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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. Different combinations of input data and time periods were explored. Noise parameters for catch and indices could be estimated. No priors were used. The model was stable and the model diagnostics and retrospective patterns were acceptable. The perception was that relative biomasse and fishing mortality were within safe biological limits.

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 tried 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 (Rigét 2020) and research survey data since 2008 (Buch et al. 2020). No research survey was performed in the years in 2017 to 2019 (Figure 1).

Results and Discussion

The SPiCT model were applied to truncated timeseries of catch and CPUE to cover only the period where a survey biomass index is available so all three timeseries cover the period from 2008 to 2020, which it is recommended in the guidelines when the catch series is much longer than the biomass index (Millenberger et al. 2019).

The model converge without the need for any prior information or restrictions on the parameter estimates.

Model diagnostics are shown in Figure 3. The residual diagnostics of the model were appropriate. The One Step Ahead (OSA) residuals were not significant different from zero and therefore not biased (above figure row). Testing of multiple lags (here 4) show no significant autocorrelation of the residuals (ACF). Also in case of individual lags (lag 1 and 2) of the survey index. The residuals were not significantly different from being normal distributed in any case.

Table 1 show the correlations between model parameters for fixed effects. Most parameters of the parameters are well separated i.e. relative low correlation. Highest correlation is between the two catchability parameters (CPUE and survey). The correlation between log Bmsy and log Fmsy was -0.43. Furthermore, 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 2).

The production curve look reasonable (Figure 4). The Bmsy/K = 0.6 is within the acceptable range of 0.1-0.9 (Millemberger et al. 2019).

Retrospective plots of fishing mortality and fishable biomass of three years show high consistency between the scenarios (Figure 5) and well inside the confidence limits. B/Bmsy three years back is an exception with much lower B/Bmsy values than in the following years, which likely is caused by the lack of survey data in the period 2017 to 2019.

Figure 6 show the relative fishing mortality (F_t/F_{MSY}) and the relative biomass (B_t/B_{MSY}) derived from the SPiCT model. F_t/F_{MSY} has been above 1 in the period 2009 until 2015 whereafter it drops below 1 and has remain below 1 since then. B/Bmsy has been below 1 from the beginning of the series in 2008 until the increase in 2019 and is now above 1. These trajectories are likely driven by the increasing CPUE in recent years and the high survey biomass found in 2020.

The assessment results is shown in Table 3. Millenberger et al. (2019) give the guideline that the confidence limits of B/Bmsy and F/Fmsy should not spand than one order of magnitude when evaluating the assessment uncertaincy. In the precent assessment the values were 0.5 and 2.8, respectively and therefore too high with regards to F/Fmsy.

Table 4 shown a forecast for 2021 with 6 senarios. Fishing at Fmsy would result in a catch of 3821 t and a 48% increase in F compared to F_{2020}.

The present a proxy for Blim for this stock has been set to 15% of the maximum survey female biomass (500 t). In the 2020 survey a record high female biomass, which would increase Blim to 1572 t. The presented surplus production model estimate Bmsy to 5969 t and using a proxy for Blim as 30% of Bmsy will derive at a Blim of 1788 t.

Conclusion

Despite the relative short timeseries the SPiCT model perform well as tool for assessment of the East Greenland shrimp stock. We therefore recommend to base the advice for 2021 on the results from the SPiCT assessment presented here.

References

BUCH, T. B. 2020. Results of the Greenland Bottom Trawl Survey for Northern shrimp (Pandalus borealis) Off East Greenland (ICES Subarea XIV b), 2008-2020. *NAFO SCR Doc*., No. 20/060Serial No.N7134.

RIGÉT, F. 2020. The Fishery for Northern Shrimp (Pandalus borealis) in Denmark Strait / off East Greenland 1978 – 2020. *NAFO SCR Doc*., No. 20/059 Serial No.N7133.

