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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. The shape parameter (n) is fixed to 2 (Schaefer) and no priors were used. Using the output from SPiCT the catch in 2023 should not be above 2 500 t.

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. At last year meeting sensitivity analyses of different configurations of SPiCT was presented and it was concluded that a Schaefer curve was the most promising set up (Rigét et al. 2021). Here is presented an update of the SPiCT model including catch, CPUE and survey data from 2022. The present document represents the base for the advice for 2023.

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. 2022) and research survey data since 2008 (Buch et al. 2022). The catch was at a much higher level until the early 2000s where catch started to decrease (Figure 1), 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 input time-series is shown in Figure 2.

Results and Discussions

The outcome of the SPiCT model is show in Table 1. The intrinsic population growth rate (r = 0.79) and is considered in the higher end. In West Greenland and the Barents Sea where surplus production models are applied for northern shrimp, the r is approximately 0.3. The standard deviation of the catch is estimated to 0.44 and is also considered in the higher end as the catch data is general considered rather precise. The carrying capacity (K) is estimated to 14 608 t and B_{msy} to 7 266 t, those values are close to or slightly higher than in last year SPiCT run. Given the rule of thump that B_{lim} is equal to 30% of B_{msy}, B_{lim} is estimated to 2 180 t. The relative Biomass/B_{msy} is 0.85, which is well below 1, but above $B_{trigger}$ (80% of B_{msy}), while the relative fishing mortality/F_{msy} is 1.63 considerably higher than 1.

The main results of the model are shown in Figure 3 showing the absolute biomass and absolute fishing mortality together with the relative biomass and fishing mortality. The Schaefer production curve show that the reason years are around the top of the curve.

Diagnostics of the model residuals are shown in Figure 4. 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 4, second row). Testing of multiple lags (here 4) show no significant autocorrelation in the residuals (ACF) however, the normality of the catch residuals is just below a p-value of 5%. We considered this as only a slight violation of the assumptions and do not invalidate model results.

Table 2 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 B_{msy} and log F_{msy} was also high (-0.88). 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 3).

Retrospective plots of fishing mortality and fishable biomass of five years lay all within the confidence limits and Mohn's rho are relatively low (-0.111 and -0.014 for B/B_{msy} and F/F_{msy}, respectively) (Figure 5).

The process error is shown in Figure 6. The residuals of the process error show in general no bias and has been relatively low the last five years. The autocorrelation was only significant for lag1, for which the p-value is just below 5%. Figure 7 the catch and process error are shown on a real scale. The process error appears not to be driving the changes in catch.

Table 4 shows forecast for 2023 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 based on this assessment B_{lim} is estimated to be equal to 30% of Bmsy, which is 2 180 t. The table shows that the probability of being above B_{msy} vary between 0.34 to 0.52, highest for fishing 1 500 t. The probability for being below B_{lim} vary between 0.01 to 0.22 highest for the

catch option of 4 000 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%. However, according to the relative reference points B/B_{msy} and F/F_{msy} the catch should not be higher than 2 500 t in 2023.

