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SC11 – SQ07
Update of the Stochastic Production model in Continuous Time (SPiCT) apply to D gigas in the FAO area 87

Republic of Chile

Update of the Stochastic Production model in Continuous Time (SPiCT) apply to *Dosidicus gigas* in the FAO area 87.

By Ignacio S. Payá C.

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Stock Assessment Department.

Chilean Fisheries Development Institute.

ABSTRACT

Recommendations for short-lived squid stock assessment include depletion models with several recruitment pulses, however, this kind of model requires a fine time scale to correctly identify the depletion events and the arrivals of new pulses of recruitments. In-season stock assessment and in-season management seems to be hard to implement for *D. gigas* in the SPRFMO area. Payá (2022) did a first attempt to apply the Stochastic Production model in Continuous Time (SPiCT) to *D. gigas* in FAO area 87, with a sensitivity analysis. Three cases analysed estimated low intrinsic growth rates (r) than the expected for a fast-growing and short-life species, and their values depended on the production model used. The aim of the present document was to update the application of SPiCT to *D. gigas* in the FAO87 area, and to evaluate: the impact of fitting the model to one global abundance index or to several indices by country; the impact of fixing the Schaefer model; the use of more informative r prior distribution; and the impact of initial year in the data. More informative r priors were defined using r values for the same or similar squid species. Seven cases were analysed to evaluate the effect of different abundance indices, productive curves, and r priors. The population growth parameter estimations were improved by r priors and by the change in the initial year. The Biomass and F did not have any important retrospective pattern, while Biomass/B_MSY and F/F_MSY did. Stock status was highly uncertain, but the stock seems to be overfished. The TAC at FMSY ranged from 473,000 (case 5) to 636,000 (case 6) tons. Further analyses are required to improve the abundance indices and to include different phenotypes in the analysis.

BACKGROUND

Recommendations for short-lived squid stock assessment include depletion models with several recruitment pulses (Payá 2009, Arkhipkin et al. 2020). However, fitting depletion models requires a fine time scale to correctly identify the depletion events and the arrivals of new pulses of recruitments. Depletion models applied to *Doryteuthis gahi* in the Falkland Islands has shown that a daily time frame resolution is necessary to identify the arrivals of new recruitments otherwise this can be mixed with previous depletion in a week time (Payá 2009). Depletion models with several pulses has been applied to *Dosidicus gigas* fisheries of large phenotype in Chilean fisheries fitted using weekly data for several years (Payá 2018a). It has been proposed to the SPRFMO SC to apply this kind of models to SPRFMO area and coastal country fisheries, integrates the results by country in a production model, and tested this procedure by a squid simulation model (Payá 2018b and 2018c). So far, the characteristics of *D. gigas* fisheries operations in the SPFRMO area, and the current monitoring of the fisheries and biological sampling make difficult to have information at daily or weekly levels. Furthermore, in-season stock assessment and in-season management seems to be hard to implement for *D. gigas* in the SPRFMO area. An alternative squid stock assessment method could be a surplus production model in continuous time, called SPiCT (Pedersen and Berg. 2017), which could allow to do stock assessment by month or quarter of the year. SPiCT is used for assessing several stocks in ICES (ICES 2021). Payá (2022) did a first attempt to apply SPiCT to D. gigas in the FAO Area 87 (Figure 1) under de assumption of one single stock, using annual data and prior distribution for intrinsic growth rate of the population. The model fitted well to D. gigas data with a global abundance index. When the model was fitted to indices by country, the model converged but the retrospective analysis failed. The model with different production models estimated similar biomasses but growth rates (r) were different. The Bmsy was estimated at 2521 thousand tons and MSY was estimated at 728 thousand tons. The stock status was highly uncertain, but the stock seems to be overfished. The need for further analyses were identified related with more informative prior for r parameter, and the quality of the different abundance indices available.

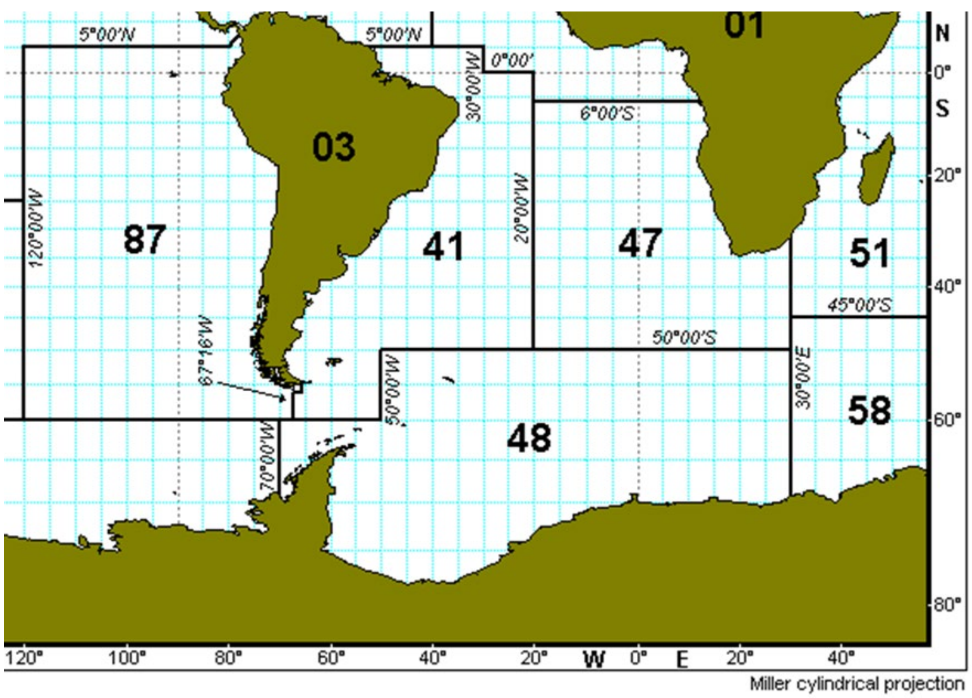

Figure 1. FAO areas. Area 87 includes SPFRMO area; Ecuador EEZ; Perú ANJ; and Chile EEZ.

OBJECTIVES

1. To update the application of the Stochastic Production model in Continuous Time (SPiCT) to *D. gigas* in the FAO87 area.
2. To evaluate the impact of fit the model to one global abundance index or to several indices by country.
3. To evaluate the impact of fixed Schafer model and use a prior distribution for the intrinsic growth rate of the population (r).

DATA AND METHODS

Catches

The catch data by country were collected from SPRFMO statistics and PRODUCE of Perú (Figure 2).

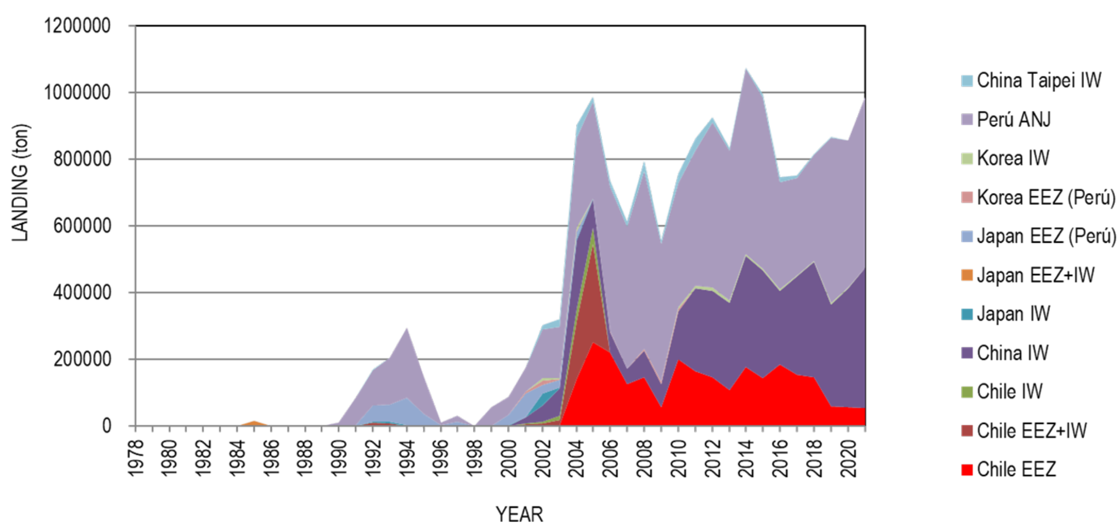

Figure 2. Catch by country.

Abundance indices in SPRFMO area

Because standardized CPUE were not available in SC national squid reports, the nominal CPUE (ton/ fishing day) available in national reports of China, China Taipei and Korea were compiled (Figure 3).

Abundance index in Chilean EEZ

Abundance index based on CPUE of artisanal boats was used (Payá 2022). CPUE was calculated as ton per fishing trip. The abundance index was the year effect of Generalized Linear Mixed Model (GLMM) with year, month and region as fixed effects and boat as random effects of the intercept. A cubic transformation was used to normalized the residuals and to use identity link function:

$$CPUE^{1/3} \sim Year + Month + Region + (1 \mid Boat)$$

Abundance in Peruvian waters

The information was taken from *D. gigas* stock assessment report by IMARPE (IMARPE 2022). Because no tables with abundance indices were included in the report, the data were approximated by digitalization of report plots. Then CPUE in tons by trip-day was calculated multiplying the number of squid/trip-day by the mean weight in the catches.

Global abundance index

A global annual index was estimated as an average of relative indices by country weighted by their annual catches. Relative indices were calculated dividing the indices by their values in year 2015.

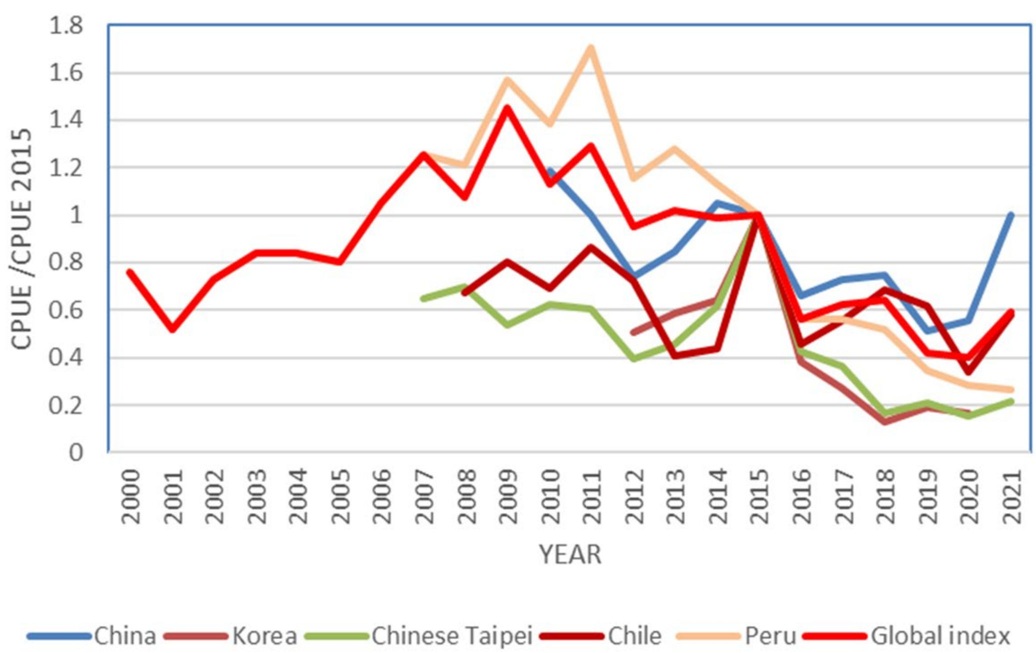

Figure 3. Relative abundance indices by country and global index.

Surplus Production model in Continuous Time (SPiCT)

SPiCT is a stochastic production model in continuous time (Pedersen & Berg, 2017) based on generalised surplus production models in the form of Pella & Tomlinson (1969). It is a state-space model that separate random variability of stock dynamics from error in observed indices of biomass. It enables error in the catch process to be reflected in the uncertainty of estimated model parameters and management quantities. It has the ability to provide estimates of exploitable biomass and fishing mortality at any point in time from data sampled at arbitrary and possibly irregular intervals. The biomass and fishing mortality are unobserved processes (random effects), and the catches and abundance indices are observed variables.

Checklist of SPiCT assessment

A SPiCT stock assessment is accepted if it passes the following check list (Mildenberger et al. 2021):

1. The assessment convergence.
2. Variance parameters of the model parameters are finite.
3. No violation of model assumptions based on one-step-ahead residuals (bias, auto-correlation, normality).
4. Consistent patterns in the retrospective analysis.
5. Realistic production curve (The shape of the production curve should not be too skewed (BMSY/K) should be between 0.1 and 0.9).
6. The main variance parameters (logsdb, logsdc, logsdi, logsdf) should not be unrealistically high.

SPiCT is implemented in a R package called "SPiCT" which is based on Template Model Building (TMB, Kristensen et al. 2016).

ICES harvesting rule and BAC in SPiCT

ICES (2021) apply SPiCT for short-life stock assessments. The biological reference points (BRP) are the fishing mortality (F_MSY) and biomass (B_MSY) at Maximum Sustainable Yield (MSY). ICES recommends a hockey-stick harvesting rule like: B_trigger = B_MSY /2 and Blim = B_MSY /3. The biological acceptable catch (BAC) recommended is the 35th percentile of distribution of catch of short projections.

Sensitivity analysis of SPiCT fits to *D. gigas* in the FAO area 87.

Growth parameter **r** for the same or similar squid species were compiled (Table 1) and they were used to define different prior normal distributions for this parameter. Seven cases were defined for analysing the effect of different abundance indices, productive curve and growth parameters (Table 2). Additionally, the of change the starting year from the year 2000 to the year 2001 was analysed.