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

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Table 1. Correlation matrix for the estimated SPiCT model parameters

	logm	logK	logq	logq	logn	logsdb
logm	1.00000000	-0.04600414	-0.57093911	-0.51104382	0.73570401	0.122069571
logK	-0.04600414	1.00000000	-0.54143541	-0.48859470	-0.66985846	-0.093746113
logq	-0.57093911	-0.54143541	1.00000000	0.88233403	-0.11859148	-0.036130484
logq	-0.51104382	-0.48859470	0.88233403	1.00000000	-0.10661207	-0.019869630
logn	0.73570401	-0.66985846	-0.11859148	-0.10661207	1.00000000	0.120863106
logsdb	0.12206957	-0.09374611	-0.03613048	-0.01986963	0.12086311	1.000000000
logsdf	0.12607762	0.07680183	-0.19407488	-0.16719730	0.04087165	-0.050756681
logsdi	-0.06624957	0.13449296	-0.04450295	-0.05312290	-0.08489473	-0.430168304
logsdi	-0.01540214	0.05264628	-0.02640151	-0.02488647	-0.03519191	-0.077766830
logsdc	-0.14647417	-0.01350695	0.11781428	0.10219141	-0.10574392	-0.007118011

	logsdf	logsdi	logsdi	logsdc
logm	0.126077622	-0.06624957	-0.015402140	-0.146474167
logK	0.076801831	0.13449296	0.052646277	-0.013506946
logq	-0.194074878	-0.04450295	-0.026401511	0.117814280
logq	-0.167197300	-0.05312290	-0.024886470	0.102191407
logn	0.040871646	-0.08489473	-0.035191908	-0.105743918
logsdb	-0.050756681	-0.43016830	-0.077766830	-0.007118011
logsdf	1.000000000	-0.27848986	0.003467057	-0.443993653
logsdi	-0.278489864	1.00000000	0.077895371	0.128621021
logsdi	0.003467057	0.07789537	1.000000000	-0.036121265
logsdc	-0.443993653	0.12862102	-0.036121265	1.000000000

Table 2. Checking of the influence of initial values on parameter estimates with 15 different initial values. Distance from the estimated parameter vector to the base parameter vector (should be close to 0).

	Distance	m	K	q	q	n	sdb	sdf	sdi	sdi	sdc
Basevec	0.00	3266.71	9212.27	0.12	1.41	4.66	0.1	0.96	0.09	0.41	0.48
Trial 1	0.01	3266.71	9212.27	0.12	1.41	4.66	0.1	0.96	0.09	0.41	0.48
Trial 2	0.00	3266.71	9212.27	0.12	1.41	4.66	0.1	0.96	0.09	0.41	0.48
Trial 3	0.02	3266.70	9212.26	0.12	1.41	4.66	0.1	0.96	0.09	0.41	0.48
Trial 4	0.01	3266.71	9212.28	0.12	1.41	4.66	0.1	0.96	0.09	0.41	0.48
Trial 5	0.00	3266.71	9212.27	0.12	1.41	4.66	0.1	0.96	0.09	0.41	0.48
Trial 6	0.02	3266.71	9212.26	0.12	1.41	4.66	0.1	0.96	0.09	0.41	0.48
Trial 7	0.03	3266.71	9212.25	0.12	1.41	4.66	0.1	0.96	0.09	0.41	0.48
Trial 8	0.01	3266.71	9212.27	0.12	1.41	4.66	0.1	0.96	0.09	0.41	0.48
Trial 9	0.02	3266.71	9212.29	0.12	1.41	4.66	0.1	0.96	0.09	0.41	0.48
Trial 10	0.03	3266.72	9212.25	0.12	1.41	4.66	0.1	0.96	0.09	0.41	0.48
Trial 11	0.10	3266.70	9212.37	0.12	1.41	4.66	0.1	0.96	0.09	0.41	0.48
Trial 12	0.01	3266.71	9212.27	0.12	1.41	4.66	0.1	0.96	0.09	0.41	0.48
Trial 13	0.06	3266.71	9212.22	0.12	1.41	4.66	0.1	0.96	0.09	0.41	0.48
Trial 14	0.01	3266.71	9212.27	0.12	1.41	4.66	0.1	0.96	0.09	0.41	0.48
Trial 15	0.01	3266.72	9212.26	0.12	1.41	4.66	0.1	0.96	0.09	0.41	0.48

