NPFC-2021-SSC PS08-WP02 (Rev. 1)

Updates of stock assessment for Pacific saury in the North Pacific Ocean up to 2021

Member: China

Summary

This working paper presents the results of update of stock assessment for the North Pacific Ocean Pacific Saury stock using the Bayesian state-space production model. The assessment was conducted based on the model specification (2 base cases and 2 sensitivity cases) updated in the 7th Meeting of the Small Scientific Committee on Pacific saury. The model parameters were estimated based on Bayesian framework with a Markov chain Monte Carlo method. The assessment results were diagnosed with the Gelman and Rubin's statistic, standardized residual plots, the shapes of posterior distributions for key parameters, and retrospective analysis. The main assessment results were concluded as follows:

The estimated median B2020 from the two base case scenarios was 390,700 (80%CI 186,700-580,500) and 404,050 (80%CI 133,100-805,600) metric tons, respectively. The median B2020/BMSY and F2020/FMSY over the two base case scenarios were 0.33 (80%CI 0.19-0.54) and 0.99 (80%CI 0.55-1.64), respectively. Over two base case scenarios, large interannual variability was shown in biomass trajectory during the most recent years. A decreasing biomass trend was found in 2019 and 2020, followed by an increase in 2021. The probability of the population being in the red Kobe quadrant in 2020 was estimated to be greater than 48%.

1. Introduction

The Pacific saury (*Cololabis sarira*) is one of the most commercially important fish species in the North Pacific Ocean. The regular update of stock assessment for Pacific saury in each year is conducted by the Small Scientific Committee on Pacific saury (SSC PS) established under the Scientific Committee of the North Pacific Fisheries Commission (NPFC). Currently, the benchmark assessment model for Pacific saury stock assessment is Bayesian state-space production model (BSSPM). In the 7th SSC PS meeting held in October 2021, the model specification and input data for BSSPM were furtherly updated and adopted by the members. The meeting participants agreed to conduct a stock assessment update with two base cases and two sensitivity cases based on updated input data.

In this report, we conducted an update of stock assessment for Pacific saury by using BSSPM, and summarized the estimates of key parameters and biological reference points as well as other assessment results for all case scenarios. The 1st Special Session of the Scientific Committee concluded that retrospective analyses showed that BSSPM projections for Pacific saury were less useful than expected and the SSC PS agreed results were likely to be misinterpreted. Therefore, we did not conduct stock projection and risk analysis in this updated stock assessment report.

2. Materials and methods

2.1. Input data

1) The catch data from 1980 to 2020 were included.
2) The Japanese fishery-independent survey biomass estimates up to 2021 were included.
3) The fishery-dependent abundance indices, including Japanese late CPUE (1994-2020), Russian CPUE (1994-2020), Chinese Taipei CPUE (2001-2020), Korean CPUE (2001-2020) and Chinese CPUE (2013-2020) were updated.

2.2. Assessment methods (Annex F in NPFC-2018-TWG PSSA03-Final Report)

The input data used in this assessment were shown in Figure 1. The assessment used a Bayesian state-space production model. The population dynamics were modeled by the following equations:

$$B_t = B_{t-1} + r \times B_{t-1}(1 - (\frac{B_{t-1}}{K})^M) - C_{t-1}$$

$$P_t = B_t/K$$

$$P_{t+1} = (P_t + r \times P_t \times (1 - P_t^M) - \frac{C_t}{K})exp(\mu_t)$$

$$\mu_t \sim N(0, \tau^2)$$

Where B_t and C_t denote biomass and catch, respectively, in year *t*. Parameters *r*, *K*, *M* represent intrinsic population growth rate, carrying capacity, and production shape parameter respectively. P_t and μ_t denote the ratio between biomass and carrying capacity and the process error, respectively, in year t. μ_t has a mean of zero and variance τ^2.

The multiple indices were modeled by the following equations:

$$I_{i,t} = q_{i,t}(KP_t)^{b_i} exp(\varepsilon_{i,t})$$

$$\varepsilon_{i,t} \sim N(0, \sigma_i^2)$$

Where $I_{i,t}$ is the relative abundance of index *i* at year *t*. $q_{i,t}$ is the catchability coefficient for index *i* at year *t*. b_i is the hyperdepletion parameter. $\varepsilon_{i,t}$ is the observation error with a mean of zero and variance σ_i^2.

All base case and sensitivity case scenarios were built based on SSC PS07 recommendation and used uniform prior distribution for catchability (*q*; besides the catchability of Japanese early CPUE), carrying capacity (K), intrinsic population growth rate (r), initial biomass as a proportion of carrying capacity (P1), and shape (s) (Table 1; Table 2). Inverse gamma prior distribution was used for the process (τ^2) and observation (σ^2) error variance (Table 2).

Random walk approach was selected to estimate the time-varying catchability of Japanese early CPUE due to its relatively well performance and its ability to obtain a realistic increase of catchability over time (Wilberg et al. 2009; NPFC-2019-TWG PSSA04-WP08).

The convergence of the posterior distributions of those parameters was examined with Gelman and Rubin's statistics (Gelman and Rubin 1992). MSY-based biological reference points were estimated from the models. Mean error between predicted and observed indices was calculated to determine the model goodness of fit. Mean errors of each scenario were used to compare the performance of models. A lower mean error indicates a better fit. A retrospective analysis was conducted to verify whether any possible systematic inconsistencies exist among the model estimates of biomass and fishing mortality based on increasing periods of data (Mohn 1999). The data were removed from the year 2021 to 2016. Sensitivity analysis was established based on the use of joint CPUE with and without Japanese early CPUE (S1 and S2).

3. Assessment results

The posterior densities of model parameters from all case scenarios showed that the densities were smooth and unimodal (Appendix Figure 1-4). The estimated mean, median, and 80% CI of posterior estimates of reference points were summarized in tables (Table 3 and Appendix Table 1-4). Mean, median, and 80% CI of the posterior estimates of model parameters from each scenario were summarized in tables (Appendix Table 5-8). The time series of biomass and fishing mortality, Bratio (B/BMSY), Fratio (F/FMSY), and B/K from two base case scenarios were summarized (Figure 2-11).

4. Diagnostics and caveats

1) All parameters from the base case and sensitivity case scenarios showed well convergence of posterior distributions with Gelman and Rubin’s statistic for all parameters were close to 1.
2) The standardized residuals between predicted and observed indices from base case scenarios and sensitivity case scenarios showed similar patterns (Appendix Figure 5-8). There was a strong temporal pattern from Chinese Taipei (Appendix Figure 5-6).
3) The sensitivity analysis results showed that the two base case scenarios 1-2 were quite different from sensitivity case scenarios 1-2 which used joint CPUE index (Figure 15-19).
4) Mohn's rho values of biomass and fishing mortality from all case scenarios were shown in Table 4 and the plot of biomass and fishing mortality from the retrospective analysis indicated stronger retrospective pattern in base case 2 (Appendix Figure 9-16).

5. Time series of stock size and harvest rate

The time trajectories of biomass and fishing mortality showed different scales between base case scenario 1 and base case scenario 2, indicating that incorporation of Japanese early CPUE would result in large changes in the time trajectories of biomass and fishing mortality. For base case scenario 2 which did not use Japanese early CPUE, the biomass was over BMSY for most of the period of time. The Bratio from base case scenarios 1 showed lower interannual variability compared to base case 2 after around 1995. The Fratio from base case scenarios 2 was similar to that of scenarios 1 after 1995. The Kobe plots showed that the Bratio2020 and Fratio2020 over two base cases were in yellow quadrant (Figure 12). The Bratio (2019-2021) and Fratio (2018-2020) over two base cases fell in the red quadrant of the Kobe plot (Figure 13). Kobe plot with time series median Fratio and Bratio from 1980 to 2020 over two base cases was shown in Figure 14.

References

China. 2019. North Pacific Ocean Saury (*Cololabis saira*) 2019 Stock Assessment Update Report. NPFC-2019-TWG PSSA04-WP08.

Gelman, A., Rubin, D.B. 1992. Inference from iterative simulation using multiple sequences. Stat. Sci. 7, 457-511.

Mohn, R. 1999. The retrospective problem in sequential population analysis: An investigation using cod fishery and simulated data. ICES J. Mar. Sci. 56, 473-488.

Small Scientific Committee on Pacific Saury. 2019. 5th Meeting Report. NPFC-2019-SSC PS05-Final Report. 44 pp.

Wilberg, M.J., Thorson, J.T., Linton, B.C., and Berkson, J. 2009. Incorporating time-varying catchability into population dynamic stock assessment models. Rev. in Fish. Sci. 18, 7-24.

Table 1. Definition of base cases and sensitivity cases (NPFC-2021-SSC PS07-Final Report Annex F).

	Base case (B1)	**Base case (B2)**	**Sensitivity case (S1)**	**Sensitivity case (S2)**
Initial year	1980	Same as left	Same as left	Same as left
Biomass survey	$I_{t,bio} = q_{bio}B_t e^{v_{t,bio}}$ $v_{t,bio} \sim N(0, cv_t^2 + \sigma_{bio}^2)$ $q_{bio} \sim U(0,1)$ (2003-2021)	Same as left	Same as left	Same as left
CPUE	CHN(2013-2020) JPN_early(1980-1993, time-varying q) JPN_late(1994-2020) KOR(2001-2020) RUS(1994-2020) CT(2001-2020) $I_{t,f} = q_f B_t^b e^{v_{t,f}}$ $v_{t,f} \sim N(0, \sigma_f^2)$ $\sigma_f^2 = c \cdot (ave(cv_t^2) + \sigma_{bio}^2)$, where $ave(cv_t^2)$ is computed except for 2020 survey	CHN(2013-2020) JPN_late(1994-2020) KOR(2001-2020) RUS(1994-2020) CT(2001-2020)	JPN_early(1980-1993, time-varying q) Joint CPUE (2001-2020) $I_{t,joint}$ $= q_{joint} B_t^b e^{v_{t,joint}}$ $v_{t,joint} \sim N(0, \sigma_{joint}^2)$ σ_{joint}^2 $= c \cdot (ave(cv_t^2)$ $+ \sigma_{bio}^2)$	Joint CPUE (2001-2020)
Variance component	Variances of logCPUEs are assumed to be common and 6 times of that log biomass (*c*=6)	Variances of logCPUEs are assumed to be common and 5 times of that log biomass(*c*=5)	Same weight between biomass and joint CPUE	Same as left
Hyper-depletion/ stability	A common parameter for all fisheries but JPN_early, with a prior distribution, b~U(0, 1) but [b for JPN_early is fixed at 1]	A common parameter for all fisheries with a prior distribution, b~U(0, 1)	b~U(0, 1)	b~U(0, 1)
Prior for other than q_biomass	Own preferred options	Own preferred options	Own preferred options	Own preferred options

Table 2. Prior assumptions of parameters that are not listed in SSC PS05 Report Annex G.

<table>
<tr><th></th><th>q_CPUE</th><th>K</th><th>r</th><th>P1</th><th>s</th><th>σ^2</th><th>τ^2</th></tr>
<tr><td>NB1</td><td rowspan="2">U(0,1) for qJPN_early, qJPN_late, and qCT;

U(0,5) for qRUS, qKOR and qCHN</td><td rowspan="4">U(63,1890)</td><td rowspan="4">U(0,3)</td><td rowspan="4">U(0,1)</td><td rowspan="4">U(0,3)</td><td rowspan="4">$1/\sigma^2$~Gamma(0.001, 0.001)</td><td rowspan="4">$1/\tau^2$~Gamma(0.001, 0.001)</td></tr>
<tr><td>NB2</td></tr>
<tr><td>NS1</td><td rowspan="2">U(0,1) for qJPN_early and qJoint</td></tr>
<tr><td>NS2</td></tr>
</table>

Table 3. Summary of reference points over 2 base case scenarios.

	Mean	Median	Lower	Upper
C2020	13.97	13.97	13.97	13.97
AveC2018-2020	25.70	25.70	25.70	25.70
AveF2018-2020	0.49	0.48	0.19	0.77
F2020	0.38	0.35	0.15	0.62
FMSY	0.38	0.37	0.18	0.58
MSY	48.39	43.36	35.47	65.30
F2020/FMSY	1.09	0.99	0.55	1.64
AveF2018-2010/FMSY	1.41	1.33	0.69	2.05
K	347.41	253.10	152.80	651.24
B2020	52.54	39.63	22.38	90.22
B2021	70.45	51.79	29.63	122.10
AveB2019-2021	64.21	46.32	27.62	113.63
BMSY	160.74	119.60	76.33	294.61
BMSY/K	0.48	0.46	0.40	0.59
B2020/K	0.17	0.16	0.08	0.25
B2021/K	0.22	0.21	0.11	0.34
B2019-2021/K	0.20	0.19	0.11	0.29
B2020/BMSY	0.35	0.33	0.19	0.54
B2021/BMSY	0.47	0.43	0.24	0.74
B2019-2021/BMSY	0.42	0.39	0.24	0.64

Table 4. Summary of rho of biomass and rho of fishing mortality from base case scenarios and sensitivity case scenarios.

