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

by

Tanja B. Buch and AnnDorte Burmeister

Pinngortitaleriffik, Greenland Institute of Natural Resources
Box 570, 3900 Nuuk, Greenland

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. The relative Biomass/B_{msy} is 0.58, which is well below 1 and below $B_{trigger}$ (80% of B_{msy}), while the relative fishing mortality/F_{msy} is 2.47 considerably higher than 1. Using the output from SPiCT the catch in 2024 should not be above 1000 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 2024. The present document represents the base for the advice for 2025.

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. 2024a) and research survey data since 2008 (Buch and Burmeister 2024b). The catch was at a much higher level until the early 2000s when 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 July to September (in 2023 and 2024 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 0.45 and is also considered in the higher end as the catch data is generally considered rather precise. More weight is given to the CPUE index where the standard deviation is estimated to 0.13. The carrying capacity (K) is estimated to 17 690 t and B_{msy} to 8771 t, those values are higher than in the 2023 SPiCT run (17262 t and 8561 t respectively). Given the rule of thumb that B_{lim} is equal to 30% of B_{msy}, B_{lim} is estimated to 2 631 t. The relative Biomass/B_{msy} is 0.58, which is well below 1 and below $B_{trigger}$ (80% of B_{msy}), while the relative fishing mortality/F_{msy} is 2.47 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 capture the recent high catches well, and the confidence intervals around the recent estimated catches are large. This could be because the increase is not seen in the two indices to the same extent.

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 one trial (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 (0.106 and -0.04 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.

Table 4 shows the forecast for 2025 with forecast for 7 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 2 631 t. The table shows that the probability of being above B_{msy} varies between 0.21 to 0.34, highest for fishing 1 000 t. The probability of B being below B_{lim} varies between 0.06 to 0.44 highest for the catch option of 4 000 t. There is no management rule for this stock. However, catches of 1000 t gives a very low (less than 10%) risk of going below B_{lim}.

References

BUCH, T., BURMEISTER, A. 2024. Results of the Greenland Bottom Trawl Survey for Northern shrimp (P*andalus borealis*). *NAFO SCR Doc*., No.24/056 Serial No. N7447.

BUCH, T., BURMEISTER, A. 2024. The Fishery for Northern Shrimp (Pandalus borealis) in Denmark Strait / off East Greenland 1978 –2024.NAFO SCR Doc., No. 24/056 Serial No.N7448

ICES. 2021. Benchmark Workshop on the development of MSY advise for category 3 stocks using Surplus Production Model in Continuous Time; SPiCT (WKMSYSPICT). ICES SCeintific Reports. 3:20, 317 pp. https://doi.org/10.17895/ices.pub.7919.

MILDENBERGER, TK., KOKKALIS, A., BERG, CW. 2019. Guidelines for the stochastic production model in continuous time (SPiCT). https://github.com/DTUAqua/spict/blob/master/spict/inst/doc/spict_guidelines.pdf

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

RIGÉT, F., BURMEISTER, A., BUCH, T. 2021. Applying a stochastic model (SPiCT) to the East Greenland Stock of Northern Shrimp. NAFO SCR Doc. No22/051 No. 7332.