References

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Table 1. Results from the SPiCT model.

```
Convergence: 0  MSG: relative convergence (4)
Objective function at optimum: 37.1970136
Euler time step (years):  1/16 or 0.0625
Nobs C: 15,  Nobs I1: 15,  Nobs I2: 11

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 1.526349e+00    0.2438777 9.552911e+00  0.4228787
 alpha2 7.183835e+00    1.3271650 3.888551e+01  1.9718333
 beta   4.727904e-01    0.1470390 1.520214e+00 -0.7491032
 r      7.925248e-01    0.5542704 1.133193e+00 -0.2325315
 rc     7.925238e-01    0.5542761 1.133179e+00 -0.2325328
 rold   7.925228e-01    0.5542757 1.133177e+00 -0.2325340
 m      2.894249e+03 1805.1038199 4.640552e+03  7.9704810
 K      1.460775e+04 6866.4885701 3.107650e+04  9.5893076
 q1     1.150187e-01    0.0745351 1.774909e-01 -2.1626608
 q2     1.350794e+00    0.7862515 2.320690e+00  0.3006929
 n      2.000002e+00    1.9960864 2.003926e+00  0.6931484
 sdb    7.267290e-02    0.0139192 3.794287e-01 -2.6217872
 sdf    9.263442e-01    0.4639354 1.849640e+00 -0.0765094
 sdi1   1.109242e-01    0.0554195 2.220190e-01 -2.1989085
 sdi2   5.220699e-01    0.3419721 7.970151e-01 -0.6499539
 sdc    4.379666e-01    0.2292628 8.366589e-01 -0.8256126

Deterministic reference points (Drp)
           estimate       cilow        ciupp   log.est
 Bmsyd 7303.8794351 3433.252135 1.553823e+04  8.896161
 Fmsyd    0.3962619    0.277138 5.665895e-01 -0.925680
 MSYd  2894.2490480 1805.103820 4.640552e+03  7.970481
Stochastic reference points (Srp)
           estimate        cilow        ciupp    log.est rel.diff.Drp
 Bmsys 7266.0308923 3421.2842753 1.543140e+04  8.8909655 -0.005208971
 Fmsys    0.3950222    0.2757294 5.659262e-01 -0.9288134 -0.003138272
 MSYs  2870.1962697 1794.3534135 4.591084e+03  7.9621357 -0.008380186

States w 95% CI (inp$msytype: s)
                    estimate        cilow        ciupp    log.est
 B_2022.94      6198.6590245 2439.0045042 15753.711662  8.7320883
 F_2022.94         0.6454784    0.0944502     4.411239 -0.4377636
 B_2022.94/Bmsy    0.8531011    0.3304266     2.202551 -0.1588772
 F_2022.94/Fmsy    1.6340307    0.2348722    11.368124  0.4910498

Predictions w 95% CI (inp$msytype: s)
                  prediction        cilow        ciupp    log.est
 B_2024.00      5205.8102997  839.5299408 32280.517419  8.5575306
 F_2024.00         0.6454786    0.0441423     9.438632 -0.4377632
 B_2024.00/Bmsy    0.7164586    0.1143402     4.489349 -0.3334348
 F_2024.00/Fmsy    1.6340314    0.1103236    24.202058  0.4910502
 Catch_2023.00  3652.1386823 1019.0181346 13089.185070  8.2030682
 E(B_inf)       2575.3341412           NA           NA  7.8537346
```

Table 2. Correlation matrix for the estimated SPiCT model parameters

	logm	logK	logq	logq	logn
logm	1.0000000000	0.932827256	-4.712770e-01	-4.029398e-01	-6.444335e-04
logK	0.9328272562	1.000000000	-5.420051e-01	-4.648725e-01	-2.874277e-03
logq	-0.4712770241	-0.542005055	1.000000e+00	8.048746e-01	-7.472487e-05
logq	-0.4029397822	-0.464872460	8.048746e-01	1.000000e+00	-2.942466e-05
logn	-0.0006444335	-0.002874277	-7.472487e-05	-2.942466e-05	1.000000e+00
logsdb	0.0623147283	0.062198191	-6.727263e-02	-5.815713e-02	-1.406160e-04
logsdf	0.1849999661	0.149827527	-1.916619e-01	-1.339222e-01	-9.649390e-05
logsdi	0.0564695926	0.160075603	-1.075043e-01	-8.394845e-02	-1.870564e-04
logsdi	0.0394951415	0.023861853	-1.455269e-02	-1.327264e-02	-9.172220e-05
logsdc	-0.2701776794	-0.263570488	1.020347e-01	5.971034e-02	8.665504e-06
	logsdb	logsdf	logsdi	logsdi	logsdc
logm	0.062314728	0.1849999661	0.0564695926	0.0394951415	-2.701777e-01
logK	0.062198191	0.1498275270	0.1600756026	0.0238618529	-2.635705e-01
logq	-0.067272633	-0.1916618902	-0.1075042614	-0.0145526850	1.020347e-01
logq	-0.058157134	-0.1339222028	-0.0839484480	-0.0132726447	5.971034e-02
logn	-0.000140616	-0.0000964939	-0.0001870564	-0.0000917222	8.665504e-06
logsdb	1.000000000	-0.0733320009	-0.0656170325	0.0417589346	5.636153e-02
logsdf	-0.073332001	1.0000000000	-0.2323575756	0.0357249815	-5.216612e-01
logsdi	-0.065617033	-0.2323575756	1.0000000000	-0.0568713486	7.652103e-02
logsdi	0.041758935	0.0357249815	-0.0568713486	1.0000000000	-2.315282e-02
logsdc	0.056361526	-0.5216611670	0.0765210252	-0.0231528180	1.000000e+00

