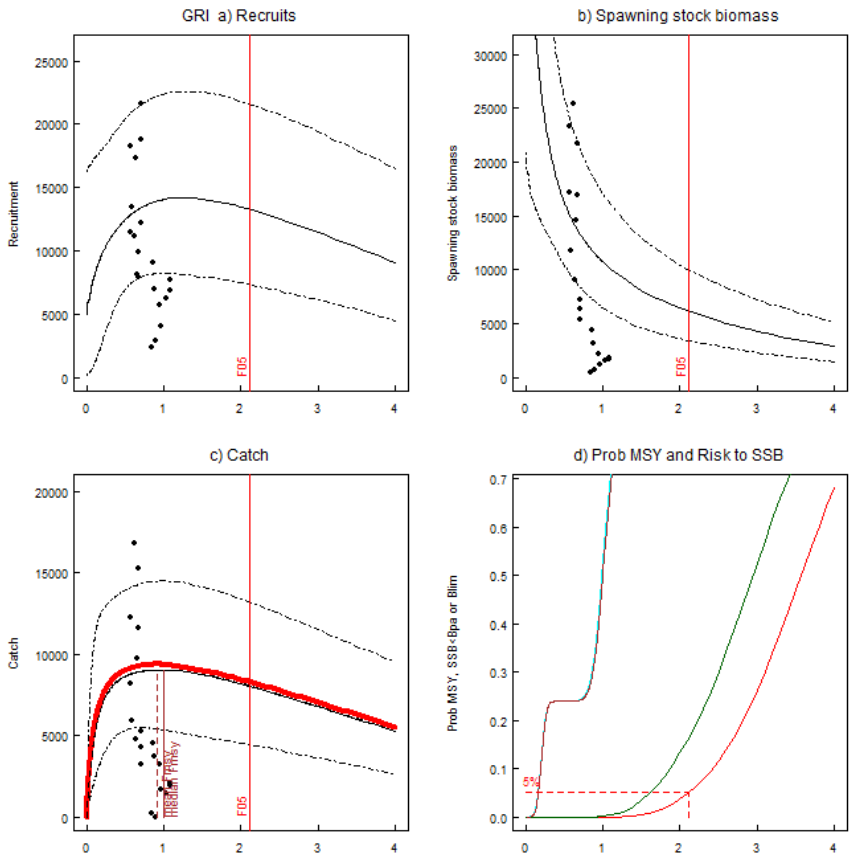

Figure 15. EqSim plots of recruitment, SSB, catch and probability of SSb falling below Bpa and Blim. F is on the x-axis.

WD09 - A SAM assessment of the East Greenland - Iceland cod stock (EGI)

Stockassessment.org run name: **WKGREEENCOD_EGI**

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Introduction

The Atlantic cod (*Gadus morhua*) in Greenland waters is primarily of three genetically distinct stocks: West Greenland inshore (GRI), West Greenland offshore (GRO), and East Greenland-Iceland (EGI) (see WD01 for details). Previously advice has been provided based on geographical areas. At WKGREENCOD data from the commercial fisheries and scientific surveys in Greenland waters are split into the three stock components (see WD01, WD02, WD05).

This document presents the results of the state-space model (SAM) (Nielsen and Berg, 2014) for the EGI stock and estimation of reference points using EqSim. This document was updated following the discussions during the WKGREENCOD meeting.

Input data

The input data for the SAM assessment model are described in WD05. The Assessment covers the period 2000-2021.

Total catches
Total catches were available for the stock EGI from 2000-2021, due to poor sampling in 2001 catch data are not included from that year (see Table 1 for input file). No discarding is believed to take place, landings are assumed to equal catches.

Catch mean weight at age
Catch mean weight at age were estimated for all years. Some age-year combination without sufficient data were left as NA in the input file (see Table 1 for input file). The given catch mean weights were then treated as observation to inform the catch weight process (GMRF with cohort and within year correlations) ($catchWeightModel, $keyCatchWeightMean and $keyCatchWeightObsVar in Table 2). See figure 1 for catch weights estimated by the model.

Landings mean weights and discard mean weights are set equal to catch mean weight without any smoothing as these are not used.

Stock mean weight at age
The same process as described to Catch mean weights were used for stock mean weights (see Table 1 for input file) ($stockWeightModel, $keyStockWEightMean and $keyStockWeightObsVar in Table 2), see figure 2 for stock weight estimated by the model.

Surveys
Survey index by age for ages 2-8 estimated using INLA (see Table 1 for input file), for details on survey data see WD05 and for details on INLA see WD03. Input data for INLA is two offshore trawl surveys. There were no surveys in 2019.

Landings fraction
Set to 1, landings are assumed to equal catches.

Natural mortality
Set to default 0.2 for all years and ages (see Table 1 for input file). See details in WD05.

Maturity
Maturity ogives are the same as the IBP2018, see WD05 for details.

F before spawning
The fraction of the fishing mortality rate, which is applied prior to spawning divided into age classes for each year. Set to 0 for all years and ages.

M before spawning
The fraction of the natural mortality rate, which is applied prior to spawning divided into age classes for each year. Set to 0 for all years and ages.

Assessment

Configurations

Recruitment
Recruitment parameters are estimated within the assessment model. The parameter structure is assumed as a plain random walk process ($stockRecruitmentModelCode in Table 2).

Fishing mortality and Fbar
Fishing mortality is estimated individually for ages 2-8, age 9 and 10 are assumed to be the same ($keyLogFsta in Table 2). It is assumed that there are no correlations across ages ($corFlag in Table 2), this is supported by changes in the selectivity pattern during the assessment period (Figure 3). The Fbar range was set to 4-7 years old as these ages constitutes the main part of the catches ($fbarRange in Table 2).

Survey
The survey catchability parameters are estimated individually for each age ($keyLogFpar in Table 2).

Variance parameters
For age 2 the coupling of the recruitment and survival process variance parameters for the log(N)-process are different from the other ages ($keyVarLogN in Table 2). In the model.R script the following was added: par$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.

The variance parameters for the catch are separate for age 2 and 3, and they are coupled for ages 4-10. 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 ($keyVarObs in Table 2).

The covariance structure for catches is assumed to be independent ($obsCorStruct in Table 2). For the tuning series the covariance structure was assumed to be AR(1). This was done to allow for year effects, it was coupled across all ages. Meaning that any year effect is assumed for

impact all ages. This was done because earlier runs showed indications of year effects in the residuals. This would also account for any effect of vessels change.

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 (see $predVarObsLink in Table 2) (see Breivik *et al* 2021).

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 number of years in the catch scaling is 10 ($noScaledYears in Table 2), the years are 2012-2021. Based on the table above the following years were grouped: 2012-2016 and 2017-2021. 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 (logscale0-5 in Table 3).

<u>Model diagnostics</u>

Uncertainty surrounding the SSB estimates are high in the recent period and there is high uncertainty around the F estimates in the most recent years (Figure 7 and 8). The model does not estimate the high catches well (Figure 4), catch scaling parameters logscale0-5 in table 3 indicates how much to the catch the model estimates for be of another stock (the red line on figure

4 gives the total estimated catches when accounting for the scaling). For both time periods where scaling was applied it showed that ages 2-4 were all considered to be from the assessed stock. For ages 5-7 there was a shift from the early period where around 40% of the catches were from a different stocks to around 70 % in the most recent period. For the oldest ages, 8-10, around 85% of the catches were from a different stock in the early period and more than 90% in the most recent period.

Parameter estimation
Parameter estimates are given in Table 3.

Residuals
Observation residuals for both catches and survey shows some tendency for larger residuals early in the time series (Figure 5). For the catches there is a group of positive residuals early in the timeseries. For the survey there are groups of both positive and negative residuals.

Stock summary

Fishing mortality
Fishing mortality peaked in 2008 at 0.884 it has since decline and has been at a stable level around 0.5 in recent years. The recent decrease should be interpreted at the model are estimating that large parts of the catches in recent years are not from this stock (Figure 6).

SSB
SSB was at a low level at the beginning of the timeseries and has since increased and has been fluctuated around 10,000 in the past 10 years (Figure 7).

Recruitment
Recruitment showed peaks in 2005, 2011 and 2017 (cohorts 2003, 2009 and 2015) (Figure 8).

Retrospective analysis
In order to test the robustness of the assessment a 5-year retrospective analysis (Figures 9-11) were conducted. For F all peels except one are within the confidence intervals and show tendency to overestimate F (Mohn'r rho=0.131) (Figure 9). For SSB all peels except one are within confidence intervals and tend underestimate SSB (Mohn'r rho= -0.015) (Figure 10). For recruitment most of the peels follow the current estimates OK (Mohn's rho=0.377) (Figure 11). It appears that the retros are impacted by the choice of groupings for the catch scaling, i.e., the first peel are in the second period for the catch scaling show a different trajectory.

Alternative settings and configurations

The first SAM model set up for this stock did not include the catch scaling, and it was not possible to account for the recent large catches in that model.
An initial run based mainly on default configurations were used as a starting point for setting up the final SAM model. Impact of each change in configuration were evaluated during the process.
A run allowing for additional uncertainty around the early catches and survey estimates did not improve the model.

Short term forecast

Short term forecasts were set up using mainly default settings for the SAM run on stockassessment.org. Uncertainty on F were taken from the model. Catch ad stock weights were taken from

the model used for these, the model is set up to estimate further ahead in time than the assessment run. For maturity and natural mortality average of the last 5 years were used, currently maturity and natural mortality is constant over time so the time period for this would not have any impact. The default for the recruitment is the last 10 years, it was decided at the meeting that this period is appropriate.

Reference points using EqSim

The estimation of reference points follows ICES Reference Points guidance, 2021. The estimation was done using the R-programme EqSim developed by D. C. M. Miller, which works directly on a specified SAM fit. The code for the final run is on the ICES sharepoint for the WKGREENCOD benchmark and named 'WKGREENCOD_EGI_EqSim_feb23_Final.R'. David Miller attended parts of the meeting where reference points were discussed and provided guidance on the ICES procedures and EqSim settings.

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 B_{lim}. The average of SSB in 2002-2004 gave a B_{lim} of 1894.

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 (Figure 17). Run settings are given in table 4. The estimated reference points are given in table 5. Due to very high estimate of F_{lim}, it was decided to not report on this value.

Due to the currently short timeseries the group recommends that reference point calculations are revisited when two more years of data are available.

Conclusion

The model presented estimates that large parts of the catches in recent years are from a different stock. This is in line with the view that large cod from the offshore Icelandic cod stock migrate between Iceland and Greenlandic waters in the Dohrn bank area and are targeted by the fishery in that area. Accepting this assumption, the assessment here represents the EGI stock, and do not account for fish from other stocks.

The assessment model is based on data for the EGI stock, rather than previous geographical data split. This improves data for younger ages which are found on the west coast of Greenland.

References

Breivik, O. N., Nielsen, A., Berg, C. W. 2021. Prediction-variance relation in a state-space fish stock assessment model. ICES Journal of Marine Science. 78 (10): 3650-3657.
Nielsen A, Berg CW. 2014. Estimation of time-varying selectivity in stock assessments using state-space models. Fisheries research. 158: 96-101.

Table 1. Input files to SAM runs (rounded values, unrounded values can be found on stock-assessment.org)

Catch in Numbers (thousands)

1	2							
2000	2021							
2	10							
1								
0.00	1.34	84.50	89.34	5.07	1.27	3.17	2.47	0.55
-1	-1	-1	-1	-1	-1	-1	-1	-1
0.12	243.39	923.39	270.90	51.44	25.57	6.97	3.30	0.01
0.00	44.60	181.19	371.64	106.53	34.20	11.41	3.97	1.42
1.19	173.29	553.84	355.32	101.01	61.13	24.59	4.89	2.08
0.40	495.71	823.61	280.35	145.27	102.56	57.67	17.34	6.78
6.52	2120.83	2018.53	394.59	178.33	113.16	13.78	0.97	0.01
5.52	957.53	6298.68	1066.42	226.28	137.92	123.92	20.41	15.20
3.56	534.70	3042.21	6769.55	2469.14	595.48	44.84	26.61	11.58
8.54	544.69	3161.91	2121.29	447.19	119.61	28.08	16.25	3.38
0.22	213.14	635.02	1329.93	545.52	352.91	61.83	10.63	8.24
0.26	78.96	1587.56	1024.79	876.23	415.37	373.65	98.84	33.02
0.91	362.56	885.58	1526.43	555.99	317.00	255.59	145.52	61.72
0.19	27.88	1605.72	977.31	952.91	356.32	267.50	168.65	105.65
0.00	9.50	284.37	1500.78	962.71	722.17	356.07	184.16	136.54
0.59	8.65	425.47	1639.65	2953.04	1816.00	980.12	281.15	195.34
0.00	9.59	433.46	2185.52	2107.65	1671.00	865.88	457.33	262.26
2.09	13.48	172.19	1334.12	1593.83	1892.84	1609.64	581.13	272.26
0.22	11.87	419.87	726.99	1159.10	1101.11	1240.00	947.62	539.05
0.00	6.08	1006.18	2116.83	1039.17	766.16	796.02	963.25	1101.72
0.60	19.65	251.72	2230.29	1531.09	599.72	512.90	478.42	918.24
3.36	52.17	276.36	911.20	2652.29	1235.16	506.16	400.08	1175.89

Table 1 *continued*

Mean Weight in Catch (kilograms)

1	3							
2000	2021							
2	10							
1								
NA	1.00	1.13	1.47	2.68	3.06	5.75	7.16	9.85
NA	NA	NA	NA	NA	NA	NA	NA	NA
0.36	0.72	1.01	1.51	2.96	3.60	4.48	6.34	3.36
NA	1.05	1.42	2.11	3.06	4.15	4.78	5.42	6.97
0.58	0.98	1.24	1.74	2.69	4.39	5.27	7.22	11.13
0.40	0.82	1.09	1.59	2.09	2.73	3.66	5.38	7.36
0.37	0.77	1.07	1.83	3.62	4.43	5.48	7.15	8.13
0.20	0.68	0.91	1.60	3.19	5.93	8.40	10.59	14.39
0.17	0.57	0.83	1.28	1.81	3.03	4.94	5.85	8.29
0.23	0.56	0.84	1.42	2.74	4.60	6.39	7.79	11.25
0.40	0.66	0.96	1.50	2.15	3.35	5.30	7.82	11.11
0.32	0.64	0.89	1.43	2.07	3.37	4.70	6.30	10.03
0.32	0.73	1.08	1.66	2.50	3.52	5.15	7.19	11.68
0.21	0.77	1.21	1.59	2.24	3.21	4.52	6.55	8.93
NA	0.67	1.21	1.90	2.56	3.60	4.77	6.36	8.84
0.13	0.61	1.08	1.65	2.20	3.41	4.76	6.90	9.22
NA	0.46	1.04	1.47	2.16	3.10	4.61	6.56	10.04
0.19	0.47	0.79	1.32	1.97	2.89	4.05	5.93	7.95
0.09	0.38	0.85	1.14	1.72	2.48	4.25	5.40	6.91
NA	0.66	0.88	1.17	1.87	2.65	3.82	5.27	6.59
0.28	0.56	0.98	1.60	2.16	3.27	4.51	5.74	6.87
0.27	0.57	1.05	1.63	3.02	3.92	4.92	6.16	7.22

Table 1 *continued*

Mean Weight in survey (kilograms)

1	3							
2000	2021							
2	10							
1								
0.17	0.38	0.73	1.07	NA	NA	NA	NA	NA
0.22	0.46	0.85	1.37	NA	NA	NA	NA	NA
0.18	0.41	0.76	0.87	1.79	NA	NA	NA	NA
0.19	0.43	0.86	1.44	1.86	NA	NA	NA	NA
0.21	0.40	0.77	1.10	1.70	2.92	NA	NA	7.11
0.16	0.44	0.78	1.54	1.73	2.66	4.27	4.51	NA
0.14	0.34	0.62	1.04	1.58	3.32	NA	NA	NA
0.12	0.32	0.72	1.48	3.35	7.11	9.27	NA	NA
0.10	0.23	0.48	1.05	1.90	3.32	5.50	8.27	8.92
0.13	0.38	0.82	1.72	2.98	4.14	5.35	7.33	10.86
0.16	0.32	0.73	1.65	2.47	3.47	5.24	7.30	10.95
0.15	0.36	0.76	1.38	2.25	3.84	5.69	7.30	10.82
0.17	0.36	0.77	1.40	2.55	3.94	5.59	7.50	10.19
0.13	0.34	0.63	1.16	2.27	3.53	4.99	7.11	10.49
0.13	0.31	0.68	1.25	2.58	3.99	5.25	6.17	8.39
0.10	0.36	0.65	1.14	1.72	2.88	4.56	6.70	9.68
0.12	0.32	0.74	1.34	2.09	3.49	5.17	6.94	10.36
0.13	0.41	0.82	1.28	1.94	3.42	4.75	6.68	11.34
NA	NA	NA	NA	NA	NA	NA	NA	NA
NA	NA	NA	NA	NA	NA	NA	NA	NA
0.12	0.41	0.66	1.56	2.45	3.59	4.97	6.72	7.42
NA	NA	NA	NA	NA	NA	NA	NA	NA

Table 1 *continued*

Proportion		Mature	at	Year	Start			
1	6							
2000	2021							
2	10							
1								
0.049	0.116	0.249	0.456	0.679	0.843	0.931	0.972	0.9891
0.049	0.116	0.249	0.456	0.679	0.843	0.931	0.972	0.9891
0.049	0.116	0.249	0.456	0.679	0.843	0.931	0.972	0.9891
0.049	0.116	0.249	0.456	0.679	0.843	0.931	0.972	0.9891
0.049	0.116	0.249	0.456	0.679	0.843	0.931	0.972	0.9891
0.049	0.116	0.249	0.456	0.679	0.843	0.931	0.972	0.9891
0.049	0.116	0.249	0.456	0.679	0.843	0.931	0.972	0.9891
0.049	0.116	0.249	0.456	0.679	0.843	0.931	0.972	0.9891
0.049	0.116	0.249	0.456	0.679	0.843	0.931	0.972	0.9891
0.049	0.116	0.249	0.456	0.679	0.843	0.931	0.972	0.9891
0.049	0.116	0.249	0.456	0.679	0.843	0.931	0.972	0.9891
0.049	0.116	0.249	0.456	0.679	0.843	0.931	0.972	0.9891
0.049	0.116	0.249	0.456	0.679	0.843	0.931	0.972	0.9891
0.049	0.116	0.249	0.456	0.679	0.843	0.931	0.972	0.9891
0.049	0.116	0.249	0.456	0.679	0.843	0.931	0.972	0.9891
0.049	0.116	0.249	0.456	0.679	0.843	0.931	0.972	0.9891
0.049	0.116	0.249	0.456	0.679	0.843	0.931	0.972	0.9891
0.049	0.116	0.249	0.456	0.679	0.843	0.931	0.972	0.9891
0.001	0.011	0.081	0.41	0.847	0.978	0.997	0.999	0.999
0.001	0.011	0.081	0.41	0.847	0.978	0.997	0.999	0.999
0.001	0.011	0.081	0.41	0.847	0.978	0.997	0.999	0.999
0.001	0.011	0.081	0.41	0.847	0.978	0.997	0.999	0.999

Table 1 *continued*

```
Natural Mortality
1 5
2000 2021
2 10
1
0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
```

Table 1 *continued*

```
TrawlSurveyIndex   INLA      COD       EGI          INLA run version: Thu Jan 26 11:34:25 2023
              102
TrawlSurveyIndex
             2000      2020
                1         1      0.58      0.65
                2         8
                1     1.364     0.526     0.218     0.017     0.073     0.049     0.118
                1     3.499     0.848     0.704     0.324     0.295     0.119     0.159
                1     1.195     1.316     0.479     0.282     0.541     0.582     0.165
                1     0.487     0.760     1.301     0.793     1.190     1.113     0.479
                1     3.055     0.350     0.254     0.689     0.690     0.774     0.340
                1    19.256     2.743     1.590     1.447     2.475     1.136     0.302
                1     2.904    15.137     2.961     0.681     1.664     1.433     0.543
                1     5.421     1.192     6.344     2.264     0.541     0.617     0.711
                1     1.792     4.194     2.135     8.384     3.777     1.269     0.698
                1     4.348     0.971     1.419     1.290     5.968     1.903     0.191
                1     1.637     2.554     0.722     1.542     1.841     4.308     1.669
                1    10.778     2.766     2.629     1.174     2.818     1.737     2.714
                1     4.092     4.483     2.351     2.724     2.333     1.878     1.036
                1     2.045     2.233     5.630     3.956     6.826     1.891     1.133
                1     1.183     1.114     1.806     5.466     4.545     3.290     1.238
                1     1.590     1.323     1.412     2.427     9.414     4.266     2.270
                1     1.292     0.392     0.663     0.934     1.612     4.902     2.318
                1     5.046     1.361     0.621     0.989     2.547     3.264     3.956
                1        -1        -1        -1        -1        -1        -1        -1
                1     3.876     1.930     7.864     3.821     1.628     1.527     1.524
                1     0.813     1.290     0.848     3.204     2.909     1.349     0.731
```