	Rho_B	Rho_F
B1	0.14	0.02
B2	1.25	-0.45
S1	-0.15	0.37
S2	-0.27	0.47

Appendix table 1. Summary of reference points from base case scenario 1.

	Mean	Median	Lower 10th	Upper 10th
C2020	13.97	13.97	13.97	13.97
AveC2018-2020	25.70	25.70	25.70	25.70
AveF2018-2020	0.55	0.55	0.31	0.78
F2020	0.38	0.36	0.17	0.54
FMSY	0.38	0.38	0.20	0.56
MSY	43.00	41.78	34.84	47.98
F2020/FMSY	1.04	0.98	0.54	1.38
AveF2018-2010/FMSY	1.54	1.47	0.91	2.01
K	289.04	224.00	116.40	347.40
B2020	44.54	39.07	18.67	58.05
B2021	53.48	48.06	23.36	71.07
AveB2019-2021	47.99	42.37	21.95	62.07
BMSY	133.90	108.90	62.24	163.50
BMSY/K	0.49	0.48	0.38	0.57
B2020/K	0.18	0.17	0.08	0.25
B2021/K	0.22	0.21	0.10	0.32
B2019-2021/K	0.19	0.19	0.11	0.29
B2020/BMSY	0.37	0.35	0.19	0.51
B2021/BMSY	0.45	0.42	0.20	0.65
B2019-2021/BMSY	0.40	0.38	0.22	0.56

Appendix table 2. Summary of reference points from base case scenario 2.

	Mean	Median	Lower 10th	Upper 10th
C2020	13.97	13.97	13.97	13.97
AveC2018-2020	25.70	25.70	25.70	25.70
AveF2018-2020	0.42	0.40	0.07	0.65
F2020	0.38	0.35	0.06	0.58
FMSY	0.37	0.36	0.14	0.56
MSY	53.78	47.13	30.32	68.11
F2020/FMSY	1.14	0.99	0.32	1.56
AveF2018-2010/FMSY	1.28	1.14	0.42	1.77
K	405.78	295.40	126.80	551.30
B2020	60.55	40.41	13.31	80.56
B2021	87.42	58.40	20.45	116.20
AveB2019-2021	80.44	53.52	19.99	106.06
BMSY	187.58	135.00	59.79	254.60
BMSY/K	0.47	0.45	0.38	0.53
B2020/K	0.15	0.14	0.07	0.22
B2021/K	0.22	0.21	0.09	0.32
B2019-2021/K	0.20	0.19	0.09	0.29
B2020/BMSY	0.33	0.31	0.14	0.48
B2021/BMSY	0.48	0.44	0.19	0.70
B2019-2021/BMSY	0.44	0.41	0.19	0.62

Appendix table 3. Summary of reference points from sensitivity case scenario 1.

	Mean	Median	Lower 10th	Upper 10th
C2020	13.97	13.97	13.97	13.97
AveC2018-2020	25.70	25.70	25.70	25.70
AveF2018-2020	0.32	0.29	0.08	0.47
F2020	0.20	0.17	0.05	0.29
FMSY	0.20	0.18	0.03	0.32
MSY	39.57	38.82	25.96	48.75
F2020/FMSY	1.41	1.01	0.40	1.68
AveF2018-2010/FMSY	2.27	1.64	0.85	2.69
K	596.83	462.95	157.60	886.50
B2020	103.44	80.82	25.83	145.80
B2021	110.68	89.49	32.36	154.80
AveB2019-2021	105.94	83.37	30.67	151.53
BMSY	276.69	214.35	79.05	399.60
BMSY/K	0.48	0.46	0.37	0.56
B2020/K	0.19	0.18	0.08	0.26
B2021/K	0.21	0.20	0.08	0.31
B2019-2021/K	0.20	0.18	0.08	0.28
B2020/BMSY	0.40	0.37	0.18	0.56
B2021/BMSY	0.45	0.41	0.18	0.65
B2019-2021/BMSY	0.42	0.38	0.19	0.58

Appendix table 4. Summary of reference points from sensitivity case scenario 2.

	Mean	Median	Lower 10th	Upper 10th
C2020	13.97	13.97	13.97	13.97
AveC2018-2020	25.70	25.70	25.70	25.70
AveF2018-2020	0.24	0.20	0.05	0.35
F2020	0.15	0.12	0.03	0.21
FMSY	0.13	0.10	0.00	0.21
MSY	34.25	33.96	16.69	46.90
F2020/FMSY	3.91	1.30	0.33	2.43
AveF2018-2010/FMSY	5.65	2.10	0.57	3.77
K	872.90	787.55	182.70	1405.00
B2020	142.41	114.45	35.03	199.00
B2021	146.29	118.00	40.81	199.40
AveB2019-2021	144.80	116.98	33.37	196.83
BMSY	394.87	351.75	89.98	607.30
BMSY/K	0.46	0.44	0.37	0.55
B2020/K	0.18	0.16	0.07	0.25
B2021/K	0.19	0.17	0.06	0.27
B2019-2021/K	0.18	0.16	0.06	0.25
B2020/BMSY	0.39	0.34	0.14	0.51
B2021/BMSY	0.41	0.36	0.14	0.57
B2019-2021/BMSY	0.39	0.35	0.15	0.53

Appendix table 5. Summary of parameter estimates from base case scenario 1.

	Mean	Median	Lower 10th	Upper 10th
r	1.16	0.93	0.28	1.79
K	289.04	224.00	116.40	347.40
qCHN	0.82	0.68	0.15	1.21
qJPN1_1980	0.02	0.01	0.00	0.02
qJPN1_1981	0.01	0.01	0.00	0.02
qJPN1_1982	0.01	0.01	0.00	0.02
qJPN1_1983	0.01	0.01	0.00	0.02
qJPN1_1984	0.01	0.01	0.00	0.02
qJPN1_1985	0.02	0.01	0.00	0.02
qJPN1_1986	0.02	0.01	0.00	0.02
qJPN1_1987	0.02	0.02	0.00	0.03
qJPN1_1988	0.02	0.02	0.01	0.03
qJPN1_1989	0.03	0.02	0.01	0.04
qJPN1_1990	0.03	0.03	0.01	0.04
qJPN1_1991	0.04	0.04	0.01	0.06
qJPN1_1992	0.06	0.05	0.02	0.08
qJPN1_1993	0.09	0.08	0.02	0.13
qJPN2	0.09	0.08	0.02	0.13
qKOR	0.28	0.23	0.05	0.41
qRUS	1.12	0.93	0.22	1.66
qCT	0.11	0.09	0.02	0.17
qBio	0.65	0.65	0.44	0.94
Shape	1.02	0.77	0.03	1.81
sigma_com	0.07	0.06	0.02	0.10
sigma_Bio	0.03	0.02	0.01	0.04
Tau	0.17	0.16	0.03	0.26
FMSY	0.38	0.38	0.20	0.56
BMSY	133.90	108.90	62.24	163.50
MSY	43.00	41.78	34.84	47.98
b	0.69	0.69	0.53	0.85

Appendix table 6. Summary of parameter estimates from base case scenario 2.

	Mean	Median	Lower 10th	Upper 10th
r	1.25	1.08	0.21	2.10
K	405.78	295.40	126.80	551.30
qCHN	1.83	1.76	0.82	2.63
qJPN2	0.26	0.25	0.12	0.37
qKOR	0.69	0.66	0.30	1.00
qRUS	2.85	2.78	1.39	4.19
qCT	0.28	0.27	0.12	0.40
qBio	0.46	0.44	0.09	0.73
Shape	0.79	0.54	0.04	1.28
sigma_com	0.07	0.06	0.02	0.10
sigma_Bio	0.03	0.03	0.01	0.05
tau	0.41	0.40	0.26	0.56
FMSY	0.37	0.36	0.14	0.56
BMSY	187.58	135.00	59.79	254.60
MSY	53.78	47.13	30.32	68.11
b	0.42	0.42	0.30	0.53

Appendix table 7. Summary of parameter estimates from sensitivity case scenario 1.

	Mean	Median	Lower 10th	Upper 10th
r	0.80	0.57	0.02	1.30
K	596.83	462.95	157.60	886.50
qBio	0.39	0.36	0.12	0.58
qJPN1_1980	0.01	0.00	0.00	0.01
qJPN1_1981	0.00	0.00	0.00	0.01
qJPN1_1982	0.00	0.00	0.00	0.01
qJPN1_1983	0.01	0.00	0.00	0.01
qJPN1_1984	0.01	0.00	0.00	0.01
qJPN1_1985	0.01	0.01	0.00	0.01
qJPN1_1986	0.01	0.00	0.00	0.01
qJPN1_1987	0.01	0.00	0.00	0.01
qJPN1_1988	0.01	0.01	0.00	0.01
qJPN1_1989	0.01	0.01	0.00	0.02
qJPN1_1990	0.01	0.01	0.00	0.01
qJPN1_1991	0.01	0.01	0.00	0.02
qJPN1_1992	0.02	0.01	0.00	0.02
qJPN1_1993	0.01	0.01	0.00	0.02
qJoint	0.39	0.34	0.04	0.66
Shape	0.93	0.66	0.01	1.70
sigma_com	0.13	0.12	0.03	0.20
sigma_Bio	0.13	0.12	0.03	0.20
tau	0.12	0.09	0.02	0.18
FMSY	0.20	0.18	0.03	0.32
BMSY	276.69	214.35	79.05	399.60
MSY	39.57	38.82	25.96	48.75
b	0.22	0.19	0.00	0.35

Appendix table 8. Summary of parameter estimates from sensitivity case scenario 2.

	Mean	Median	Lower 10th	Upper 10th
r	0.71	0.42	0.00	1.23
K	872.90	787.55	182.70	1405.00
qBio	0.29	0.25	0.09	0.44
qJoint	0.38	0.34	0.01	0.62
Shape	0.82	0.47	0.00	1.62
sigma_com	0.11	0.09	0.02	0.17
sigma_Bio	0.11	0.09	0.02	0.17
tau	0.10	0.08	0.02	0.15
FMSY	0.13	0.10	0.00	0.21
BMSY	394.87	351.75	89.98	607.30
MSY	34.25	33.96	16.69	46.90
b	0.22	0.19	0.00	0.35

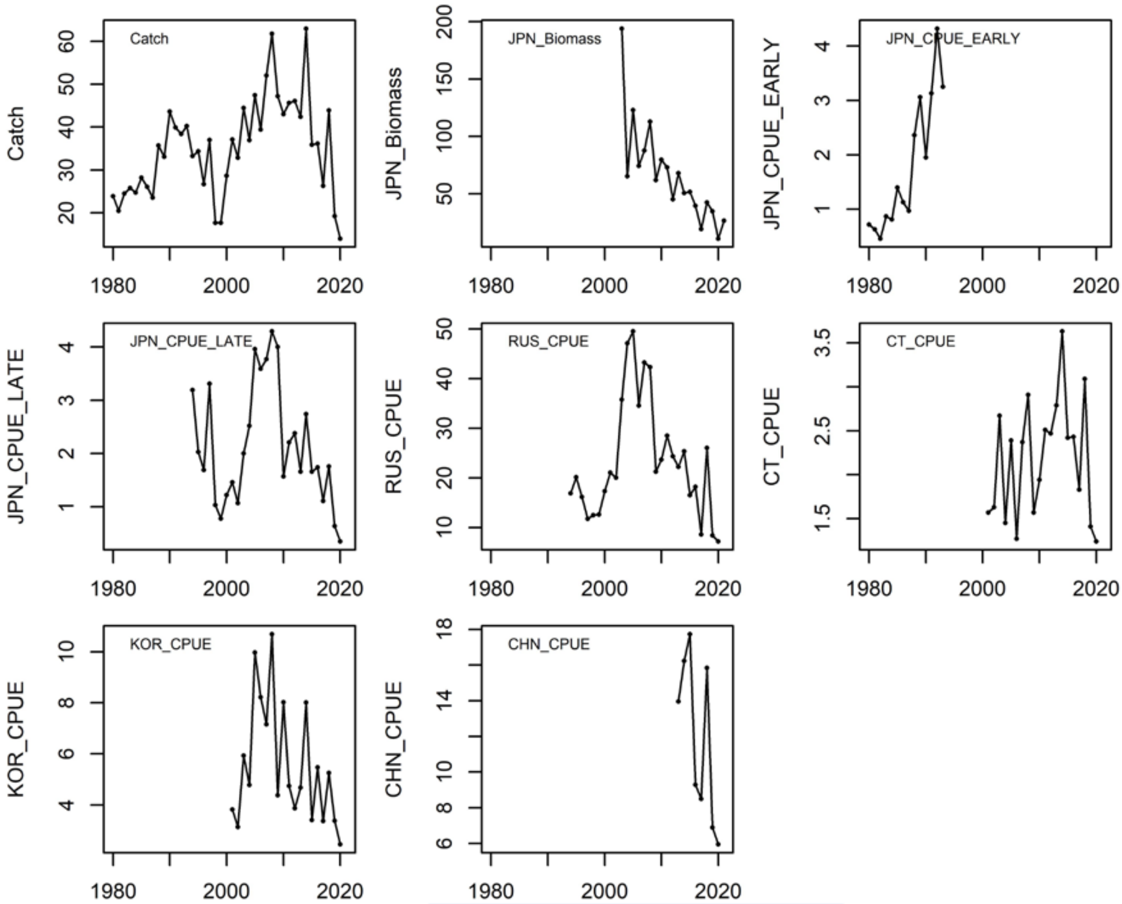


Figure 1. Input data for 2021 Pacific saury stock assessment.