Table 3. 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	2894.25	14607.75	0.12	1.35	2	0.07	0.93	0.11	0.52	0.44
Trial 1	0.01	2894.25	14607.74	0.12	1.35	2	0.07	0.93	0.11	0.52	0.44
Trial 2	0.16	2894.23	14607.59	0.12	1.35	2	0.07	0.93	0.11	0.52	0.44
Trial 3	0.06	2894.24	14607.69	0.12	1.35	2	0.07	0.93	0.11	0.52	0.44
Trial 4	0.01	2894.24	14607.74	0.12	1.35	2	0.07	0.93	0.11	0.52	0.44
Trial 5	0.01	2894.25	14607.74	0.12	1.35	2	0.07	0.93	0.11	0.52	0.44
Trial 6	0.03	2894.25	14607.72	0.12	1.35	2	0.07	0.93	0.11	0.52	0.44
Trial 7	0.01	2894.25	14607.74	0.12	1.35	2	0.07	0.93	0.11	0.52	0.44
Trial 8	0.01	2894.25	14607.74	0.12	1.35	2	0.07	0.93	0.11	0.52	0.44
Trial 9	0.01	2894.25	14607.74	0.12	1.35	2	0.07	0.93	0.11	0.52	0.44
Trial 10	0.04	2894.24	14607.72	0.12	1.35	2	0.07	0.93	0.11	0.52	0.44
Trial 11	0.11	2894.27	14607.86	0.12	1.35	2	0.07	0.93	0.11	0.52	0.44
Trial 12	0.02	2894.25	14607.73	0.12	1.35	2	0.07	0.93	0.11	0.52	0.44
Trial 13	0.02	2894.25	14607.77	0.12	1.35	2	0.07	0.93	0.11	0.52	0.44
Trial 14	0.03	2894.25	14607.78	0.12	1.35	2	0.07	0.93	0.11	0.52	0.44
Trial 15	0.01	2894.25	14607.74	0.12	1.35	2	0.07	0.93	0.11	0.52	0.44
Trial 16	0.01	2894.25	14607.76	0.12	1.35	2	0.07	0.93	0.11	0.52	0.44
Trial 17	0.02	2894.25	14607.77	0.12	1.35	2	0.07	0.93	0.11	0.52	0.44
Trial 18	0.03	2894.25	14607.78	0.12	1.35	2	0.07	0.93	0.11	0.52	0.44
Trial 19	0.01	2894.25	14607.74	0.12	1.35	2	0.07	0.93	0.11	0.52	0.44
Trial 20	0.06	2894.24	14607.69	0.12	1.35	2	0.07	0.93	0.11	0.52	0.44

Table 4. Forecast for 2023 with eight scenarios and forecast with 6 catch options.

```
       Observations              Management
    2008.00 - 2023.00        2023.00 - 2024.00
 |----------------------| ----------------------|

Management evaluation: 2024.00

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

                              C B/Bmsy F/Fmsy
1. Keep current catch    4045.7   0.66   1.89
2. Keep current F        3652.1   0.72   1.63
3. Fish at Fmsy          2485.0   0.89   1.00
4. No fishing               4.8   1.24   0.00
5. Reduce F by 25%       2931.8   0.82   1.23
6. Increase F by 25%     4270.6   0.62   2.04
7. MSY hockey-stick rule 2485.0   0.89   1.00
8. ICES advice rule      1859.9   0.98   0.71
```

Catch options and relative reference points

Catch (t)	B/Bmsy	F/Fmsy	Prob B > Bmsy	Prob B < Blim
1500	1.03	0.56	0.52	0.01
2000	0.96	0.77	0.47	0.03
2500	0.89	1.01	0.43	0.06
3000	0.81	1.26	0.40	0.10
3500	0.74	1.54	0.37	0.16
4000	0.66	1.86	0.34	0.22

