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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 2025 should not be above 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 2025. The present document presents the base for the advice for 2026.

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 and Burmeister. 2025a) and research survey data since 2008 (Buch and Burmeister 2025b). The catch was at a high level until the early 2000s when it started to

decrease (Figure 2), and it is believed 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 therefore the time point for the biomass data is shifted a bit by adding 0.66 in the model, to specify that estimates are taken around August. No surveys were conducted in 2017, 2018, 2019 and 2021. Catch and CPUE is only available for the first half of 2025, it is assumed that the total catch for 2025 will be the same as the enacted TAC (7550 t). The standard deviation (SD) of the catch and CPUE in the present year was applied by a factor 2 as it only data for the first half of the year are available. 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 = 0.71) is considered too high. In West Greenland and the Barents Sea where surplus production models are applied for northern shrimp, the r is approximately 0.3 (Burmeister and Buch, 2025, ICES, 2022). The standard deviation of the catch is estimated to 0.49 and is also considered in the higher end as the catch data is generally considered rather precise. The carrying capacity (K) is estimated to 19 052 t and B_{msy} to 9 435 t. B_{lim} is equal to 30% of B_{msy}, B_{lim} is estimated to 2 831 t. The relative Biomass/B_{msy} end of 2025 is 0.48, which is well below 1 and below $B_{trigger}$ (75% of B_{msy}), while the relative fishing mortality/F_{msy} is 2.22 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. The model does not estimate the most recent high catches well. The model follows the CPUE index well, but do not capture the fluctuations in the survey index.

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 below a p-value of 5% (Figure 4, fourth row). 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 with the exception of two trials which did not converge (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 (0.040 and 0.048 for B/B_{msy} and F/F_{msy} , respectively) (Figure 5). Hindcasting was done to check the ability of the model to predict data points for each index by removing a data point and keeping the catch information. For both indices the MASE predictor was below 1, which is considered good (Figure 6).

The process error is shown in Figure 7. The residuals of the process error generally show no bias and has been relatively low the last five years.

Table 4 shows the forecast for 2026 with 3 F scenarios (based on NAFO precautionary approach for stocks in the Cautious Zone) and 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). There is no management plan for this stock. However, catches of 500 t gives a very low (less than 10%) risk of going below B_{lim}.

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Table 1. Results from the SPiCT model.

```
Convergence: 0  MSG: relative convergence (4)
Objective function at optimum: 46.7030749
Euler time step (years):  1/16 or 0.0625
Nobs C: 18,  Nobs I1: 18,  Nobs I2: 14

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 1.370210e+00    0.1857058 1.010995e+01  0.3149644
 alpha2 6.454890e+00    1.1245902 3.704959e+01  1.8648380
 beta   6.135736e-01    0.2387716 1.576706e+00 -0.4884551
 r      7.088423e-01    0.4492757 1.118372e+00 -0.3441223
 rc     7.088413e-01    0.4492795 1.118359e+00 -0.3441237
 rold   7.088403e-01    0.4492795 1.118356e+00 -0.3441251
 m      3.376172e+03 2005.2056748 5.684472e+03  8.1244977
 K      1.905177e+04 7847.5476515 4.625265e+04  9.8549152
 q1     8.953360e-02    0.0550859 1.455229e-01 -2.4131418
 q2     1.050287e+00    0.5814339 1.897212e+00  0.0490637
 n      2.000003e+00    1.9960867 2.003927e+00  0.6931486
 sdb    9.555900e-02    0.0170914 5.342751e-01 -2.3480119
 sdf    7.919221e-01    0.4322029 1.451033e+00 -0.2332922
 sdi1   1.309359e-01    0.0680757 2.518405e-01 -2.0330475
 sdi2   6.168226e-01    0.4204478 9.049163e-01 -0.4831739
 sdc    4.859025e-01    0.2869932 8.226719e-01 -0.7217474

Deterministic reference points (Drp)
          estimate        cilow        ciupp   log.est
 Bmsyd 9525.8894964 3923.7833298 2.312629e+04  9.161769
 Fmsyd    0.3544206    0.2246397 5.591797e-01 -1.037271
 MSYd  3376.1717320 2005.2056748 5.684472e+03  8.124498
Stochastic reference points (Srp)
          estimate        cilow        ciupp   log.est rel.diff.Drp
 Bmsys 9435.2553411 3914.7596854 2.274062e+04  9.152209 -0.009605904
 Fmsys    0.3522436    0.2216958 5.596659e-01 -1.043432 -0.006180460
 MSYs  3323.3113726 1991.5968111 5.545499e+03  8.108717 -0.015905930

States w 95% CI (inp$msytype: s)
                   estimate        cilow        ciupp    log.est
 B_2025.94      4540.7006487 1681.5884284 12261.003961  8.4208366
 F_2025.94         0.7836344    0.1666866     3.684057 -0.2438127
 B_2025.94/Bmsy    0.4812483    0.1499050     1.544978 -0.7313719
 F_2025.94/Fmsy    2.2246942    0.4541498    10.897868  0.7996195

Predictions w 95% CI (inp$msytype: s)
                 prediction        cilow        ciupp    log.est
 B_2027.00      3556.8328761  478.6075194 26433.057558  8.1766258
 F_2027.00         0.7836347    0.0845932     7.259253 -0.2438124
 B_2027.00/Bmsy    0.3769726    0.0444328     3.198276 -0.9755827
 F_2027.00/Fmsy    2.2246950    0.2333409    21.210458  0.7996198
 Catch_2026.00  3145.2511844 1160.3946514  8525.207352  8.0536490
 E(B_inf)               NaN           NA           NA        NaN
```