Table 3. Results from the SPiCT model including parameter estimates, reference points and predictions

Convergence: 0 MSG: relative convergence (4)
Objective function at optimum: 39.5934374
Euler time step (years): 1/16 or 0.0625
Nobs C: 13, Nobs I1: 13, Nobs I2: 10

Residual diagnostics (p-values)

	shapiro	bias	acf	LBox	shapiro	bias	acf	LBox
C	0.2767	0.8934	0.3456	0.5935	-	-	-	-
I1	0.1697	0.8439	0.1782	0.3531	-	-	-	-
I2	0.3526	0.2954	0.0514	0.1719	-	-	.	-

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	0.9454887	0.0735211	1.215908e+01	-0.0560533
alpha2	4.2859523	0.5747830	3.195882e+01	1.4553428
beta	0.5034178	0.1588471	1.595430e+00	-0.6863349
r	2.5172159	0.1880808	3.368965e+01	0.9231535
rc	1.0797728	0.6614949	1.762537e+00	0.0767506
rold	0.6872960	0.4867063	9.705561e-01	-0.3749903
m	3266.7132359	1775.9590646	6.008818e+03	8.0915396
K	9212.2746683	4226.1860684	2.008099e+04	9.1282921
q1	0.1202006	0.0737714	1.958506e-01	-2.1185935
q2	1.4128874	0.8143210	2.451430e+00	0.3456354
n	4.6624920	0.5274588	4.121428e+01	1.5395501
sdb	0.0953067	0.0139112	6.529522e-01	-2.3506552
sdf	0.9580371	0.4660944	1.969204e+00	-0.0428688
sdi1	0.0901114	0.0317076	2.560917e-01	-2.4067085
sdi2	0.4084800	0.2613342	6.384771e-01	-0.8953124
sdc	0.4822929	0.2553300	9.110029e-01	-0.7292037

Deterministic reference points (Drp)

	estimate	cilow	ciupp	log.est
Bmsyd	6050.7420068	3385.5618936	1.081400e+04	8.7079362
Fmsyd	0.5398864	0.3307474	8.812685e-01	-0.6163966
MSYd	3266.7132359	1775.9590646	6.008818e+03	8.0915396

Stochastic reference points (Srp)

	estimate	cilow	ciupp	log.est	rel.diff.Drp
Bmsys	5968.6718367	3332.9493947	10688.744195	8.6942797	-0.01375016
Fmsys	0.5327065	0.3349416	0.847241	-0.6297846	-0.01347813
MSYs	3178.9612546	1802.6247322	5606.155556	8.0643098	-0.02760398

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

	estimate	cilow	ciupp	log.est
B_2020.00	7823.8173470	4643.3806709	1.318266e+04	8.9649279
F_2020.00	0.2747099	0.0898076	8.403023e-01	-1.2920395
B_2020.00/Bmsy	1.3108138	1.0239455	1.678051e+00	0.2706482
F_2020.00/Fmsy	0.5156872	0.1634594	1.626908e+00	-0.6622549

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

	prediction	cilow	ciupp	log.est
B_2021.00	7690.5053317	4021.8232450	14705.736343	8.9477418

F_2021.00	0.3594815	0.0719802	1.795313	-1.0230925
B_2021.00/Bmsy	1.2884785	0.9822406	1.690194	0.2534621
F_2021.00/Fmsy	0.6748209	0.1359898	3.348658	-0.3933079
Catch_2021.00	2735.8502698	561.2593411	13335.861252	7.9141976
E(B_inf)	7359.7537202	NA	NA	8.9037817

Table 4. Forecast for 2021 with with six scenarios.