Table 2. SAM configurations for WKGREENCOD_EGI

```
# 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

Table 3. Table of SAM model parameters.

Parameter name	par	sd(par)	exp(par)	Low	High
logFpar_0	-7.666	0.154	0.000	0.000	0.001
logFpar_1	-7.864	0.136	0.000	0.000	0.001
logFpar_2	-7.510	0.147	0.001	0.000	0.001
logFpar_3	-6.875	0.153	0.001	0.001	0.001
logFpar_4	-5.608	0.161	0.004	0.003	0.005
logFpar_5	-4.818	0.186	0.008	0.006	0.012
logFpar_6	-4.334	0.237	0.013	0.008	0.021
logSdLogFsta_0	-1.170	0.178	0.310	0.217	0.443
logSdLogN_0	-0.384	0.178	0.681	0.477	0.971
logSdLogObs_0	3.288	1.713	26.799	0.872	824.011
logSdLogObs_1	4.970	0.744	144.063	32.548	637.646
logSdLogObs_2	2.377	0.707	10.771	2.618	44.315

logSdLogObs_3	-0.659	0.182	0.518	0.360	0.744
logSdLogObs_4	-0.836	0.178	0.433	0.303	0.619
logSdLogObs_5	-0.726	0.111	0.484	0.388	0.603
logSdLogObs_6	-0.970	0.247	0.379	0.231	0.621
logSdLogObs_7	-0.992	0.308	0.371	0.200	0.686
transfIRARdist_0	-0.021	0.266	0.979	0.575	1.668
logScale_0	0.493	0.381	1.638	0.764	3.510
logScale_1	-0.540	0.222	0.583	0.374	0.908
logScale_2	-1.834	0.309	0.160	0.086	0.296
logScale_3	0.610	0.539	1.841	0.626	5.412
logScale_4	-1.113	0.251	0.328	0.199	0.543
logScale_5	-2.551	0.312	0.078	0.042	0.146
predVarObs_0	-20.114	28765.964	0.000	0.000	Inf
predVarObs_1	-0.991	0.318	0.371	0.197	0.701
logPhiSW_0	2.767	1.456	15.910	0.865	292.737
logPhiSW_1	2.346	1.526	10.443	0.494	220.825
logSdProcLogSW_0	-0.558	0.641	0.573	0.159	2.064
meanLogSW_0	-1.950	0.070	0.142	0.124	0.164
meanLogSW_1	-1.026	0.064	0.358	0.315	0.408
meanLogSW_2	-0.335	0.062	0.715	0.632	0.809
meanLogSW_3	0.253	0.060	1.287	1.141	1.452
meanLogSW_4	0.752	0.061	2.122	1.876	2.399
meanLogSW_5	1.260	0.065	3.526	3.098	4.012
meanLogSW_6	1.639	0.069	5.150	4.488	5.911
meanLogSW_7	1.875	0.073	6.522	5.634	7.551
meanLogSW_8	2.216	0.079	9.167	7.822	10.743
logSdLogSW_0	-1.977	0.107	0.138	0.112	0.171
logPhiCW_0	2.486	1.130	12.009	1.254	115.034
logPhiCW_1	2.813	1.099	16.660	1.850	150.010
logSdProcLogCW_0	-0.028	0.473	0.972	0.378	2.505
meanLogCW_0	-1.348	0.099	0.260	0.213	0.316
meanLogCW_1	-0.404	0.088	0.667	0.560	0.795
meanLogCW_2	0.016	0.083	1.016	0.860	1.201
meanLogCW_3	0.431	0.081	1.539	1.308	1.810
meanLogCW_4	0.878	0.081	2.405	2.046	2.827
meanLogCW_5	1.254	0.082	3.505	2.974	4.131
meanLogCW_6	1.589	0.085	4.900	4.132	5.809
meanLogCW_7	1.868	0.090	6.474	5.403	7.758
meanLogCW_8	2.125	0.099	8.374	6.867	10.212
logSdLogCW_0	-2.143	0.208	0.117	0.077	0.178

Table 4. Run setting for EqSim

From R scripts	description	Value
stockName	Name of the stock	EGI
SAOAssessment	Name of assessment on stockassessmet.org	WKGREENCOD_EGI
sigmaF	From SAM assessment	0.226
sigmaSSB	From SAM assessment	0.243
noSims	Recommended minimum 1000	1500
SRused	Models used in the simulations (usually segmented regression, Ricker, beverton-holt). Weight given to the model in the simulation given in brackets.	Segmented regression (72%) Ricker (22%) Beverton-Holt (7%)
SRyears_min	Same as assessment	2000
SRyears_max	Same as assessment	2020
rhoRec	Autocorrelation in recruitment	F (default)
numAvgYrsB	Years used for the average Weight at age	10
numAvgYrsS	Years used for the average selectivity	10
cvF	Forecast error F	Default = 0.212
phiF	Forecast error F	Default = 0.423
cvSSB	Forecast error SSB	Default = 0
phiSSB	Forecast error SSB	Default = 0
SSB05	5th percentile of SSB in the final year of the assessment, used in MSY Btrigger calculation. If set at 0, ignored.	Set to 0
rmSRRYrs	Which years (SSB years, not recruitment years) to exclude from the SRR fits	2003

Table 5. Reference points estimated from EqSim.

Framework	Reference point	Value	Technical basis
Precautionary approach	B_{lim}	1894	Average of SSB in 2002-2004. The lowest observed SSB in 2000 and 2001 were deemed likely to impair recruitment.
	B_{pa}	2826	Bpa = Blim × exp(1.645 × σ), σ=0.243
	F_{lim}	NA	The fishing mortality rate (F) that in stochastic equilibrium will result in median (SSB) = Blim (i.e. 50% probability of SSB being above or below Blim).
	Fpa	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).
MSY approach	F_{MSY}	0.26	F that provides maximum yield
	MSY $B_{trigger}$	2826	MSY Btrigger = maximum (Bpa, the 5th percentile of the distribution of SSB when fishing at FMSY)

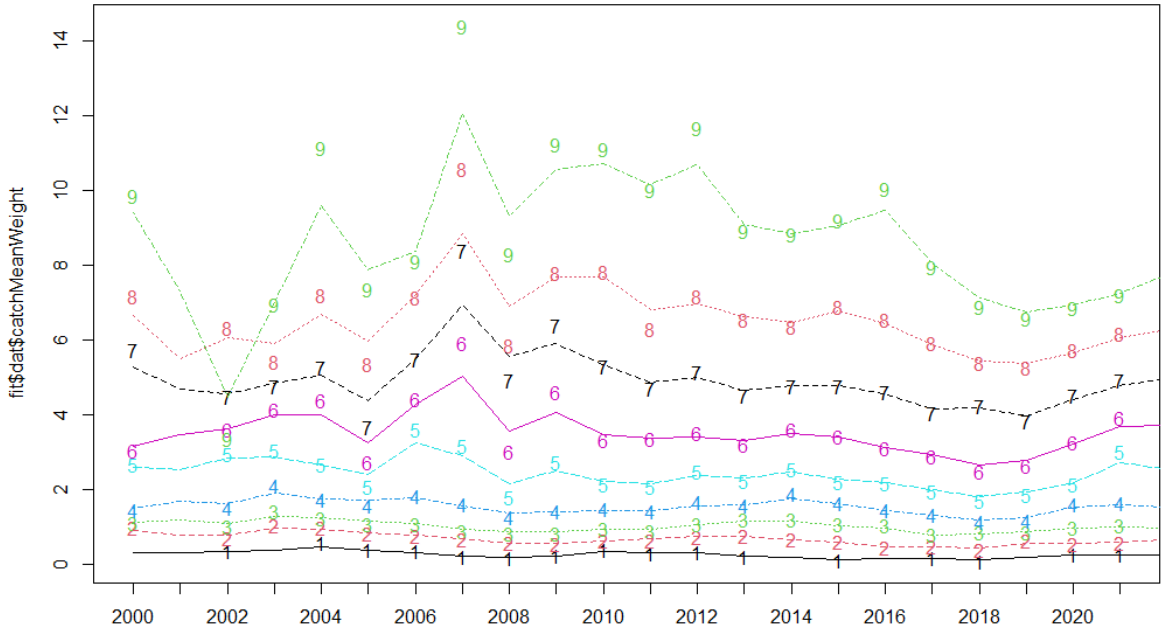

Figure 1. Catch weight at age (in kilograms). Numbers give the input values by age, the line give the estimates from the model

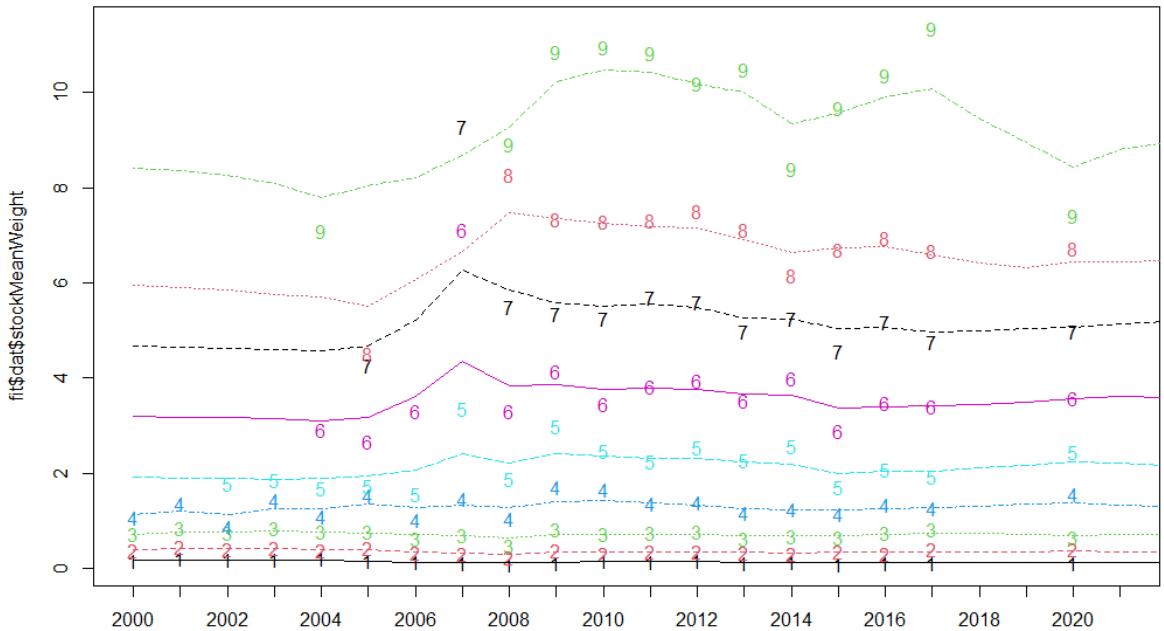

Figure 2. Stock weight at age (in kilograms). Numbers gives the input values by age, the line give the estimates from the model.

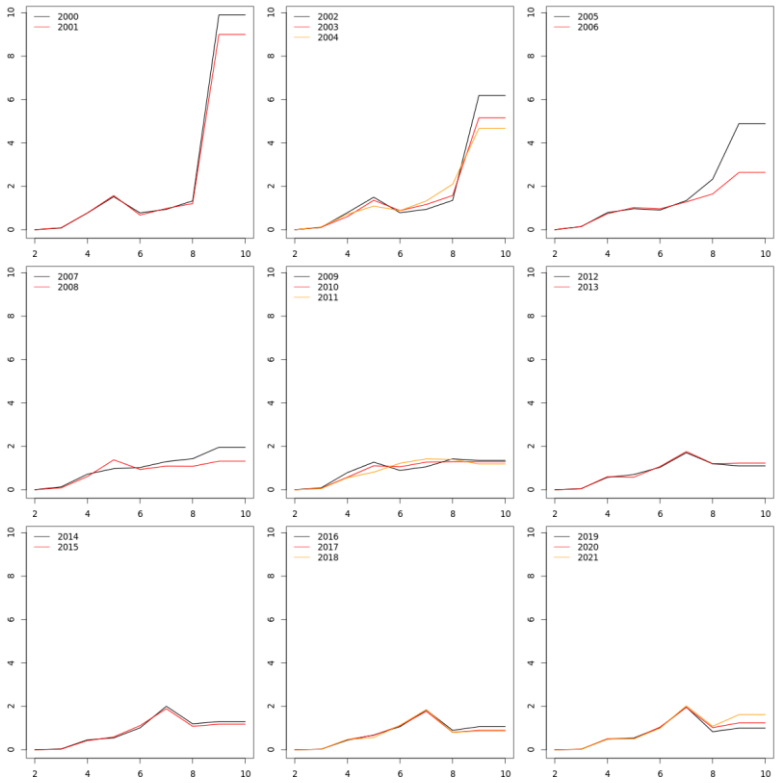

Figure 3. Selection pattern (F_{age}/Fbar) from the SAM model.

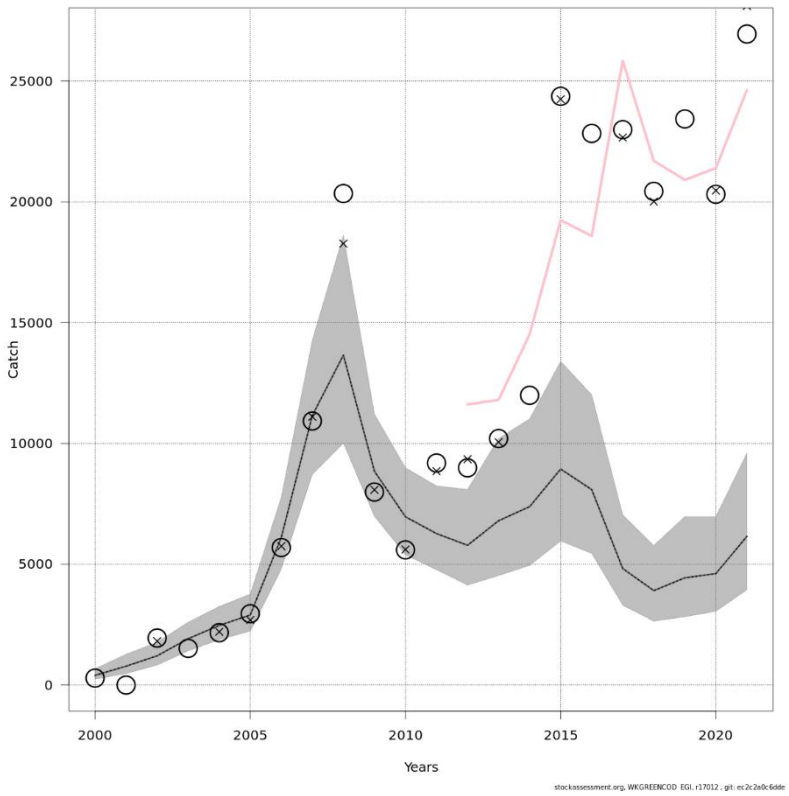

Figure 4. Estimated (line), observed catches (x), and catches based on smoothed catch weights (o). Estimated catch is shown with 95% confidence intervals. The red line covers the period were catch scaling was applied and gives the estimated catch combined with the scaled catch.

Figure 5. Normalized residuals derived from SAM. Blue indicate positive residuals (observation larger than predicted) and red circles indicated negative residuals.

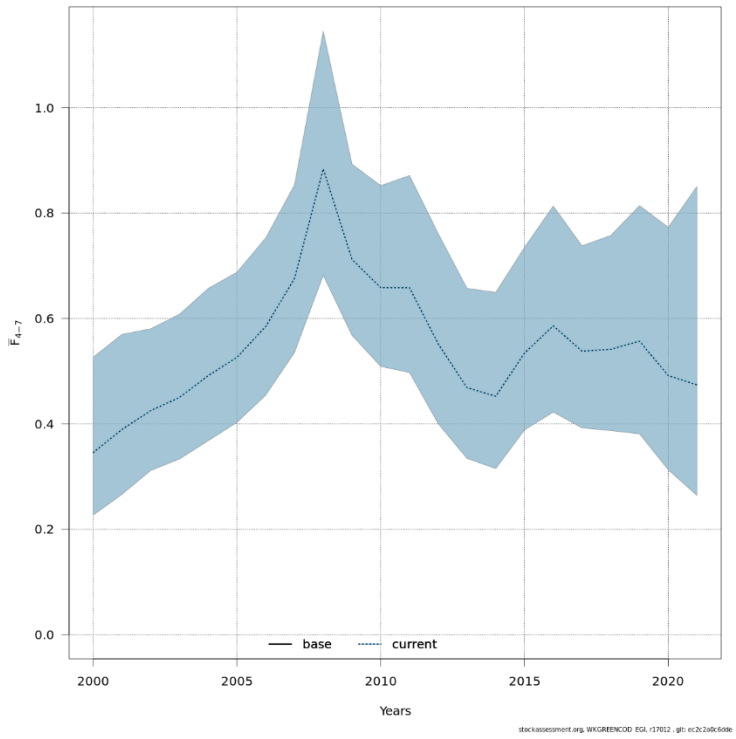

Figure 6. Estimated historical pattern of fishing mortality (Fbar4-7). The shaded area is 95% confidence intervals.

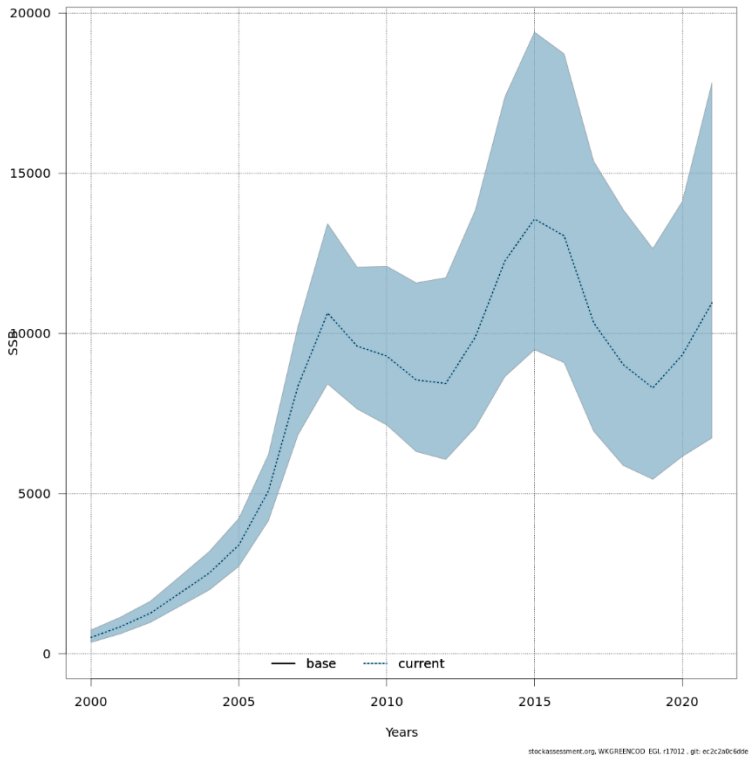

Figure 7. Estimated historical patterns of spawning stock biomass (SSB). The shaded area is 95% confidence intervals.

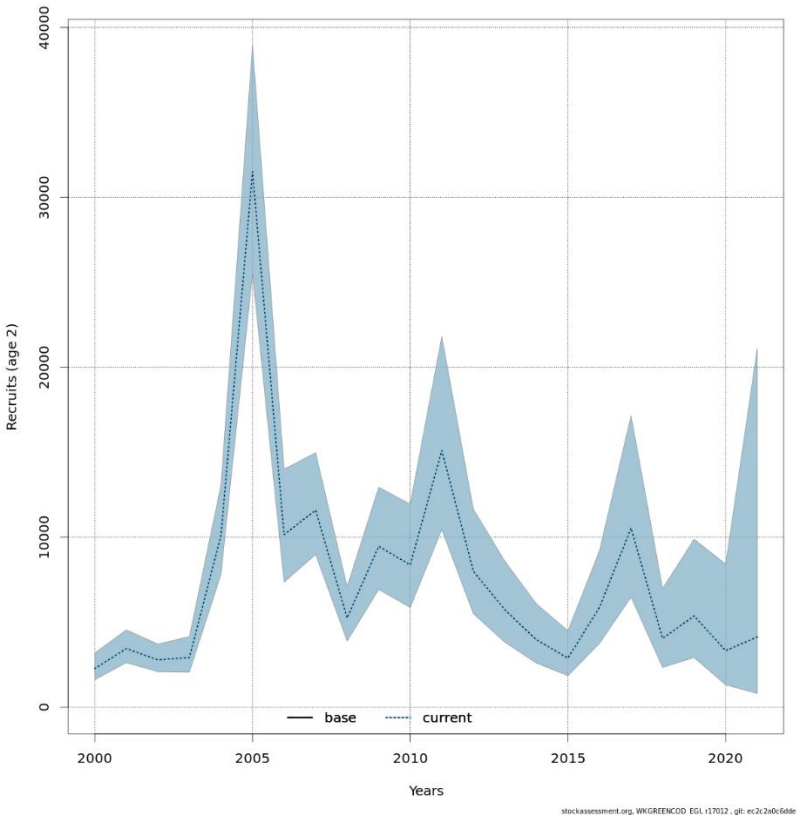

Figure 8. Estimated historical patterns of age 2 recruitment. The shaded area is 95% confidence intervals.

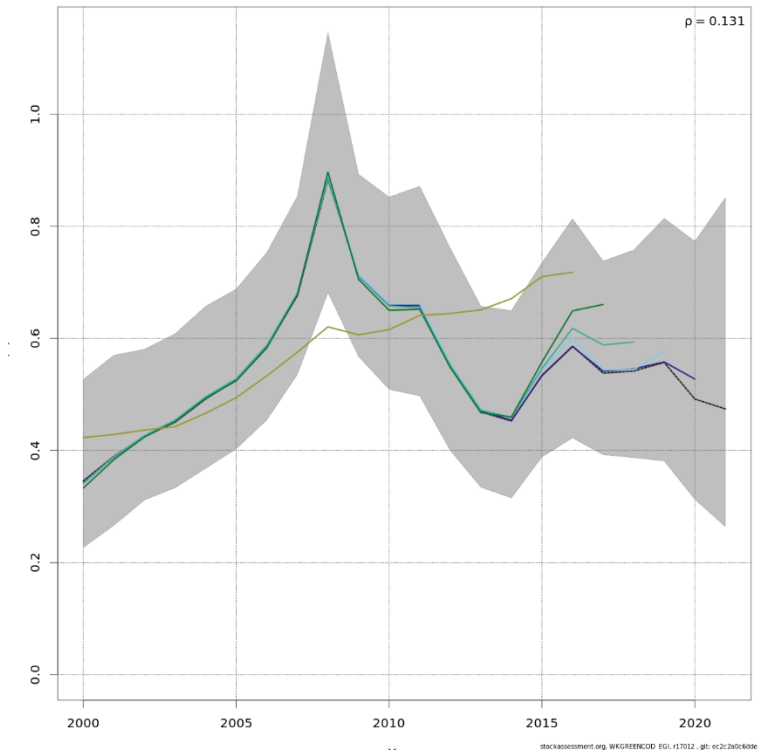

Figure 9. Retrospective plots of Fbar (5 years peel). Mohn's rho is given in the upper right corner.

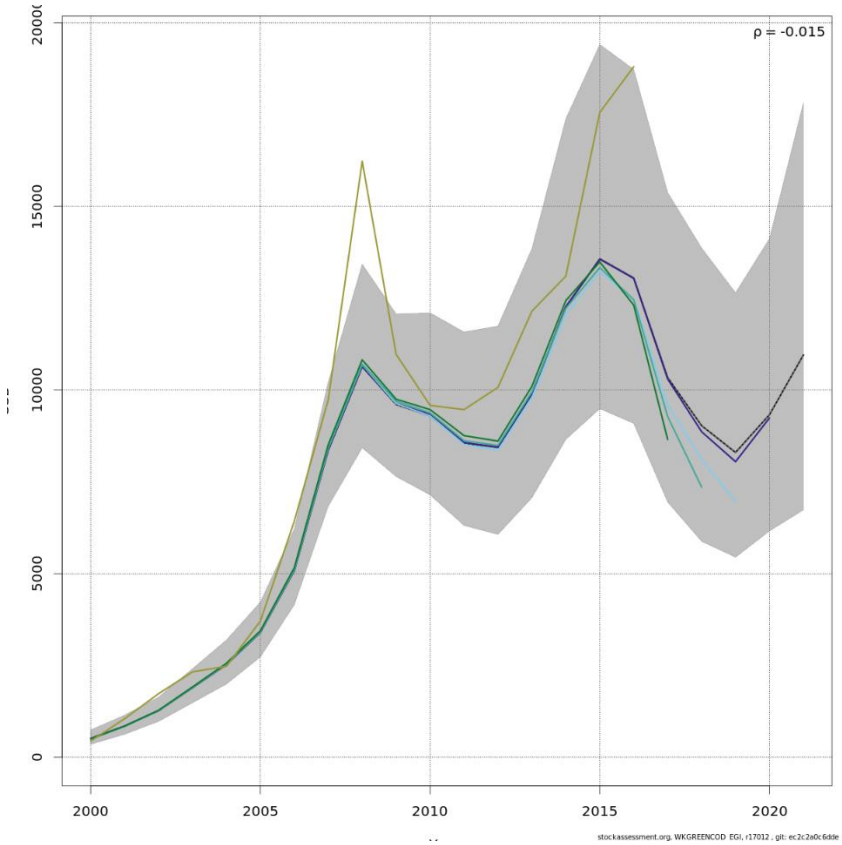

Figure 10. Retrospective plots of SSB (5 years peel). Mohn's rho is given in the upper right corner.

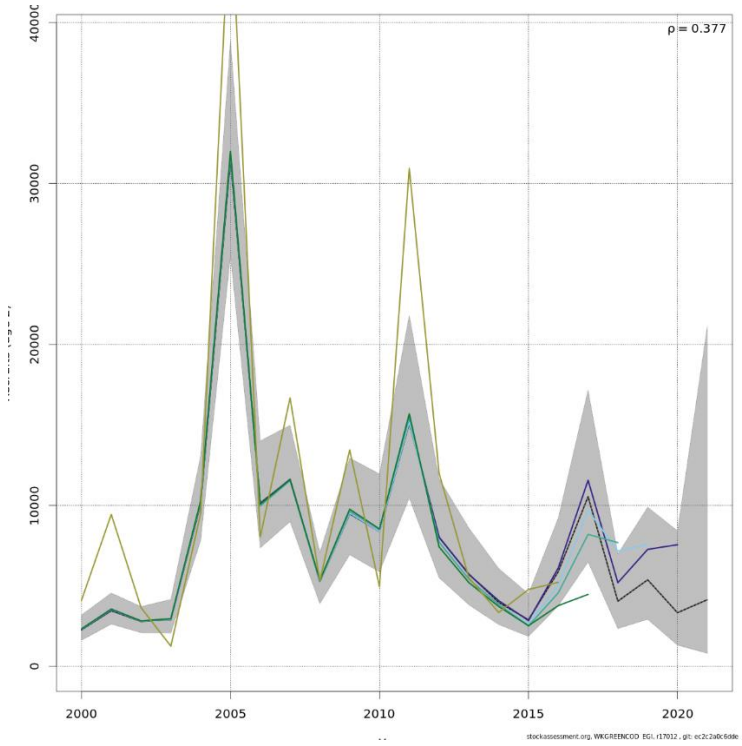

Figure 11. Retrospective plots of age 2 recruitment (5 years peel). Mohn's rho is given in the upper right corner.

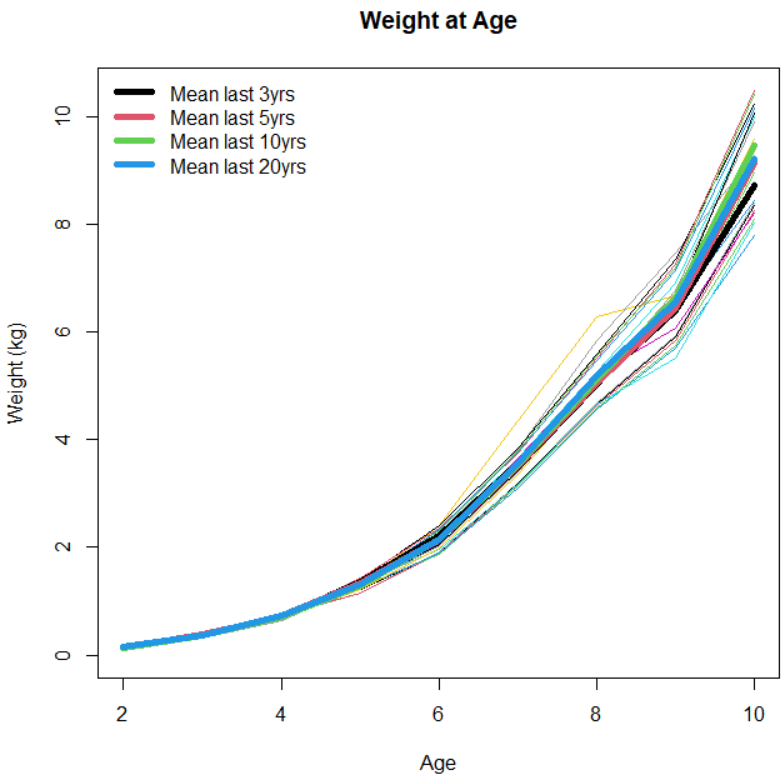

Figure 12. Stock weight at age for all years, bold line show means.

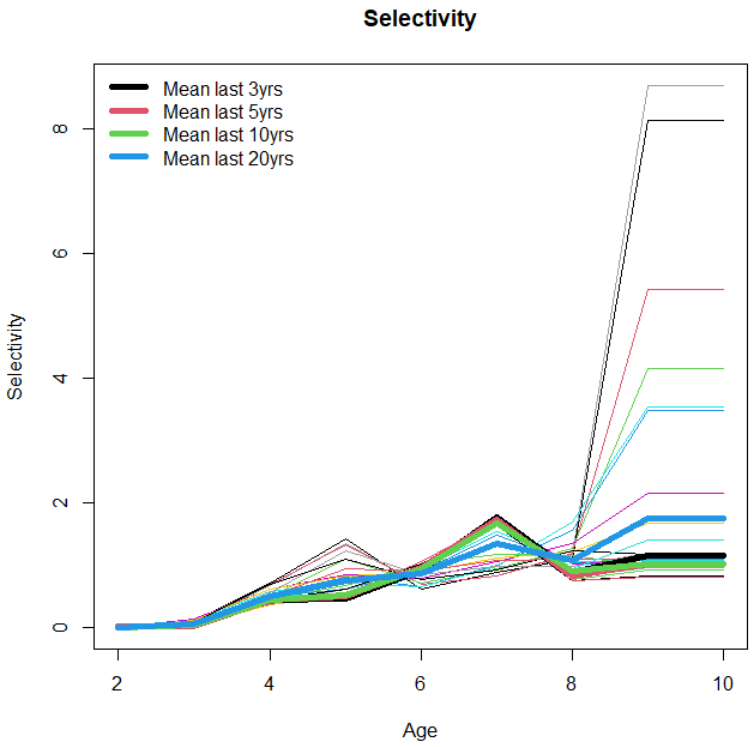

Figure 13. Selectivity at age for all years, bold line show means.

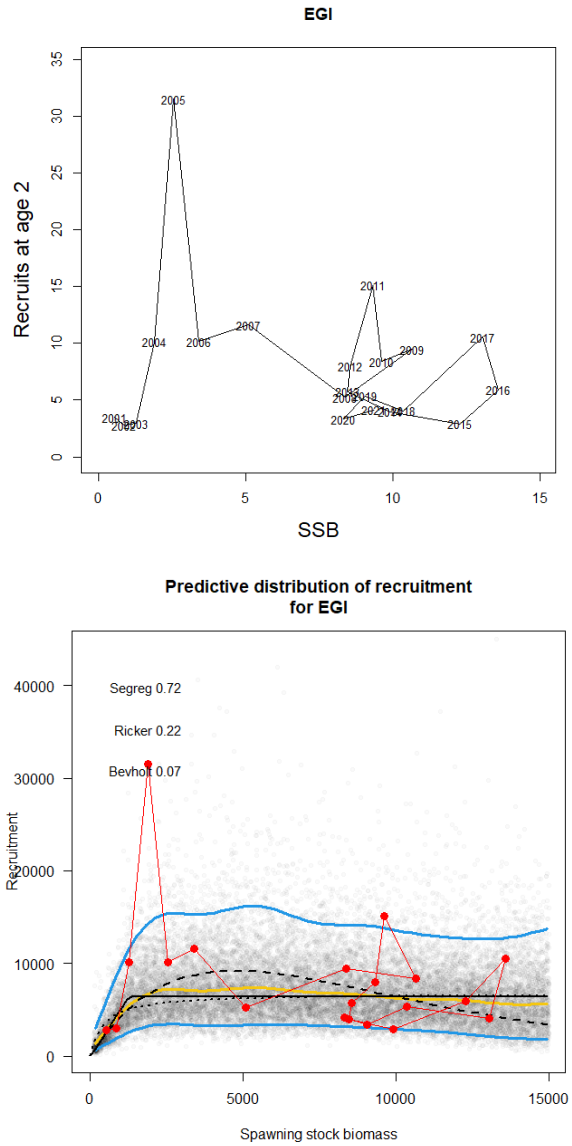

Figure 14. left: SSB-recruitment relationship, labels indicate recruitment year. right: SSB-recruitment relationship estimated by simulation using EqSim with fitted SSB-recruitment relationships. Dashed: Ricker curve. Dotted: Beverton-Holt curve. Solid: Segmented regression. The curve fits are indicated.

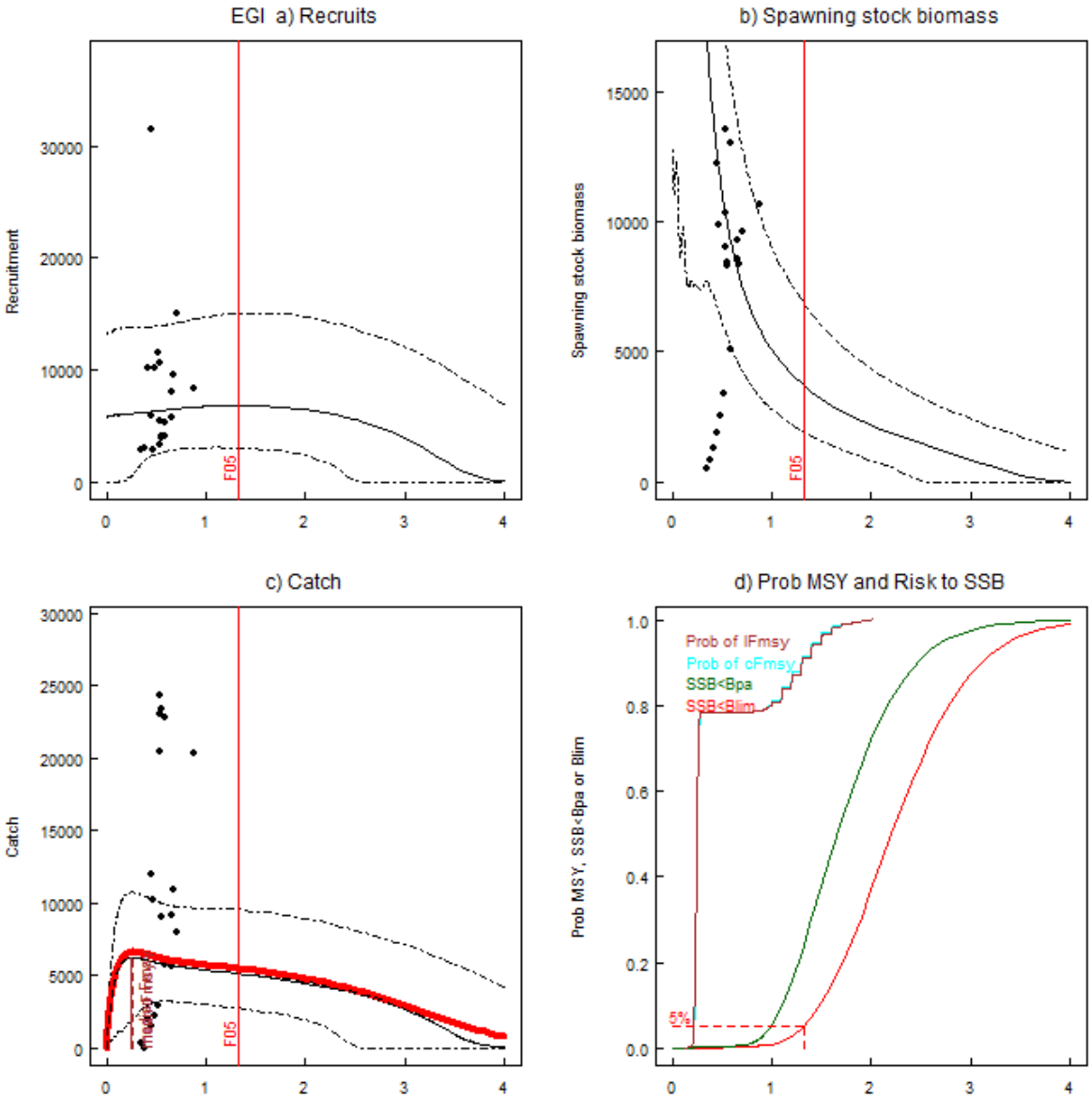

Figure 15. EqSim plots of recruitment, SSB, catch and probability of SSB falling below Bpa and Blim. F is on the x-axis.

WD 10 - A SAM assessment of the northern part of West Greenland inshore cod stock (GRI north)

Stockassessment.org run name: **WKGREEENCOD_GRI_North**

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Introduction

The Atlantic cod (*Gadus morhua*) in Greenland waters is primarily of three genetically distinct stocks: West Greenland inshore (GRI), West Greenland offshore (GRO), and East Greenland-Iceland (EGI) (see WD01 for details). Previously advice has been provided based on geographical areas. At WKGREENCOD data from the commercial fisheries and scientific surveys in Greenland waters are split into the three stock components (see WD01, WD02, WD05).

This document presents the results of the state-space model (SAM) (Nielsen and Berg, 2014) for the GRI north stock and estimated reference points using EqSim. It was not possible to do a EqSim run that could be accepted, therefore, an alternative approach to getting F_{msy} and F_{pa} was used. The GRI north stock represents the GRI stock in NAFO aeras 1A, 1B and 1C. This document was updated following the discussions during the WKGREENCOD meeting.

Input data

The input data for the SAM assessment model are described in WD05. The Assessment covers the period 2000-2021.

Total catches
Total catches were available for the stock GRI south from 2000-2021, due to poor sampling in 2001 catch data are not included from that year (see Table 1 for input file). No discarding is believed to take place, landings are assumed to equal catches. The catches are from NAFO areas 1A, 1B and 1C. There are many zero catches for age 2, therefore age 2 was removed from in the input files, configurations for age 2 catches was set to -1 indicating not data (see Table 2).

Catch mean weight at age
Catch mean weight at age were estimated for all years. Some age-year combination without sufficient data were left as NA in the input file (see Table 1 for input file). The given catch mean weights were then treated as observation to inform the catch weight process (GMRF with cohort and within year correlations) ($catchWeightModel, $keyCatchWeightMean and $keyCatchWeightObsVar in Table 2). See figure 1 for catch weights estimated by the model.

Landings mean weights and discard mean weights are set equal to catch mean weight without any smoothing as these are not used.

Stock mean weight at age
The same process as described to Catch mean weights were used for stock mean weights (see Table 1 for input file) ($stockWeightModel, $keyStockWeightMean and $keyStockWeightObsVar in Table 2), see figure 2 for stock weight estimated by the model.

Surveys
Survey CPUE index by age for ages 2-8 estimated from inshore gillnet survey in area 1D (see Table 1 for input file), for details on survey data see WD05 and for details on index calculations see WD06.

Landings fraction
Set to 1, landings are assumed to equal catches.

Natural mortality
Set to default 0.2 for all years and ages (see Table 1 for input file). See details in WD05.

Maturity
Maturity ogive is based on genetic dataset presented in WD01 (see Table 1 for input file). The ogive is based on the entire GRI stock. Not enough data to produce annual maturity ogives. Details are given in WD05.

F before spawning
The fraction of the fishing mortality rate, which is applied prior to spawning divided into age classes for each year. Set to 0 for all years and ages.

M before spawning
The fraction of the natural mortality rate, which is applied prior to spawning divided into age classes for each year. Set to 0 for all years and ages.

Assessment

Configurations

Recruitment
Recruitment parameters are estimated within the assessment model. The parameter structure is assumed as a plain random walk process ($stockRecruitmentModelCode in Table 2).

Fishing mortality and Fbar
Fishing mortality is estimated individually for ages 3-8, age 9 and 10 are assumed to be the same, age 2 is set to -1 and therefore not used ($keyLogFsta in Table 2). It is assumed that there are no correlations across ages ($corFlag in Table 2), this is supported by changes in the selectivity pattern during the assessment period, meaning that correlations between ages are unlikely to be consistent throughout the period (Figure 3). The Fbar range was set to 4-7 years old as these ages constitutes the main part of the catches ($fbarRange in Table 2).

Survey
The survey catchability parameters are estimated individually for age 2, 3 and 4. Ages 5 and 6 and coupled and ages 7 and 8 are coupled ($keyLogFpar in Table 2).

Variance parameters
For age 2 the coupling of the recruitment and survival process variance parameters for the log(N)-process are different from the other ages ($keyVarLogN in Table 2). In the model.R script the following was added: par$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.

The variance parameters for the catch are separate for age 3 and they are coupled for ages 4-10. Age to is set to -1 and not used. The variance parameters for the survey are separate for age 2 and 3, ages 4-6 are coupled and ages 7 and 8 are coupled ($keyVarObs in Table 2).

The covariance structure for catch is assumed to be independent ($obsCorStruct in Table 2). For the survey the covariance structure is assumed to follow an AR(1) structure. This was done because there was evidence of year effects in the observation residuals for the survey.

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 (see $predVarObsLink in Table 2) (see Breivik *et al* 2021).

Model diagnostics

Uncertainty surrounding the SSB and F estimates appears reasonable (Figure 7 and 8), although high on F for the most recent years in the time series. The estimated catches follow the same trend as the observed catches, but do not capture the large catches in 2016 and 2017 (Figure 4).

Parameter estimation
Parameter estimates are given in Table 3.

Residuals