Table 1. Growth parameters for the same or similar squid species

r	Species	Area	Reference
1.19	*Ommastrephes bartramii*	North Pacific	Ichii et al., 2006
0.85	*Illex illecebrosus*	North Atlantic	Ichii et al., 2006
0.53 (0.16-1.71)	*Illex coindetii and Todaropsis eblanae*	Northwest Iberian Peninsula	Larivain et al., 2021
1.71-1.90	*Ommastrephes bartramii*	Northwest Pacific	Wang et al. 2016
1.23 – 1.68	*D. gigas*	México	Urías-Sotomayor et al., 2018
1.33	*D. gigas*	Perú	Csirke et al., 2015

Table 2. Description of cases. Prior distribution as normal distribution (mean, std).

	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7
Abundance Indices	Global Index (average of country weighted by catch)	5 Indices. 1. China 2. Korea 3. China Taipei 4. Chile 5. Perú	Global Index (average of country weighted by catch)	5 Indices. 1. China 2. Korea 3. China Taipei 4. Chile 5. Perú	Global Index (average of country weighted by catch)	5 Indices. 1. China 2. Korea 3. China Taipei 4. Chile 5. Perú	5 Indices. 1. China 2. Korea 3. China Taipei 4. Chile 5. Perú
Shape of productive curve ("parameter n")	Free	Free	Free	Free	Schaefer Model	Schaefer Model	Free
Parameter "r"	Free	Free	Prior (1, 0.6)	Prior (1, 0.5)	Prior (1, 0.5)	Prior (1.5, **0.15**)	Prior (1.5, **0.15**)

The input data used in cases 1,3, y 5 are shown in the figure 4, while the input data for cases 2, 4, 6 y 7 in the figure 5.

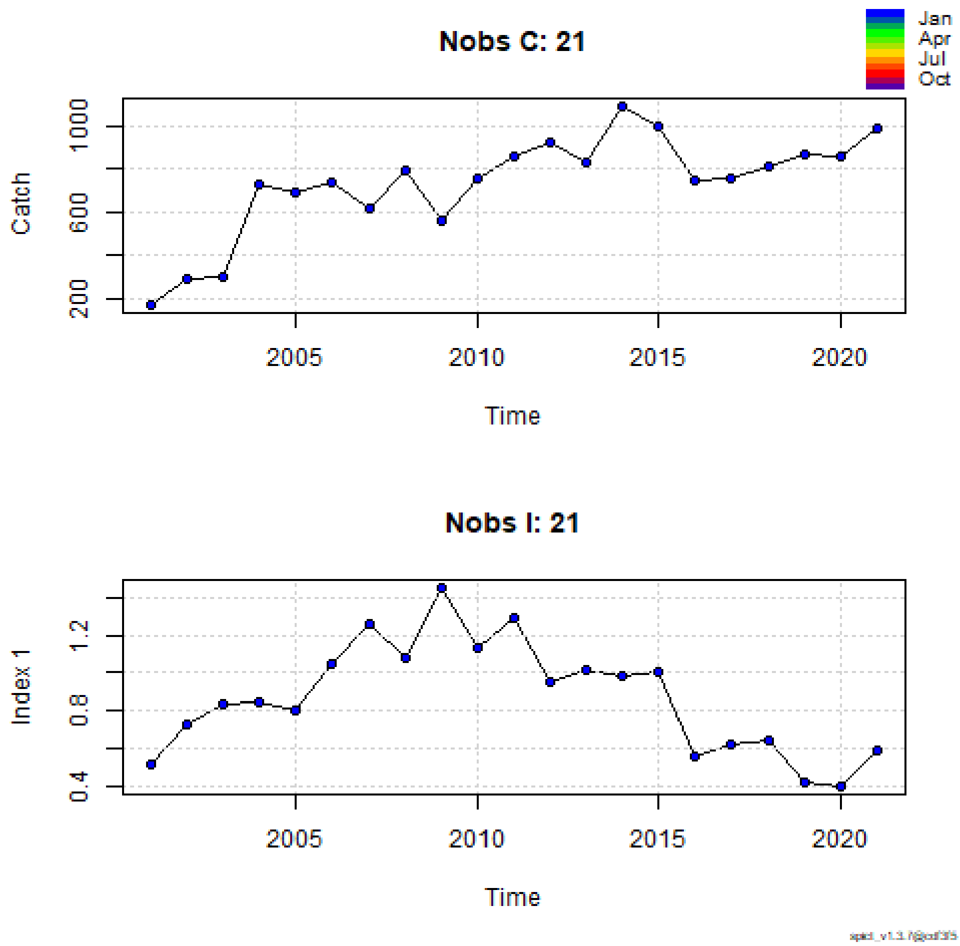

Figure 4. Input data used in cases 1, 3, and 5 (C: Catch; I: Global abundance index).

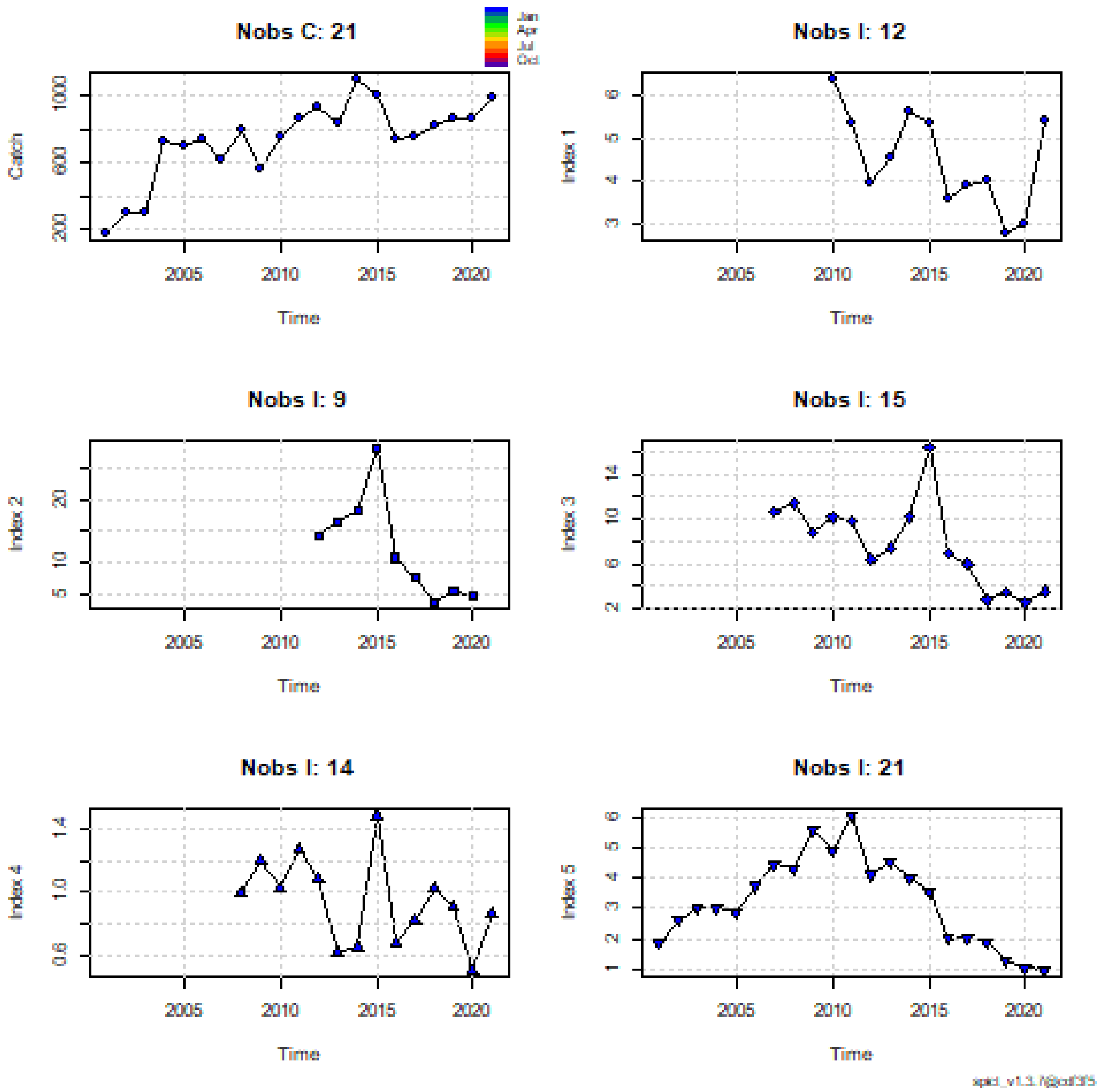

Figure 5. Input data used in cases 1, 3, and 5. "I" corresponds from top to down and form left to right to the abundance indices of China, Korea, China Taipei, Chile and Peru.

RESULTS.

The model fits by case are presented in the Annex A, the retrospective patterns in Annex B and the summary of main results in the Annex C.

The change in the initial year increases r parameter estimations, almost double them (Table 3). The r prior distributions produced r estimations that were in the range expected for a fast-growing and short-life squid.

Table 3. Growth parameter (r, rc, rold) and Fmsy estimated by the different cases.

	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7
Abundance Indices	Global Index (average of country weighted by catch)	5 Indices. 1. China 2. Korea 3. China Taipei 4. Chile 5. Perú	Global Index (average of country weighted by catch)	5 Indices. 1. China 2. Korea 3. China Taipei 4. Chile 5. Perú	Global Index (average of country weighted by catch)	5 Indices. 1. China 2. Korea 3. China Taipei 4. Chile 5. Perú	5 Indices. 1. China 2. Korea 3. China Taipei 4. Chile 5. Perú
Shape of productive curve (“parameter n”)	Free	Free	Free	Free	Schaefer Model	Schaefer Model	Free
Parameter “r”	Free	Free	Prior (1, 0.6)	Prior (1, 0.5)	Prior (1, 0.5)	Prior (1.5, 0.15)	Prior (1.5, 0.15)
Initial Year	2000	2000	2000	2000	2000	2000	2000
r	0.16	0.32	0.68	0.87	0.58		
rc	**0.51**	**0.91**	**0.51**	**0.85**	**0.58**		
rold	0.42	0.98	0.4	0.82	0.58		
Initial Year	2001	2001	2001	2001	2001	2001	2001
r	0.18	0.31	0.59	0.82	0.78	1.451	1.456
rc	**0.9**	**1.49**	**0.84**	**1.43**	**0.78**	**1.451**	**1.378**
rold	0.3	0.52	1.47	5.76	0.78	1.451	1.308
Fmsy	**0.45**	**0.75**	**0.42**	**0.717**	**0.39**	**0.725**	**0.68**

The highest r parameter was estimated by case 2, and the lowest one by case 5 (Table 4). The carrying capacity was highest in case 1 and lowest in case 6. Bmsy was highest in case 2 and lowest in case 2. The highest maximum sustainable yield was estimated at 881 thousand tons in case 7 and the lowest a 750 thousand tons in case 1.

Table 4. Main population parameters estimated by the different cases.

Case	rc	K	Bmsys	MSYs
1	0.91	7605	1657	750
2	1.50	4793	1054	793
3	0.85	4302	1856	787
4	1.44	3065	1177	844
5	0.79	4073	2031	799
6	1.45	2548	1226	880
7	1.38	2635	1295	881

The models that were fitted to the global index (cases 1, 3, and 5) estimated the higher biomass and lower fishing mortality (Figures 6 and 7). All cases estimated decreasing trends in the biomasses during the last 10 years, while the fishing mortalities had increasing trends until the last 3-2 years, and then decreased.

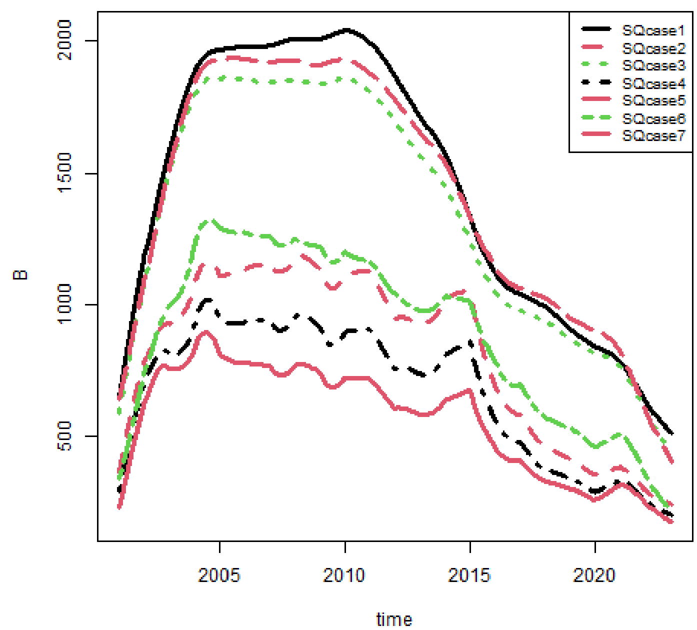

Figure 6. Biomass (thousands of tons) by case

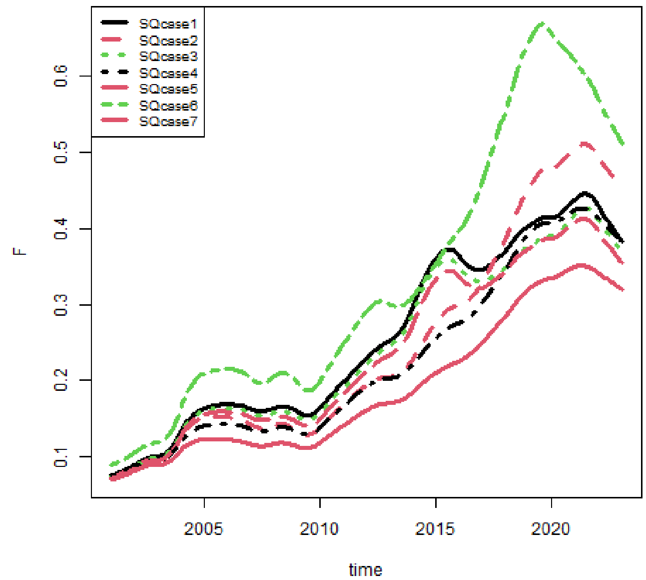

Figure 7. Fishing mortality by case.

All cases had similar pattern in the kobe plot with an overfished stock status for the year 2022 (Figure 8).