Observed interval, index: 2008.00 - 2020.00
Observed interval, catch: 2008.00 - 2021.00

Fishing mortality (F) prediction: 2022.00
Biomass (B) prediction: 2022.00
Catch (C) prediction interval: 2021.00 - 2022.00

Predictions

	C	B	F	B/Bmsy	F/Fmsy	perc.dB	perc.dF
1. Keep current catch	2966.0	7371.3	0.403	1.235	0.756	-4.2	12.1
2. Keep current F	2735.9	7551.6	0.359	1.265	0.675	-1.8	0.0
3. Fish at Fmsy	3821.3	6774.8	0.533	1.135	1.000	-11.9	48.2
4. No fishing	3.1	9039.1	0.000	1.514	0.001	17.5	-99.9
5. Reduce F 25%	2113.4	7944.7	0.270	1.331	0.506	3.3	-25.0
6. Increase F 25%	3317.6	7150.4	0.449	1.198	0.844	-7.0	25.0
7. MSY advice rule	3821.3	6774.8	0.533	1.135	1.000	-11.9	48.2

95% CIs of absolute predictions

	C.lo	C.hi	B.lo	B.hi	F.lo	F.hi
1. Keep current catch	2963.2	2968.8	3554.4	15287.2	0.115	1.412
2. Keep current F	561.3	13335.9	3418.8	16680.2	0.030	4.260
3. Fish at Fmsy	885.4	16492.2	2448.6	18744.6	0.045	6.313
4. No fishing	0.5	18.8	4584.2	17823.2	0.000	0.004
5. Reduce F 25%	407.8	10952.6	3889.1	16229.3	0.023	3.195
6. Increase F 25%	724.7	15188.1	2910.5	17566.9	0.038	5.325
7. MSY advice rule	885.4	16492.2	2448.6	18744.6	0.045	6.313

95% CIs of relative predictions

	B/Bmsy.lo	B/Bmsy.hi	F/Fmsy.lo	F/Fmsy.hi
1. Keep current catch	0.982	1.554	0.226	2.535
2. Keep current F	0.780	2.051	0.057	7.964
3. Fish at Fmsy	0.530	2.431	0.085	11.801
4. No fishing	1.025	2.238	0.000	0.008
5. Reduce F 25%	0.913	1.941	0.043	5.973
6. Increase F 25%	0.645	2.225	0.071	9.954
7. MSY advice rule	0.530	2.431	0.085	11.801

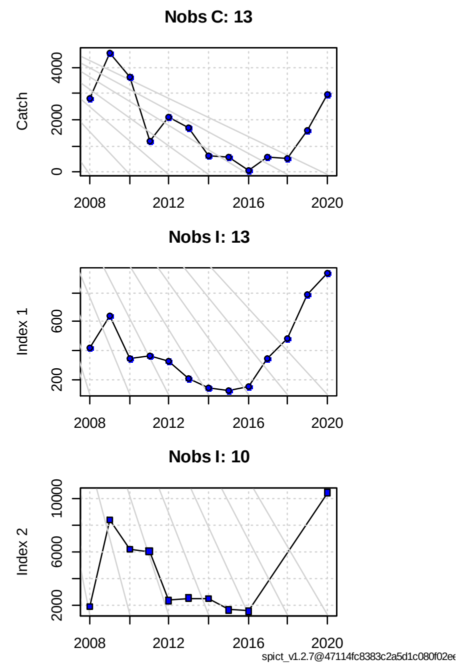

Figure 1. Input data for the SPiCT models of East Greenland northern shrimp stock.Top: Catch, Mittel: CPUE index, Bottom: Survey index.

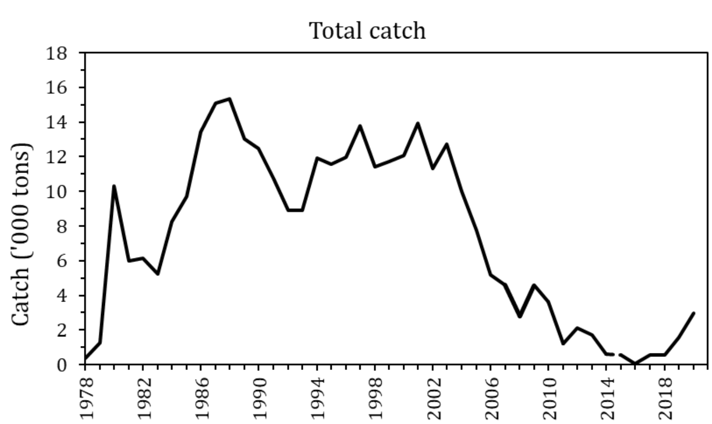

Figure 2. Total catch of East Greenland northern shrimp.