Observation residuals for both catches and survey shows some tendency for larger residuals early in the time series (Figure 5). There is a block of negative residuals for the survey residuals early in the timeseries. For the catch residuals there are a block of positive residuals, showing that the model underestimate catches in these years.

Stock summary

Fishing mortality
Fishing mortality peaked in 2004 at 1.152 and then decreased to the lowest level of 0.486 in the assessment time period in 2014, it has since increase and is at 0.946 (Figure 6).

SSB
SSB was at a low level at the beginning of the timeseries and increased from 180 in 2000 to 17676 in 2016. Since the SSB has since decreased (Figure 7).

Recruitment
Recruitment was at a low level at the beginning of the assessment period, it increased and had a peak in 2013 (cohort 2011). Recruitment has been decreasing since. The three most recent years have had low recruitment, although these estimates were associated with very large confidence intervals (Figure 8).

Retrospective analysis
In order to test the robustness of the assessment a 5-year retrospective analysis (Figures 9-11) were conducted. For F all peels are within the confidence intervals. With some peels above and some below the current estimate (Mohn'r rho=-0.011) (Figure 9). All peels for SSB, except the oldest, are within confidence intervals. The oldest peel underestimate SSB and remaining fluctuate around the current estimate (Mohn'r rho= -0.051) (Figure 10). For recruitment the three most recent peels are within the confidence limits (Mohn's rho=0.047) (Figure 11).

Alternative settings and configurations
An initial run based mainly on default configurations were used as a starting point for setting up the final SAM model. Impact of each change in configuration were evaluated during the process.

A run with additional uncertainty for the early period (2000-2010) for both catches and CPUE index, did not improve the model.

Short term forecast

Short term forecasts were set up using mainly default settings for the SAM run on stockassessment.org. Uncertainty on F were taken from the model. Catch ad stock weights were taken from the model used for these, the model is set up to estimate further ahead in time than the assessment run. For maturity and natural mortality average of the last 5 years were used, currently maturity and natural mortality is constant over time so the time period for this would not have any impact. The default for the recruitment is the last 10 years, it was decided at the meeting that this period is appropriate.

Reference points

The estimation of reference points follows ICES Reference Points guidance, 2021. The estimation was done using the R-programme EqSim developed by D. C. M. Miller, which works directly on a specified SAM fit. The code for the final run is on the ICES sharepoint for the WKGREENCOD benchmark and named 'WKGREENCOD_GRInorth_EqSim_feb23.R'. David Miller attended parts of the meeting where reference points were discussed and provided guidance on the ICES procedures and EqSim settings.

Following ICES guidelines the stock-recruitment relationship appears to follow a type 2 stock type, where B_{lim}= segmented regression change point. The segmented regression then gave a B_{lim} of 2147.

The simulation settings for the stock-recruitment relationship were as follows. The number of simulations were set to 1500. No years were excluded. For assessment error sigmaF was set to default of 0.2 and sigmaSSB was 0.207 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 there has been a reduction in weight-at-age in the assessment period. For selectivity the last 5 years were used, there appear to have been a change in selectivity early in the assessment period (Figure 17). Run settings are given in table 4. The estimated reference points are given in table 5. This run was not accepted, alternative runs were conducted. One run with only segmented regression and beverton-holt were tried, but the arguments for removing the ricker model was not strong. This run was therefore rejected. A run without the two most recent years of recruitment (with high uncertainty) were tried, this did not improve the EqSim run.

Given the problems estimating reference points for this stock using EqSim it was decided to look at the two stocks most similar to this, GRO and GRI south. The benchmark group therefore gives F_{msy} at the average of the two other stock and also suggest carrying out forecast covering the range of F_{msy}. Similarly, F_{pa} is given as a range based on the other two stocks and using the average as the actual F_{pa} value. B_{lim} and thus B_{pa} is based on B_{lim} from the segmented regression. Table 6 gives the final reference points. F_{msy} for other ICES cod stocks range from 0.22-0.4, the F_{msy} for this stock are within this range as well.

Due to the currently short timeseries the group recommends that reference point calculations are revisited when two more years of data are available.

Conclusion

The model presented here fit the observation reasonably well and seem to capture trends in stock size and fishing mortality well.

The assessment model is based on data for the GRI stock in the northern part of the stock area (NAFO area 1A-1C), rather than previous geographical data split. The model in combination with one for GRIsouth provides a useful tool for assessing the GRI stock.

References

Breivik, O. N., Nielsen, A., Berg, C. W. 2021. Prediction-variance relation in a state-space fish stock assessment model. ICES Journal of Marine Science. 78 (10): 3650-3657.

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

Table 1. Input files to SAM runs.

Catch in Numbers (thousands)

1	2						
2000	2021						
3	10						
1							
6.07E-01	29.71124	46.80806	1.037279	0.036011	0.021783	1.00E-04	1.00E-04
-1	-1	-1	-1	-1	-1	-1	-1
177.203	746.1835	242.5542	10.72184	3.532048	0.236177	0.089929	0.025824
30.57395	94.54335	424.5185	54.13105	4.400906	0.654109	0.781522	0.345844
203.2271	585.7022	249.4302	45.34129	15.31931	0	0	0
337.7726	601.3776	316.4406	29.42704	2.408367	0	0	0
1013.426	738.8832	232.7994	9.556364	0	0	0	0
732.2815	983.7631	137.0869	16.28565	8.591565	2.821534	1.839124	0.17914
126.8207	1078.987	663.9626	110.5444	12.75263	2.485582	0.895604	0
109.7959	306.7895	439.0385	64.06421	1.68651	0.24958	0	0.038332
5.663403	139.9319	424.193	540.0403	74.53714	14.71628	10.3551	13.55405
13.81085	365.9629	669.2655	383.6974	75.84789	32.71796	3.284585	1.979717
121.8418	231.8746	319.9466	170.242	43.88972	8.800281	5.655165	0.464673
60.28212	737.0156	561.5209	217.2269	75.30691	24.34073	22.27176	4.327689
12.56756	437.9039	1260.126	743.3164	116.9087	59.28299	38.82033	22.08059
9.397696	658.7132	1951.818	1019.194	369.181	46.13105	4.194344	3.49914
3.048666	805.7617	3718.689	2286.684	436.4422	98.81648	23.07591	1.305643
15.18248	585.605	2639.574	2172.973	1421.687	173.6695	90.08852	19.54201
1.835971	835.004	1233.413	1210.771	688.9632	275.0077	51.60653	27.76879
18.50824	384.9419	1741.141	554.0151	266.3197	130.2099	30.01549	8.338905
20.40741	345.14	956.7755	1089.725	163.9837	82.86631	23.7646	12.25035
0.811847	385.4009	1301.604	615.3769	489.4241	39.85356	27.68191	5.077864

Table 1 *continued*

Mean Weight in Catch (kilograms)

1	3							
2000	2021							
2	10							
1								
NA	0.641808	1.120983	1.453028	2.378079	2.62124	2.41E+00	NA	NA
NA	NA	NA	NA	NA	NA	NA	NA	NA
0.36	0.707845	0.998694	1.397425	2.317673	1.884027	2.852515	3.559567	3.355852
NA	1.059815	1.445614	2.099405	2.510019	3.897149	5.351454	4.539769	6.682845
NA	0.996253	1.263823	1.508814	2.370574	2.77441	NA	NA	NA
0.409169	0.762842	1.100555	1.733057	2.535642	2.737143	NA	NA	NA
0.362207	0.756374	0.962649	1.477489	3.14623	NA	NA	NA	NA
NA	0.708493	1.068338	1.648738	2.502677	3.85461	5.700676	6.181906	9.364545
NA	0.679658	0.914161	1.557812	2.360278	3.989533	5.773668	7.230218	NA
NA	0.644946	1.094873	1.612401	2.441408	5.400206	5.85566	NA	8.32
0.5	0.718109	1.189489	1.697284	2.229235	3.192263	4.870627	6.908032	8.998366
NA	0.738917	1.106841	1.584711	2.252494	3.284271	5.590581	8.229545	11.32777
0.501301	0.822557	1.214086	1.994926	2.828482	4.02976	6.063904	6.715323	9.82974
0.244788	0.765717	1.324334	1.695647	2.292495	3.457692	4.273011	4.690375	7.965748
NA	0.684112	1.235951	1.95369	2.535565	3.458614	5.303593	5.721852	7.887216
NA	0.83171	1.196312	1.853055	2.587638	3.455797	5.142805	7.905535	12.75891
NA	0.593306	1.099032	1.523588	2.253571	3.094113	3.785904	3.960809	9.439398
NA	0.459906	0.792035	1.26643	1.870536	2.625705	3.64948	4.115393	7.523062
NA	0.365097	0.929099	1.195353	1.856092	2.383417	3.060385	3.821474	5.972629
NA	0.805831	0.84232	1.132917	1.61714	2.412471	2.873127	3.774655	4.958655
NA	0.510467	0.881216	1.270516	1.614355	2.25629	3.169389	4.162675	5.646375
NA	0.468559	1.071691	1.370519	1.544346	1.841878	3.398364	4.244325	5.375734

Table 1 *continued*

Mean Weight in survey (kilograms)

1	3							
2000	2021							
2	10							
1								
NA	NA	NA	NA	NA	NA	NA	NA	NA
NA	NA	NA	NA	NA	NA	NA	NA	NA
0.18728	0.314506	0.973401	1.497055	2.129043	NA	NA	NA	NA
0.220046	0.627332	1.001243	1.924273	2.897059	2.940008	NA	NA	NA
0.227572	0.646046	1.082603	1.574459	2.451771	NA	NA	NA	NA
0.210871	0.448512	1.152832	1.842503	2.104168	2.791503	NA	NA	NA
0.193722	0.608725	0.863184	1.224629	3.322458	NA	NA	NA	NA
0.14344	0.355987	0.947606	1.827024	NA	NA	NA	NA	NA
NA	NA	NA	NA	NA	NA	NA	NA	NA
NA	NA	NA	NA	NA	NA	NA	NA	NA
0.22805	0.502794	1.020537	1.589429	2.253434	4.048524	NA	NA	NA
0.188659	0.332421	0.999684	1.516439	2.037505	2.364617	NA	NA	NA
0.178104	0.516642	1.072986	1.996787	2.481649	NA	NA	NA	NA
0.144032	0.404394	1.034623	1.521078	2.094321	3.250749	3.452862	NA	NA
0.143966	0.395951	1.061385	1.748976	2.618193	3.887714	5.446533	4.46	NA
0.1328	0.432874	1.061223	1.85679	2.675811	4.109938	5.515501	NA	16.1
0.112029	0.296831	0.788504	1.38407	2.167135	3.050181	4.429416	3.53	11.33
0.086084	0.225429	0.547748	1.186792	1.793003	2.629981	3.462295	4.695517	12.5
0.084338	0.251163	0.550678	1.174448	1.794501	2.822427	4.130168	6.535	NA
0.0915	0.284233	0.690476	1.124321	1.620562	2.79595	3.57283	NA	NA
0.113738	0.345108	0.715193	1.315154	2.049699	2.534174	2.890874	3.312	NA
0.131996	0.259201	0.904157	1.360411	1.629656	2.259701	NA	NA	NA

Table 1 *continued*

Proportion		Mature	at	Year	Start			
1	6							
2000	2021							
2	10							
1								
0.020	0.085	0.299	0.661	0.899	0.976	0.995	0.999	1.000
0.020	0.085	0.299	0.661	0.899	0.976	0.995	0.999	1.000
0.020	0.085	0.299	0.661	0.899	0.976	0.995	0.999	1.000
0.020	0.085	0.299	0.661	0.899	0.976	0.995	0.999	1.000
0.020	0.085	0.299	0.661	0.899	0.976	0.995	0.999	1.000
0.020	0.085	0.299	0.661	0.899	0.976	0.995	0.999	1.000
0.020	0.085	0.299	0.661	0.899	0.976	0.995	0.999	1.000
0.020	0.085	0.299	0.661	0.899	0.976	0.995	0.999	1.000
0.020	0.085	0.299	0.661	0.899	0.976	0.995	0.999	1.000
0.020	0.085	0.299	0.661	0.899	0.976	0.995	0.999	1.000
0.020	0.085	0.299	0.661	0.899	0.976	0.995	0.999	1.000
0.020	0.085	0.299	0.661	0.899	0.976	0.995	0.999	1.000
0.020	0.085	0.299	0.661	0.899	0.976	0.995	0.999	1.000
0.020	0.085	0.299	0.661	0.899	0.976	0.995	0.999	1.000
0.020	0.085	0.299	0.661	0.899	0.976	0.995	0.999	1.000
0.020	0.085	0.299	0.661	0.899	0.976	0.995	0.999	1.000
0.020	0.085	0.299	0.661	0.899	0.976	0.995	0.999	1.000
0.020	0.085	0.299	0.661	0.899	0.976	0.995	0.999	1.000
0.020	0.085	0.299	0.661	0.899	0.976	0.995	0.999	1.000
0.020	0.085	0.299	0.661	0.899	0.976	0.995	0.999	1.000
0.020	0.085	0.299	0.661	0.899	0.976	0.995	0.999	1.000
0.020	0.085	0.299	0.661	0.899	0.976	0.995	0.999	1.000

Table 1 *continued*

Natural Mortality
1 5
2000 2021
2 10
1

0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2

Table 1 *continued*

Inshore Gillnet (1B)	CPUE	GRI					
102							
GillnetSurveyIndex							
2002	2021						
1	1	0.5	0.6				
2.00E+00	8						
1	123.1543	32.95872	11.74558	4.225117	0.308821	0	0
1	41.70751	35.5878	8.876106	1.779744	0.139037	0.011021	0
1	28.96315	14.91029	7.437457	2.054313	0.417774	0	0
1	92.10771	13.78045	2.594565	3.454132	0.276118	0.197659	0
1	92.05388	26.85968	12.0433	4.637258	0.434615	0	0
1	104.8338	40.13615	14.58883	0.394243	0	0	0
1	-1	-1	-1	-1	-1	-1	-1
1	-1	-1	-1	-1	-1	-1	-1
1	91.31911	58.91142	30.36508	7.285386	0.760525	0.238347	0
1	163.9483	72.27203	20.98498	12.50463	2.651586	0.188868	0
1	102.0312	125.7955	15.52359	4.666716	1.901229	0	0
1	87.6564	59.45671	48.47826	16.39256	5.551691	0.911717	0.29798
1	25.38967	25.39727	13.88017	9.438055	2.51347	0.239682	0.322748
1	14.21866	25.01654	33.39517	27.08309	20.74663	2.069862	0.508871
1	17.73337	46.26496	23.87534	19.82226	12.25512	3.424493	0.797581
1	3.680524	41.77362	43.49133	18.21005	11.95906	4.889784	0.397463
1	9.952892	14.60077	15.30433	8.591906	3.041498	0.861558	0.30731
1	29.44252	65.05322	11.08746	21.05034	6.557056	0.751386	0.78549
1	13.33541	38.30404	23.87907	9.042987	3.547321	0.409815	0.281299
1	92.2346	29.9301	13.61797	16.42876	1.381919	1.402462	0

Table 2. SAM configurations for WKGREENCOD_GRI_North