Table 2 **Results from SPiCT model.** 2024 and 2023 estimates are based on a SPiCT model with only half year data for the terminal year.

	Estimate	CI lower	CI upper	log.est	2024 est	2023 estimate
alpha1 (noise term for CPUE, $\alpha = SD_{Index}/SD_{Biomass}$)	1.37	0.19	10.11	0.31	1.42	1.49
alpha2 (noise term for survey, $\alpha = SD_{Index}/SD_{Biomass}$)	6.45	1.12	37.05	1.86	6.92	5.68
beta ($\beta = SD_{Catch}/SD_F$)	0.61	0.24	1.58	-0.49	0.54	0.54
r (intrinsic population growth rate)	0.71	0.45	1.12	-0.34	0.73	0.73
m (SPiCT parameter)	3376.17	2005.21	5684.47	8.12	3227	3171
K (Carrying capacity (tons))	19051.77	7847.55	46252.65	9.85	17690	17263
q1 (Catchability for CPUE)	0.09	0.06	0.15	-2.41	0.10	0.11
q2 (Catchability for survey)	1.05	0.58	1.90	0.05	1.12	1.25
*n (*shape of the production curve, set to 2)	2.00	2.00	2.00	0.69	2.00	2.00
sdb (Standard deviation, biomass)	0.10	0.02	0.53	-2.35	0.09	0.09
sdf (Standard deviation, fishing mortality)	0.79	0.43	1.45	-0.23	0.84	0.85
sdi1 (Standard deviation, CPUE)	0.13	0.07	0.25	-2.03	0.13	0.13
sdi2 (Standard deviation, Survey)	0.62	0.42	0.90	-0.48	0.63	0.51
Sdc (Standard deviation, catch)	0.49	0.29	0.82	-0.72	0.45	0.46
B (Biomass end of 2025)	4540.70	1681.59	12261.00	8.42	5061	6693
F (Fishing mortality end of 2025)	0.78	0.17	3.68	-0.24	0.90	0.58
Relative reference points						
B/B_{msy}, end current year (proj.) (%)	0.48	0.15	1.54	-0.73	0.58	0.78
F/F_{msy}, end current year (proj.) (%)	2.22	0.45	10.90	0.80	2.47	1.59

Table 3. Correlation matrix for the estimated SPiCT model parameters

	logm	logK	logq	logq	logn	logsdb	logsdf	logsdi	logsdi	logsdc
logm	1.00	0.92	-0.38	-0.32	0.00	0.15	0.16	0.11	0.01	-0.39
logK	0.92	1.00	-0.51	-0.43	0.00	0.17	0.14	0.21	-0.01	-0.40
logq	-0.38	-0.51	1.00	0.82	0.00	-0.20	-0.20	-0.17	0.02	0.16
logq.1	-0.32	-0.43	0.82	1.00	0.00	-0.15	-0.15	-0.16	0.04	0.11
logn	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00
logsdb	0.15	0.17	-0.20	-0.15	0.00	1.00	-0.02	-0.27	0.04	-0.09
logsdf	0.16	0.14	-0.20	-0.15	0.00	-0.02	1.00	-0.22	0.08	-0.39
logsdi	0.11	0.21	-0.17	-0.16	0.00	-0.27	-0.22	1.00	-0.09	0.09
logsdi.1	0.01	-0.01	0.02	0.04	0.00	0.04	0.08	-0.09	1.00	-0.08
logsdc	-0.39	-0.40	0.16	0.11	0.00	-0.09	-0.39	0.09	-0.08	1.00

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).

