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Applying a stochastic surplus production model (SPiCT) to the Greenland halibut stock in the Upernavik area

by

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Summary

A stochastic surplus production model (SPiCT) was applied to the Greenland halibut stock in the fjords in the Upernavik area located in West Greenland. Input data used were the RV Sanna gillnet survey index, catches, and two commercial CPUE indices. Sensitivity analyses were conducted using fixation of critical model parameters, use of parameter priors, and changing time periods for the input data. Based on several diagnostic variables the model where the shape parameter (n) is essentially fixed to 2 (Schaefer) and a prior on r being close to 0.25 was identified as the most promising model setup for the use of SPiCT in the future assessment of the stock. This selected model run provided stable results, acceptable model diagnostics, and acceptable retrospective patterns. According to these results, biomass is slightly above B_{MSY}, though F is also above F_{MSY}.

Introduction

The SPiCT model is a stochastic surplus production model in continuous time (Pedersen & Berg, 2017). Previously no analytical assessment of the stock of Greenland halibut in the fjords near Upernavik has been performed and the assessment was based on qualitative evaluation of fishery and survey data. The SPiCT model was applied to evaluate its potential as assessment model.

The model assumptions are:

1. The intrinsic growth rate represents a combination of natural mortality, growth, and recruitment.
2. The biomass refers to the exploitable part of the stock.
3. The stock is closed to migration.
4. Age and size-distribution are stable in time.
5. Constant catchability of the gear used to gather information for the biomass index.

No migration is assumed in the model, even though it would be more realistic to assume that at least some migration is occurring. However, tagging experiments indicate that migration is most common in smaller fish, which are not modelled with SPiCT, and the overall recapture rate (as a proxy of migration) between different stocks is low (Vihtakari et al. 2022).

Materials and methods

Catch and commercial CPUE data are available in SCR 24/027 (Nygaard et al. 2024a) and research survey data are reported in SCR 24/028 (Nygaard et al. 2024b) (Fig. 1). Unreliable early estimates were excluded from each time series. The applied time series for catches was 35 years long, while the time series for the survey index was 9 years, the CPUE from longline logbook data was 18 years, and the CPUE from factory landings was 12 years long (Fig. 1). Several model configuration runs (including shorter catch time series) were tested and evaluated before converging on a near-optimal configuration. For the latter, the prior for the shape of the production curve (n) was set at log(2, 0.001), meaning it was essentially fixed and the prior for r was set at log(0.25, 0,25), which translated into an r prior similar to other Greenland halibut stocks allowing for some variance.

Results and Discussion

Results from comparative model runs with configuration variations are compiled in Table 1. In general, when using the long catch time series (35 years) it was necessary to fix n to 2 (which is equivalent to the Schaefer production curve) for the model to converge. In addition, most reliable results are obtained when r is essentially fixed to 0.25, which is a realistic assumption as it is also the suggested r value in FishBase for the species, based on 10 stock assessments. Recent Greenland halibut stock assessments in NAFO Subarea 0+1 use r = 0.26 and in East Greenland r = 0.16 (Nogueira et al. 2024, ICES, 2024). However there seems to be little difference in the model whether fixing r to 0.25 or allowing for some variability in r. The selected model run (run 14 highlighted in green in Table 1) has a slightly higher AIC than some other runs, such as for example similar configurations albeit with shorter catch time series. The latter, however, were not robust to initial parameter estimates and/or to ACF lag 1 process error estimation. In addition, the selected model run provides biomass estimates that are much closer to earlier perceptions of the stock and are therefore deemed more realistic.

The main results from the selected SPiCT model run are presented in Table 2 and Fig. 2. Diagnostics of model residuals were generally acceptable (Fig. 3). One-step-ahead (OSA) residuals were not different from zero, as were the autocorrelation tests and Shapiro tests ($p > 0.05$ for all). Correlation between model parameters were low for many, but relatively high for some parameters, which, to some extent, is expected and was considered acceptable here. Retrospective analyses of fishable biomass and fishing mortality all lay within confidence limits and Mohn's rho are clearly < 0.20 and therefore within acceptable limits (-0.025 for B/B_{MSY} and 0.072 for F/F_{MSY}) (Fig. 4).

