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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). The SPiCT model was accepted for assessment of the East Greenland shrimp stock in 2022. Prior to the 2022 meeting sensitivity analyses of different configurations of SPiCT were 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 2023. The present document represents the base for the advice for 2024.

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. 2023) and research survey data since 2008 (Buch et al. 2023). The catch was at a much higher level until the early 2000s when 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 July to September (in 2023 it was in July, a bit earlier than previous years) 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 standard deviation (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 shown in Table 1 and 2. The intrinsic population growth rate (r = 0.73) 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 0.46 and is also considered in the higher end as the catch data is generally considered rather precise. The carrying capacity (K) is estimated to 17 262 t and B_{msy} to 8 561 t, those values are higher than in the 2022 SPiCT run (14 608 t and 7 266 t respectively). Given the rule of thump that B_{lim} is equal to 30% of B_{msy}, B_{lim} is estimated to 2 568 t. The relative Biomass/B_{msy} is 0.78, which is well below 1 and at $B_{trigger}$ (80% of B_{msy}), while the relative fishing mortality/F_{msy} is 1.59 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 shows that the recent 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 significantly different from zero and therefore not biased (Figure 4, second row). Testing of multiple lags (here 4) shows 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 3 shows 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 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 4, Distance should be close to 0).

Retrospective plots of fishing mortality and fishable biomass of five years lay all within the confidence limits and Mohn's rho are relatively low (0.051 and -0.057 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%.

Table 4 shows the forecast for 2024 with forecast for 6 catch options. SPiCT uses relative reference points because the use of ratios reduces the variance which is 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 2 568 t. The table shows that the probability of being above B_{msy} varies between 0.31 to 0.47, highest for fishing 1 500 t. The probability of B being below B_{lim} varies between 0.02 to 0.20 highest for the catch option of 4 000 t. There is no management rule for this stock. However, with the aim of fishing at F/F_{msy}=1 the catch should not be higher than 2 500 t in 2024.

References

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Table 1. Results from the SPiCT model.

```
Convergence: 0  MSG: relative convergence (4)
Objective function at optimum: 40.116896
Euler time step (years):  1/16 or 0.0625
Nobs C: 16,  Nobs I1: 16,  Nobs I2: 12

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 1.492842e+00    0.2097204 1.062642e+01  0.4006818
 alpha2 5.680220e+00    0.9911850 3.255185e+01  1.7369900
 beta   5.375088e-01    0.1696516 1.702995e+00 -0.6208102
 r      7.348682e-01    0.4774645 1.131040e+00 -0.3080641
 rc     7.348675e-01    0.4774690 1.131027e+00 -0.3080651
 rold   7.348667e-01    0.4774691 1.131024e+00 -0.3080662
 m      3.171441e+03 1743.5096878 5.768845e+03  8.0619413
 K      1.726265e+04 6725.1691685 4.431101e+04  9.7563004
 q1     1.051266e-01    0.0647085 1.707906e-01 -2.2525896
 q2     1.247353e+00    0.7044112 2.208782e+00  0.2210240
 n      2.000002e+00    1.9960860 2.003926e+00  0.6931482
 sdb    8.944390e-02    0.0161398 4.956803e-01 -2.4141440
 sdf    8.533718e-01    0.4268599 1.706048e+00 -0.1585600
 sdi1   1.335256e-01    0.0688844 2.588260e-01 -2.0134622
 sdi2   5.080609e-01    0.3358194 7.686447e-01 -0.6771541
 sdc    4.586948e-01    0.2441644 8.617183e-01 -0.7793701

Deterministic reference points (Drp)
           estimate        cilow        ciupp   log.est
 Bmsyd 8631.3276278 3362.5921487 2.215547e+04  9.063154
 Fmsyd    0.3674337    0.2387345 5.655134e-01 -1.001212
 MSYd  3171.4409212 1743.5096878 5.768845e+03  8.061941
Stochastic reference points (Srp)
          estimate        cilow        ciupp   log.est rel.diff.Drp
 Bmsys 8560.816407 3348.3906625 2.188740e+04  9.054951 -0.008236507
 Fmsys    0.365535    0.2365569 5.648358e-01 -1.006393 -0.005194391
 MSYs  3129.144038 1730.7489290 5.657402e+03  8.048515 -0.013517078

States w 95% CI (inp$msytype: s)
                   estimate        cilow        ciupp    log.est
 B_2023.94      6693.0467955 2848.4817805 15726.579581  8.8088245
 F_2023.94         0.5796528    0.1062650     3.161882 -0.5453260
 B_2023.94/Bmsy    0.7818234    0.2885064     2.118663 -0.2461264
 F_2023.94/Fmsy    1.5857656    0.2802928     8.971519  0.4610673

Predictions w 95% CI (inp$msytype: s)
                 prediction        cilow        ciupp    log.est
 B_2025.00      5911.2236978 1271.3278231 27485.094695  8.6846081
 F_2025.00         0.5796531    0.0516071     6.510685 -0.5453255
 B_2025.00/Bmsy    0.6904977    0.1353167     3.523489 -0.3703427
 F_2025.00/Fmsy    1.5857663    0.1375954    18.275712  0.4610677
 Catch_2024.00  3636.6231582 1048.7642761 12610.105337  8.1988108
 E(B_inf)       3386.4748783           NA           NA  8.1275448
```

