North Pacific Fisheries Commission

NPFC-2021-SCsm01-WP03

North Pacific Ocean Pacific Saury 2019 Stock Assessment Update Report

Member: China

1. Introduction

The Pacific saury (*Cololabis sarira*) stock assessment used a series of CPUE (catch per unit effort) up to 2018 in SSC PS06, which produced assessment results with a 3-year time lag between the data and the report to the upcoming Commission meeting. Noting that the CPUE data for 2019 have become available and recognizing the importance of using all available scientific information for the stock assessment, it is suggested to conduct an updated Pacific saury stock assessment using the 2019 CPUE data. This would reduce the time lag between data availability and the report to the Commission. Based on the total catch, biomass estimates and CPUE data up to 2019, this report presents an update of Pacific saury stock assessment using the Bayesian state-space production model (BSSPM). During the SSC PS05, the participants revised base case scenarios from the previous stock assessment. The participants agreed to conduct a stock assessment update with two new base cases and four sensitivity analyses (Table 1; NPFC-2019-SSC PS05-Final Report). In this report, we summarized the estimates of key parameters and MSY-based biological reference points for new base cases (NB1-NB2) and sensitivity analyses (NS1-NS4). We also conducted stochastic projections to provide estimated exploitable biomass from 2020-2024.

2. Materials and methods

2.1. Input data

1) The catch data from 1980 to 2019 were included.

2) The Japanese fishery-independent survey biomass estimates up to 2019 were included.

3) Japanese late CPUE (1994-2019), Russian CPUE (1994-2019), Chinese Taipei CPUE (2001-2019), Korean CPUE (2001-2019) and Chinese CPUE (2013-2019) were updated.

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

This assessment used catch data (1980-2019), fishery-independent biomass index (2003-2019), Japanese early CPUE (1980-1993), Japanese late CPUE (1994-2019), Russian CPUE (1994-2019), Chinese Taipei CPUE (2001-2019), Korean CPUE (2001-2019) and Chinese CPUE (2013-2019) as input data (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. 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 PS05 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 2019 to 2014. Sensitivity analysis was conducted to understand whether the assessment model was robust with the change of prior range of Japanese biomass survey catchability (NS1-NS2) and the use of joint CPUE (NS3-NS4).

Stochastic projections were applied to the assessment to show the possible changes in exploitable biomass. A five-year catch scenario was projected starting in 2020. The catch was set at 0, 0.7, 0.8, 0.9, 1.0, 1.1, 1.2, and 1.3 multiples average catch of the recent 3 years. A risk analysis was conducted to show how the probabilities of biomass fall in each quadrant of the Kobe plot change as projected catch changes in the future.

3. Assessment results

The posterior densities of model parameters from all case scenarios showed that the densities were smooth and unimodal (Appendix Figure 1-6). The estimated mean, median, and 80% CI of posterior estimates of reference points were summarized in tables (Table 3 and

Appendix Table 1-6). Mean, median, and 80% CI of the posterior estimates of model parameters from each scenario were summarized in tables (Appendix 7-12). 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 7-12). There was a strong temporal pattern from Chinese Taipei (Appendix Figure 7-10).
3) The sensitivity analysis results showed that the two base case scenarios 1-2 were similar to sensitivity case scenarios 1-2 but were quite different from sensitivity case scenarios 3-4 which used joint CPUE index (Figure 16-20).
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 a scale instability but not a typical retrospective pattern in the present assessment (Appendix Figure 13-20).

5. Stock size and harvest rate

The time trajectories of biomass and fishing mortality showed different trends before 2000 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 biomass was below BMSY during the years around 2000 and 2017. The Bratio from base case scenarios 1 showed similar trends with base case 2 after around 1995. Before 1995, the biomass from base case scenarios 1 increased over time from below BMSY to above BMSY around 1990 and below BMSY again. The Fratio from base case scenarios 2 was similar to that of scenarios 1 after 1995. The Kobe plots showed that the Bratio2019 and Fratio2019 from base case scenario 1-2 were in yellow quadrant (Figure 12). The Bratio (2017-2019) and Fratio (2017-2019) from base case scenario 1-2 fell in the red quadrant of the Kobe plot (Figure 13).