Trial	Distance	m	K	q	q	n	sdb	sdf	sdi	sdi	sdc
Base		3376.17	19051.77	0.09	1.05	2	0.1	0.79	0.13	0.62	0.49
1	0.21	3376.17	19051.98	0.09	1.05	2	0.1	0.79	0.13	0.62	0.49
2	0.23	3376.17	19052	0.09	1.05	2	0.1	0.79	0.13	0.62	0.49
3	0.2	3376.17	19051.97	0.09	1.05	2	0.1	0.79	0.13	0.62	0.49
4	0.25	3376.18	19052.02	0.09	1.05	2	0.1	0.79	0.13	0.62	0.49
5	0	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
6	0.23	3376.17	19052	0.09	1.05	2	0.1	0.79	0.13	0.62	0.49
7	0	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
8	0	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
9	0.25	3376.18	19052.01	0.09	1.05	2	0.1	0.79	0.13	0.62	0.49
10	0.23	3376.17	19052	0.09	1.05	2	0.1	0.79	0.13	0.62	0.49
11	0.23	3376.17	19052	0.09	1.05	2	0.1	0.79	0.13	0.62	0.49
12	0.26	3376.18	19052.03	0.09	1.05	2	0.1	0.79	0.13	0.62	0.49
13	0.23	3376.17	19052	0.09	1.05	2	0.1	0.79	0.13	0.62	0.49
14	0.29	3376.18	19052.06	0.09	1.05	2	0.1	0.79	0.13	0.62	0.49
15	0	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
16	0.23	3376.17	19052	0.09	1.05	2	0.1	0.79	0.13	0.62	0.49
17	0.23	3376.17	19052	0.09	1.05	2	0.1	0.79	0.13	0.62	0.49
18	0.24	3376.17	19052.01	0.09	1.05	2	0.1	0.79	0.13	0.62	0.49
19	0.23	3376.17	19052	0.09	1.05	2	0.1	0.79	0.13	0.62	0.49

Table 5. Forecast for end of 2026 with eight scenarios and forecast with 6 catch options.

Catch options and relative reference points

	Catch (t) 2026	B/B_{msy}	F/F_{msy}	**P($F > F_{lim}$)**	**P($B < B_{lim}$)**	**P($F > F_{Target}$)**	**P($B < B_{trigger}$)**	**P($B_{end2026} > B_{end2025}$)**
Cautious Zone								
F lower edge leaf	291	0.74	0.15	5%	6%	6%	51%	100%
F midrib leaf	628	0.7	0.33	17%	9%	20%	55%	100%
F upper edge leaf	1023	0.65	0.56	30%	12%	36%	59%	97%
Catch Scenarios (catch in 2026)								
500	500	0.71	0.26	12%	8%	15%	53%	100%
1000	1000	0.65	0.54	30%	12%	35%	58%	97%
1500	1500	0.59	0.86	45%	18%	50%	63%	82%
2000	2000	0.53	1.21	56%	25%	62%	67%	62%
2500	2500	0.46	1.61	66%	32%	71%	70%	48%
3000	3000	0.4	2.07	74%	40%	78%	73%	38%

