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Northwest Atlantic Fisheries Organization

Serial No. N7242 **NAFO SCR Doc. 21/044**

NAFO/ICES WG *PANDALUS* ASSESSMENT GROUP—November 2021

Applying a stochastic surplus production model (SPiCT) to the East Greenland Stock of Northern Shrimp

by

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Summary

A stochastic surplus production model (SPiCT) was applied to the East Greenland stock of *Pandalus borealis*. Input data composed of time-series of survey fishable biomass, catch and 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 fixed to 2 (Schaefer) and no priors were used were chosen as the most promising model setup for the use of SPiCT in the future assessment of the East Greenland shrimp stock. We do not suggest applying SPiCT for this year assessment mainly because of the lack of survey data in 2020 (and 2017 to 2019).

Introduction

The SPiCT model is a stochastic surplus production model in continuous time (Pedersen & Berg, 2016). Previously no analytical assessment of the East Greenland shrimp stock has been performed and the assessment has been 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.

Material and Methods

Catch and CPUE data are available since 1980 (Buch et al. 2021) and research survey data since 2008 (Buch 2020). No research survey was performed in the years in 2017 to 2019 and 2021 (Figure 1).

Results and Discussion

<u>Model setup</u>

The basic model

The SPiCT model were applied to truncated timeseries of catch and CPUE to cover only the period where a survey biomass index is available, 2008 to 2021 (Figure 1). It is recommended to truncate the catch series if it is much longer than the biomass index (Millenberger et al. 2019) or alternatively to add a prior to b/k close to 1 if it could be assumed that stock status in the beginning was close to be virgin (ICES 2021). However, different length of catch and CPUE timeseries have also been tested (see later). Furthermore, the catch was at a much higher level until the early 2000s where catch started to decrease (Figure 2), and we believe that the East Greenland ecosystem regime may have shifted and is different today compared to the late 1980s and 1990s. The research survey is performed in the autumn; therefore, the biomass data is shifted a bit by adding 0.66 in the model. No surveys were conducted in 2017, 2018, 2019 and 2021. The SD of the catch and CPUE in the present year was applied by a factor 2 as it only covers the first half of the year.

The Basic model is defined as the standard model using the default settings, not fixing any parameters, and only using the default non-informative priors for n (shape of the production curve) and alfa and beta (noise parameters). The outcome of the Basic model is show in Table 1. For the Basic model there are concerns related to the values of some parameter estimates, such as a high value of the intrinsic population growth rate (r = 3.44), high standard deviation on the catch (sdc = 0.45) and the shape of the production curve (n = 6.14). Therefore, sensitivity analysis was carried out to explore the outcome of the model by using fixation of the parameter values of n, alpha and beta, use of different priors for the parameters n, r and sdc, and changing the input data.

The Mohn's rho value for B of the Basic model was the only one among all the different setting that was acceptable. However, it should be noted that research survey data are available for only one year of the last three years as used here in the retrospective analysis. It may therefore be expected that Mohn's rho for B creates problems in the diagnostic.

Survey or CPUE as input data

The model was also run removing either the survey data or the CPUE data, such that the model was fitted to either catch or survey data alone (orange lines in Table2). The main results and parameters estimated when using only CPUE data were rather like that obtained in the Basic model, while there were problems with the diagnostic and no reliable reference values were obtained using only survey data. The CPUE data therefore seem to drive the Basic model.

Length of catch and CPUE input data

The sensitivity of using different periods of catch and CPUE input data on the model outcome is shown as pink lines in Table 2. Using input data of catch and CPUE data from 1980 to 2021 with the default setting and with fixing n = 2 and using a prior for the b/k fraction. The catches in the 1990s were much higher than today (Figure 2). The relative biomass (B/Bmsy) got very high with a wide confidence limits and very low relative fishing mortality (F/Fmsy). The most appealing with these runs were that the growth rate and the SD on catch were much lower than in all the other settings that were tried. The same happened, although to a less extent, if input catch and CPUE data from 1999 to 2021 are applied as input data.

The shape parameter (n)

The Basic model estimates a highly right-skewed production curve (n = 6.14), right-skewed curves are uncommon for short-lived species (Casper W. Berg, pers.com). Two models were run; one where n was fixed to 2 (Schaefer), and a second with a tighter prior for logn than the default prior was chosen (green lines in Table 2). Mohn's rho got high for B. However, retrospective pattern is often related to uncertainty about the shape (n) parameter and fixing it or constraining it using prior, often reduce the retrospective pattern (ICES 2021). The confidence limits of the relative reference points B/Bmsy and F/Fmsy got wider for both runs. The correlation between K and m and between Bmsy and Fmsy get high. This happen when n is fixed then the remaining parameters gets more intercorrelated. In addition, the models had less robustness to initial values. Although the diagnostics of these two models showed some weaknesses, they both estimate lower growth rate (r), which may be more realistic and especially the Schaefer model may serve as an alternative to the Basic model.

Fixing noise parameters

For short time series or time series with limited contrast it is suggested to try to reduce the number of parameters to be estimated to stabilize the parameter estimates, especially when the model do not converge. Two runs were performed where the default priors on the noise parameters logalpha (logsdi-logsdb) and logbeta (logsdc-logsdf) one by one were fixed to 1, and one run with both n and beta were fixed (brown lines in Table 2). Fixing alpha to 1 is to assume that the process error of B and the observation error of the index are equal, and similar fixing beta to 1 is to assume that the process error of F is equal to the observation error of the catch. The outcome of the models with fixed logbeta or fixed logalpha were rather similar to the outcome of the Basic model, although the n and r values decreased, they were still considered in the high end. The run with both n and beta were fixed, was close to the run where only n was fixed, and it may therefore be unnecessary to add the assumption of the error terms of F and beta to be equal.

Intrinsic growth rate and SD on the catch

The intrinsic population rate (r) is defined in another way than in most other surplus production models. However, it should roughly be comparable to r in other production models (Casper W. Berg, pers com). In West Greenland and the Barents Sea where surplus production models are applied for northern shrimp, the r is approximately 0.3, which is considerably lower than estimated by the Basic model. The prior for r was centered to 0.3 and a relative tight sd was applied (blue lines in Table 2). The estimated r was lower than for the basic model and the production curve got left-skewed. However, the model loses its stability, expressed by the very high Mohn's rho values for B and the relative reference points got considerably wider confidence limits. A model with a prior for sdc was applied. The prior was centered around 0.2. We believe that the catch data for the East Greenland shrimp in general is quite reliable and that the sdc estimated to 0.45 is high. The prior of sdc was given a rather tight sd. This resulted in a decrease in the estimate of sdc but not very much and at the same time the estimates of n and r got high. In general, it appears not possible to decrease the value of sdc considerably either by using different priors for sd or by any of the above-mentioned model settings.