Table 2 Results from SPiCT model

	Estimate	CI lower	CI upper	log.est	2022 estimate
alpha1 (noise term for CPUE, $\alpha = SD_{Index}/SD_{Biomass}$)	1.49	0.21	10.63	0.40	1.53
alpha2 (noise term for survey, $\alpha = SD_{Index}/SD_{Biomass}$)	5.68	0.99	32.55	1.74	7.18
beta ($\beta = SD_{Catch}/SD_F$)	0.54	0.17	1.70	-0.62	0.47
r (intrinsic population growth rate)	0.73	0.48	1.13	-0.31	0.79
m (SPiCT parameter)	3171	1744	5769	8.06	2894
K (Carrying capacity)	17263	6725	44311	9.76	14608
q1 (Catchability for CPUE)	0.11	0.06	0.17	-2.25	0.12
q2 (Catchability for survey)	1.25	0.70	2.21	0.22	1.35
*n (*shape of the production curve, set to 2)	2.00	2.00	2.00	0.69	2.00
sdb (Standard deviation, biomass)	0.09	0.02	0.50	-2.41	0.07
sdf (Standard deviation, fishing mortality)	0.85	0.43	1.71	-0.16	0.93
sdi1 (Standard deviation, CPUE)	0.13	0.07	0.26	-2.01	0.11
sdi2 (Standard deviation, Survey)	0.51	0.34	0.77	-0.68	0.52
Sdc (Standard deviation, catch)	0.46	0.24	0.86	-0.78	0.44
B (Biomass end of 2023)	6693	2849	15727	8.81	6199*
F (Fishing mortality end of 2023)	0.58	0.11	3.16	-0.55	0.65*
Relative reference points					
B/B_{msy}, end current year (proj.) (%)	0.78	0.29	2.12	-0.25	0.85
F/F_{msy}, end current year (proj.) (%)	1.59	0.28	8.97	0.46	1.63

Table 3. Correlation matrix for the estimated SPiCT model parameters

	logm	logK	logq	logq	logn
logm	1.000000000	0.940322933	-3.456068e-01	-3.286936e-01	-1.080388e-03
logK	0.940322933	1.000000000	-4.714521e-01	-4.387901e-01	-2.845839e-03
logq	-0.345606800	-0.471452125	1.000000e+00	8.472930e-01	1.698379e-05
logq	-0.328693616	-0.438790142	8.472930e-01	1.000000e+00	6.351028e-05
logn	-0.001080388	-0.002845839	1.698379e-05	6.351028e-05	1.000000e+00
logsdb	0.105003213	0.094593701	-1.184271e-01	-1.063923e-01	-1.248910e-04
logsdf	0.198642927	0.175025939	-1.987293e-01	-1.538170e-01	-1.493073e-04
logsdi	0.018181189	0.125242031	-1.530443e-01	-1.292453e-01	-9.034874e-05
logsdi	0.025251139	0.008835635	-3.460856e-03	8.668715e-03	-8.656599e-05
logsdc	-0.327246455	-0.326589621	1.320243e-01	8.940919e-02	1.381378e-04