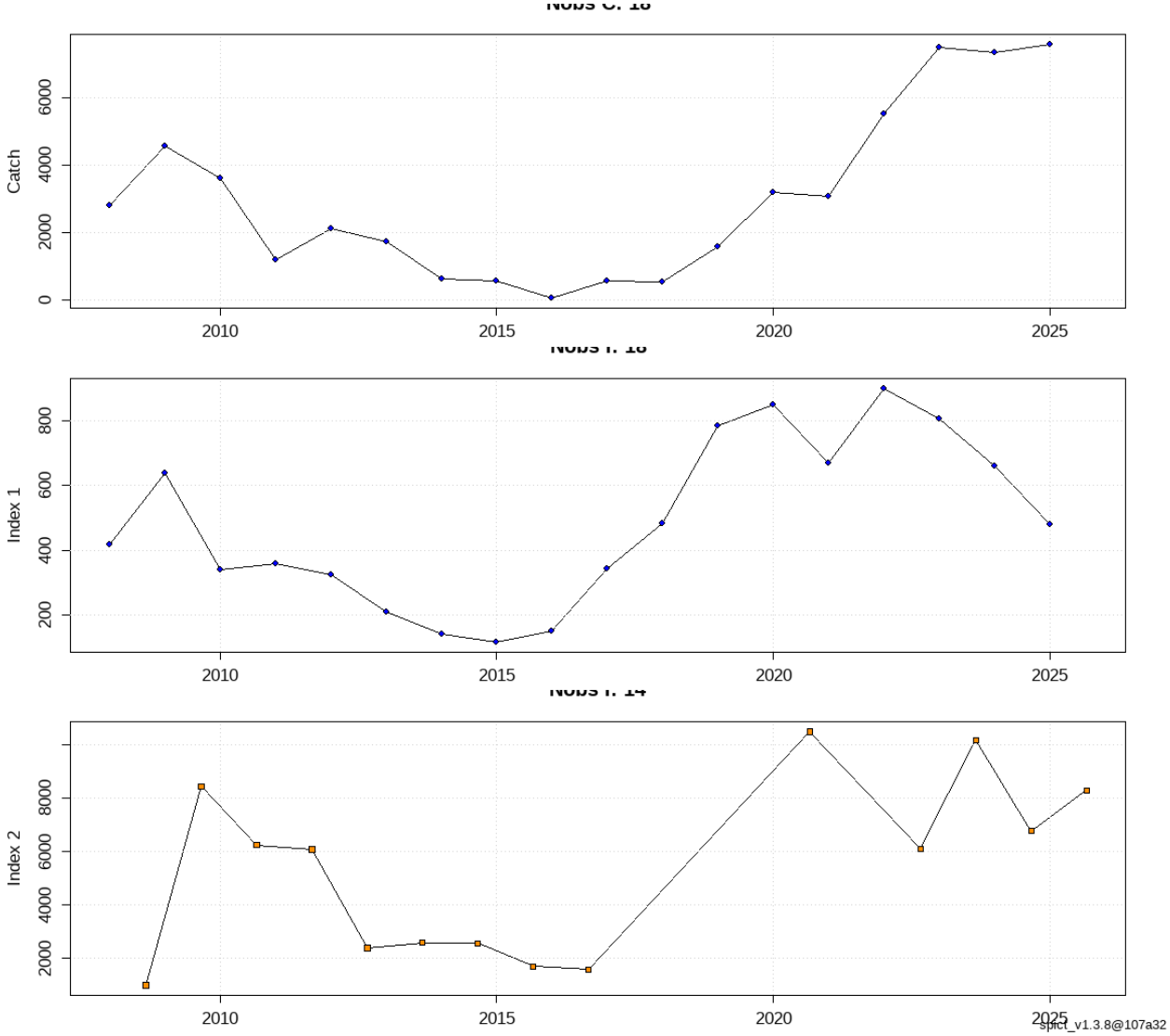

Figure 1. Input data for the SPiCT models of East Greenland northern shrimp stock. Top: Catch, Middle: CPUE index, Bottom: Survey index.

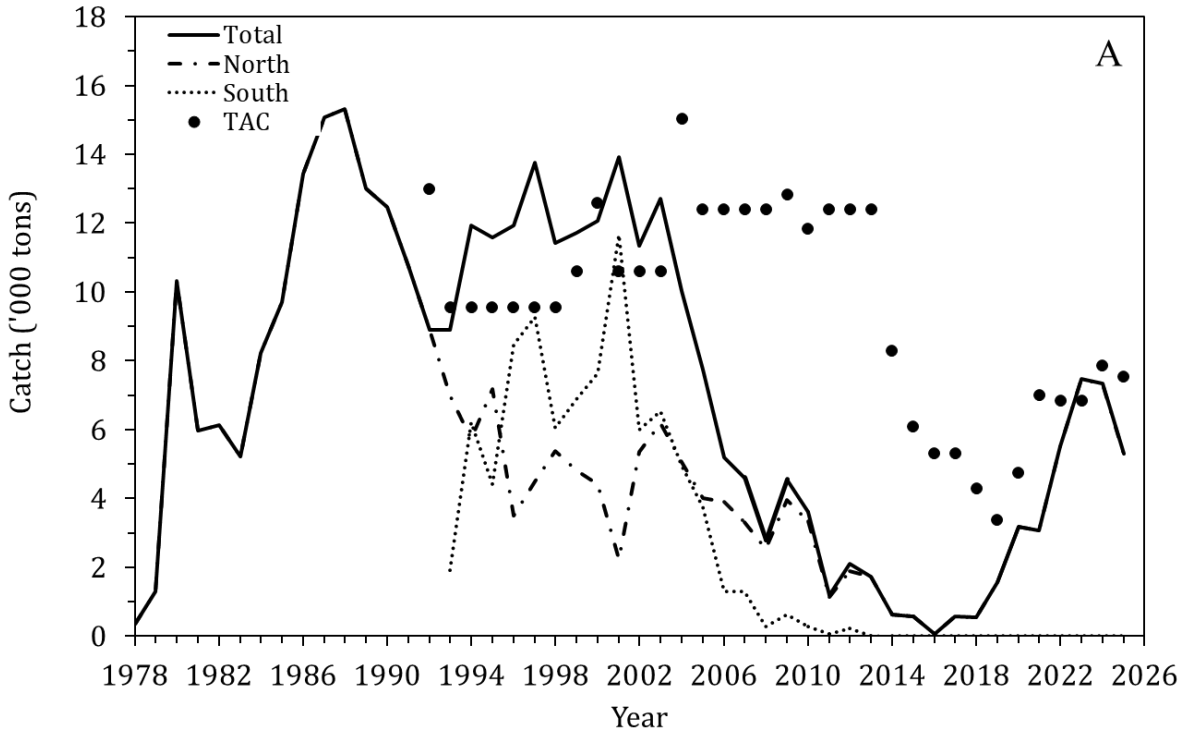

Figure 2. Total catch and TAC of East Greenland northern shrimp. The 2025 value is half year data.