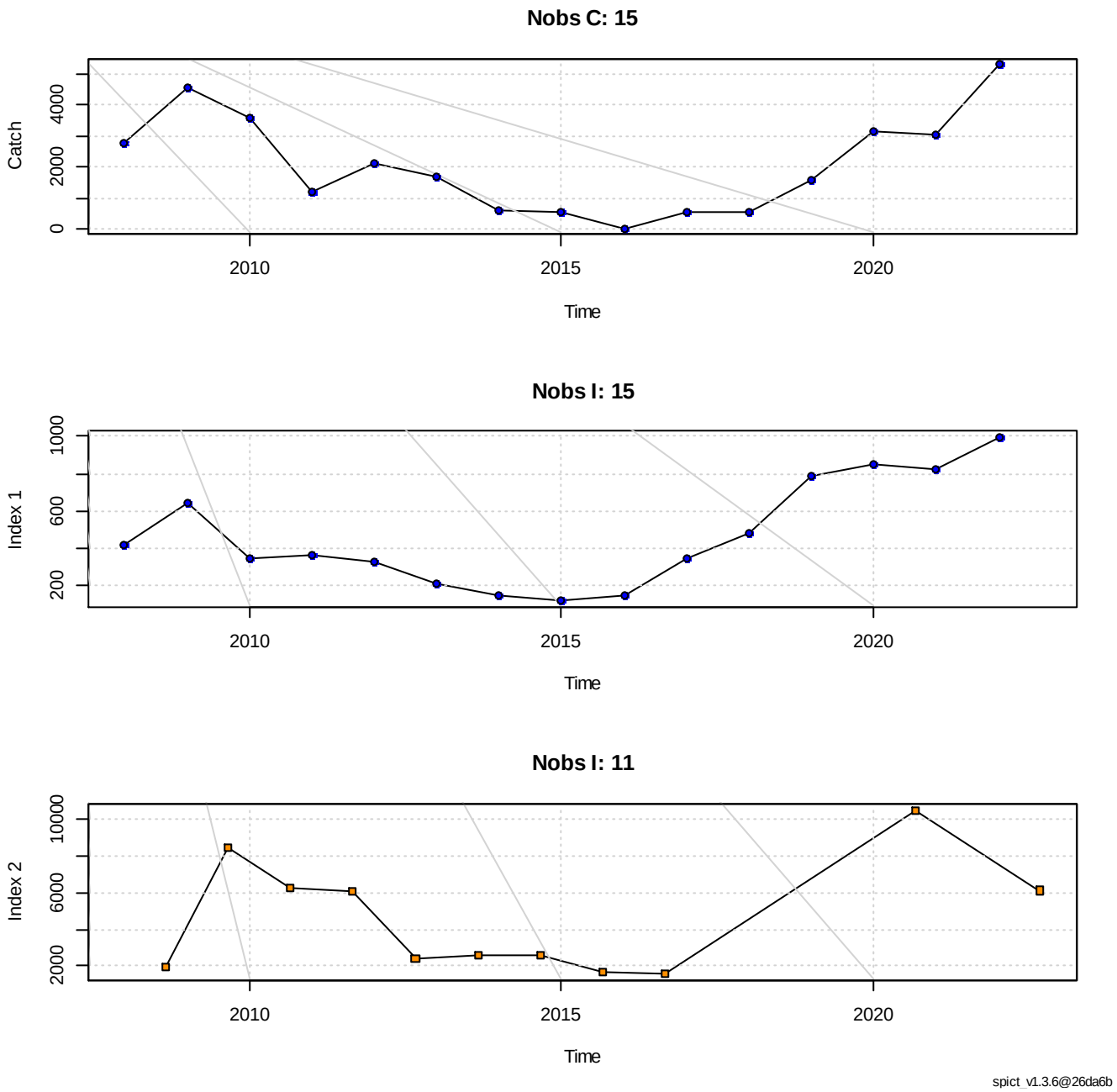

Figure 1. Input data for the SPiCT models of East Greenland northern shrimp stock. Top: Catch, Mittel: CPUE index, Bottom: Survey index.