6. Projection

A five-year projection was conducted for all scenarios. 0, 0.7, 0.8, 0.9, 1.0, 1.1, 1.2, and 1.3 of average catch over the last 3 years was assumed for the future projection. For all case scenarios, there were some mixed pictures on the exploitable biomass compared with BMSY (Appendix Figure 21-24). The probabilities of being in the green, yellow, orange, and red quadrants of Kobe plot under different catch scenarios were summarized in the Table 5. For all base case scenarios, the Pacific saury would have greater than 25% probability to be in the green quadrant.

7. Conclusion

This working paper presents the results of stock assessment for the North Pacific Ocean Pacific Saury stock using the BSSPM. The assessment was conducted based on the specification (2 base cases and 4 sensitivity cases) agreed in the SSC PS05. The model parameters were estimated based on Bayesian framework with a MCMC 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. We also conducted stochastic projections to provide estimated exploitable biomass from 2020-2024. The main assessment results were concluded as follows:

The estimated median B2019 from the two base case scenarios was 388,800 (80%CI 236,700-572,600) and 446,200 (80%CI 214,200-783,400) metric tons, respectively. The median B2019/BMSY and F2019/FMSY over the two base case scenarios were 0.46 (80%CI 0.30-0.67) and 0.99 (80%CI 0.64-1.46), respectively. Over two base case scenarios, large interannual variability was shown in biomass trajectory during the most recent years. An increase was found in 2018 followed by a decrease in 2019. The fishing mortality in 2019 (F2019=0.47; 80%CI 0.22-0.69) was quite lower than that in 2018 (F2018=0.71; 80%CI 0.33-1.04). The probability of the population being in the yellow Kobe quadrant in 2019 was estimated to be greater than 50%.

References

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Table 1. Definition of base cases and sensitivity cases (NPFC-2019-SSC PS05-Final Report Annex G).

	New base case (NB1)	New base case (NB2)	Sensitivity case (NS1, NS2)	Sensitivity case (NS3, NS4)
Initial year	1980	1980	1980	1980/2001
Biomass survey	B_obs=B_est*q1~ LN(log(q*B), s^2) q~U(0, 1)	Same as left	q~U(0, 2)	q~U(0, 1) 2003-2019
CPUE	CHN(2013-2019) JPN_early(1980-1993) (with time-varying q) JPN_late(1994-2019) KOR(2001-2019) RUS(1994-2019) CT(2001-2019)	CHN(2013-2019) JPN_late(1994-2019) KOR(2001-2019) RUS(1994-2019) CT(2001-2019)	Two sets as on the left for NS1 and NS2, respectively	NS3: Joint CPUE 2001-2019 (no JPN_early) NS4: Joint CPUE 2001-2019 and JPN_early
Variance component	Variances of logCPUEs are assumed to be common and 6 times of that logbiomass	Variances of logCPUEs are assumed to be common and 5 times of that logbiomass	Same as base cases 1 and 2, respectively	Same weight between biomass and joint CPUE
Hyper-depletion/ stability	A common parameter for all fisheries but JPN_early, with a prior distribution, b~U(0, 1) but [b_JPN_early=1]	A common parameter for all fisheries with a prior distribution, b~U(0, 1)	Same as base cases 1 and 2, respectively	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.

	q_CPUE	K	r	P1	s	σ^2	τ^2
NB1	U(0,1) for qJPN_early, qJPN_late, and qCT; U(0,5) for qRUS, qKOR and qCHN	U(63,1890)	U(0,3)	U(0,1)	U(0,3)	$1/\sigma^2$~Gamma(0.001, 0.001)	$1/\tau^2$~Gamma(0.001, 0.001)
NB2							
NS1							
NS2							
NS3	U(0,1)						
NS4							

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

	Mean	Median	Lower	Upper
C2019	19.24	19.24	19.24	19.24
AveC2017-2019	29.80	29.80	29.80	29.80
AveF2017-2019	0.62	0.64	0.30	0.92
F2019	0.46	0.47	0.22	0.69
FMSY	0.46	0.47	0.24	0.67
MSY	44.91	42.56	35.86	55.10
F2019/FMSY	1.05	0.99	0.64	1.46
AveF2017-2019/FMSY	1.42	1.35	0.91	1.91
K	266.64	200.00	134.40	449.22
B2018	79.48	61.71	42.24	132.70
B2019	53.35	41.18	27.78	88.98
AveB2017-2019	59.63	46.52	32.27	98.34
BMSY	119.85	90.20	63.17	196.61
BMSY/K	0.46	0.44	0.40	0.54
B2018/K	0.32	0.32	0.20	0.45
B2019/K	0.22	0.21	0.13	0.30
B2017-2019/K	0.24	0.24	0.15	0.33
B2018/BMSY	0.72	0.69	0.45	1.02
B2019/BMSY	0.48	0.46	0.30	0.67
B2017-2019/BMSY	0.54	0.53	0.35	0.74

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

	Rho_B	Rho_F
NB1	0.29	-0.06
NB2	0.94	-0.25
NS1	0.33	-0.08
NS2	1.06	-0.29
NS3	0.41	-0.20
NS4	0.48	-0.19

Table 5. Risk table over new base case scenarios.