Using effort data as input

It is possible to use effort data in the model instead of CPUE. Doing this avoids using the same information twice (catch as catch and catch again with calculating CPUE (catch/effort)). Using effort as input index was tested using default model settings and with different time span of the input timeseries (grey lines in Table 2). The model would only converge when using the period 1980 to 2020 as input. The model has several problems with the residuals, Mohn's rho values were high and there was no robustness to initial values.

In summary, it appears not possible to create a setup that would decrease the estimated values by the Basic model of growth rate (r), shape of production curve (n) and SD of the catch (sdc) to more realistic levels and at the same time get reliable outcome of the model. Severa1 settings may be considered as candidate settings.

Fixing of n or using tight prior on r or using tight prior on r combined with fixing of n. They all decrease the value of r. It is difficult to choose one of those, but we find that the Schaefer model (fixing n to 2) appears to be the most suitable choice in the future and in the following more detail description of the outcome of that model is given.

Model diagnostics for final model

Diagnostics of the model residuals are shown in Figure 3. In general, the residual diagnostics of the model were appropriate. The One Step Ahead (OSA) residuals were not significant different from zero and therefore not biased (Figure 3, second row). Testing of multiple lags (here 4) show no significant autocorrelation in the residuals (ACF), however, the second log of the survey residuals is just above a p-value of 5%. We considered this as only a slight violation of the assumptions and do not invalidate model results. No violation of the normality of the residuals.

Table 3 show the correlations between model parameters for fixed effects. Most of the parameters are well separated i.e., relative low correlation. Highest correlation is between K and m, and that of the two catchability parameters (CPUE and survey). The correlation between log Bmsy and log Fmsy was also high (-0.89). The parameter estimates should not be influenced by the initial values (Millenberger et al. 2019), which appear not to be the case in the present assessment (Table 5).

Retrospective plots of fishing mortality and fishable biomass of three years show low consistency between the scenarios especially for B/Bmsy (Figure 4). B/Bmsy three-years-back curve lay very close to the border of the confidence limit. The model consequently underestimates the B/Bmy and when next year data point is available the B/Bmsy is upgraded. We believe that this is a consequence of only one survey data point in the last three years and this will probably be stabilized in the future when more survey data are available. High values of Mohn's rho are seen in most of the model settings applied (Table 2).

Figure 5 shows the Schaefer production curve. In recent years the production was around the maximum.

The process error is shown in Figure 6. The residuals of the process error show in general no bias. However, it should be noted that in the years with no survey data (2017 to 2019) the residuals are positive and relatively high. The autocorrelation was not significant but very close with regard to lag 1. Figure 7 the catch and process error are shown on a real scale. The process error appears not to drive the changes in catch.

Results

The results of the model with n fixed to 2 is shown in Table 3 and Figure 8. B/Bmsy is just above 1 and F/Fmsy is just below 1. The relative fishing mortality (F_t/F_{MSY}) was above 1 in the period 2009 until 2016 whereafter it drops below 1 and followed by a gradually increase. B/Bmsy was below 1 since 2010 until an increase in recent years These trajectories are likely driven by the increasing CPUE in recent years and the high survey biomass found in 2020. The plot of the relative B/Bmsy versus the relative F/Fmsy show that the stock has moved in to the upper most corner of the "green" zone.

The confidence limits of B/Bmsy and F/Fmsy are wide and show the assessment uncertainty is high especially for F/Fmsy. It appears to be the "price to pay" when fixing the n or applying a tight prior for n.

Table 4 shows forecast for 2022 with 8 scenarios together with forecast for 6 catch options. SPiCT use relative reference points because the use of ratios reduces the variance which it more stable than absolute estimates (ICES, 2021). No fishing mortality reference point is defined for the stock, but a Blim of 580 t is defined. The table shows that the probability of being above Bmsy decrease from 0.62 to 0.39 when catch increase from 2000 to 4500 t. There is no management rule for this stock as e.g., for the West Greenland shrimp stock where the probability of the total mortality (Z) must not be higher than 35%.

Conclusion

We do not suggest the presented SPiCT as a basis for the advice for 2022. The main reason is the lack of survey data in 2017 to 2019 and again in 2021. However, we believed that the SPiCT model is a promising tool for stock assessment for the East Greenland shrimp stock in the near future.

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Table 1. Results from the Basic model.

Convergence: 0 MSG: relative convergence (4)
Objective function at optimum: 42.8288675
Euler time step (years): 1/16 or 0.0625
Nobs C: 14, Nobs I1: 14, Nobs I2: 10

Priors
logn ~ dnorm[log(2), 2^2]
logalpha ~ dnorm[log(1), 2^2]
logbeta ~ dnorm[log(1), 2^2]

Model parameter estimates w 95% CI

	estimate	cilow	ciupp	log.est
alpha1	1.1731746	0.1337918	1.028716e+01	0.1597134
alpha2	6.6098344	1.1092507	3.938687e+01	1.8885586
beta	0.4781479	0.1551622	1.473461e+00	-0.7378353
r	3.4448277	0.3362055	3.529639e+01	1.2368739
rc	1.1228434	0.7627697	1.652894e+00	0.1158642
rold	0.6707349	0.5039854	8.926555e-01	-0.3993813
m	3204.5040962	1820.5925092	5.640387e+03	8.0723126
K	8126.0167549	4643.2083972	1.422123e+04	9.0028261
q1	0.1181462	0.0756012	1.846336e-01	-2.1358328
q2	1.4432380	0.8270706	2.518450e+00	0.3668892
n	6.1359007	0.8069525	4.665612e+01	1.8141569
sdb	0.0801077	0.0137653	4.661900e-01	-2.5243829
sdf	0.9417139	0.4748085	1.867753e+00	-0.0600537
sdi1	0.0939804	0.0392101	2.252560e-01	-2.3646695
sdi2	0.5294988	0.3403752	8.237057e-01	-0.6358243
sdc	0.4502785	0.2396658	8.459727e-01	-0.7978890

Deterministic reference points (Drp)

	estimate	cilow	ciupp	log.est
Bmsyd	5707.8381095	3439.6362941	9471.7618664	8.649596
Fmsyd	0.5614217	0.3813848	0.8264469	-0.577283
MSYd	3204.5040962	1820.5925092	5640.3870996	8.072313

Stochastic reference points (Srp)

	estimate	cilow	ciupp	log.est rel.	diff.Drp
Bmsys	5639.711385	3424.9061889	9286.7783080	8.6375882	-0.01207982
Fmsys	0.554437	0.3837824	0.8009758	-0.5898021	-0.01259780
MSYs	3126.388934	1861.0793877	5251.9563822	8.0476339	-0.02498575

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

	estimate	cilow	ciupp	log.est
B_2021.94	6902.7433039	3742.3823550	12731.960714	8.8396742
F_2021.94	0.3757972	0.0571631	2.470536	-0.9787058
B_2021.94/Bmsy	1.2239533	0.8801949	1.701966	0.2020860
F_2021.94/Fmsy	0.6777995	0.1035411	4.437003	-0.3889037