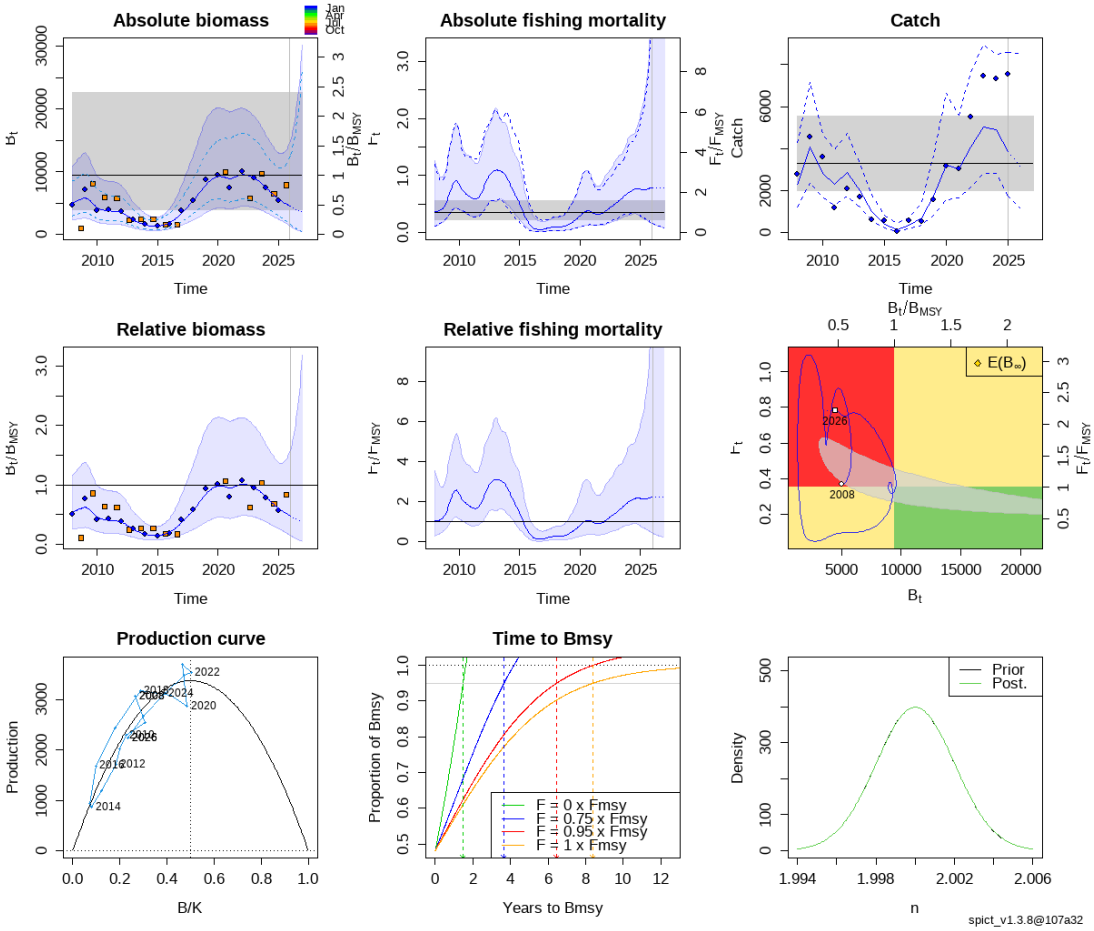

Figure 3. Main results of the model with n fixed to 2.