	logsdb	logsdf	logsdi	logsdi	logsdc
logm	0.105003213	0.1986429274	1.818119e-02	2.525114e-02	-0.3272464549
logK	0.094593701	0.1750259388	1.252420e-01	8.835635e-03	-0.3265896213
logq	-0.118427075	-0.1987292976	-1.530443e-01	-3.460856e-03	0.1320243367
logq	-0.106392254	-0.1538170306	-1.292453e-01	8.668715e-03	0.0894091947
logn	-0.000124891	-0.0001493073	-9.034874e-05	-8.656599e-05	0.0001381378
logsdb	1.000000000	-0.0449172228	-2.126221e-01	3.913326e-02	0.0145090077
logsdf	-0.044917223	1.0000000000	-2.329628e-01	9.116991e-02	-0.5178472199
logsdi	-0.212622148	-0.2329627647	1.000000e+00	-7.804576e-02	0.1016116707
logsdi	0.039133264	0.0911699101	-7.804576e-02	1.000000e+00	-0.0821624197
logsdc	0.014509008	-0.5178472199	1.016117e-01	-8.216242e-02	1.0000000000

Table 4. 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	3171.44	17262.65	0.11	1.25	2	0.09	0.85	0.13	0.51	0.46
Trial	1	0	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Trial	2	0.01	3171.44	17262.65	0.11	1.25	2	0.09	0.85	0.13	0.51	0.46
Trial	3	0	3171.44	17262.65	0.11	1.25	2	0.09	0.85	0.13	0.51	0.46
Trial	4	0.01	3171.44	17262.65	0.11	1.25	2	0.09	0.85	0.13	0.51	0.46
Trial	5	0	3171.44	17262.65	0.11	1.25	2	0.09	0.85	0.13	0.51	0.46
Trial	6	0.01	3171.44	17262.65	0.11	1.25	2	0.09	0.85	0.13	0.51	0.46
Trial	7	0.07	3171.44	17262.58	0.11	1.25	2	0.09	0.85	0.13	0.51	0.46
Trial	8	0	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Trial	9	0.04	3171.45	17262.68	0.11	1.25	2	0.09	0.85	0.13	0.51	0.46
Trial	10	0.01	3171.44	17262.66	0.11	1.25	2	0.09	0.85	0.13	0.51	0.46
Trial	11	0.01	3171.44	17262.66	0.11	1.25	2	0.09	0.85	0.13	0.51	0.46
Trial	12	0.01	3171.44	17262.65	0.11	1.25	2	0.09	0.85	0.13	0.51	0.46
Trial	13	0	3171.44	17262.65	0.11	1.25	2	0.09	0.85	0.13	0.51	0.46
Trial	14	0.01	3171.44	17262.65	0.11	1.25	2	0.09	0.85	0.13	0.51	0.46
Trial	15	0.01	3171.44	17262.65	0.11	1.25	2	0.09	0.85	0.13	0.51	0.46
Trial	16	0.01	3171.44	17262.65	0.11	1.25	2	0.09	0.85	0.13	0.51	0.46
Trial	17	0.03	3171.44	17262.68	0.11	1.25	2	0.09	0.85	0.13	0.51	0.46
Trial	18	0.01	3171.44	17262.64	0.11	1.25	2	0.09	0.85	0.13	0.51	0.46
Trial	19	0	3171.44	17262.65	0.11	1.25	2	0.09	0.85	0.13	0.51	0.46
Trial	20	0	3171.44	17262.65	0.11	1.25	2	0.09	0.85	0.13	0.51	0.46

Table 5. Forecast for 2023 with eight scenarios and forecast with 6 catch options.

```
SPiCT timeline:

      Observations              Management
    2008.00 - 2024.00        2024.00 - 2025.00
 |-----------------------| ----------------------|

Management evaluation: 2025.00

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

                 C B/Bmsy F/Fmsy
1. Scenario 1 1500   0.96   0.56
2. Scenario 2 2000   0.90   0.77
3. Scenario 3 2500   0.84   0.99
4. Scenario 4 3000   0.77   1.24
5. Scenario 5 3500   0.71   1.51
6. Scenario 6 4000   0.64   1.80

95% confidence intervals for states:

              B/Bmsy.lo B/Bmsy.hi F/Fmsy.lo F/Fmsy.hi
1. Scenario 1      0.34      2.73      0.05      6.40
2. Scenario 2      0.28      2.85      0.07      8.83
3. Scenario 3      0.23      3.00      0.09     11.44
4. Scenario 4      0.19      3.20      0.11     14.28
5. Scenario 5      0.15      3.44      0.13     17.38
6. Scenario 6      0.11      3.76      0.16     20.79
```