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

	prediction	cilow	ciupp	log.est	
B_2023.00	6908.6179017	3298.9770182	14467.818675	8.8405249	
F_2023.00	0.3757974	0.0258456	5.464118	-0.9787052	
B_2023.00/Bmsy	1.2249949	0.7306732	2.053740	0.2029367	
F_2023.00/Fmsy	0.6777999	0.0467558	9.825796	-0.3889031	
Catch_	2022.00	2595.4462322	432.4102478	15578.588108	7.8615137
E(B_inf)	6810.6001238	NA	NA	8.8262355	

Table 2. Model settings and model performance

Model	Convergence	Fixed parameters	Priors	Diagnostic problems			Cor m and K	Cor Bmsy and Fmsy	Mohn's rho B	Mohn's rho F	Robustness to initial	ACF lag 1 process error	n	r	sdc	AIC
				OSA	ACF	Quantile										
Basic	yes	none		no	no	no	0.01	-0.31	0.087	0.021	yes	0.268	6.14	3.44	0.45	105.7
only survey	yes	none		no	no	no	0.97	-0.01	problems	problems	no	problems	0.85	0.72	0.62	
only cpue	yes	none		no	no	no	-0.05	-0.23	-0.202	0.077	yes	0.350	5.72	3.18	0.44	
1980-2021	yes	none		no	no	yes	0.42	-0.94	-0.238	0.689	yes	problems	0.59	0.16	0.37	
1980-2021 B/K	yes	n	log(0.8),2^2	no	no	yes	0.77	-0.83	0.010	-0.190	no	problems	2	0.32	0.37	
1999-2021	yes	none		no	no	yes	0.64	-0.57	problems	problems	no	problems	2.41	0.38	0.52	
N=2	yes	n		no	no	no	0.95	-0.89	-0.293	-0.083	yes	0.481	2	0.81	0.46	91.8
N=2	yes	none	log(2),0.5^2	no	no	no	0.60	-0.84	-0.327	0.009	yes	0.472	2.59	1.19	0.46	104.0
beta	yes	logbeta		no	no	yes	0.15	-0.42	-0.016	-0.087	less	0.376	5.46	3.18	0.61	92.0
alpha	yes	logalpha		no	no	yes	0.09	-0.82	0.202	-0.171	no	0.532	4.86	2.38	0.61	88.9
Both n and beta	yes	logn logbeta		no	no	yes	0.94	-0.89	-0.273	-0.128	no	0.504	2	0.87	0.62	78.0
r	yes	none	log(0.3),1^2	no	no	no	0.94	-0.96	-0.603	0.044	yes	0.498	1.57	0.51	0.46	109.7
sdc	yes	none	log(0.2),1^2	no	no	no	-0.03	-0.32	-0.209	0.087	less	0.252	6.12	3.46	0.40	111.1
r/sdc	yes	none	log(0.3),1^2 log(0.2),1^2	no	no	no	0.94	-0.97	-0.626	0.072	yes	0.518	1.58	0.52	0.41	115.2
r/n	yes	n	log(0.3),1^2	no	no	no	0.96	-0.89	-0.448	-0.076	yes	0.500	2	0.78	0.46	94.6
n/r/sdc	yes	n	log(0.3),1^2 log(0.2),1^2	no	no	no	0.96	-0.90	-0.476	-0.055	no	0.497	2	0.77	0.41	100.1
Effort																
1980-2020	yes	none		no	yes	yes	0.45	-0.92	0.87	-0.23	no	problems	2.64	1.49	0.27	
1999-2020	no															
2008-2020	Problems with estimation stochastic reference points															

Table 2 continued. Model settings and relative reference points

Model	Relative reference points B/Bmsy	low	high	F/Fmsy	low	high
Basic	1.22	0.88	1.70	0.68	0.10	1.44
only survey	3.86	0.85	1.17	0.01	0.00	306.7
only cpue	1.22	0.87	1.70	0.68	0.10	4.64
1980-2021	5.01	1.03	18.89	0.02	0.01	0.26
1980-2021 B/K	2.81	1.49	5.31	0.05	0.01	0.23
1999-2021	2.37	0.71	7.85	0.10	0.01	1.95
N=2	1.04	0.49	2.20	0.94	0.14	6.50
N=2	1.17	0.64	2.17	0.83	0.12	5.77
beta	1.27	0.92	1.74	0.63	0.13	3.12
alpha	1.46	0.84	2.54	0.67	0.12	3.61
Both n and beta	1.13	0.53	2.40	0.88	0.17	4.60
r	0.77	0.08	7.22	1.15	0.12	11.18
sdc	1.22	0.89	1.68	0.67	0.10	4.45
r/sdc	0.77	0.08	7.04	1.10	0.11	10.67
r/n	1.01	0.45	2.23	0.95	0.14	6.56
n/r/sdc	1.00	0.47	2.12	0.93	0.13	6.49
Effort						
1980-2020	0.21			1.51		
1999-2020						
2008-2020						

Table 3. Results from the model with n fixed to 2.

Convergence: 0 MSG: both X-convergence and relative convergence (5)
Objective function at optimum: 35.9122083
Euler time step (years): 1/16 or 0.0625
Nobs C: 14, Nobs I1: 14, Nobs I2: 10

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

Model parameter estimates w 95% CI

	estimate	cilow	ciupp	log.est
alpha1	1.374167e+00	0.1950040	9.683575e+00	0.3178480
alpha2	6.857700e+00	1.1976781	3.926601e+01	1.9253720
beta	4.941599e-01	0.1588122	1.537627e+00	-0.7048962
r	8.126987e-01	0.5461464	1.209345e+00	-0.2073948
rc	8.126978e-01	0.5461515	1.209331e+00	-0.2073959
rold	8.126970e-01	0.5461514	1.209328e+00	-0.2073970
m	2.796589e+03	1586.4169087	4.929921e+03	7.9361557
K	1.376446e+04	5629.8937679	3.365259e+04	9.5298455
q1	1.197837e-01	0.0748076	1.918007e-01	-2.1220675
q2	1.456738e+00	0.8164228	2.599248e+00	0.3761995
n	2.000002e+00	1.9960861	2.003926e+00	0.6931483
sdb	7.732140e-02	0.0139965	4.271495e-01	-2.5597845
sdf	9.371398e-01	0.4662104	1.883766e+00	-0.0649228
sdi1	1.062525e-01	0.0483170	2.336568e-01	-2.2419365
sdi2	5.302469e-01	0.3408135	8.249726e-01	-0.6344125
sdc	4.630969e-01	0.2483137	8.636605e-01	-0.7698190

Deterministic reference points (Drp)

	estimate	cilow	ciupp	log.est
Bmsyd	6882.2352480	2814.9526841	1.682627e+04	8.8366988
Fmsyd	0.4063489	0.2730758	6.046653e-01	-0.9005431
MSYd	2796.5888580	1586.4169087	4.929921e+03	7.9361557