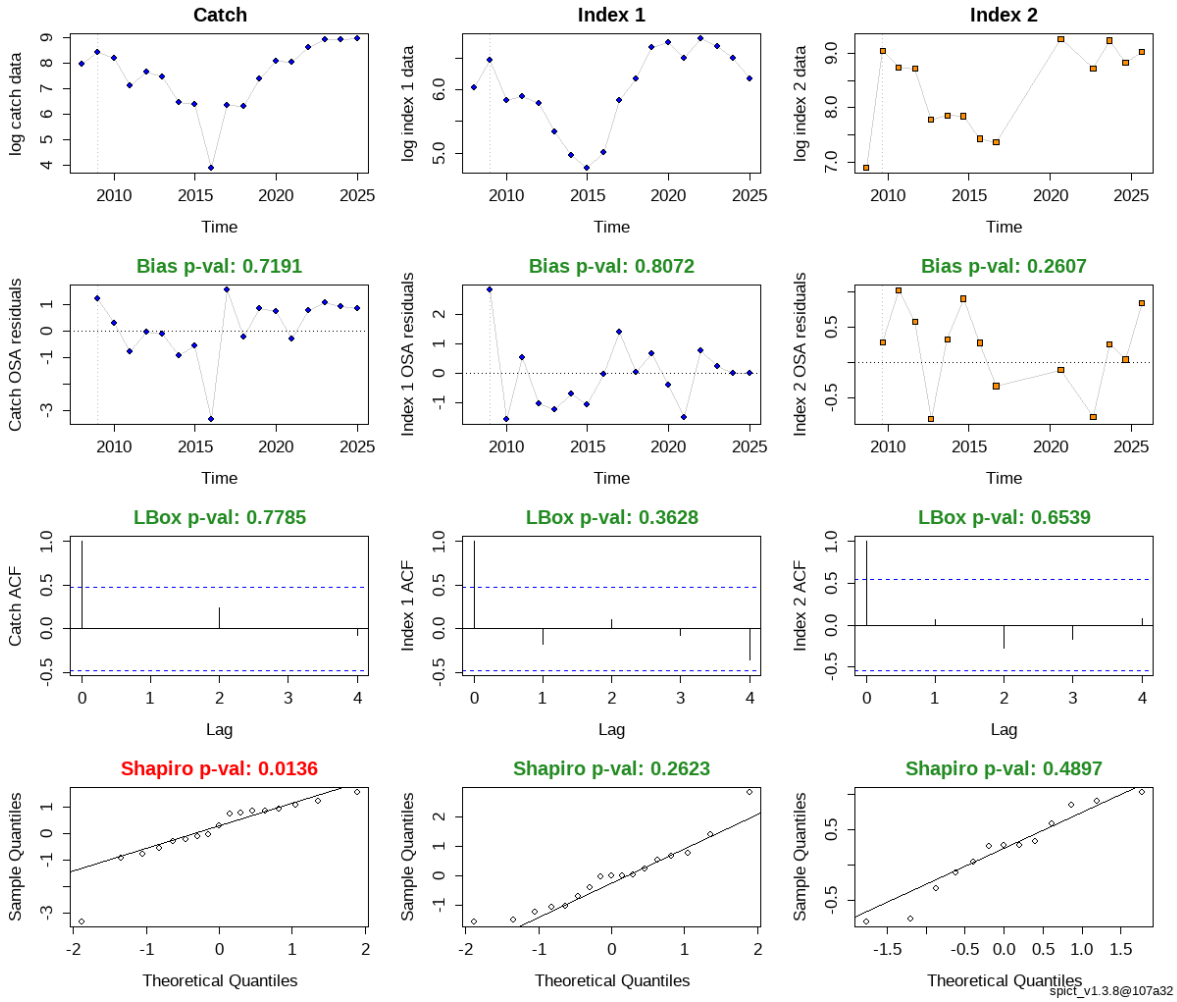

Figure 4. Diagnostics. First row show log of the input data series; catch, CPUE and survey index. Second row "one-step ahead" (OSA) residuals and a test for bias. Third row show the autocorrelation of the residuals including Ljung-Box test of multiple lags and tests for the individual lags. Fourth row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