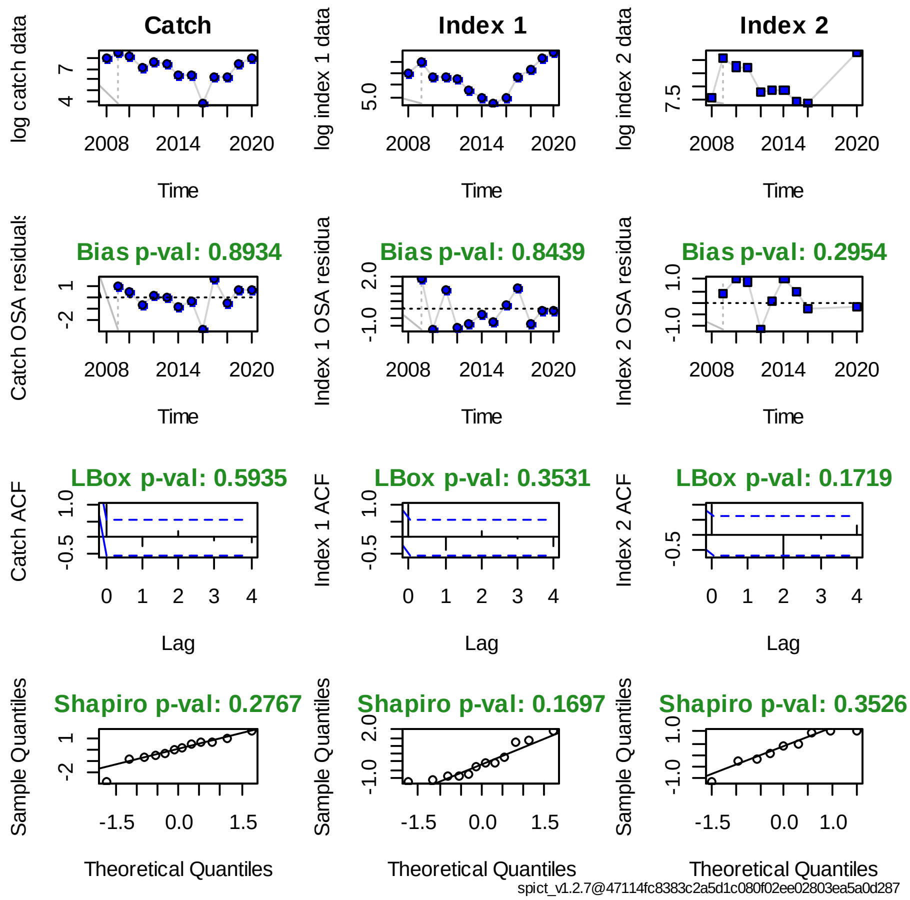

Figure 3. Diagnostics. First row show log of the input data series; catch, CPUE and survey index. Second row "one-step ahead" (OSA) residuals and a test for bias. Third row show the autocorrelation of the residuals including Ljung-Box test of multiple lags and tests for the individual lags. Fourth row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

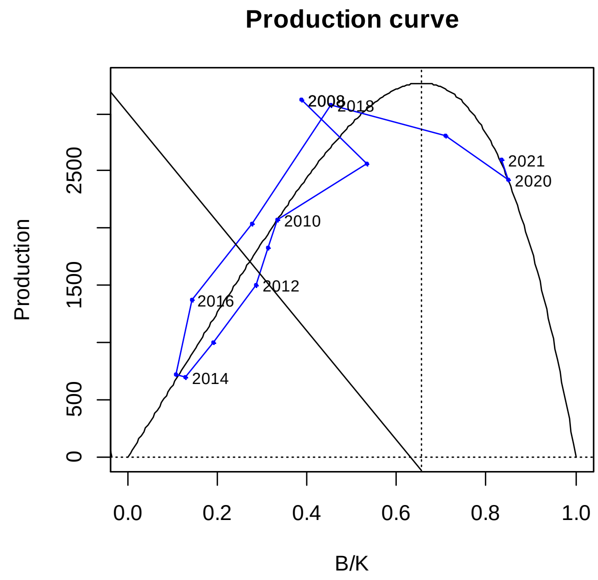

Figure 4. Production curve.

