INTER-BENCHMARK PROTOCOL ON EAST AND SOUTHWEST GREENLAND COD 2 (IBPGCOD2)

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Contents

i Executive summary

The Inter-Benchmark Protocol on East and Southwest Greenland Cod 2 (IBPGCOD2) was established as a result of the rejection of the regular assessment in 2021 conducted by the Northwestern Working Group (NWWG) of cod (*Gadus morhua*) in ICES Subarea 14 and NAFO Division 1.F (East Greenland, Southwest Greenland). This was due to a violation of the predefined limits for retrospective bias. IBPGCOD2 decided to focus on a short-term technical fix to solve the assessment problems, as data for a more systematic solution are not available. The most likely explanation for the difficulties in assessing the stock arises from the mixing of the stock with both the neighbouring Icelandic cod on Dohrn Bank and the West Greenland cod stock, a process which has increased in recent years as indicated by changes in fishing patterns and abundance of older fish. IBPGCOD2 suggests, following an in-depth sensitivity analysis, altering the natural mortality (M) to account for changes in immigration and emigration. M is therefore reduced for age groups 5+ to 0.2. The immediate assessment problems could be solved with this technical fix; the retrospective pattern has improved considerably. The stock now appears to be slightly smaller, updated reference points are similar with the exception of F_{msy} and F_{pa} which are now much lower. The advice based on F_{msy} gives a slightly higher catch for 2022 than for the rejected assessment. Solving the biological problems with the assessment of this stock will *inter alia* require work on stock definitions and stock separation in the catches and surveys. It is expected that such data will be available for the next benchmark planned for 2023.

ii Expert group information

Expert group name	Inter-Benchmark Protocol on East and Southwest Greenland Cod 2 (IBPGCOD2)
Expert group cycle	Annual
Year cycle started	2021
Reporting year in cycle	1/1
Chair	Christopher Zimmermann, Germany
Meeting venue and dates	12, 16, and 18 August 2021, online meeting, (12 participants)

1 Introduction

Inter-Benchmark Protocol on East and Southwest Greenland Cod 2

At the 2021 NWWG meeting, the assessment of the East Greenland cod stock showed poor behaviour as judged from the retrospective performance; SSB is underestimated and F is overestimated, and the Mohn's rho for both parameters exceeds 0.2 by far (Figure 3.2). Further, the assessment showed a high sensitivity for leaving out one of the main tuning series, i.e. the German survey. Without this survey, the final estimates of F and SSB are outside the confidence limits of the model. This survey also contains the longest time-series, so obviously, the dataseries have a high weight in the model estimation.

From fisheries and survey data it appears that the retro pattern might be caused by a recent higher abundance of older cod in the northern area adjacent to Icelandic Waters in parallel with a change in fishery distribution to these northern areas.

The survey data indicate 1) some improved recruitment from around 2010 passing through the time-series and now showing up as relatively old fish, 2) an overall increase in abundance of old and large cod in Dohrn Bank.

The fishing pattern in East Greenland has changed in the last 15 years from catching relatively younger fish in the southwestern area of the stock boundary to relatively older fish in the northeastern area of the stock boundary. Since approximately 2016, a larger part is taken in the Dohrn Bank area (Q1–Q2, up to above 65%). This catch is composed of larger and older cod. The bulk of the current fisheries in East Greenland occurs on the eastern boundary of the currently defined stock distribution area at the border of the Icelandic and Greenlandic EEZ. This area is quite close to the westernmost area of the Icelandic fisheries, it is bounded by the relatively deep Denmark Straight. Therefore, the cod in the Dohrn Bank area is likely to be a mix of cod from both East Greenland and Iceland.

At the moment it is not possible to separate the catch into the different cod components. Considerable tagging and otolith chemistry are planned to take place in the near future to evaluate whether it is possible to split the commercial and survey catches into stock components. A benchmark of the East Greenland cod is scheduled for the year 2023 to take into account this new information.

2 IBP assessment: approach, sensitivity analysis, and settings

The main issue for this inter-benchmark was to improve the poor performance of the analytical assessment. The approach therefore focused on technical solutions to improve the assessment. Solving the overall problems on stock connectivity for the East Greenland cod stock was considered to be beyond the remit of this group. This will be addressed at the forthcoming benchmark scheduled for 2023.

Downgrading the assessment to a category 3, using either relative results of the analytical assessment or survey indices only, was discussed but not considered beneficial for providing advice for 2022 (see: Retzel and Jansen, 2021, WD03). Specifically, important survey data are not available for 2019, an important year for calculating the reference period.

The SAM model configuration was changed to reflect an altered fishing pattern/fish abundance within the stock area. Since fishing distribution and abundance of older cod seem to have changed from around 2016, based on survey indices, landings at age and residuals from catch matrix, the assumed emigration that is currently contained in the M at age was changed from 2016 and onwards (Table 2.1). M for the years 2016–2020 was changed accordingly from having an increasing M from age 5 to 9 (older fish emigrating) to a constant 0.2 (the assumed natural mortality) for all ages. This should not be interpreted as the cod had “ceased migrating” to Iceland but rather reflecting the mix of cod stocks in the Dohrn Bank area over the Greenland and Iceland EEZs (stock border).

Table 2.1. Cod in East Greenland and 1F: Settings of natural mortality (M) in the 2018 IBPGCOD (ICES, 2018) and this 2021 IBPGCOD2.

M in the period 2016–2020	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	Age 10+
2018 IBPGCOD	0.2	0.2	0.2	0.2	0.3	0.4	0.5	0.5	0.5	0.5
2021 IBPGCOD2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2

The second change in the SAM configuration was on the assumption of “no correlation in F across ages (independent estimation)” where it was previously assumed to be an “autoregressive process (AR1)”, meaning some parallel development between age groups exists. However, with the known (separate) distribution of cod age groups, this might not be the case. By changing this assumption to “no correlation across ages (independent)”, a further improvement on the retrospective pattern was observed. Although the model fit was slightly worse measured by e.g. AIC, the model fit for the most recent part of the time-series improved.

A sensitivity analysis of the choices of emigration rate (0, 0.1, and 0.2) and the starting year of changing the emigration was performed by judging the AIC, Mohn’s rho and the leave out survey plots (Riget *et al.*, 2021a, WD01). An emigration rate of 0 was preferable whereas the starting year could be from 2012 to 2016. 2016 was chosen based on the changed fishing pattern and catch composition.

An analysis using only the long German survey in the tuning (Hjörleifsson, 2021, WD04) showed among other things that assuming a power relationship between stock in number and survey indices and decoupling of observation variance among age groups improved the fit (AIC). This also indicated better long-term retrospective patterns in particular in association with the relatively strong 2003 year class passing through the surveys and the fisheries. This finding was not considered further in the current process.

3 IBP assessment results

With the agreed changes in the model assumptions, the assessment quality improved significantly. The retrospective pattern in SSB and F are minimized and trajectories of both parameters are now within the confidence limits of the model (Figure 3.3). Mohn's rho is now within the acceptable range (−0.069 for SSB and 0.104 for F).

The perception of stock development changes with the agreed modifications; SSB is scaled downwards in recent years (changed from 66 000 t to 59 000 t in 2020) while F remains unchanged (Table 3.1).

The sensitivity of the tuning data showed that, when tuning with the Greenlandic survey only, results in point estimates within the confidence limits and is therefore acceptable.

The accepted SAM model for this inter-benchmark is available on stockassessment.org as run codEastNWWGM_indepF. Further elaboration on results is presented in Riget *et al*. 2021a (WD01 in Annex 5).

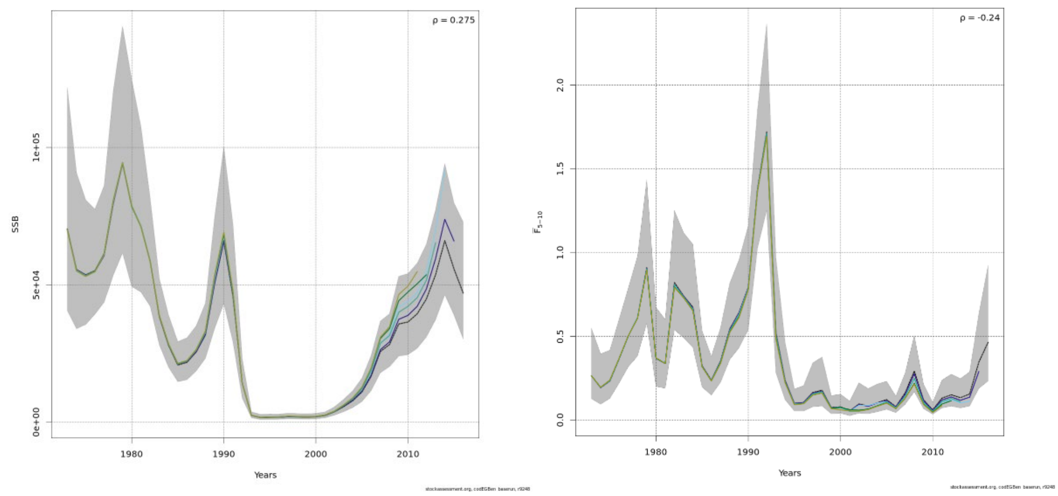

Figure 3.1 Cod in East Greenland and 1F: Retrospective plots of SSB (left) and Fbar (right) in the accepted assessment in the 2018 benchmark. (Stockid in stockassement.org: EastCod_2017_final).

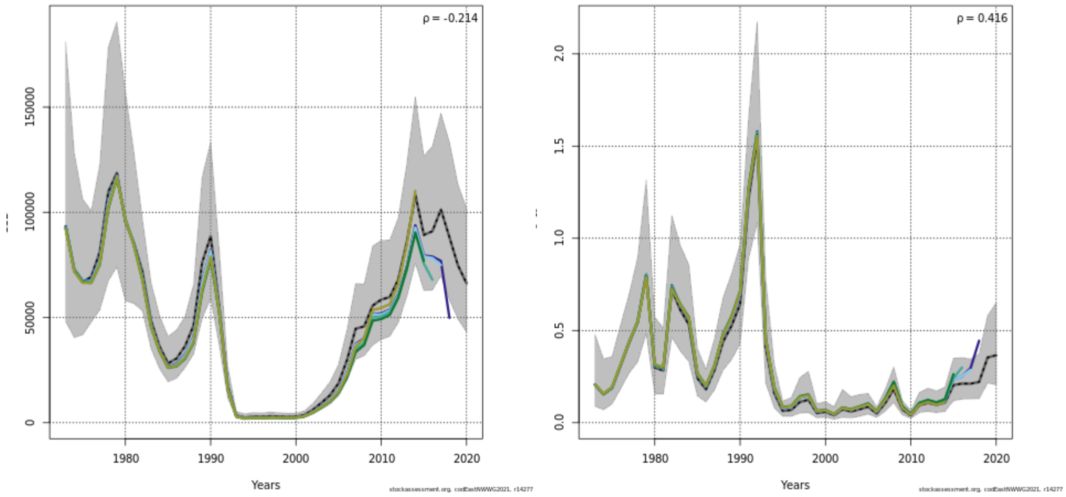

Figure 3.2. Cod in East Greenland and 1F: Retrospective plots of SSB (left) and Fbar (right) in the rejected assessment in NWWG 2021 based on the benchmark 2018 setup of SAM. (Stockid in stockassement.org: codEastNWWG2021).

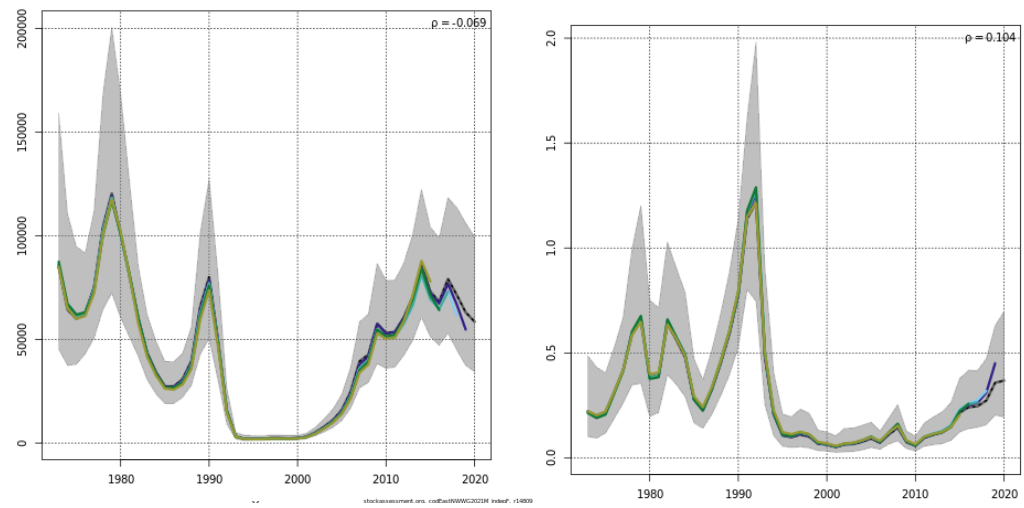

Figure 3.3. Cod in East Greenland and 1F: Retrospective plots of SSB (left) and Fbar (right) in the accepted assessment in IBPGCOD2 2021. (Stockid in stockassement.org: codEastNWWG2021M_indepF).

Table 3.1. Cod in East Greenland and 1F: Summary of the IBPGCOD2 assessment. Estimated recruitment, spawning-stock biomass (SSB), and average fishing mortality.

Year	R (age 1)	Low	High	SSB	Low	High	Fbar 5-10	Low	High	TSB	Low	High
1973	52131	15051	180567	85035	45414	159224	0.222	0.101	0.488	111807	65294	191455
1974	194208	58964	639652	64382	37440	110712	0.202	0.094	0.432	95108	60661	149115
1975	30679	9468	99409	60019	38007	94780	0.218	0.118	0.406	112800	74054	171817
1976	13566	4191	43910	62909	43119	91783	0.315	0.188	0.528	147728	90953	239942
1977	12712	3926	41160	75315	50594	112114	0.418	0.261	0.671	181950	107243	308698
1978	20739	6441	66774	104184	64414	168508	0.589	0.348	0.997	198180	117055	335529
1979	7455	2291	24253	120454	72352	200535	0.654	0.355	1.203	180591	109540	297728
1980	15387	5174	45762	100971	60485	168558	0.386	0.197	0.753	134332	84092	214587
1981	5202	1911	14162	80376	51184	126219	0.393	0.216	0.716	104469	70136	155608
1982	5475	2226	13463	59776	41843	85394	0.638	0.395	1.030	81960	59038	113783
1983	2274	859	6016	43574	30618	62011	0.563	0.350	0.906	64346	45895	90213
1984	4168	1774	9792	34169	23753	49152	0.480	0.291	0.789	49662	35450	69572
1985	150818	64239	354081	27412	19039	39469	0.281	0.167	0.473	42342	30607	58578
1986	116062	48494	277772	27396	19097	39302	0.230	0.141	0.374	56836	39708	81351
1987	2987	1272	7012	30886	22034	43295	0.326	0.207	0.513	84742	57242	125451
1988	2556	1108	5898	39634	27933	56236	0.450	0.295	0.687	118204	77470	180356
1989	729	314	1697	65976	42850	101583	0.592	0.395	0.886	148148	95912	228832
1990	1451	599	3513	80133	50418	127360	0.775	0.527	1.139	130154	83722	202335
1991	2374	971	5805	49917	30437	81865	1.141	0.802	1.622	65676	41025	105140
1992	822	350	1933	15649	9201	26618	1.216	0.747	1.982	18996	11502	31373
1993	727	305	1733	3239	2012	5216	0.480	0.253	0.910	4447	2965	6668
1994	3382	1363	8390	2142	1201	3822	0.207	0.105	0.408	3331	2114	5251
1995	236	90	616	2194	1306	3688	0.107	0.055	0.209	3737	2453	5693
1996	309	109	879	2172	1327	3555	0.099	0.050	0.197	3750	2489	5650
1997	1520	546	4235	2478	1547	3970	0.111	0.053	0.233	4071	2693	6153
1998	5036	2085	12167	2460	1551	3903	0.101	0.048	0.214	3821	2534	5761
1999	9792	3989	24038	2379	1488	3804	0.068	0.035	0.133	4192	2828	6214
2000	13497	5609	32476	2479	1581	3886	0.064	0.033	0.124	5549	3792	8119

Year	R (age 1)	Low	High	SSB	Low	High	Fbar 5-10	Low	High	TSB	Low	High
2001	8260	3449	19784	3165	2108	4752	0.052	0.026	0.105	8297	5682	12115
2002	1540	593	3998	5192	3510	7681	0.064	0.029	0.141	12515	8556	18305
2003	36368	15276	86582	7984	5412	11779	0.066	0.031	0.143	16989	11691	24687
2004	318375	124355	815108	11186	7594	16478	0.077	0.038	0.156	30586	20245	46208
2005	62150	25632	150695	16045	10936	23543	0.092	0.050	0.170	64900	37815	111385
2006	34173	14793	78942	24935	16951	36680	0.073	0.041	0.128	96408	58034	160154
2007	14014	6297	31189	39462	26617	58507	0.112	0.066	0.191	111544	71309	174480
2008	21167	10300	43499	42715	29302	62269	0.144	0.081	0.255	82149	56191	120096
2009	47717	22873	99549	57677	38366	86706	0.075	0.044	0.129	100693	69438	146017
2010	51597	25079	106155	53170	36017	78491	0.059	0.033	0.104	87181	61549	123486
2011	10239	4912	21345	53709	36655	78698	0.096	0.056	0.166	85914	61101	120804
2012	5390	2608	11138	60623	42297	86889	0.110	0.063	0.195	104753	74974	146361
2013	2602	1262	5367	70506	49460	100508	0.122	0.068	0.220	115653	82345	162435
2014	987	459	2120	86220	60783	122304	0.148	0.083	0.263	124696	88519	175661
2015	5096	2425	10709	73173	51335	104299	0.216	0.123	0.379	94011	66803	132301
2016	46410	21709	99217	68324	47151	99005	0.242	0.139	0.419	83394	58662	118552
2017	3732	1622	8585	79218	52998	118409	0.246	0.146	0.416	97746	67644	141242
2018	7284	2252	23559	71426	44873	113691	0.273	0.158	0.474	87536	57934	132264
2019	6925	2287	20967	63087	37472	106211	0.359	0.204	0.631	86242	55512	133983
2020	23741	8552	65906	58617	34515	99550	0.369	0.195	0.698	81301	50693	130390

4 Updated reference points

Based on the new SAM settings reference points were updated. The estimation of reference points follows the ICES Reference Points Guidance (ICES, 2021), using the R-programme EqSim. The setup of the EqSim programme was the same as in the 2018 benchmark except that the average of the biological variable M was decreased from 10 to 5 years because of the change of migration pattern from year 2016 in the SAM model (WD 01).

The simulation was performed with 2000 runs, scanning F from 0 to 3 divided into 100 intervals. The age group assumed representative for recruitment is age 1. The stock-recruitment simulation was based on the time-series 1973–2018 assuming a segmented regression relationship. 2019 and 2020) were omitted as the SAM model estimated numbers of recruits for these most recent years are considered too uncertain.