Catch options and relative reference points

Catch (t)	B/Bmsy	F/Fmsy	Prob B > Bmsy	Prob B < Blim	Prob F>Fmsy
1500	0.96	0.56	0.47	0.02	0.32
2000	0.90	0.77	0.43	0.03	0.42
2500	0.84	0.99	0.39	0.06	0.50
3000	0.77	1.24	0.36	0.10	0.57
3500	0.71	1.51	0.33	0.14	0.63
4000	0.64	1.81	0.31	0.20	0.68

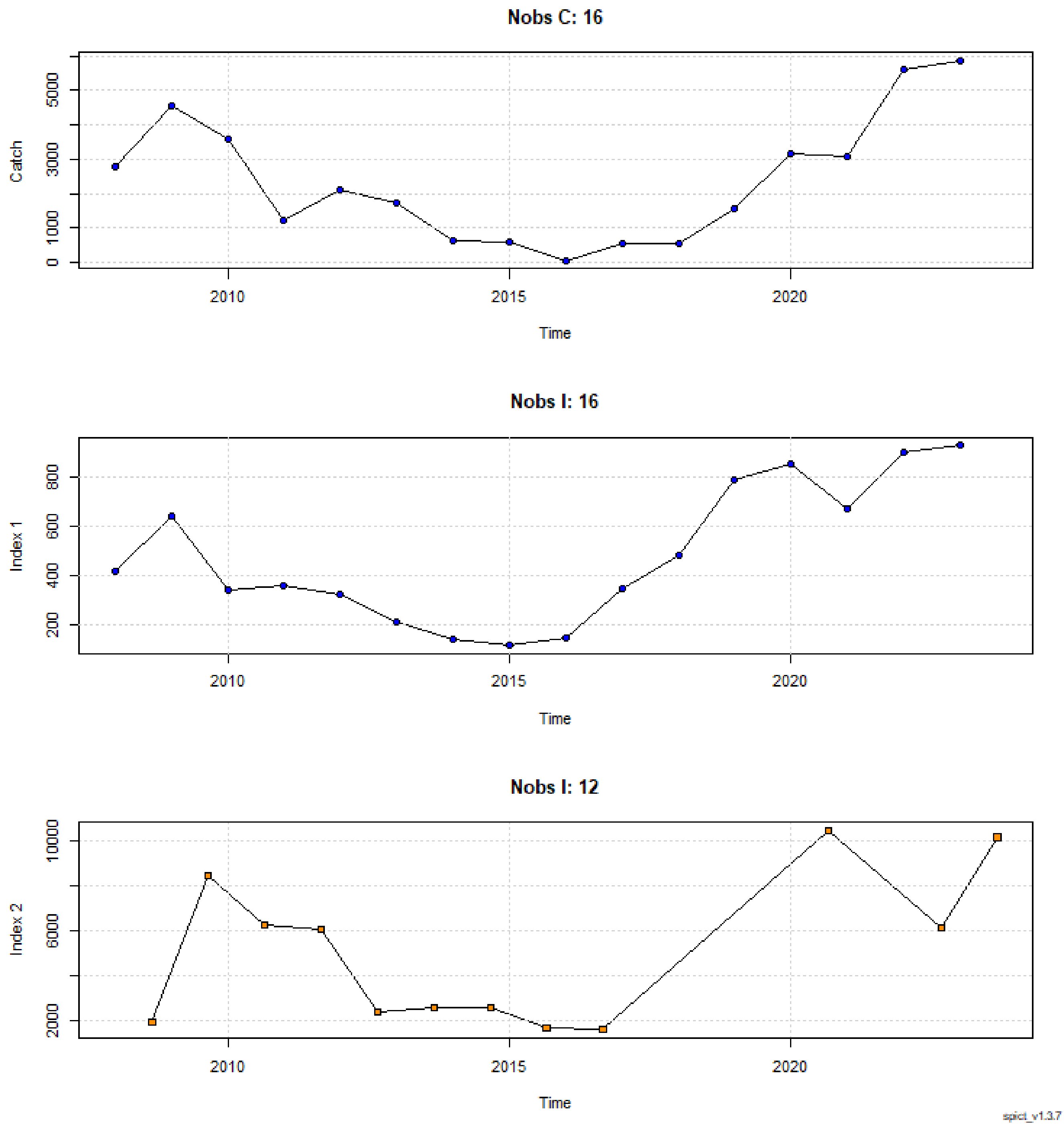

Figure 1. Input data for the SPiCT models of East Greenland northern shrimp stock. Top: Catch, Middle: CPUE index, Bottom: Survey index.