```
# Configuration saved: Mon Jan 16 14:23:05 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.
  -1 0  1  2  3  4  5  6  6
 -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  3  4  4  -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)
   -1   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
   -1   0   1   1   1   1   1   1   1
   1   2   3   3   3   4   4  -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 con-
stant, 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

$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

Table 3. Table of SAM model parameters.

Parameter name	par	sd(par)	exp(par)	Low	High
logFpar_0	-4.631	0.355	0.010	0.005	0.020
logFpar_1	-4.486	0.178	0.011	0.008	0.016
logFpar_2	-4.871	0.171	0.008	0.005	0.011
logFpar_3	-4.753	0.165	0.009	0.006	0.012
logFpar_4	-5.185	0.221	0.006	0.004	0.009
logSdLogFsta_0	-1.111	0.173	0.329	0.233	0.466
logSdLogN_0	-0.964	0.211	0.382	0.250	0.582
logSdLogObs_0	2.291	5.868	9.890	0.000	1235368.151
logSdLogObs_1	0.382	0.166	1.466	1.052	2.043
logSdLogObs_2	-0.350	0.174	0.705	0.498	0.998
logSdLogObs_3	-0.354	0.144	0.702	0.526	0.936
logSdLogObs_4	-0.219	0.198	0.803	0.540	1.194
transfIRARdist_0	-0.526	0.341	0.591	0.298	1.170
predVarObs_0	0.137	1.492	1.147	0.058	22.654
predVarObs_1	-0.363	0.084	0.695	0.587	0.823
logPhiSW_0	4.083	1.562	59.305	2.608	1348.347
logPhiSW_1	4.975	1.694	144.792	4.887	4290.213
logSdProcLogSW_0	0.590	0.694	1.804	0.450	7.230
meanLogSW_0	-1.900	0.125	0.150	0.116	0.192
meanLogSW_1	-0.977	0.123	0.377	0.295	0.481
meanLogSW_2	-0.145	0.121	0.865	0.679	1.102
meanLogSW_3	0.373	0.121	1.453	1.141	1.849
meanLogSW_4	0.747	0.122	2.111	1.655	2.692
meanLogSW_5	1.050	0.125	2.857	2.225	3.668
meanLogSW_6	1.317	0.136	3.732	2.841	4.903
meanLogSW_7	1.377	0.150	3.962	2.936	5.346
meanLogSW_8	2.477	0.179	11.910	8.334	17.021
logSdLogSW_0	-2.070	0.175	0.126	0.089	0.179
logPhiCW_0	4.286	1.426	72.708	4.201	1258.505
logPhiCW_1	5.384	1.416	217.923	12.834	3700.437
logSdProcLogCW_0	0.792	0.663	2.207	0.586	8.317
meanLogCW_0	-1.110	0.159	0.330	0.240	0.453
meanLogCW_1	-0.436	0.144	0.647	0.485	0.862
meanLogCW_2	0.008	0.142	1.008	0.758	1.339
meanLogCW_3	0.372	0.142	1.451	1.093	1.927
meanLogCW_4	0.730	0.142	2.075	1.562	2.756
meanLogCW_5	1.023	0.143	2.783	2.090	3.705
meanLogCW_6	1.365	0.145	3.914	2.927	5.234
meanLogCW_7	1.546	0.148	4.694	3.490	6.313
meanLogCW_8	1.912	0.152	6.764	4.995	9.159
logSdLogCW_0	-2.157	0.139	0.116	0.088	0.153

Table 4. Run setting for EqSim

From R scripts	description	Value
stockName	Name of the stock	GRInorth
SAOAssessment	Name of assessment on stockassessmet.org	WKGREEN-COD_GRI_North
sigmaF	From SAM assessment	0.2
sigmaSSB	From SAM assessment	0.207
noSims	Recommended minimum 1000	1500
SRused	Models used in the simulations (usually segmented regression, Ricker, beverton-holt). Weight given to the model in the simulation given in brackets.	Segmented regression (20%) Ricker (52%) Beverton-Holt (27%)
SRyears_min	Same as assessment	2000
SRyears_max	Same as assessment	2020
rhoRec	Autocorrelation in recruitment	F (default)
numAvgYrsB	Years used for the average Weight at age	10
numAvgYrsS	Years used for the average selectivity	5
cvF	Forecast error F	Default = 0.212
phiF	Forecast error F	Default = 0.423
cvSSB	Forecast error SSB	Default = 0
phiSSB	Forecast error SSB	Default = 0
SSB05	5th percentile of SSB in the final year of the assessment, used in MSY Btrigger calculation. If set at 0, ignored.	Set to 0
rmSRRYrs	Which years (SSB years, not recruitment years) to exclude from the SRR fits	none

Table 5. Reference points estimated from EqSim. These were not accepted.