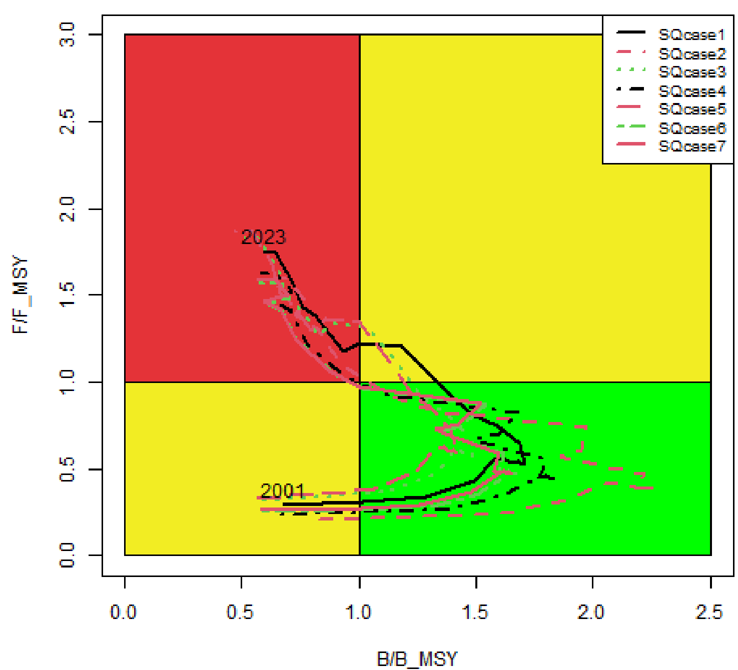

Figure 8. Kobe plot by case.

The total allowable catches (TAC) estimated by case using different harvesting rules are shown in Table 4 and Figure 9. The highest TAC at Fmsy was estimated at 636 thousand tons by case 6, and the lowest one at 473 thousand tons by case 5. To fish at current F was similar to fish at 1.25*Fmsy.

Table 4. Total allowable catch (TAC) by case and different harvesting rules.

	TAC (Thousands of tons)						
Case	1	2	3	4	5	6	7
Number of indices	1	5	1	5	1	5	5
Keep.current.catch	863	904	856	922	852	931	929
Keep.current.F	808	828	779	838	760	843	840
Fish.at.Fmsy	530	612	495	615	473	636	627
No.fishing	1	1	1	1	1	1	1
Reduce.F.by.25.	655	692	634	704	618	710	705
Increase.F.by.25.	936	933	899	940	878	941	941
MSY.hockey.stick.rule	530	612	495	615	473	636	627
ICES.advice.rule	496	568	461	566	439	583	570

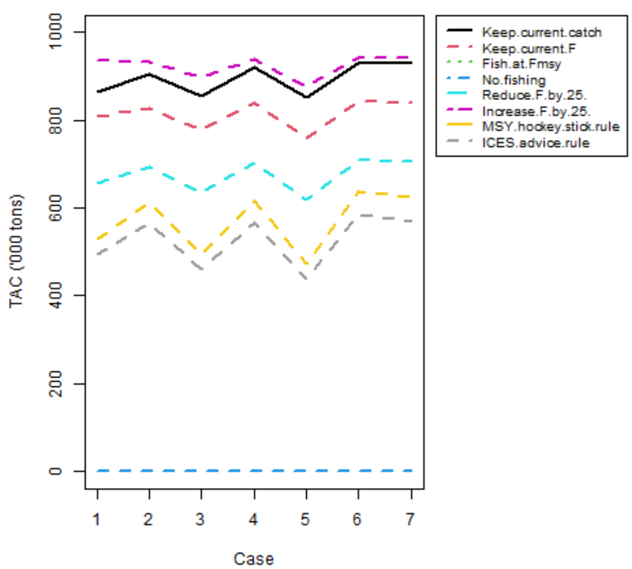

Figure 9. Total allowable catch (TAC) by case and different harvesting rules.

DISCUSION

The updated models estimated population growth parameters (r) are well in the range expected for fast-growing and short-life species, which corrected the low r figures estimated in the first attempt to apply SPiCT to this fishery (Payá 2022). This was because of more informative prior distributions were used and of the change of the initial year from the year 2000 to the year 2001. The new r priors are now more reliable as they are based on r estimated for the same or similar species. The year 2000 should be excluded from the data as the initial year, the fishing effort was very low during that year, and its inclusion in the data had a strong effect on r parameter estimations.

In most of the cases, the biomass and fishing mortality did not have a significant retrospective pattern, but when they were divided by their MSY values they did, which implies that the biological reference points had retrospective patterns, probably related to the length of the time series. Anyway, all cases estimated an overfished stock status and TAC estimations were lower than the current catch.

SPiCT is based on the assumption that the abundance indices are unbiased indices of the whole stock, and therefore the squid abundance indices available need to be improved. Although, the recent standardization of the CPUE of the Chinese fleet showed that nominal CPUE had a similar trend to the standardized CPUE (Dr. Gang Li´s presentation), all nominal CPUE series need to be standardized. The CPUE model should include the spatiotemporal variability and the presence of different squid sizes by time and area, for example, the Chinese catch small squids when fishing in equatorial waters but large squid when fishing in the area off south of Perú.

The main assumption to fit SPiCT to *D. gigas* in the FAO area 87 is a single unit stock distributed throughout the whole area. However, three phenotypes have been defined by the length of maturity or longevity (Nigmatullin et al. 2001), so far, these three phenotypes are present in Peruvian waters, although their relative predominance by year seems to depend on the environmental conditions, the small one in the equatorial waters and the large one in Chilean EEZ and also in international waters off south of Perú. It is expected that these three phenotypes have different intrinsic growth rates and carrying capacities, and therefore dissimilar productive curves. Although SPiCT as a state-space model estimates a process error for biomass, it is not clear if this process error can handle the phenotypes issue. In the same way, the interannual productivity variability, that seems to depend on environmental conditions as well, could be considered as part of the process error of biomass.

CONCLUSIONS

1. The population growth parameter (r) estimations were improved.
2. Abundance indices need to be improved.
3. The Biomass and F did not have any important retrospective pattern.
4. The Biomass/B_MSY and F/F_MSY have retrospective pattern.
5. Stock status is highly uncertain, but the stock seems to be overfished.
6. TAC at FMSY ranged from 473,000 (case 5) to 636,000 (case 6) tons.

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Annex A.

Models fits by case

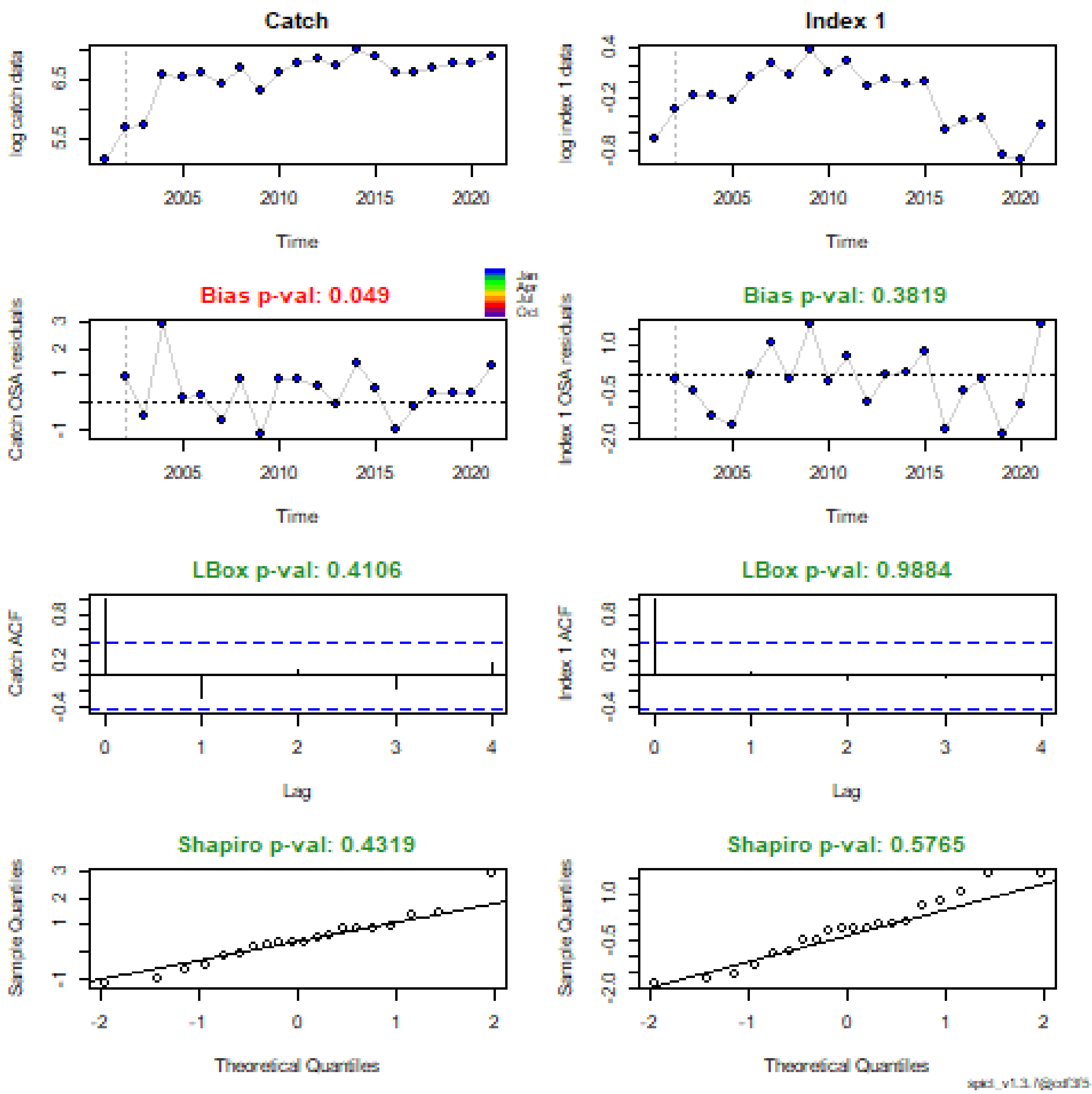

Figure A.1. Model fits to case 1.

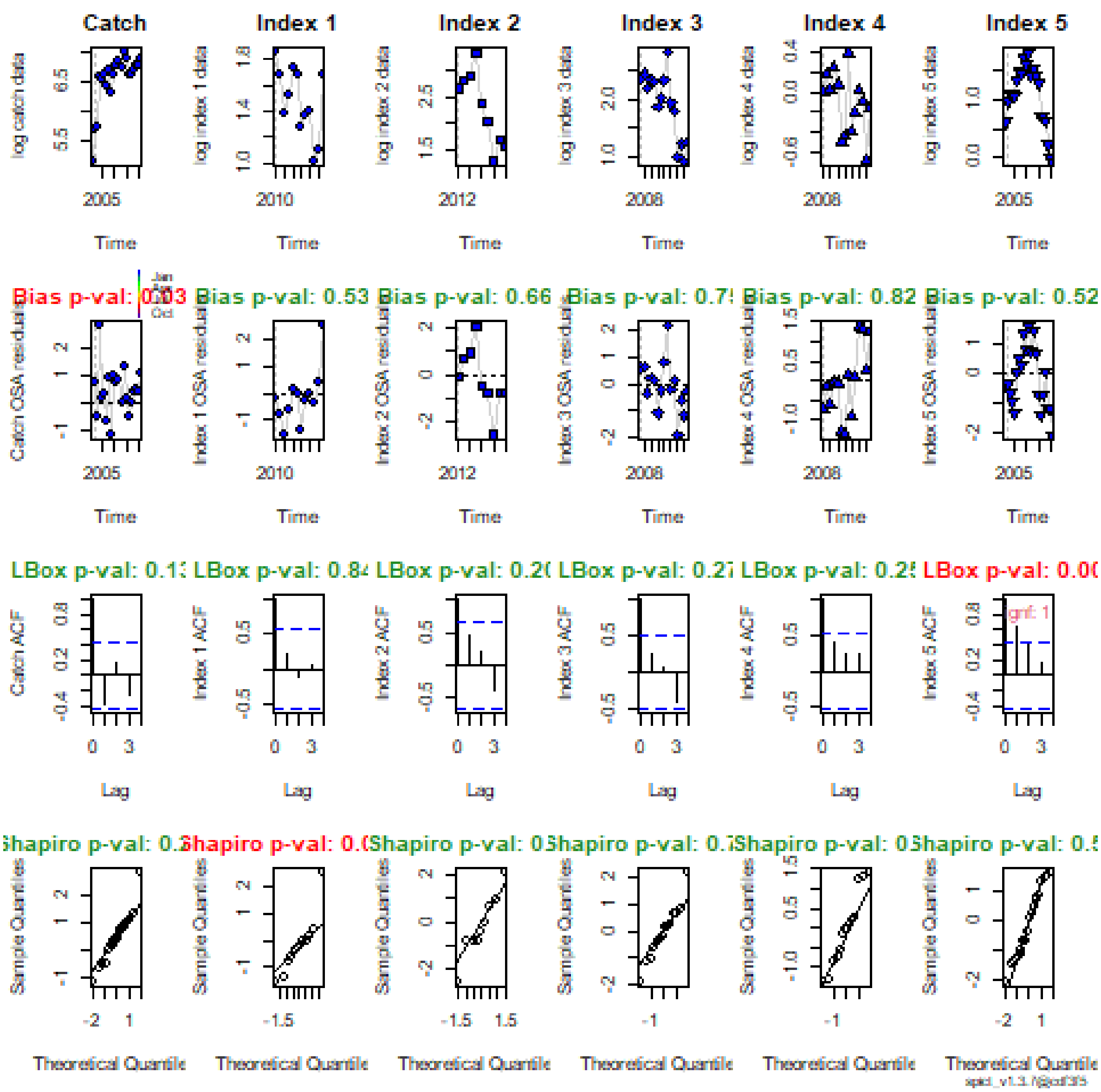

Figure A.2. Model fits to case 2.