Ratio	Year	Green	Yellow	Orange	Red
1.3	2020	0.25	0.07	0.01	0.68
1.3	2021	0.27	0.06	0.01	0.67
1.3	2022	0.28	0.05	0.01	0.66
1.3	2023	0.28	0.05	0.01	0.67
1.3	2024	0.28	0.05	0	0.67
1.2	2020	0.25	0.1	0	0.64
1.2	2021	0.29	0.09	0	0.62
1.2	2022	0.31	0.08	0	0.61
1.2	2023	0.32	0.07	0	0.6
1.2	2024	0.33	0.07	0	0.6
1.1	2020	0.26	0.14	0	0.6
1.1	2021	0.31	0.13	0	0.56
1.1	2022	0.34	0.12	0	0.54
1.1	2023	0.37	0.11	0	0.52
1.1	2024	0.39	0.09	0	0.52
1	2020	0.26	0.19	0	0.55
1	2021	0.33	0.17	0	0.5
1	2022	0.38	0.15	0	0.47
1	2023	0.41	0.13	0	0.46
1	2024	0.43	0.12	0	0.44
0.9	2020	0.26	0.25	0	0.49
0.9	2021	0.34	0.22	0	0.44
0.9	2022	0.41	0.19	0	0.4
0.9	2023	0.46	0.16	0	0.38
0.9	2024	0.49	0.14	0	0.37
0.8	2020	0.26	0.31	0	0.43
0.8	2021	0.36	0.27	0	0.37
0.8	2022	0.44	0.23	0	0.33
0.8	2023	0.5	0.19	0	0.31
0.8	2024	0.54	0.16	0	0.3
0.7	2020	0.26	0.38	0	0.37
0.7	2021	0.38	0.31	0	0.31
0.7	2022	0.48	0.25	0	0.27
0.7	2023	0.54	0.21	0	0.25
0.7	2024	0.59	0.17	0	0.24

0	2020	0.26	0.74	0	0
0	2021	0.51	0.49	0	0
0	2022	0.69	0.31	0	0
0	2023	0.78	0.22	0	0
0	2024	0.83	0.17	0	0

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

	Mean	Median	Lower 10th	Upper 10th
C2019	19.24	19.24	19.24	19.24
AveC2017-2019	29.80	29.80	29.80	29.80
AveF2017-2019	0.66	0.67	0.41	0.94
F2019	0.49	0.49	0.30	0.71
FMSY	0.51	0.51	0.33	0.68
MSY	42.65	41.71	34.97	48.19
F2019/FMSY	0.98	0.97	0.63	1.28
AveF2017-2019/FMSY	1.32	1.31	0.91	1.70
K	203.03	180.60	112.60	256.90
B2018	67.79	58.04	36.26	84.91
B2019	45.23	38.88	23.67	57.26
AveB2017-2019	51.16	44.00	28.51	63.93
BMSY	91.75	82.16	54.09	113.30
BMSY/K	0.46	0.44	0.39	0.51
B2018/K	0.34	0.34	0.23	0.46
B2019/K	0.23	0.23	0.15	0.30
B2017-2019/K	0.26	0.26	0.18	0.33
B2018/BMSY	0.75	0.72	0.48	0.98
B2019/BMSY	0.50	0.48	0.34	0.67
B2017-2019/BMSY	0.57	0.55	0.39	0.73