In conclusion, the selected model run is suggested to be used for stock assessment of Greenland halibut in the Upernavik area.

References

Pedersen, M. W., & Berg, C. W. (2017). A stochastic surplus production model in continuous time. Fish and Fisheries, 18(2), 226-243.

Vihtakari, M., Elvarsson, B. Þ., Treble, M., Nogueira, A., Hedges, K., Hussey, N. E., ... & Boje, J. (2022). Migration patterns of Greenland halibut in the North Atlantic revealed by a compiled mark–recapture dataset. ICES Journal of Marine Science, 79(6), 1902-1917.

Riget, F. and J. Boje (1989). Fishery and some biological aspects of Greenland halibut (*Reinhardtius hippoglossoides*) in West Greenland waters. NAFO Sci.Council Studies(13): 41-52.

Riget and Nygaard (2017). An analyses of logbooks of Greenland Halibut Stock Component in NAFO Division 1A Inshore. NAFO SCR 18/023. Serial No N

Bjare and Nygaard (2022). A new longline based CPUE for Greenland halibut in NAFO division 1A inshore based on factory landing reports. NAFO SCR 12/024. Serial No N

Table1. Comparison of several SPiCT model configuration runs for Greenland halibut in the Upernavik area.

	Model spec.				Convergence
Run	Name	Input	Fixed parameters	Priors	
run1	basic	Catch, Survey, CPUE1, CPUE2	-	default	no
run2	only survey	Catch, Survey	-	default	no
run3	only CPUE1	Catch, CPUE1	-	default	no
run4	only CPUE2	Catch, CPUE2	-	default	no
run5	fixed n	Catch, Survey, CPUE1, CPUE2	n = 2	default	yes
run6	prior n	Catch, Survey, CPUE1, CPUE2	-	logn = log(2), 0.25	yes
run7	prior n + r	Catch, Survey, CPUE1, CPUE2	-	logn = log(2), 0.25; logr = log(0.5), 0.25	no
run8	prior n + r	Catch, Survey, CPUE1, CPUE2	-	logn = log(2), 0.25; logr = log(0.5), 0.001	no
run9	prior n + r	Catch, Survey, CPUE1, CPUE2	-	logn = log(2), 0.001; logr = log(0.5), 0.001	yes
run14	prior n + r	Catch, Survey, CPUE1, CPUE2	-	logn = log(2), 0.001; logr = log(0.25), 0.25	yes
run10	prior n + r	Catch, Survey, CPUE1, CPUE2	-	logn = log(2), 0.001; logr = log(0.25), 0.001	yes
run11	catch truncated to 200	Catch, Survey, CPUE1, CPUE2	-	default	yes
run12	catch truncated to 200	Catch, Survey, CPUE1, CPUE2	-	logn = log(2), 0.001	yes
run13	catch truncated to 200	Catch, Survey, CPUE1, CPUE2	-	logn = log(2), 0.001; logr = log(0.25), 0.001	yes

	Diagnostic problems			Corm	Cor BMSY	Mohn's rho B	Mohn's rho F	Robustness to initial	ACF lag 1 process	n	r	sdc	AIC
Run	OSA	ACF	Quantile										
run1													
run2													17.58
run3													-9.45
run4													-1.96
run5	no	no	no	0.36	-0.92	-0.04	0.06	no		0.40	2.00	0.65	0.09	-18.41
run6	no	no	no	0.07	-0.98	-	-	no		0.44	2.19	0.77	0.09	-20.66
run7														-37.62
run8														
run9	no	no	no	1.00	0.01	-0.03	0.07	no		0.35	2.00	0.50	0.09	-42.59
run14	no	no	no	0.47	-0.78	-0.03	0.09	yes		0.34	2.00	0.33	0.08	-26.86
run10	no	no	no	1.00	-0.14	-0.02	0.07	yes		0.32	2.00	0.25	0.08	-36.74
run11	no	no	no	0.02	-0.99	0.01	0.02	no	problems		1.50	4.03	0.06	-34.66
run12	no	no	no	0.17	-0.92	0.01	0.03	no	problems		2.00	4.59	0.06	-49.74
run13	no	no	no	1.00	-0.26	0.05	-0.14	yes	problems		2.00	0.25	0.07	-48.38