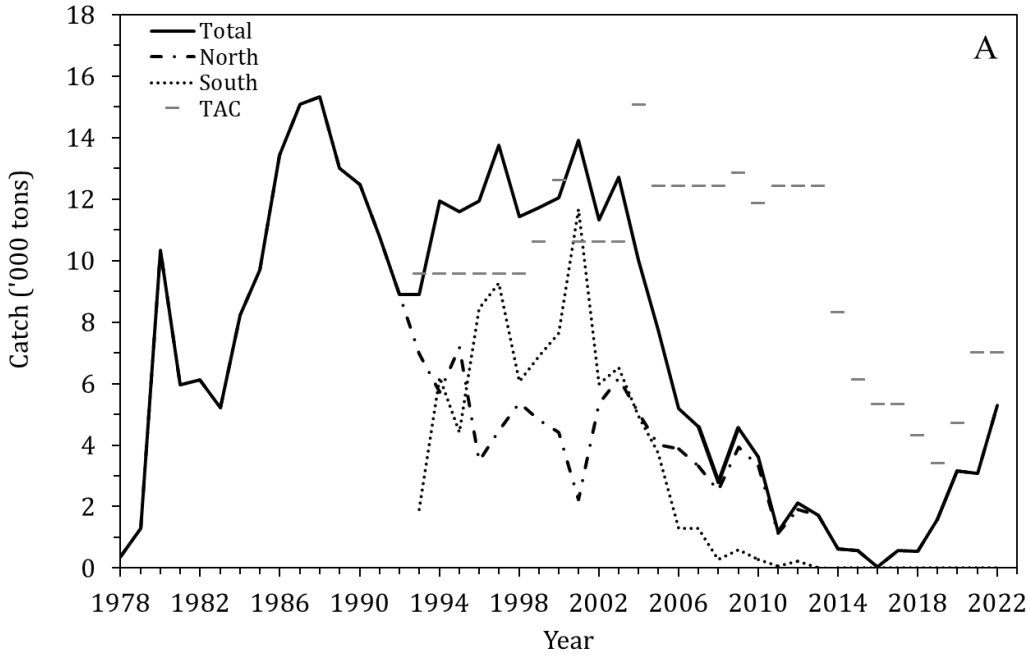

Figure 2. Total catch and TAC of East Greenland northern shrimp.