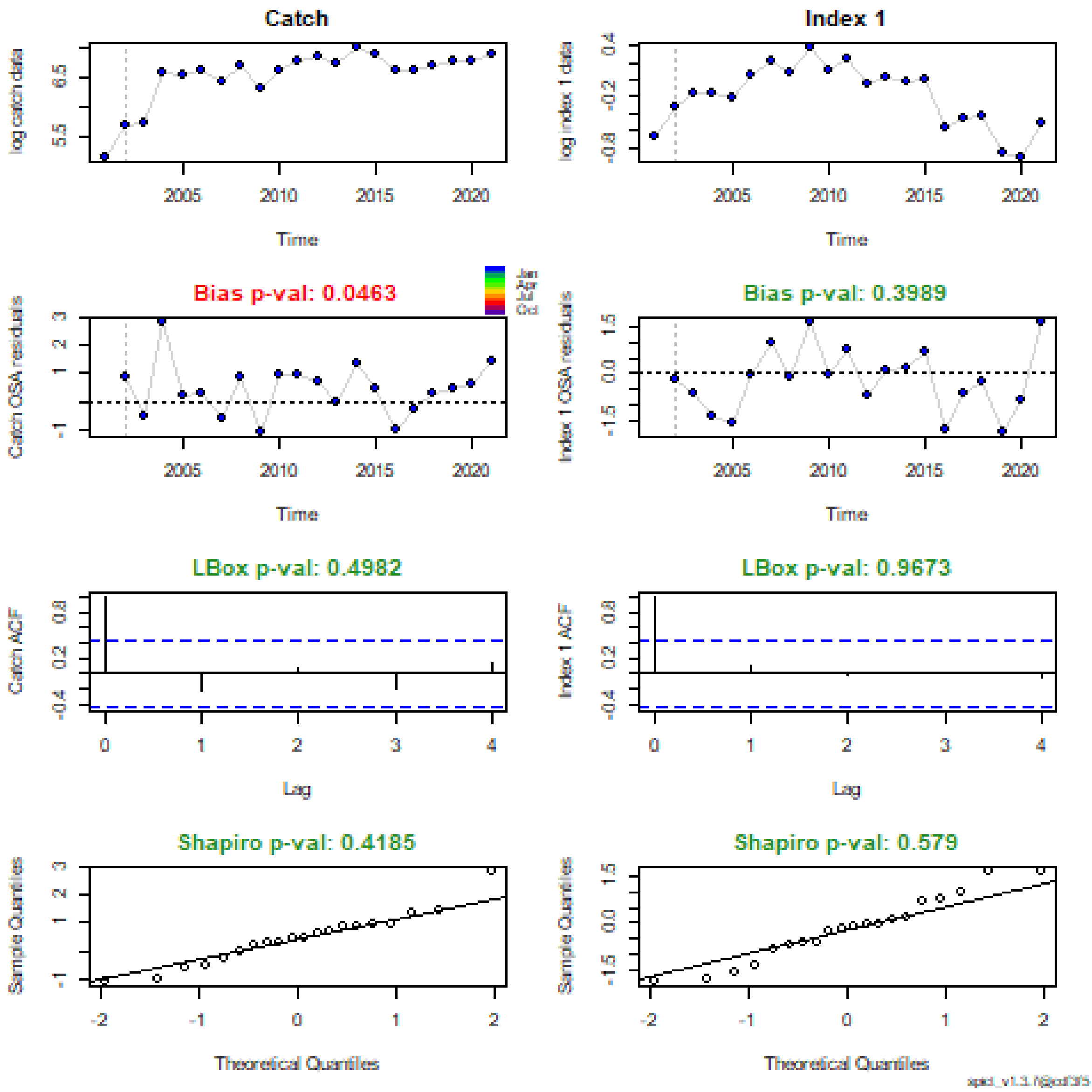

Figure A.3. Model fits to case 3.

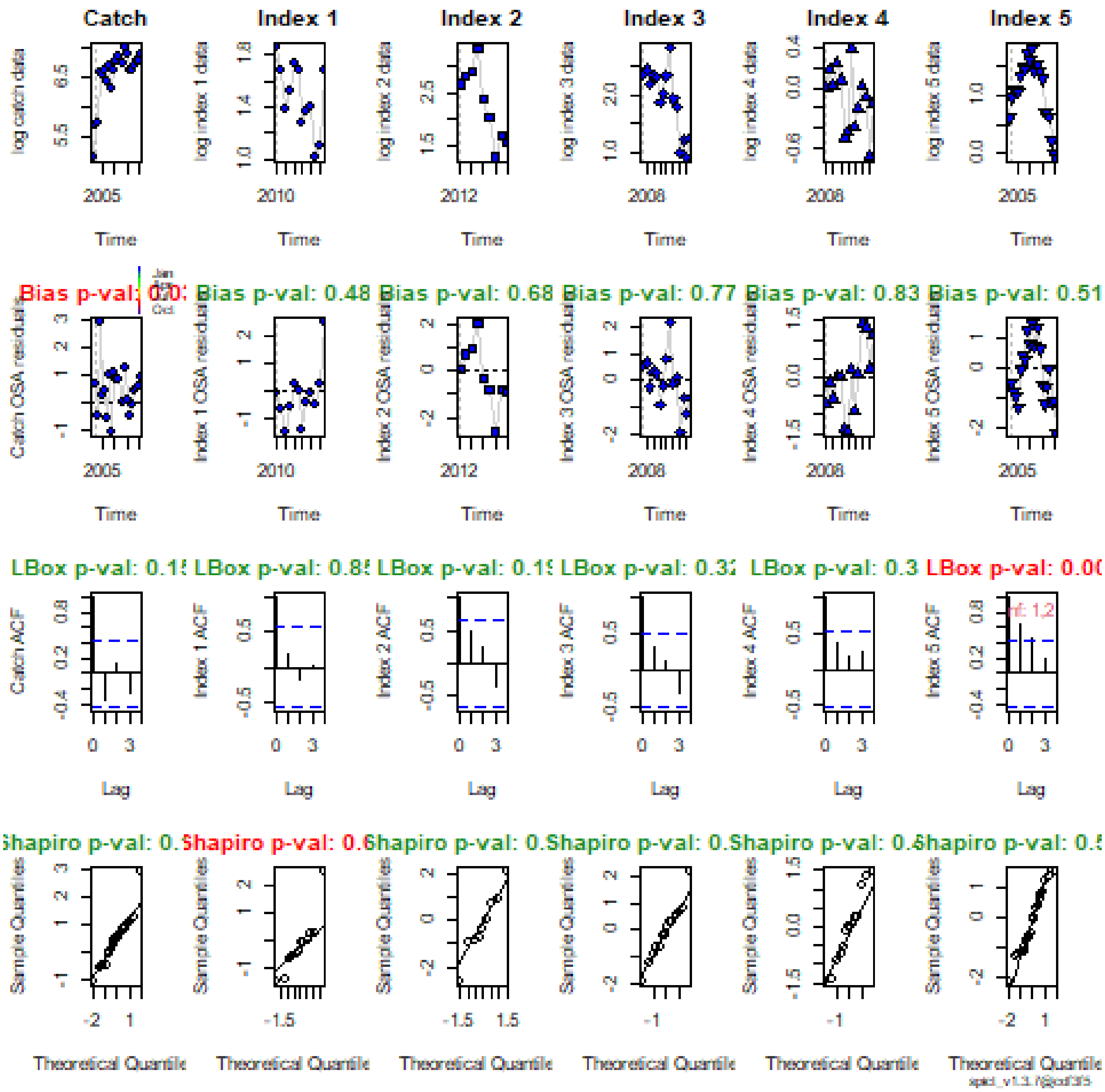

Figure A.4. Model fits to case 4.

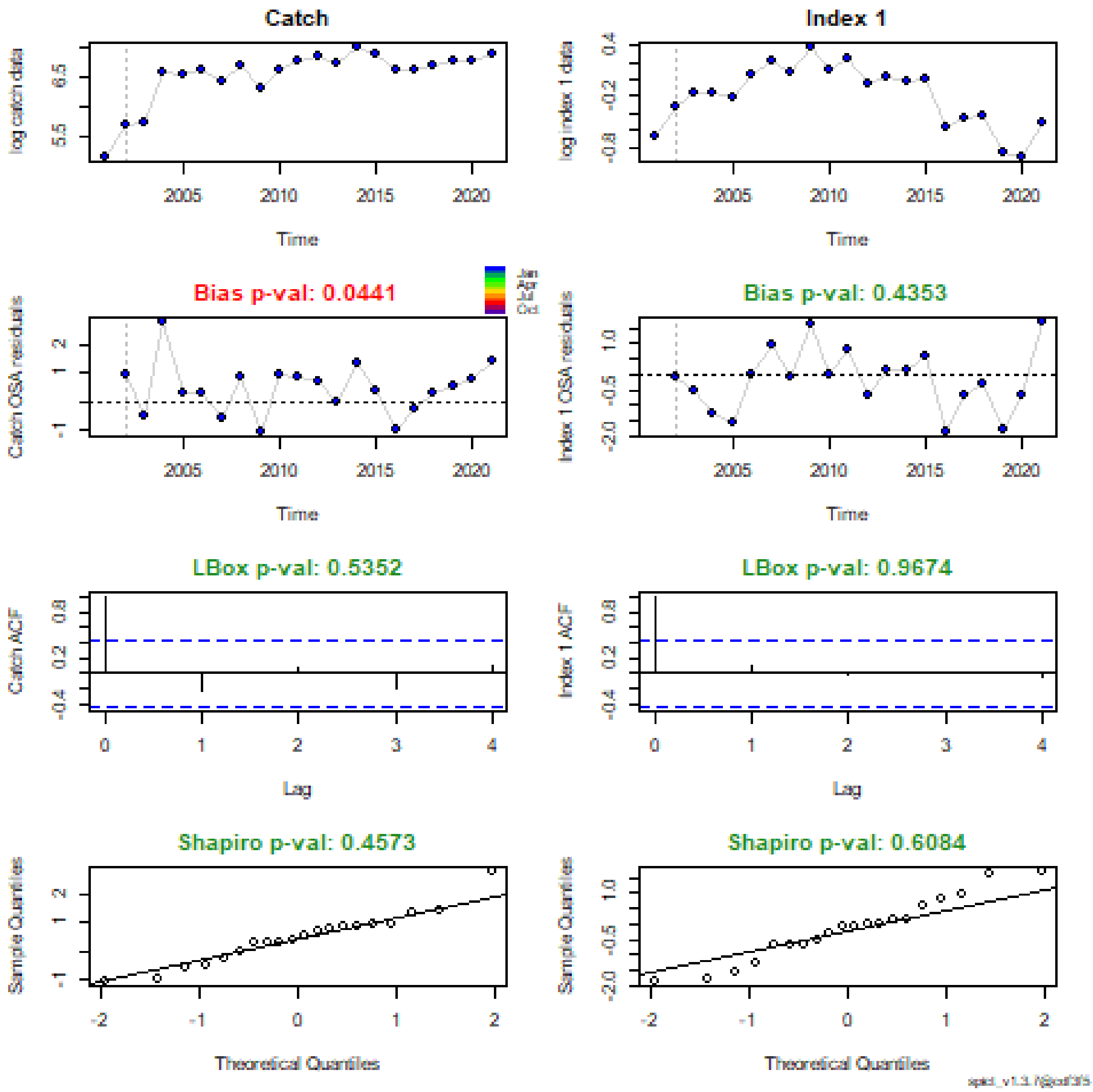

Figure A.5. Model fits to case 5.

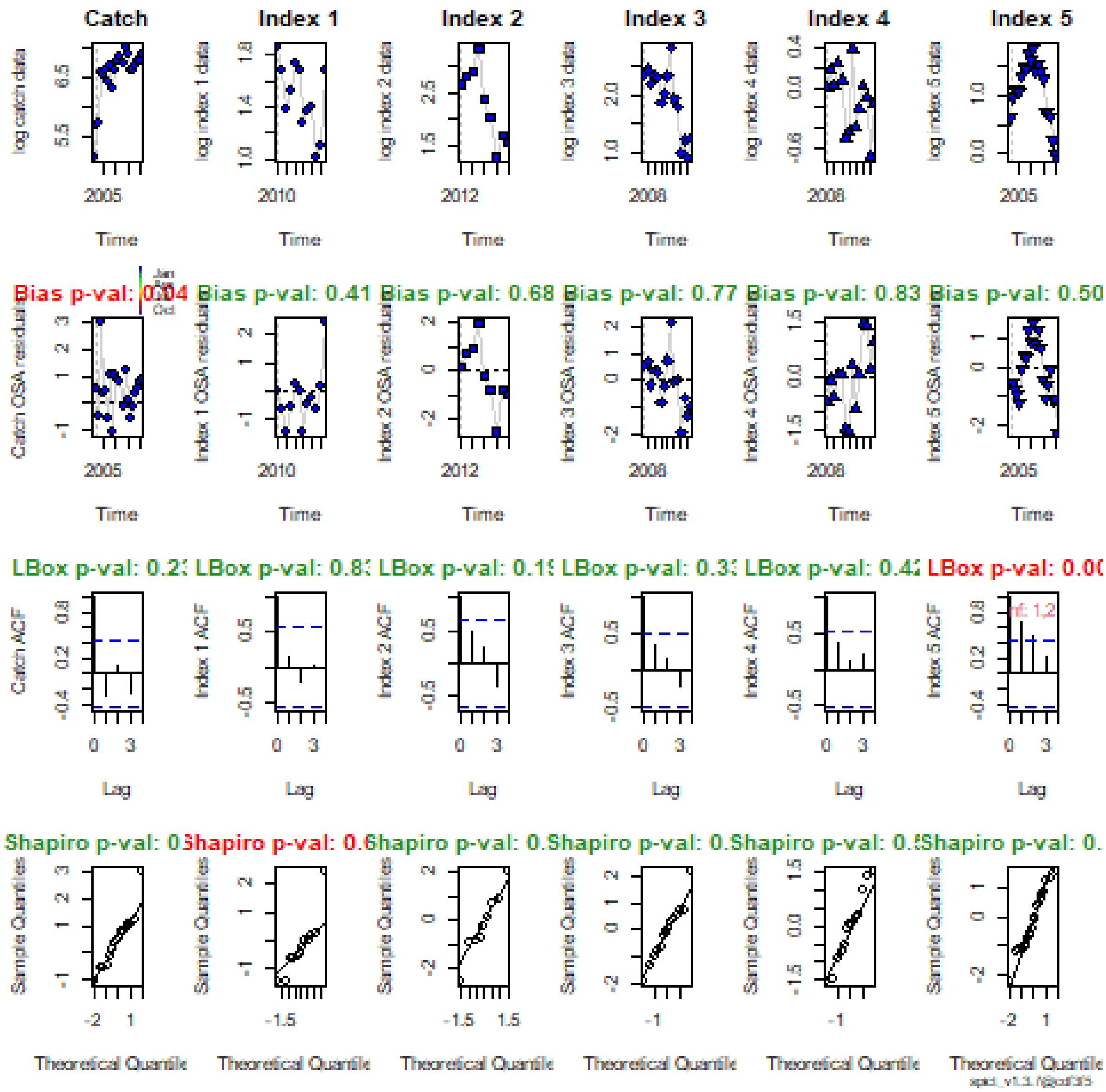

Figure A.6. Model fits to case 6.