The SR relation was assessed to be a category 1, 'Spasmodic stocks—stocks with occasional large year classes' (ICES guidelines for reference points for category 1 and 2 stocks, ICES 2021). In that case, B_{lim} is based on the lowest SSB which still gave a large recruitment. This was the 2003 year class, and B_{lim} is calculated as the mean of this and the following two year classes (2003, 2004 and 2005)[1]. B_{lim} is therefore calculated as 11 738 t (Table 4.1). B_{pa} is calculated from the formula $B_{pa} = B_{lim} * \exp(1.645 * \sigma)$, where σ is SD of ln(SSB) in 2020—here estimated by SAM to 0.265. B_{pa} is then 18 146 t.

F_{lim} is estimated by simulation using the above values of B_{lim} and B_{pa}, setting Fcv, Fphi and SSBcv = 0 (no assessment and advice noise) and with no $B_{trigger}$. The range of years is from 1996 to 2019. This resulted in a F_{lim} of 1.98.

F_{msy} is initially estimated as the F that maximize median long-term yield in the simulation under constant F exploitation. The default values of cvF = 0.212, phiF = 0.423 and cvSSB = 0 were applied to the simulation. The initial F_{msy} was estimated at 0.29, which is below the above estimated F_{pa}. The final F_{msy} is estimated by a simulation using the default Fcv, Fphi, the estimated B_{lim}, B_{pa} and $B_{trigger}$ which is equal to B_{pa}. Fp05 (the F that leads to SSB ≥ Blim with 95% probability) was estimated to 0.65. Following the ICES guidelines (ICES, 2021) Fp05 equals F_{pa}. The final F_{msy} estimate was 0.29. The precautionary principle states that if F_{msy} > F05, which is not the case here, F_{msy} should be reduced to F05.

Table 4.1. Cod in East Greenland and 1F: Reference points calculated at IBPGCOD2 2021 compared to reference points calculated at IBPGCOD 2018.

Framework	Reference point	2021 IBPGCOD2	2018 IBPCOD
MSY approach	MSY $B_{trigger}$	18 146	14 803
	F_{MSY}	0.29	0.46
Precautionary approach	B_{lim}	11 738	10 354
	B_{pa}	18 146	14 803
	F_{lim}	1.98	2.34

[1] An error was detected in the IBPGCOD report 2018, Section 3.5.2 line 10, where it is wrongly stated that the average of the year classes 2002, 2003 and 2004 have been used for this calculation.

Framework	Reference point	2021 IBPGCOD2	2018 IBPCOD
	F_{pa*}	0.65	1.33
Management plan	SSB_{mgt}	-	-
	F_{mgt}	-	-

***Fpa for IBPGCOD2 is based on Fp0.05**

Further elaboration on reference points are presented in Riget *et al.* 2021b (WD02 in Annex 5).

5 Forecast for 2022

Based on the updated reference points a short-term forecast for 2022 was performed (Table 5.1), using a catch constraint of $Catch_{2021}$ = TAC_{2021} (26 091 t), which is considered to be the most realistic option.

Table 5.1. Cod in East Greenland and 1F: Short-term forecast for 2022.

Basis	Total catch (2022)	F (2022)	SSB (2023)	% SSB change
$F=F_{MSY}$	8768	0.29	53 622	+4
F=0	0	0	68 680	+34
$F=F_{lim}$	28 423	1.98	24 763	−52
$F_{2022}=F_{2021}$	19 261	0.89	38 053	−26
$SSB(2022)=B_{lim}$	41 326	6.6	11 738	−77
$SSB(2022)=B_{pa}$	35 002	3.4	18 146	− 65

When the F_{msy} approach is applied, catches in 2022 should not be more than 8768 t.

6 Recommendations and future work needs

IBPGCOD2 recommends that national institutes:

- Gain further insight into the stock structure and migration patterns of cod stocks across the relevant areas using tools such as genetics, otolith chemistry, tagging, and analysis of existing catch and survey data. A progress report should be delivered to NWWG 2022.

IBPGCOD2 recommends to the future benchmark group:

- Develop a modelling approach that will utilize a spatial resolution of genetics data to estimate the split between the stocks adjacent to the East Greenland cod stock. This would account for differences in spatio-temporal stock dynamics and may improve the understanding of migration patterns.
- Organize a dedicated workshop prior to the benchmark to identify and solve ageing issues between Greenland and German age readers.
- On the basis of available information on population structure, and stock mixing, consider shifting to assessments and advice based on alternative stock definitions.
- Propose a harmonized management approach in Greenlandic and Icelandic Waters, possibly based on the Icelandic Management Plan.

7 References

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Annex 1: List of participants

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Annex 2: Resolutions

Inter-Benchmark Process on East and Southwest Greenland Cod 2 (IBPGCOD2)

2021/2/FRSG69 An **Inter-Benchmark Process on East and Southwest Greenland Cod 2** (IBPG-Cod-2), chaired by Christopher Zimmermann, Germany, and attended by two invited external experts, Anders Nielsen, Denmark, and Rasmus Hedeholm, Greenland, will be established and will meet by correspondence on 12, 16, and 18 of August 2021 to:

a) evaluate and if necessary revise current assumptions in natural mortality and migration as well as recent information on changes in fishing patterns;
b) investigate the sources of the larger than acceptable retrospective inconsistencies in F and SSB, this may include model assumptions and qualities of the input data; explore mechanisms to reduce the retrospective inconsistencies with no detriment to other diagnostics of the stock assessment;
c) agree and document the preferred method for evaluating stock status and short-term forecast and update the stock annex as appropriate. If no robust analytical assessment method can be agreed, then propose alternative methods to provide advice including data-limited methods;
d) update the stock annex as appropriate;
e) if required re-examine and update MSY and PA reference points according to ICES guidelines (see Technical document on reference points).

Stock	**Stock leader**
Cod (*Gadus morhua*) in ICES Subarea 14 and NAFO Division 1F (East Greenland, Southwest Greenland)	Anja Retzel

The inter-benchmark will report by 25 August 2021 for the attention of FRSG and ACOM.

Annex 3: Stock annex update

1.1 Stock Annex: Cod (*Gadus morhua*) in ICES Subarea 14 and NAFO Division 1.F (East Greenland, South Greenland)

Stock specific documentation of standard assessment procedures used by ICES.

Stock:	Cod
Working Group:	North Western Working Group (NWWG)
Last revised:	18/08/2021
Timeline of revisions:	Last revised during IPBGCOD2
Main revisions:	Change in assessment settings and revised Biological Reference Points
Last benchmark:	IPBGCOD2 August 2021

A. General

A.1. Stock definition

Cod found in Greenland is a mixture of four separate "stocks" that are defined by their spawning areas: i) offshore West Greenland waters; ii) West Greenland fiords cod iii) offshore East Greenland and offshore Icelandic waters and iv) inshore Icelandic waters (Therkildsen *et al*., 2013).

A substantial part of the offspring from the East Greenland and Icelandic component settles along the western coast of Greenland and subsequently migrate back when reaching maturity at age of 5–7 years. These drifts events are believed to occur irregular (Buch *et al*., 1994; Schopka, 1994) and of varying intensity.

Tagging information and recent studies clearly demonstrate this spawning migration (Storr-Paulsen *et al*., 2004; Bonanomi *et al*., 2016). The information also illustrates that the spawning migration is a one-way event; i.e. when the fish have migrated from West Greenland to East Greenland/Iceland, they do not return. Instead the cod appear to continue a northward migration with age, such that the oldest cod are found in the northern part of the area in East Greenland (Figure A.1.1).

Before 2016 cod in East Greenland was considered part of a larger offshore stock complex with West Greenland. Hence, advice was given for the whole area. Since 2016 the assessment area of the East Greenland cod is defined as the area comprising NAFO Division 1F in SouthWest Greenland and ICES Subarea 14 (East Greenland, Figure A.1.2).

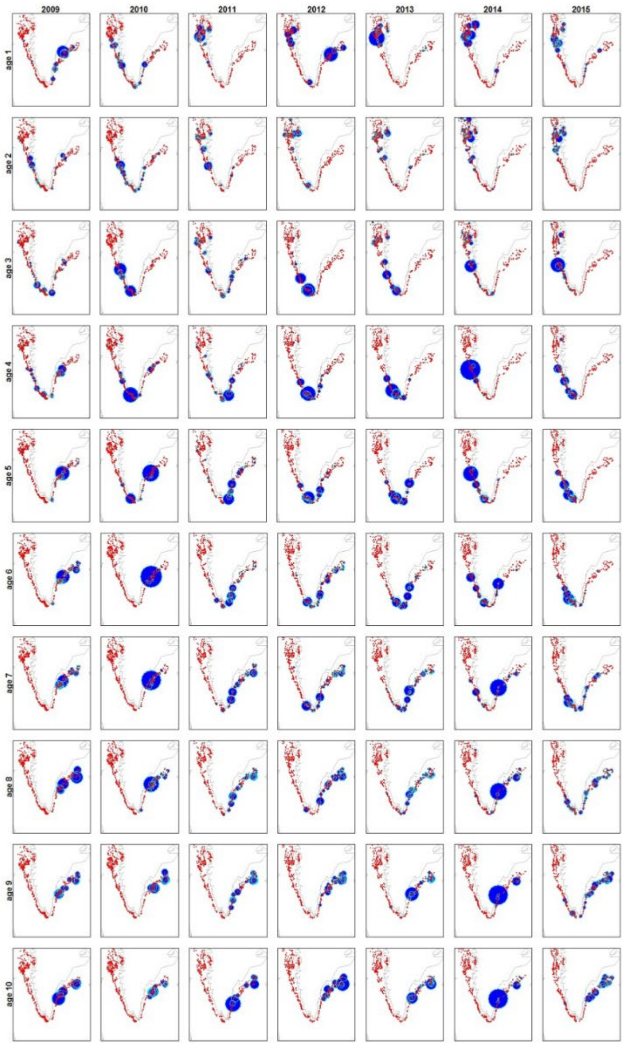

Figure A.1.1. Abundance (%) of ages 1–10 in the years 2009–2015 from the Greenland survey. The size of blue circles denotes the percentage of the cohort in the given year, where each square equals 100%. Red circles are trawl stations.

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

A.2. Fishery

A.2.1 General description

A short historical review

The fishery in East Greenland started in 1954 as a trawl fishery (Horsted, 2000).

Landings of about 30–60 kt dominated until the early 1970s, followed by a decrease to 10–30 kt until the early 1990s supported by the large year classes 1973 and 1984. For more than a decade (from mid-90´s) catches were close to null, and cod was only caught as bycatch in the redfish fishery until the mid-2000s.

The present fishery

Landings in East and South Greenland increased from 1 000 tonnes in 2005 to 15 000 tonnes in 2008. The landings in 2008 were primarily fished in SouthWest Greenland (NAFO Division 1F), as East Greenland was closed (see 'fishery management regulations' below). In the following years landings dropped to 2 500 tonnes in 2010. Since then catches have increased to average of 15 000 tonnes in the period 2015 - 2020. The distribution of the fishery has changed since 2010 from SouthWest Greenland to East Greenland where the majority of the catches since 2019 have been fished on the southern slope of the Dohrn Bank region close to the EEZ to Iceland.

The cod fishery in East Greenland has traditionally been a bottom trawl fishery, but in recent years the longliners have been taken an increasing share of the TAC, amouting to approximately 1/3 of the total landings.

The majority of landings are taken by Greenland (>75%), with EU, Norway and the Faroe Islands landing minor quantums.

Since discards are not taking place landings are equivalent to catches.

A.2.2. Fishery management regulations

In the offshore fisheries vessels are above 75BT/120BT and restricted to an area more than 3 nm off the baseline. The vessels require a licence that stipulates a unique vessel quota. Trawl and longlines are the main fishing gears. Mesh size in the trawl fishery is 140 mm and no sorting grid is used. There is no regulation on hook size in the longline fishery. Comparison of length measurement of cod caught in the trawl fishery and longline fishery show similar length distributions

No directed offshore fishery was allowed for the period 1993–2005, except for some minor allocations to Norway and the Færoe Islands.

After an experimental fishery in East Greenland in 2007, when dense concentrations of large spawning cod were found, the area was subject to several area closures. In 2008 fishing was not allowed north of N63°00′ in order to protect the potential spawning segments, especially on Kleine Banke. In 2009–2010 the delinitation was at N62°00′ and additionally NAFO Division 1F was closed in 2010, primarily to protect the relatively strong incoming year classes.

In 2011 a management plan was implemented that allowed a small experimental fishery of 5000 tons per year in the period 2011–2013 in all offshore areas in Greenland (both West and East). However fishing for cod in East Greenland (ICES Subarea 14) was closed from 1 January to 30 June.

The management plan was opdated in 2014 where the distinction between the inshore and two offshore stocks was implemented. The two offshore stocks are defined in the regions: West Greenland offshore stock (NAFO divisions 1A-1E) and East Greenland offshore stock (ICES division 14b and NAFO division 1F). The management plan from 2014 has been modified during the years with TAC being distributed between management areas within the region South and East Greenland (NAFO 1F and ICES 14b). The number of management areas within this region has varied between two to four. In 2020 the government operated with three management areas which was reduced to two in 2021. The area around the spawning grounds of Kleine Bank is closed for fishery from 1st of March – 31st of May.

A.3. Ecosystem aspects

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

Greenland during the first summer (Stein and Borokov, 2004), as well as the size of the Iceland cod stock.

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

B. Data

B.1. Commercial catch

The information on landings in weight are compiled and processed by the Greenland Fisheries License Control (GFLK). The offshore information is available through logbooks on a haul-by-haul basis.

Offshore sampling is laborious, as most vessels produce frozen fillets that are commonly landed outside Greenland. Since 2011 sampling of length frequencies and information on age, weights and maturities are collected be the vessels and compiled by the Greenland Institute of Natural Resources.

To facilitate the ICES procedure, catches are raised and reported in a catch-at-age matrix.

B.1.2. Discards estimates

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

B.1.3 Recreational catches

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

B.2. Biological sampling

B.2.1 Maturity

Due to lack of data it is not possible to generate a year specific maturity ogive (Table B.2.1.1). Hence, the proportion of mature fish by age are left unchanged from year to year from 1973–2017 (Table B.2.1.2). The maturity ogive is based on 1557 samples with maturity information on collections made in the spawning season april and may. No data on maturity in the spawning season exist before 2005. The majority of the maturity information is based on a survey in 2009 and on extensive sampling from commercial experimental fishery in 2007. The maturity ogive was estimated by a general linear model (GLM) with binomial errors. L50 was estimated to 5.19 years (SE = 0.07). Since 2018 a separate ogive was estimated based on cod sampled from an experimental fishery in the same spawning area as in 2007 (GINR, 2018). The two maturity ogives were similar.

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

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

Table B.2.1.2: Maturity ogive by age

Age group	Proportion mature 2073-2017	Proportion mature 2018-present
1	0.020	0
2	0.049	0.001
3	0.116	0.011
4	0.249	0.081
5	0.456	0.410
6	0.679	0.847
7	0.843	0.978
8	0.931	0.997
9	0.972	0.999
10	0.989	0.999

B.2.2. Natural mortality

Natural mortalty is differentiated by age. Tagging data clearly illustrate a migration from East Greenland to Iceland (Storr-Paulsen *et al.*, 2004, ICES 2018). Because this migration hinges on the onset of spawning and appears to be consistent acroos year-classes, natural mortality is estimated at 0.2 for ages 1–4, 0.3 for age 5, 0.4 for age 6 and 0.5 for older in the period 1973-2015. In the period 2016-present natural mortality was changed to 0.2 for all years (table B2.2.1). The reason for this change is that the assumption on migration may not be valid for the older cod found in the Dohrn Bank area which in recent years have been an increasing part of the total numbers in the catch at age for the commercial fishery. The older cod might possibly migrate back and forth across the EEZ border between Greenland and Iceland waters as indicated by the continuum of catches across this border and a recapture of a large cod in East Greenland waters tagged in Iceland waters.

Table B2.2.1: Settings of natural mortality (M) in the period 1973-2015 and 2016-present.

M	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	Age 10+
1973-2015	0.2	0.2	0.2	0.2	0.3	0.4	0.5	0.5	0.5	0.5
2016-present	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2

There are no data to estimate the predation pressure on cod of various sizes and how this may alter M between years.

B.2.3. Weight-at-age

Mean stock weight-at-age is provided from the Greenland shrimp and fish survey in the period 2008–2016 (GRL-GFS). The mean weight at age for this period are applied to the years before. Mean catch weight-at-age is calculated from annually sampled commercial catches. There are no sampling from the fishery in the period 1996–2004 and the weight-at-age applied in these years is an average of weight-at-age in the period 1973–1995 and 2005–2016. Mean stock weights are also available from the German survey. However, the weight-at-age patterns in the two surveys differ, with higher weight-at-age in the German survey than the Greenland survey especially for older age groups.

Work to identify the reason for the discrepancy is ongoing, but as approximately 80% of the fishery takes place from January-August, the German survey takes place outside the main part of the fishery season and is therefore most likely not representative of the fishable biomass. Therefore the assessment is based on the weight-at-age from the Greenland survey. The survey started in 2008, and for the 1973–2007 period an average of the weight-at-age from 2008–2016 was used.

B.2.4. Recruitment

In addition to the recruitment from cod spawning in East Greenland there is substantial recruitment from spawning in Iceland waters (Bonanomi *et al.*, 2016). It is not possible to distinguish between these sources of recruitment, but from age 2 the surveys in the region document the size of each yearclass. Often the recruits are found in West Greenland, and do not show up in East Greenland before age 4–5.

B.3. Surveys

Two survey series are available for this assessment (Figure B.3.1 and B.3.2):

- A Greenland mid-year bottom trawl survey (GRL-GFS) which covers the entire area in August-September each year from 0–600 m. It has been undertaken since 2008, except 2018 and 2019, and has approximately 130 stations per year.

  The survey uses a 2600/20-mesh "Cosmos" 2000 trouser bottom trawl equipped with 'rock-hopper' ground gear comprising steel bobbins and rubber disks. Trawl doors are 7.5 m^2 weighing 2 800 kg. Towing speed is 2.5 knots with each haul being 15 minutes.

  Survey abundance and biomass is based on swept area estimates raised to survey stratum area, *i.e.* wingspread x towed distance, where wingspread is inferred from Scanmar recordings and the towed distance is measured by GPS.

- The German groundfish survey commenced in 1982 and was designed for the assessment of cod and covers 0–400 m. The survey includes approximately 80–100 stations per year. In 2013, the survey was re-stratified and now has 5 strata in East Greenland in the depth intervals 0–200 m and 200–400 m. Biomass indices for the time-series were accordingly recalculated. For further information about the restratification see WD 25, ICES 2013. The survey was carried out by the research vessel (R/V) WALTHER HERWIG II 1982–1993 (except in 1984 were R/V ANTON DOHRN was used) and since 1994 by R/V WALTHER HERWIG III. The fishing gear used is a standardized 140-feet wide bottom trawl, composed of a net frame rigged with heavy ground gear due to the rough nature of the fishing grounds. A small mesh liner (10 mm) was used inside the cod end. The horizontal distance between wing-ends was 25 m and the vertical net opening being 4 m at 300 m depth. In 1994 smaller Polyvalent doors (4.5 m^2, 1 500 kg) were used for the first time in order to reduce net damages due to overspread caused by bigger doors (6 m^2, 1 700 kg), which have been used earlier.