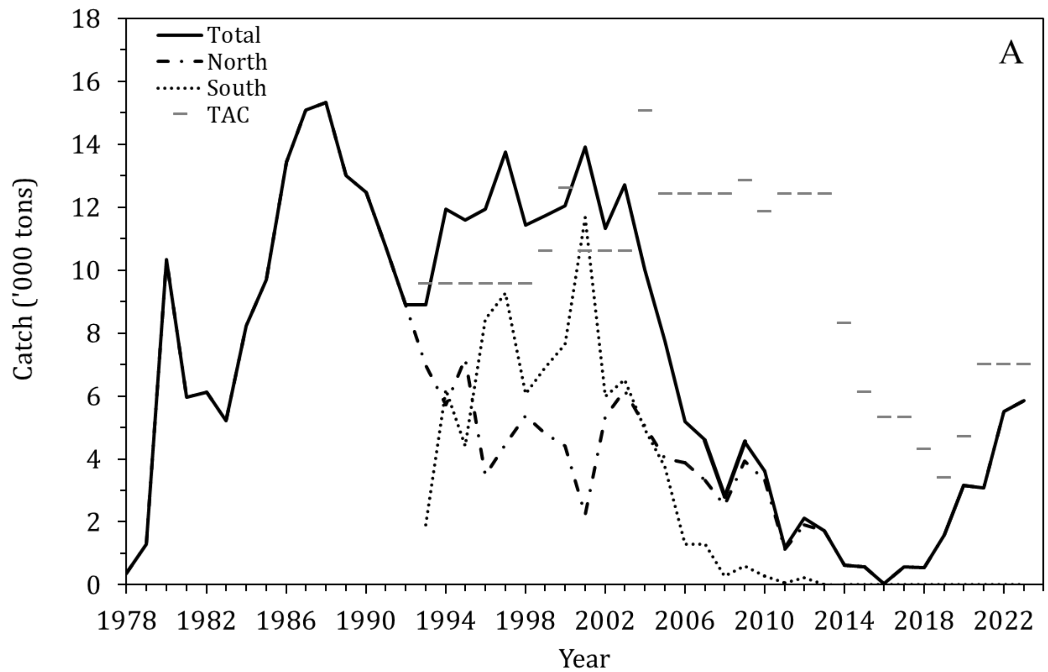

Figure 2. Total catch and TAC of East Greenland northern shrimp.