Framework	Reference point	Value	Technical basis
Precautionary approach	B_{lim}	2147	Segmented regression.
	B_{pa}	3015	Bpa = Blim × exp(1.645 × σ), σ=0.207
	F_{lim}	NA	The fishing mortality rate (F) that in stochastic equilibrium will result in median (SSB) = Blim (i.e. 50% probability of SSB being above or below Blim).
	Fpa	NA	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).
MSY approach	F_{MSY}	0.79	F that provides maximum yield
	MSY $B_{trigger}$	3015	MSY Btrigger = maximum (Bpa, the 5th percentile of the distribution of SSB when fishing at FMSY)

Table 6. Reference points based on Blim from a segmented regression and Fmsy and Fpa based on the GRO and GRI south stocks.

Reference point	Value	Basis
B_{lim}	2147	Segmented regression
F_{msy}	0.24	Based on the average of Fmsy from the GRO (Fmsy=0.18) and GRI south (Fmsy=0.29) stock
F_{pa}	2.63	Based on the average of Fpa from the GRO (Fpa=1.34) and GRI south (Fpa=3.92) stock
F_{lim}	NA	NA
B_{pa}	3015	Bpa = Blim × exp(1.645 × σ), σ=0.207

Figure 1. Catch weight at age (in kilograms). Numbers give the input values by age, the line give the estimates from the model

Figure 2. Stock weight at age (in kilograms). Numbers gives the input values by age, the line give the estimates from the model.

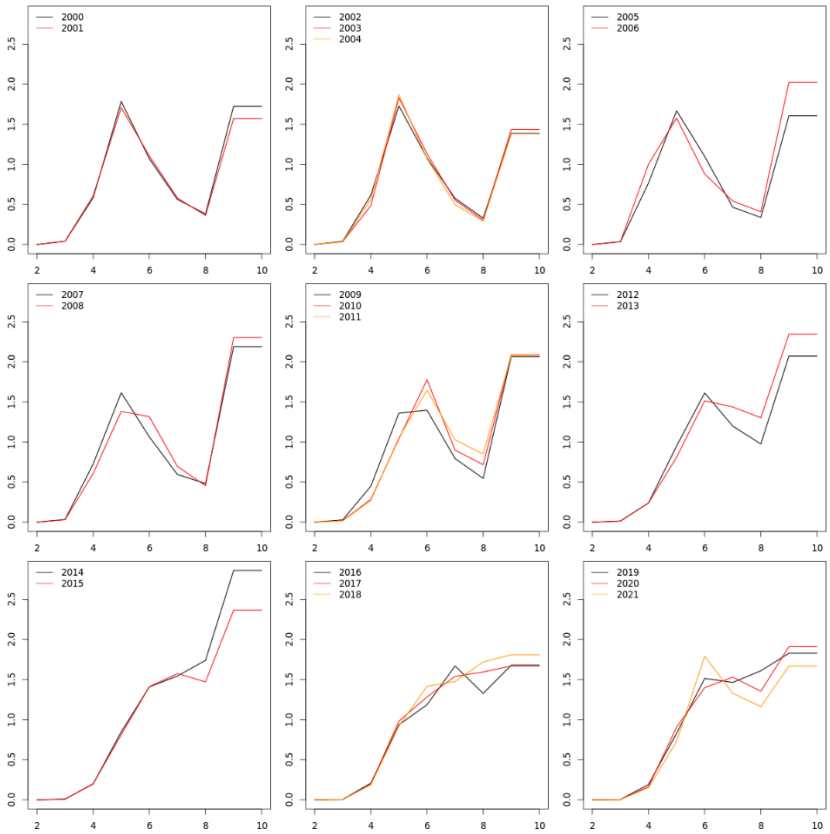

Figure 3. Selection pattern (F_{age}/F_{bar}) from the SAM model.

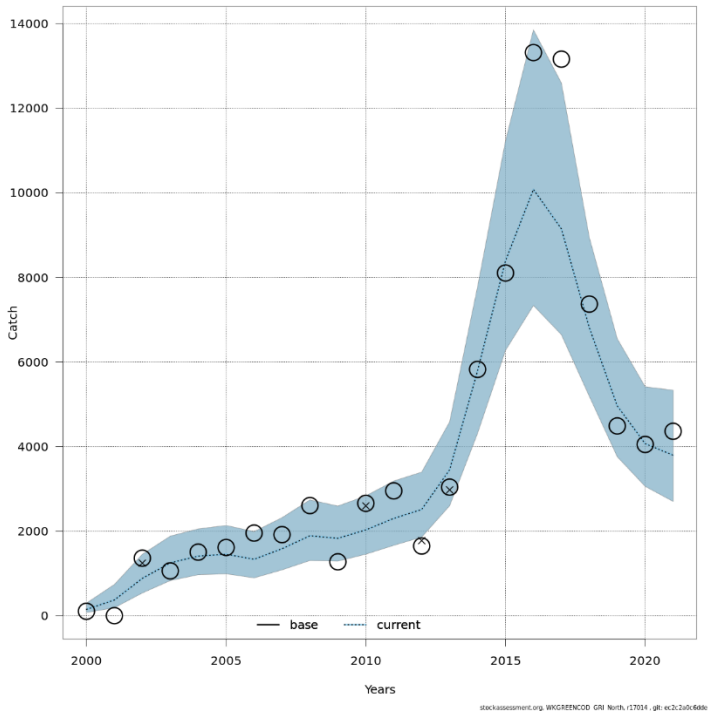

Figure 4. Estimated (line), observed catches (x), and catches based on smoothed catch weights (o). Estimated catch is shown with 95% confidence intervals.

Figure 5. Normalized residuals derived from SAM. Blue indicate positive residuals (observation larger than predicted) and red circles indicated negative residuals.

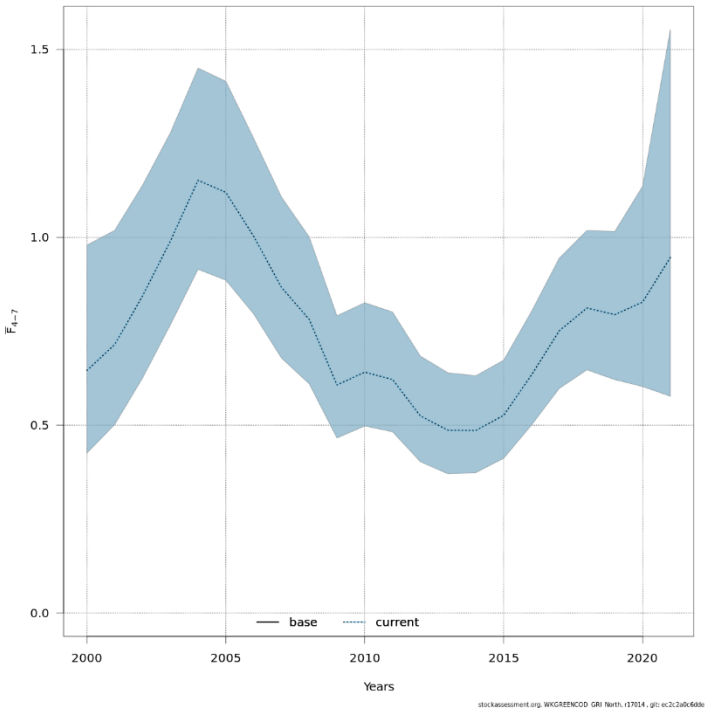

Figure 6. Estimated historical pattern of fishing mortality (Fbar4-7). The shaded area is 95% confidence intervals.

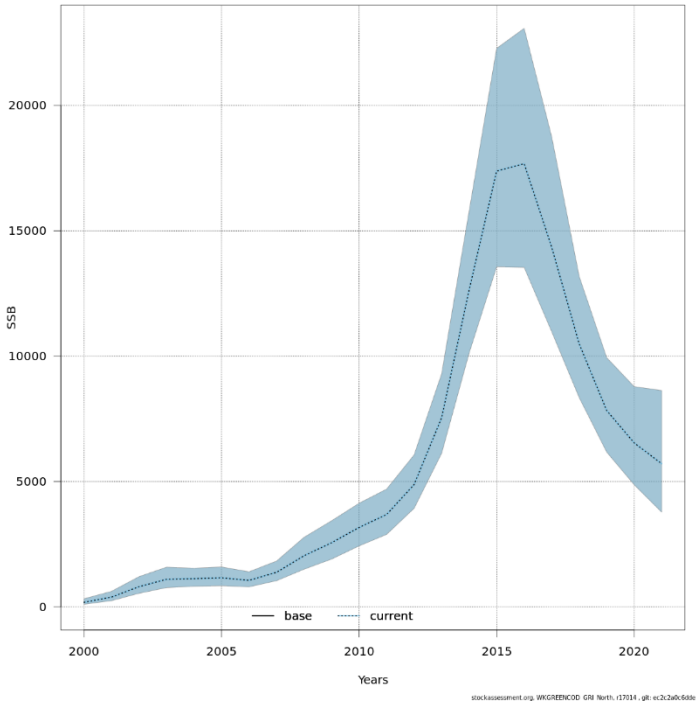

Figure 7. Estimated historical patterns of spawning stock biomass (SSB). The shaded area is 95% confidence intervals.

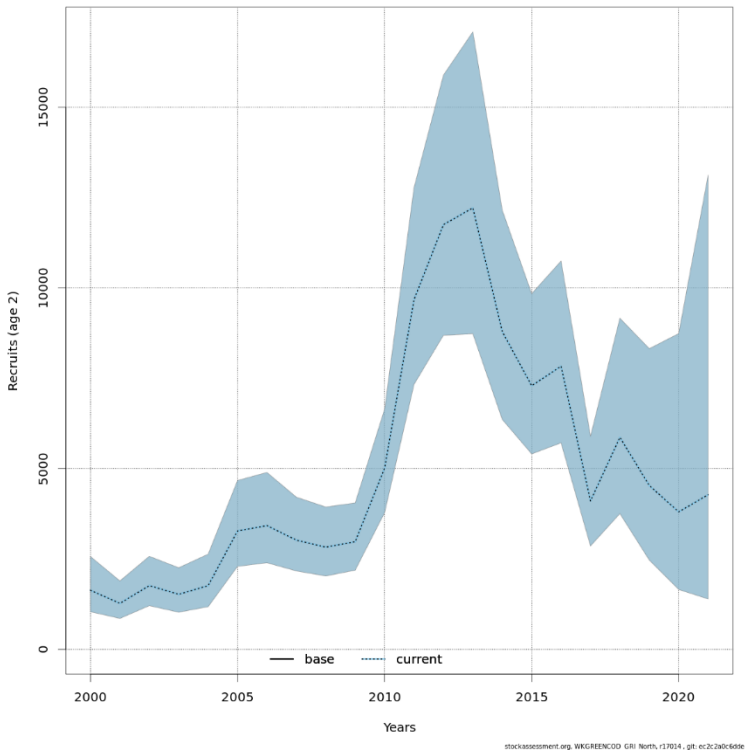

Figure 8. Estimated historical patterns of age 2 recruitment. The shaded area is 95% confidence intervals.

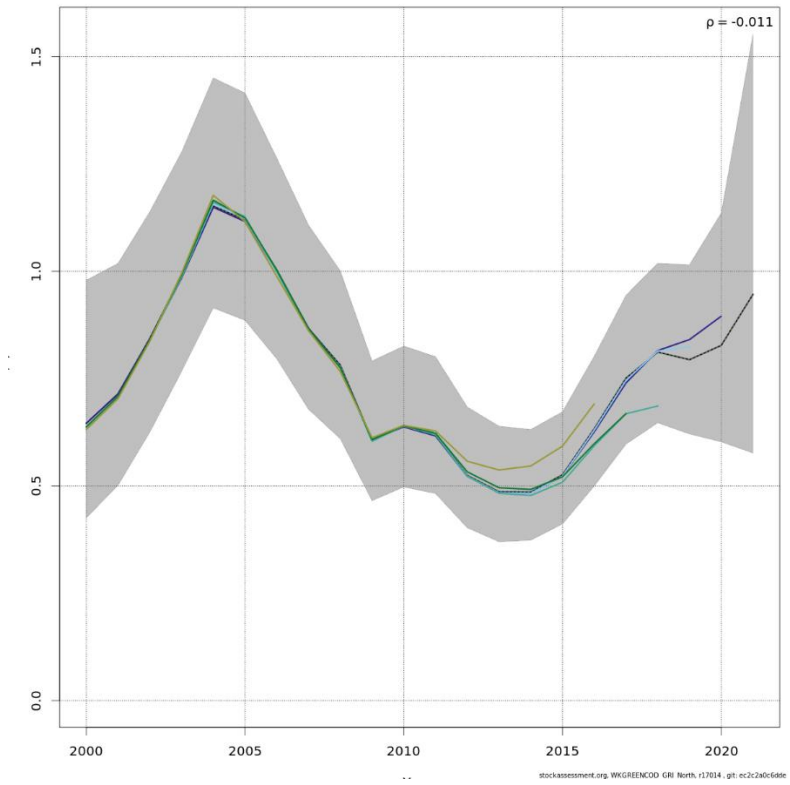

Figure 9. Retrospective plots of Fbar (5 years peel). Mohn's rho is given in the upper right corner.

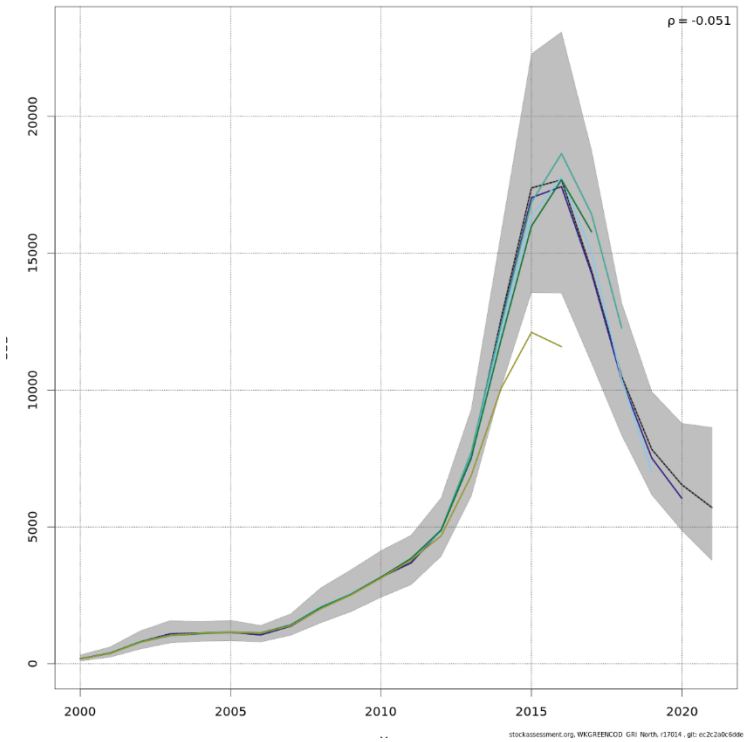

Figure 10. Retrospective plots of SSB (5 years peel). Mohn's rho is given in the upper right corner.

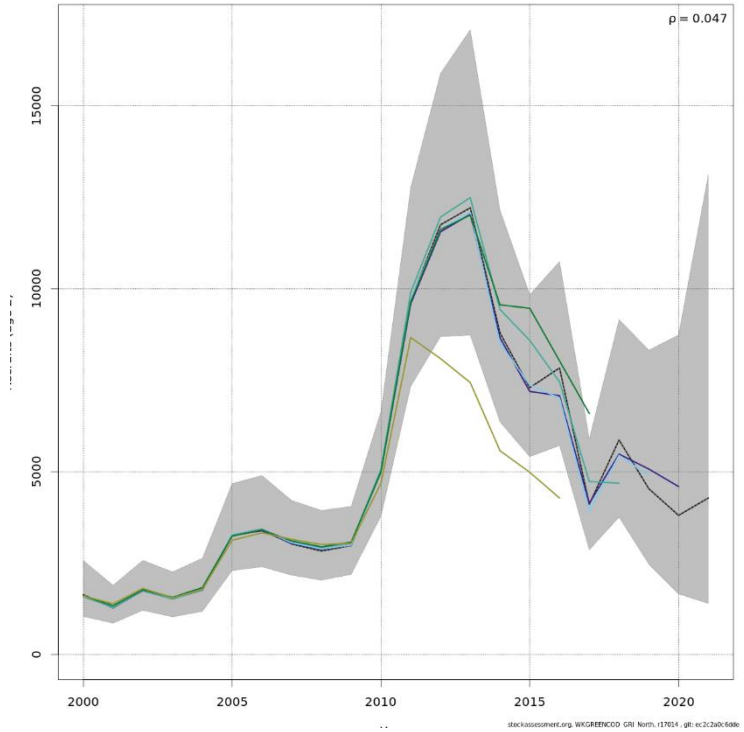

Figure 11. Retrospective plots of age 2 recruitment (5 years peel). Mohn's rho is given in the upper right corner.

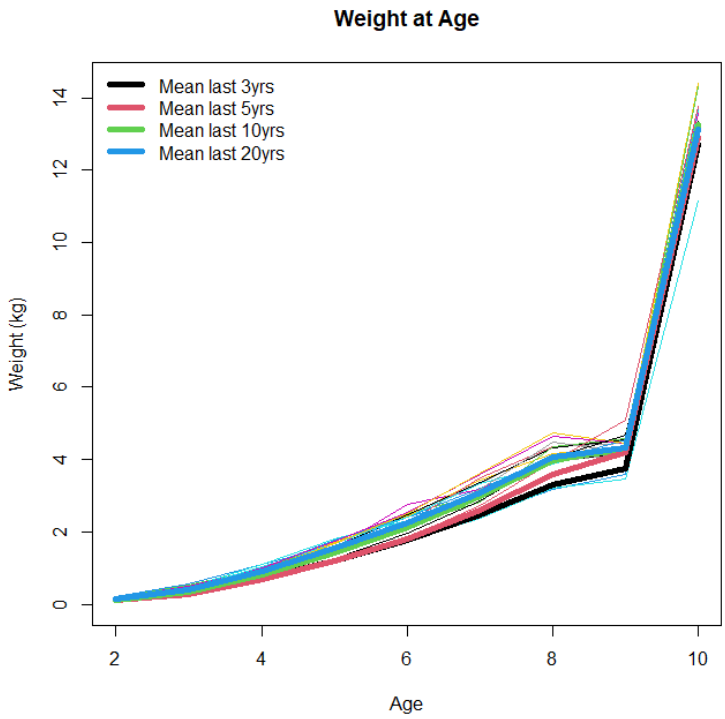

Figure 12. Stock weight at age for all years, bold line show means.

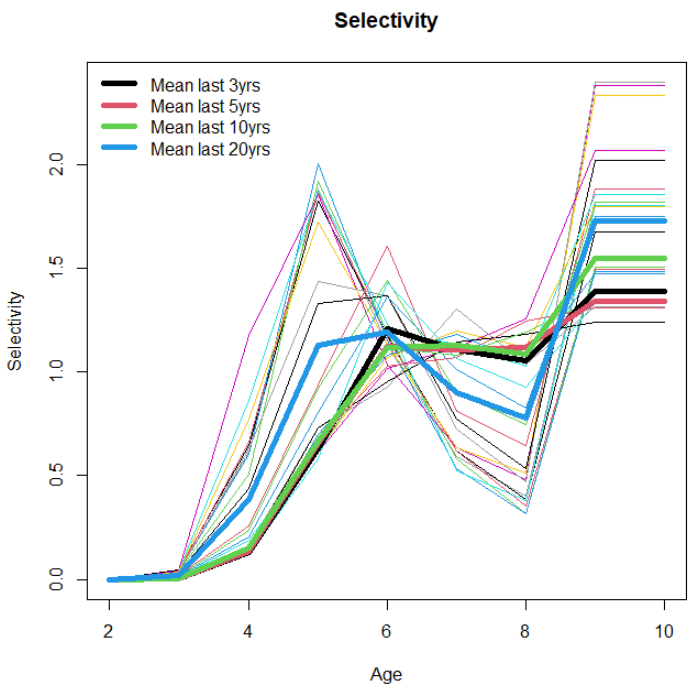

Figure 13. Selectivity at age for all years, bold line show means.