Table 1. Results from the SPiCT model.

```
Convergence: 0  MSG: relative convergence (4)
Objective function at optimum: 44.3412815
Euler time step (years):  1/16 or 0.0625
Nobs C: 17,  Nobs I1: 17,  Nobs I2: 13

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 1.415367e+00    0.1994074 1.004609e+01  0.3473889
 alpha2 6.917486e+00    1.2451318 3.843096e+01  1.9340524
 beta   5.379025e-01    0.1847413 1.566185e+00 -0.6200780
 r      7.297428e-01    0.4779095 1.114279e+00 -0.3150631
 rc     7.297419e-01    0.4779139 1.114266e+00 -0.3150643
 rold   7.297410e-01    0.4779140 1.114263e+00 -0.3150656
 m      3.227225e+03 1898.4394058 5.486074e+03  8.0793778
 K      1.768967e+04 7429.5410222 4.211894e+04  9.7807361
 q1     9.965790e-02    0.0626092 1.586300e-01 -2.3060122
 q2     1.124906e+00    0.6265920 2.019518e+00  0.1176995
 n      2.000002e+00    1.9960864 2.003926e+00  0.6931484
 sdb    9.051720e-02    0.0167514 4.891145e-01 -2.4022158
 sdf    8.438801e-01    0.4431219 1.607083e+00 -0.1697448
 sdi1   1.281150e-01    0.0656957 2.498407e-01 -2.0548269
 sdi2   6.261512e-01    0.4238666 9.249734e-01 -0.4681634
 sdc    4.539252e-01    0.2495692 8.256152e-01 -0.7898228

Deterministic reference points (Drp)
          estimate       cilow        ciupp   log.est
 Bmsyd 8844.838525 3714.779400 2.105944e+04  9.087589
 Fmsyd    0.364871    0.238957 5.571331e-01 -1.008212
 MSYd  3227.224763 1898.439406 5.486074e+03  8.079378
Stochastic reference points (Srp)
           estimate        cilow        ciupp   log.est rel.diff.Drp
 Bmsys 8770.5522472 3699.0843183 2.079503e+04  9.079155 -0.008469966
 Fmsys    0.3629246    0.2366796 5.565088e-01 -1.013560 -0.005362999
 MSYs  3182.9047099 1883.7135480 5.378144e+03  8.065549 -0.013924405

States w 95% CI (inp$msytype: s)
                    estimate        cilow        ciupp    log.est
 B_2024.94      5060.5590385 1815.8480402 14103.194329  8.5292322
 F_2024.94         0.8978879    0.1989239     4.052819 -0.1077101
 B_2024.94/Bmsy    0.5769943    0.1808356     1.841023 -0.5499228
 F_2024.94/Fmsy    2.4740341    0.5374834    11.387970  0.9058501

Predictions w 95% CI (inp$msytype: s)
                  prediction        cilow        ciupp    log.est
 B_2026.00      3497.5376752  392.2514072 31186.044374  8.1598145
 F_2026.00         0.8978882    0.0922514     8.739195 -0.1077097
 B_2026.00/Bmsy    0.3987819    0.0414103     3.840281 -0.9193406
 F_2026.00/Fmsy    2.4740349    0.2509013    24.395449  0.9058504
 Catch_2025.00  3773.3496334 1446.6342778  9842.271592  8.2357184
 E(B_inf)                NaN           NA           NA        NaN
```

Table 2. Results from SPiCT model

	Estimate	CI lower	CI upper	log.est	2023 estimate
alpha1 (noise term for CPUE, α = $SD_{Index}/SD_{Biomass}$)	1.42	0.20	10.05	0.35	1.49
alpha2 (noise term for survey, α = $SD_{Index}/SD_{Biomass}$)	6.92	1.25	38.43	1.93	5.68
beta (β = SD_{Catch}/SD_F)	0.54	0.18	1.57	-0.62	0.54
r (intrinsic population growth rate)	0.73	0.48	1.11	-0.32	0.73
m (SPiCT parameter)	3227.23	1898.44	5486.07	8.08	3171
K (Carrying capacity)	17689.67	7429.54	42118.94	9.78	17263
q1 (Catchability for CPUE)	0.10	0.06	0.16	-2.31	0.11
q2 (Catchability for survey)	1.12	0.63	2.02	0.12	1.25
*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	0.49	-2.40	0.09
sdf (Standard deviation, fishing mortality)	0.84	0.44	1.61	-0.17	0.85
sdi1 (Standard deviation, CPUE)	0.13	0.07	0.25	-2.05	0.13
sdi2 (Standard deviation, Survey)	0.63	0.42	0.92	-0.47	0.51
Sdc (Standard deviation, catch)	0.45	0.25	0.83	-0.79	0.46
B (Biomass end of 2024)	5061	1816	14103	8.53	6693
F (Fishing mortality end of 2024)	0.90	0.20	4.05	-0.11	0.58
Relative reference points					
B/B_{msy}, end current year (proj.) (%)	0.58	0.18	1.84	-0.55	0.78
F/F_{msy}, end current year (proj.) (%)	2.47	0.54	11.39	0.91	1.59

Table 3. Correlation matrix for the estimated SPiCT model parameters

	logm	logK	logq	logq	logn
logm	1.000000000	0.928706219	-3.397225e-01	-2.898492e-01	-1.035941e-03
logK	0.928706219	1.000000000	-4.710711e-01	-3.991248e-01	-2.972054e-03
logq	-0.339722492	-0.471071138	1.000000e+00	7.965654e-01	2.510192e-05
logq	-0.289849244	-0.399124783	7.965654e-01	1.000000e+00	4.496931e-05
logn	-0.001035941	-0.002972054	2.510192e-05	4.496932e-05	1.000000e+00
logsdb	0.109828034	0.101833185	-1.284563e-01	-1.004821e-01	-1.155381e-04
logsdf	0.154492782	0.127905643	-1.425808e-01	-9.422398e-02	-1.194604e-04
logsdi	0.090913558	0.201558132	-1.951801e-01	-1.671449e-01	-2.172238e-04
logsdi	0.007893778	-0.008026800	1.491941e-02	2.549146e-02	-3.942625e-05
logsdc	-0.346006459	-0.345992613	9.397268e-02	4.968765e-02	1.707108e-04