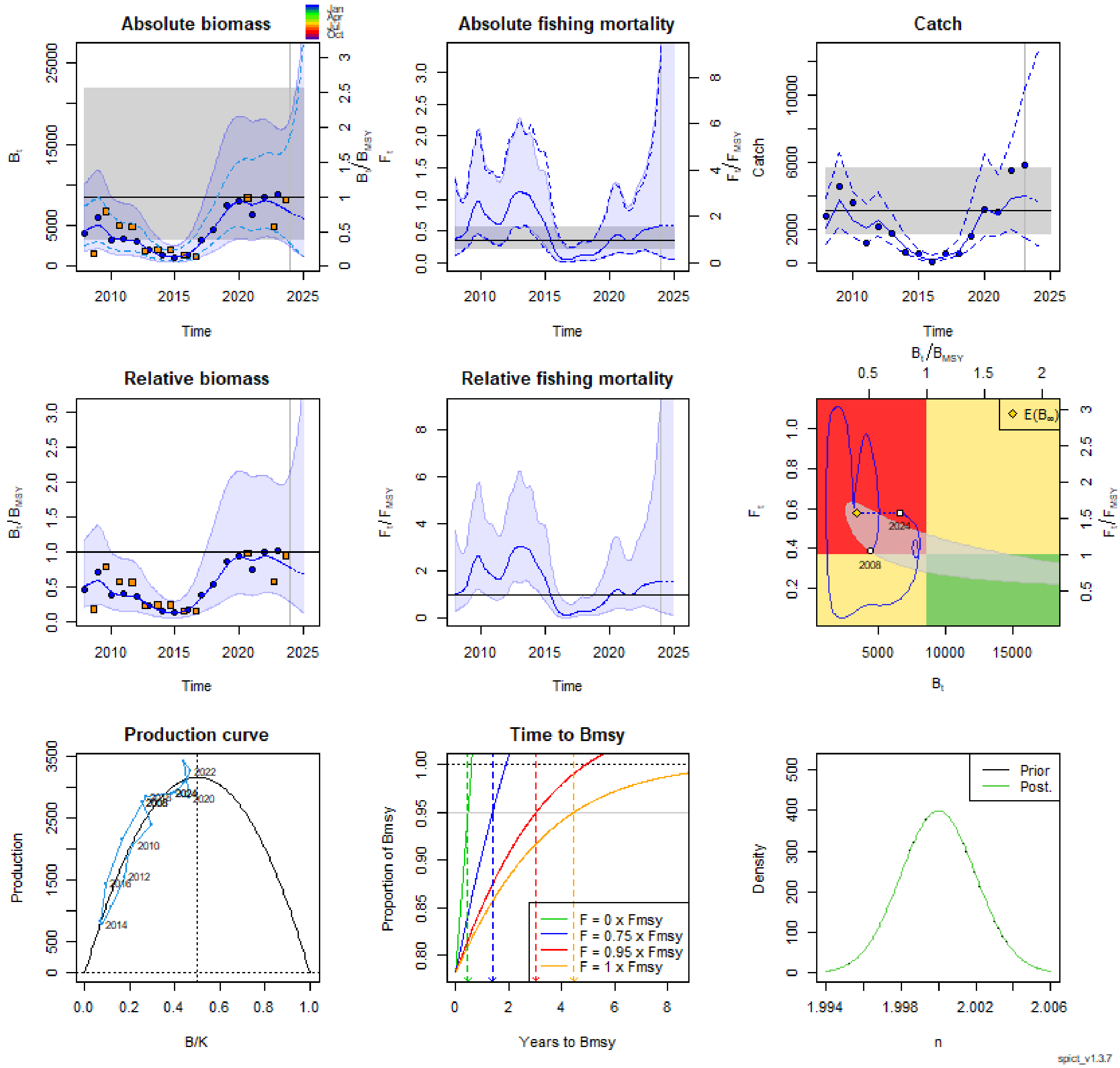

Figure 3. Main results of the model with n fixed to 2.