	Comments	Relative reference points							
Run		BMSY (det.)	FMSY (det.)	B/BMSY	low	high	F/FMSY	low	high
run1	could not fit model								
run2									
run3									
run4									
run5		22492.94	0.33	1.08	0.85	1.38	0.92	0.57	1.48
run6	could not fit retro	20830.06	0.35	1.06	0.81	1.39	0.94	0.59	1.50
run7									
run8	could not fit model								
run9		29011.46	0.25	1.08	0.82	1.43	0.94	0.55	1.59
run14		42004.05	0.17	1.05	0.74	1.50	1.00	0.51	1.97
run10		53325.95	0.13	1.02	0.68	1.54	1.08	0.51	2.32
run11		3065.43	2.68	1.24	0.71	2.14	0.75	0.37	1.54
run12		3493.28	2.29	1.19	0.34	4.23	0.79	0.20	3.10
run13		63133.24	0.13	1.39	1.02	1.87	0.68	0.30	1.55

Table 2. Main results from the selected SPiCT model run for Greenland halibut in the Upernavik area.

Convergence: 0 MSG: relative convergence (4)
Convergence: 0 MSG: relative convergence (4)
Objective function at optimum: -25.4302839
Euler time step (years): 1/16 or 0.0625
Nobs C: 35, Nobs I1: 9, Nobs I2: 18, Nobs I3: 12

Priors
logn ~ dnorm[log(2), 0.001^2] (fixed)
logalpha ~ dnorm[log(1), 2^2]
logbeta ~ dnorm[log(1), 2^2]
logr ~ dnorm[log(0.25), 0.25^2]

Model parameter estimates w 95% CI

	estimate	cilow	ciupp	log.est
alpha1	3.574549e+00	1.237240e+00	1.032734e+01	1.2738391
alpha2	1.278895e+00	3.434210e-01	4.762588e+00	0.2459965
alpha3	4.433417e-01	3.611490e-02	5.442401e+00	-0.8134145
beta	4.420649e-01	1.604035e-01	1.218311e+00	-0.8162986
r	3.318907e-01	2.018912e-01	5.455980e-01	-1.1029495
rc	3.318920e-01	2.018912e-01	5.456024e-01	-1.1029456
rold	3.318933e-01	2.018896e-01	5.456110e-01	-1.1029418
m	6.970404e+03	4.904592e+03	9.906336e+03	8.8494285
K	8.400822e+04	4.825311e+04	1.462575e+05	11.3386700
q1	3.567000e-04	1.725000e-04	7.374000e-04	-7.9386889
q2	9.139000e-04	4.524000e-04	1.846200e-03	-6.9977471
q3	9.732000e-04	4.797000e-04	1.974500e-03	-6.9348873
n	1.999992e+00	1.996076e+00	2.003916e+00	0.6931433
sdb	7.049130e-02	2.550140e-02	1.948525e-01	-2.6522667
sdf	1.904192e-01	1.166063e-01	3.109563e-01	-1.6585274
sdi1	2.519745e-01	1.591066e-01	3.990477e-01	-1.3784275
sdi2	9.015090e-02	5.669880e-02	1.433398e-01	-2.4062702
sdi3	3.125170e-02	6.043200e-03	1.616149e-01	-3.4656812
sdc	8.417760e-02	4.293680e-02	1.650304e-01	-2.4748260

Deterministic reference points (Drp)

	estimate	cilow	ciupp	log.est
Bmsyd	42004.048770	2.412647e+04	7.312881e+04	10.645521
Fmsyd	0.165946	1.009456e-01	2.728012e-01	-1.796093
MSYd	6970.403991	4.904592e+03	9.906336e+03	8.849429

Stochastic reference points (Srp)

	estimate	cilow	ciupp	log.est	rel.diff.Drp
Bmsys	4.163014e+04	2.404402e+04	7.207896e+04	10.636580	-0.008981781
Fmsys	1.647139e-01	9.967830e-02	2.721824e-01	-1.803545	-0.007480259
MSYs	6.856603e+03	4.833402e+03	9.726688e+03	8.832967	-0.016597352