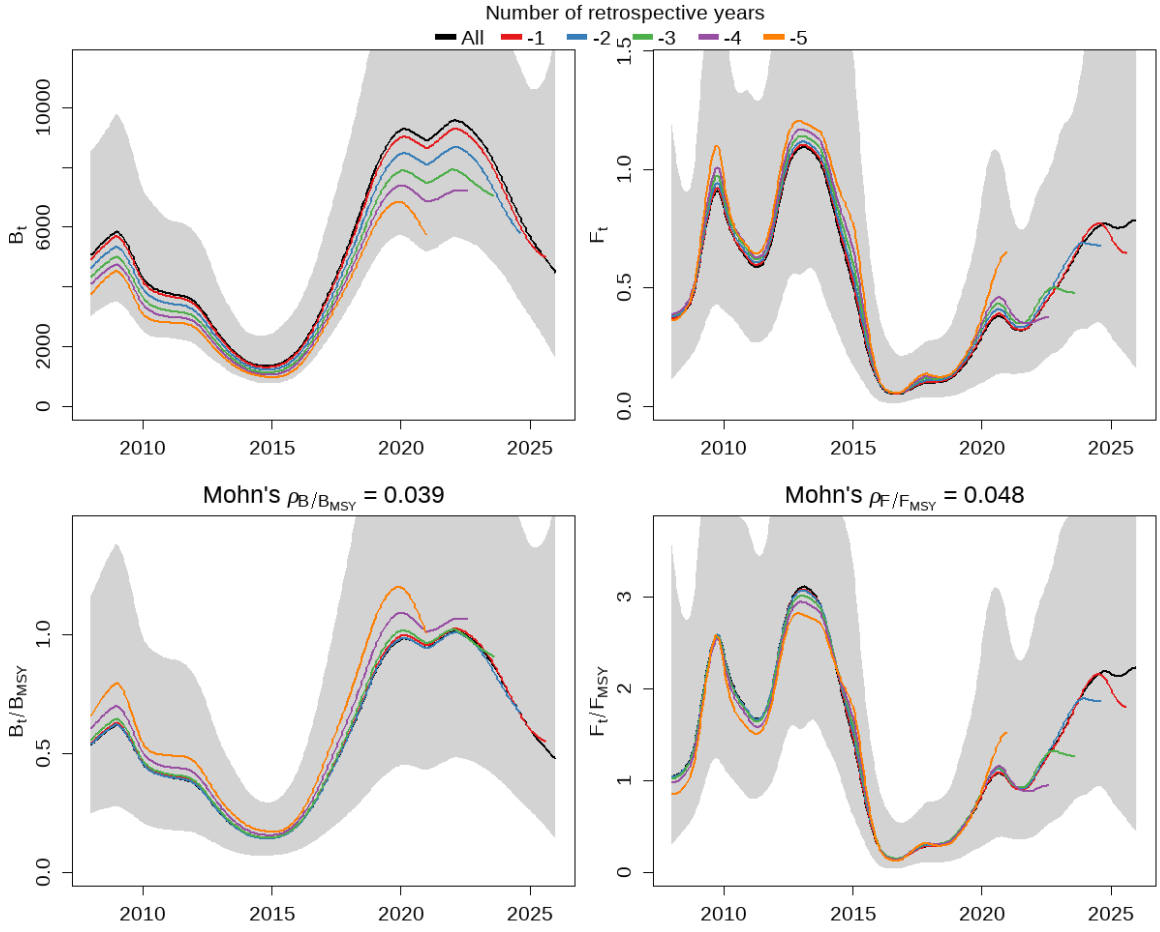

Figure 5. Five years retrospective plots of fishing mortality and fishable biomass.