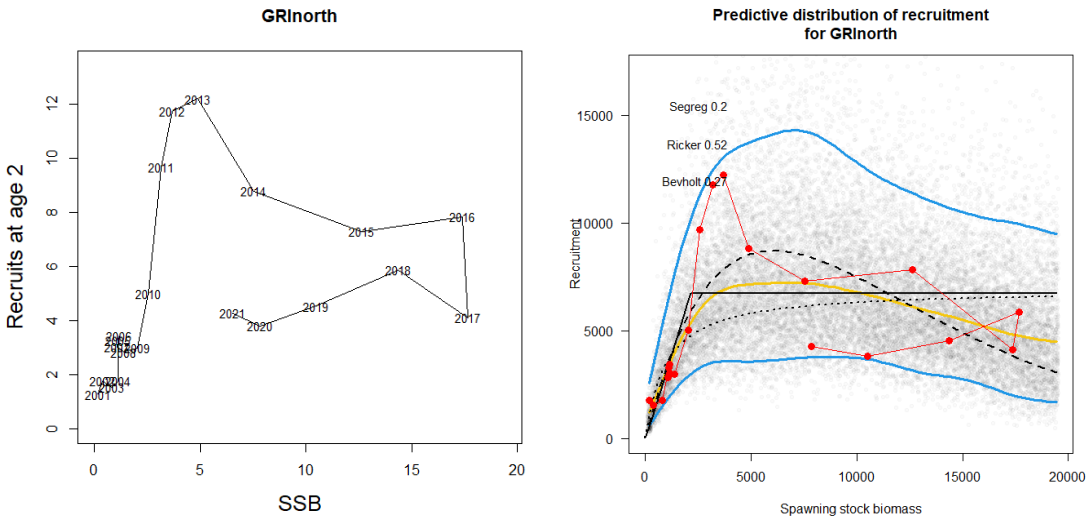

Figure 14. left: SSB-recruitment relationship, labels indicate recruitment year. right: SSB-recruitment relationship estimated by simulation using EqSim with fitted SSB-recruitment relationships. Dashed: Ricker curve. Dotted: Beverton-Holt curve. Solid: Segmented regression. The curve fits are indicated.

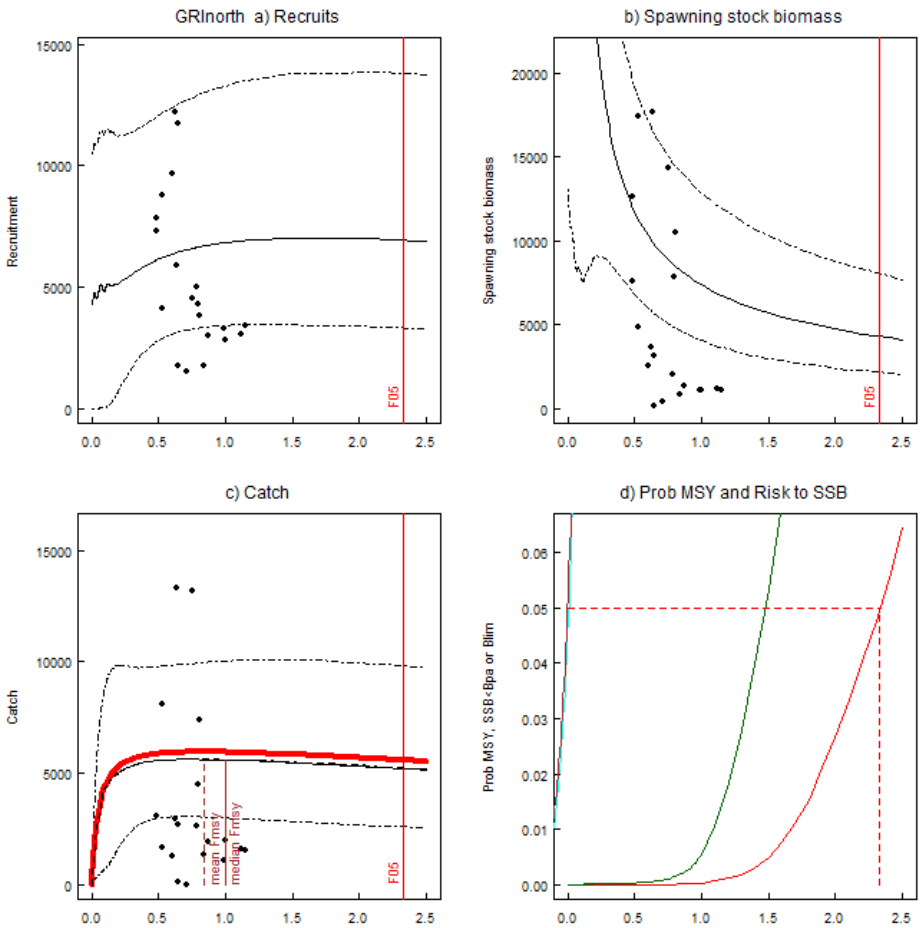

Figure 15. EqSim plots of recruitment, SSB, catch and probability of SSB falling below Bpa and Blim. F is on the x-axis.

WD 11 - A SAM assessment of the southern part of West Greenland inshore cod stock (GRI south)

Stockassessment.org run name: **WKGREEENCOD_GRI_South**

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Introduction

The Atlantic cod (*Gadus morhua*) in Greenland waters is primarily of three genetically distinct stocks: West Greenland inshore (GRI), West Greenland offshore (GRO), and East Greenland-Iceland (EGI) (see WD01 for details). Previously advice has been provided based on geographical areas. At WKGREENCOD data from the commercial fisheries and scientific surveys in Greenland waters are split into the three stock components (see WD01, WD02, WD05).

This document presents the results of the state-space model (SAM) (Nielsen and Berg, 2014) for the GRI south stock and estimated reference points using EqSim. The GRI south stock represents the GRI stock in NAFO aeras 1D, 1E and 1F. This document was updated following the discussions during the WKGREENCOD meeting.

Input data

The input data for the SAM assessment model are described in WD05. The Assessment covers the period 2000-2021.

Total catches
Total catches were available for the stock GRI south from 2000-2021, due to poor sampling in 2001 catch data are not included from that year (see Table 1 for input file). No discarding is believed to take place, landings are assumed to equal catches. The catches are from NAFO areas 1D, 1E and 1F. There are many zero catches for age 2, rather than removing age 2 in the input files, configurations for age 2 catches was set to -1 indicating not data (see Table 2).

Catch mean weight at age
Catch mean weight at age were estimated for all years. Some age-year combination without sufficient data were left as NA in the input file (see Table 1 for input file). The given catch mean weights were then treated as observation to inform the catch weight process (GMRF with cohort and within year correlations) ($catchWeightModel, $keyCatchWeightMean and $keyCatchWeightObsVar in Table 2). See figure 1 for catch weights estimated by the model.

Landings mean weights and discard mean weights are set equal to catch mean weight without any smoothing as these are not used.

Stock mean weight at age
The same process as described to Catch mean weights were used for stock mean weights (see Table 1 for input file) ($stockWeightModel, $keyStockWeightMean and $keyStockWeightObsVar in Table 2), see figure 2 for stock weight estimated by the model.

Surveys
Survey CPUE index by age for ages 2-8 estimated from inshore gillnet survey in area 1D (see Table 1 for input file), for details on survey data see WD05 and for details on index calculations see WD06.

Landings fraction
Set to 1, landings are assumed to equal catches.

Natural mortality
Set to default 0.2 for all years and ages (see Table 1 for input file). See details in WD05.

Maturity
Maturity ogive is based on genetic dataset presented in WD01 (see Table 1 for input file). The ogive is based on the entire GRI stock. Not enough data to produce annual maturity ogives. Details are given in WD05.

F before spawning
The fraction of the fishing mortality rate, which is applied prior to spawning divided into age classes for each year. Set to 0 for all years and ages.

M before spawning
The fraction of the natural mortality rate, which is applied prior to spawning divided into age classes for each year. Set to 0 for all years and ages.

Assessment

Configurations

Recruitment
Recruitment parameters are estimated within the assessment model. The parameter structure is assumed as a plain random walk process ($stockRecruitmentModelCode in Table 2).

Fishing mortality and Fbar
Fishing mortality is estimated individually for ages 3-8, age 9 and 10 are assumed to be the same, age 2 is set to -1 and therefore not used ($keyLogFsta in Table 2). It is assumed that there are no correlations across ages ($corFlag in Table 2), this is supported by changes in the selectivity pattern during the assessment period, meaning that correlations between ages are unlikely to be consistent throughout the period (Figure 3). The Fbar range was set to 4-7 years old as these ages constitutes the main part of the catches ($fbarRange in Table 2).

Survey
The survey catchability parameters are estimated individually for ages, 2, 3 and 4. They are coupled for ages 5 and 6 and for ages 7 and 8 ($keyLogFpar in Table 2).

Variance parameters
For age 2 the coupling of the recruitment and survival process variance parameters for the log(N)-process are different from the other ages ($keyVarLogN in Table 2). In the model.R script the following was added: par$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.

The variance parameters for the catch are separate for age 3 and they are coupled for ages 4-10. Age to is set to -1 and not used. The variance parameters for the survey are separate for age 2 and 3, ages 4-8 are coupled ($keyVarObs in Table 2).

The covariance structure for catch is assumed to be independent ($obsCorStruct in Table 2). For the survey the covariance structure is assumed to follow an AR(1) structure. This was done because there was evidence of year effects in the observation residuals for the survey.

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 (see $predVarObsLink in Table 2) (see Breivik *et al* 2021).

Model diagnostics

Uncertainty surrounding the SSB and F estimates appears reasonable (Figure 7 and 8), although high on F for the first couple of years in the time series. The estimated catches follow the same trend as the observed catches, but fluctuations are smaller (Figure 4).

Parameter estimation
Parameter estimates are given in Table 3.

Residuals
Observation residuals for both catches and survey shows some tendency for larger residuals early in the time series (Figure 5). There is a block of negative residuals for the survey residuals early in the timeseries and a block of positive residuals in the most recent years. For the catch residuals there are a block of positive residuals, showing that the model underestimate catches in these years. The most recent year have negative residuals for all ages.

Stock summary

Fishing mortality
Fishing mortality peaked in 2008 at 1.073 and then decreased to the lowest level in the assessment time period in 2017, It has since increase and is close to 0.6 (Figure 6).

SSB
SSB was at a low level at the beginning of the timeseries and increased from 194 in 2000 to 7376 in 2018. Since the SSB has since decreased but remain at a high level relative to the assessment period (Figure 7).

Recruitment
Recruitment was at a low level at the beginning of the assessment period, it increased and had a peak in 2016 (cohort 2014). Recruitment has been going down since. The two most recent years have had low recruitment, although these estimates were associated with very large confidence intervals (Figure 8).

Retrospective analysis
In order to test the robustness of the assessment a 5-year retrospective analysis (Figures 9-11) were conducted. For F all peels, except one, are within the confidence intervals. The oldest peels show a tendency to overestimate F, whereas the three most recent peels show some tendency to underestimate F (Mohn'r rho=0.119) (Figure 9). All peels for SSB, except the two oldest, are within confidence intervals. The oldest peels show a tendency to underestimate SSB and the three most recent peels shows a tendency to overestimate SSB (Mohn'r rho= 0.001) (Figure 10). For recruitment the three most recent peels are within the confidence limits (Mohn's rho=0.004) (Figure 11).

Alternative settings and configurations

An initial run based mainly on default configurations were used as a starting point for setting up the final SAM model. Impact of each change in configuration were evaluated during the process.
A run with additional uncertainty for the early period (2000-2010) for both catches and CPUE index, did not improve the model.

Short term forecast

Short term forecasts were set up using mainly default settings for the SAM run on stockassessment.org. Uncertainty on F were taken from the model. Catch ad stock weights were taken from the model used for these, the model is set up to estimate further ahead in time than the assessment run. For maturity and natural mortality average of the last 5 years were used, currently maturity and natural mortality is constant over time so the time period for this would not have any impact. The default for the recruitment is the last 10 years, it was decided at the meeting that this period is appropriate.

Reference points

The estimation of reference points follows ICES Reference Points guidance, 2021. The estimation was done using the R-programme EqSim developed by D. C. M. Miller, which works directly on a specified SAM fit. The code for the final run is on the ICES sharepoint for the WKGREENCOD benchmark and named 'WKGREENCOD_GRIsouth_EqSim_feb23_Final.R'. David Miller attended parts of the meeting where reference points were discussed and provided guidance on the ICES procedures and EqSim settings.

Following ICES guidelines the stock-recruitment relationship appears to follow a type 2 stock type, where B_{lim}= segmented regression change point. Following initial runs it was decided to exclude the two most recent recruitment estimates due to very high uncertainty (recruitment in 2020 and 2021, SSB in 2018 and 2019), this is in line with ICES guidelines. The segmented regression then gave a B_{lim} of 1067.

The simulation settings for the stock-recruitment relationship were as follows. The number of simulations were set to 1500. The years 2018 and 2019 (recruitment in 2020 and 2021) were excluded. For assessment error sigmaF was set to default of 0.2 and sigmaSSB was 0.211 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 5 years were used, based on figure 16 there has been a reduction in weight-at-age in the assessment period. For selectivity the last 5 years were used, there appear to have been a change in selectivity early in the assessment period (Figure 17). Run settings are given in table 4. The estimated reference points are given in table 5. Due to very high estimate of F_{lim}, it was decided to not report on this value.

Due to the currently short timeseries the group recommends that reference point calculations are revisited when two more years of data are available.

Conclusion

The model presented here fit the observation reasonably well and seems to capture trends in stock size and fishing mortality well.

The assessment model is based on data for the GRI stock in the southern part of the stock area (NAFO area 1D-1F), rather than previous geographical data split. The model in combination with one for GRInorth provides a useful tool for assessing the GRI stock.

References

Breivik, O. N., Nielsen, A., Berg, C. W. 2021. Prediction-variance relation in a state-space fish stock assessment model. ICES Journal of Marine Science. 78 (10): 3650-3657.
Nielsen, A., Berg, C. W. 2014. Estimation of time-varying selectivity in stock assessments using state-space models. Fisheries research. 158: 96-101.

Table 1. Input files to SAM runs.

Catch in Numbers (thousands)

1	2							
2000	2021							
2	10							
1								
1.00E-04	0.928558	35.99224	70.96803	1.694404	0.054856	0.030109	1.00E-04	1.00E-04
-1	-1	-1	-1	-1	-1	-1	-1	-1
0.019283	38.30673	225.2038	51.83193	4.594154	1.612912	0.1151	0.048207	0.015274
0	7.536766	50.70565	64.25757	22.70905	12.16678	4.628473	4.399006	3.601581
0	7.444737	59.81705	161.9609	45.26664	3.248741	0.897308	0	0
0.000164	89.04098	171.4492	43.73009	40.05798	10.45536	4.810328	1.448233	0.036358
2.426479	498.4544	700.5379	147.3002	5.938401	1.011671	0.358117	0.233004	0.000474
0.078514	67.65275	991.4197	352.0663	45.14039	11.27554	4.077024	2.332452	3.385351
0	143.2124	964.8479	569.3445	113.2094	23.29087	1.245976	0	0
0.096718	61.84708	1007.206	640.0617	53.46956	7.104585	1.696896	0.209987	2.658125
0.020276	70.25679	252.7033	621.4748	239.5199	12.88795	1.521011	0.36762	0.896331
0.021115	25.25628	667.9347	506.4967	352.3304	54.90128	31.04863	2.449746	1.429648
0.020677	83.17542	476.4914	954.1641	251.0809	48.82573	2.240674	4.463094	7.608784
0	4.24473	517.9352	570.4977	360.4135	119.2789	37.29461	9.696471	1.891763
0	8.033631	245.6324	452.3234	405.669	51.22461	10.04522	4.701601	2.356432
0.046261	2.297173	430.7394	972.5048	413.0918	295.3817	17.83655	1.554506	0.91815
0	11.75441	320.3376	1305.019	516.1808	98.66419	22.49244	5.270679	2.697665
0.010093	7.366668	177.191	701.3847	384.3027	176.8913	100.0814	11.89067	8.25121
0.001979	8.302032	302.2693	1067.471	968.2877	525.9043	165.5136	44.89691	17.47666
0	2.387515	353.0259	1658.78	1364.132	624.6718	145.1845	27.79892	7.736065
0	39.59515	624.2231	1071.949	1355.039	255.5791	150.179	28.94555	9.238447
0.004402	0.957426	420.9276	807.2834	518.3614	373.2968	27.7515	10.94716	6.003142

Table 1 *continued*

Mean Weight in Catch (kilograms)

1	3							
2000	2021							
2	10							
1								
NA	0.641808	1.120983	1.453028	2.378079	2.62124	2.408667	NA	NA
NA	NA	NA	NA	NA	NA	NA	NA	NA
0.36	0.707845	0.998694	1.397425	2.317673	1.884027	2.852515	3.559567	3.355852
NA	1.0204	1.32872	1.914603	2.64373	3.118567	3.82932	5.178636	6.981696
NA	0.890787	1.090179	1.660006	2.00526	4.324258	6.131665	NA	NA
0.303882	0.912482	1.11696	1.696514	2.342408	2.624497	2.922158	6.945617	7.472069
0.361632	0.74227	0.934201	1.602003	2.800394	3.746119	5.119804	7.447826	8.126823
0.194885	0.689953	0.962931	1.495943	2.615339	4.264836	5.008299	6.886959	10.37499
NA	0.59202	0.862632	1.348874	2.000197	3.00954	3.897189	NA	NA
0.249029	0.629244	0.844354	1.357548	2.426457	4.030954	5.750872	8.517065	14.20877
0.504894	0.657785	0.892682	1.438772	1.96037	3.065803	4.982523	7.225296	17.6289
0.375716	0.627108	0.842564	1.341903	1.813296	3.331775	5.084872	6.711352	8.747497
0.3405	0.732774	1.050187	1.748909	2.58193	3.047601	5.214072	7.07804	13.93713
NA	0.760085	1.234997	1.564657	2.26213	2.681637	3.096598	2.473897	6.949191
NA	0.687983	1.213295	1.846676	2.451163	3.234664	4.976361	5.378249	8.396564
0.126285	0.501383	1.025824	1.508379	2.248992	3.186749	4.451812	7.035874	8.856504
NA	0.465655	0.893808	1.312802	1.939415	2.720931	3.185446	3.644291	8.773471
0.168877	0.633663	0.797449	1.275509	1.795134	2.547849	3.020776	4.232205	5.89861
0.090885	0.38619	0.74319	1.024648	1.373977	1.907327	2.640313	3.125542	4.012623
NA	0.400377	0.738891	1.024633	1.330177	1.531696	1.930739	3.411007	4.592637
NA	0.545974	0.960179	1.213777	1.365062	1.690228	2.167916	2.605725	3.982513
0.283159	0.612855	0.989498	1.33354	1.499772	1.75194	2.378915	3.674002	6.386683

Table 1 *continued*

Mean Weight in survey (kilograms)

1	3							
2000	2021							
2	10							
1								
NA	NA	NA	NA	NA	NA	NA	NA	NA
NA	NA	NA	NA	NA	NA	NA	NA	NA
0.178227	0.371075	1.159806	1.665757	NA	NA	NA	NA	NA
0.199812	0.518788	0.906122	1.315102	2.940008	2.940008	NA	NA	NA
0.244075	0.410688	1.009232	1.55249	1.814468	3.23	5.1	NA	NA
0.215513	0.401993	1.196545	1.361459	NA	NA	NA	NA	NA
0.180451	0.502066	0.905904	1.921917	2.88	4.46	NA	NA	NA
NA	NA	NA	NA	NA	NA	NA	NA	NA
0.106161	0.313866	0.549723	1.272554	2.236465	NA	NA	NA	NA
0.134604	0.373693	0.794195	1.154633	2.34852	NA	4.62	NA	NA
0.18647	0.414161	0.841845	1.524054	1.824015	NA	NA	NA	NA
0.20343	0.443259	0.859114	1.269391	1.685378	2.677321	3.14	NA	NA
0.191605	0.558088	1.142427	1.805508	3.083072	4.742049	6.835218	NA	NA
0.121805	0.314994	1.174448	1.429433	2.163204	2.52158	2.616292	2.246	NA
0.12034	0.35178	0.97854	1.675022	2.130812	1.921566	5.042	NA	NA
0.10434	0.272737	0.712077	1.382668	2.10981	3.129194	NA	NA	NA
0.109679	0.281588	0.783649	1.199841	1.726229	2.227985	3.534	3.216	8.534193
0.140558	0.277787	0.636374	1.143938	1.674345	2.140525	3.491963	NA	3.98
0.105458	0.263593	0.533799	0.878629	1.279543	1.731237	2.005302	2.38014	2.878
0.088732	0.232142	0.496841	0.782456	1.211378	1.444686	1.836684	2.648738	4.91041
0.123591	0.28589	0.607731	0.968357	1.25445	1.407795	1.922999	2.009857	3.418
0.118665	0.33165	0.657031	1.081508	1.300201	1.509166	2.393556	2.452352	2.61