  Up to 2008 strata with less than 5 hauls were excluded in the annual stock calculations. From 2009 all valid hauls have been included and biomass indices for the entire time-series have been corrected. For strata with less than 5 haul samples, GLM and quasi-likelihood estimates have been recalculated based on year and stratum effects from the time-series. In some years (notable 1992 and 1994) several strata were uncovered, implying that the survey estimate implicitly refers to varying geographical areas. The survey was not undertaken in 2018 due to vessel breakdown.

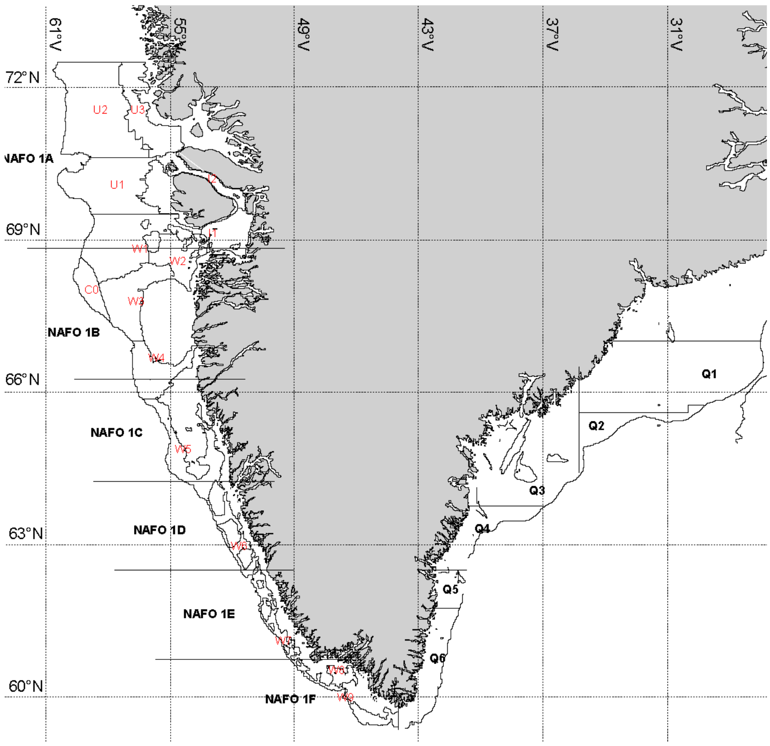

Figure B.3.1. The stratification areas used in the Greenland shrimp and fish survey. In West Greenland each strata is divided in depth strata of 150–200 m, 200–300 m, 300–400 m and 400–600 m. "Shallow" water strata of 0–100 m and 100–150 m are delimited by the 3 nm line (not shown) and the NAFO divisions.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

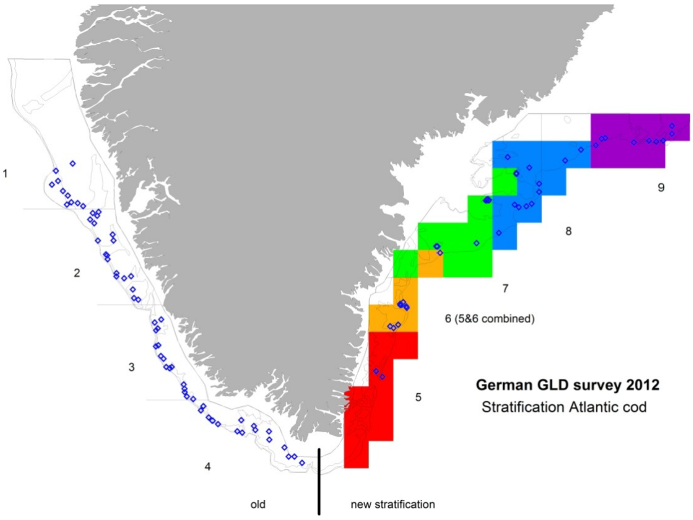

Figure B.3.2. The Stratification areas used in the German Greenland groundfish survey. Each stratum is divided into two depth zones, 0–200 m and 201–400 m.

B.4. Commercial CPUE

Commercial CPUE data are available. However, due to the limited time-series they are not used in the assessment.

B.5. Other relevant data

Both the Greenland and the German surveys also cover the West Greenland area (NAFO 1A-1E). Because this area is a nursery ground for the East Greenland stock, the abundance of especially pre-spawning individuals is an indicator of the level of immigration expected in the East Greenland area in the next couple of years.

C. Assessment method and settings

C.1 Choice of stock assessment model

Based on availability of age disaggregated data from two surveys and commercial catches in combination with a good understanding of migration this stock has since 2018 been subject to a full analytical assessment.

C.2 Model used as basis for advice

The stock is assessed using the state-space model SAM (Nielsen and Berg, 2014)

C.3 Assessment model configuration

Two survey indices are used with commercial catch-at-age data. No commercial fleets with effort information are used. The available data are listed in table 3.1

Table 3.1: Input data

Type	Name	Year range	Age range	Variable from year to year
Caton	Catch in tonnes	1973–present	1–10+	Yes
Canum	Catch-at-age in numbers	1973–present	1–10+	Yes
Weca	Weight-at-age in the commercial catch	1973–present	1–10+	Yes
West	Weight-at-age in the stock	1973–2007 2008–present	1–10+ 1–10+	Mean 2008–2016 Yes
Mprop	Proportion of natural mortality before spawning	1973–present	1–10+	No
Fprop	Proportion of fishing mortality before spawning	1973–present	1–10+	No
Matprop	Proportion mature at age	1973–2017 2017-present	1–10+ 1-10+	No No
Natmor	Natural mortality	1973–2015 2016-present	1–10+ 1-10+	No, but differentiated by age. No

In the period 1996 to 2004 no age aggregated catch-at-age data existed because of the very limited fishery. The annual total weight of catch for this period was included in the model configuration as a "third survey". This "technical" solution was preferred instead having missing information.

No discarding is belived to take place.

Mean weight-at-age in the stock for the period 2008–2016 derive from the Greenland survey (GRL-GFS). The average mean weight-at-age for this period was applied for the 1973–2007 period.

The natural mortality is estimated at 0.2 for ages 1–4, 0.3 for age 5, 0.4 for age 6 and 0.5 for age 7 and older in order to mimic the emigration to the Icelandic area in the period 1973-2015. In the period 2016-present natural mortality was changed to 0.2 for all ages as a consequence of the changed pattern in the fishery with higher proportion of old cod dominating the commercial catches.

Estimation of recruitment is an integrated part of the model. Recruitment parameters are estimated within the assessment model. The parameter structure is assumed as a random walk process.

The correlation of fishing mortalities across ages is set to no correlation (independent) as fishing mortalities in recent years seem to be different across ages. As a consequence the model fit better for the recent years of the time series at the expense of the earlier part.

The model is tuned with two surveys (Table below)

Tuning data:

Type	Name	Year range	Age range
Tuning fleet 1	Greenland GRL-GFS	2008–present	1–9+
Tuning fleet 2	German G3244 DTS (GFS)	1982–present	1–9+

D. Short-Term Projection

Table D.1. Forecast assumptions. [Note that the values that appear in the catch options table of the advice sheet are medians from the distributions that result from the stochastic forecast.]

Initial stock size	Starting populations are simulated from the estimated distribution at the start of the intermediate year (including co-variances).
Maturity	Maturity is fixed until new information becomes available.
Natural mortality	Natural mortality is fixed between years.
F and M before spawning	Both taken as zero.
Weight at age in the catch	Average of final three years of assessment data.
Weight at age in the stock	Based on the latest GRL-GFS survey
Exploitation pattern	Catch set according to most recent TAC
Intermediate year assumptions	NA
Stock recruitment model used	Recruitment for the intermediate (the year the WG meets) is taken from the SAM assessment and asummes a random walk.

E. Medium-Term Projections

Medium-term projections are not carried out for this stock.

F. Long-Term Projections

Long-term projections are not carried out for this stock.

G. Biological Reference Points

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

Framework	Reference point	Value	Technical basis	Source
MSY approach	MSY $B_{trigger}$	18 146 t	The default option of B_{pa}.	ICES advice technical guidelines
	F_{MSY}	0.29	F_{MSY} simulated should be lower than F05 = 0.65	ICES advice technical guidelines
Precautionary approach	B_{lim}	11 738 t	Mean of three lowest SSB given large recruitment	IBPGCod2 2021
	B_{pa}	18 146 t	Blim * exp(1.645 * σ), σ = 0.23	IBPGCod2 2021
	F_{lim}	1.98	F50 deterministic simulated	
	F_{pa}	0.65	$F_{0.05}$	IBPGCod2 2021

H. Other Issues

There are no other issues.

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Annex 4: Reviewer comments

Background

The inter benchmark for East and Southwest Greenland cod (IBPGCOD2) was conducted via three half-day online meetings (12, 16, and 18 August 2021). Prior to the meeting 6 background documents were supplied (previous benchmark report, stock annex, and documents from previous assessment meetings) and 4 working documents explaining the reason for the current inter benchmark, showing suggested options for improving the assessment procedure. At the meeting the supplied documents were presented by the assessment team. The reviewers would like to thank the assessment team for providing a detailed and transparent documentation and presentation of all the steps taken.

The inter-benchmark was called because a larger than acceptable retrospective pattern was observed at the latest expert group meeting and the updated assessment was rejected at the ICES advice drafting group). The retrospective was -21% for SSB and +41% for average F. An inter-benchmark was held in 2018 and a full benchmark is planned for 2023. The purpose of this inter-benchmark is to provide an acceptable assessment solution for the next few years until the next full benchmark has been given time to research and address the more fundamental issues with this stock.

A larger issue with this assessment, which is beyond the scope of this inter-benchmark to fully solve, appears to be the interaction with neighbouring stocks. It is hypothesized that older fish are moving between Greenland and Iceland waters. In the most recent years the fishery has been increasingly concentrated near the border towards the Icelandic cod stock and it is believed that part of the catches are originating in the Icelandic cod stock.

Assessment

In the last few years, the stock assessment model used to provide advice for the East and Southwest Greenland cod has performed increasingly poorly. The model has an unacceptable biased retrospective pattern and when leaving out the main survey index, the stock perception changes drastically. The changing stock perception when leaving out the main survey index is unfortunate, but less surprising because very little survey data remains.

The main driver causing the retrospective pattern in the stock assessment is presumably a shift in the fishery pattern in the last few years. The fleet have increasingly fished in the north-western part of the stock distribution, and in this area, there is apparently a link to the Iceland cod stock. This link manifests itself as an un-quantified spill over of older cod from Iceland to Greenland waters, and that has shifted the Greenland catch-at-age matrix towards larger cod in recent years.

The IBPGCOD2 suggested two updates to the previous assessment model:

The previous assessment model had configured larger natural mortalities for ages five and above as a rudimentary way to account for the older fish moving out of the area, but as the fishery is increasingly concentrating near the Icelandic cod stock this adjustment does not remain valid. It was suggested to remove the increased natural mortality adjustment for the most recent years (from and including 2016).

The previous assessment model estimated a correlation between fishing mortalities at age. For most of the historic time-series this is reasonable, because fishing mortality at any given age generally tend to follow the trend of fishing mortalities at neighbouring ages. However, the increased fishing near the Icelandic cod stock has caused an increase in fishing mortality of older fish, which is not matched by fishing mortality for ages 4 and 5. To avoid this problem the model was changed to use independent fishing mortality-at-age.

The IBPGCOD2 concluded that these two changes provided an improved assessment model that can be used as the interim assessment model until a better model can be developed and scrutinized at the already planned 2023 benchmark. The retrospective pattern is reduced to be within acceptable limits (-7% for SSB and 10% for average F) and the issue with the model being highly sensitive to leaving out the main survey time-series was solved. However, these two changes do not attempt to reflect the stock-mixing situation adequately, which limits the model's ability to predict the stock dynamics and future catch options.

IBPGCOD2 briefly discussed downgrading this assessment to a category 3, but it was agreed that this presented a far from ideal solution that should be avoided. When sticking to a category 1 assessment the model assumptions remain explicit and transparent. Which is important when the spatial mixing issues and the changing fishing pattern needs to be closely monitored.

Reference points

The reference points were calculated following as closely as possible the procedure outlined during the 2018 benchmark but based on the revised assessment. The stock reference points were calculated using the EqSIM software. The average period for the biological parameters had to be changed from the most recent 10 years to the most recent 5 years, because the natural mortality was changed in the assessment model for the last five years. Using ten years would have averaged over the "old" setup with increased M at older ages and IBPGCOD2 did not consider this appropriate to the following years.

Conclusions

The reviewers agree with the group that the analytical stock assessment model (both the original and less so the revised model) has many shortcomings and that major improvements are warranted. The major challenge is how to incorporate the complex biological interactions in Greenland and between Greenland and Iceland (i.e. migration and fishing on mixed-stocks). The ToRs of the group were, however, not to explore assessment models that addressed this issue in a new way, but only to evaluate if the revised assessment model presented to the group could serve as an interim solution before more complex models can be explored during the 2023 benchmark. The group reached the following conclusions.

- The revised assessment procedure can be used as basis for the advice (category 1 stock).
- The assessment model is modified, with M fixed at 0.2 for all ages (from 2016) and independent fishing mortalities at age for all ages.
- The solution should be interim, and a better assessment model should be developed prior to the planned 2023 benchmark.

The reviewers find that the conclusions are well supported and that the efforts have strengthened confidence in this assessment. The retrospective problem (and the less problematic leave-one-out issue) has been adequately addressed and the model now pass the standard model diagnostics. The changes in M and in F process assumptions are based on observed changes in spatial fishing pattern and resulting age compositions (and not purely on model diagnostics). The group applying the model is well aware of the limitations of using this single-stock approach in a mixed-stock setting, so results will be critically scrutinized.

Annex 5: Working documents

WD01: Improving the East Greenland cod stock assessment

WD02: New reference points based on the changed emigration in the SAM model

WD03: 2022 advice for East Greenland cod as a category 3 stock

WD04: ecod ass explorations

ICES IBPGCOD2 August 2021, WD01

Improving the East Greenland cod stock assessment

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Introduction

The East Greenland cod stock (cod.2127.1f14) was benchmarked in 2018 where the assessment was upgraded to category 1 with a SAM model (ICES, 2018). Reference points were also defined subsequently. At the 2021 NWWG the assessment of the East Greenland cod stock shows strong retrospective patterns with consistent underestimation of the spawning stock and corresponding overestimating of fishing mortality. Mohn's rho for SSB is -0.214 and for F above 0.4 (Rigét et al. 2021). For the fleet sensitivity analyses, omission of the German survey from the assessment causes SSB to double in recent years and correspondingly fishing mortality to reduce approx. 50%. Both of these scenarios are outside the confidence limits. The assessment thus requires improvement in behavior in order to be reliable and predictive. In this paper we argue for a change in the configuration of the SAM model to improve the quality of the assessment. One issue is the assumptions of emigration to Iceland in recent years based on a changed fishing pattern around 2016. Another issue is an option of no correlation in F across age instead of an autoregressive process. A change in these two assumptions improves the model diagnostics considerably. On stockassessment.org the two SAM runs are named codEastNWWG2021 (2018 benchmark configuration) and codEastNWWG2021M_indepF (the final assessment, changing the migration and adding a changed F correlation).

Commercial catches

Since 2012 catches from the commercial fishery in the Dohrn Bank area (Q1-Q2) have constituted a considerable part of the total catch, and this has further increased to above 65% from 2019 to 2020, and first part of 2021 (Table 1, see also Figure 4 in Retzel, 2021). Previously the fishery for cod were in the more southern part and Div. 1F. The cod on Dohrn Bank are composed of large and old fish (Figure 6 in Retzel, 2021).

The fishery for cod in East Greenland and Iceland is almost a continuum where catches on the southern slope of the Dohrn Bank are close to the Icelandic EEZ and the Icelandic fisheries for cod within Icelandic EEZ (Figure 1). Given this distribution of the fishery there is much likely mix over the EEZ border. The cod in the Dohrn Bank area is believed to be a mix of cod from both the West/East Greenland and from Iceland. In the 2018 benchmark setting only a one-way migration to Iceland was attempted to be adjusted for. On the 26.01.2021 one tagged cod (96 cm) was caught at position 65°29′N-30°09′W in East Greenland waters at depth of 400 m, which was tagged the 09.03.2019 at position 66°02′N-26°01′W in Iceland waters (Figure 2) indicating some mixing over the EEZ.

The relative proportion at age shows that older cod has been an increasing part of the catch in recent years and especially in the last 4 years cod older than 8 years has increased (Figure 3). These older cod are only weakly trackable in the catch plot (Figure 3), i.e. they first appear as age 6-7.

A separate SAM was performed to evaluate the diagnostic of the SAM run assuming a constant selection over time instead of variable selection in order to detect whether the fishing selection has changed. This separate SAM did not lead to an improvement. The overall fit had higher AIC, the rho's were still outside the acceptable ranges and the sensitivity plot of the German survey were still outside the confidence limits of the model estimate (Table 2).

The catch matrix was also evaluated by performing a separable VPA. Since 2015, the residuals for the older age groups (7 to 10 years old) tend to be positive (red) meaning more older cod are caught than assumed with a constant selection pattern (Figure 4). Same tendencies of positive residuals for the older age groups were also seen in the separate SAM. This suggest a change in selection around 2016.

In summary, the change in fishery distribution in recent years, with a larger part of the total catch in area 14 taken in the Dohrn Bank area composed of relative old cod in combination with a higher abundance of larger cod in the area, is therefore believed to be the cause of the apparent change in selection pattern as visible in catch residuals.

Stock distribution

The German survey has been carried out in autumn since 1982 and the East Greenland survey since 2008. Since 2010 the abundance of older and larger cod (age 8-11+) has increased in both surveys and was especially high in 2017 (Figure 5). Similarly, the biomass indices in the northern part of East Greenland have increased since 2013 (Figure 6 and German survey WD18 Table 7). This increase of the older ages of the stock in the northeast have most likely caused a reallocation of commercial fishing effort into these areas.

Changing of the SAM configuration

In the SAM configuration from the benchmark in 2018, the M is set to 0.2 from age 1 to age 4 and increased to 0.3 for age 5, 0.4 for age 6 and 0.5 for age 7 to 9 to account for emigration to Iceland. This was based on historical well documented migration from West Greenland to East Greenland and further to Iceland. However, this assumption may not be valid for the older cod found in the Dohrn Bank area which in recent years have been an increasing part of the total numbers in the catch at age for the commercial fishery. The older cod might possibly migrate back and forth across the EEZ border between Greenland and Iceland waters as indicated by the continuum of catches across this border (Figure 1) and a recapture of a large cod in East Greenland waters tagged in Iceland waters.

Such a possible migration of older cod in the Dohrn Bank area has implications for the assumptions of the assessment as part of the fishing effort and the stock has increased in the southern area of the Dohrn Bank in recent years.

The changed fishing distribution has occurred especially in the most recent years. Table 2 shows SAM diagnostics with different scenarios of emigration to Iceland in the SAM setup from 2012 and onwards. The Mohn's rho for both F and SSB are improved in the setup starting in any of the years between 2012 and 2016 compared to the benchmark SAM. The differences between AIC values for these starting years are small and can hardly be used for model selection. Also, the fleet sensitivity plot for the German survey is improved and behaves within the confidence limits for the past 10 years.

Table 2 also shows SAM diagnostics for a setup with changed emigration from 2012 from 0 to 0.1 and 0.2. In both cases the Mohn's rho for F and SSB are getting worser than the setup with no emigration.