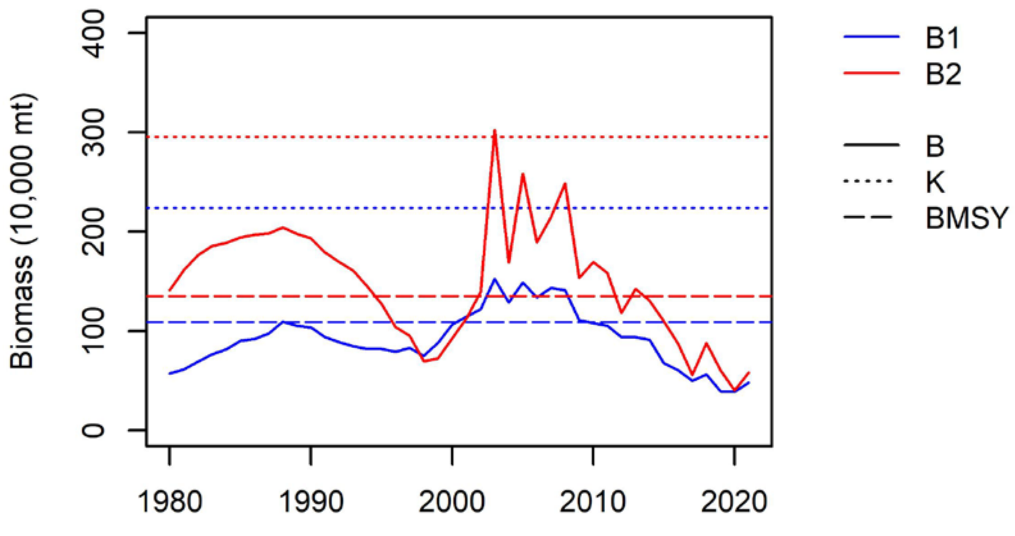


Figure 2. Median biomass over time from each base case scenario (B1-B2).

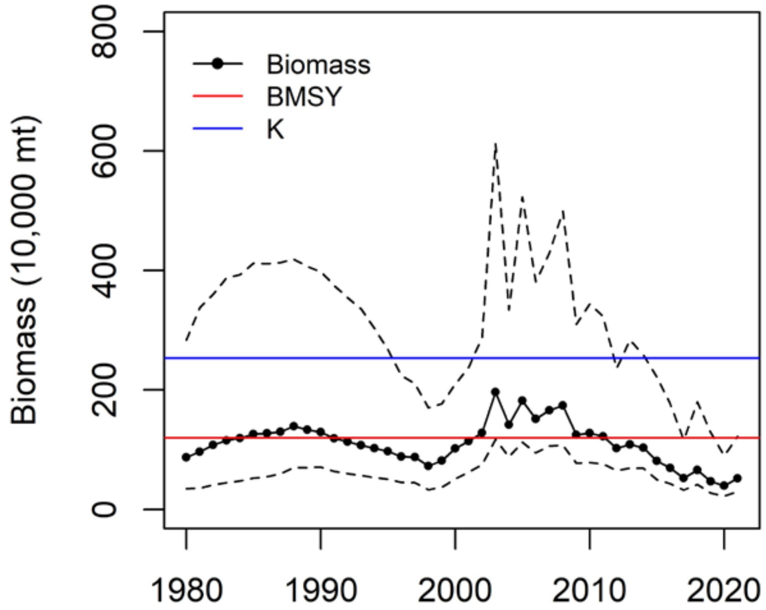


Figure 3. Median biomass and 80% CI over base case scenarios 1-2.

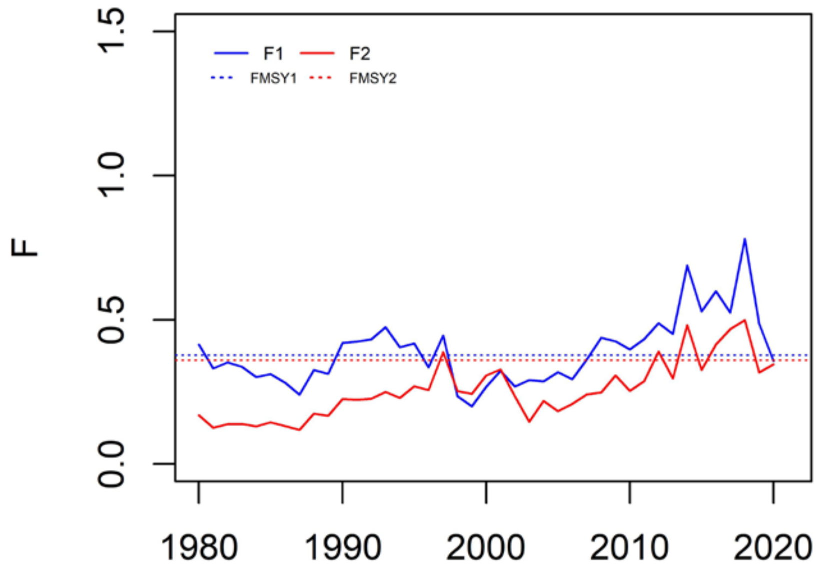


Figure 4. Median fishing mortality over time from two base case scenarios (B1-B2).

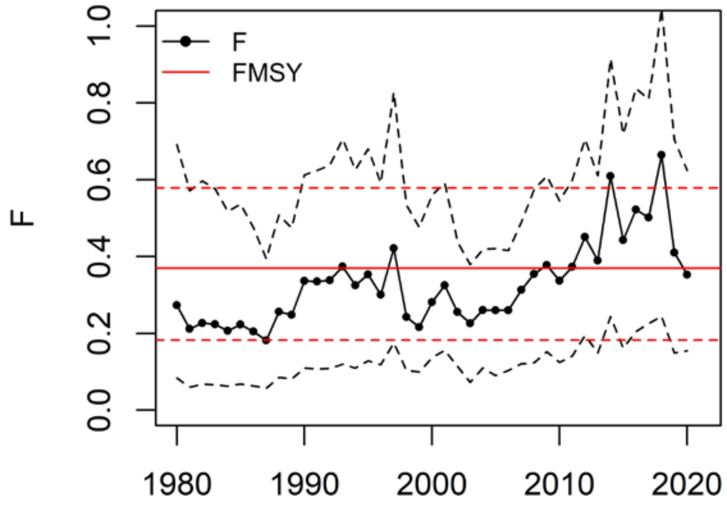


Figure 5. Median fishing mortality and 80% CI over base case scenarios 1-2.

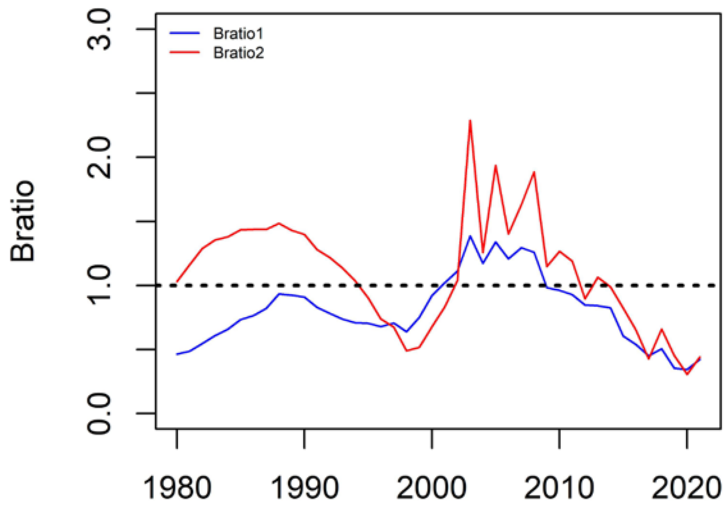


Figure 6. Median Bratio over time from each base case scenario (1-2).

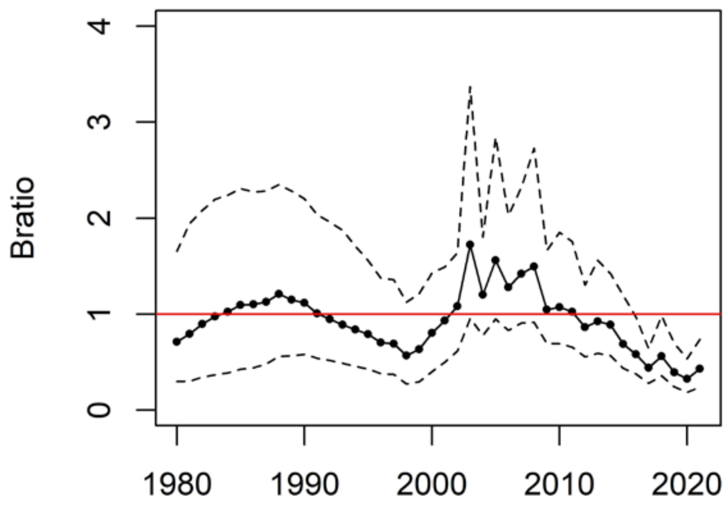


Figure 7. Median Bratio and 80% CI over base case scenarios 1-2.

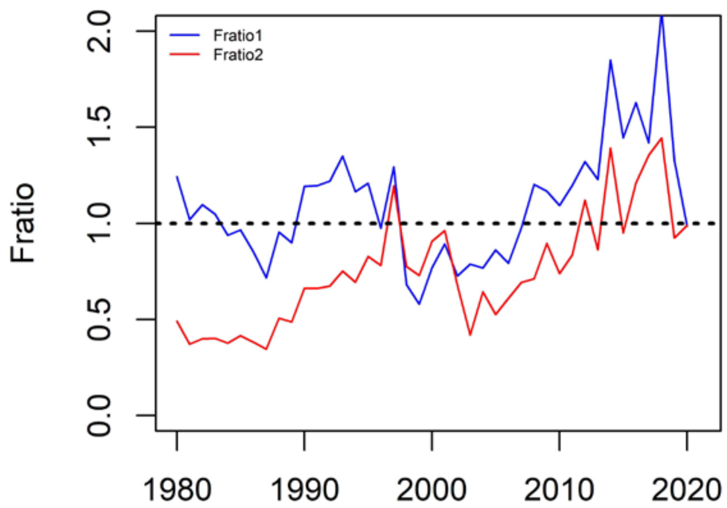


Figure 8. Median Fratio over time from each base case scenario (1-2).

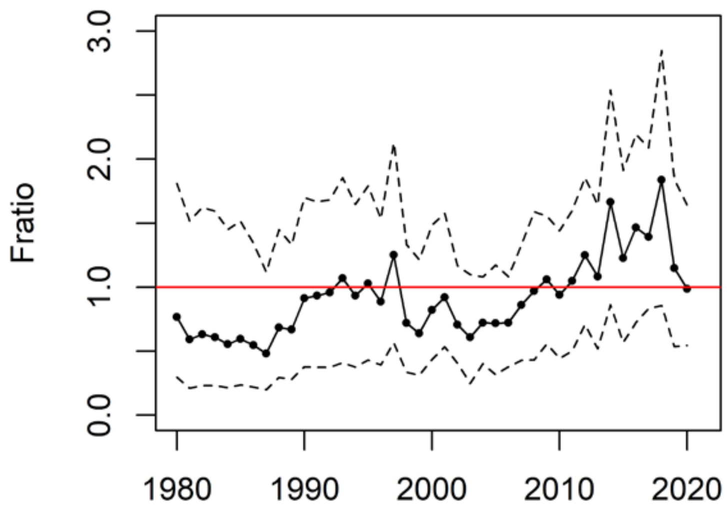


Figure 9. Median Fratio and 80% CI over base case scenarios 1-2.