Stochastic reference points (Srp)

	estimate	cilow	ciupp	log.est	rel.diff.Drp
Bmsys	6842.3654959	2801.4553111	1.671202e+04	8.8308888	-0.005826896
Fmsys	0.4049514	0.2716131	6.037473e-01	-0.9039881	-0.003451080
MSYs	2770.7700512	1573.8495446	4.877955e+03	7.9268806	-0.009318278

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

	estimate	cilow	ciupp	log.est
B_2021.94	7133.0538649	3021.3001337	16840.583586	8.8724947
F_2021.94	0.3824926	0.0545051	2.684163	-0.9610459
B_2021.94/Bmsy	1.0424836	0.4936791	2.201374	0.0416060
F_2021.94/Fmsy	0.9445395	0.1373385	6.496029	-0.0570578

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

	prediction	cilow	ciupp	log.est
B_2023.00	7170.5443035	2057.0209853	24995.712720	8.8777368
F_2023.00	0.3824928	0.0252780	5.787662	-0.9610453
B_2023.00/Bmsy	1.0479628	0.3526414	3.114285	0.0468481
F_2023.00/Fmsy	0.9445400	0.0633294	14.087537	-0.0570572
Catch_2022.00	2736.0779645	545.9667010	13711.683540	7.9142808
E(B_inf)	7162.3161059	NA	NA	8.8765887

Table 4. Correlation matrix for the estimated SPiCT model parameters

	logm	logK	logq	logq	logn
logm	1.0000000000	0.949687537	-5.283453e-01	-4.485826e-01	-7.119021e-04
logK	0.9496875375	1.000000000	-5.805501e-01	-4.958098e-01	-2.588384e-03
logq	-0.5283452522	-0.580550119	1.000000e+00	8.130395e-01	3.754734e-06
logq	-0.4485825975	-0.495809843	8.130395e-01	1.000000e+00	3.041351e-05
logn	-0.0007119021	-0.002588384	3.754734e-06	3.041351e-05	1.000000e+00
logsdb	0.0083256733	0.010570486	-5.654725e-02	-4.606704e-02	-9.993876e-05
logsdf	0.0965695613	0.072383918	-1.958153e-01	-1.572173e-01	-1.792374e-05
logsdi	0.1890114607	0.270652680	-1.336502e-01	-1.137709e-01	-3.493023e-04
logsdi	-0.0137586390	-0.023259785	-5.100952e-03	1.802519e-03	-1.830338e-05
logsdc	-0.1991782152	-0.198580636	1.332651e-01	1.017390e-01	-6.259135e-05

	logsdb	logsdf	logsdi	logsdi	logsdc
logm	8.325673e-03	9.656956e-02	0.1890114607	-1.375864e-02	-1.991782e-01
logK	1.057049e-02	7.238392e-02	0.2706526803	-2.325978e-02	-1.985806e-01
logq	-5.654725e-02	-1.958153e-01	-0.1336501904	-5.100952e-03	1.332651e-01
logq	-4.606704e-02	-1.572173e-01	-0.1137708887	1.802519e-03	1.017390e-01
logn	-9.993876e-05	-1.792374e-05	-0.0003493023	-1.830338e-05	-6.259135e-05
logsdb	1.000000e+00	-7.666673e-02	-0.1003589450	4.740767e-02	4.812113e-02
logsdf	-7.666673e-02	1.000000e+00	-0.2668431829	5.362854e-02	-4.741228e-01
logsdi	-1.003589e-01	-2.668432e-01	1.0000000000	-7.025745e-02	8.834984e-02
logsdi	4.740767e-02	5.362854e-02	-0.0702574489	1.000000e+00	-4.010561e-02
logsdc	4.812113e-02	-4.741228e-01	0.0883498379	-4.010561e-02	1.000000e+00

Table 5. Checking of the influence of initial values on parameter estimates with 20 random selected initial values. Distance from the estimated parameter vector to the base run parameter vector (should be close to 0).

	Distance	m	K	q	q	n	sdb	sdf	sdi	sdi	sdc
Basevec	0.00	2796.59	13764.46	0.12	1.46	2	0.08	0.94	0.11	0.53	0.46
Trial 1	0.14	2796.57	13764.32	0.12	1.46	2	0.08	0.94	0.11	0.53	0.46
Trial 2	0.01	2796.59	13764.47	0.12	1.46	2	0.08	0.94	0.11	0.53	0.46
Trial 3	0.00	2796.59	13764.46	0.12	1.46	2	0.08	0.94	0.11	0.53	0.46
Trial 4	0.01	2796.59	13764.47	0.12	1.46	2	0.08	0.94	0.11	0.53	0.46
Trial 5	0.04	2796.59	13764.50	0.12	1.46	2	0.08	0.94	0.11	0.53	0.46
Trial 6	0.08	2796.58	13764.39	0.12	1.46	2	0.08	0.94	0.11	0.53	0.46
Trial 7	0.00	2796.59	13764.47	0.12	1.46	2	0.08	0.94	0.11	0.53	0.46
Trial 8	0.00	2796.59	13764.46	0.12	1.46	2	0.08	0.94	0.11	0.53	0.46
Trial 9	0.00	2796.59	13764.46	0.12	1.46	2	0.08	0.94	0.11	0.53	0.46
Trial 10	0.00	2796.59	13764.47	0.12	1.46	2	0.08	0.94	0.11	0.53	0.46
Trial 11	0.13	2796.60	13764.59	0.12	1.46	2	0.08	0.94	0.11	0.53	0.46
Trial 12	0.00	2796.59	13764.46	0.12	1.46	2	0.08	0.94	0.11	0.53	0.46
Trial 13	0.00	2796.59	13764.47	0.12	1.46	2	0.08	0.94	0.11	0.53	0.46
Trial 14	0.01	2796.59	13764.47	0.12	1.46	2	0.08	0.94	0.11	0.53	0.46
Trial 15	0.00	2796.59	13764.46	0.12	1.46	2	0.08	0.94	0.11	0.53	0.46
Trial 16	0.01	2796.59	13764.45	0.12	1.46	2	0.08	0.94	0.11	0.53	0.46
Trial 17	0.00	2796.59	13764.47	0.12	1.46	2	0.08	0.94	0.11	0.53	0.46
Trial 18	0.00	2796.59	13764.47	0.12	1.46	2	0.08	0.94	0.11	0.53	0.46
Trial 19	0.00	2796.59	13764.46	0.12	1.46	2	0.08	0.94	0.11	0.53	0.46
Trial 20	0.00	2796.59	13764.47	0.12	1.46	2	0.08	0.94	0.11	0.53	0.46

Table 6. Forecast for 2022 with eight scenarios and forecast with 6 catch options.

```
   Observations          Management
  2008.00 - 2022.00      2022.00 - 2023.00
|-----------------------| ----------------------|
```

Management evaluation: 2023.00

Predicted catch for management period and states at management evaluation time:

```
                          C B/Bmsy F/Fmsy
1. Keep current catch    2799.8  1.04  0.97
2. Keep current F        2736.1  1.05  0.94
3. Fish at Fmsy          2869.8  1.03  1.00
4. No fishing            3.2  1.43  0.00
5. Reduce F by 25%       2135.7  1.13  0.71
6. Increase F by 25%     3287.3  0.97  1.18
7. MSY hockey-stick rule 2869.8  1.03  1.00
8. ICES advice rule      2098.0  1.14  0.69
```