Table 1 *continued*

Proportion		Mature	at	Year	Start			
1	6							
2000	2021							
2	10							
1								
0.020	0.085	0.299	0.661	0.899	0.976	0.995	0.999	1.000
0.020	0.085	0.299	0.661	0.899	0.976	0.995	0.999	1.000
0.020	0.085	0.299	0.661	0.899	0.976	0.995	0.999	1.000
0.020	0.085	0.299	0.661	0.899	0.976	0.995	0.999	1.000
0.020	0.085	0.299	0.661	0.899	0.976	0.995	0.999	1.000
0.020	0.085	0.299	0.661	0.899	0.976	0.995	0.999	1.000
0.020	0.085	0.299	0.661	0.899	0.976	0.995	0.999	1.000
0.020	0.085	0.299	0.661	0.899	0.976	0.995	0.999	1.000
0.020	0.085	0.299	0.661	0.899	0.976	0.995	0.999	1.000
0.020	0.085	0.299	0.661	0.899	0.976	0.995	0.999	1.000
0.020	0.085	0.299	0.661	0.899	0.976	0.995	0.999	1.000
0.020	0.085	0.299	0.661	0.899	0.976	0.995	0.999	1.000
0.020	0.085	0.299	0.661	0.899	0.976	0.995	0.999	1.000
0.020	0.085	0.299	0.661	0.899	0.976	0.995	0.999	1.000
0.020	0.085	0.299	0.661	0.899	0.976	0.995	0.999	1.000
0.020	0.085	0.299	0.661	0.899	0.976	0.995	0.999	1.000
0.020	0.085	0.299	0.661	0.899	0.976	0.995	0.999	1.000
0.020	0.085	0.299	0.661	0.899	0.976	0.995	0.999	1.000
0.020	0.085	0.299	0.661	0.899	0.976	0.995	0.999	1.000
0.020	0.085	0.299	0.661	0.899	0.976	0.995	0.999	1.000
0.020	0.085	0.299	0.661	0.899	0.976	0.995	0.999	1.000
0.020	0.085	0.299	0.661	0.899	0.976	0.995	0.999	1.000

Table 1 *continued*

Natural Mortality
1 5
2000 2021
2 10
1

0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2

Table 1 *continued*

Inshore Gillnet (1D)	CPUE	GRI					
102							
GillnetSurveyIndex							
2002	2021						
1	1	0.5	0.6				
2.00E+00	8						
1	3.106598	1.951169	1.187028	0.24356	0	0	0
1	3.352643	1.588799	1.424791	0.603593	0.063886	0.009455	0
1	24.3388	5.486622	1.308428	0.991419	0.16556	0.031306	0.102846
1	24.51629	3.916646	1.005479	0.340368	0	0	0
1	65.81121	14.71506	5.587709	0.590099	0.164509	0.19265	0
1	-1	-1	-1	-1	-1	-1	-1
1	1.848983	18.54157	29.83958	4.179623	0.036358	0	0
1	27.67473	5.701012	38.31948	17.20682	0.441751	0	0.207592
1	13.91449	60.21661	9.180834	17.51794	1.406457	0	0
1	10.66173	1.625085	8.139238	3.968082	3.12921	1.453927	0.16831
1	25.98561	13.94867	19.94518	38.07227	2.117606	0.265327	0.363016
1	33.07434	23.86637	28.06194	18.18611	8.723209	2.394178	1.164768
1	21.2303	40.63905	25.77731	11.6913	4.630489	0.536275	0.176981
1	20.23717	43.90069	38.13312	16.51109	3.004409	1.437826	0
1	34.41809	53.80365	18.92368	25.39228	4.455697	0.268817	0.447519
1	7.200247	46.37458	34.52073	26.99003	8.401603	0.764416	0.679069
1	6.881178	29.80287	36.4168	25.15232	13.70545	4.71717	0.809779
1	7.208765	11.59839	18.63221	25.6347	15.36035	5.574993	0.360233
1	1.728807	19.62826	15.90509	22.2312	42.97805	14.70874	4.330278
1	11.20347	8.431624	53.05194	39.75754	36.0057	30.01227	2.716398