States w 95% CI (inp$msytype: s)

	estimate	cilow	ciupp	log.est
B_2023.94	4.390815e+04	2.095428e+04	9.200628e+04	10.6898551
F_2023.94	1.650159e-01	7.648620e-02	3.560153e-01	-1.8017134
B_2023.94/Bmsy	1.054720e+00	7.424955e-01	1.498238e+00	0.0532755
F_2023.94/Fmsy	1.001833e+00	5.099812e-01	1.968053e+00	0.0018316

Predictions w 95% CI (inp$msytype: s)

```
                  prediction       cilow       ciupp   log.est
B_2025.00       4.352111e+04 1.978569e+04 9.573014e+04 10.6810014
F_2025.00       1.650161e-01 6.984280e-02 3.898801e-01 -1.8017123
B_2025.00/Bmsy 1.045423e+00 6.935366e-01 1.575850e+00  0.0444218
F_2025.00/Fmsy 1.001834e+00 4.605741e-01 2.179176e+00  0.0018328
Catch_2024.00  7.212524e+03 5.153666e+03 1.009388e+04  8.8835742
E(B_inf)       4.065984e+04          NA          NA 10.6129961
```

Table 2. Correlation matrix of model parameters from the selected SPiCT model run for Greenland halibut in the Upernavik area.

	logm	logK	logq	logq	logq	logn
logm	1	0.471765	-0.64905	-0.66318	-0.66642	-5.38E-04
logK	0.471765	1	-0.88797	-0.91356	-0.91209	1.96E-03
logq	-0.64905	-0.88797	1	0.971475	0.973567	-1.89E-03
logq	-0.66318	-0.91356	0.971475	1	0.997258	-1.95E-03
logq	-0.66642	-0.91209	0.973567	0.997258	1	-1.94E-03
logn	-0.00054	0.001957	-0.00189	-0.00195	-0.00194	1.00E+00
logsdb	0.146616	0.161746	-0.09087	-0.09667	-0.09901	2.12E-04
logsdf	-0.13809	0.012712	0.008029	0.007135	0.00969	4.10E-04
logsdi	0.023786	0.022075	-0.01342	-0.01419	-0.01452	2.06E-05
logsdi	-0.05903	-0.07383	0.022557	0.024298	0.02625	-1.07E-04
logsdi	-0.02427	-0.06148	-0.01004	-0.00463	-0.00422	-1.22E-04
logsdc	0.059392	-0.05056	0.0151	0.017355	0.016174	-3.59E-04
	logsdb	logsdf	logsdi	logsdi	logsdi	logsdc
logm	0.146616	-0.13809	2.38E-02	-0.05903	-0.02427	0.059392
logK	0.161746	0.012712	2.21E-02	-0.07383	-0.06148	-0.05056
logq	-0.09087	0.008029	-1.34E-02	0.022557	-0.01004	0.0151
logq	-0.09667	0.007135	-1.42E-02	0.024298	-0.00463	0.017355
logq	-0.09901	0.00969	-1.45E-02	0.02625	-0.00422	0.016174
logn	0.000212	0.00041	2.06E-05	-0.00011	-0.00012	-0.00036
logsdb	1	-0.29384	1.28E-01	-0.50885	-0.76452	-0.0694
logsdf	-0.29384	1	-3.42E-02	0.118322	0.202832	-0.50583
logsdi	0.127858	-0.03417	1.00E+00	-0.09427	-0.10237	-0.01396
logsdi	-0.50885	0.118322	-9.43E-02	1	0.425248	0.063499
logsdi	-0.76452	0.202832	-1.02E-01	0.425248	1	0.078431
logsdc	-0.0694	-0.50583	-1.40E-02	0.063499	0.078431	1

```
> cov2cor(get.cov(res,'logBmsy','logFmsy'))
       [,1]       [,2]
[1,]  1.0000000 -0.7822266
[2,] -0.7822266  1.0000000
```

Table 3. Sensitivity analysis to investigate the influence of initial values on parameter estimates from the selected SPiCT model run for Greenland halibut in the Upernavik area. Twenty trials were run, and the distance from the estimated parameter vector to the base run parameter vector is shown (low distance indicates high robustness). All trial runs converged successfully.