	logsdb	logsdf	logsdi	logsdi	logsdc
logm	0.1098280343	0.1544927815	0.0909135578	7.893778e-03	-0.3460064588
logK	0.1018331851	0.1279056427	0.2015581316	-8.026800e-03	-0.3459926126
logq	-0.1284562602	-0.1425807735	-0.1951801458	1.491941e-02	0.0939726757
logq	-0.1004821020	-0.0942239752	-0.1671449250	2.549146e-02	0.0496876523
logn	-0.0001155381	-0.0001194604	-0.0002172238	-3.942625e-05	0.0001707108
logsdb	1.0000000000	-0.0361391359	-0.2434146348	4.391988e-02	-0.0198796382
logsdf	-0.0361391359	1.0000000000	-0.2262674309	7.353627e-02	-0.4792895072
logsdi	-0.2434146348	-0.2262674309	1.0000000000	-7.038295e-02	0.0924212221
logsdi	0.0439198836	0.0735362694	-0.0703829549	1.000000e+00	-0.0638505370
logsdc	-0.0198796382	-0.4792895072	0.0924212221	-6.385054e-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**	**3227.22**	**17689.67**	**0.1**	**1.12**	**2**	**0.09**	**0.84**	**0.13**	**0.63**	**0.45**
Trial	**1**	**0.01**	**3227.23**	**17689.68**	**0.1**	**1.12**	**2**	**0.09**	**0.84**	**0.13**	**0.63**	**0.45**
Trial	**2**	**0.02**	**3227.23**	**17689.68**	**0.1**	**1.12**	**2**	**0.09**	**0.84**	**0.13**	**0.63**	**0.45**
Trial	**3**	**0.02**	**3227.23**	**17689.68**	**0.1**	**1.12**	**2**	**0.09**	**0.84**	**0.13**	**0.63**	**0.45**
Trial	**4**	**0.02**	**3227.23**	**17689.68**	**0.1**	**1.12**	**2**	**0.09**	**0.84**	**0.13**	**0.63**	**0.45**
Trial	**5**	**0.02**	**3227.23**	**17689.68**	**0.1**	**1.12**	**2**	**0.09**	**0.84**	**0.13**	**0.63**	**0.45**
Trial	**6**	**0.01**	**3227.23**	**17689.68**	**0.1**	**1.12**	**2**	**0.09**	**0.84**	**0.13**	**0.63**	**0.45**
Trial	**7**	**0.02**	**3227.23**	**17689.69**	**0.1**	**1.12**	**2**	**0.09**	**0.84**	**0.13**	**0.63**	**0.45**
Trial	**8**	**0.02**	**3227.23**	**17689.68**	**0.1**	**1.12**	**2**	**0.09**	**0.84**	**0.13**	**0.63**	**0.45**
Trial	**9**	**0.01**	**3227.23**	**17689.68**	**0.1**	**1.12**	**2**	**0.09**	**0.84**	**0.13**	**0.63**	**0.45**
Trial	**10**	**0.02**	**3227.23**	**17689.68**	**0.1**	**1.12**	**2**	**0.09**	**0.84**	**0.13**	**0.63**	**0.45**
Trial	**11**	**0**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**
Trial	**12**	**0.04**	**3227.22**	**17689.63**	**0.1**	**1.12**	**2**	**0.09**	**0.84**	**0.13**	**0.63**	**0.45**
Trial	**13**	**0.09**	**3227.21**	**17689.58**	**0.1**	**1.12**	**2**	**0.09**	**0.84**	**0.13**	**0.63**	**0.45**
Trial	**14**	**0.02**	**3227.23**	**17689.68**	**0.1**	**1.12**	**2**	**0.09**	**0.84**	**0.13**	**0.63**	**0.45**
Trial	**15**	**0.01**	**3227.23**	**17689.68**	**0.1**	**1.12**	**2**	**0.09**	**0.84**	**0.13**	**0.63**	**0.45**
Trial	**16**	**0.02**	**3227.23**	**17689.69**	**0.1**	**1.12**	**2**	**0.09**	**0.84**	**0.13**	**0.63**	**0.45**
Trial	**17**	**0.02**	**3227.23**	**17689.68**	**0.1**	**1.12**	**2**	**0.09**	**0.84**	**0.13**	**0.63**	**0.45**
Trial	**18**	**0.14**	**3227.21**	**17689.53**	**0.1**	**1.12**	**2**	**0.09**	**0.84**	**0.13**	**0.63**	**0.45**
Trial	**19**	**0.06**	**3227.23**	**17689.73**	**0.1**	**1.12**	**2**	**0.09**	**0.84**	**0.13**	**0.63**	**0.45**
Trial	**20**	**0.02**	**3227.23**	**17689.68**	**0.1**	**1.12**	**2**	**0.09**	**0.84**	**0.13**	**0.63**	**0.45**