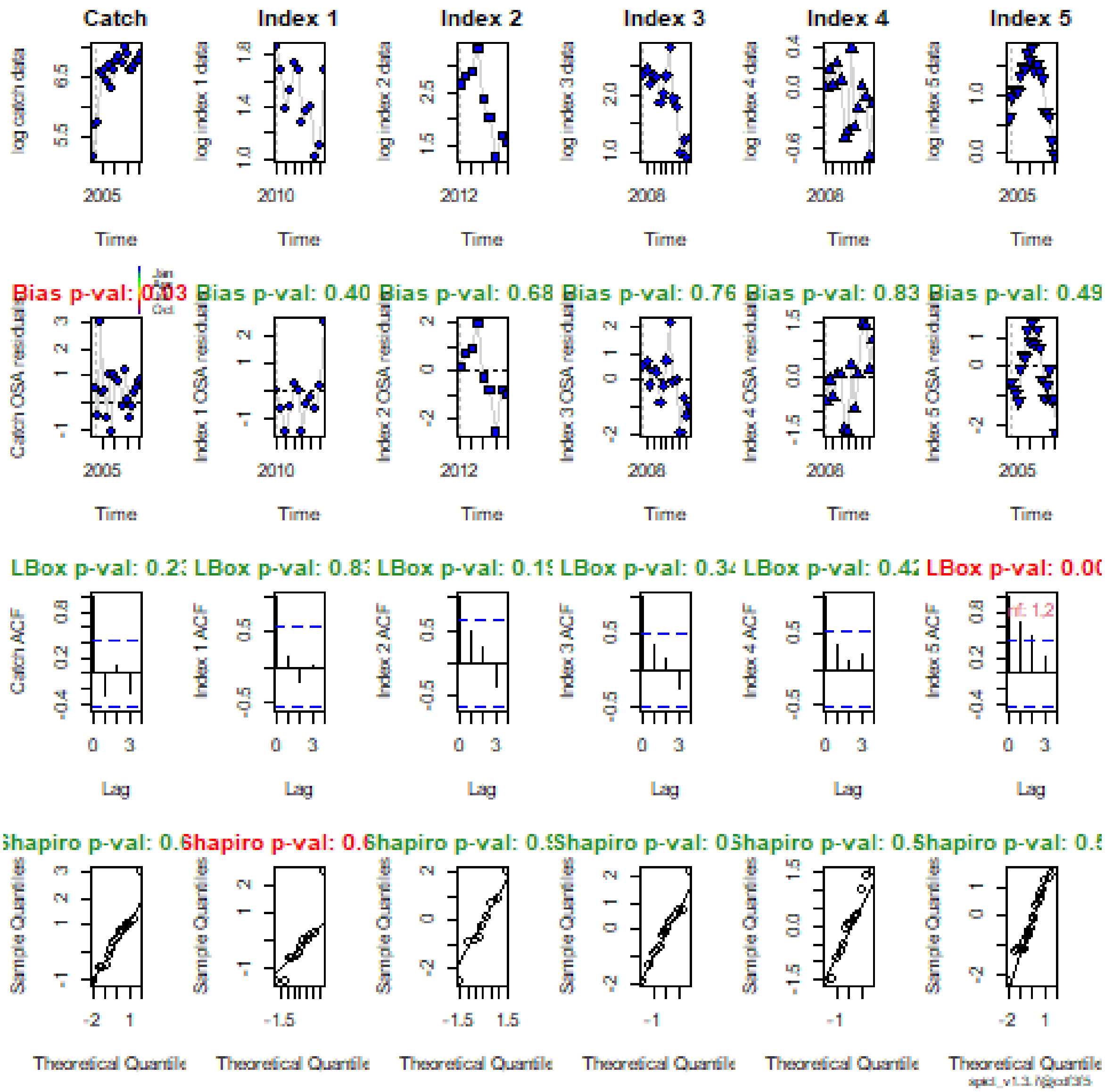

Figure A.6. Model fits to case 7.

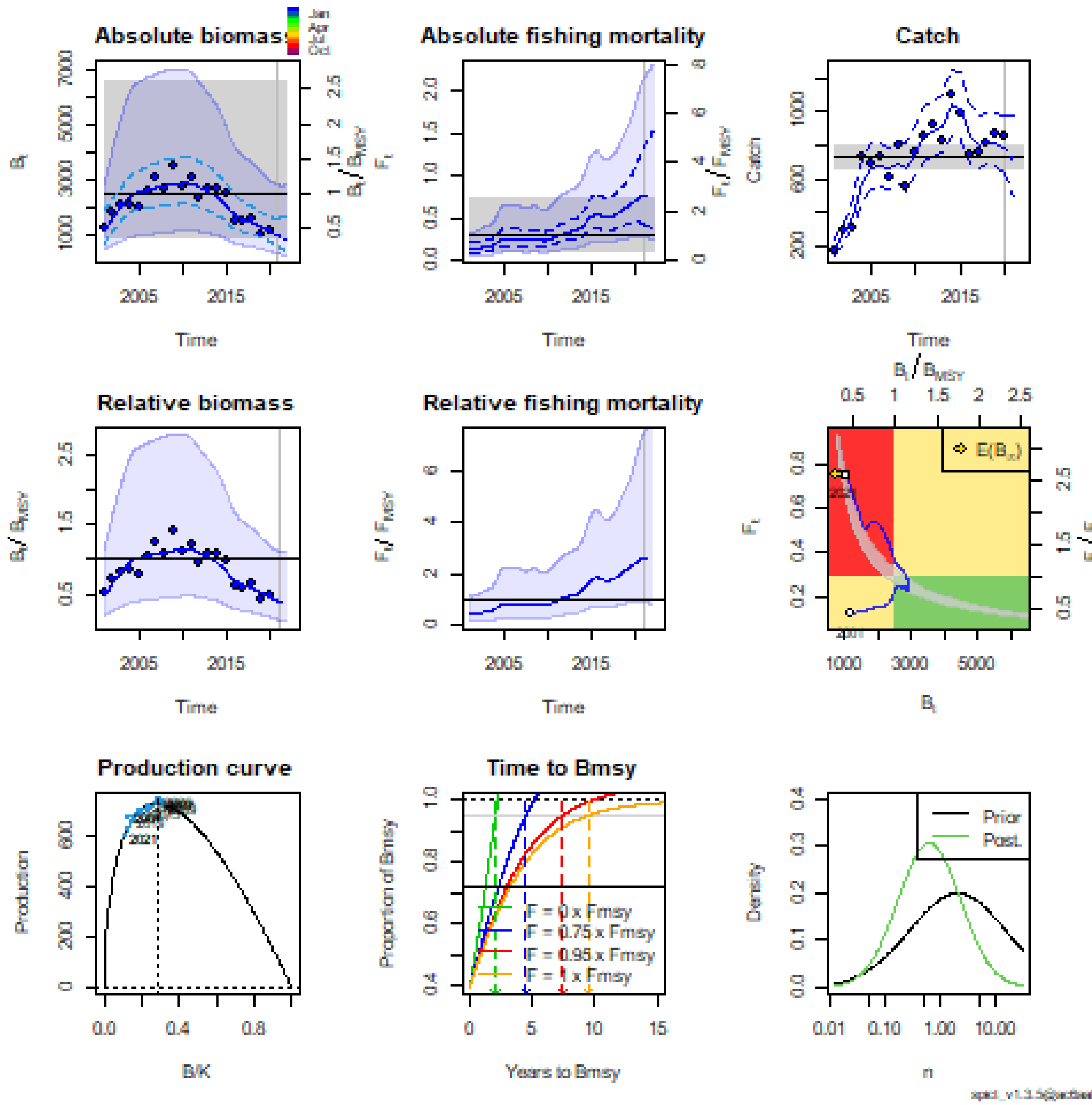

Figure A.1. Main chart results for case 1

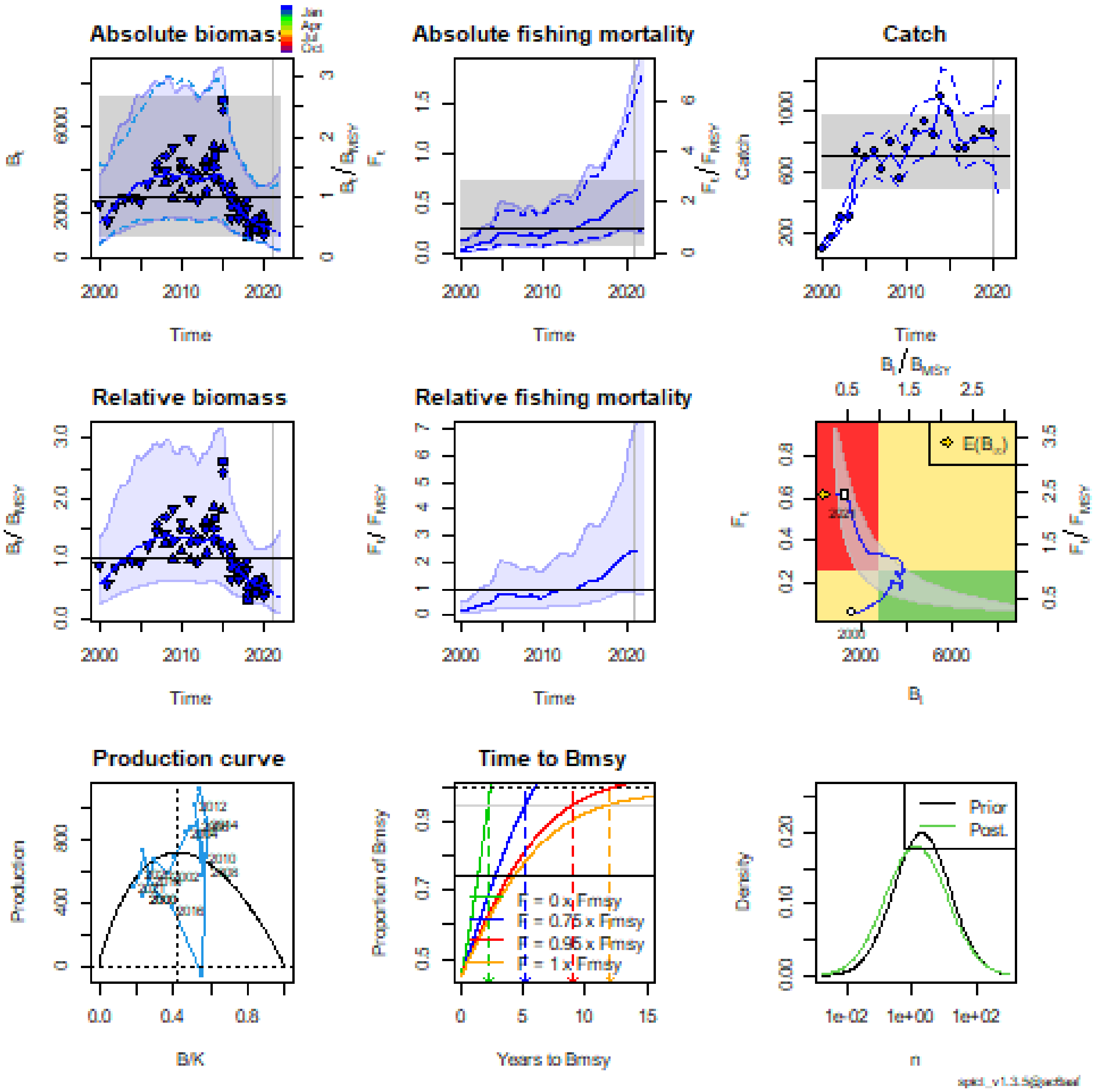

Figure 5. Main results chart for case 2.