Catch options and relative reference points

Catch (t)	**B/Bmsy**	**F/Fmsy**	**Prob B > Bmsy**	**Prob B < Blim**
2000	1.15	0.66	0.62	< 0.01
2500	1.08	0.85	0.56	< 0.01
3000	1.01	1.05	0.51	< 0.01
3500	0.94	1.28	0.46	< 0.01
4000	0.86	1.52	0.43	< 0.01
4500	0.79	1.79	0.39	< 0.01

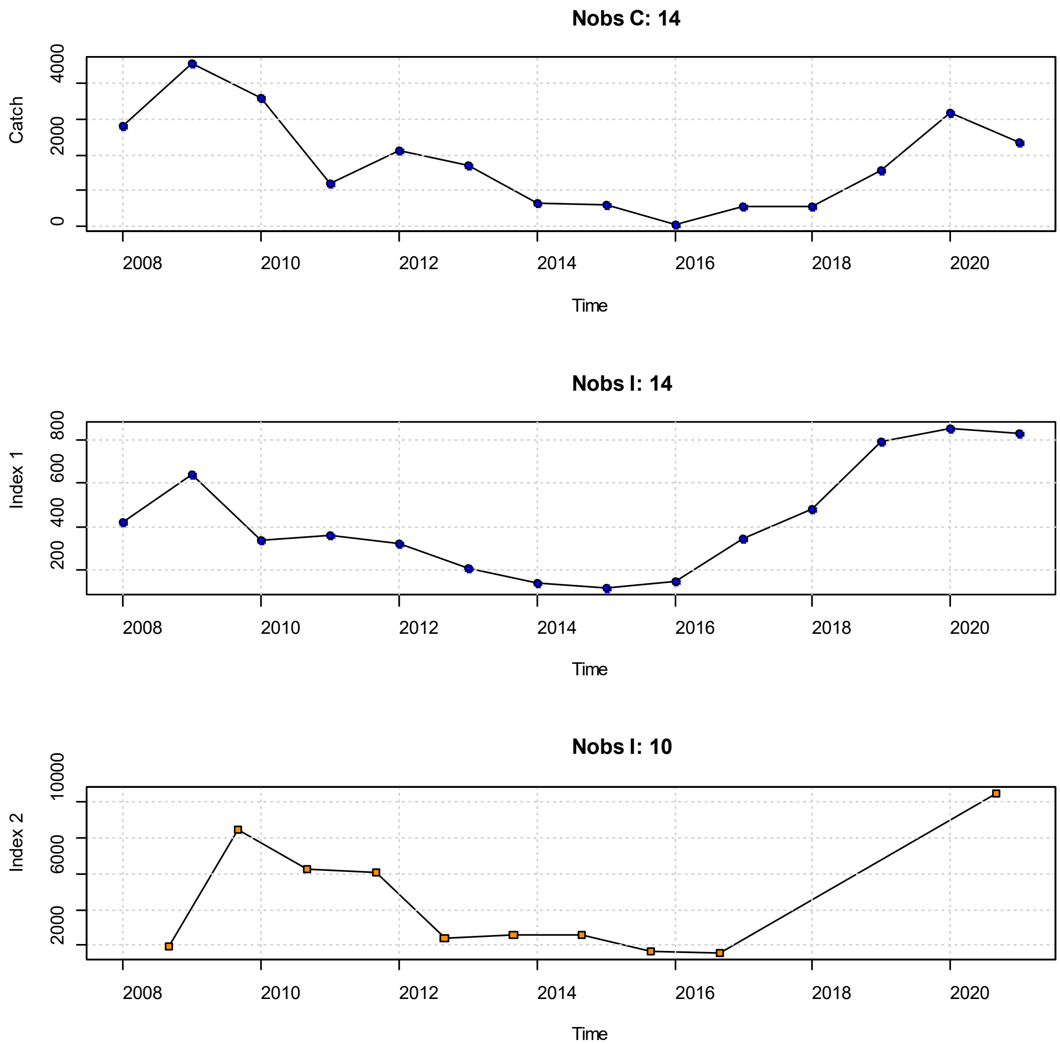

Figure 1. Input data for the SPiCT models of East Greenland northern shrimp stock. Top: Catch, Mittel: CPUE index, Bottom: Survey index.

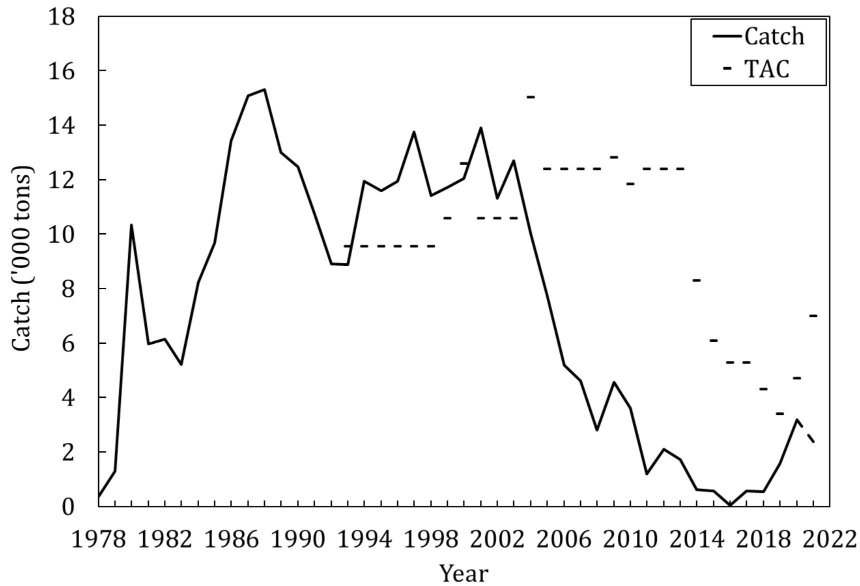

Figure 2. Total catch and TAC of East Greenland northern shrimp.