Table 5. Forecast for 2025 with eight scenarios and forecast with 7 catch options.

```
SPiCT timeline:

      Observations              Management
    2008.00 - 2025.00        2025.00 - 2026.00
 |-----------------------| ----------------------|

Management evaluation: 2026.00

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

                 C  B/Bmsy F/Fmsy
1. Scenario 1 1000   0.77   0.48
2. Scenario 2 1500   0.71   0.75
3. Scenario 3 2000   0.64   1.05
4. Scenario 4 2500   0.57   1.38
5. Scenario 5 3000   0.51   1.76
6. Scenario 6 3500   0.44   2.20
7. Scenario 7 4000   0.37   2.72

95% confidence intervals for states:

              B/Bmsy.lo B/Bmsy.hi F/Fmsy.lo F/Fmsy.hi
1. Scenario 1      0.23      2.57      0.05      4.70
2. Scenario 2      0.19      2.65      0.08      7.37
3. Scenario 3      0.15      2.78      0.11     10.32
4. Scenario 4      0.11      2.97      0.14     13.62
5. Scenario 5      0.08      3.22      0.18     17.37
6. Scenario 6      0.05      3.58      0.22     21.70
7. Scenario 7      0.03      4.10      0.28     26.85
```

Catch options and relative reference points

Catch (t)	B/Bmsy	F/Fmsy	Prob B < Bmsy	Prob B < Blim	Prob F>Fmsy
1000	0.77	0.48	0.66	0.06	0.26
1500	0.71	0.75	0.70	0.10	0.40
2000	0.64	1.05	0.72	0.16	0.52
2500	0.57	1.38	0.75	0.22	0.61
3000	0.51	1.76	0.77	0.29	0.69
3500	0.44	2.20	0.78	0.36	0.75
4000	0.37	2.72	0.79	0.44	0.81