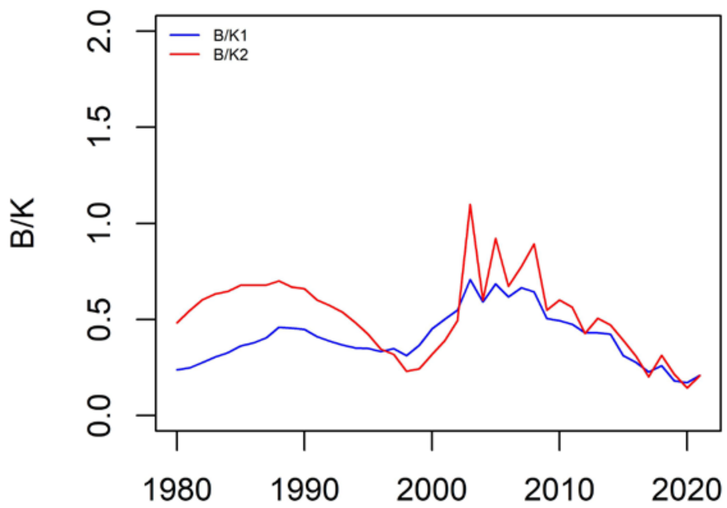


Figure 10. Median B/K over time from each base case scenario (1-2).

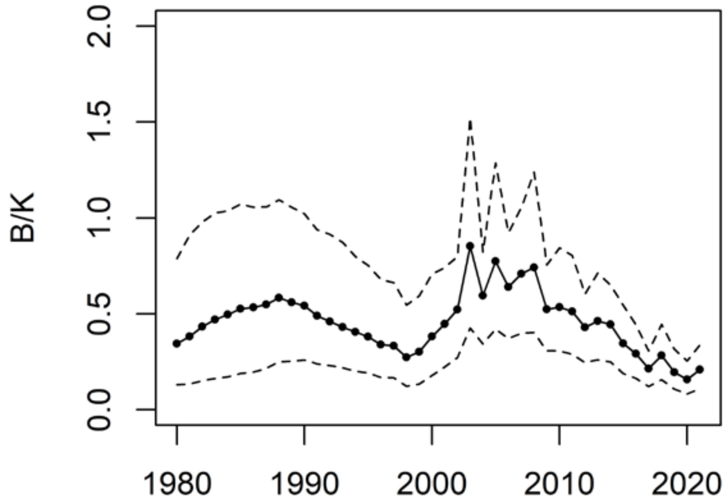


Figure 11. Median B/K and 80% CI over base case scenarios 1-2.

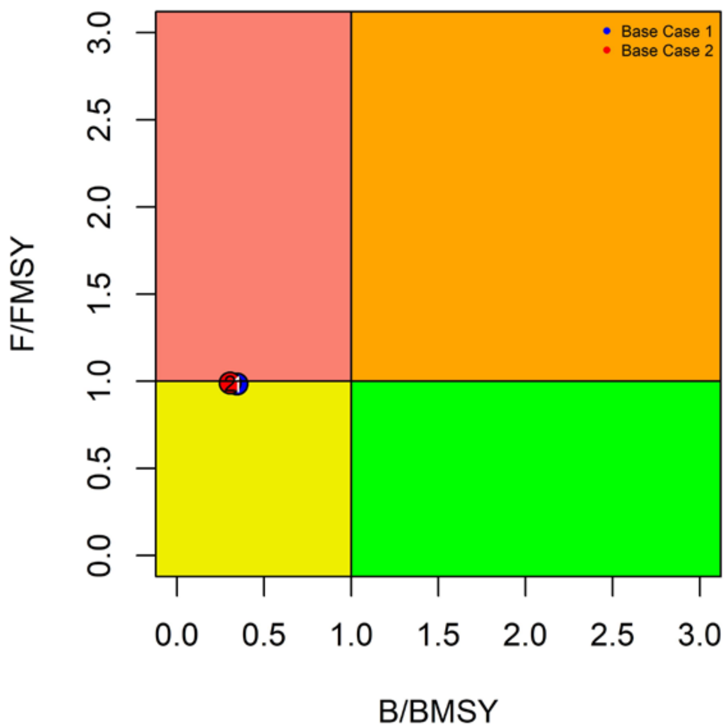


Figure 12. Median Fratio2020 and Bratio2020 calculated from each base case scenario (1-2).

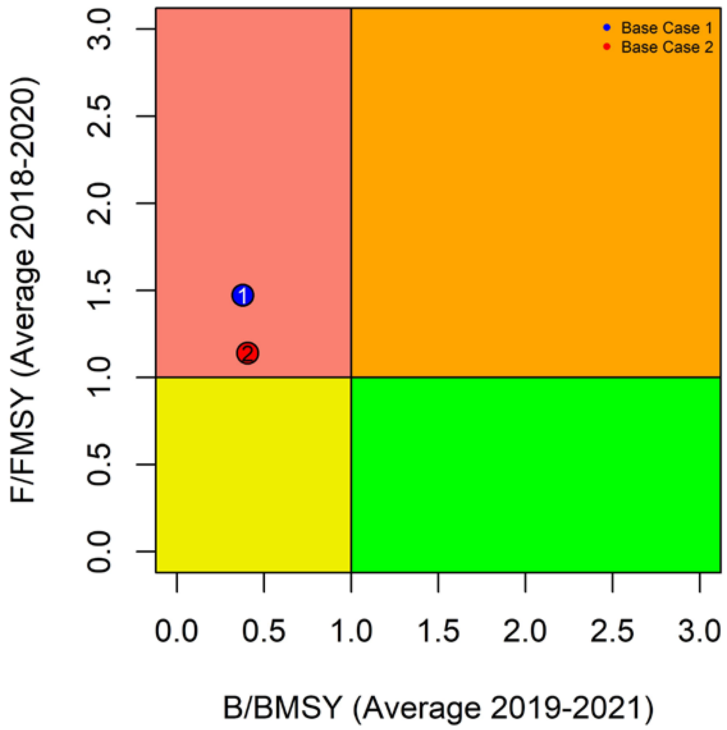


Figure 13. Median Fratio (average from 2018-2020) and Bratio (average from 2019-2021) calculated from each base case scenario (1-2).

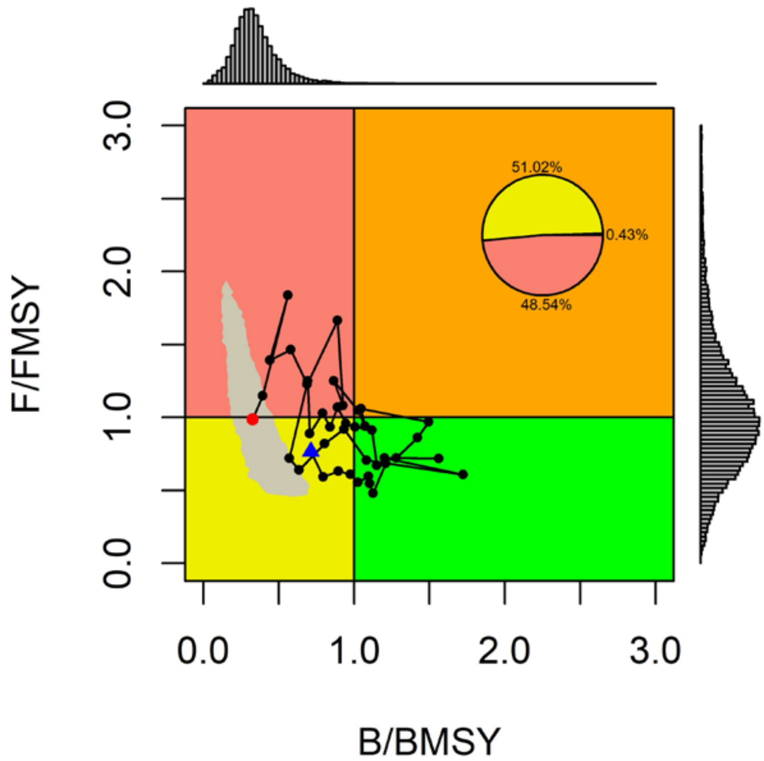


Figure 14. Kobe plot with time series median Fratio and Bratio from 1980 to 2020 over base case scenarios 1-2. The blue dot represents initial year 1980 and the red dot represents the terminal year 2020.

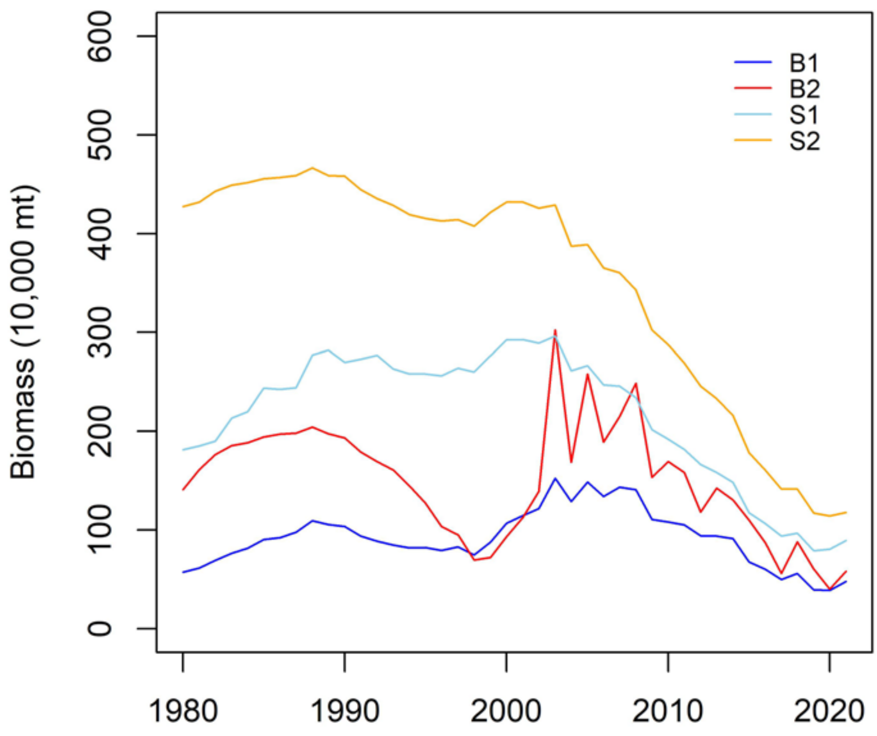


Figure 15. Median biomass over time from each case scenario.

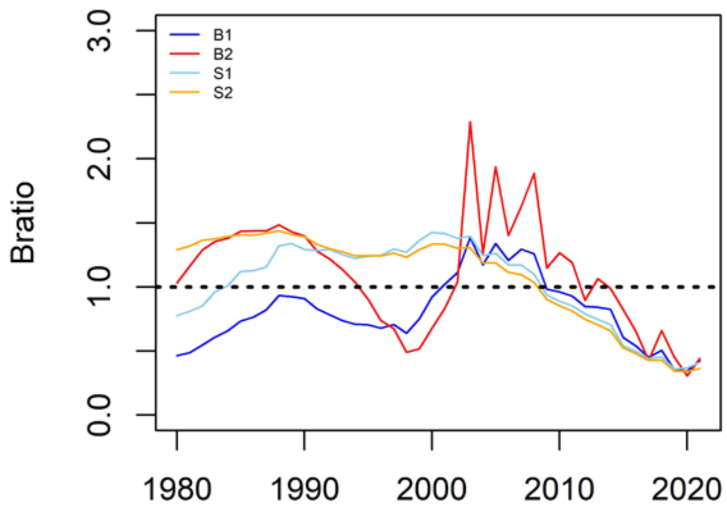


Figure 16. Median Bratio over time from each case scenario.

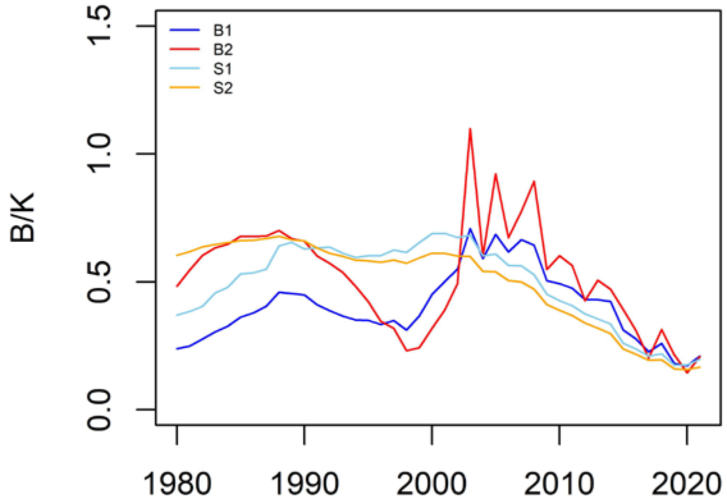


Figure 17. Median B/K over time from each case scenario.