	Distance	m	K	q	q	q	n	sdb	sdf	sdi	sdi	sdi	sdc
Basevec	0.00	6970.40	84008.22	0	0	0	2	0.07	0.19	0.25	0.09	0.03	0.08
Trial 1	0.02	6970.40	84008.20	0	0	0	2	0.07	0.19	0.25	0.09	0.03	0.08
Trial 2	0.01	6970.40	84008.21	0	0	0	2	0.07	0.19	0.25	0.09	0.03	0.08
Trial 3	0.04	6970.40	84008.18	0	0	0	2	0.07	0.19	0.25	0.09	0.03	0.08
Trial 4	0.06	6970.40	84008.16	0	0	0	2	0.07	0.19	0.25	0.09	0.03	0.08
Trial 5	0.01	6970.40	84008.24	0	0	0	2	0.07	0.19	0.25	0.09	0.03	0.08
Trial 6	0.01	6970.40	84008.21	0	0	0	2	0.07	0.19	0.25	0.09	0.03	0.08
Trial 7	0.03	6970.41	84008.26	0	0	0	2	0.07	0.19	0.25	0.09	0.03	0.08
Trial 8	0.07	6970.40	84008.16	0	0	0	2	0.07	0.19	0.25	0.09	0.03	0.08
Trial 9	0.01	6970.40	84008.23	0	0	0	2	0.07	0.19	0.25	0.09	0.03	0.08
Trial 10	0.04	6970.41	84008.18	0	0	0	2	0.07	0.19	0.25	0.09	0.03	0.08
Trial 11	0.44	6970.44	84008.66	0	0	0	2	0.07	0.19	0.25	0.09	0.03	0.08
Trial 12	0.01	6970.40	84008.23	0	0	0	2	0.07	0.19	0.25	0.09	0.03	0.08
Trial 13	0.44	6970.41	84007.78	0	0	0	2	0.07	0.19	0.25	0.09	0.03	0.08
Trial 14	0.02	6970.40	84008.21	0	0	0	2	0.07	0.19	0.25	0.09	0.03	0.08
Trial 15	0.01	6970.40	84008.24	0	0	0	2	0.07	0.19	0.25	0.09	0.03	0.08
Trial 16	0.03	6970.41	84008.20	0	0	0	2	0.07	0.19	0.25	0.09	0.03	0.08
Trial 17	0.01	6970.40	84008.21	0	0	0	2	0.07	0.19	0.25	0.09	0.03	0.08
Trial 18	0.01	6970.40	84008.21	0	0	0	2	0.07	0.19	0.25	0.09	0.03	0.08
Trial 19	0.10	6970.40	84008.32	0	0	0	2	0.07	0.19	0.25	0.09	0.03	0.08
Trial 20	0.03	6970.41	84008.26	0	0	0	2	0.07	0.19	0.25	0.09	0.03	0.08