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

	Mean	Median	Lower 10th	Upper 10th
C2019	19.24	19.24	19.24	19.24
AveC2017-2019	29.80	29.80	29.80	29.80
AveF2017-2019	0.59	0.59	0.27	0.94
F2019	0.43	0.43	0.16	0.68
FMSY	0.42	0.42	0.16	0.64
MSY	47.17	43.86	32.39	55.31
F2019/FMSY	1.12	1.02	0.55	1.50
AveF2017-2019/FMSY	1.52	1.40	0.79	1.98
K	330.26	231.90	109.30	421.40
B2018	91.18	66.98	33.15	116.40
B2019	61.47	44.62	21.42	78.34
AveB2017-2019	68.10	50.19	26.02	86.16
BMSY	147.96	102.90	51.65	187.50
BMSY/K	0.45	0.44	0.38	0.50
B2018/K	0.31	0.30	0.16	0.43
B2019/K	0.20	0.20	0.11	0.29
B2017-2019/K	0.23	0.23	0.12	0.32
B2018/BMSY	0.68	0.66	0.34	0.94
B2019/BMSY	0.45	0.44	0.24	0.65
B2017-2019/BMSY	0.51	0.49	0.29	0.71

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

	Mean	Median	Lower 10th	Upper 10th
C2019	19.24	19.24	19.24	19.24
AveC2017-2019	29.80	29.80	29.80	29.80
AveF2017-2019	0.77	0.75	0.35	1.13
F2019	0.58	0.56	0.23	0.84
FMSY	0.56	0.55	0.31	0.78
MSY	43.56	42.27	35.72	48.82
F2019/FMSY	1.04	1.02	0.66	1.36
AveF2017-2019/FMSY	1.38	1.37	0.95	1.78
K	203.68	168.00	85.48	245.10
B2018	63.62	51.96	25.67	80.02
B2019	42.30	34.50	16.03	53.37
AveB2017-2019	47.97	39.52	19.35	60.16
BMSY	91.49	76.12	42.70	108.80
BMSY/K	0.46	0.45	0.39	0.51
B2018/K	0.33	0.32	0.21	0.43
B2019/K	0.22	0.21	0.14	0.29
B2017-2019/K	0.25	0.24	0.17	0.33
B2018/BMSY	0.72	0.68	0.45	0.95
B2019/BMSY	0.47	0.45	0.30	0.63
B2017-2019/BMSY	0.54	0.52	0.36	0.71

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

	Mean	Median	Lower 10th	Upper 10th
C2019	19.24	19.24	19.24	19.24
AveC2017-2019	29.80	29.80	29.80	29.80
AveF2017-2019	0.70	0.66	0.21	1.06
F2019	0.52	0.48	0.13	0.78
FMSY	0.50	0.48	0.19	0.75
MSY	45.59	43.86	34.14	53.26
F2019/FMSY	1.10	1.04	0.62	1.46
AveF2017-2019/FMSY	1.48	1.41	0.92	1.93
K	260.82	205.00	88.62	338.70
B2018	76.73	59.90	23.53	104.50
B2019	51.48	39.93	14.73	70.10
AveB2017-2019	57.41	45.20	18.36	78.30
BMSY	117.94	92.32	43.50	150.50
BMSY/K	0.46	0.45	0.39	0.51
B2018/K	0.31	0.30	0.19	0.41
B2019/K	0.21	0.20	0.12	0.28
B2017-2019/K	0.23	0.23	0.14	0.30
B2018/BMSY	0.68	0.64	0.42	0.91
B2019/BMSY	0.45	0.43	0.27	0.60
B2017-2019/BMSY	0.51	0.48	0.32	0.67

Appendix table 5. Summary of reference points from sensitivity case scenario 3.

	Mean	Median	Lower 10th	Upper 10th
C2019	19.24	19.24	19.24	19.24
AveC2017-2019	29.80	29.80	29.80	29.80
AveF2017-2019	0.35	0.29	0.07	0.55
F2019	0.26	0.21	0.04	0.40
FMSY	0.23	0.19	0.00	0.38
MSY	37.25	38.38	24.17	48.56
F2019/FMSY	2.63	1.20	0.41	2.21
AveF2017-2019/FMSY	3.46	1.62	0.73	3.01
K	614.65	438.00	108.30	1016.00
B2018	142.55	106.60	32.92	199.30
B2019	124.58	90.80	21.40	176.30
AveB2017-2019	134.53	100.07	27.65	191.00
BMSY	280.76	202.55	58.37	450.70
BMSY/K	0.47	0.45	0.37	0.55
B2018/K	0.25	0.24	0.14	0.34
B2019/K	0.22	0.20	0.10	0.29
B2017-2019/K	0.24	0.22	0.13	0.31
B2018/BMSY	0.55	0.52	0.30	0.69
B2019/BMSY	0.47	0.43	0.23	0.63
B2017-2019/BMSY	0.51	0.48	0.28	0.65

Appendix table 6. Summary of reference points from sensitivity case scenario 4.