Table 2. SAM configurations for WKGREENCOD_GRI_South

```
# Configuration saved: Mon Jan 16 14:23:05 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.
   -1 0   1   2   3   4   5   6   6
  -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   3   4   4  -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)
  -1   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
  -1   0   1   1   1   1   1   1   1
   1   2   3   3   3   4   4  -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.
 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

$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 obser-
vations 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

Table 3. Table of SAM model parameters.

Parameter name	par	sd(par)	exp(par)	Low	High
logFpar_0	-5.570	0.415	0.004	0.002	0.009
logFpar_1	-5.202	0.193	0.006	0.004	0.008
logFpar_2	-4.826	0.149	0.008	0.006	0.011
logFpar_3	-4.469	0.138	0.011	0.009	0.015
logFpar_4	-4.280	0.280	0.014	0.008	0.024
logSdLogFsta_0	-0.968	0.174	0.380	0.268	0.538
logSdLogN_0	-0.781	0.203	0.458	0.305	0.688
logSdLogObs_0	1.751	1.862	5.758	0.139	238.319
logSdLogObs_1	0.571	0.202	1.771	1.183	2.652
logSdLogObs_2	-0.225	0.183	0.798	0.554	1.151
logSdLogObs_3	-0.483	0.129	0.617	0.476	0.799
logSdLogObs_4	0.077	0.150	1.080	0.799	1.459
transfIRARdist_0	0.237	0.327	1.268	0.659	2.440
predVarObs_0	-0.356	0.824	0.701	0.135	3.641
predVarObs_1	-0.619	0.123	0.538	0.421	0.688
logPhiSW_0	4.771	1.530	118.094	5.543	2516.150
logPhiSW_1	6.113	1.563	451.823	19.840	10289.339
logSdProcLogSW_0	1.134	0.699	3.109	0.768	12.582
meanLogSW_0	-1.908	0.197	0.148	0.100	0.220
meanLogSW_1	-1.031	0.196	0.357	0.241	0.528
meanLogSW_2	-0.219	0.195	0.803	0.544	1.187
meanLogSW_3	0.232	0.195	1.261	0.855	1.862
meanLogSW_4	0.614	0.196	1.848	1.250	2.734
meanLogSW_5	0.843	0.198	2.324	1.564	3.452
meanLogSW_6	1.146	0.201	3.147	2.106	4.703
meanLogSW_7	0.983	0.214	2.673	1.743	4.101
meanLogSW_8	1.404	0.222	4.071	2.614	6.342
logSdLogSW_0	-1.820	0.122	0.162	0.127	0.207
logPhiCW_0	3.754	1.257	42.677	3.456	527.044
logPhiCW_1	4.427	1.236	83.688	7.070	990.636
logSdProcLogCW_0	0.797	0.580	2.218	0.695	7.083
meanLogCW_0	-1.385	0.163	0.250	0.181	0.347
meanLogCW_1	-0.445	0.153	0.641	0.472	0.870
meanLogCW_2	-0.043	0.150	0.958	0.710	1.292
meanLogCW_3	0.344	0.148	1.410	1.049	1.896
meanLogCW_4	0.678	0.148	1.970	1.465	2.648
meanLogCW_5	0.955	0.150	2.597	1.925	3.505
meanLogCW_6	1.226	0.153	3.408	2.509	4.631
meanLogCW_7	1.518	0.159	4.562	3.320	6.268
meanLogCW_8	1.941	0.166	6.965	4.999	9.704
logSdLogCW_0	-2.119	0.199	0.120	0.081	0.179

Table 4. Run setting for EqSim

From R scripts	description	Value
stockName	Name of the stock	GRIsouth
SAOAssessment	Name of assessment on stockassessmet.org	WKGREENCOD_GRI_South
sigmaF	From SAM assessment	0.2
sigmaSSB	From SAM assessment	0.211116
noSims	Recommended minimum 1000	1500
SRused	Models used in the simulations (usually segmented regression, Ricker, beverton-holt). Weight given to the model in the simulation given in brackets.	Segmented regression (35%) Ricker (18%) Beverton-Holt (47%)
SRyears_min	Same as assessment	2000
SRyears_max	Same as assessment	2020
rhoRec	Autocorrelation in recruitment	F (default)
numAvgYrsB	Years used for the average Weight at age	5
numAvgYrsS	Years used for the average selectivity	5
cvF	Forecast error F	Default = 0.212
phiF	Forecast error F	Default = 0.423
cvSSB	Forecast error SSB	Default = 0
phiSSB	Forecast error SSB	Default = 0
SSB05	5th percentile of SSB in the final year of the assessment, used in MSY Btrigger calculation. If set at 0, ignored.	Set to 0
rmSRRYrs	Which years (SSB years, not recruitment years) to exclude from the SRR fits	2018 and 2019

Table 5. Reference points estimated from EqSim.

Framework	Reference point	Value	Technical basis
Precautionary approach	B_{lim}	1067	Segmented regression.
	B_{pa}	1510	Bpa = Blim × exp(1.645 × σ), σ=0.211
	F_{lim}	NA	The fishing mortality rate (F) that in stochastic equilibrium will result in median (SSB) = Blim (i.e. 50% probability of SSB being above or below Blim).
	Fpa	3.9	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).
MSY approach	F_{MSY}	0.29	F that provides maximum yield
	MSY $B_{trigger}$	1510	MSY Btrigger = maximum (Bpa, the 5th percentile of the distribution of SSB when fishing at FMSY)

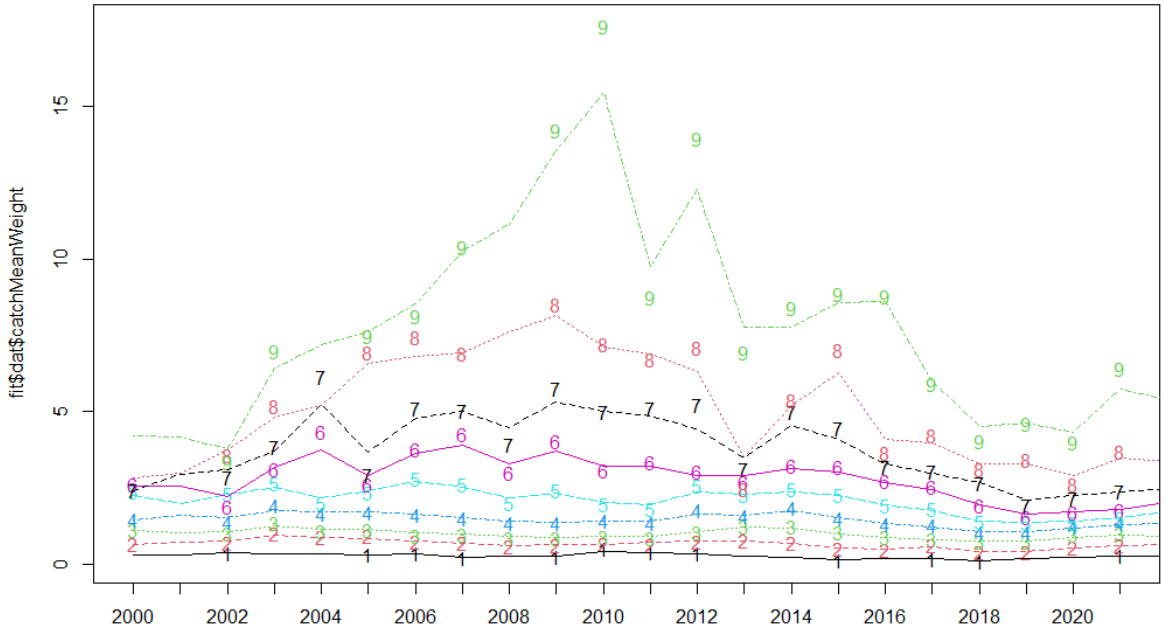

Figure 1. Catch weight at age (in kilograms). Numbers give the input values by age, the line give the estimates from the model

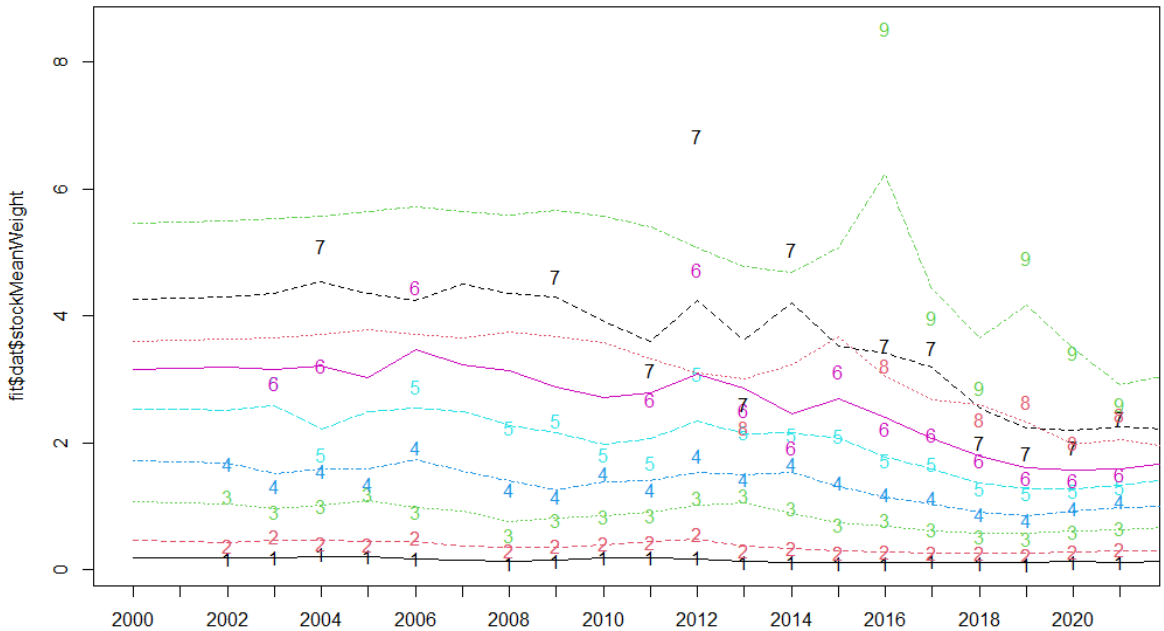

Figure 2. Stock weight at age (in kilograms). Numbers gives the input values by age, the line give the estimates from the model.

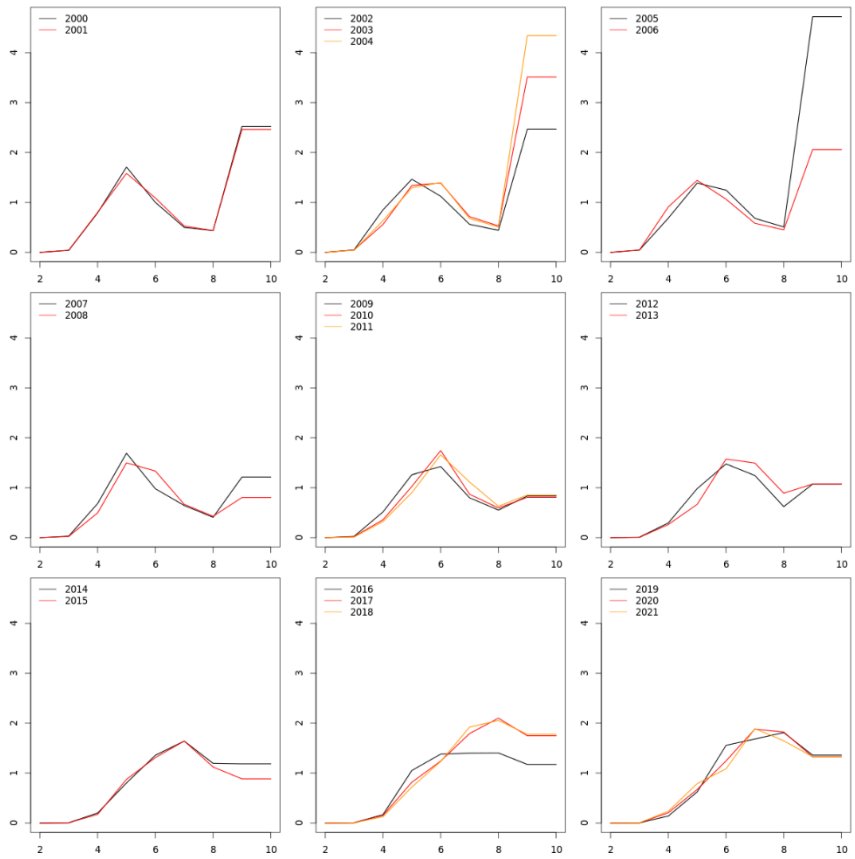

Figure 3. Selection pattern (F_{age}/Fbar) from the SAM model.

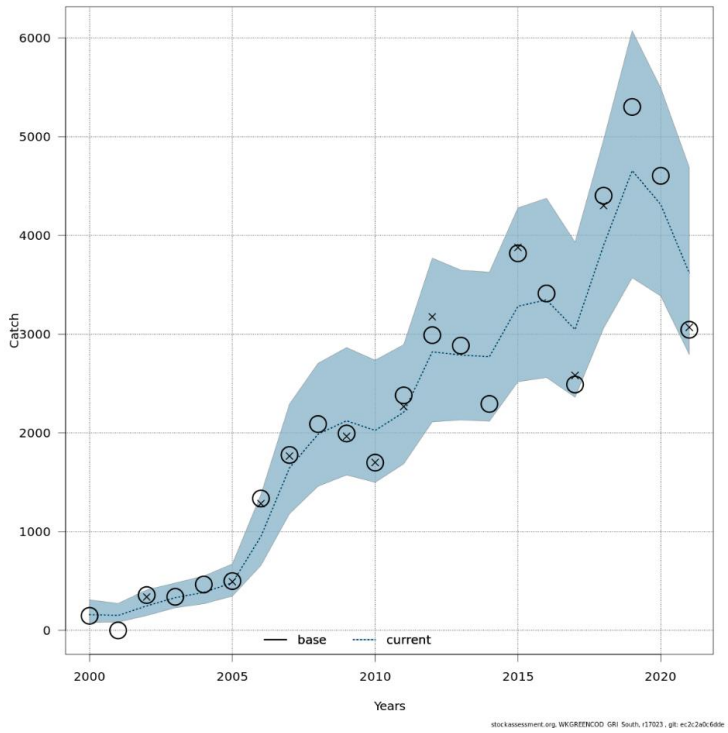

Figure 4. Estimated (line), observed catches (x), and catches based on smoothed catch weights (o). Estimated catch is shown with 95% confidence intervals.

Figure 5. Normalized residuals derived from SAM. Blue indicate positive residuals (observation larger than predicted) and red circles indicated negative residuals.

Figure 6. Estimated historical pattern of fishing mortality (Fbar4-7). The shaded area is 95% confidence intervals.

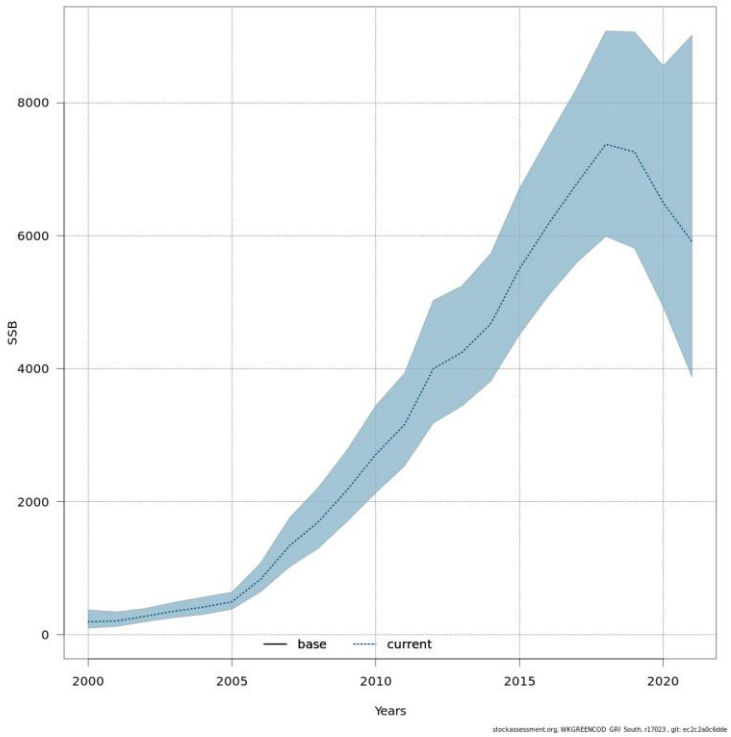

Figure 7. Estimated historical patterns of spawning stock biomass (SSB). The shaded area is 95% confidence intervals.

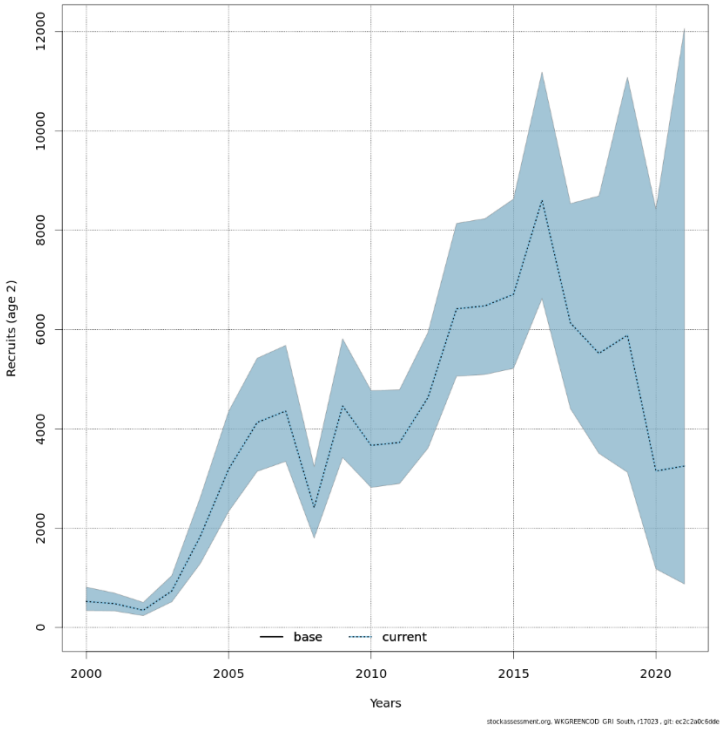

Figure 8. Estimated historical patterns of age 2 recruitment. The shaded area is 95% confidence intervals.

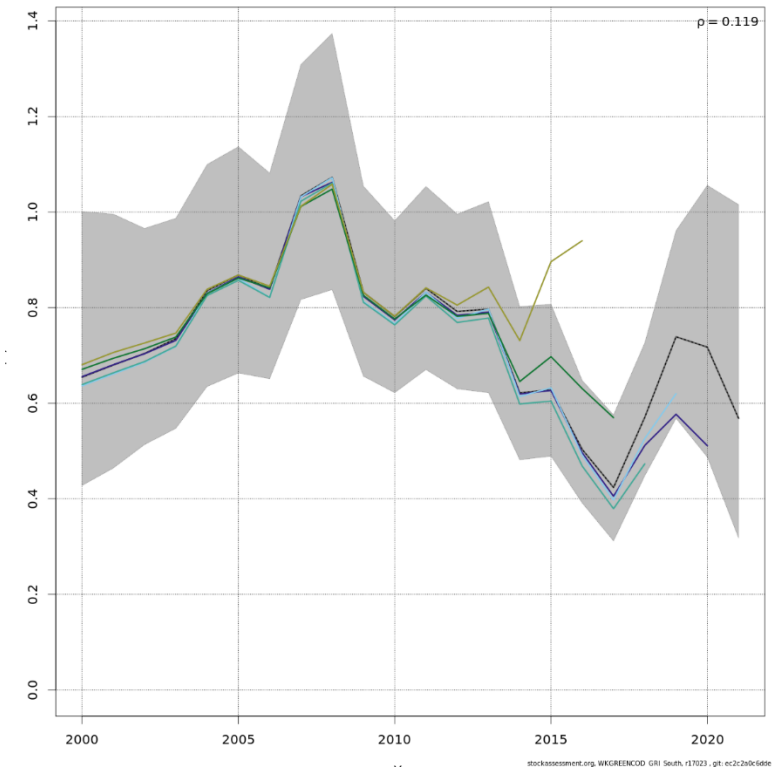

Figure 9. Retrospective plots of Fbar (5 years peel). Mohn's rho is given in the upper right corner.

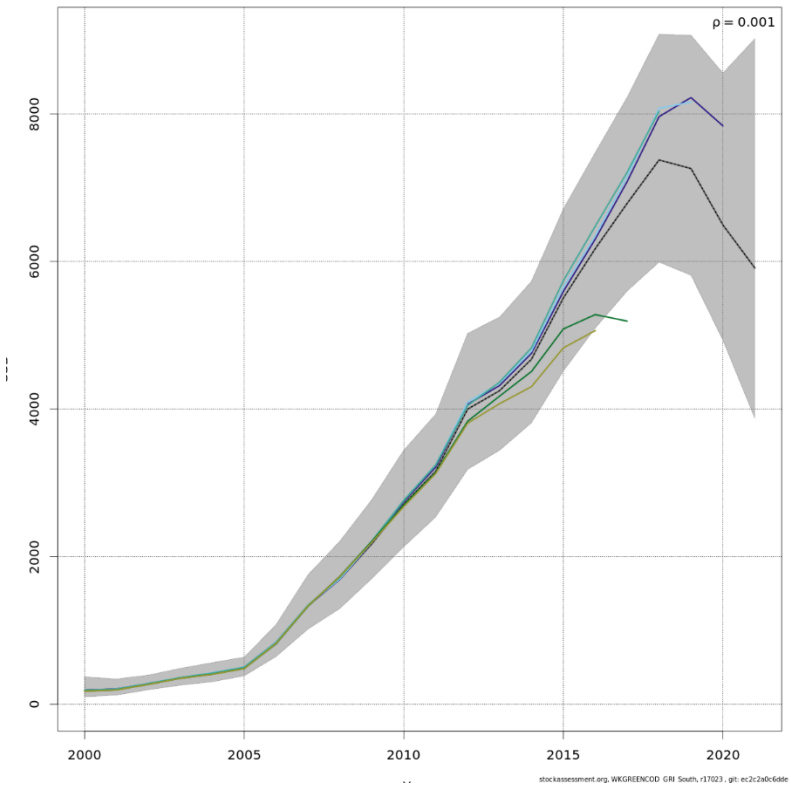

Figure 10. Retrospective plots of SSB (5 years peel). Mohn's rho is given in the upper right corner.

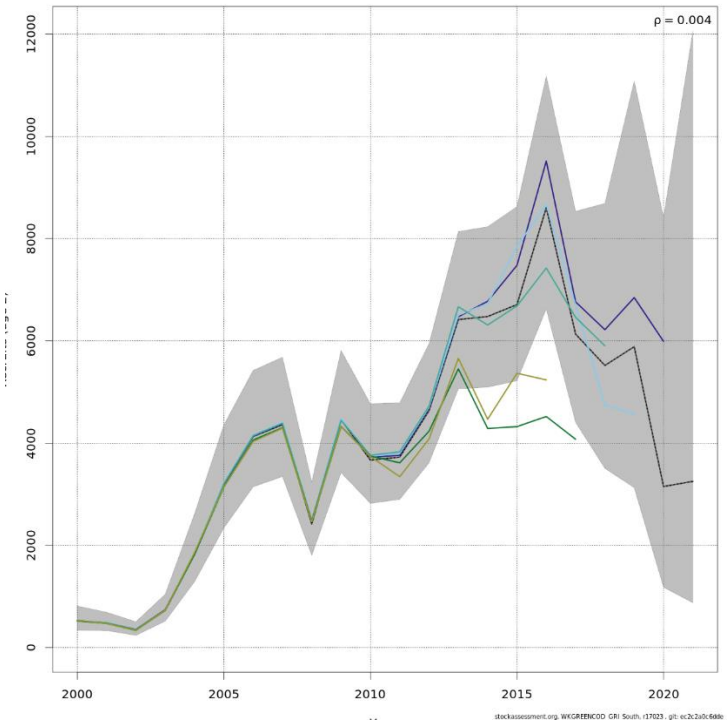

Figure 11. Retrospective plots of age 2 recruitment (5 years peel). Mohn's rho is given in the upper right corner.

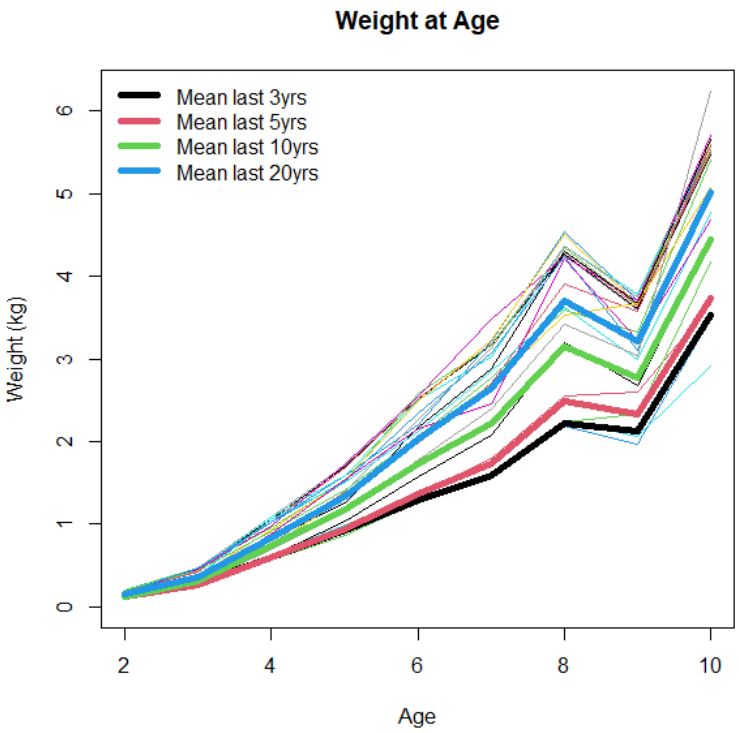

Figure 12. Stock weight at age for all years, bold line show means.

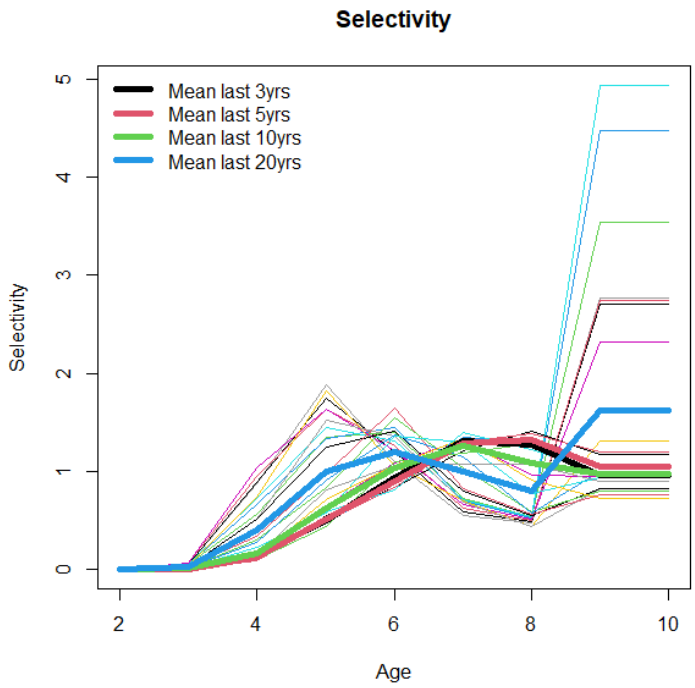

Figure 13. Selectivity at age for all years, bold line show means.

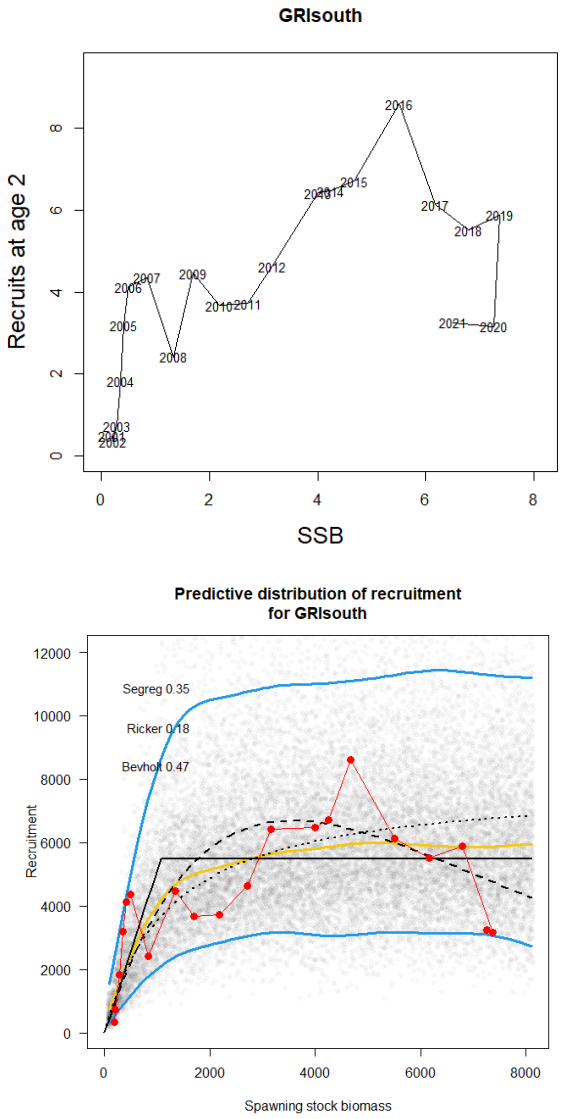

Figure 14. left: SSB-recruitment relationship, labels indicate recruitment year. right: SSB-recruitment relationship estimated by simulation using EqSim with fitted SSB-recruitment relationships. Dashed: Ricker curve. Dotted: Beverton-Holt curve. Solid: Segmented regression. The curve fits are indicated.

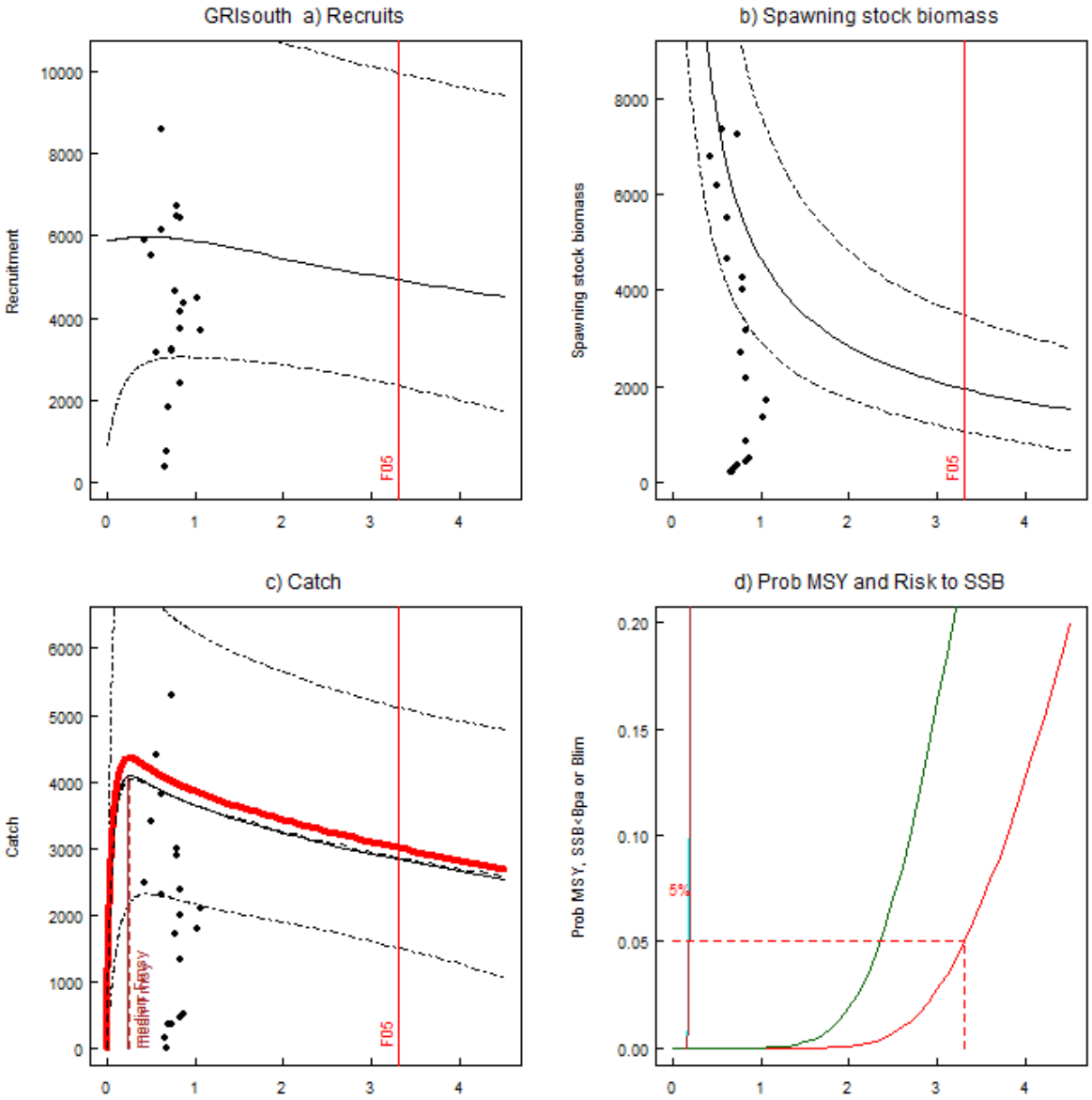

Figure 15. EqSim plots of recruitment, SSB, catch and probability of SSB falling below Bpa and Blim. F is on the x-axis.

Annex 1: List of participants

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Annex 2: Resolutions

WKBGREENCOD - Benchmark Workshop on three Greenland cod (*Gadus morhua*) stocks

2021/02/FRSG39 A **Benchmark Workshop on three Greenland cod stocks (WKBGREENCOD)**, chaired by External Chair Rick Rideout, Canada, and ICES Chair, Arved Staby, Norway, and attended by invited external experts Helen Dobby, UK, and, Johan Lövgreen, Sweden, will be established and will meet 12–14 December 2022 for a data evaluation workshop (DEWK), and on 7–10 February 2023. Both meetings will take place at ICES HQ, Copenhagen, with hybrid meeting access for all participants. If additional time is needed to agree to reference points and the short-term forecast, the benchmark can agree to additional meeting days. Preparatory work on splitting of stocks based on DNA markers was conducted and presented at the NWWG 2022 meeting. Further evaluation of results will take place at a dedicated scoping workshop at DTU AQUA (Lyngby, Denmark) 27–30 September 2022. Stakeholders are invited to contribute data in advance of the data evaluation workshop (including data from non-traditional sources) and to contribute to data preparation and evaluation of data quality. WKGREENCOD will work to:

1) As part of the data evaluation workshop
   i) Consider the quality of data proposed for use in the assessment;
   ii) Consider stock identity and migration issues;
   iii) Make a proposal to the benchmark on the use and treatment of data for each assessment, including discards, surveys, life history, etc

2) In preparation for the assessment methods workshop:
   a) Following the DEWK, produce working documents to be reviewed during the Benchmark assessment meeting at least 14 days prior to the meeting.

3) As part of the assessment methods workshop, agree to and thoroughly document the most appropriate, data, methods and assumptions for:
   a) Obtaining population abundance and exploitation level estimates (conducting the stock assessment);
   b) Estimating fisheries and biomass reference points that are in line with ICES guidelines (see Technical document in reference points);
      1) If additional time is needed to conduct the work and agree to reference points, a short additional reference point workshop will be scheduled to conduct this work.
   c) Conducting the short-term forecast.

4) As part of the assessment methods workshop, a full suite of diagnostics (regarding data, retrospective behaviour, model fit, predictive power etc.) should be examined as a whole to evaluate the appropriateness of any model developed and proposed for use in generating advice.

5) If no analytical assessment method can be agreed, then an alternative method (the former method, or following the ICES data-limited stock approach see WKLIFE X (https://doi.org/10.17895/ices.pub.5985) should be put forward by the benchmark;

6) Update the stock annex as appropriate; and

7) Develop recommendations for future improvements of the assessment methodology and data collection.

Stock	Description	Model	ICES stock category	Assessors
cod.2127.1f14	Cod (Gadus morhua) in ICES Subarea 14 and NAFO Division 1F (East Greenland, Southwest Greenland)	SAM	1	Anja Retzel Tanja Baagoe Buch
cod.21.1	Cod (Gadus morhua) in NAFO Subarea 1, inshore (West Greenland cod)	SAM	1	Anja Retzel Tanja Baagoe Buch
cod.21.1a-e	Cod (Gadus morhua) in NAFO divisions 1A–1E, offshore (West Greenland)	NA, Survey-trends based assessment	3	Anja Retzel Tanja Baagoe Buch

The Benchmark Workshop will report by 10 March 2023 for the attention of ACOM.