We choose the setup with 0 emigration for all age groups from year 2016 as the baseline setup for a closer comparison with the benchmark SAM assessment setup.

M settings in the period 2016-2020	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	Age 10+
2018 benchmark	0.2	0.2	0.2	0.2	0.3	0.4	0.5	0.5	0.5	0.5
IBPGCOD2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2

It should not be perceived as the cod had "stopped migrating" but rather that an increasing part of the catch taken at Dohrn Bank, where larger cod may have migrated across the EEZ between Greenland and Iceland (and thus between two defined cod stocks).

In the configuration of the 2018 benchmark SAM run an autoregressive process of the correlation of the fishing mortality across ages was assumed. This means that it was assumed that changes in fishing mortality between years would affect neighboring age groups similarly. However, with the known (separable) distribution of cod age groups this might not be the case. By changing this assumption to no correlation across ages (independent) a further improvement was observed on the retrospective pattern. The model now fits better for the recent years of the time series at the expense of the earlier part compared to not making this change in the model configuration.

Comparisons between the SAM output using the baseline setup (2018 benchmark) and the inter-benchmark setup.

Figure 7 shows the retrospective plots for F and SSB using the 2018 benchmark setup. F are consequently overestimated and reduced when next year data are added. SSB is consequently underestimated and is increased when next year data are added. Consequently, the Mohn's rho are relatively high. With the suggested setup with no emigration from 2016 and no correlation in fishing mortality between age groups the retrospective plots for Fbar and SSB are considerable improved and the Mohn's rho are lower and within the acceptable range (Figure 8).

Figure 9 (above) using the 2018 benchmarked setup, shows that leaving out the German survey as a calibrating tuning series increased the SSB far out of the confidence limit of the model, while this is not the case with the assumption of zero migration from 2016 and no correlation in fishing mortality across ages (Figure 9, below).

Lastly, it should be mentioned that measured with the AIC values the model with the changed migration pattern no correlation in fishing mortality across ages performed better than the 2018 benchmarked model (2031 versus 2046 both with 23 parameters).

Reference points based on this changed configurations of SAM was estimated by the EqSim program to Fmsy = 0.29, Flim = 1.98 and Fpa = 0.65 (see WD 02).

In conclusion, changing the migration pattern and no correlation in fishing mortality across ages in the assessment model is argued to better reflect the suggested migration patterns for cod in East Greenland in the latest years and with a larger part of the commercial catch taken in the Dohrn Bank area where larger cod have been more abundant. These assumptions improve the model diagnostics. In Table 3 a TAC-constrained short-term forecast is given underlining the impact on the advice.

References:

ICES, 2018. Report of the InterBenchmark Protocol on Greenland Cod (IBPGCod). ICES CM 2018/ACOM:30.

Retzel, A. 2021. Greenland commercial data for Atlantic cod in East Greenland offshore waters for 2020. ICES North Western Working Group (NWWG) April 22-29, 2021, WD 03

Riget, F., Retzel, A., Buch, T.B. 2021. A SAM assessment of the East Greenland cod stock. ICES North Western Working Group (NWWG) April 22-29, 2021, WD 11.

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Table 1. The percentage of the total catch taken at the Dohrn Banke.

	Dohrn Bank (Q1-Q2)	Total (tons)
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	77% (20000 t)	26091 (TAC)

Table 2. SAM diagnostic with different setup of SAM

SAM setup	AIC	rho-Fbar	rho_SSB	Outside CL leave out German survey
benchmark SAM	2046.39	0.416	-0.214	Yes
separable SAM	2113.28	0.348	-0.230	Yes
E changed to 0 from 2016	2030.58	0.197	-0.099	No
E changed to 0.1 from 2016	2036.19	0.313	-0.168	Close
E changed to 0.2 from 2016	2041.67	0.423	-0.226	Yes
year of change 2012	2036.73	0.199	-0.076	No
year of change 2013	2035.13	0.191	-0.073	No
year of change 2014	2034.79	0.187	-0.076	No
year of change 2015	2033.08	0.187	-0.082	No
year of change 2016	2030.58	0.197	-0.099	No
year of change 2017	2031.65	0.238	-0.136	No
year of change 2018	2036.08	0.315	-0.184	Yes
year of change 2019	2039.79	0.418	-0.232	Yes

Table 3a: Short-term forecast for 2022 with the new proposed settings in M and no correlation in fishing mortality across ages, assuming that Catch=TAC_{2021}(26,091 t). Fmsy = 0.29, Fpa =1.17 and Flim = 1.98 estimated by the EqSim programme.

Basis	Total catch (2022)	F (2022)	SSB (2023)	% SSB change
F=F_{MSY}	8768	0.29	53622	+4
F=0	0	0	68680	+34
F=F_{pa}	22309	1.17	33379	-35
F=F_{lim}	28423	1.98	24763	-52
F_{2022}=F_{2021}	19261	0.89	38053	-26
SSB(2022)=Blim	41326	6.6	11738	-77
SSB(2022)=Bpa	35002	3.4	18146	-65

Table 3b: Short-term forecast for 2022 with the 2018 benchmark settings in M, assuming that Catch=TAC_{2021}(26,091 t). (Fmsy = 0.46, Fpa = 1.33 and Flim = 2.34 estimated by EqSim programme.

Basis	Total catch (2022)	F (2022)	SSB (2023)	% SSB change
F=F_{MSY}	8469	0.46	36643	-13
F=0	0	0	49226	+17
F=F_{pa}	16927	1.33	26728	-13
F=F_{lim}	22664	2.34	20680	-51
F_{2022}=F_{2021}	14783	1.03	29061	-31
SSB(2022)=Blim	34163	3.17	10081	-76
SSB(2022)=Bpa	28395	4.32	14819	-65

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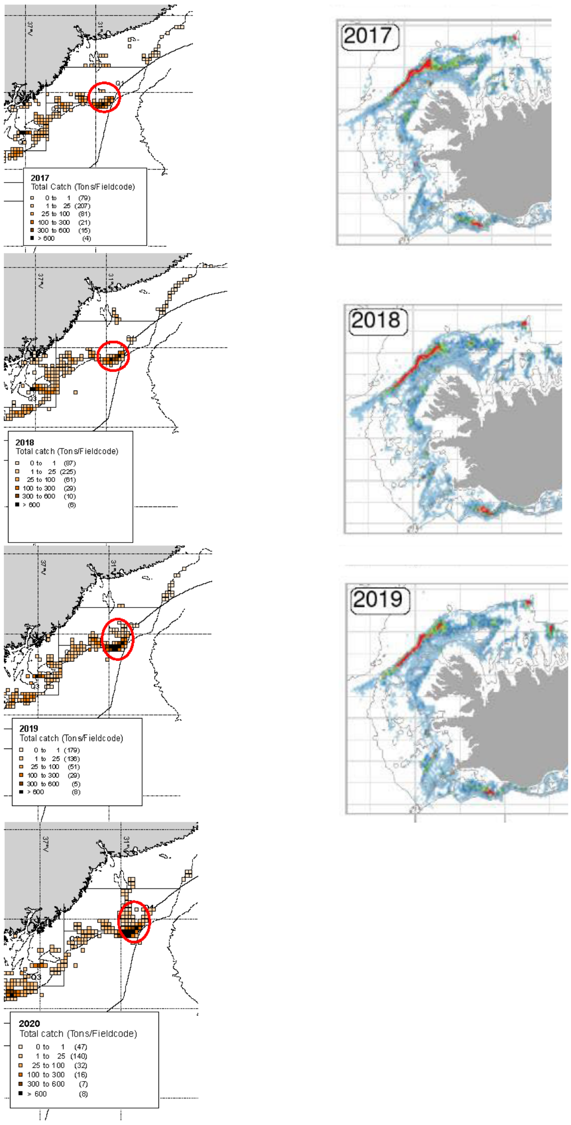

Figure 1. Total catch distribution of cod in recent years from the northeastern part of Greenland and the western part of Iceland.

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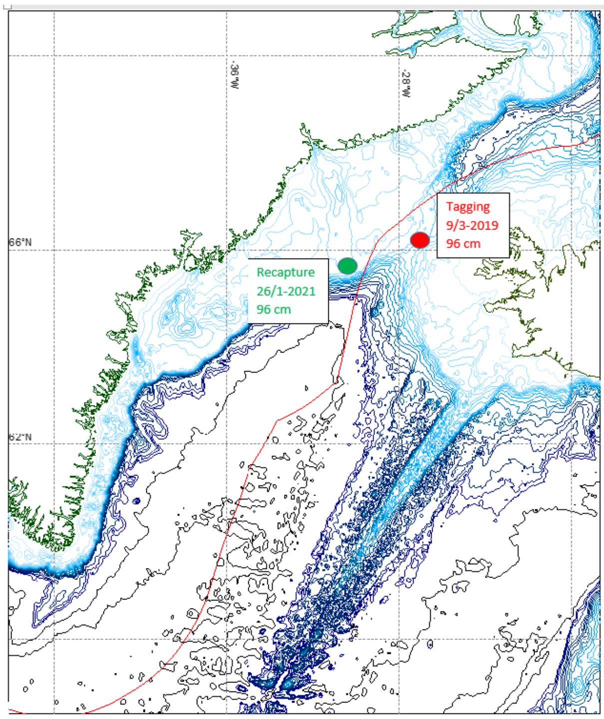

Figure 2. Tagging (09.03.2019) and recapture (26.01.2021) positions of a 96 cm cod.

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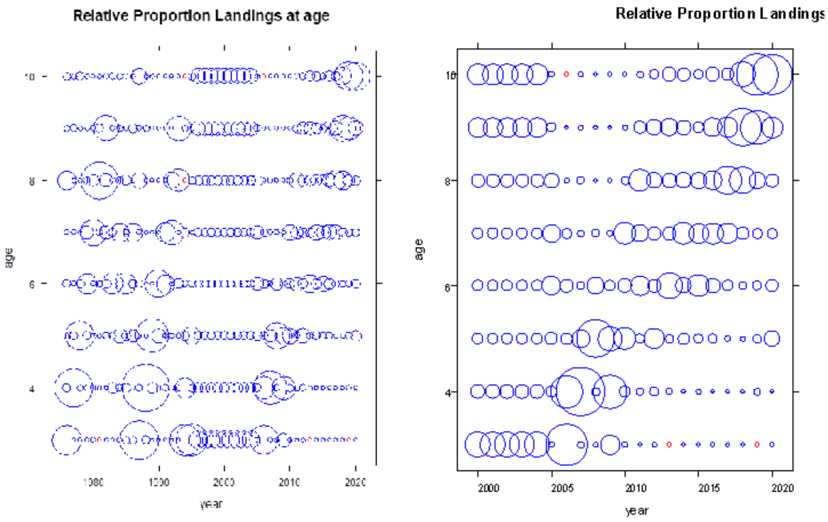

Figure 3. Relative proportion of landings at age; left: entire time series 1976-2020, right 2000-2020.

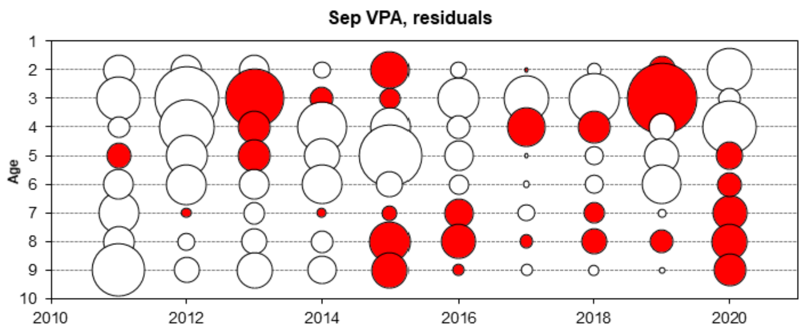

Figure 4. Residuals from a separable VPA. Red is positive and white is negative.

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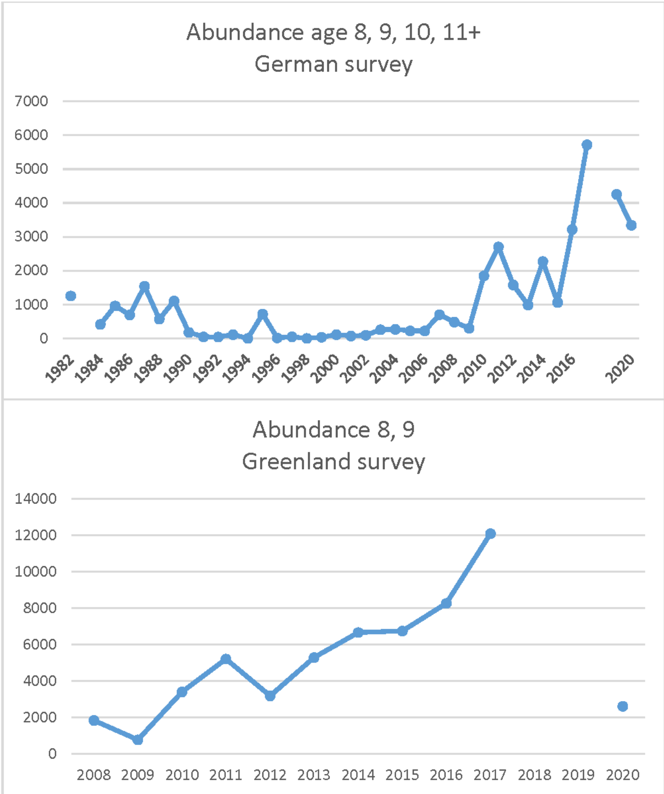

Figure 5. Abundance of older cod in East Greenland + Div. 1F found in the German and Greenland surveys.

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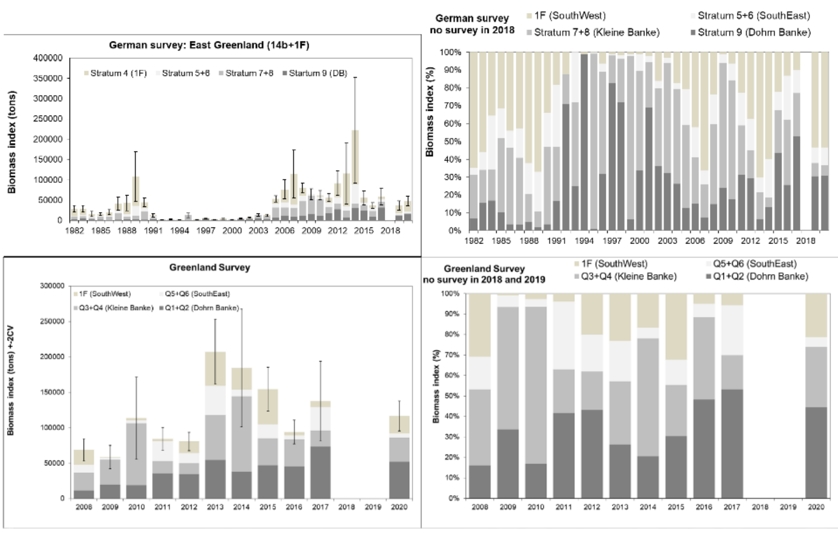

Figure 6. Biomass index and proportion (%) of biomass between 4 different survey areas in East Greenland. German survey (top) and Greenland survey (bottom). Dohrn Bank furthest to the north in East Greenland.

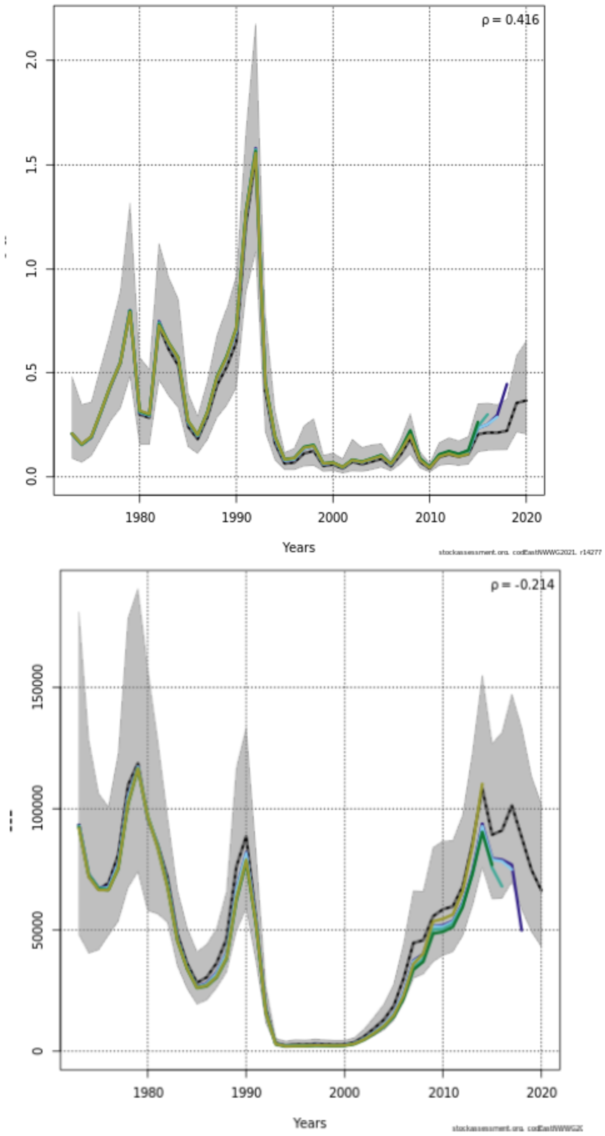

Figure 7. Retrospective plots of Fbar (above) and SSB (below) with the migration patterns as in the benchmark setup of SAM.

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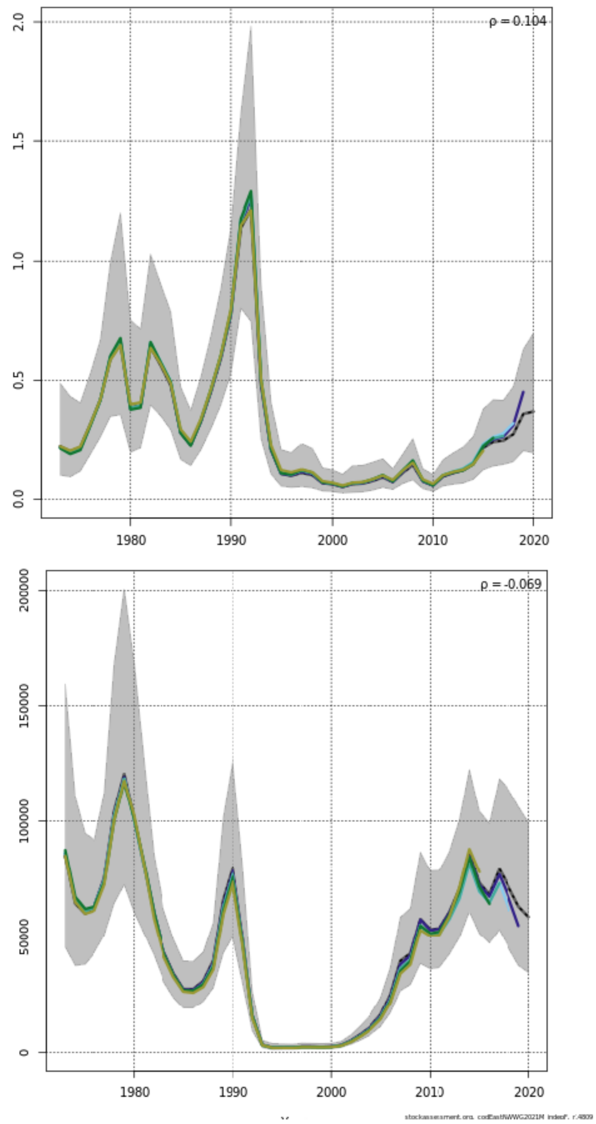

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Figure 8. Retrospective plots of Fbar (above) and SSB (below) with the changed configuration of SAM (no emigration from 2016 and uncorr F at age).