	Mean	Median	Lower 10th	Upper 10th
C2019	19.24	19.24	19.24	19.24
AveC2017-2019	29.80	29.80	29.80	29.80
AveF2017-2019	0.48	0.46	0.18	0.74
F2019	0.35	0.33	0.11	0.54
FMSY	0.35	0.34	0.13	0.53
MSY	43.02	42.25	36.07	48.10
F2019/FMSY	1.07	0.99	0.54	1.52
AveF2017-2019/FMSY	1.46	1.39	0.86	1.91
K	341.25	266.80	122.20	435.70
B2018	92.37	69.73	34.13	113.30
B2019	80.32	58.58	22.45	101.50
AveB2017-2019	85.41	63.70	28.43	105.07
BMSY	157.95	123.70	62.71	199.40
BMSY/K	0.47	0.46	0.38	0.54
B2018/K	0.27	0.26	0.17	0.36
B2019/K	0.23	0.22	0.12	0.31
B2017-2019/K	0.25	0.24	0.16	0.33
B2018/BMSY	0.58	0.55	0.37	0.73
B2019/BMSY	0.50	0.46	0.26	0.66
B2017-2019/BMSY	0.53	0.50	0.34	0.67

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

	Mean	Median	Lower 10th	Upper 10th
r	1.64	1.57	0.68	2.52
K	203.03	180.60	112.60	256.90
qCHN	0.52	0.48	0.20	0.73
qJPN1_1980	0.02	0.02	0.00	0.03
qJPN1_1981	0.02	0.02	0.00	0.03
qJPN1_1982	0.02	0.01	0.00	0.02
qJPN1_1983	0.02	0.01	0.00	0.03
qJPN1_1984	0.02	0.02	0.00	0.03
qJPN1_1985	0.02	0.02	0.01	0.03
qJPN1_1986	0.02	0.02	0.01	0.03
qJPN1_1987	0.02	0.02	0.01	0.03
qJPN1_1988	0.03	0.02	0.01	0.04
qJPN1_1989	0.03	0.03	0.01	0.04
qJPN1_1990	0.03	0.03	0.01	0.05
qJPN1_1991	0.04	0.04	0.02	0.06
qJPN1_1992	0.06	0.05	0.02	0.08
qJPN1_1993	0.07	0.06	0.03	0.10
qJPN2	0.07	0.06	0.03	0.10
qKOR	0.32	0.30	0.12	0.45
qRUS	0.72	0.67	0.26	0.99
qCT	0.07	0.07	0.03	0.10
qBio	0.67	0.68	0.47	0.99
Shape	0.69	0.49	0.10	1.03
sigma_com	0.33	0.33	0.30	0.36
sigma_Bio	0.13	0.13	0.12	0.15
Tau	0.28	0.28	0.19	0.35
FMSY	0.51	0.51	0.33	0.68
BMSY	91.75	82.16	54.09	113.30
MSY	42.65	41.71	34.97	48.19
b	0.79	0.79	0.70	0.89

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

	Mean	Median	Lower 10th	Upper 10th
r	1.52	1.47	0.42	2.48
K	330.26	231.90	109.30	421.40
qCHN	1.51	1.41	0.61	2.12
qJPN2	0.22	0.21	0.09	0.32
qKOR	1.01	0.93	0.37	1.40
qRUS	2.20	2.06	0.85	3.09
qCT	0.22	0.21	0.08	0.31
qBio	0.56	0.57	0.25	0.90
Shape	0.63	0.45	0.05	0.95
sigma_com	0.34	0.33	0.30	0.37
sigma_Bio	0.15	0.15	0.13	0.17
tau	0.35	0.34	0.23	0.45
FMSY	0.42	0.42	0.16	0.64
BMSY	147.96	102.90	51.65	187.50
MSY	47.17	43.86	32.39	55.31
b	0.51	0.51	0.39	0.63

Appendix table 9. Summary of parameter estimates from sensitivity case scenario 1.