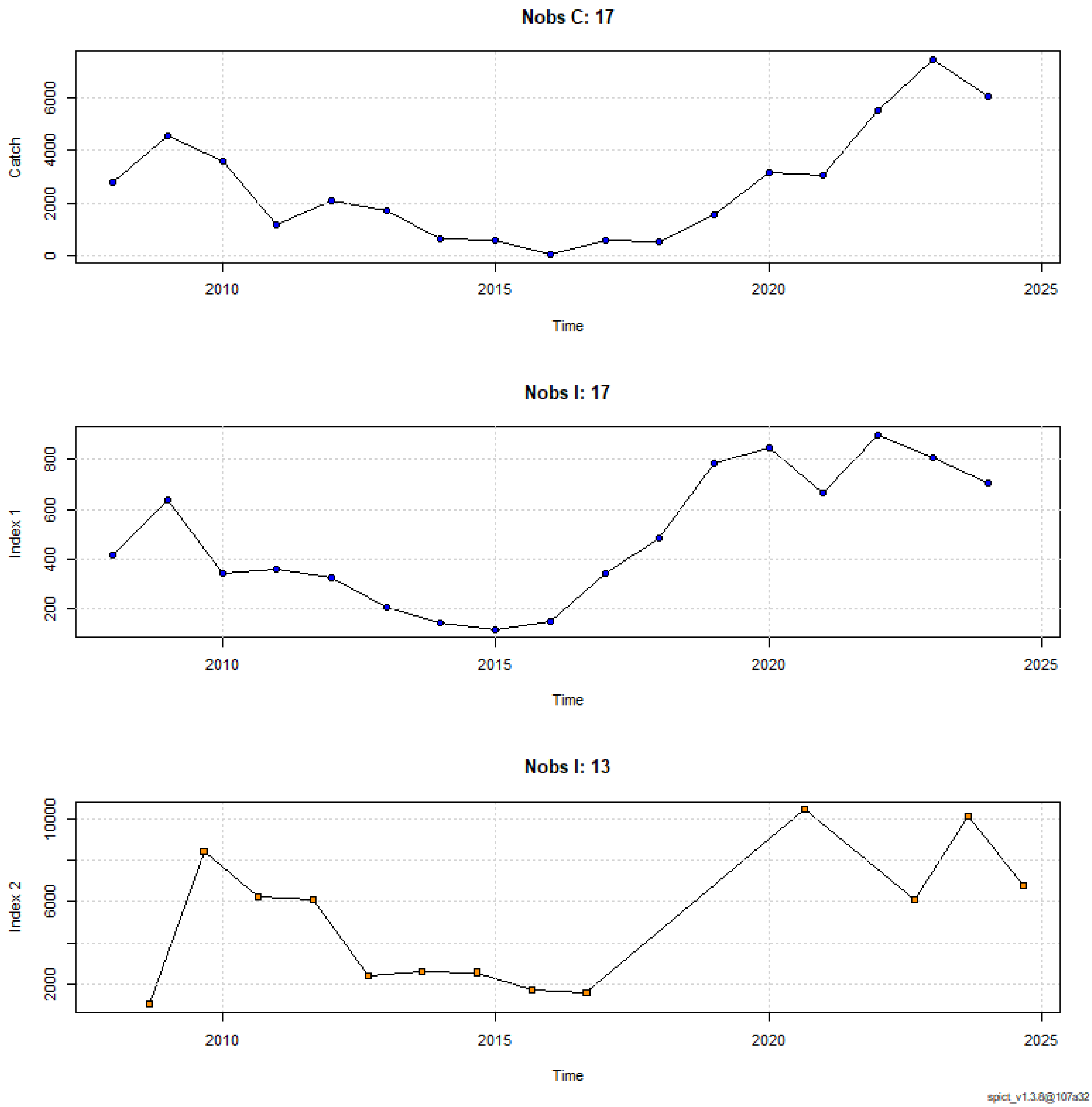

Figure 1. Input data for the SPiCT models of East Greenland northern shrimp stock. Top: Catch, Middle: CPUE index, Bottom: Survey index.

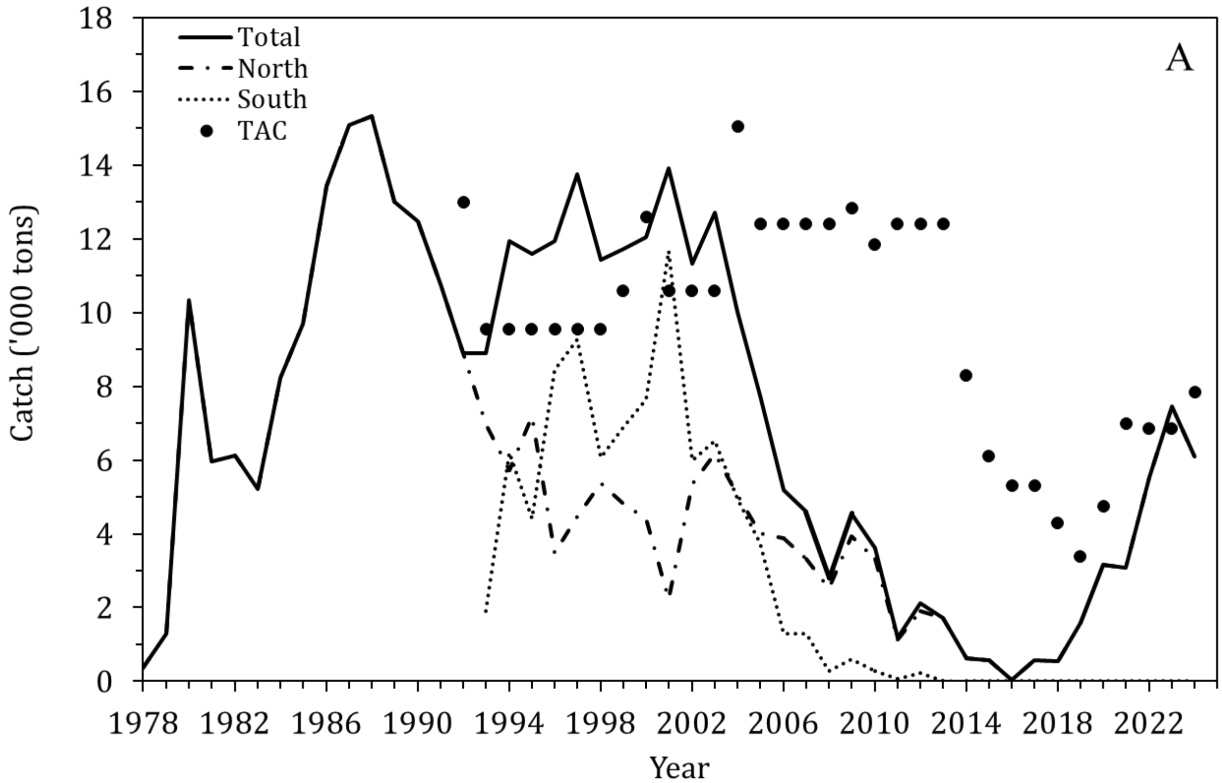

Figure 2. Total catch and TAC of East Greenland northern shrimp.