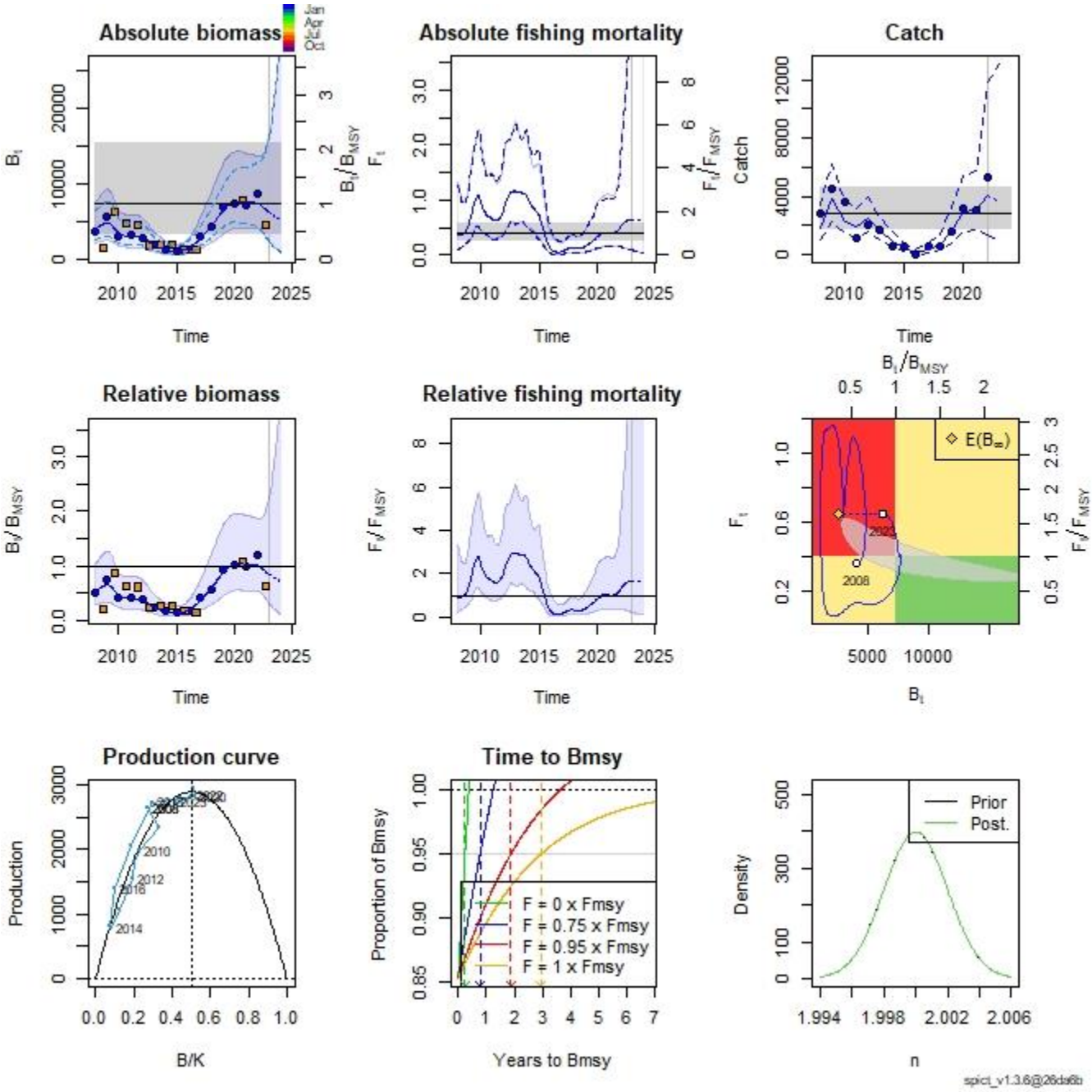

Figure 3. Main results of the model with n fixed to 2.