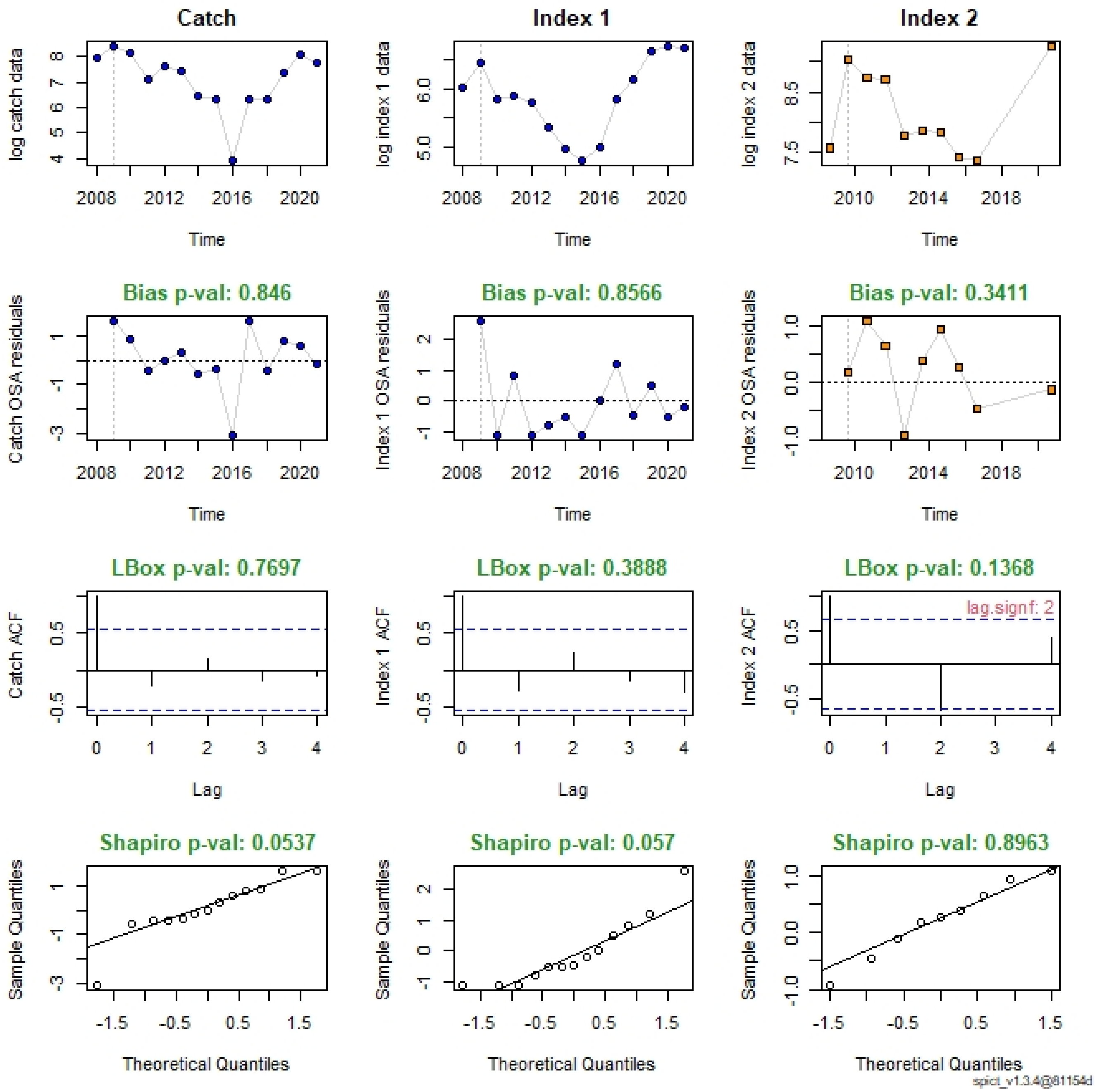

Figure 3. Diagnostics. First row show log of the input data series; catch, CPUE and survey index. Second row "one-step ahead" (OSA) residuals and a test for bias. Third row show the autocorrelation of the residuals including Ljung-Box test of multiple lags and tests for the individual lags. Fourth row show the results of Shapiro test for normality of the residuals.

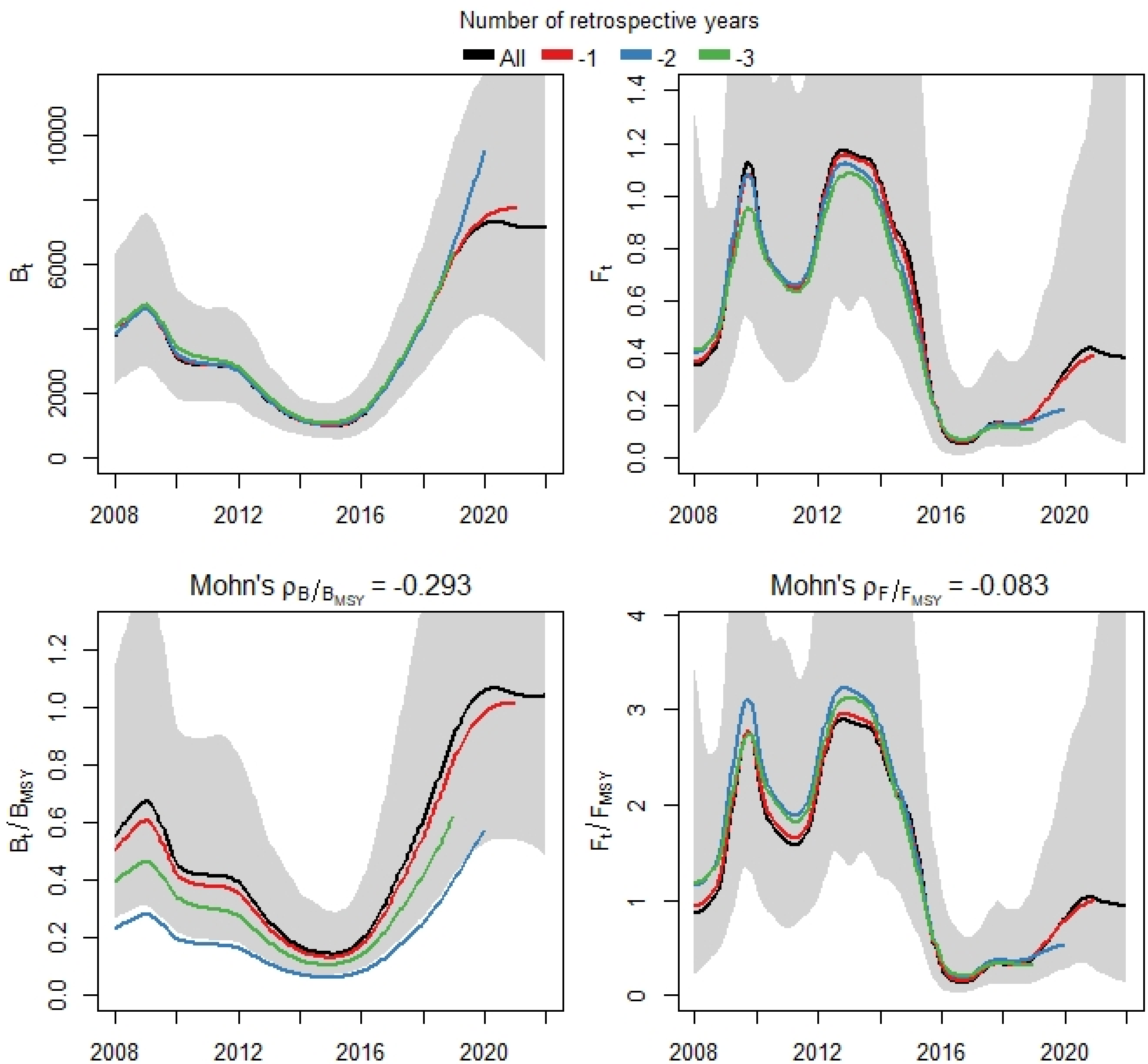

Figure 4. Three years retrospective plots of fishing mortality and fishable biomass.