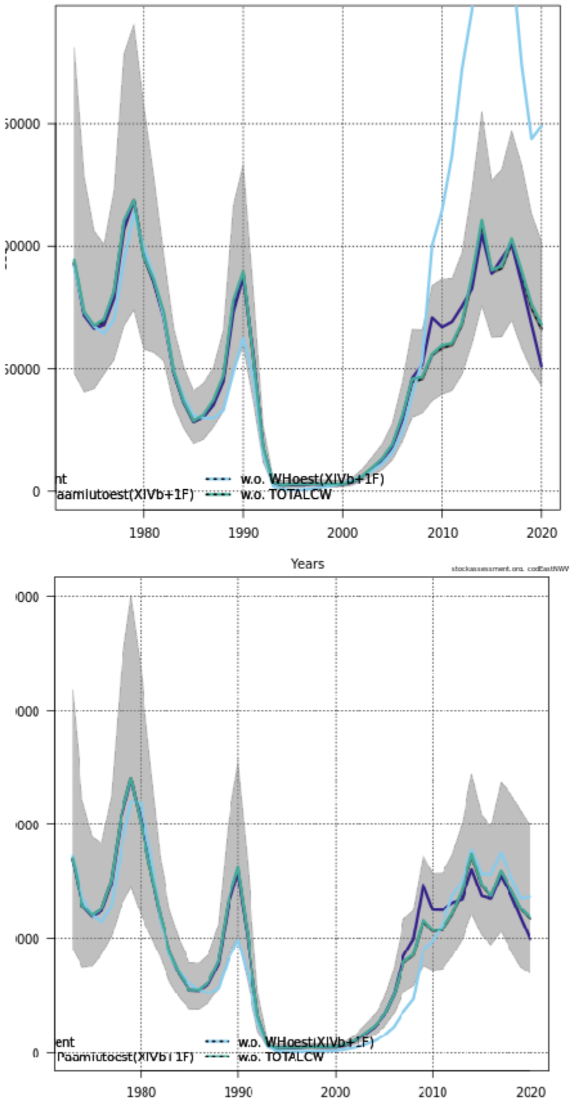

Figure 9. Leave out plots of SSB with the migration pattern as the benchmarked SAM (above) and the changed configuration of SAM (below).

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New reference points based on the changed emigration in the SAM model

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Reference points

The estimation of reference points follows the ICES Reference Points Guidance, January 2016. The estimation has been done using the simulation R-programme EqSim developed by D.C.M. Miller, which works directly on a specified SAM fit. The setup of the EqSim programme was the same as in 2018 benchmark except that the average of biological variable was decreased from 10 to 5 years because of the change of migration pattern from year 2016 in the SAM model (WD 01).

The simulation settings for the Stock-Recruitment relationship were as follows. The simulation was done with 2000 runs, scanning F from 0 to 3 divided into 100 intervals. The age group assumed representative for recruitment is age 1. No years were omitted from the SR relationship (Figure 1) except the two last years (2019 and 2020) as the SAM model estimated numbers of recruits for these most recent years are considered too uncertain. The segmented regression were applied to the time series, 1973-2020.

The SR relation is assessed to a be type 1, 'Spasmodic stocks – stocks with occasional large year classes' (ICES guidelines for reference points for category 1 and 2 stocks). In that case B_{lim} is based on the lowest SSB where large recruitment is observed. Years with high recruitment are considered to be 2003, 2004 and 2005, and we chose the mean of those years to base the **Blim** estimate on. We therefore consider SSB with large recruitment as Blim = 11 738 t.

Bpa is calculated from the formula Bpa = Blim * exp(1.645 *σ), where σ is SD of ln(SSB) in 2020 - here estimated by SAM to 0.265. Bpa is then 18 146 t.

Flim is estimated by simulation using the above values of Blim and Bpa, setting Fcv, Fphi and SSBcv = 0 (no assessment and advice noise) and with no Btrigger. The range of years are from 1996 to 2019. Here estimated to 1.98 (Table 1).

Fpa is calculated as F05 (Table 1).

MSY reference points (MSY $B_{trigger}$ and F_{MSY})

F_{MSY} is initially estimated as the F that maximize median long-term yield in the simulation under constant F exploitation. The default values of cvF = 0.212, phiF = 0.423 and cvSSB = 0 were applied to the simulation. The initial F_{MSY} was estimated at 0.29, which is below the above estimated Fpa.

The final F_{MSY} is estimated by a simulation using the default Fcv, Fphi, the estimated Blim, Bpa and $B_{trigger}$ which is equal to Bpa. **F05** was estimated to 0.65. The final $\mathbf{F_{MSY}}$ estimate was 0.29. The

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precautionary principle states that if F_{MSY} > F05, which is not the case here, otherwise F_{MSY} should be reduced to F05 (Table 1).

Table 1. Reference points. Cod in 14b and NAFO division 1F.

Framework	Reference Point	Value	Technical basis
MSY approach	MSY $B_{trigger}$	18146	MSY $B_{trigger}$ = B_{pa}
	F_{MSY}	0.29	F_{MSY} simulated should be lower than F05 = 0.65
Precautionary approach	B_{lim}	11738	Mean of three lowest SSB given large recruitment
	B_{pa}	18146	Blim * exp(1.645 * σ), σ = 0.23
	F_{lim}	1.98	F50 deterministic simulated
	F_{pa}	0.65	F05
Y/R approach	$F_{0.1}$	0.33	SAM estimated
	F_{max}	0.93	SAM estimated
	F_{35spr}	0.47	SAM estimated

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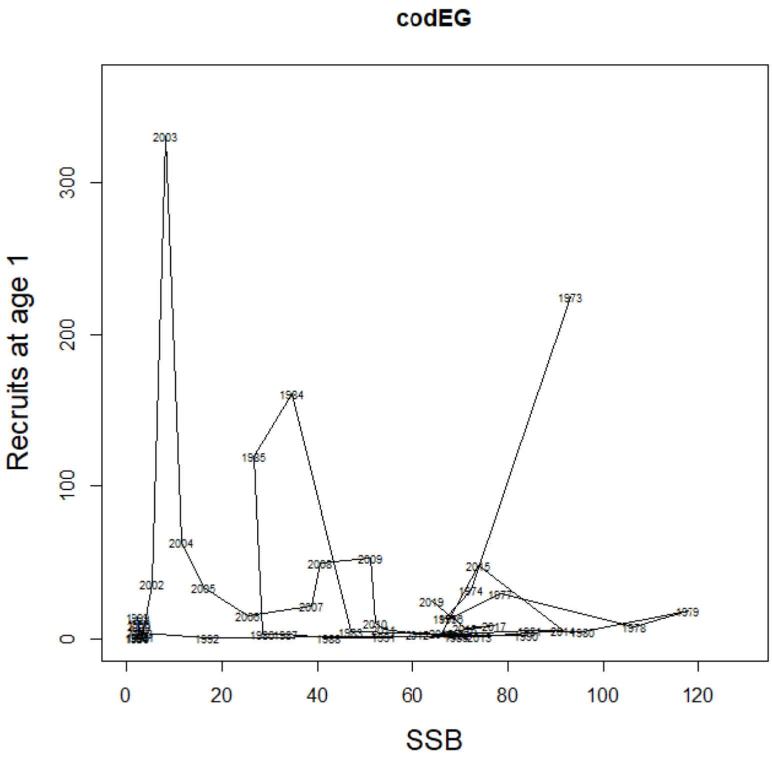

Figure 1. SSB-R relationship. Year denotes year-class.

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2022 advice for East Greenland cod as a category 3 stock

Anja Retzel, Teunis Jansen

Introduction

The East Greenland cod stock (cod.2127.1f14) was benchmarked in 2018 where the stock was upgraded to category 1 with a SAM model (ICES, 2018). At the 2021 NWWG the assessment of the East Greenland cod stock shows strong retrospective patterns with consistent underestimation of the spawning stock and corresponding overestimating of fishing mortality. Mohn's rho for SSB is -0.214 and for F above 0.4 (Rigét et al. 2021a). Based on this the assessment was rejected. This document will show options for downgrading the stock to category 3 if the model improvement (Rigét et al. 2021b) cannot be accepted.

Index

Two surveys are covering the stock. A survey conducted by Greenland, which takes place in August/September and a survey conducted by Germany, which take place in October/November. The Greenland survey in 2018 and 2019, and the German survey in 2018 (figure 1) were *not* conducted. These holes in the timeseries makes it difficult to use survey indices as basis for the index calculation.

The development in the relative spawning stock biomass produced by the original SAM assessment (figure 2) can be used as basis for the index calculation. To base the advice on assessment indicative of trends is done for several stocks: Cod in Kattegat (cod.27.21), Plaice in the Baltic Seas (ple.27.24-32), Plaice in the Bristol Channel (ple.27.7fg) and Herring West of Scotland and Ireland (her.27.6a7bc).

Table 1 shows the index based on surveys and SAM.

Multiplier

There is a large discrepancy between advice and total catches of up to 20.000 tons in 2021 (Table 2). This makes it difficult to define the multiplier on the index ratio. Comparing the development in the relative catch, F and spawning stock (figure 3) show a stable development in F and SSB in the time period 2015-2018. In comparison with the stable development in the two surveys since 2015 suggest that the stock seems relatively stable in this time period.

As the spawning stock has been underestimated by the SAM model and consequently advice the following year has increased even though spawning stock has decreased makes the latest advice for 2021 (6.091 t) a dubious choice as multiplier.

We suggest to use the average of the total catch in the time period 2015-2018 (15.485 tons) as the multiplier (table 3).

For advice next year (2023) it is advice to use the advice for 2022 as the multiplier.

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Advice

Table 3 shows catch options where the trend in SSB from the original SAM output is used as index and the average catch from the period 2015-2018 is used as the multiplier. As the index ratio is higher than 20% the uncertainty cap (0.8) is applied instead of the index ratio. As this is the first year advice as category 3 is given the Precautionary buffer is also applied. These rules follow the ICES guidelines (ICES, 2012)

References

ICES, 2012. ICES Implementation of Advice for Datalimited Stocks in 2012 in its 2012 Advice. ICES cm 2012/ACOM 68.

ICES, 2018. Report of the InterBenchmark Protocol on Greenland Cod (IBPGCod). ICES CM 2018/ACOM:30.

Riget, F., Retzel, A., Buch, T.B. 2021a. A SAM assessment of the East Greenland cod stock. ICES North Western Working Group (NWWG) April 22-29, 2021, WD 11.

Riget, F., Retzel, A., Boje, J. Buch, T.B. 2021b. Changing the migration pattern in the East Greenland cod stock SAM. ICES InterBenchmark Protocol on Greenland Cod (IBPGCod), August 2021, WD 01.

Tables

Table 1. Index calculations based on surveys and SAM runs.

Greenland survey Biomass no survey in 2018+2019	Index A (2020)	115752
	Index B (2016-2017)	116803
	Index ratio	**0.991**
German survey Biomass no survey in 2018	Index A (2019-2020)	42034
	Index B (2016-2017)	47827
	Index ratio	**0.879**
Original SAM SSB	Index A (2019-2020)	1.371
	Index B (2016-2018)	1.818
	Index ratio	**0.754**
Modified SAM SSB	Index A (2019-2020)	1.305

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	Index B (2016-2018)	1.522
	Index ratio	**0.858**

Table 2. Summary of total catch and advice in tons. Advice first given in 2016 for this stock.

Year	Total catch	Advice
2011	5113	
2012	5411	
2013	5511	
2014	7893	
2015	15755	
2016	14818	7577
2017	16224	7930
2018	14980	12151
2019	18030	5363
2020	15917	3409
2021	26091 (TAC)	6091

Table 3. Catch options with index based on SSB from original SAM output.

Index A (2019-2020)	1.370732
Index B (2016-2018)	1.817601
Index ratio	0.754144
Average Catch (2015-2018)	15485
Advice (average catch 2015-2018) X Uncertainty Cap (0.8)	12388
Advice (average catch 2015-2018) X Uncertainty Cap (0.8) X Precautionary buffer (0.8)	**9910**

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Figures

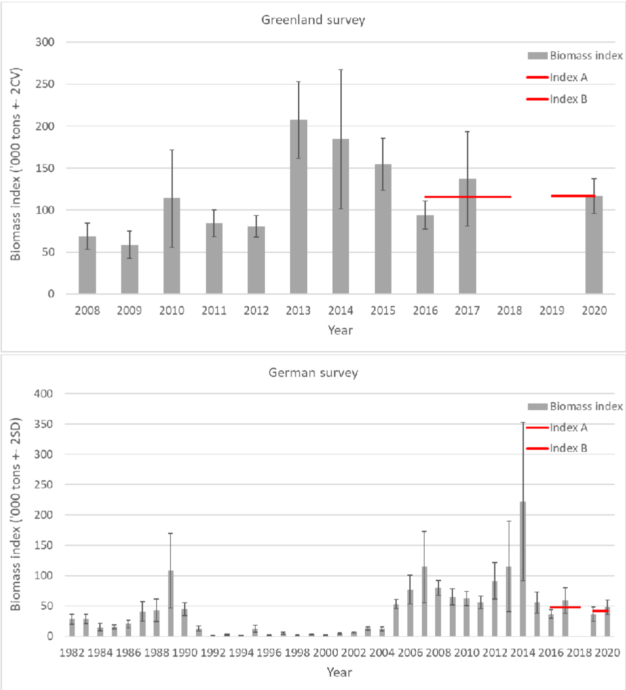

Figure 1. Biomass index (tons) of the Greenland survey (top, no survey in 2018 and 2019) and German survey (bottom, no survey in 2018).

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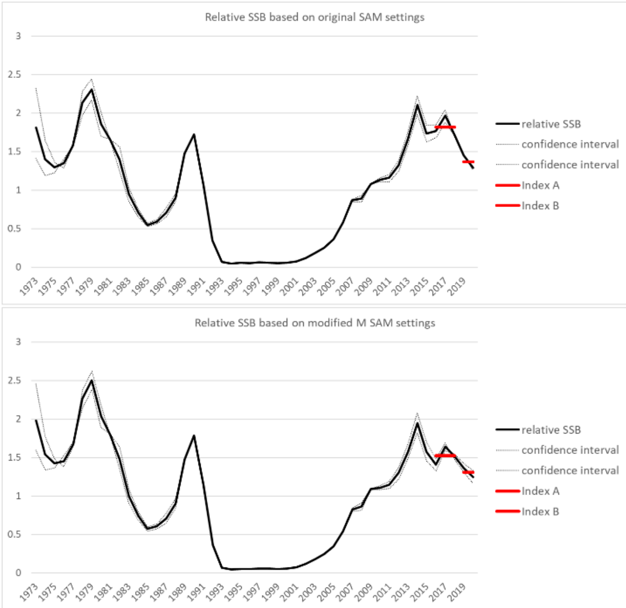

Figure 2. Relative spawning stock biomass output from the original SAM (top) and the modified SAM (bottom).

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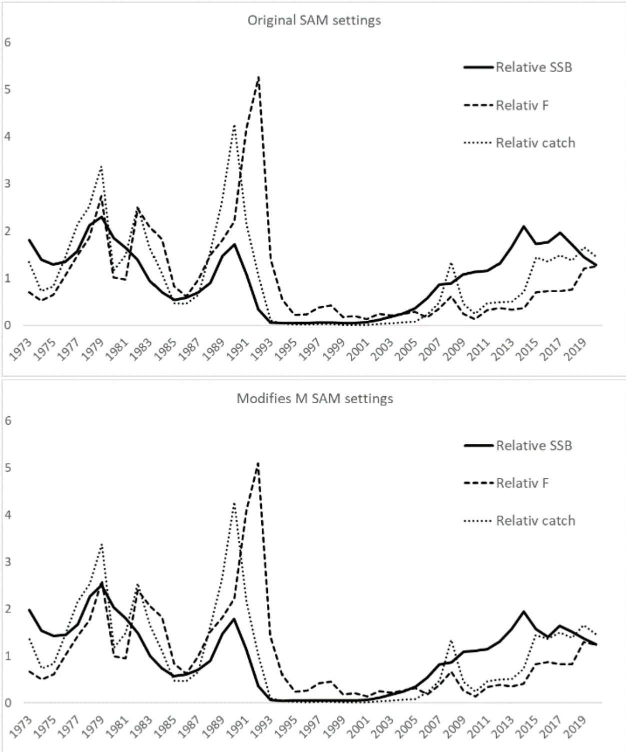


Figure 3. Relative spawning stock biomass (SSB), fishing mortality (F) and total catch in output from original SAM settings (top) and modified Natural Mortality (M) SAM settings (bottom).

ecod ass explorations

Einar Hjörleifsson

2021-08-12 09:05:26

```
library(raster)
library(sf)
library(stars)
library(lubridate)
library(stockassessment)
# remotes::install_github("einarhjorleifsson/fishvice")
library(fishvice)
library(tidyverse)
library(ggnewscale)
library(patchwork)
```

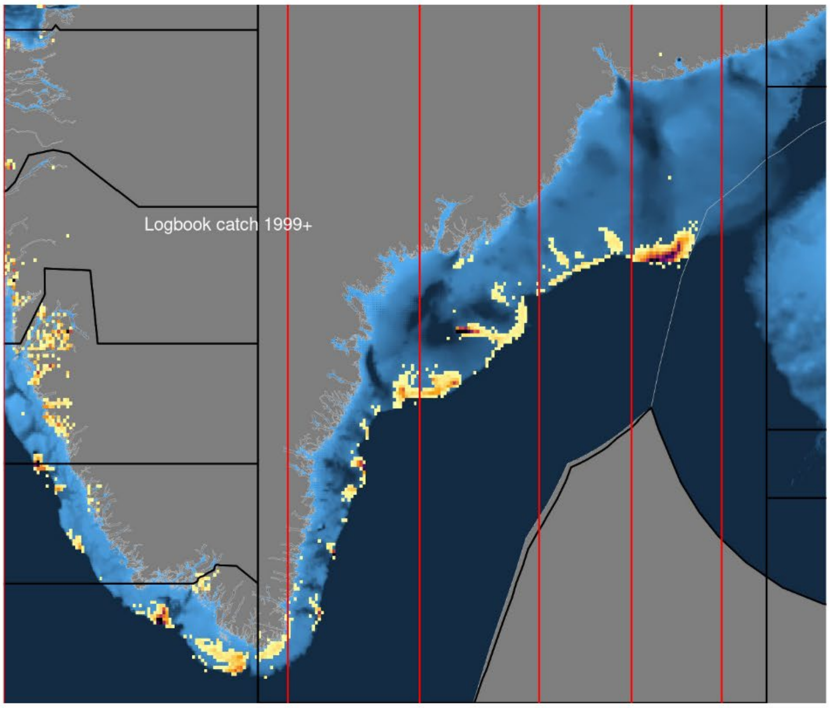
First some ad-hoc exploration of input data.

```
fao <-
  read_sf("igcod/data/spatial/fao.gpkg")
eez <- read_sf("igcod/data/spatial/eez.gpkg")
bb <- st_bbox(c(xmin = -52.5, ymin = 59,
                xmax = -10,    ymax = 69.2),
              crs = 4326)
r <-
  raster("igcod/data/spatial/bathymetry.tif")
i <- values(r)  <= -650
values(r)[i] <- -650
i <- values(r)  > 0
values(r)[i] <- NA
s <-
  r %>%
  st_as_stars() %>%
  st_crop(bb)
d <-
  s %>%
  as_tibble() %>%
  rename(z = bathymetry)

m <-
  ggplot() +
  theme_void() +
  geom_stars(data = s) +
  #geom_contour(data = d,
  #             aes(x, y, z = z),
  #             breaks = c(-100, -200, -300, -400, -500, -600),
  #             size=c(0.3),
  #             colour="grey") +
  geom_sf(data = eez %>% st_cast("MULTILINESTRING"),
          colour = "grey",
```