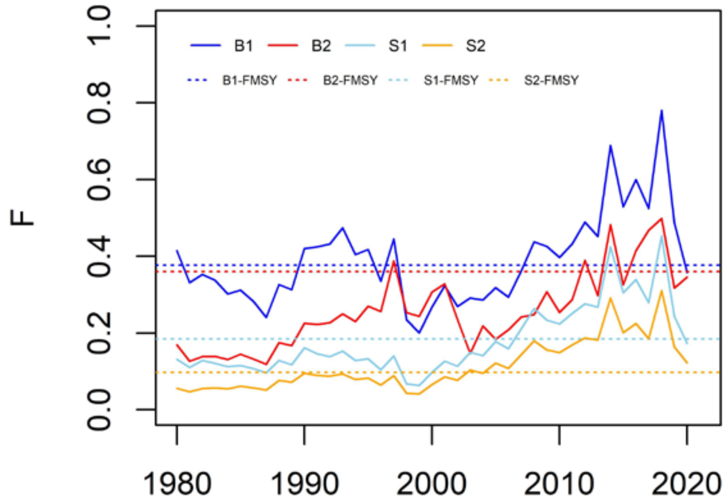


Figure 18. Median F over time from each case scenario.

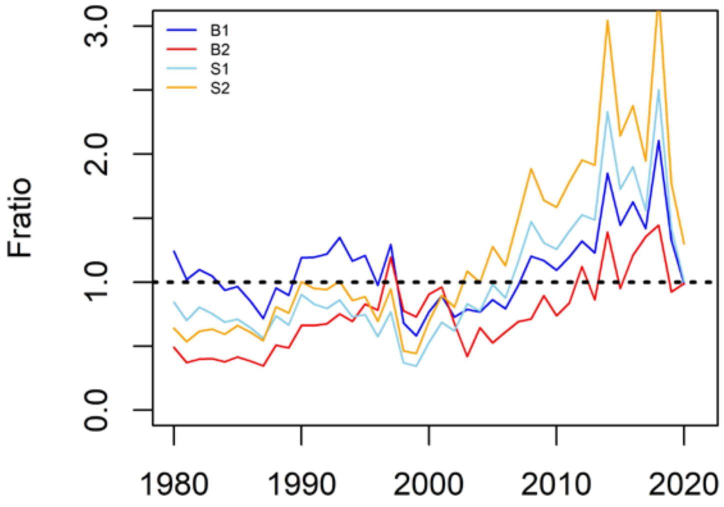
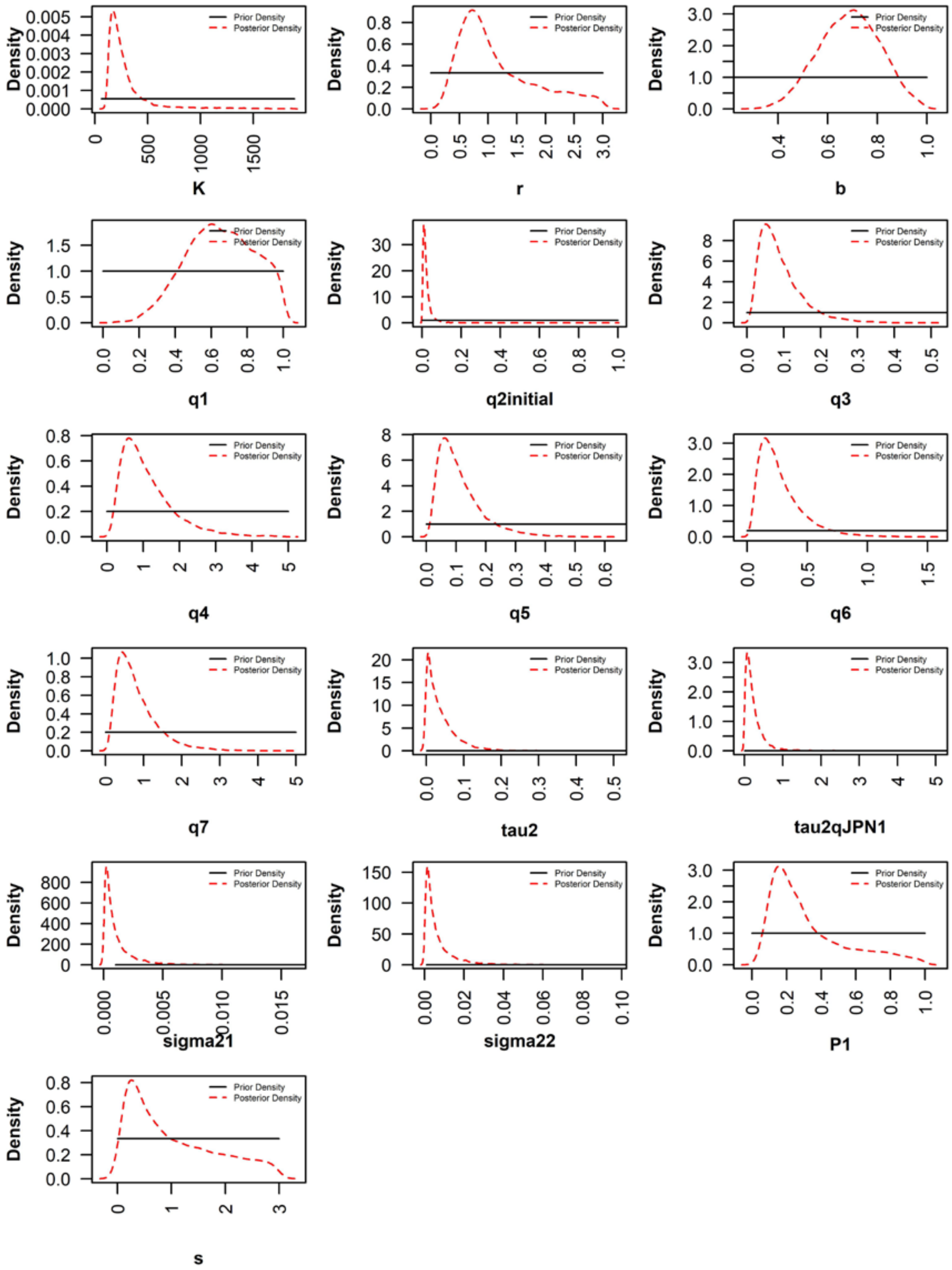
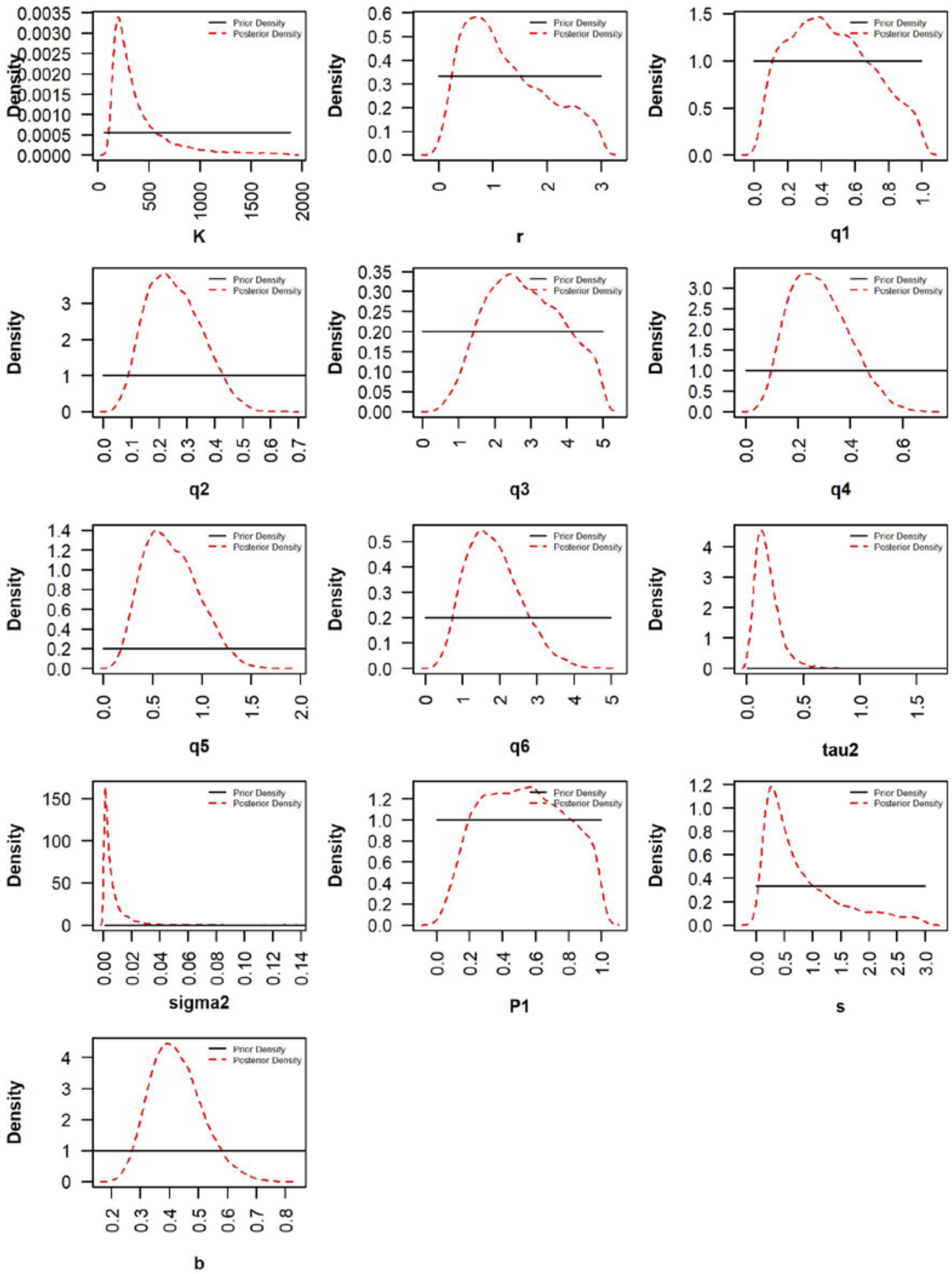


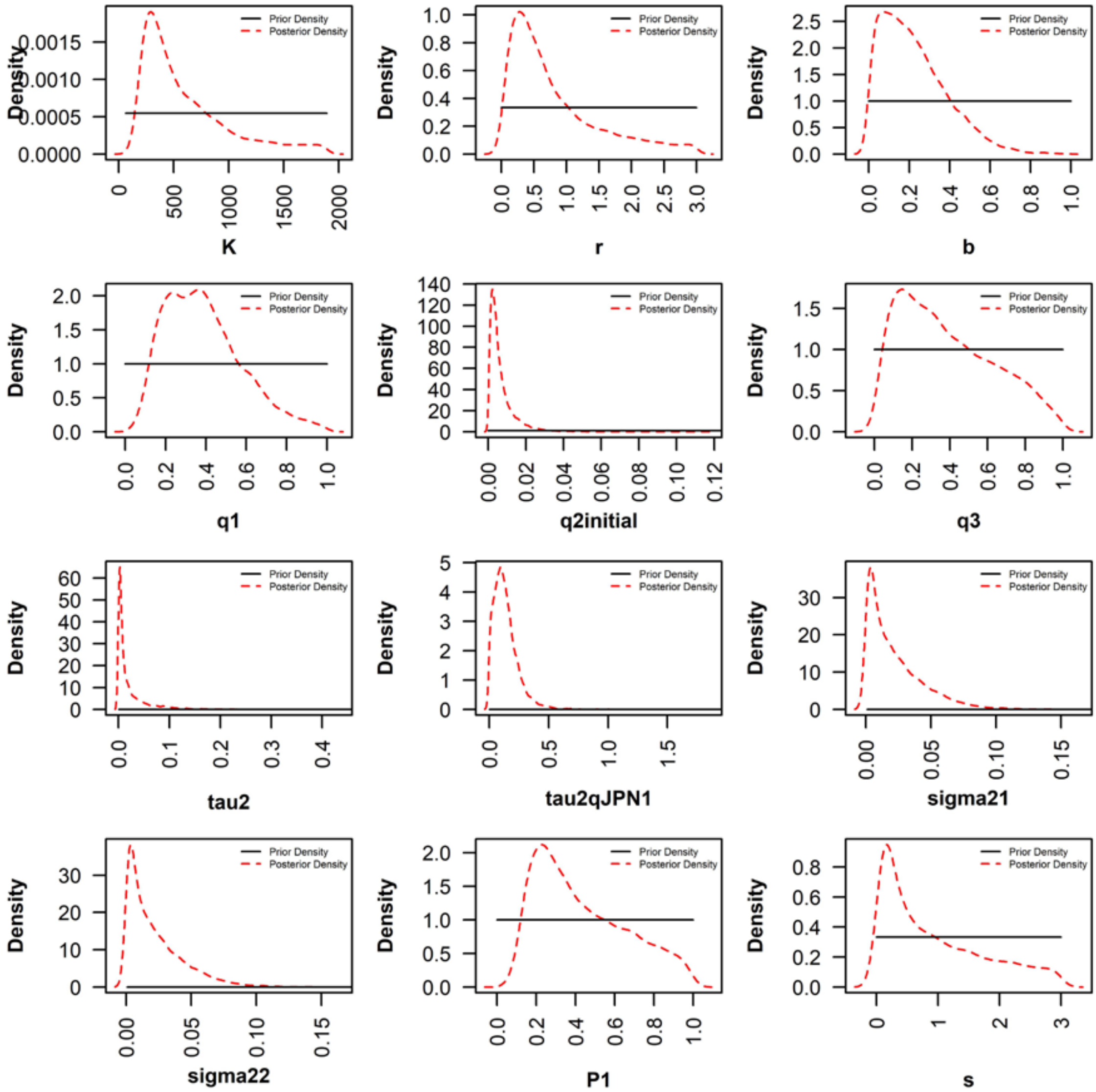
Figure 19. Median Fratio over time from each case scenario.