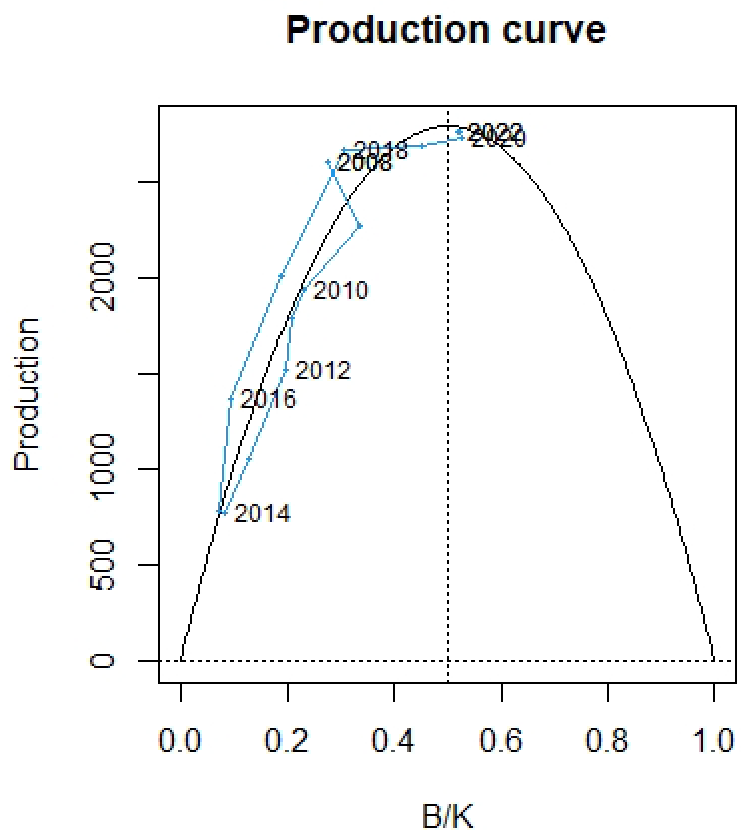

Figure 5. Schaefer production curve.

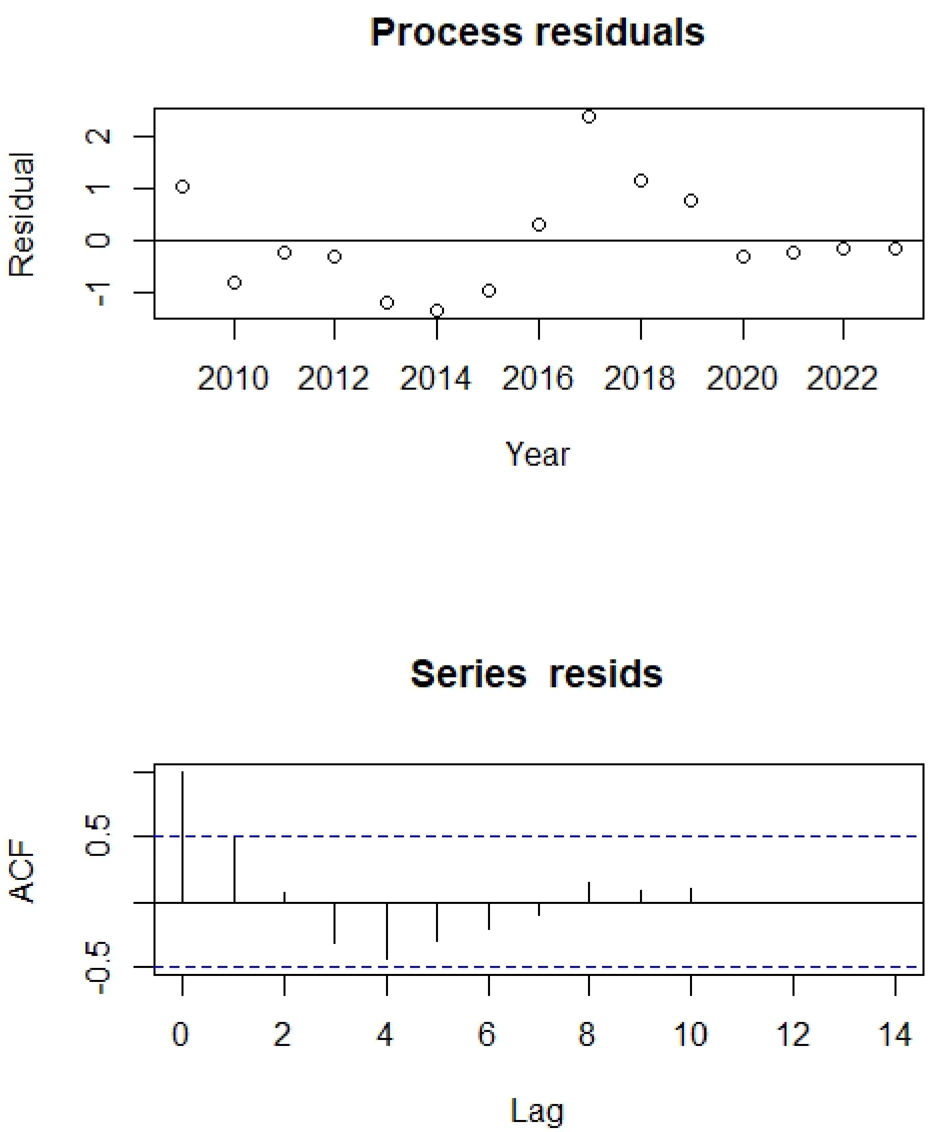

Figure 6. Above is shown the process error. Below is shown the autocorrelation of the process error.