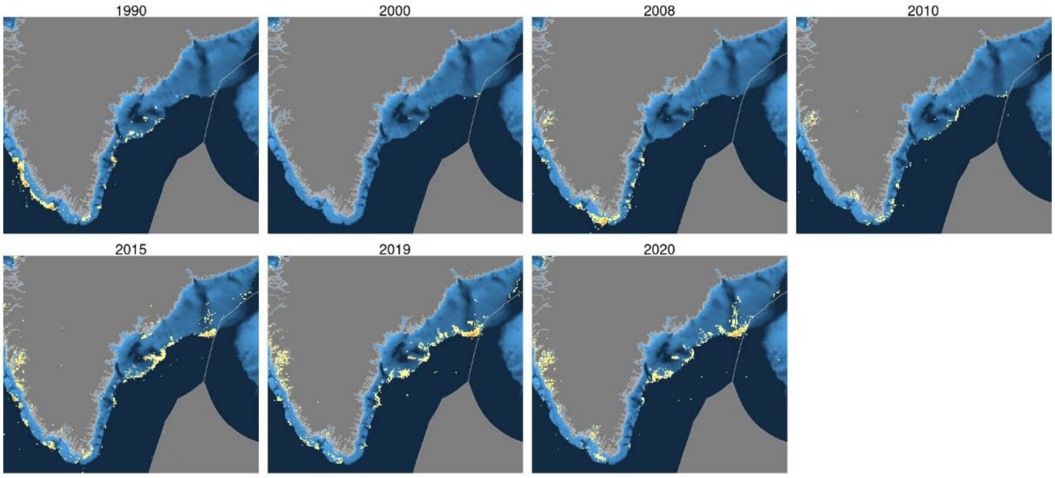
```
          lwd = 0.1) +
  coord_sf(xlim = c(bb$xmin, bb$xmax),
           ylim = c(bb$ymin, bb$ymax),
           expand = 0) +
  theme(legend.position = "none") +
  new_scale_fill()
```

```
lgs.gre <-
  read_rds("igcod/data/gre/gre_lgs-merged.rds") %>%
  mutate(source = "grl",
         date = as_date(t1),
         year = year(t1)) %>%
  dplyr::select(source, year, date, lon = lon1, lat = lat1, catch, effort)
```

```
g.by <-
  lgs.gre %>%
  filter(between(lon, bb$xmin, bb$xmax),
         between(lat, bb$ymin, bb$ymax)) %>%
  mutate(lon = gisland::grade(lon, 0.1),
         lat = gisland::grade(lat, 0.1/2)) %>%
  group_by(year, source, lon, lat) %>%
  summarise(catch = sum(catch, na.rm = TRUE) / 1e3,
            .groups = "drop") %>%
  st_as_sf(coords = c("lon", "lat"),
           crs = 4326,
           remove = FALSE) %>%
  st_join(fao %>% mutate(div = paste0(area, ".", div)) %>% dplyr::select(div)) %>%
  st_drop_geometry()
g <-
  g.by %>%
  filter(year >= 1999) %>%
  group_by(source, div, lon, lat) %>%
  summarise(catch = sum(catch),
            .groups = "drop")
m +
  geom_tile(data =
              g %>%
              mutate(catch = ifelse(catch > 2000, 2000, catch)) %>%
              filter(catch > 20),
            aes(lon, lat, fill = catch)) +
  scale_fill_viridis_c(option = "B", direction = -1) +
  geom_sf(data = fao %>% st_cast("MULTILINESTRING")) +
  geom_vline(xintercept = c(bb$xmin, -43, -38.6, -34.6, -31.5, -28.5, -16.5),
             colour = "red") +
  coord_sf(xlim = c(bb$xmin, -25),
           ylim = c(bb$ymin, bb$ymax),
           expand = c(0, 0)) +
  annotate("text", x = -45, y = 66, label = "Logbook catch 1999+",
           colour = "white")
```

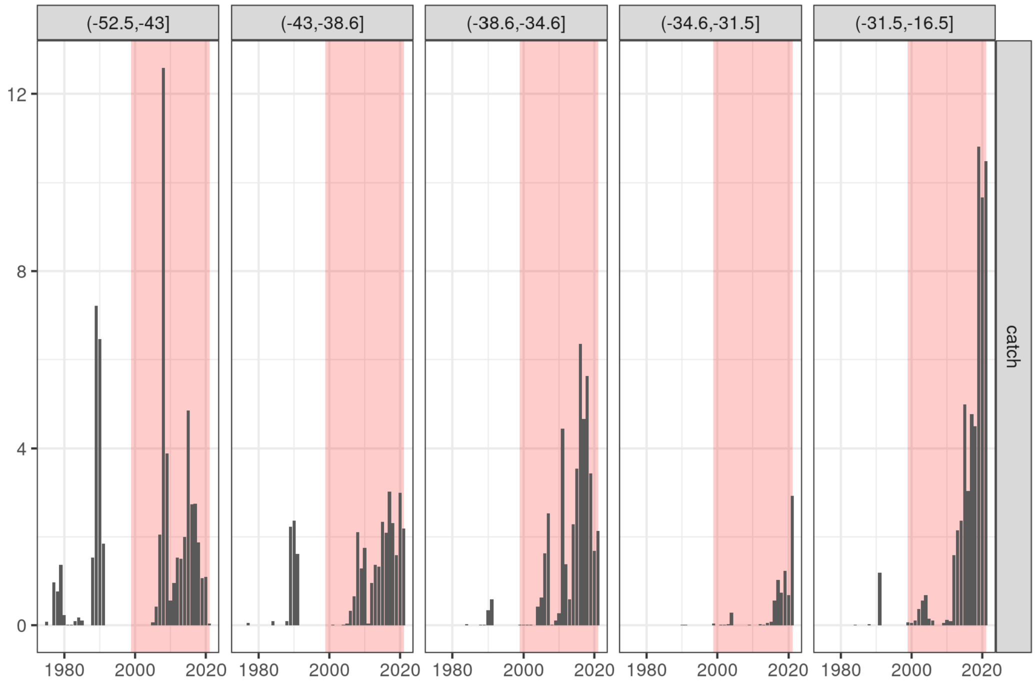



```r
m +
  geom_tile(data = g.by %>% filter(year %in% c(1990, 2000, 2008, 2010,
                                               2015, 2019, 2020)),
            aes(lon, lat, fill = catch)) +
  scale_fill_viridis_c(option = "B", direction = -1) +
  coord_sf(xlim = c(bb$xmin, -25),
           ylim = c(bb$ymin, bb$ymax),
           expand = c(0, 0)) +
  facet_wrap(~ year, nrow = 2)
```

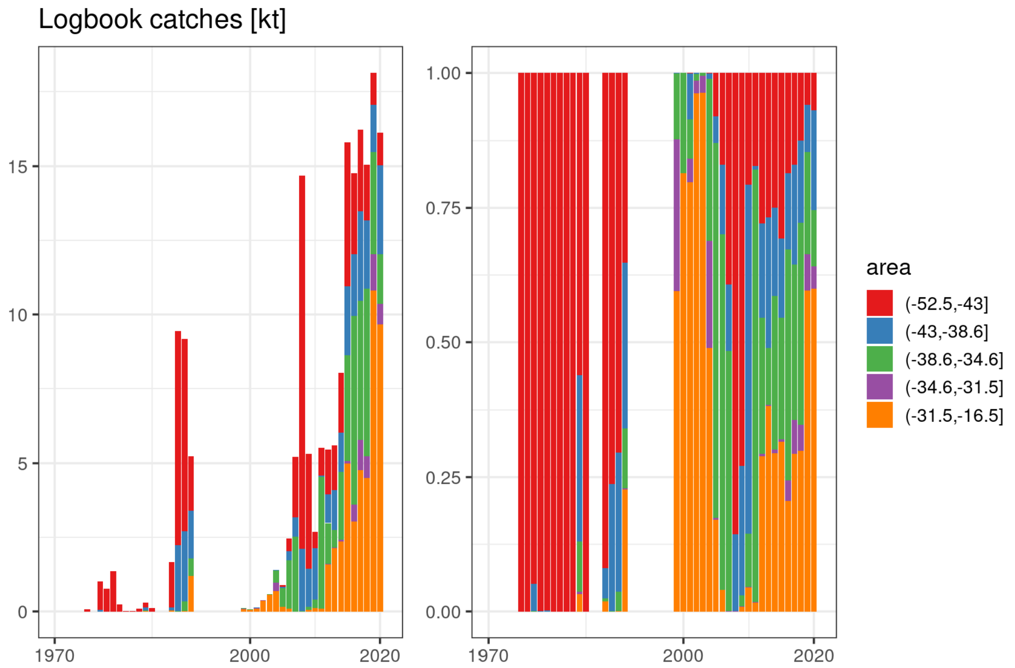



```r
d <-
  lgs.gre %>%
  dplyr::select(year, lon, lat, catch, effort) %>%
  filter(!is.na(lon), !is.na(lat)) %>%
  st_as_sf(coords = c("lon", "lat"),
           crs = 4326,
           remove = FALSE) %>%
  st_join(fao  %>% dplyr::select(area, div, sdiv)) %>%
  st_drop_geometry() %>%
  filter((area == 21 & div == 1 & sdiv == "F") |
           (area == 27 & div == 14)) %>%
  mutate(area = cut(lon, breaks = c(bb$xmin, -43, -38.6, -34.6, -31.5, -16.5))) %>%
  gather(var, val, catch:effort) %>%
  drop_na() %>%
  group_by(year, var, area) %>%
  summarise(val = sum(val))

d %>%
  filter(var == "catch") %>%
  ggplot(aes(year, val / 1e6)) +
  theme_bw(base_size = 14) +
  annotate("rect", ymin = -Inf, ymax = Inf,
           xmin = 1998.9, xmax = 2021.1,
           fill = "red", alpha = 0.2) +
```

```
  geom_col() +
  facet_grid(var ~ area, scales = "free_y") +
  labs(x = NULL, y = NULL) +
  scale_x_continuous(breaks = c(1980, 2000, 2020))
```




```
p <-
  d %>%
  filter(var == "catch") %>%
  ggplot(aes(year, val / 1e6, fill = area)) +
  theme_bw(base_size = 14) +
  annotate("rect", ymin = -Inf, ymax = Inf,
           xmin = 1998.9, xmax = 2021.1,
           fill = "red", alpha = 0.2) +
  labs(x = NULL, y = NULL) +
  scale_x_continuous(breaks = c(1970, 2000, 2020),
                     limits = c(1970, 2021)) +
  scale_fill_brewer(palette = "Set1")
p1 <- p + geom_col() + labs(title = "Logbook catches [kt]")
p2 <- p + geom_col(position = "fill")
p1 + p2 + plot_layout(guides = "collect")
```

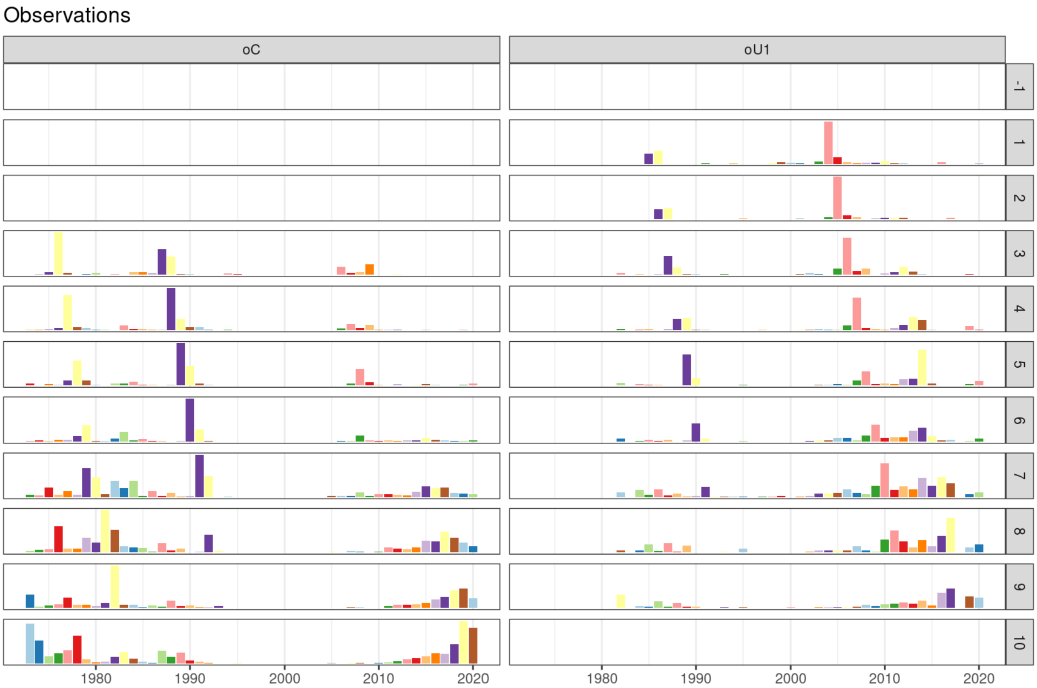



```r
# Just a printout of the code above
lh <- stockassessment::read.ices
# The SPALY assumption on M (constant over time, variable with age)
dat.spaly <-
  setup.sam.data(surveys = lh("ass/sam/spaly/data/survey_german.dat"),
                 residual.fleet = lh("ass/sam/spaly/data/cn.dat"),
                 prop.mature = lh("ass/sam/spaly/data/mo.dat"),
                 stock.mean.weight = lh("ass/sam/spaly/data/sw.dat"),
                 catch.mean.weight = lh("ass/sam/spaly/data/cw.dat"),
                 dis.mean.weight = lh("ass/sam/spaly/data/cw.dat"),
                 land.mean.weight = lh("ass/sam/spaly/data/cw.dat"),
                 prop.f = lh("ass/sam/spaly/data/pf.dat"),
                 prop.m = lh("ass/sam/spaly/data/pm.dat"),
                 natural.mortality = lh("ass/sam/spaly/data/nm.dat"),
                 land.frac = lh("ass/sam/spaly/data/lf.dat"))
# The interbenchmark proposed change, M lowered in recent years
dat.dm <-
  setup.sam.data(surveys = lh("ass/sam/spaly/data/survey_german.dat"),
                 residual.fleet = lh("ass/sam/spaly/data/cn.dat"),
                 prop.mature = lh("ass/sam/spaly/data/mo.dat"),
                 stock.mean.weight = lh("ass/sam/spaly/data/sw.dat"),
                 catch.mean.weight = lh("ass/sam/spaly/data/cw.dat"),
                 dis.mean.weight = lh("ass/sam/spaly/data/cw.dat"),
                 land.mean.weight = lh("ass/sam/spaly/data/cw.dat"),
```

```
                 prop.f = lh("ass/sam/spaly/data/pf.dat"),
                 prop.m = lh("ass/sam/spaly/data/pm.dat"),
                 natural.mortality = lh("ass/sam/spaly/data/nm_dm.dat"),
                 land.frac = lh("ass/sam/spaly/data/lf.dat"))
dat.dm0 <-
  setup.sam.data(surveys = lh("ass/sam/spaly/data/survey_german.dat"),
                 residual.fleet = lh("ass/sam/spaly/data/cn.dat"),
                 prop.mature = lh("ass/sam/spaly/data/mo.dat"),
                 stock.mean.weight = lh("ass/sam/spaly/data/sw.dat"),
                 catch.mean.weight = lh("ass/sam/spaly/data/cw.dat"),
                 dis.mean.weight = lh("ass/sam/spaly/data/cw.dat"),
                 land.mean.weight = lh("ass/sam/spaly/data/cw.dat"),
                 prop.f = lh("ass/sam/spaly/data/pf.dat"),
                 prop.m = lh("ass/sam/spaly/data/pm.dat"),
                 natural.mortality = lh("ass/sam/spaly/data/nm_dm0.dat"),
                 land.frac = lh("ass/sam/spaly/data/lf.dat"))
# setup
# load("ass/sam/changeM/run/model.RData")
# conf <- fit$conf
conf.spaly <- stockassessment::defcon(dat.spaly)
conf.spaly$maxAgePlusGroup <- c(1, 0, 0)
conf.spaly$keyLogFsta[1, ] <- c(-1, -1, 0, 1, 2, 3, 4, 5, 6, 6)
conf.spaly$keyLogFpar[3, 1] <- -1
conf.spaly$keyVarObs[1, 1:2] <- c(-1, -1)
conf.spaly$keyVarObs[3, 1] <- -1
conf.spaly$fbarRange <- c(5, 10)
conf.spaly$keyBiomassTreat[3] <- 3
conf.spaly$fixVarToWeight <- 1
saveConf(conf.spaly, "conf.spaly.txt")
saveConf(conf, "conf.txt")


conf.spaly.ar <- conf.spaly
conf.spaly.ar$obsCorStruct[2] <- c("AR")
conf.spaly.ar$keyCorObs[2, 1:8] <- 0

conf.spaly.ar.var <- conf.spaly.ar
conf.spaly.ar.var$keyVarObs[1, ] <- c(-1, -1, 0, 1, 2, 2, 2, 3, 3, 3)
conf.spaly.ar.var$keyVarObs[2, ] <- c(4, 5, 6, 6, 6, 6, 7, 7, 7,  -1)

conf.spaly.ar.var.power <- conf.spaly.ar.var
conf.spaly.ar.var.power$keyQpow[2, 1:5] <- c(0, 1, 2, 3, 4)

fit.spaly <- sam.fit(dat.spaly, conf.spaly, defpar(dat.spaly, conf.spaly))
fit.dm <- sam.fit(dat.dm, conf.spaly, defpar(dat.dm, conf.spaly))
fit.spaly.ar <- sam.fit(dat.spaly, conf.spaly.ar, defpar(dat.spaly, conf.spaly.ar))
fit.spaly.ar.var <- sam.fit(dat.spaly, conf.spaly.ar.var, defpar(dat.spaly, conf.spaly.ar.var)
)
fit.spaly.ar.var.power <- sam.fit(dat.spaly, conf.spaly.ar.var.power, defpar(dat.spaly, conf.s
paly.ar.var.power))
fit.spaly.ar.var.power.dm <- sam.fit(dat.dm, conf.spaly.ar.var.power, defpar(dat.dm, conf.spal
y.ar.var.power))
fit.spaly.ar.var.power.dm0 <- sam.fit(dat.dm0, conf.spaly.ar.var.power, defpar(dat.dm0, conf.s
paly.ar.var.power))
```

```
ret.spaly <- retro(fit.spaly, year = 18)
ret.dm <- retro(fit.dm, year = 18)
ret.spaly.ar <- retro(fit.spaly.ar, year = 18)
ret.spaly.ar.var <- retro(fit.spaly.ar.var, year = 18)
ret.spaly.ar.var.power <- retro(fit.spaly.ar.var.power, year = 18)
ret.spaly.ar.var.power.dm <- retro(fit.spaly.ar.var.power.dm, year = 18)
ret.spaly.ar.var.power.dm0 <- retro(fit.spaly.ar.var.power.dm0, year = 18)
```

```
rbya <- sam_rbya(fit.spaly, 1000)
rbya %>%
  dplyr::select(year, age, oC, oU1) %>%
  gather(var, val, -c(year, age)) %>%
  mutate(yc = factor(year - age)) %>%
  group_by(var, age) %>%
  mutate(val = val / mean(val[year %in% c(1983:2021)], na.rm = TRUE)) %>%
  ggplot() +
  theme_bw() +
  geom_col(aes(year, val, fill = yc)) +
  facet_grid(age ~ var, scales = "free_y") +
  ggmisc::scale_fill_crayola() +
  theme(legend.position = "none") +
  scale_y_continuous(NULL, NULL) +
  labs(x = NULL, title = "Observations")
```