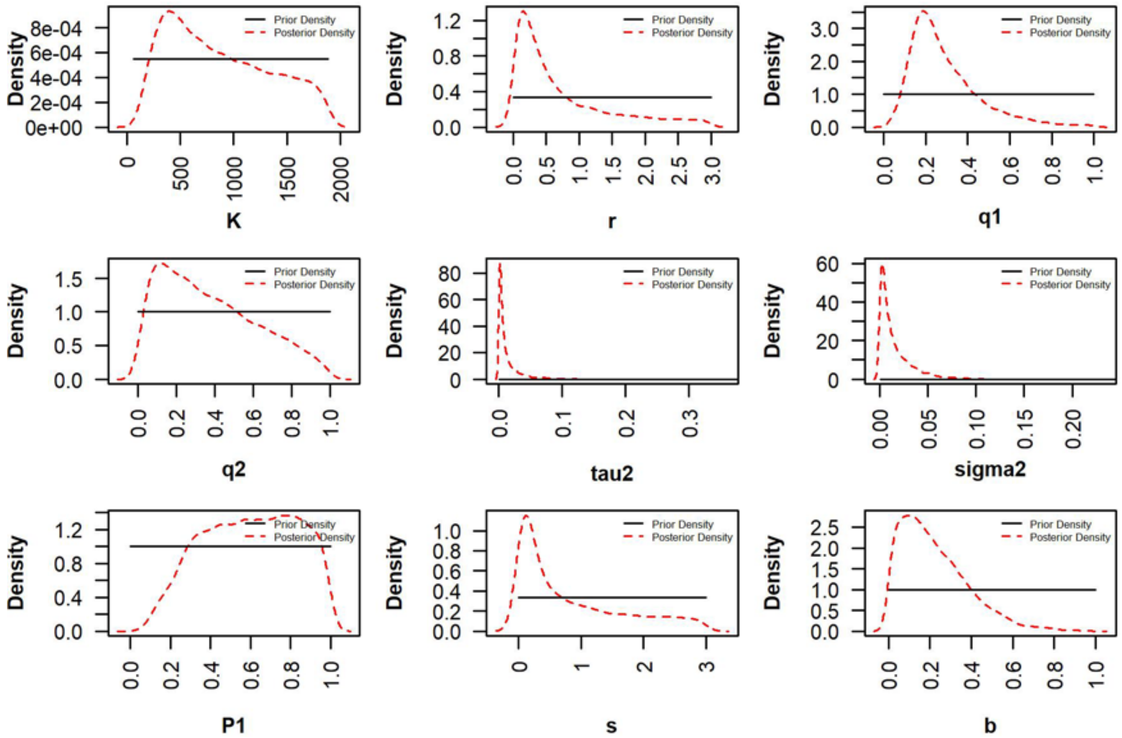
Appendix Figure 1. Prior and posterior distributions of parameters from base case scenario 1. q1 to q7 represent catchability of fishery-independent survey biomass index, Japanese early CPUE, Japanese late CPUE, Russian CPUE, Chinese Taipei CPUE, Korean CPUE, and Chinese CPUE respectively. q2initial represents q1980. tau2 represents process error variance, tau2qJPN1 represents error variance of Japanese early CPUE, sigma21 represents observation variance of biomass index, and sigma22 represents common observation variance of CPUE. P1 represents B1/K and s represents shape.



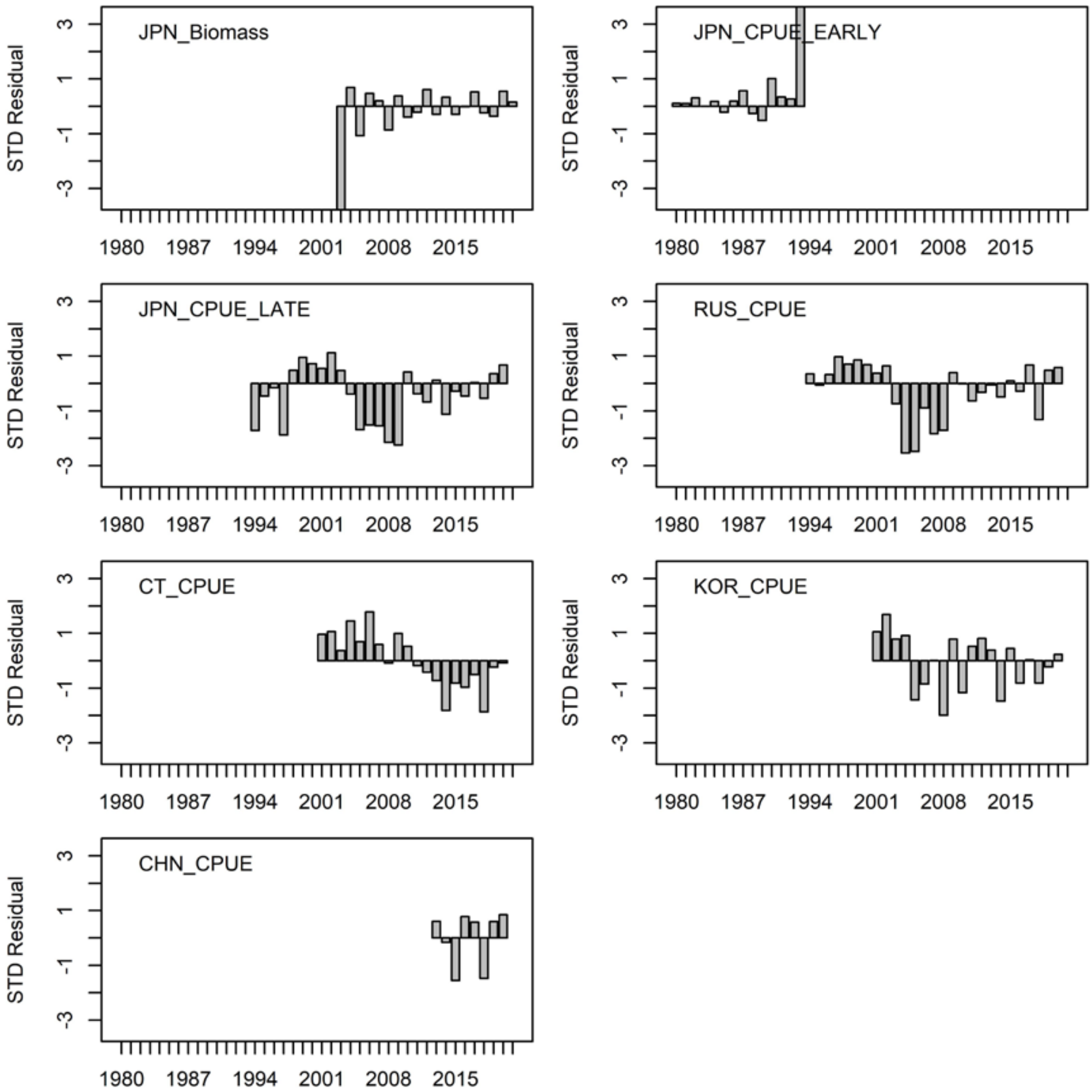
Appendix Figure 2. Prior and posterior distributions of parameters from base case scenario 2. q1 to q6 represent catchability of fishery-independent survey biomass index, Japanese late CPUE, Russian CPUE, Chinese Taipei CPUE, Korean CPUE, and Chinese CPUE respectively. tau2 represents process error variance, sigma2 represents common observation variance of CPUE. P1 represents B1980/K and s represents shape.



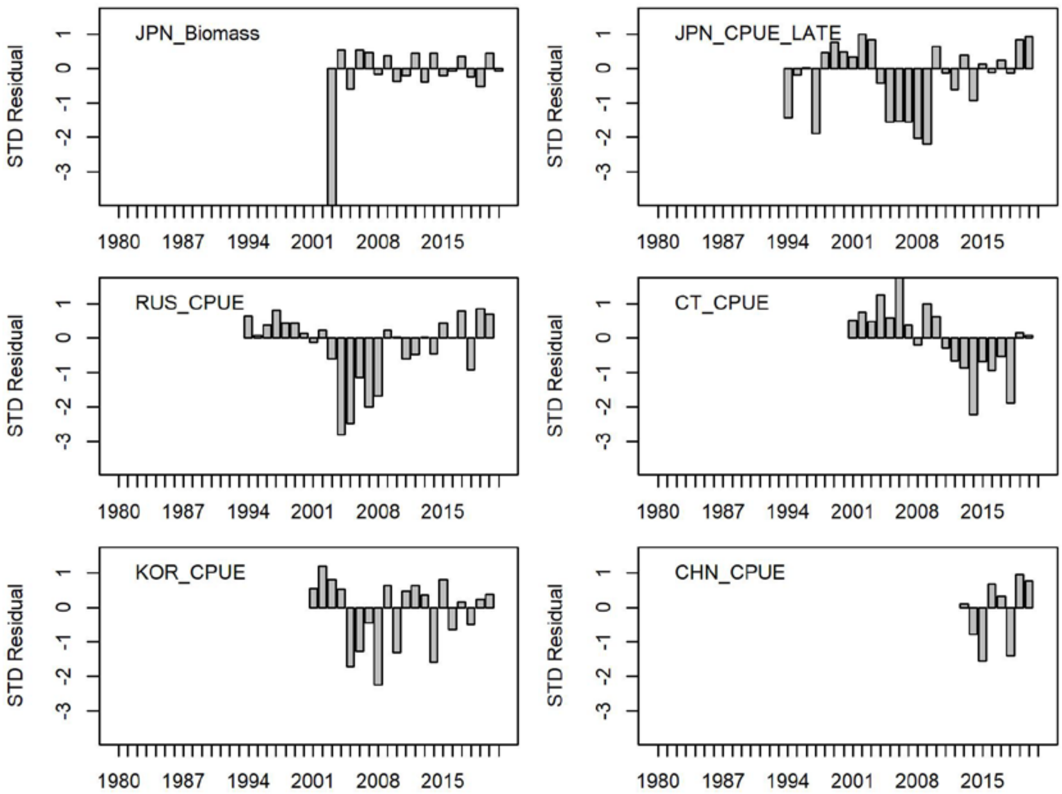
Appendix Figure 3. Prior and posterior distributions of parameters from sensitivity case scenario 1. q1 to q3 represent catchability of fishery-independent survey biomass index, Japanese early CPUE, and joint CPUE respectively. q2initial represents q1980. tau2 represents process error variance, tau2qJPN1 represents error variance of Japanese early CPUE, sigma21 represents observation variance of biomass index, and sigma22 represents observation variance of joint CPUE. P1 represents B1/K and s represents shape.