	Mean	Median	Lower 10th	Upper 10th
r	1.74	1.72	0.86	2.72
K	203.68	168.00	85.48	245.10
qCHN	0.60	0.55	0.19	0.88
qJPN1_1980	0.02	0.02	0.00	0.03
qJPN1_1981	0.02	0.01	0.00	0.03
qJPN1_1982	0.02	0.01	0.00	0.02
qJPN1_1983	0.02	0.01	0.00	0.03
qJPN1_1984	0.02	0.01	0.00	0.03
qJPN1_1985	0.02	0.02	0.01	0.03
qJPN1_1986	0.02	0.02	0.01	0.03
qJPN1_1987	0.02	0.02	0.01	0.03
qJPN1_1988	0.03	0.02	0.01	0.04
qJPN1_1989	0.03	0.03	0.01	0.05
qJPN1_1990	0.04	0.03	0.01	0.05
qJPN1_1991	0.05	0.04	0.02	0.07
qJPN1_1992	0.06	0.06	0.02	0.09
qJPN1_1993	0.08	0.07	0.02	0.12
qJPN2	0.08	0.07	0.02	0.12
qKOR	0.37	0.34	0.11	0.54
qRUS	0.83	0.75	0.23	1.19
qCT	0.08	0.07	0.02	0.12
qBio	0.78	0.76	0.35	1.13
Shape	0.70	0.51	0.12	1.05
sigma_com	0.33	0.33	0.29	0.36
sigma_Bio	0.13	0.13	0.12	0.15
tau	0.28	0.28	0.19	0.36
FMSY	0.56	0.55	0.31	0.78
BMSY	91.49	76.12	42.70	108.80
MSY	43.56	42.27	35.72	48.82
b	0.79	0.79	0.68	0.88

Appendix table 10. Summary of parameter estimates from sensitivity case scenario 2.

	Mean	Median	Lower 10th	Upper 10th
r	1.60	1.58	0.59	2.62
K	260.82	205.00	88.62	338.70
qCHN	1.57	1.49	0.64	2.21
qJPN2	0.23	0.21	0.10	0.33
qKOR	1.04	0.97	0.43	1.50
qRUS	2.27	2.14	0.94	3.26
qCT	0.23	0.22	0.10	0.33
qBio	0.67	0.63	0.19	1.01
Shape	0.69	0.51	0.08	1.04
sigma_com	0.34	0.34	0.30	0.37
sigma_Bio	0.15	0.15	0.13	0.17
tau	0.34	0.33	0.23	0.44
FMSY	0.50	0.48	0.19	0.75
BMSY	117.94	92.32	43.50	150.50
MSY	45.59	43.86	34.14	53.26
b	0.52	0.52	0.39	0.63

Appendix table 11. Summary of parameter estimates from sensitivity case scenario 3.

	Mean	Median	Lower 10th	Upper 10th
r	0.89	0.67	0.00	1.53
K	614.65	438.00	108.30	1016.00
qBio	0.37	0.32	0.07	0.58
qJoint	0.46	0.43	0.10	0.73
Shape	0.85	0.55	0.00	1.56
sigma_com	0.29	0.29	0.24	0.34
sigma_Bio	0.29	0.29	0.24	0.34
tau	0.09	0.07	0.02	0.13
FMSY	0.23	0.19	0.00	0.38
BMSY	280.76	202.55	58.37	450.70
MSY	37.25	38.38	24.17	48.56
b	0.17	0.15	0.00	0.27

Appendix table 12. Summary of parameter estimates from sensitivity case scenario 4.

	Mean	Median	Lower 10th	Upper 10th
r	1.19	1.00	0.14	1.97
K	341.25	266.80	122.20	435.70
qBio	0.51	0.50	0.22	0.80
qJPN1_1980	0.01	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	0.01	0.01	0.00	0.02
qJPN1_1986	0.01	0.01	0.00	0.02
qJPN1_1987	0.01	0.01	0.00	0.02
qJPN1_1988	0.01	0.01	0.00	0.02
qJPN1_1989	0.02	0.02	0.00	0.02
qJPN1_1990	0.02	0.02	0.00	0.02
qJPN1_1991	0.02	0.02	0.01	0.03
qJPN1_1992	0.02	0.02	0.01	0.03
qJPN1_1993	0.02	0.02	0.01	0.03
qJoint	0.49	0.48	0.16	0.80
Shape	0.85	0.59	0.04	1.46
sigma_com	0.29	0.28	0.24	0.32
sigma_Bio	0.29	0.28	0.24	0.32
tau	0.10	0.08	0.02	0.14
FMSY	0.35	0.34	0.13	0.53
BMSY	157.95	123.70	62.71	199.40
MSY	43.02	42.25	36.07	48.10
b	0.17	0.14	0.00	0.26