Following are some sam exploration on the egcod data. **Only the german survey is used**, mostly in the interest of generating a reasonably long retrospective analysis into the period when the 2003 year class was entering the survey and the fisheries. Words are here few, code, tables and figures hopefully speaking for them selves. The runs are:

- **spaly**: The last interbenchmark setting
- **spaly.ar**: spaly setup adding year factor
- **spaly.ar.var**: spaly.ar adding adding decoupling of variance estimates by age, probably an overkill for non-recruiting ages.
- **spaly.ar.var.power**: spaly.ar.var adding power on stock in number vs survey indices for recruiting ages (1 to 5).
- **spaly.ar.var.power.dm**: spaly.ar.var.power with M=0.2 for all ages in the last 5 years
- **spaly.ar.var.power.dmo**: spaly.ar.var.power with M=0.0 for ages 5+ in the last 5 years - for fun
- **dm**: spaly with M=0.2 for all ages in the last 5 years - this is the WD01 proposal

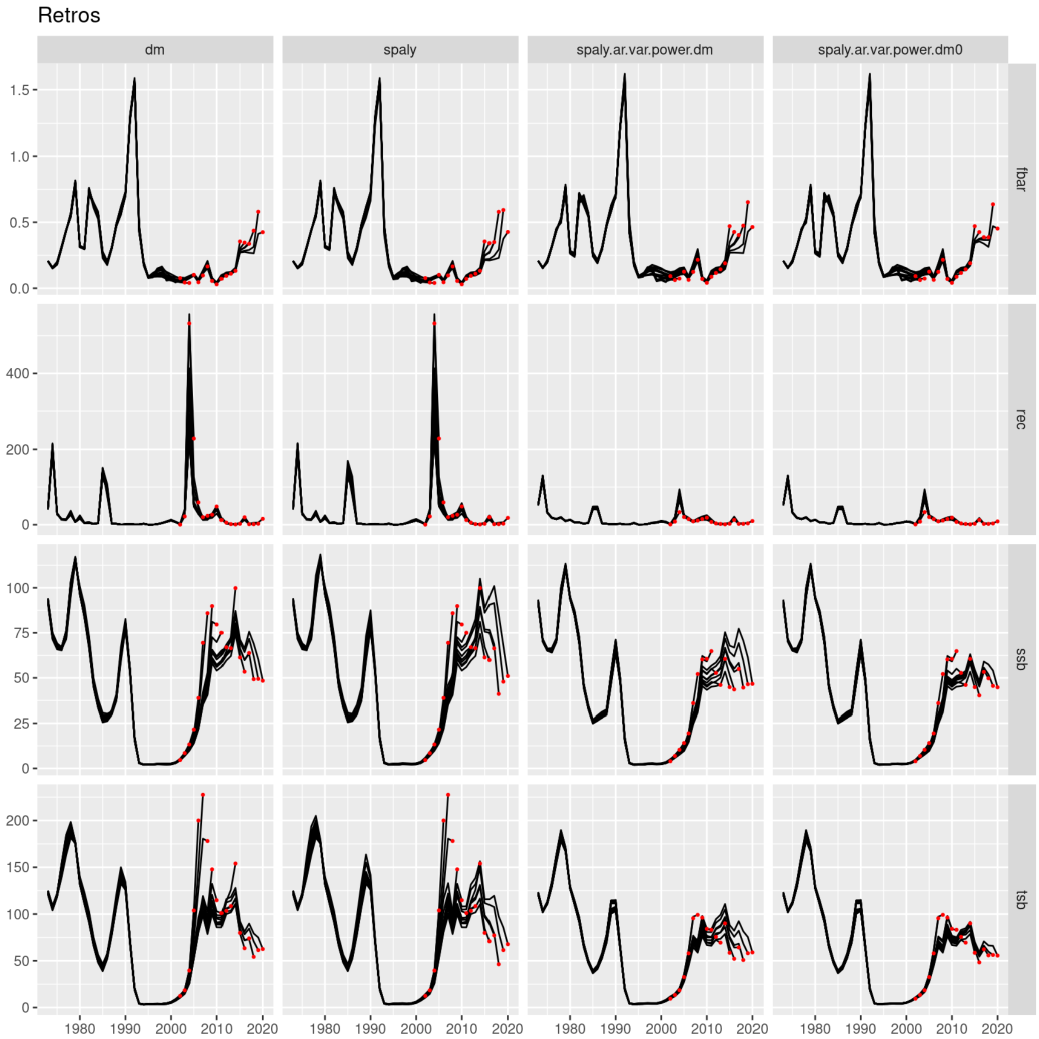
```
modeltable(c(spaly = fit.spaly,
             spaly.ar = fit.spaly.ar,
             spaly.ar.var = fit.spaly.ar.var,
             spaly.ar.var.power = fit.spaly.ar.var.power,
             spaly.ar.var.powerdm = fit.spaly.ar.var.power.dm,
             spaly.ar.var.powerdm0 = fit.spaly.ar.var.power.dm0,
             dm = fit.dm)) %>%
  knitr::kable(caption = "Key summary stat")
```

Key summary stat

	log(L)	#par	AIC
spaly	-894.3145	14	1816.629
spaly.ar	-853.7446	15	1737.489
spaly.ar.var	-803.3566	21	1648.713
spaly.ar.var.power	-787.4408	26	1626.882
spaly.ar.var.powerdm	-779.6225	26	1611.245
spaly.ar.var.powerdm0	-775.7603	26	1603.521
dm	-885.7692	14	1799.538

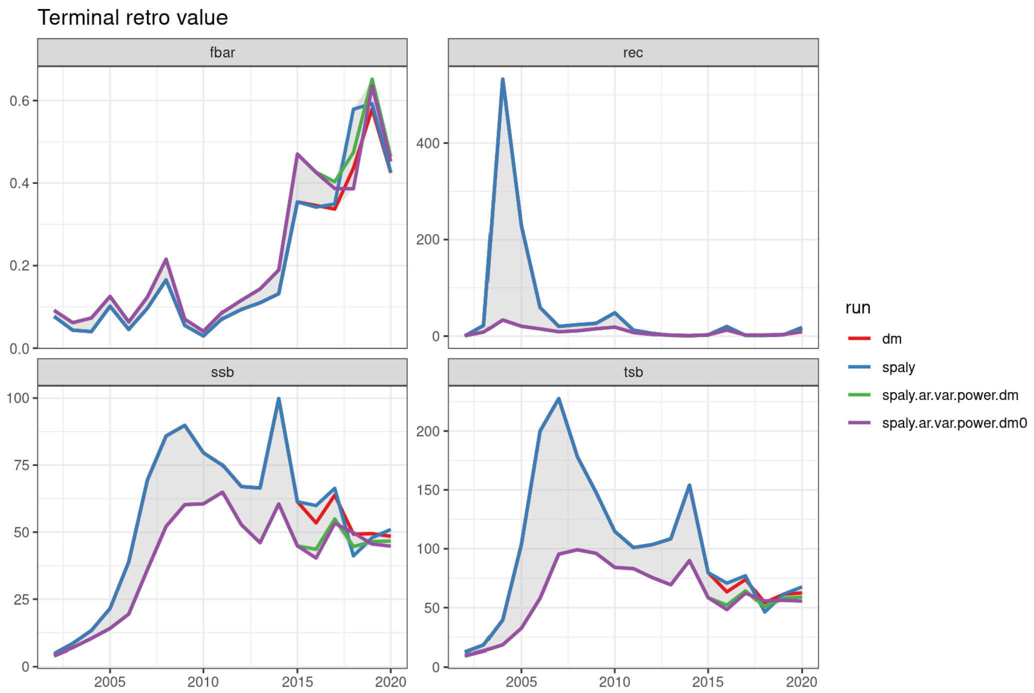
```
lh <- function(retro, ass) {
  retro <-
    map({{retro}}, fishvice::sam_rby, 1000) %>%
    bind_rows(.id = "peel")
  ass <-
    sam_rby( {{ass}}, 1000) %>%
    mutate(peel = "0")
  bind_rows(ass, retro)
}
d <-
  bind_rows(lh(ret.spaly, fit.spaly) %>% mutate(run = "spaly"),
            lh(ret.spaly.ar.var.power.dm, fit.spaly.ar.var.power.dm) %>% mutate(run = "spaly.a
r.var.power.dm"),
            lh(ret.spaly.ar.var.power.dm0, fit.spaly.ar.var.power.dm0) %>% mutate(run = "spaly
.ar.var.power.dm0"),
            lh(ret.dm, fit.dm) %>% mutate(run = "dm")) %>%
  group_by(run, peel) %>%
  mutate(assyear = max(year)) %>%
  ungroup()
d2 <-
  d %>%
  filter(assyear == 2020) %>%
  select(year, estterm = est, variable, run) %>%
  full_join(d) %>%
  mutate(r = est / estterm) %>%
  filter(variable != "catch")
```

```
d2 %>%
  mutate(peel = paste(run, peel)) %>%
  ggplot(aes(year, est, group = peel)) +
  geom_line() +
  geom_point(data = d2 %>% filter(year == assyear),
             colour = "red",
             size = 0.5) +
  facet_grid(variable ~ run, scale = "free_y") +
  scale_colour_brewer(palette = "Set1") +
  labs(x = NULL, y = NULL, title = "Retros")
```

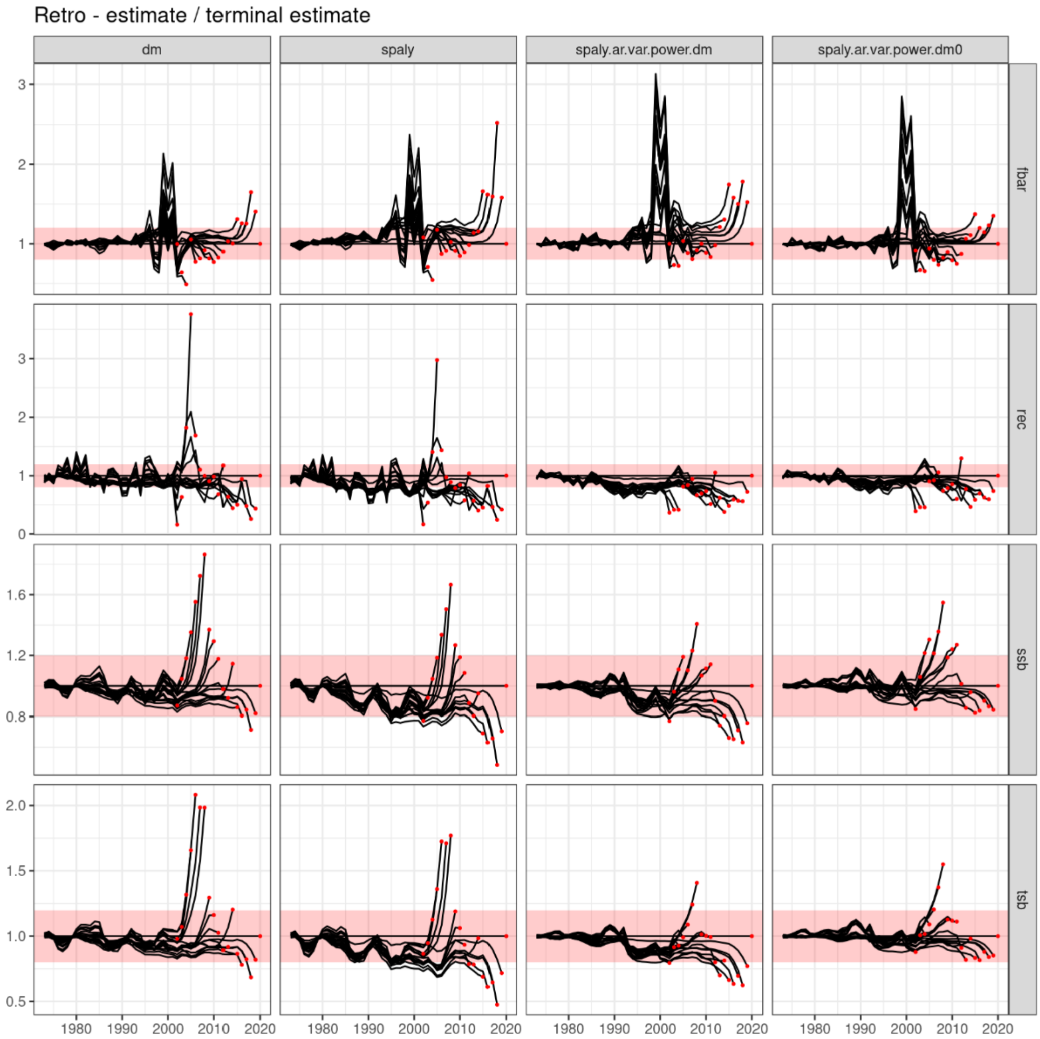



```
d %>%
  filter(year == assyear,
         variable != "catch") %>%
  group_by(year, variable) %>%
  mutate(ymin = min(est), ymax = max(est)) %>%
  ggplot() +
  theme_bw() +
  geom_ribbon(aes(year, ymin = ymin, ymax = ymax),
              fill = "grey", alpha = 0.4) +
  geom_line(data = d %>%
```

```
            filter(year == assyear,
                   variable != "catch"),
          aes(year, est, colour = run),
          lwd = 1) +
  facet_wrap(~ variable, scales = "free_y") +
  scale_colour_brewer(palette = "Set1") +
  labs(x = NULL, y = NULL, title = "Terminal retro value")
```

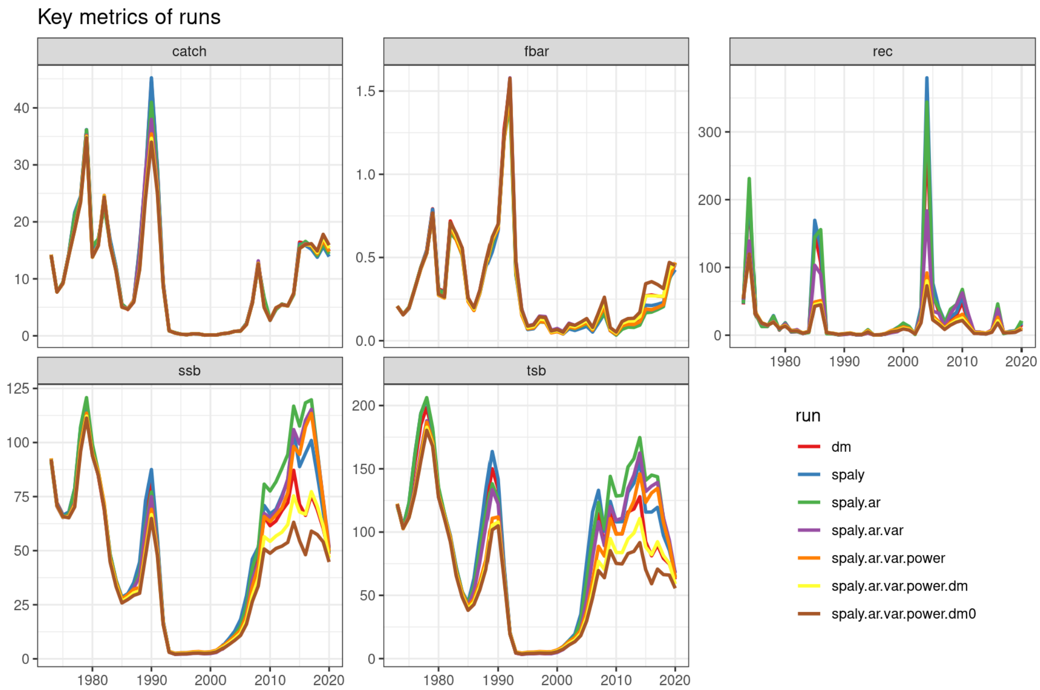



```
d2 %>%
  mutate(peel = paste(run, peel)) %>%
  ggplot(aes(year, r, group = peel)) +
  theme_bw() +
  annotate("rect", xmin = -Inf, xmax = Inf, ymin = 0.8, ymax = 1.2,
           fill = "red", alpha = 0.2) +
  geom_line() +
  geom_point(data = d2 %>% filter(year == assyear),
             colour = "red",
             size = 0.5) +
  facet_grid(variable ~ run, scale = "free_y") +
  scale_colour_brewer(palette = "Set1") +
  labs(x = NULL, y = NULL, title = "Retro - estimate / terminal estimate")
```