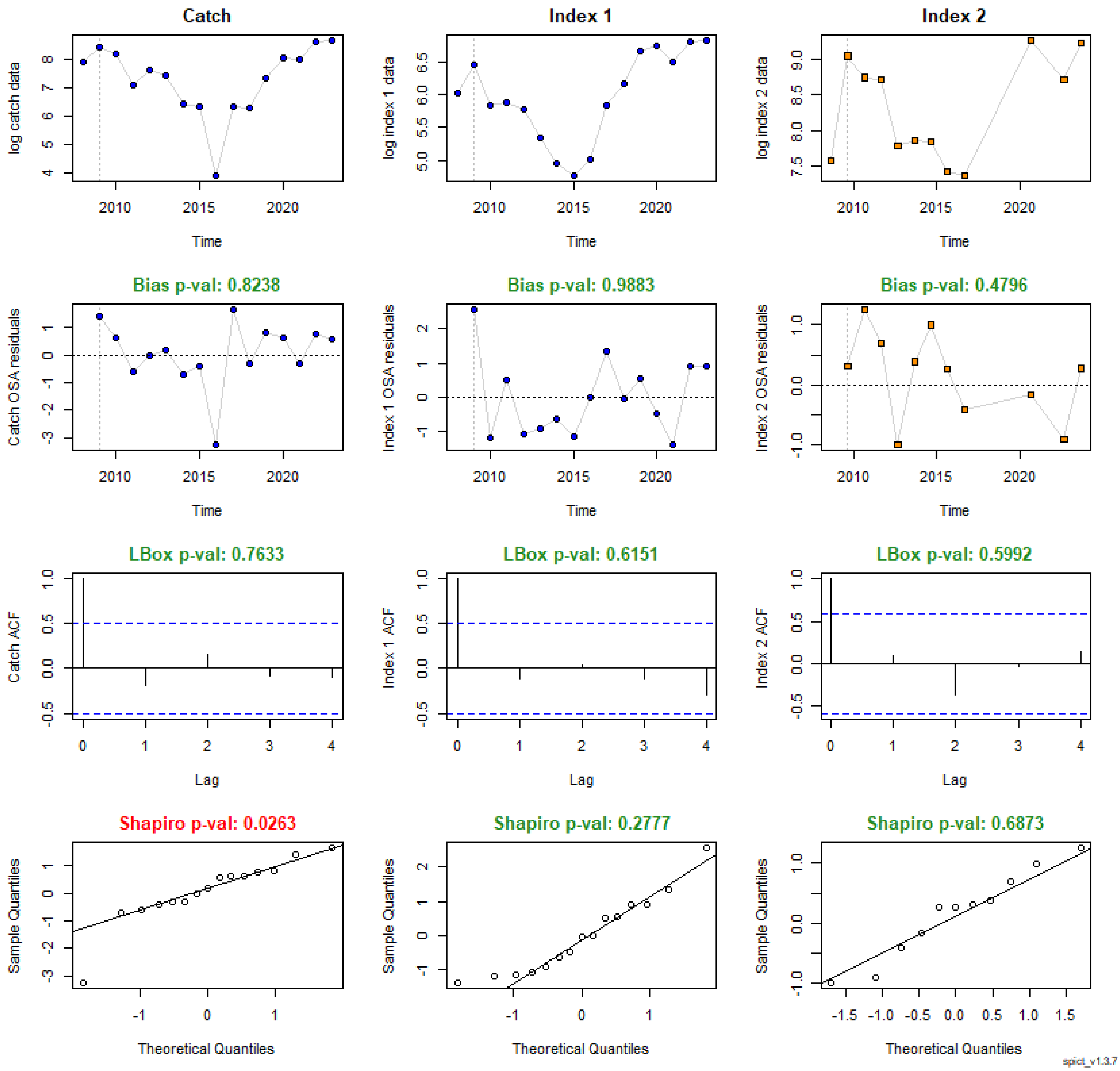

Figure 4. Diagnostics. First row show log of the input data series; catch, CPUE and survey index. Second row "one-step ahead" (OSA) residuals and a test for bias. Third row show the autocorrelation of the residuals including Ljung-Box test of multiple lags and tests for the individual lags. Fourth row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