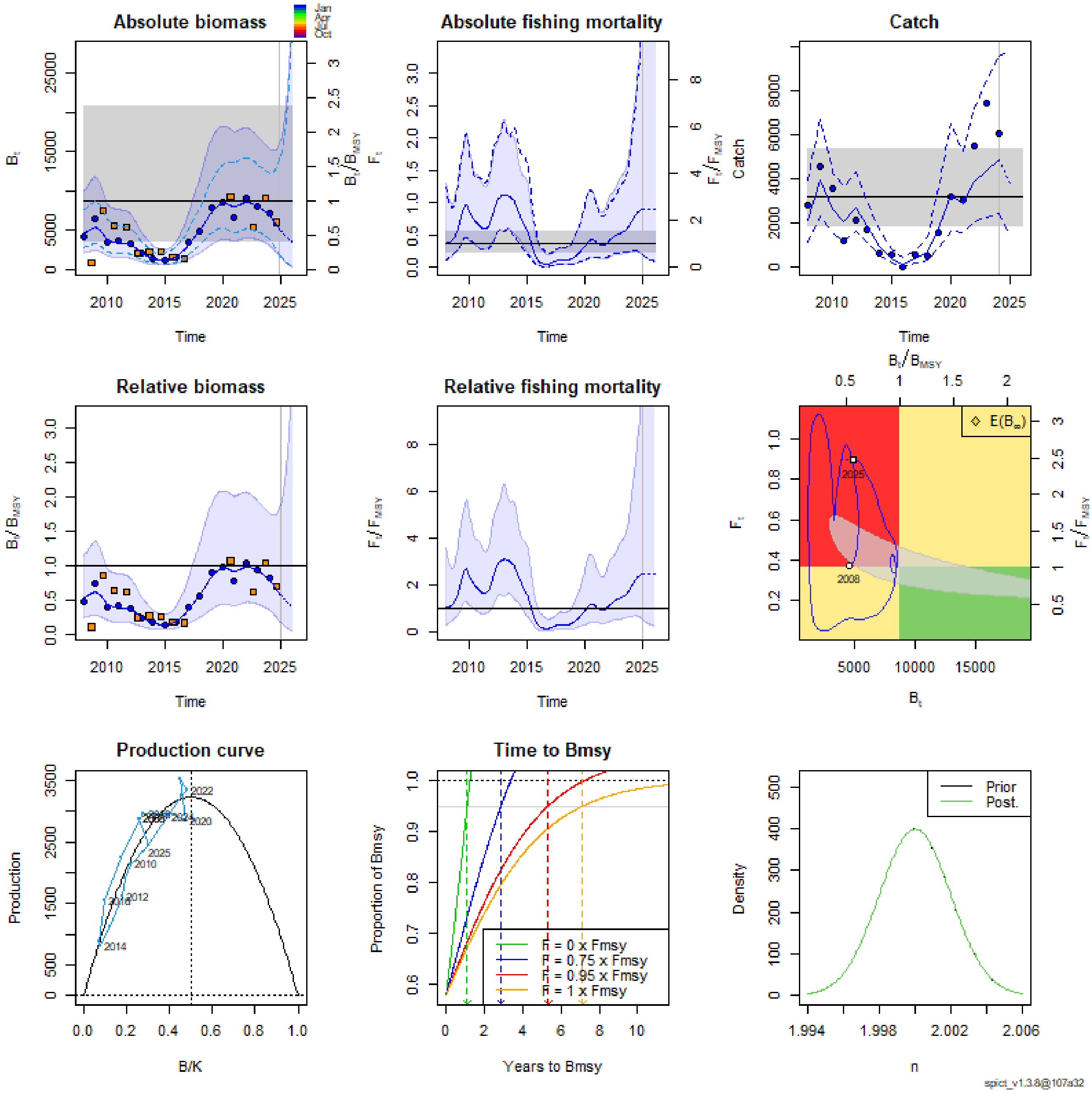

Figure 3. Main results of the model with n fixed to 2.