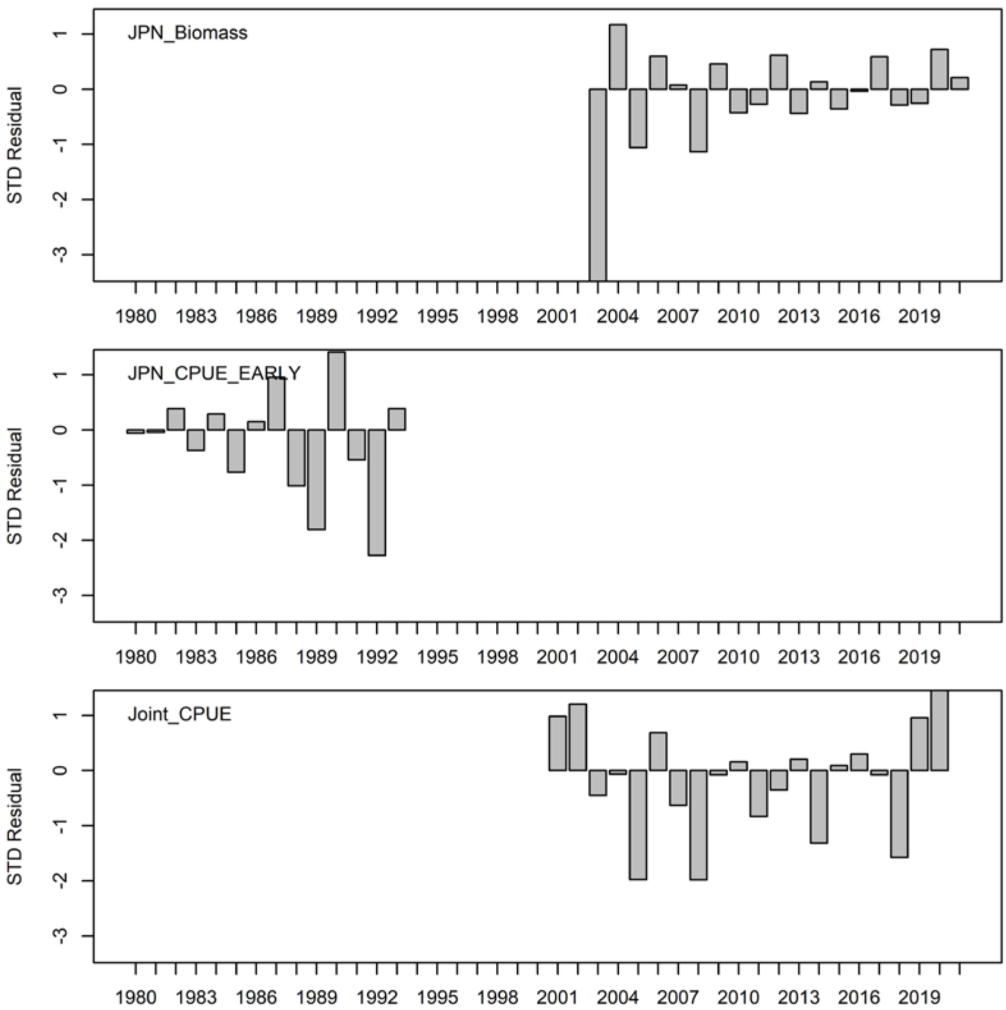
Appendix Figure 4. Prior and posterior distributions of parameters from sensitivity case scenario 2. q1 and q2 represent catchability of fishery-independent survey biomass index and joint CPUE respectively. tau2 represents process error variance, sigma2 represents common observation variance of CPUE. P1 represents B1980/K and s represents shape.



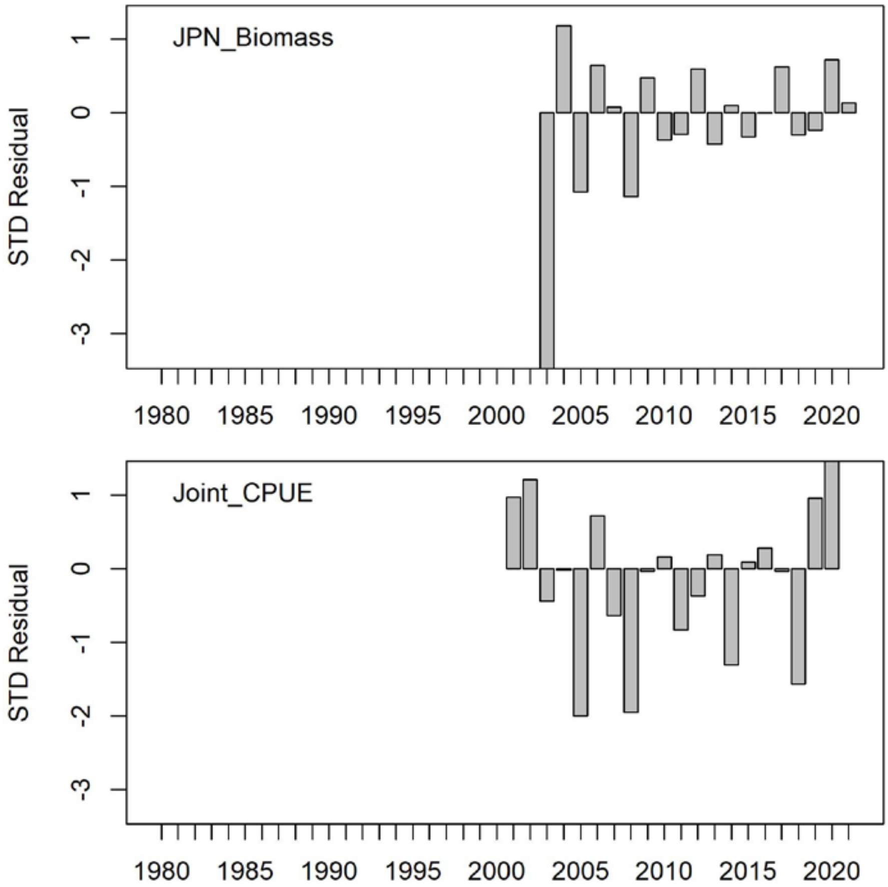
Appendix Figure 5. Standardized residuals between predicted and observed indices from base case scenario 1.



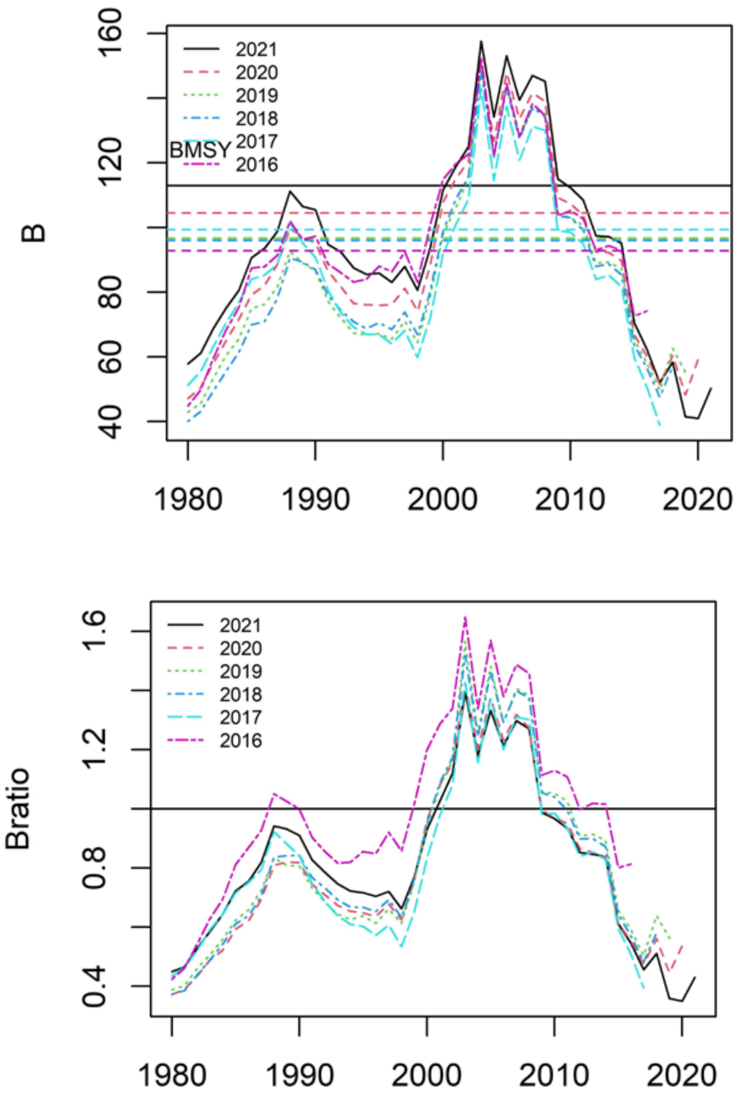
Appendix Figure 6. Standardized residuals between predicted and observed indices from base case scenario 2.



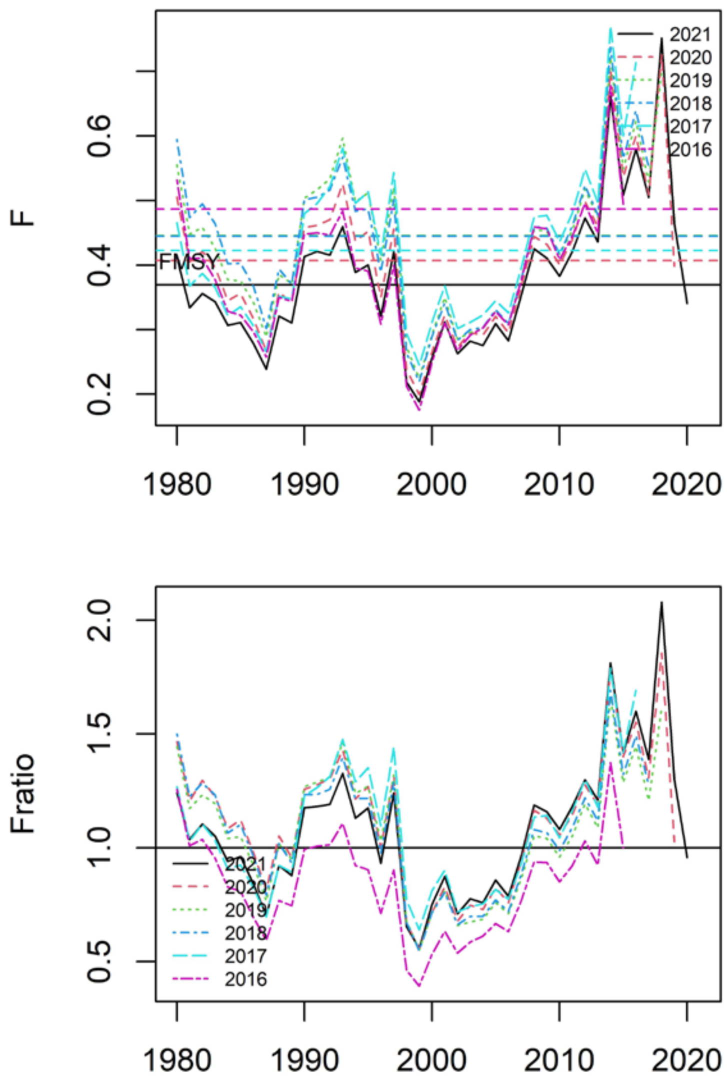
Appendix Figure 7. Standardized residuals between predicted and observed indices from sensitivity case scenario 1.



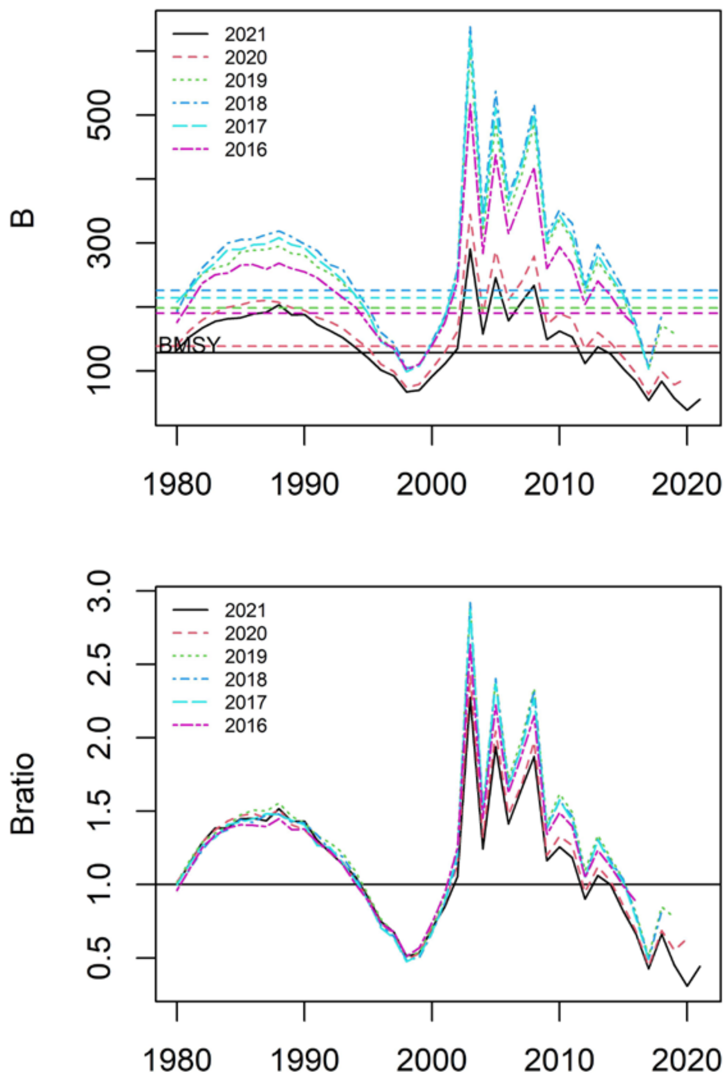
Appendix Figure 8. Standardized residuals between predicted and observed indices from sensitivity case scenario 2.