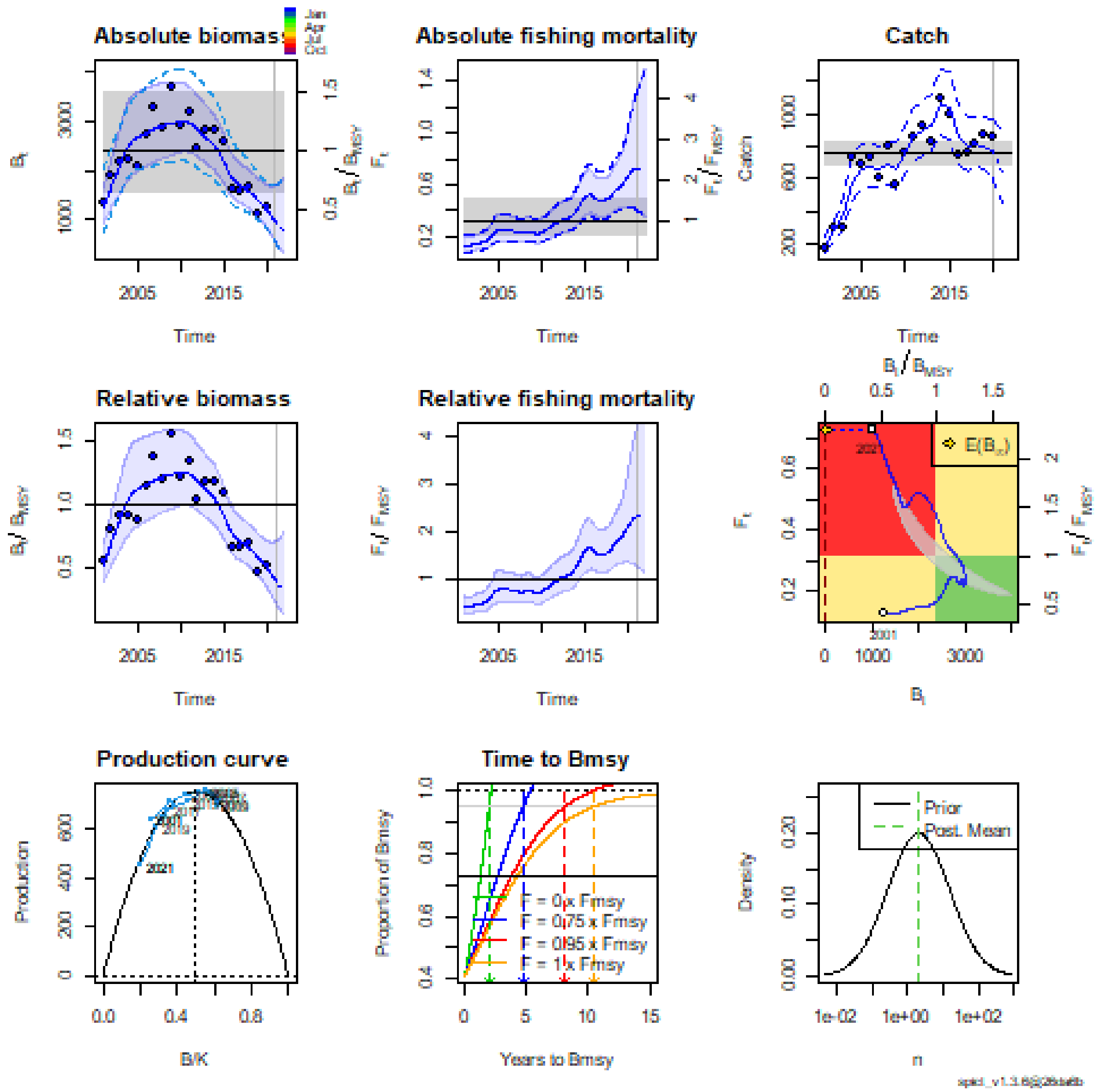

Figure 6. Main results chart for case 3.

Annex B.

Retrospective patterns by case

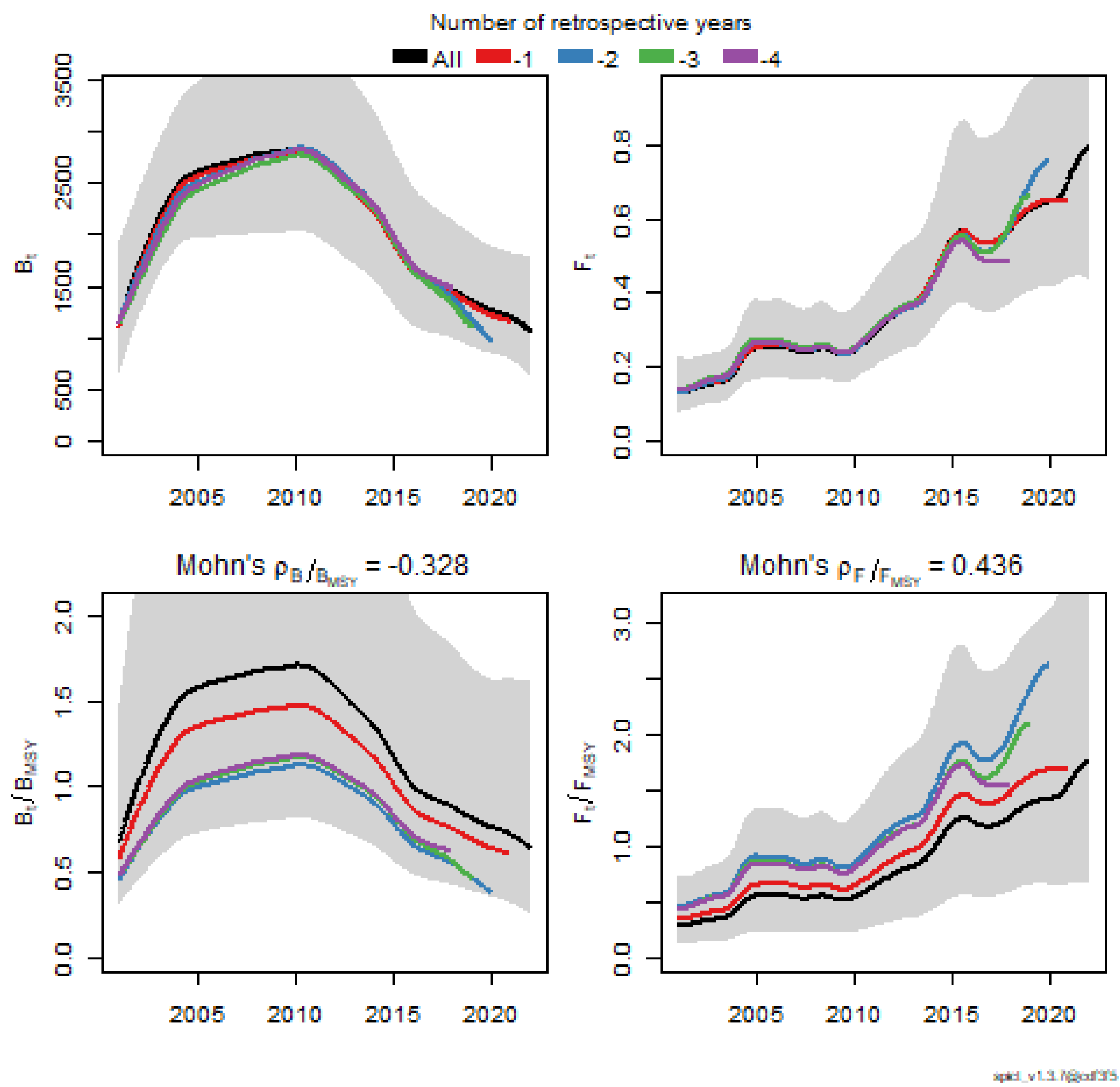

Figure B.1. Retrospective patterns of case 1.

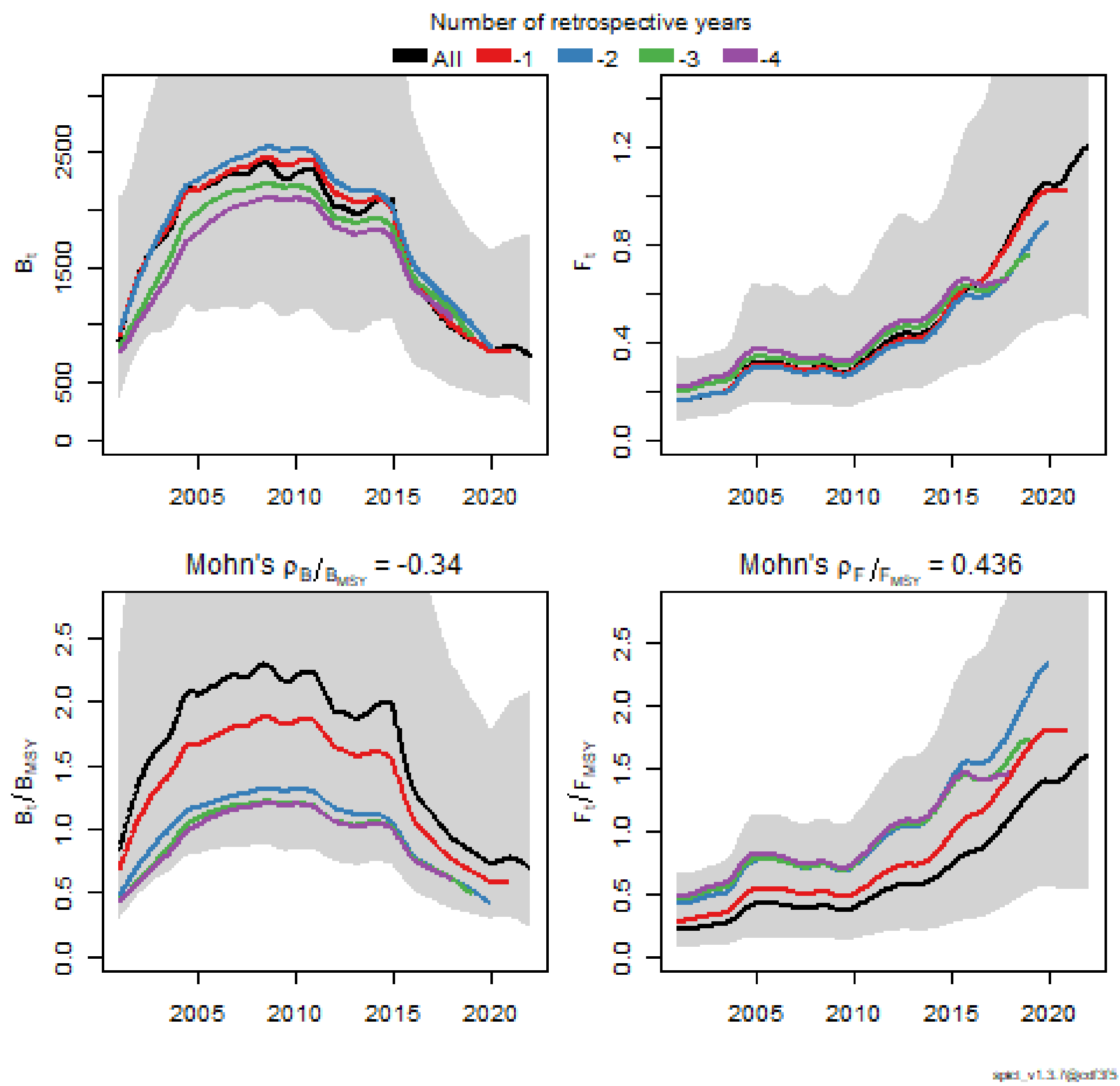

Figure B.2. Retrospective patterns of case 2.

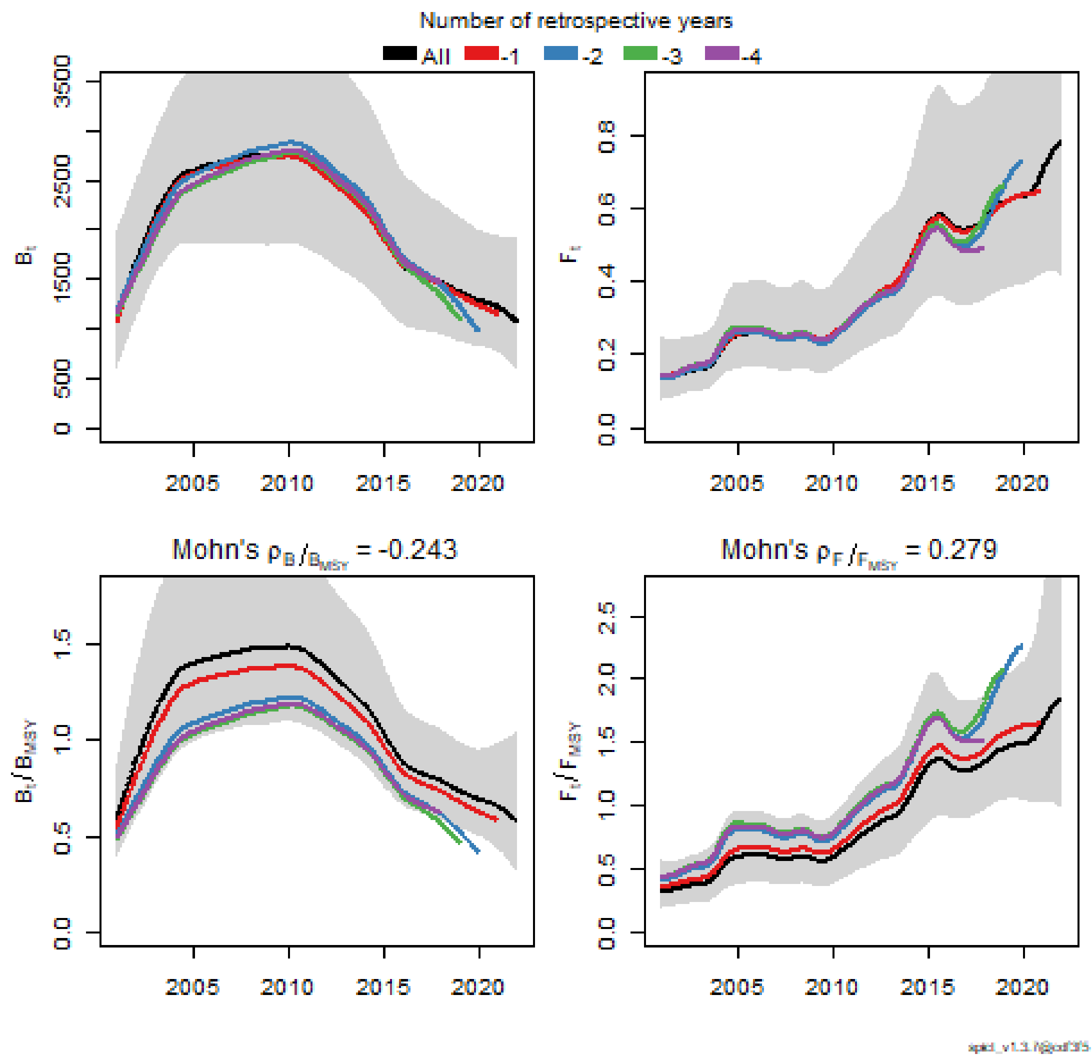

Figure B3. Retrospective patterns of case 3.