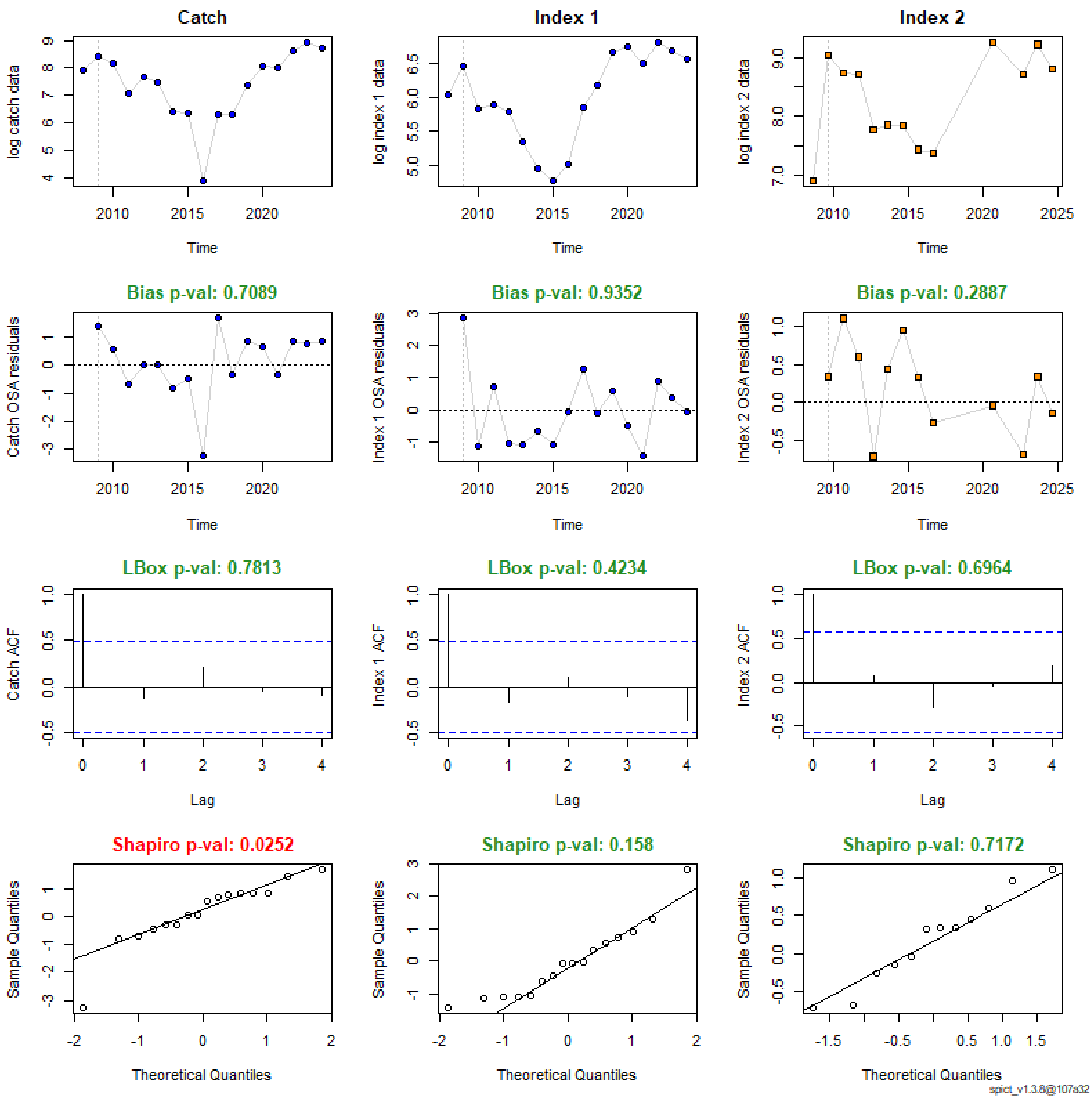

Figure 4. Diagnostics. First row show log of the input data series; catch, CPUE and survey index. Second row "one-step ahead" (OSA) residuals and a test for bias. Third row show the autocorrelation of the residuals including Ljung-Box test of multiple lags and tests for the individual lags. Fourth row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