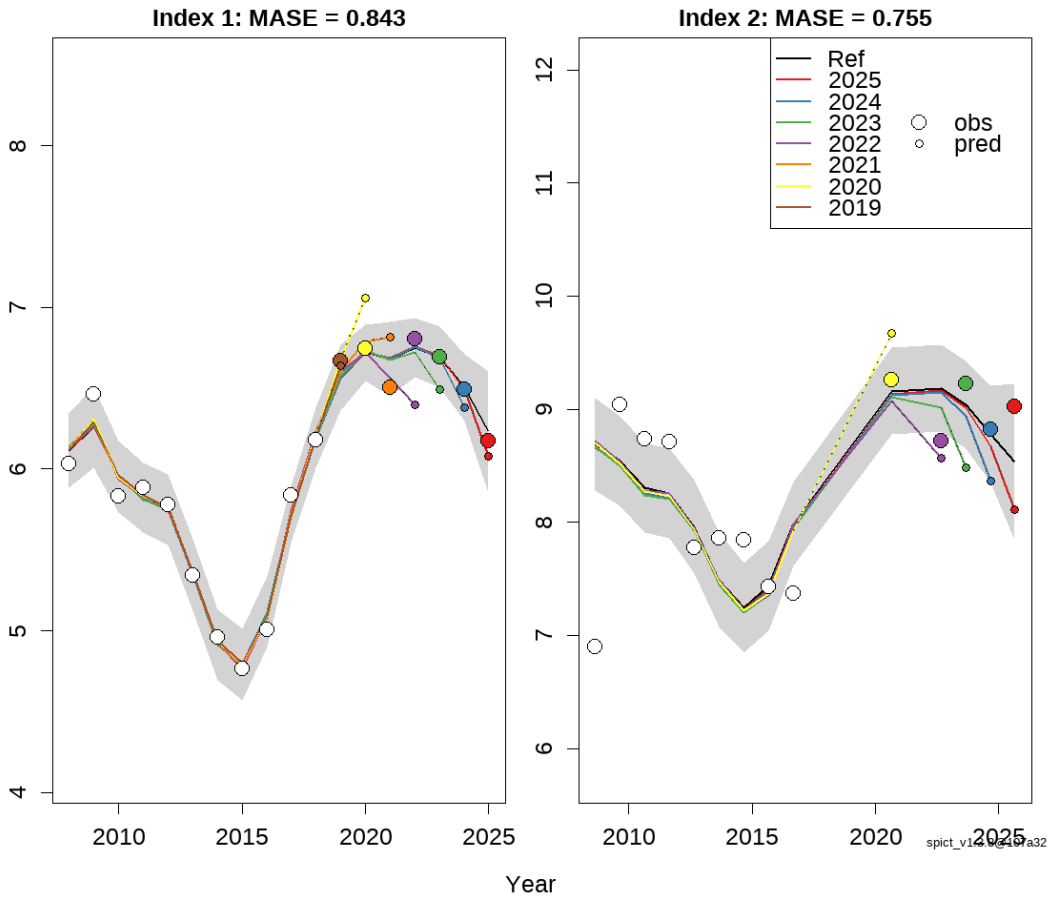

Figure 6. Hindcast by removing the 7 most recent data points for index 1(CPUE) and index 2 (survey index). MASE values given for each index.

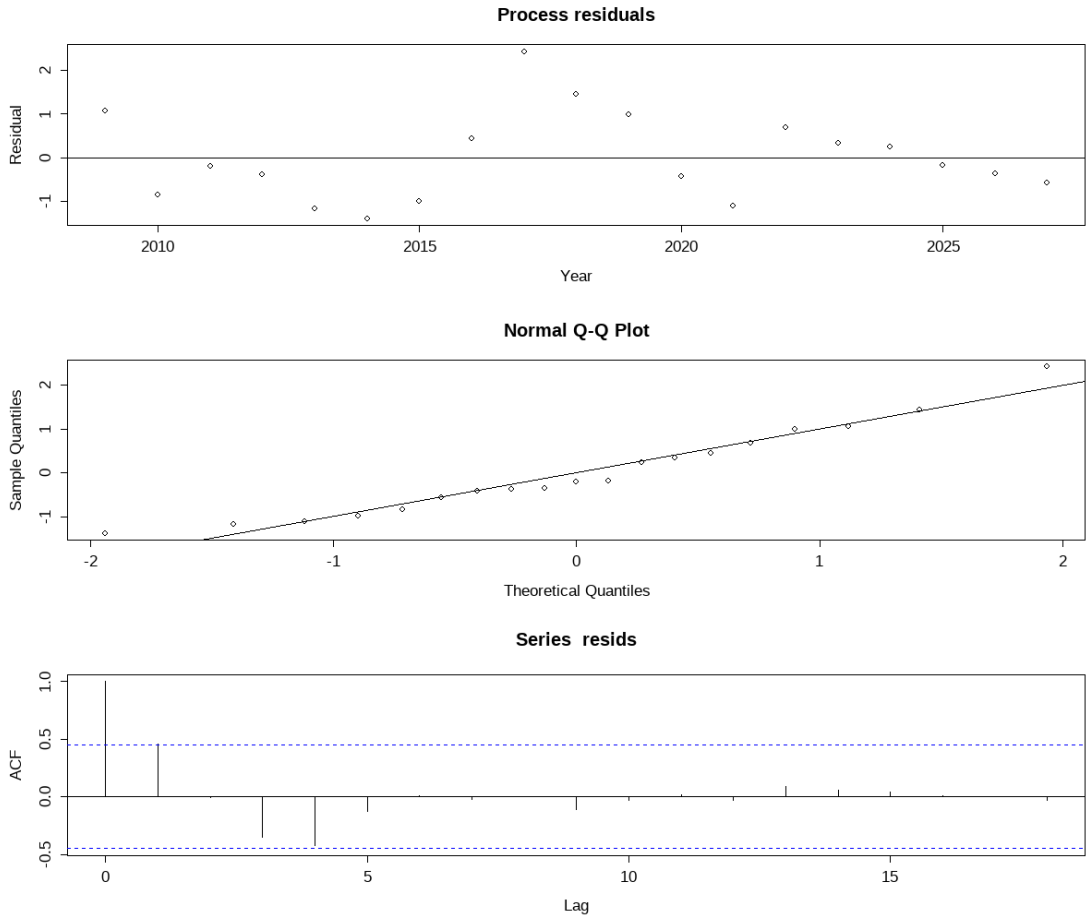

Figure 7. Top plot shows the process residuals. Middle plot shows the normalized process error. Bottom plot shows the autocorrelation of the process error.