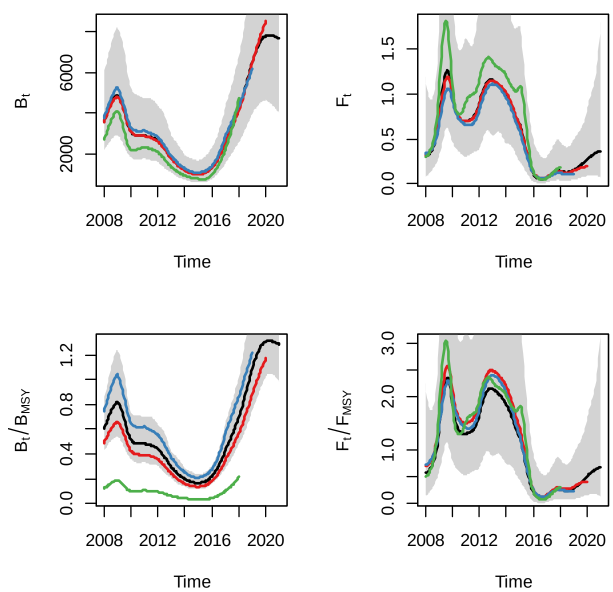

Figure 5. Three years retrospective plots of fishing mortality and fishable biomass.

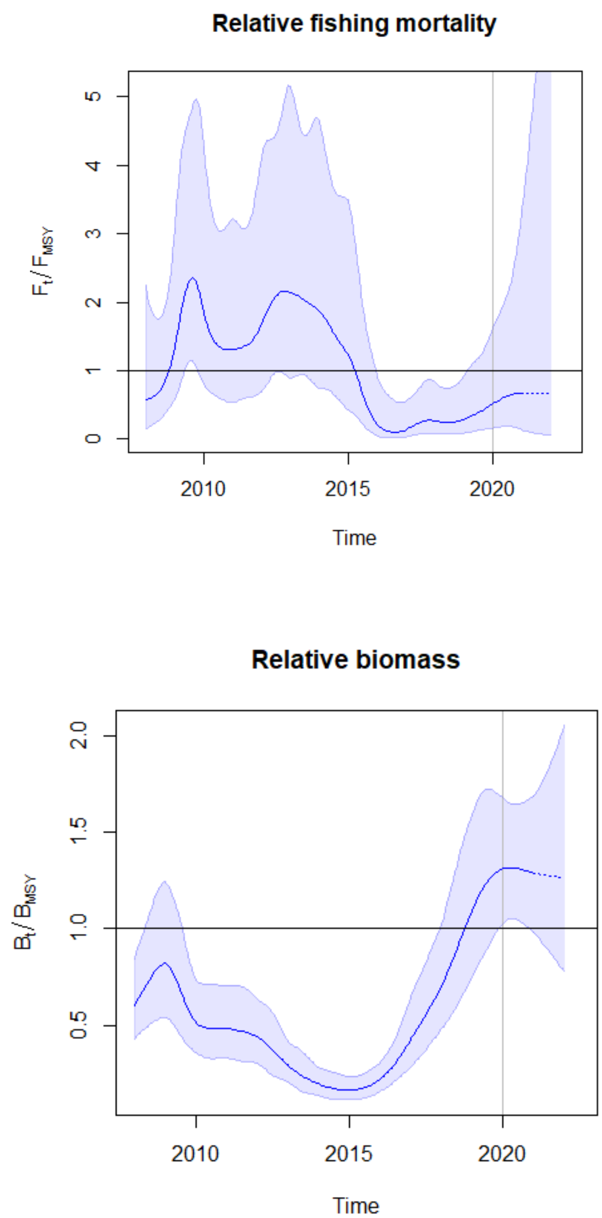

Figure 6. Plot of the estimated relative fishing mortality (F_t/F_{MSY}) and relative biomass (B_t/B_{MSY}) trough time.