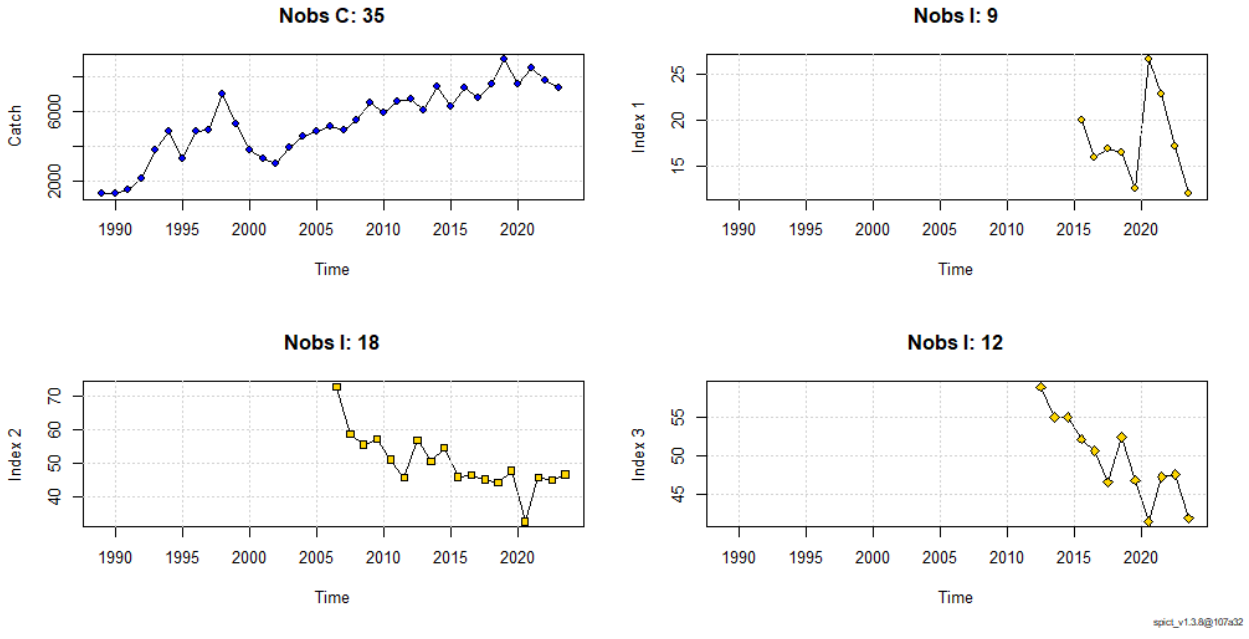

Figure 1. Input data used in the selected SPiCT model run for Greenland halibut in the Upernavik area. Top left: catches (C) time series of 35 years; top right: gillnet survey index (I) time series of 9 years; bottom left: longline CPUE index time series from logbook data (18 years); bottom right: longline CPUE index time series from factory landings (12 years).