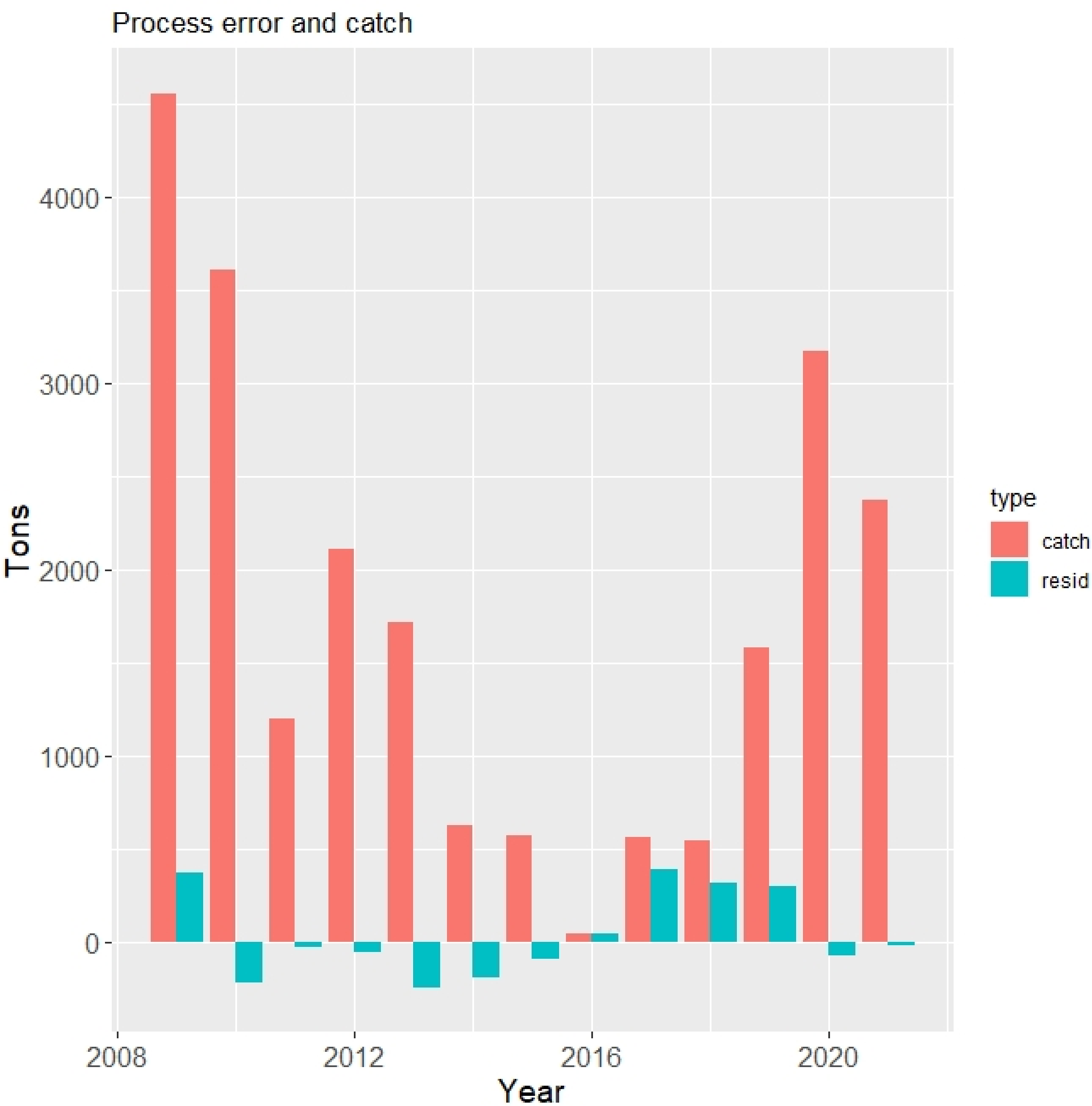

Figure 7. Catch and process error on a real scale

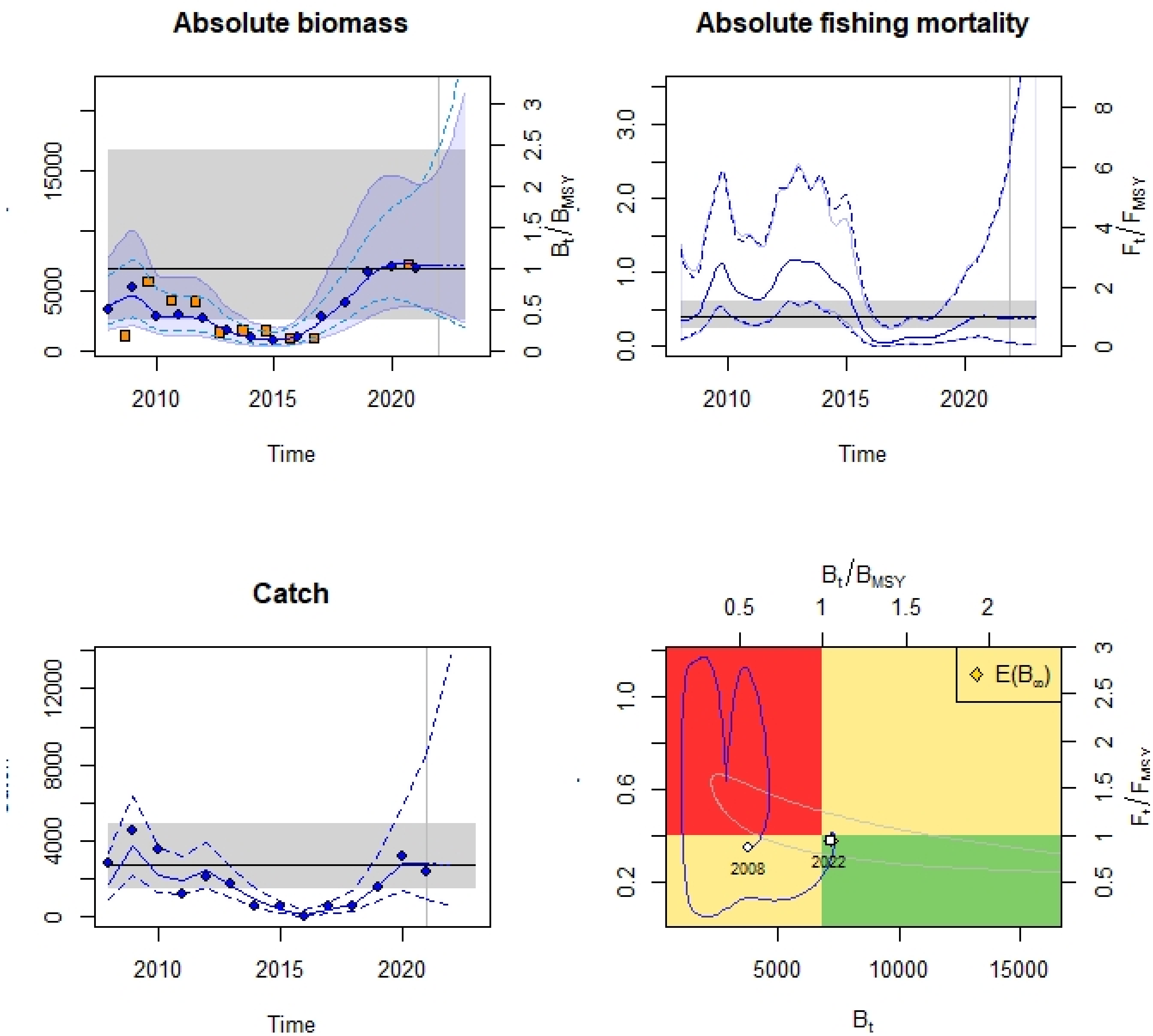

Figure 8. Main results of the model with n fixed to 2.