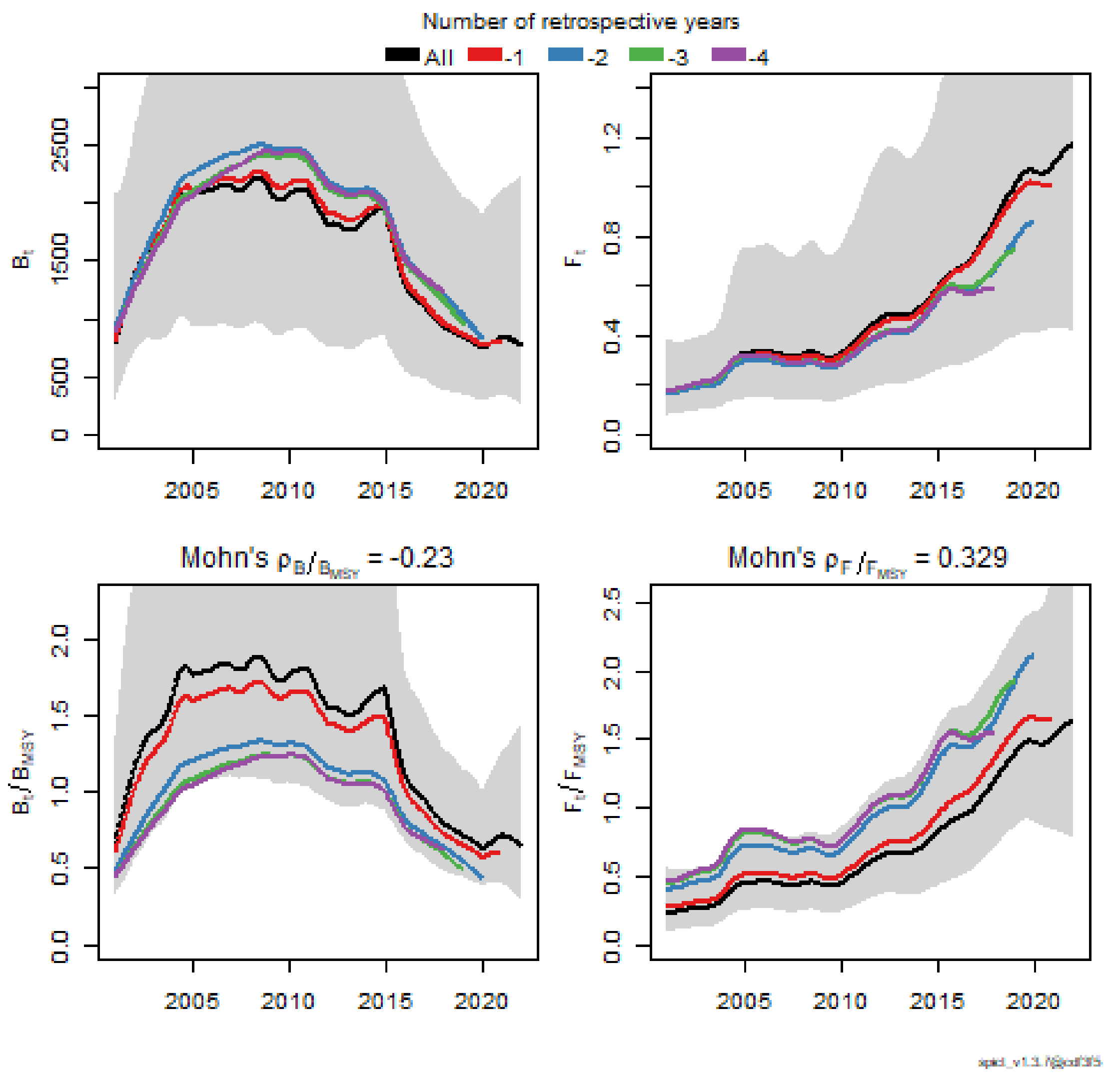

Figure B4. Retrospective patterns of case 4.

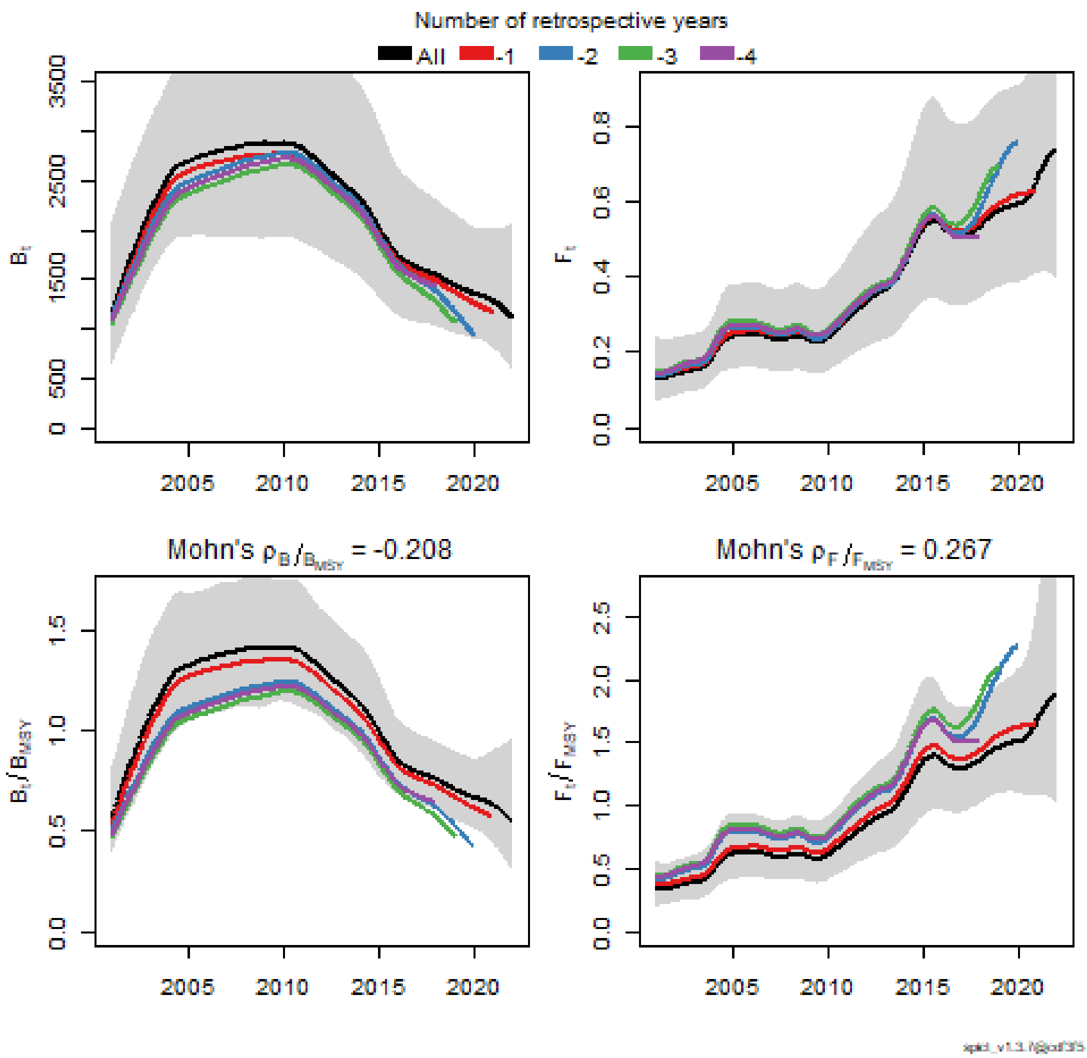

Figure B5. Retrospective patterns of case 5.

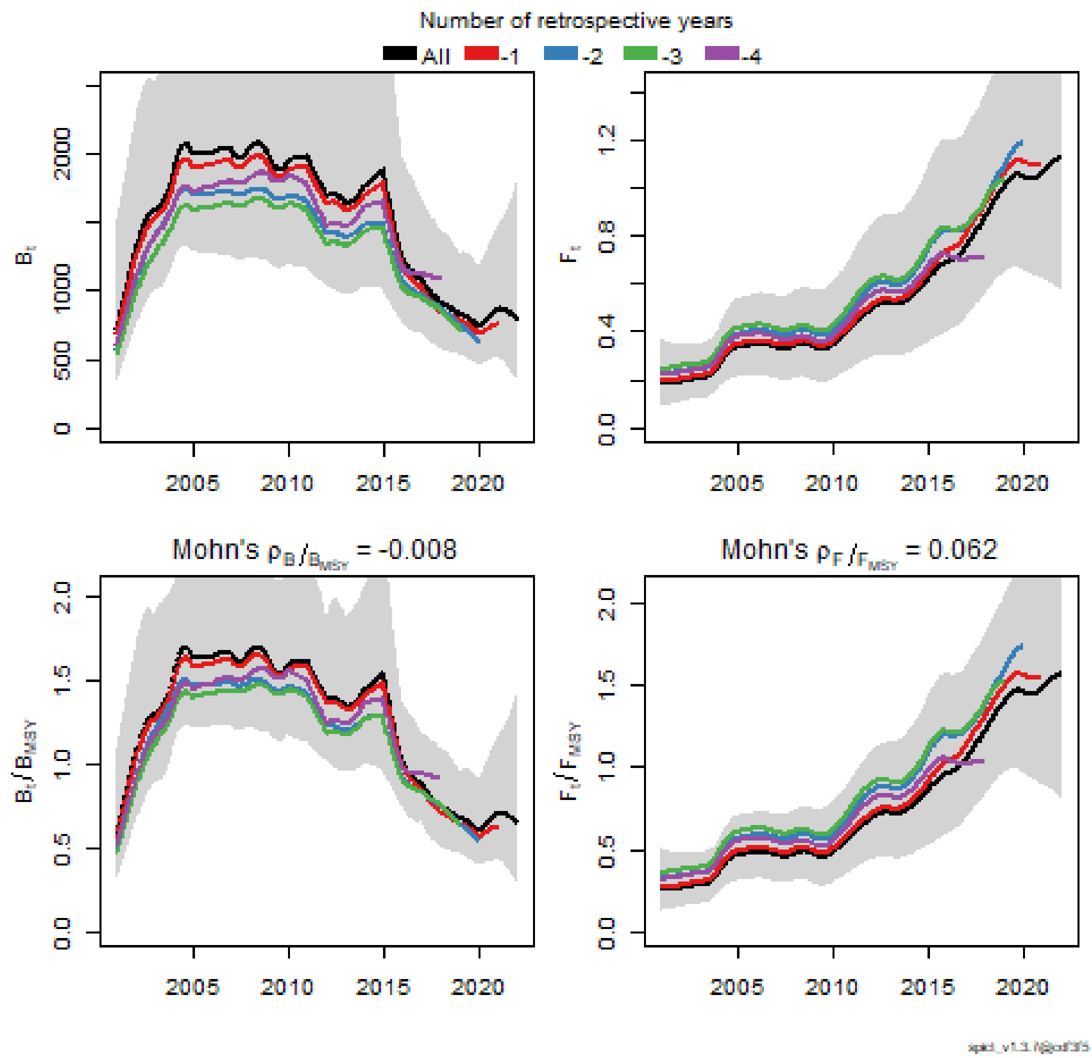

Figure B6. Retrospective patterns of case 6.

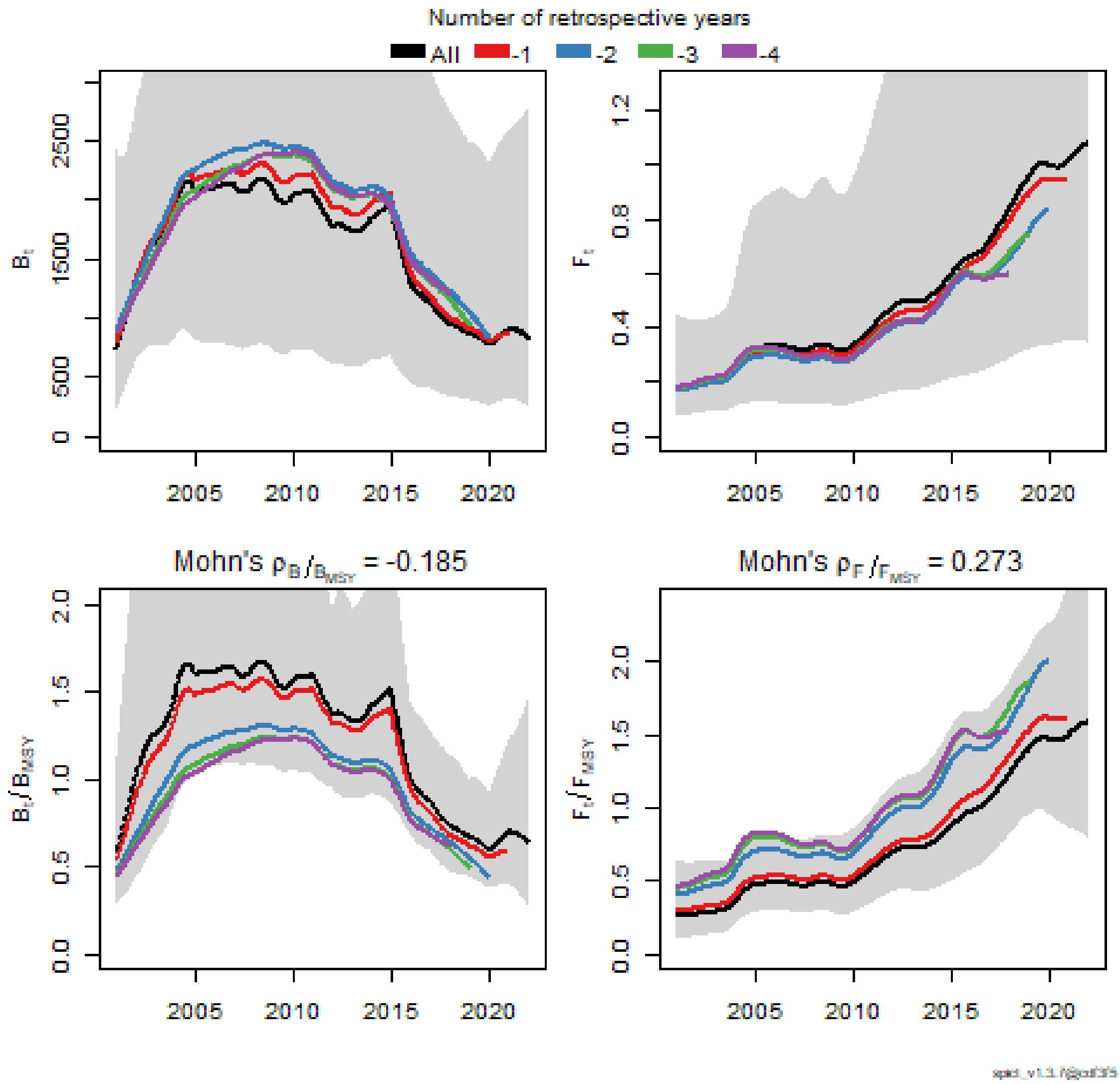

Figure B7. Retrospective patterns of case 7.