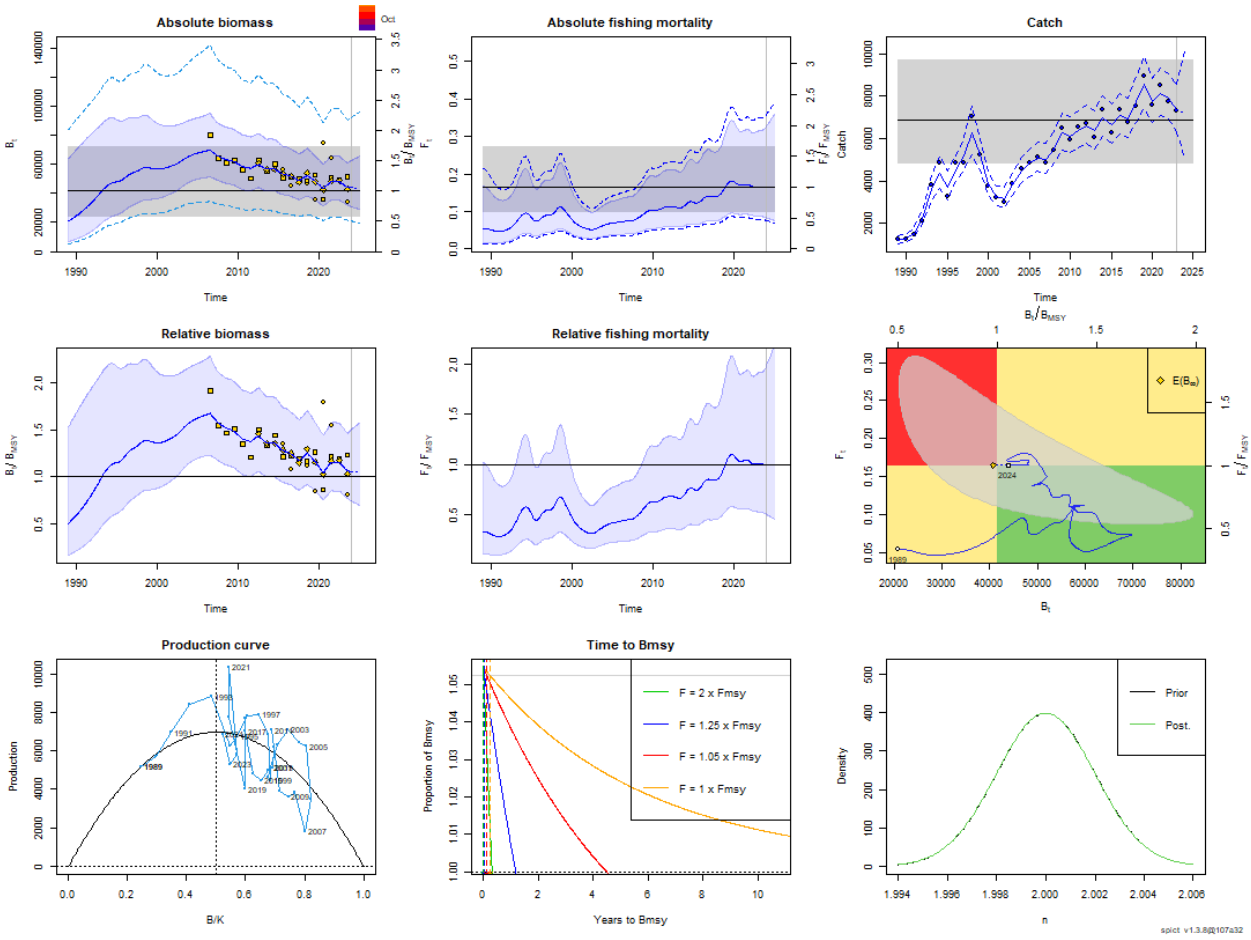

Figure 2. Main results of the selected SPiCT model run for Greenland halibut in the Upernavik area.