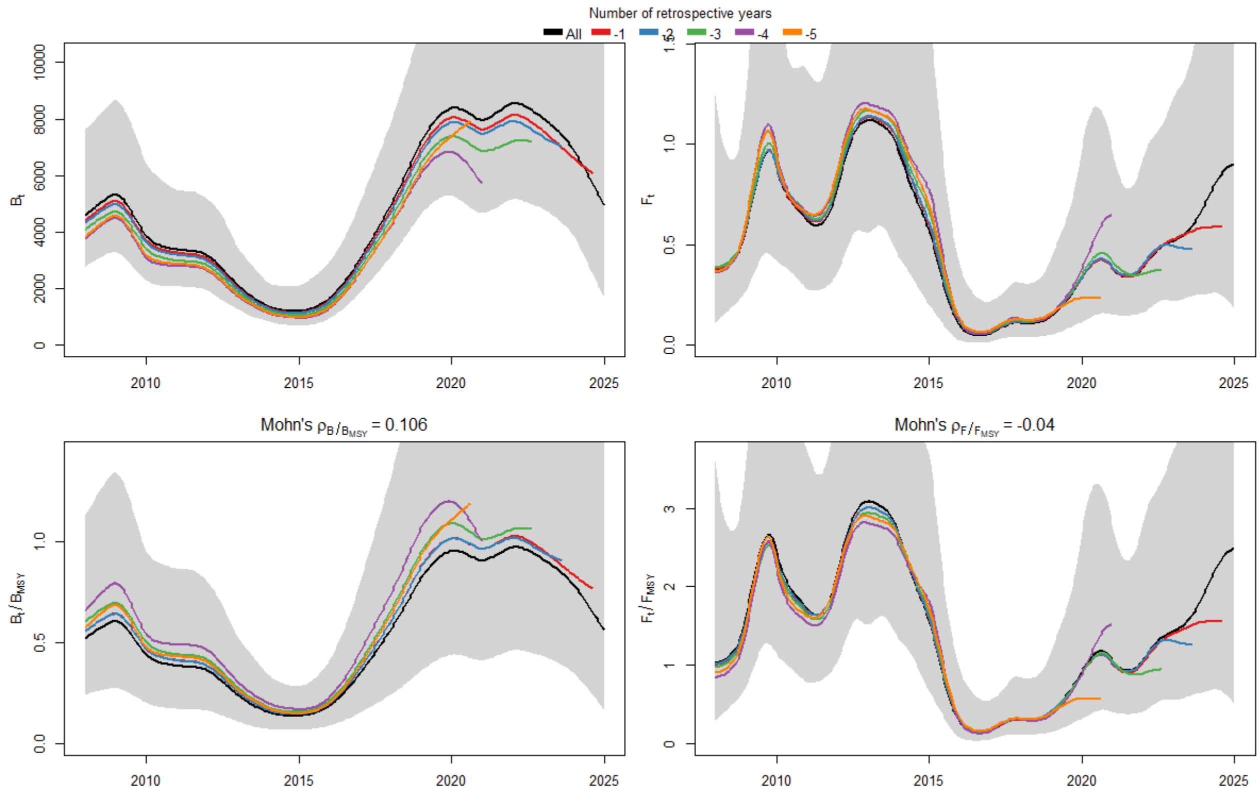

Figure 5. Five years retrospective plots of fishing mortality and fishable biomass.

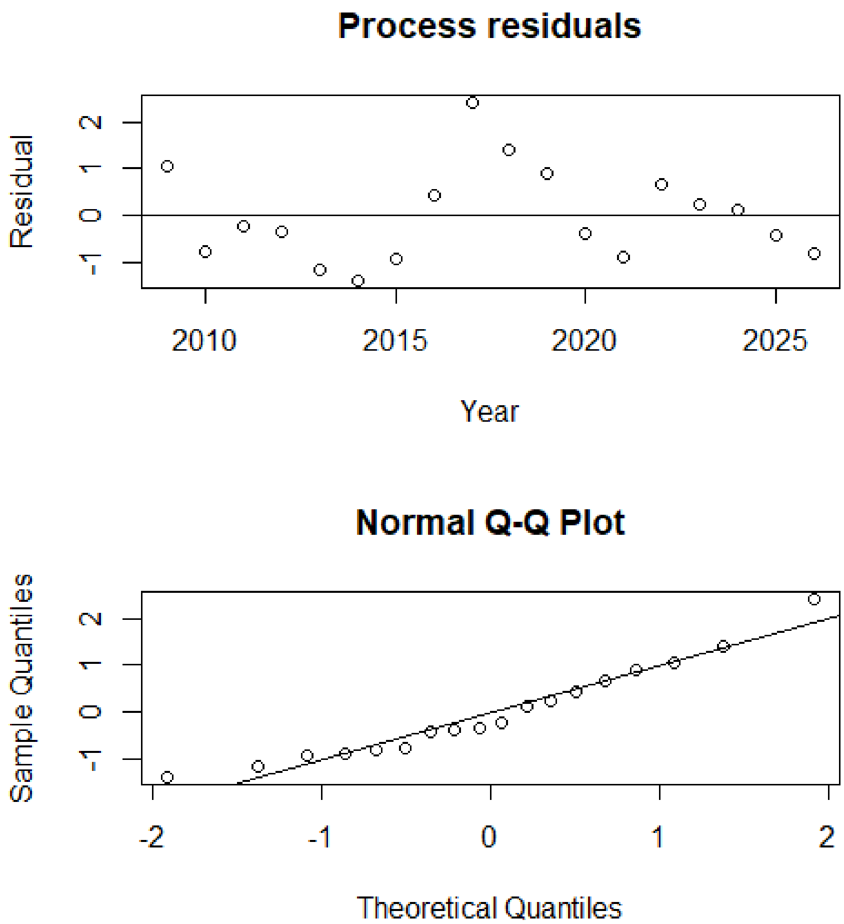

Figure 6. Above is shown the normalized process error. Below is shown the autocorrelation of the process error.