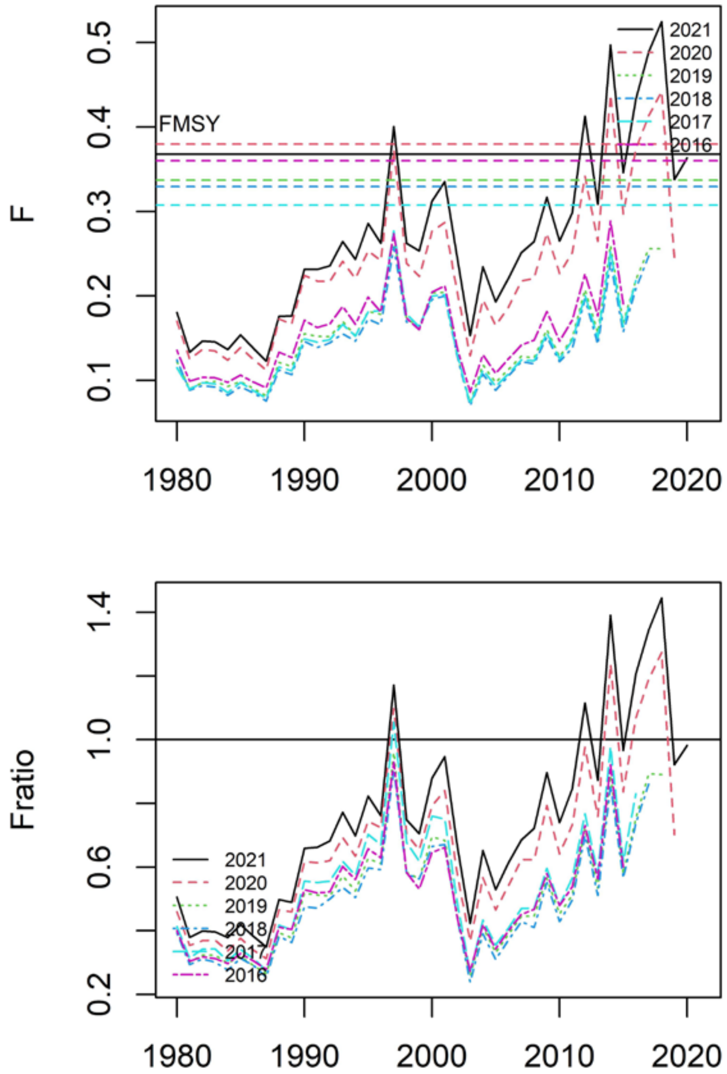
Appendix Figure 9. Time trajectories of biomass and Bratio from a retrospective analysis of base case scenario 1.



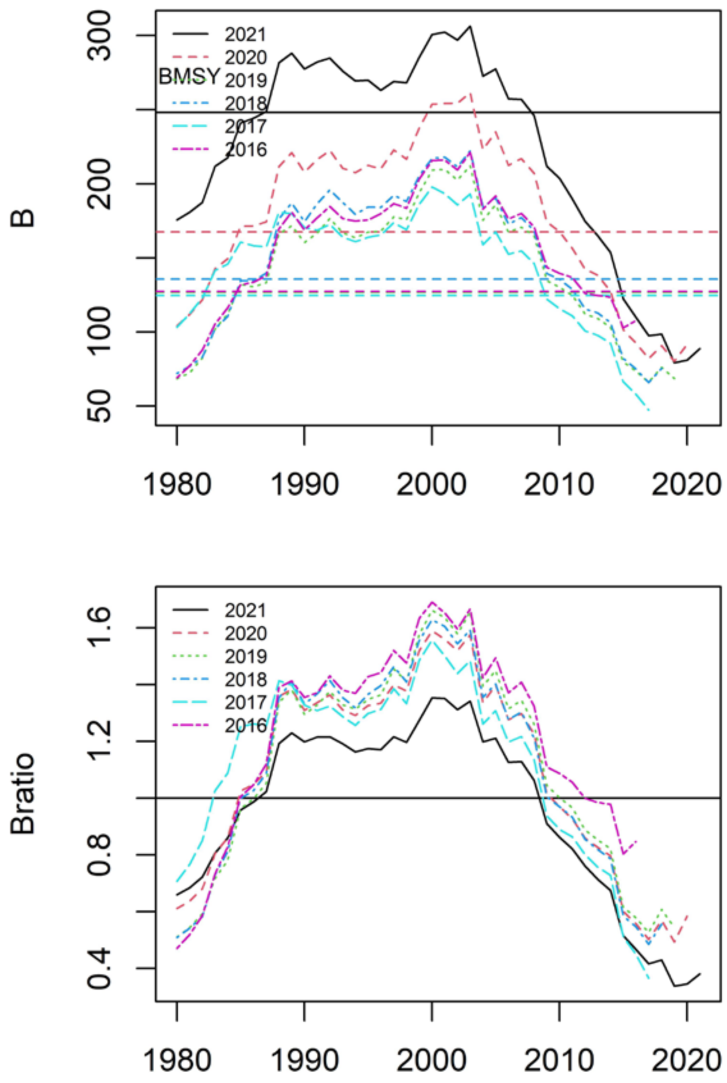
Appendix Figure 10. Time trajectories of fishing mortality and Fratio from retrospective analysis of base case scenario 1.



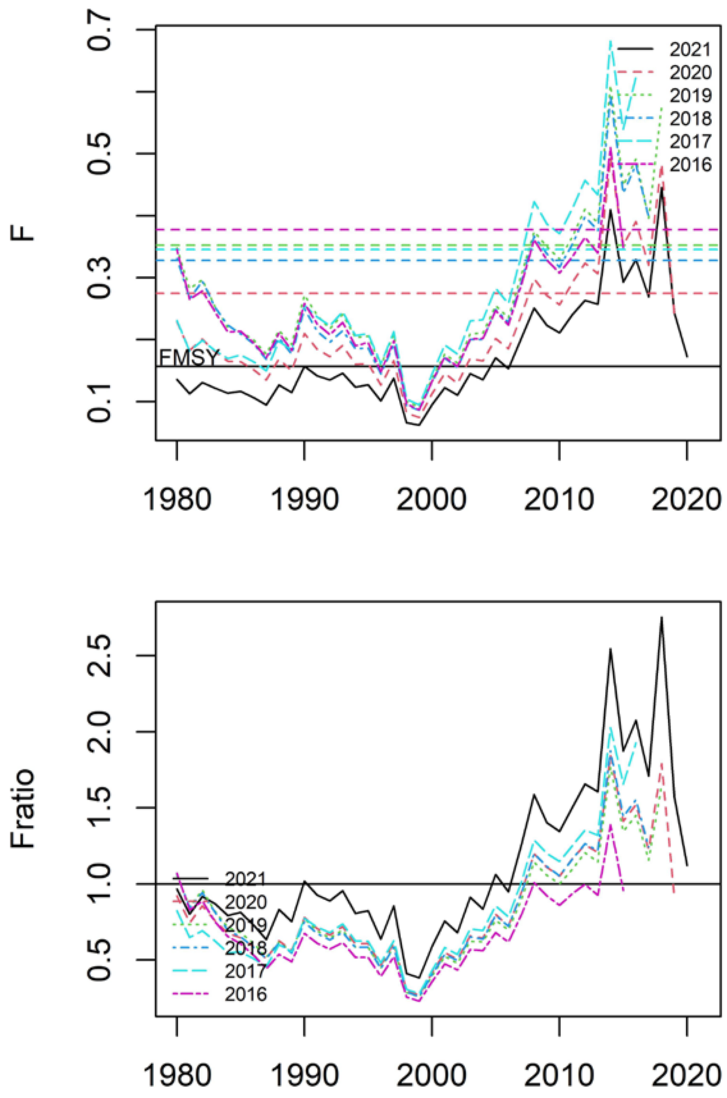
Appendix Figure 11. Time trajectories of biomass and Bratio from a retrospective analysis of base case scenario 2.



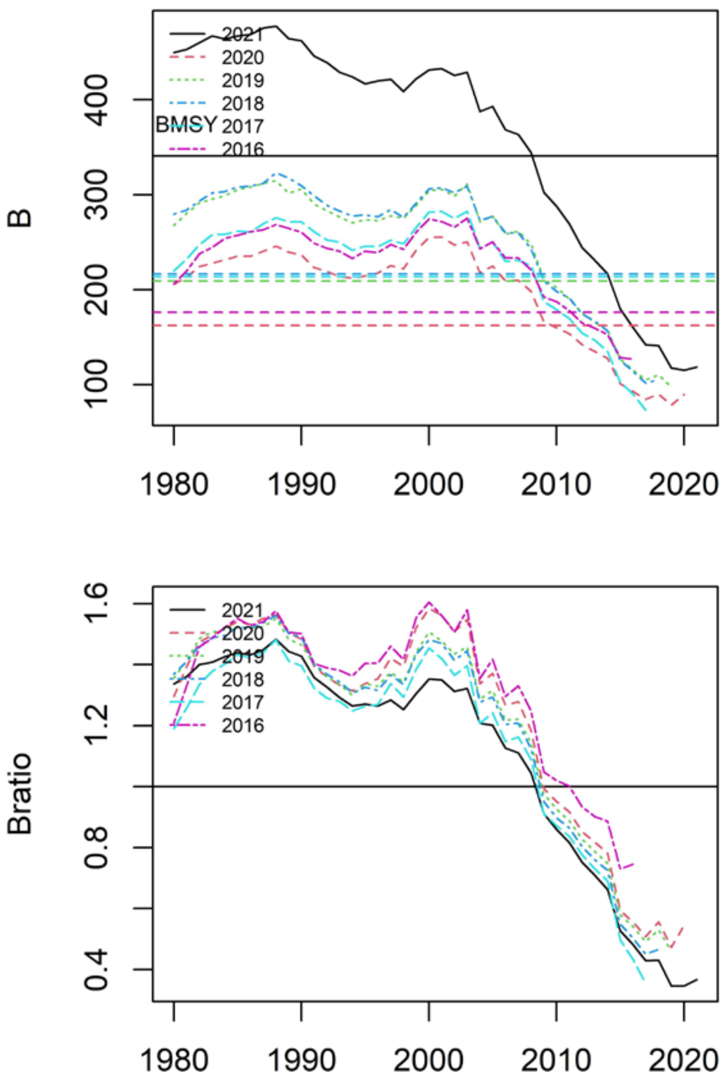
Appendix Figure 12. Time trajectories of fishing mortality and Fratio from retrospective analysis of base case scenario 2.



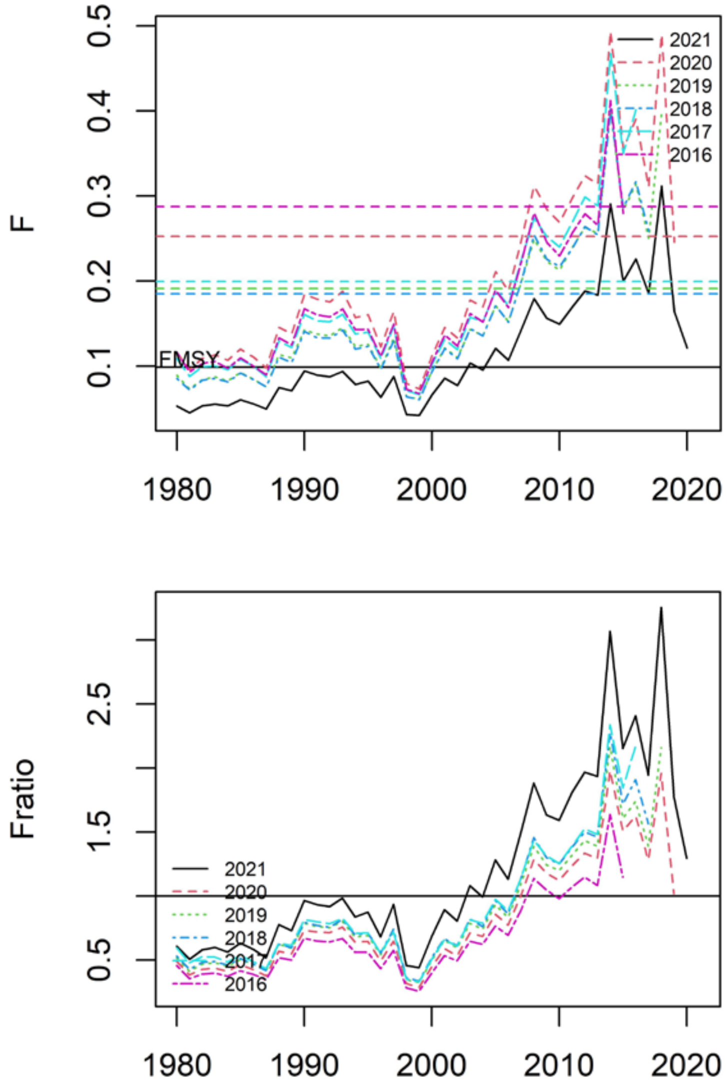
Appendix Figure 13. Time trajectories of biomass and Bratio from a retrospective analysis of sensitivity case scenario 1.



Appendix Figure 14. Time trajectories of fishing mortality and Fratio from retrospective analysis of sensitivity case scenario 1.



Appendix Figure 15. Time trajectories of biomass and Bratio from a retrospective analysis of sensitivity case scenario 2.



Appendix Figure 16. Time trajectories of fishing mortality and Fratio from retrospective analysis of sensitivity case scenario 2.