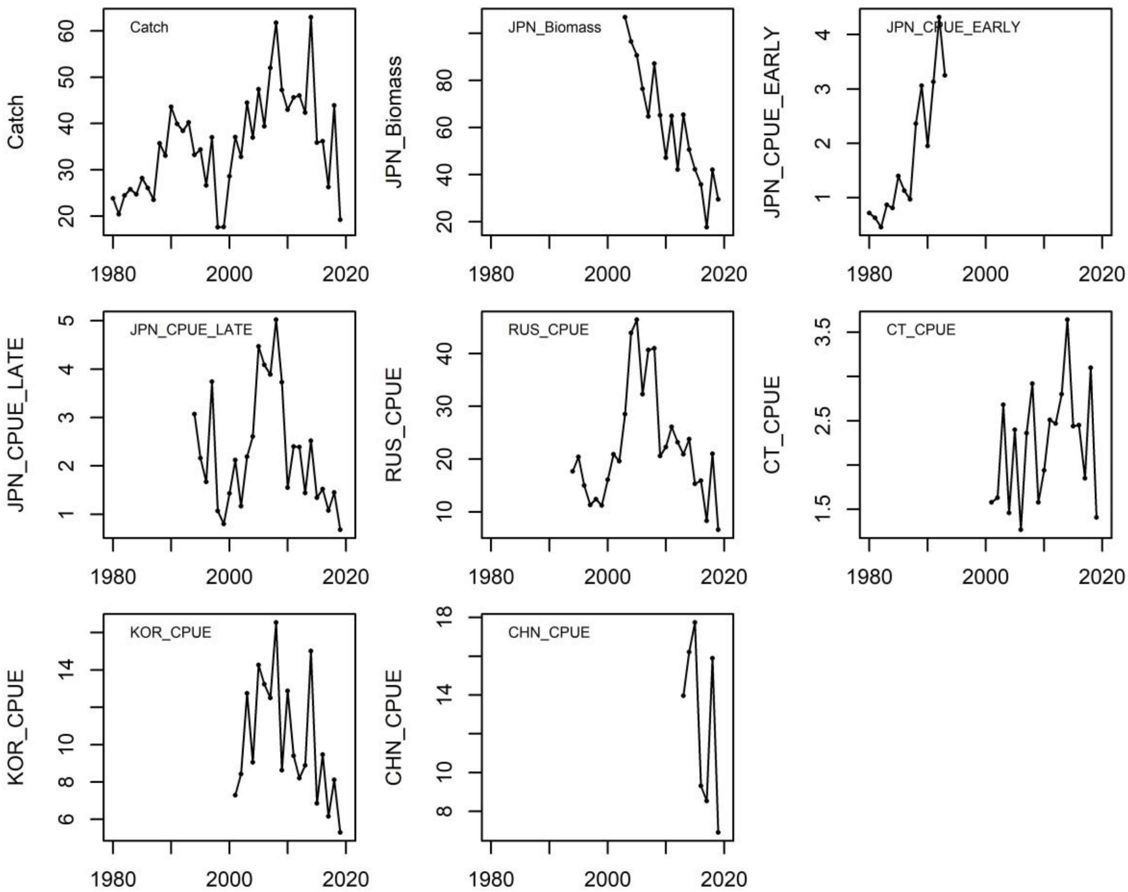


Figure 1. Input data for 2019 Pacific saury stock assessment.

Figure 2. Median biomass over time from each base case scenario (NB1-NB2).

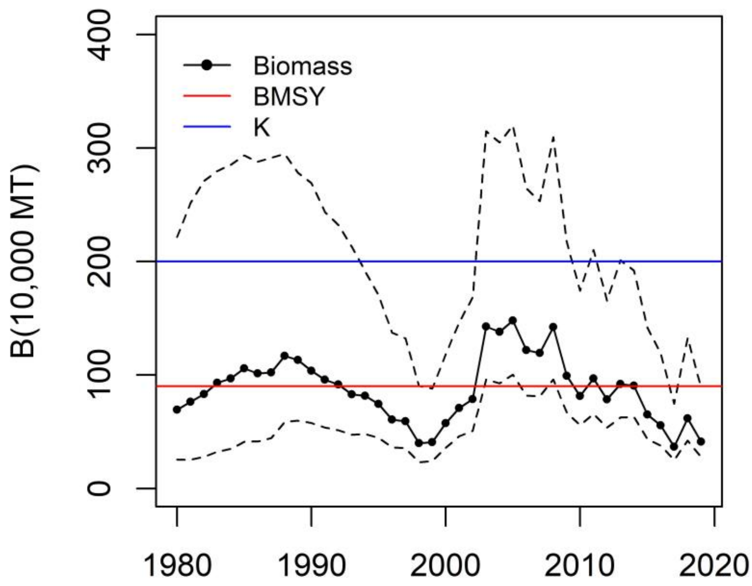


Figure 3. Median biomass and 80% CI over base case scenarios 1-2.