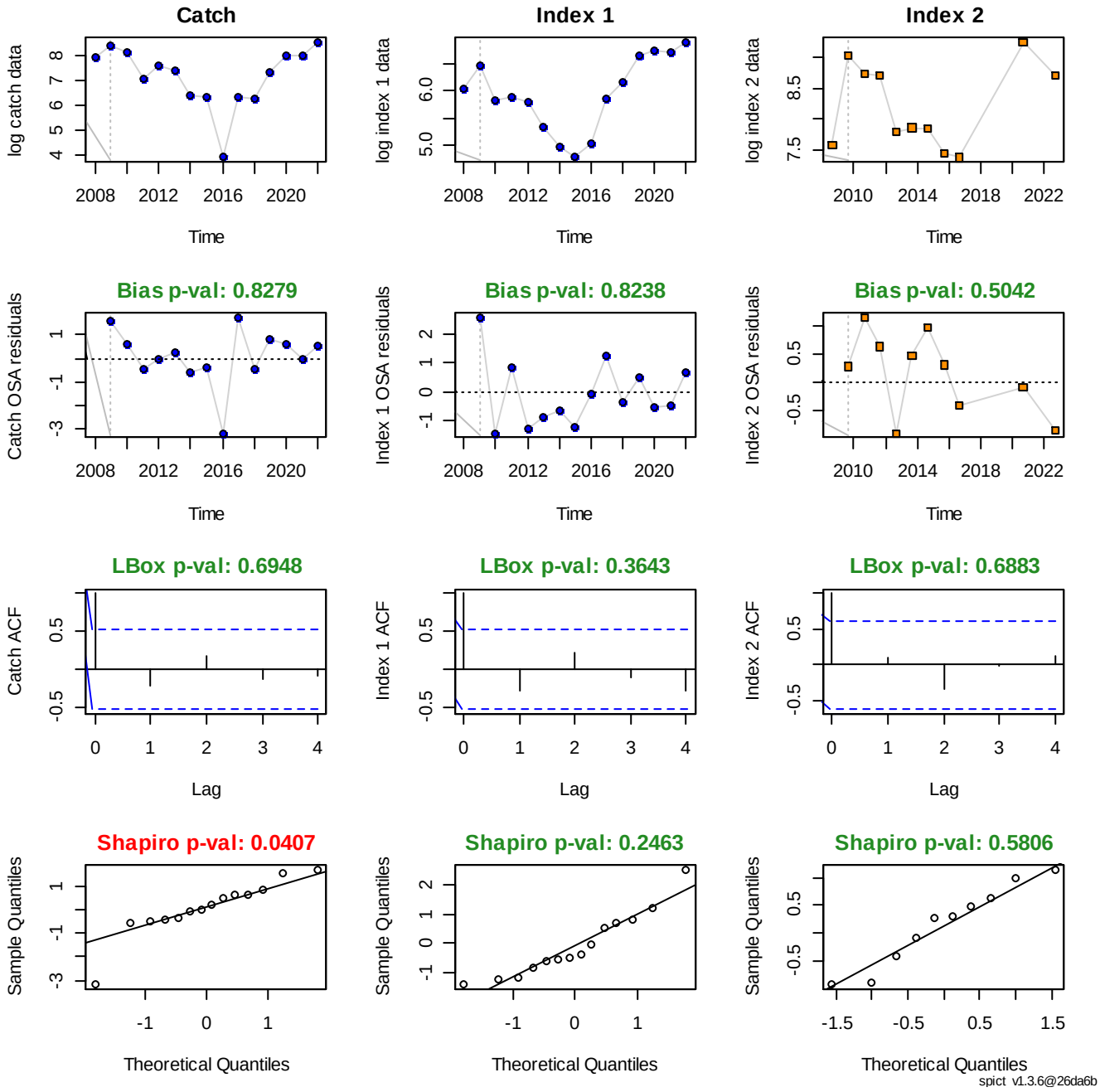

Figure 4. Diagnostics. First row show log of the input data series; catch, CPUE and survey index. Second row "one-step ahead" (OSA) residuals and a test for bias. Third row show the autocorrelation of the residuals including Ljung-Box test of multiple lags and tests for the individual lags. Fourth row show the results of Shapiro test for normality of the residuals.