Annex C.

Summary of main results by case

Table.C1. Summary of main results for case 1.

```
Convergence: 0  MSG: relative convergence (4)
Objective function at optimum: 9.3068514
Euler time step (years):  1/16 or 0.0625
Nobs C: 21,  Nobs I1: 21

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
 alpha     5.2835961    0.5988393 4.661749e+01  1.6646070
 beta      0.6992431    0.2777611 1.760293e+00 -0.3577569
 r         0.1821914    0.0220137 1.507869e+00 -1.7026973
 rc        0.9055581    0.3610167 2.271462e+00 -0.0992038
 rold      0.3048641    0.0079288 1.172213e+01 -1.1878891
 m       750.6146296  666.1207776 8.458261e+02  6.6208924
 K      7604.8538461 2060.1413420 2.807274e+04  8.9365420
 q         0.0004044    0.0002870 5.699000e-04 -7.8131340
 n         0.4023848    0.0370223 4.373404e+00 -0.9103463
 sdb       0.0323978    0.0039143 2.681473e-01 -3.4296648
 sdf       0.2013478    0.1118436 3.624787e-01 -1.6027215
 sdi       0.1711769    0.1187217 2.468085e-01 -1.7650579
 sdc       0.1407911    0.0830857 2.385744e-01 -1.9604784

Deterministic reference points (Drp)
           estimate       cilow       ciupp   log.est
 Bmsyd 1657.7945200 694.5073465 3957.168609  7.413243
 Fmsyd    0.4527791   0.1805083    1.135731 -0.792351
 MSYd   750.6146296 666.1207776  845.826074  6.620892
Stochastic reference points (Srp)
           estimate       cilow       ciupp    log.est  rel.diff.Drp
 Bmsys 1656.7697961 694.3755409 3953.028290  7.4126251 -0.0006185071
 Fmsys    0.4529224   0.1805606    1.136121 -0.7920344  0.0003164979
 MSYs   750.3883627 666.1450053  845.285471  6.6205909 -0.0003015330
```

Table.C2. Summary of main results for case 2.

```
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     1.9987946     0.6818312 5.859486e+00  0.6925443
 alpha2     2.0504153     0.5976612 7.034426e+00  0.7180424
 alpha3     1.5394556     0.4601237 5.150623e+00  0.4314289
 alpha4     2.4468838     0.8871443 6.748892e+00  0.8948153
 alpha5     1.4305954     0.5204038 3.932722e+00  0.3580907
 beta       0.6029643     0.2129170 1.707547e+00 -0.5058974
 r          0.3104094     0.0332226 2.900257e+00 -1.1698632
 rc         1.4998487     0.4137873 5.436479e+00  0.4053642
 rold       0.5296374     0.0101533 2.762804e+01 -0.6355626
 m        797.9158884   637.2546015 9.990823e+02  6.6820032
 K       4792.6537228  1250.4083326 1.836962e+04  8.4748396
 q1         0.0030357     0.0014875 6.195300e-03 -5.7973055
 q2         0.0071952     0.0034752 1.489740e-02 -4.9343419
 q3         0.0042757     0.0021267 8.596100e-03 -5.4548154
 q4         0.0005829     0.0002839 1.196700e-03 -7.4475598
 q5         0.0017815     0.0009074 3.497800e-03 -6.3302802
 n          0.4139210     0.0300587 5.699875e+00 -0.8820803
 sdb        0.1635569     0.0662187 4.039778e-01 -1.8105942
 sdf        0.2167350     0.1191727 3.941682e-01 -1.5290796
 sdi1       0.3269167     0.1795907 5.951005e-01 -1.1180499
 sdi2       0.3353596     0.1854089 6.065839e-01 -1.0925518
 sdi3       0.2517886     0.1533361 4.134545e-01 -1.3791653
 sdi4       0.4002048     0.2474886 6.471566e-01 -0.9157789
 sdi5       0.2339838     0.1258309 4.350950e-01 -1.4525035
 sdc        0.1306835     0.0654720 2.608470e-01 -2.0349770

Deterministic reference points (Drp)
           estimate       cilow      ciupp   log.est
 Bmsyd 1063.9951986 307.5106136 3681.45271  6.969786
 Fmsyd    0.7499243   0.2068937    2.71824 -0.287783
 MSYd   797.9158884 637.2546015  999.08226  6.682003
```

Table.C3. Summary of main results for case 3.

Model parameter estimates w 95% CI

	estimate	cilow	ciupp	log.est
alpha	3.8823966	0.3192787	47.2095464	1.3564526
beta	0.7204864	0.2854212	1.8187181	-0.3278287
r	0.5971315	0.2306424	1.5459691	-0.5156179
rc	0.8488024	0.4823832	1.4935542	-0.1639289
rold	1.4671618	0.0655990	32.8139873	0.3833298
m	789.0949066	698.9580524	890.8557094	6.6708866
K	4302.4111531	2726.7400133	6788.5979743	8.3669309
q	0.0004085	0.0002747	0.0006074	-7.8029569
n	1.4069977	0.4561637	4.3397638	0.3414582
sdb	0.0456693	0.0043087	0.4840624	-3.0863296
sdf	0.1992106	0.1092879	0.3631221	-1.6133927
sdi	0.1773062	0.1193260	0.2634590	-1.7298769
sdc	0.1435285	0.0848621	0.2427519	-1.9412214

Deterministic reference points (Drp)

	estimate	cilow	ciupp	log.est
Bmsyd	1859.3135751	1077.2397267	3209.1714453	7.5279627
Fmsyd	0.4244012	0.2411916	0.7467771	-0.8570761
MSYd	789.0949066	698.9580524	890.8557094	6.6708866

Table.C4. Summary of main results for case 4.

Model parameter estimates w 95% CI

	estimate	cilow	ciupp	log.est
alpha1	1.5292703	0.6460378	3.620017e+00	0.4247907
alpha2	1.7931458	0.5059968	6.354529e+00	0.5839715
alpha3	1.3167595	0.3861129	4.490540e+00	0.2751738
alpha4	1.9355477	0.8453080	4.431928e+00	0.6603903
alpha5	1.3722800	0.4633594	4.064129e+00	0.3164736
beta	0.6056049	0.1978092	1.854097e+00	-0.5015274
r	0.8202253	0.3377865	1.991700e+00	-0.1981762
rc	1.4361208	0.4937673	4.176953e+00	0.3619456
rold	5.7649087	0.0001206	2.755719e+05	1.7517893
m	864.1072122	704.4929942	1.059885e+03	6.7616968
K	3065.1751197	1577.3404383	5.956418e+03	8.0278600
q1	0.0032274	0.0013812	7.541300e-03	-5.7360846
q2	0.0076641	0.0032169	1.825890e-02	-4.8712112
q3	0.0045659	0.0019777	1.054140e-02	-5.3891299
q4	0.0006221	0.0002655	1.457700e-03	-7.3824109
q5	0.0018965	0.0008489	4.237000e-03	-6.2677270
n	1.1422790	0.2783657	4.687363e+00	0.1330254
sdb	0.1931110	0.0853152	4.371070e-01	-1.6444902
sdf	0.2099993	0.1106064	3.987086e-01	-1.5606510
sdi1	0.2953189	0.1481471	5.886937e-01	-1.2196995
sdi2	0.3462762	0.1778406	6.742395e-01	-1.0605187
sdi3	0.2542807	0.1411360	4.581304e-01	-1.3693164
sdi4	0.3737755	0.2209773	6.322285e-01	-0.9840999
sdi5	0.2650023	0.1501159	4.678136e-01	-1.3280166
sdc	0.1271766	0.0616019	2.625551e-01	-2.0621784

Deterministic reference points (Drp)

	estimate	cilow	ciupp	log.est
Bmsyd	1203.3907228	404.0212501	3584.339268	7.0928985
Fmsyd	0.7180604	0.2468836	2.088477	-0.3312016
MSYd	864.1072122	704.4929942	1059.884598	6.7616968

Table.C5. Summary of main results for case 5.

Model parameter estimates w 95% CI

	estimate	cilow	ciupp	log.est
alpha	3.3665137	0.2522488	44.9295078	1.2138777
beta	0.7295959	0.2882791	1.8465093	-0.3152645
r	0.7885601	0.4997314	1.2443224	-0.2375467
rc	0.7885601	0.4997314	1.2443224	-0.2375467
rold	0.7885601	0.4997314	1.2443224	-0.2375467
m	802.9926228	705.0721467	914.5123025	6.6883455
K	4073.2097582	2696.0100415	6153.9228264	8.3121866
q	0.0003901	0.0002661	0.0005720	-7.8490115
sdb	0.0525142	0.0047510	0.5804536	-2.9466717
sdf	0.1989457	0.1086110	0.3644143	-1.6147233
sdi	0.1767898	0.1165922	0.2680679	-1.7327940
sdc	0.1451500	0.0856242	0.2460578	-1.9299878

Deterministic reference points (Drp)

	estimate	cilow	ciupp	log.est
Bmsyd	2036.60488	1348.0050207	3076.9614132	7.6190394
Fmsyd	0.39428	0.2498657	0.6221612	-0.9306939
MSYd	802.99262	705.0721467	914.5123025	6.6883455

Table.C6. Summary of main results for case 6.

Model parameter estimates w 95% CI

	estimate	cilow	ciupp	log.est
alpha1	1.2840542	0.5978799	2.7577365	0.2500224
alpha2	1.7093613	0.4759404	6.1392477	0.5361198
alpha3	1.2515706	0.3552490	4.4093837	0.2243993
alpha4	1.6731038	0.8172286	3.4253282	0.5146804
alpha5	1.3567047	0.4379580	4.2027946	0.3050588
beta	0.6217298	0.2052625	1.8831882	-0.4752498
r	1.4509783	1.0963234	1.9203621	0.3722380
rc	1.4509783	1.0963234	1.9203621	0.3722380
rold	1.4509783	1.0963234	1.9203621	0.3722380
m	924.1301552	735.3310549	1161.4041567	6.8288529
K	2547.6057952	1805.0647318	3595.6025142	7.8429093
q1	0.0033430	0.0021856	0.0051133	-5.7009007
q2	0.0079505	0.0049951	0.0126545	-4.8345163
q3	0.0047541	0.0031140	0.0072580	-5.3487530
q4	0.0006469	0.0004161	0.0010058	-7.3432612
q5	0.0019760	0.0013039	0.0029945	-6.2266956
sdb	0.2110218	0.0994740	0.4476569	-1.5557936
sdf	0.2043409	0.1071370	0.3897366	-1.5879654
sdi1	0.2709635	0.1205676	0.6089632	-1.3057712
sdi2	0.3607126	0.1767414	0.7361805	-1.0196738
sdi3	0.2641087	0.1357774	0.5137338	-1.3313943
sdi4	0.3530615	0.1975754	0.6309105	-1.0411132
sdi5	0.2862943	0.1600661	0.5120661	-1.2507348
sdc	0.1270448	0.0618814	0.2608278	-2.0632152

Deterministic reference points (Drp)

	estimate	cilow	ciupp	log.est
Bmsyd	1273.8028976	902.5323659	1797.8012571	7.1497621
Fmsyd	0.7254891	0.5481617	0.9601811	-0.3209092
MSYd	924.1301552	735.3310549	1161.4041567	6.8288529

Table.C7. Summary of main results for case 7.

Model parameter estimates w 95% CI

	estimate	cilow	ciupp	log.est
alpha1	1.3028648	0.5718491	2.9683645	0.2645655
alpha2	1.7423421	0.4577454	6.6319751	0.5552302
alpha3	1.2766544	0.3400528	4.7929222	0.2442429
alpha4	1.6982803	0.7787028	3.7037957	0.5296161
alpha5	1.3769756	0.4246471	4.4650295	0.3198895
beta	0.6326484	0.1988305	2.0129910	-0.4578404
r	1.4564759	1.0882346	1.9493243	0.3760198
rc	1.3782543	0.4497436	4.2237067	0.3208177
rold	1.3080065	0.1521314	11.2460725	0.2685042
m	927.4072225	721.6296658	1191.8636347	6.8323928
K	2635.3903890	1178.3043463	5894.3027108	7.8767866
q1	0.0031995	0.0011453	0.0089385	-5.7447504
q2	0.0076067	0.0026578	0.0217705	-4.8787288
q3	0.0045516	0.0016389	0.0126406	-5.3922872
q4	0.0006193	0.0002209	0.0017361	-7.3869001
q5	0.0018961	0.0007137	0.0050373	-6.2679673
n	2.1135082	0.6573762	6.7950691	0.7483492
sdb	0.2076089	0.0911138	0.4730509	-1.5720993
sdf	0.2021362	0.1015724	0.4022651	-1.5988135
sdi1	0.2704863	0.1199930	0.6097259	-1.3075338
sdi2	0.3617257	0.1770744	0.7389294	-1.0168690
sdi3	0.2650448	0.1359204	0.5168375	-1.3278564
sdi4	0.3525781	0.1969394	0.6312162	-1.0424831
sdi5	0.2858724	0.1587544	0.5147764	-1.2522098
sdc	0.1278811	0.0622685	0.2626300	-2.0566540

Deterministic reference points (Drp)

	estimate	cilow	ciupp	log.est
Bmsyd	1345.7707936	398.4530100	4545.326510	7.2047222
Fmsyd	0.6891272	0.2248718	2.111853	-0.3723294
MSYd	927.4072225	721.6296658	1191.863635	6.8323928