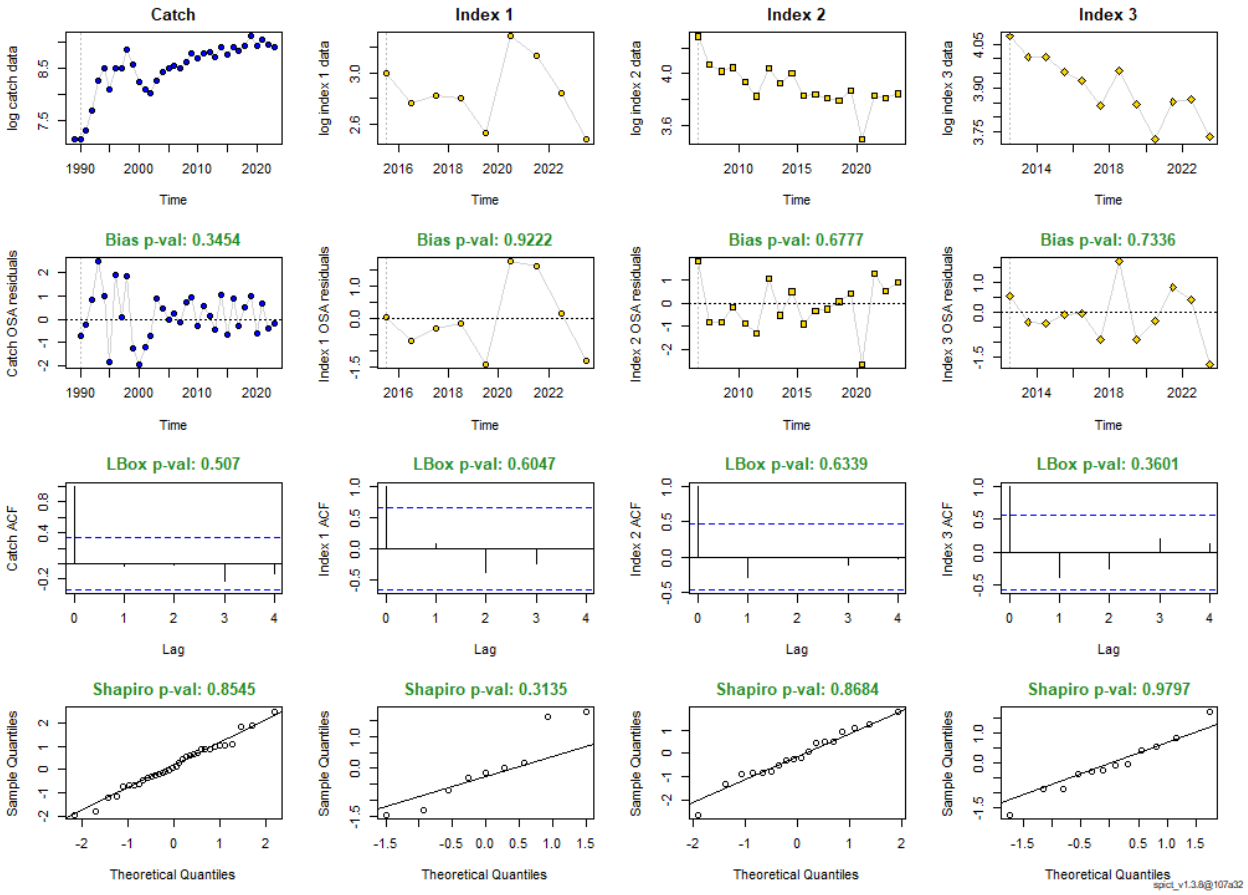

Figure 3. Diagnostics of the selected SPiCT model run for Greenland halibut in the Upernavik area.

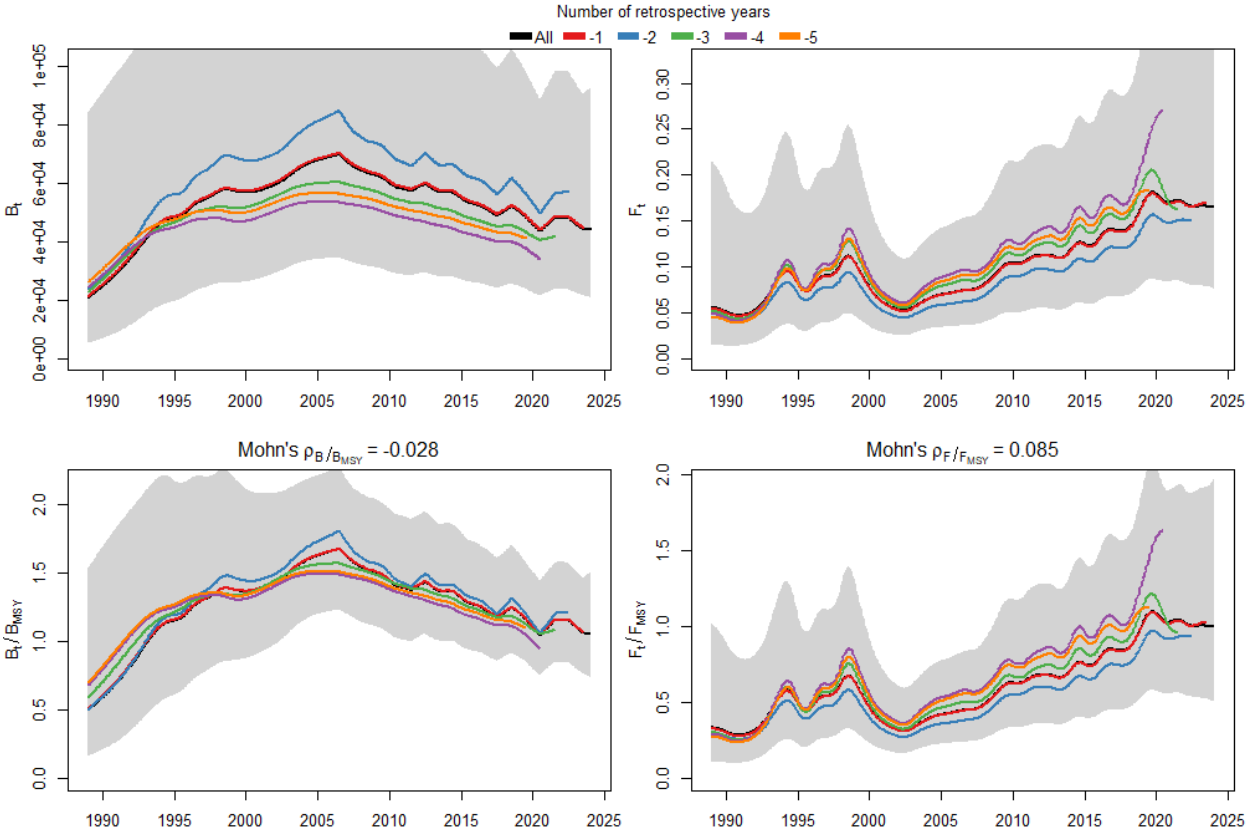

Figure 4. Five-year retrospective analyses of the selected SPiCT model run for Greenland halibut in the Upernavik area.