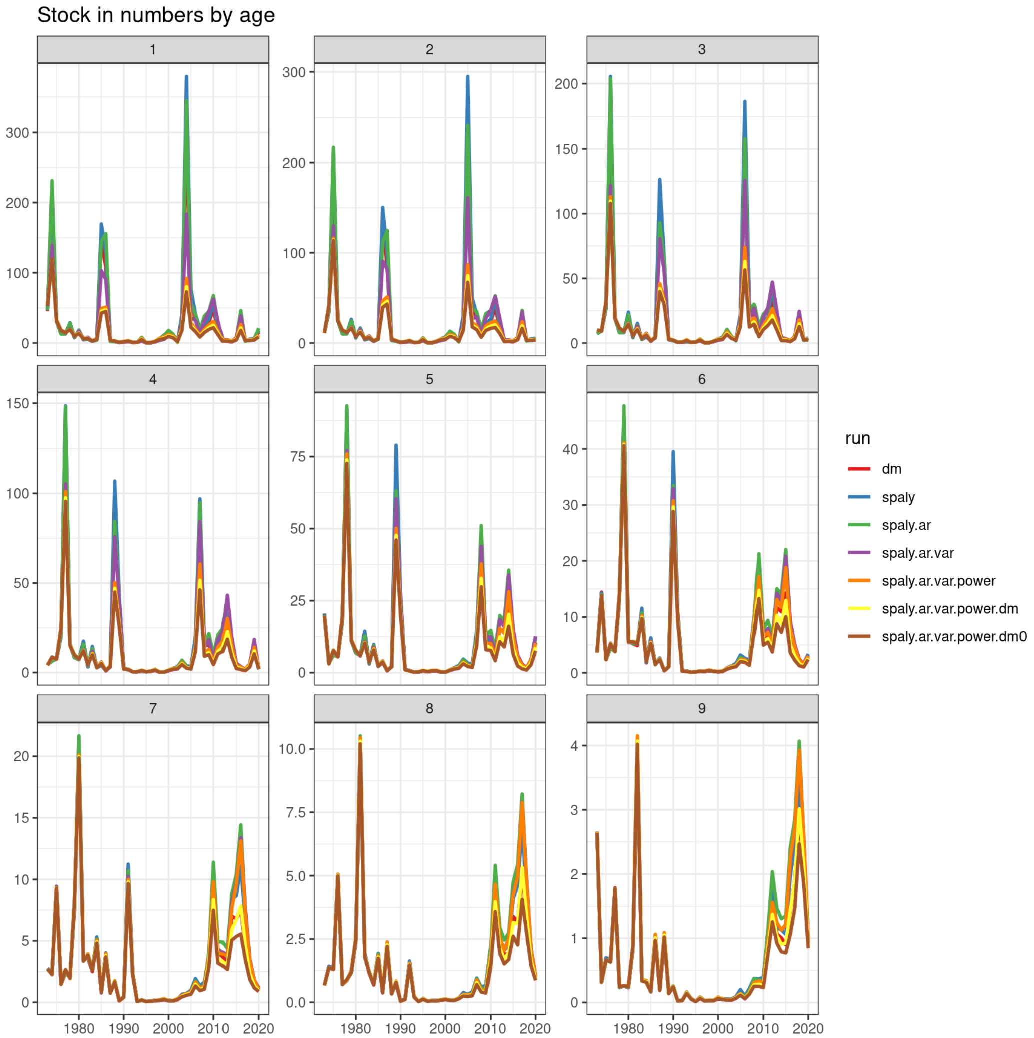



```
bind_rows(sam_rby(fit.spaly, 1000) %>% mutate(run = "spaly"),
          sam_rby(fit.spaly.ar, 1000) %>% mutate(run = "spaly.ar"),
          sam_rby(fit.spaly.ar.var, 1000) %>% mutate(run = "spaly.ar.var"),
          sam_rby(fit.spaly.ar.var.power, 1000) %>% mutate(run = "spaly.ar.var.power"),
          sam_rby(fit.spaly.ar.var.power.dm, 1000) %>% mutate(run = "spaly.ar.var.power.dm"),
          sam_rby(fit.spaly.ar.var.power.dm0, 1000) %>% mutate(run = "spaly.ar.var.power.dm0")
,
          sam_rby(fit.dm, 1000) %>% mutate(run = "dm")) %>%
  ggplot(aes(year, est, colour = run)) +
  theme_bw() +
```

```
  geom_line(lwd = 1) +
  facet_wrap(~ variable, scales = "free_y") +
  scale_color_brewer(palette = "Set1") +
  labs(x = NULL, y = NULL, title = "Key metrics of runs") +
  theme(legend.position = c(0.85, 0.25))
```

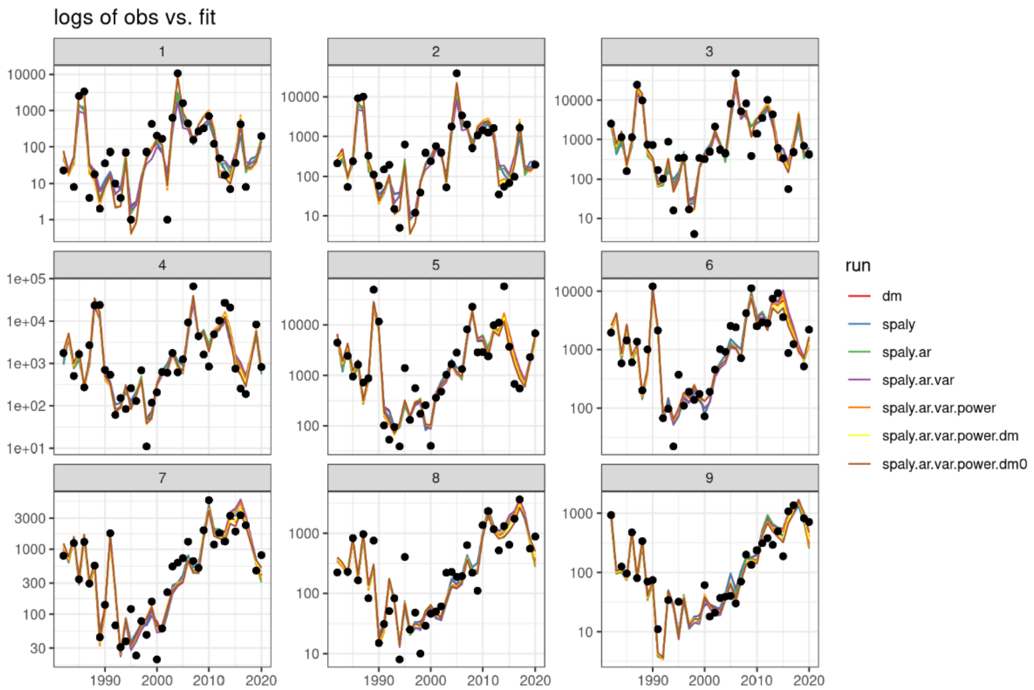



```
bind_rows(sam_rbya(fit.spaly, 1000) %>% mutate(run = "spaly"),
          sam_rbya(fit.spaly.ar, 1000) %>% mutate(run = "spaly.ar"),
          sam_rbya(fit.spaly.ar.var, 1000) %>% mutate(run = "spaly.ar.var"),
          sam_rbya(fit.spaly.ar.var.power, 1000) %>% mutate(run = "spaly.ar.var.power"),
          sam_rbya(fit.spaly.ar.var.power.dm, 1000) %>% mutate(run = "spaly.ar.var.power.dm"),
          sam_rbya(fit.spaly.ar.var.power.dm0, 1000) %>% mutate(run = "spaly.ar.var.power.dm0"
),
          sam_rbya(fit.dm, 1000) %>% mutate(run = "dm")) %>%
  filter(age %in% 1:9) %>%
  ggplot(aes(year, n / 1e3, colour = run)) +
  theme_bw() +
  geom_line(lwd = 1) +
  facet_wrap(~ age, scales = "free_y") +
  scale_color_brewer(palette = "Set1") +
  labs(x = NULL, y = NULL, title = "Stock in numbers by age")
```

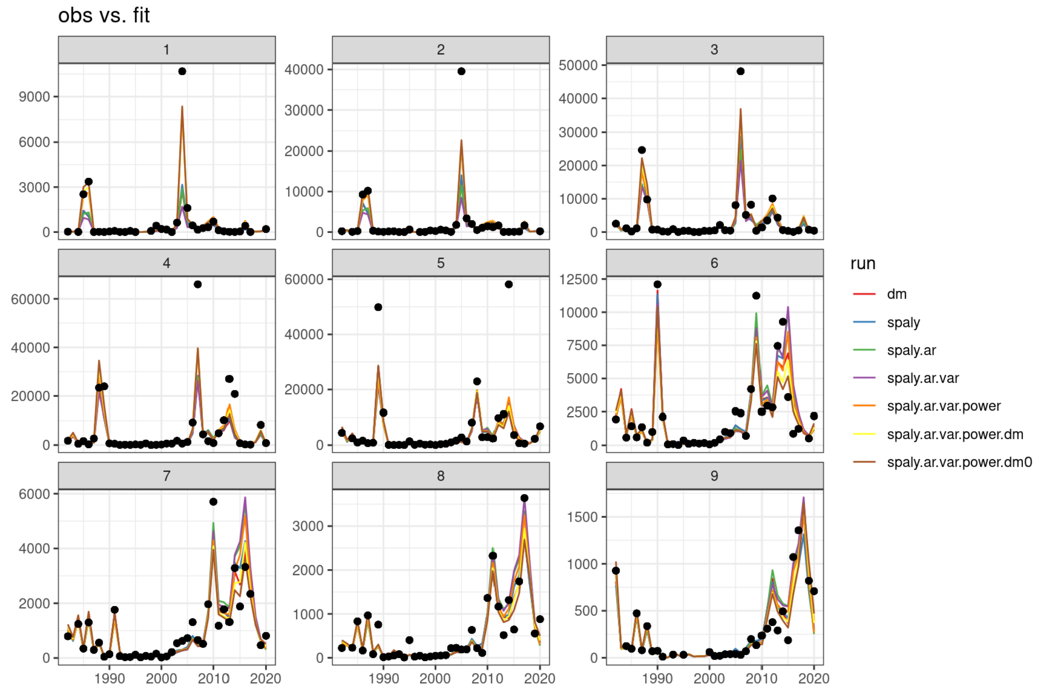



```
d <-
  bind_rows(sam_rbx(fit.spaly, 1000)$opr %>% mutate(run = "spaly"),
            sam_rbx(fit.spaly.ar, 1000)$opr %>% mutate(run = "spaly.ar"),
            sam_rbx(fit.spaly.ar.var, 1000)$opr %>% mutate(run = "spaly.ar.var"),
            sam_rbx(fit.spaly.ar.var.power, 1000)$opr %>% mutate(run = "spaly.ar.var.power"),
            sam_rbx(fit.spaly.ar.var.power.dm, 1000)$opr %>% mutate(run = "spaly.ar.var.power.
dm"),
            sam_rbx(fit.spaly.ar.var.power.dm0, 1000)$opr %>% mutate(run = "spaly.ar.var.power
.dm0"),
            sam_rbx(fit.dm, 1000)$opr %>% mutate(run = "dm")) %>%
```

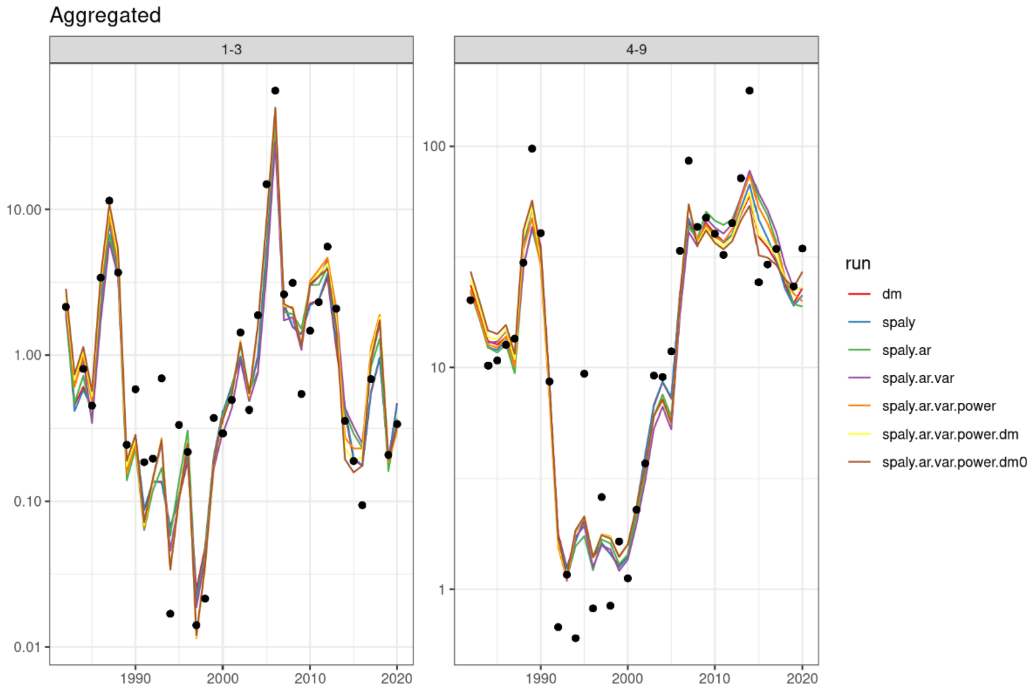
```
  filter(fleet == "WHoest(XIVb+1F)") %>%
  left_join(sam_rbya(fit.spaly) %>% select(year, age, cW)) %>%
  mutate(recruits = ifelse(age %in% 1:3, "1-3", "4-9"))
p <-
  d %>%
  ggplot(aes(year)) +
  theme_bw() +
  geom_line(aes(y = exp(p), colour = run)) +
  geom_point(aes(y = exp(o))) +
  facet_wrap(~ age, scales = "free_y") +
  scale_colour_brewer(palette = "Set1") +
  labs(x = NULL, y = NULL)
p + labs(title = "logs of obs vs. fit") + scale_y_log10()
```



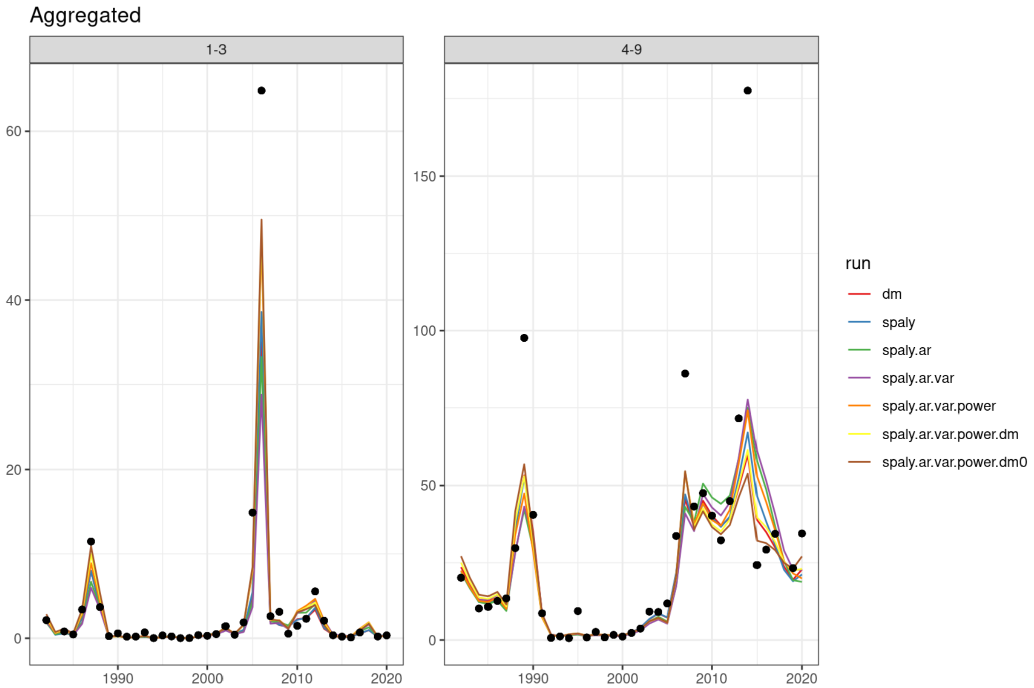

```
p + labs(title = "obs vs. fit")
```



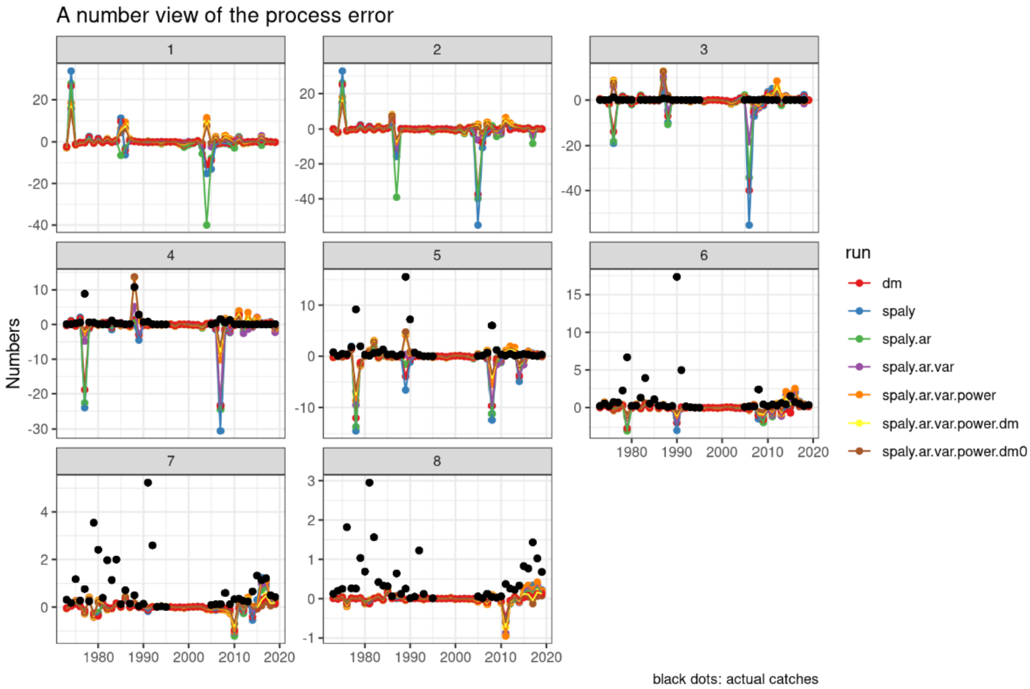

```
p <-
  d %>%
  group_by(year, run, recruits) %>%
  summarise(o = sum(exp(o) * cW / 1e3, na.rm = TRUE),
            p = sum(exp(p) * cW / 1e3, na.rm = TRUE),
            .groups = "drop") %>%
  mutate(o = ifelse(o == 0, NA, o)) %>%
  ggplot() +
  theme_bw() +
  geom_line(aes(year, p, colour = run)) +
  geom_point(aes(year, o)) +
  scale_colour_brewer(palette = "Set1") +
  facet_wrap(~ recruits, scales = "free_y") +
  labs(x = NULL, y = NULL)
p + labs(title = "Aggregated") + scale_y_log10()
```




```
p + labs(title = "Aggregated")
```




```
bind_rows(sam_process_error(sam_rbya(fit.spaly), TRUE, TRUE)$rbya %>% mutate(run = "spaly"),
          sam_process_error(sam_rbya(fit.spaly.ar), TRUE, TRUE)$rbya %>% mutate(run = "spaly.a
r"),
          sam_process_error(sam_rbya(fit.spaly.ar.var), TRUE, TRUE)$rbya %>% mutate(run = "spa
ly.ar.var"),
          sam_process_error(sam_rbya(fit.spaly.ar.var.power), TRUE, TRUE)$rbya %>% mutate(run
= "spaly.ar.var.power"),
          sam_process_error(sam_rbya(fit.spaly.ar.var.power.dm), TRUE, TRUE)$rbya %>% mutate(r
un = "spaly.ar.var.power.dm"),
          sam_process_error(sam_rbya(fit.spaly.ar.var.power.dm0), TRUE, TRUE)$rbya %>% mutate(
run = "spaly.ar.var.power.dm0"),
          sam_process_error(sam_rbya(fit.dm), TRUE, TRUE)$rbya %>% mutate(run = "dm")) %>%
  ggplot() +
  theme_bw() +
  geom_point(aes(year, n.d / 1e3, colour = run)) +
  geom_line(aes(year, n.d / 1e3, colour = run)) +
  geom_point(aes(year, oC / 1e3)) +
  facet_wrap(~ age, scale = "free_y") +
  scale_color_brewer(palette = "Set1") +
  labs(x = NULL, y = "Numbers", title = "A number view of the process error",
       caption = "black dots: actual catches")
```


A number view of the process error
1
2
3
4
5
6
7
8
Numbers
run
dm
spaly
spaly.ar
spaly.ar.var
spaly.ar.var.power
spaly.ar.var.power.dm
spaly.ar.var.power.dm0
black dots: actual catches