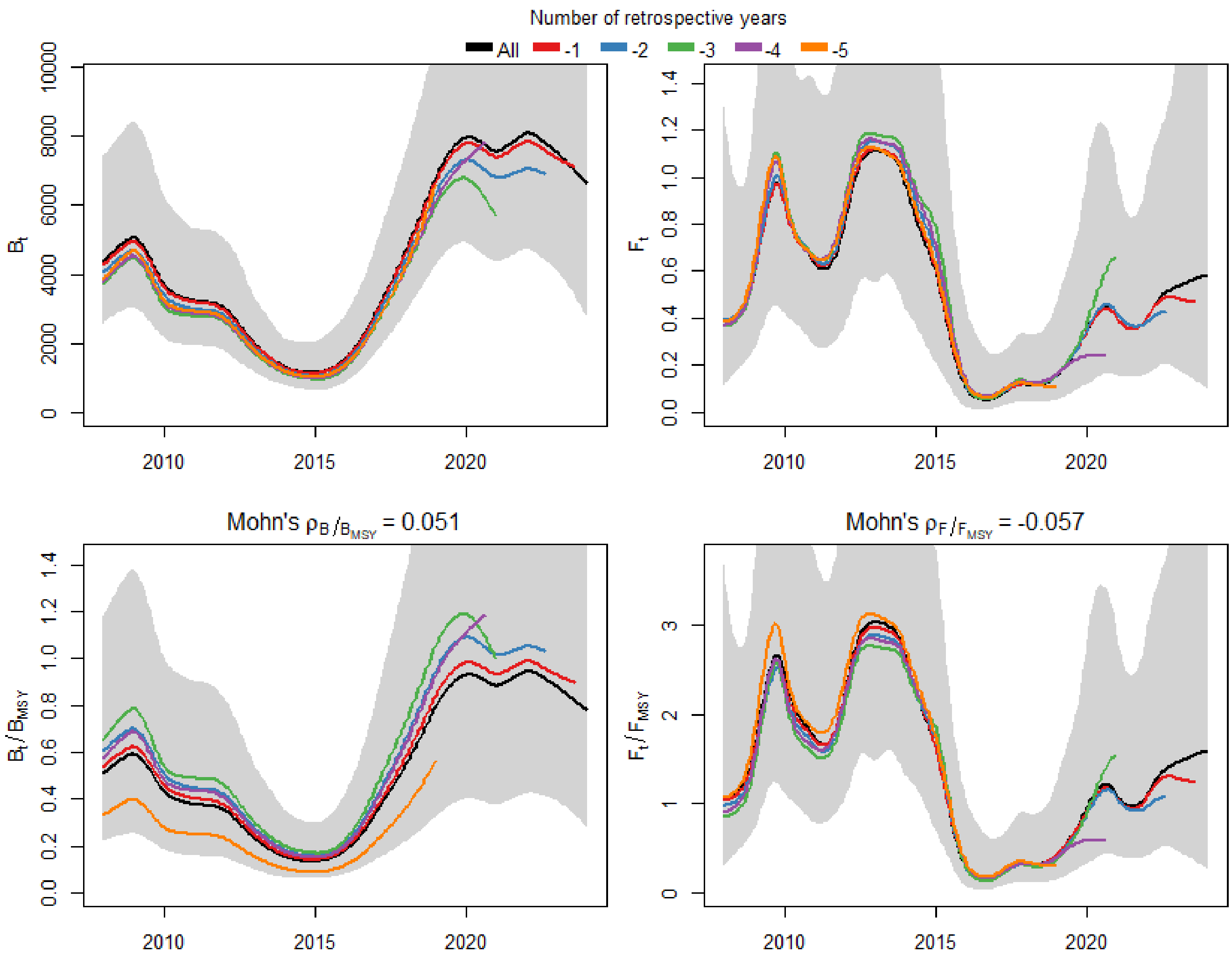

Figure 5. Five years retrospective plots of fishing mortality and fishable biomass.

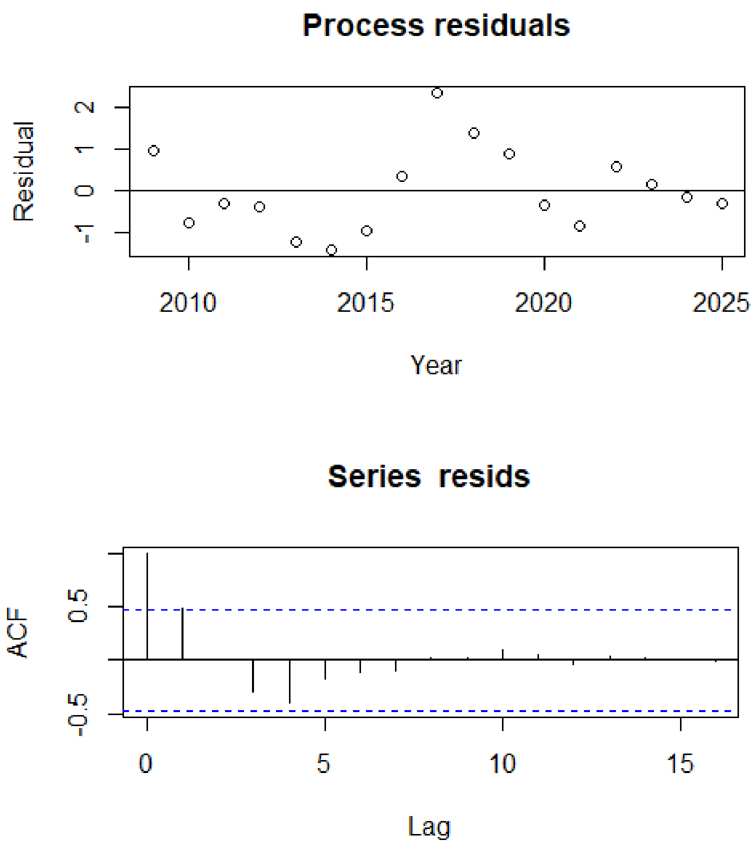

Figure 6. Above is shown the normalized process error. Below is shown the autocorrelation of the process error.