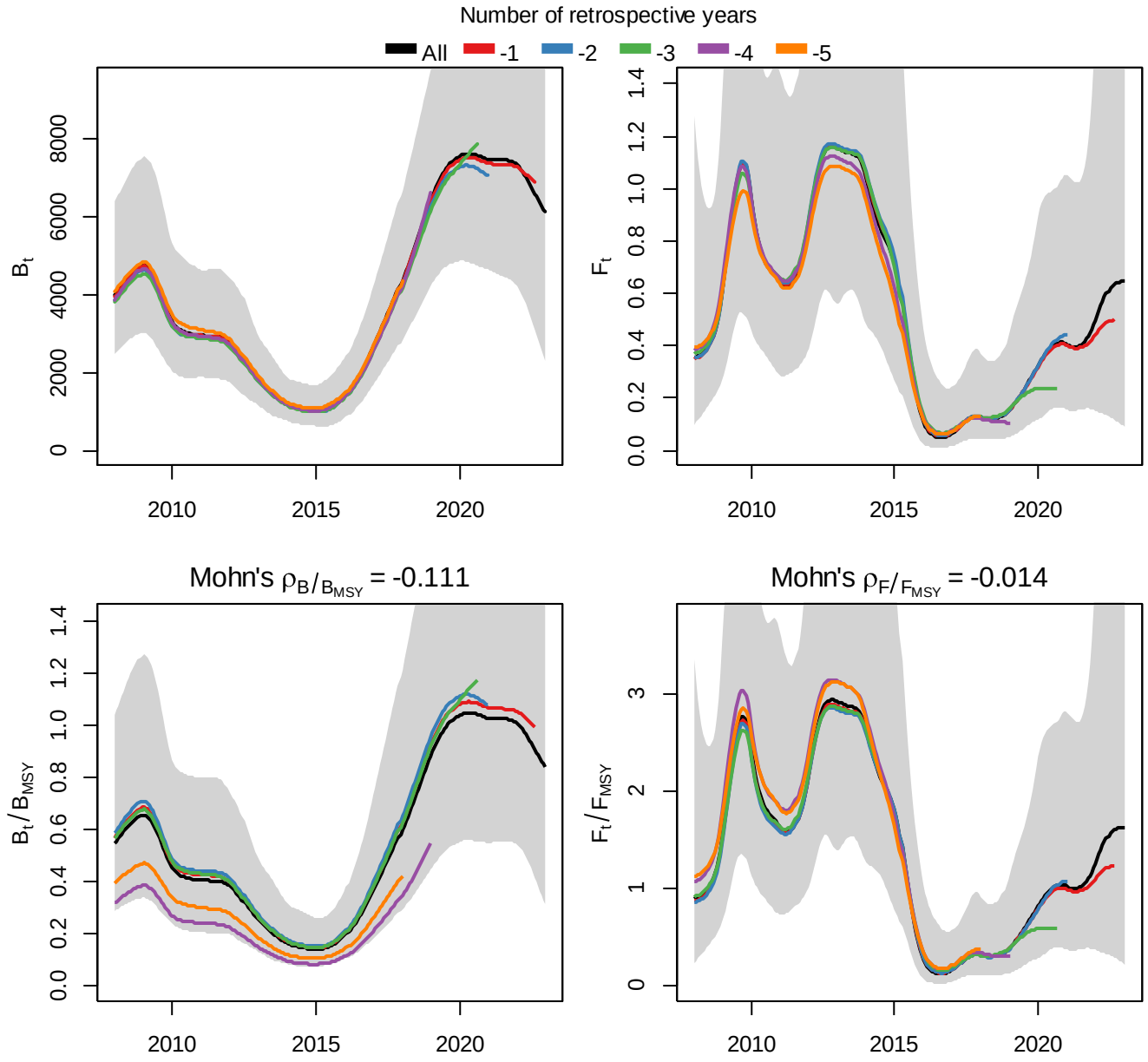

Figure 5. Five years retrospective plots of fishing mortality and fishable biomass.

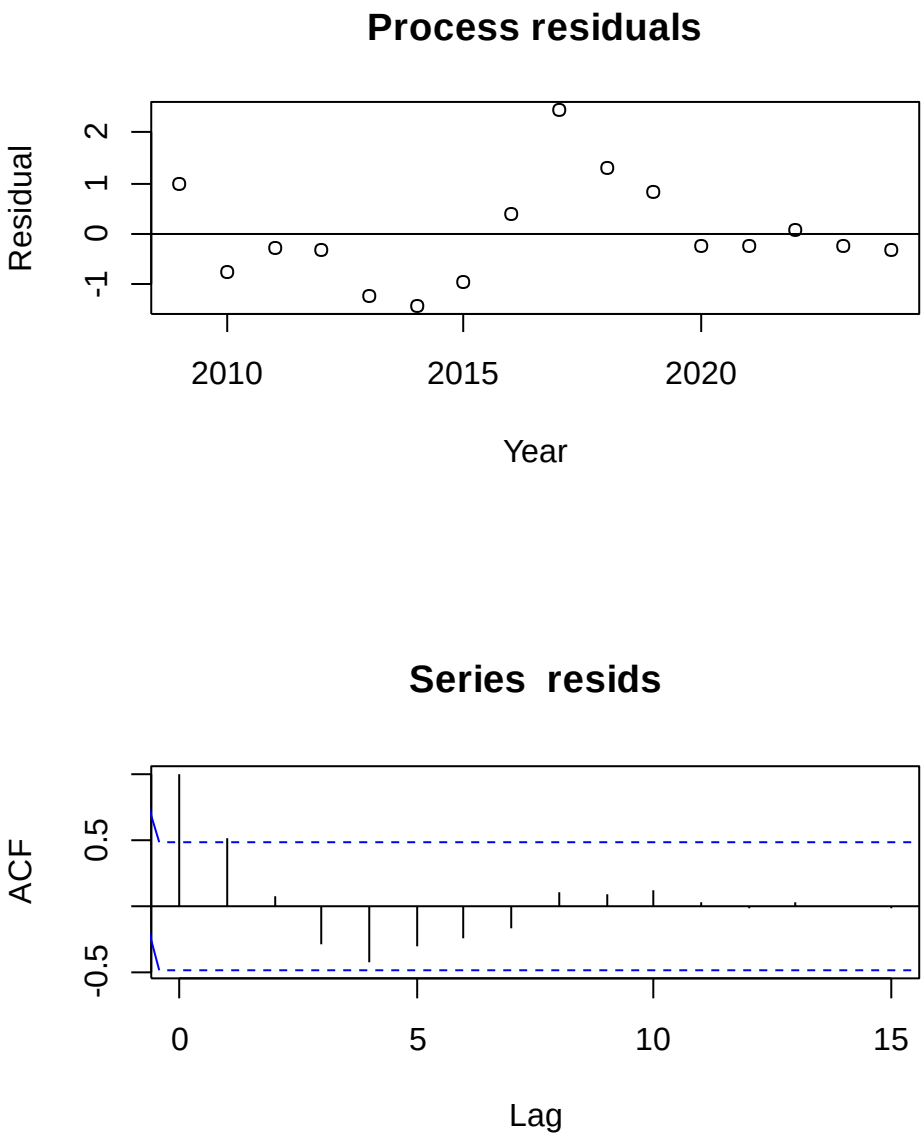

Figure 6. Above is shown the normalized process error. Below is shown the autocorrelation of the process error.

Figure 7. Catch and process error on a real scale