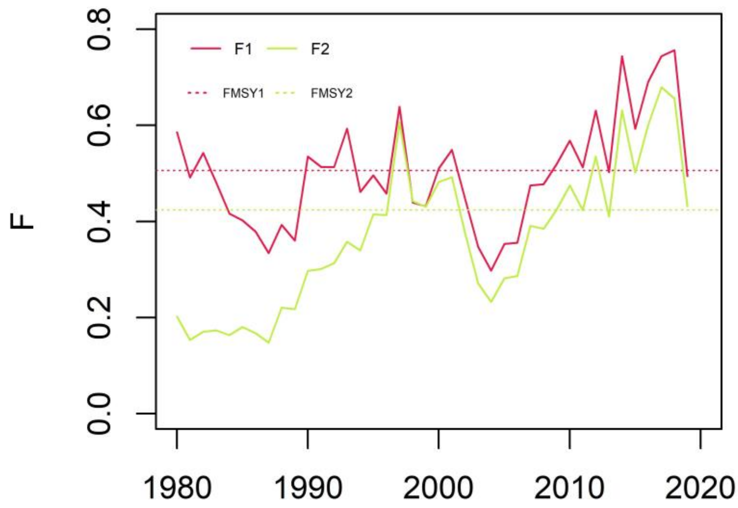


Figure 4. Median fishing mortality over time from two base case scenarios (NB1-NB2).

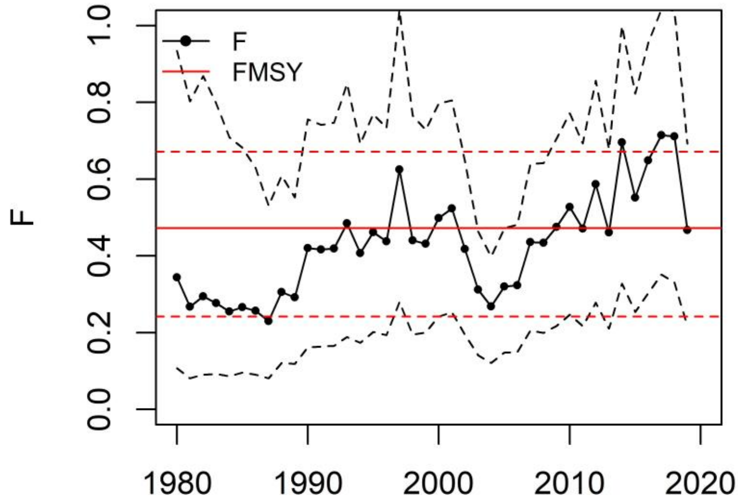


Figure 5. Median fishing mortality and 80% CI over base case scenarios 1-2.

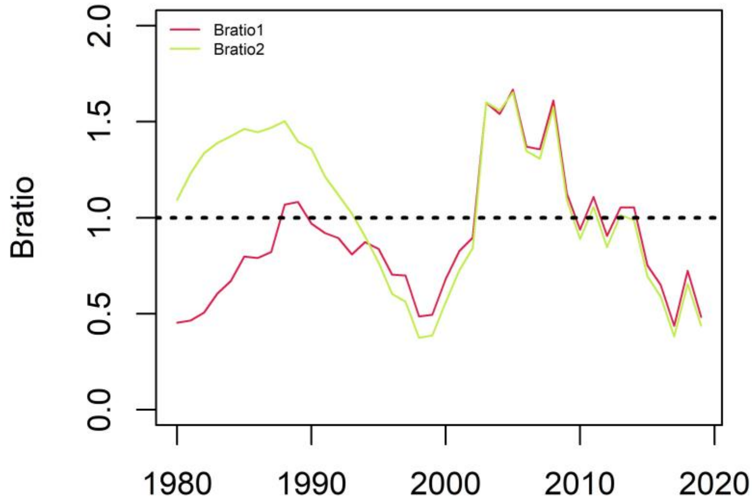


Figure 6. Median Bratio over time from each base case scenario (1-2).

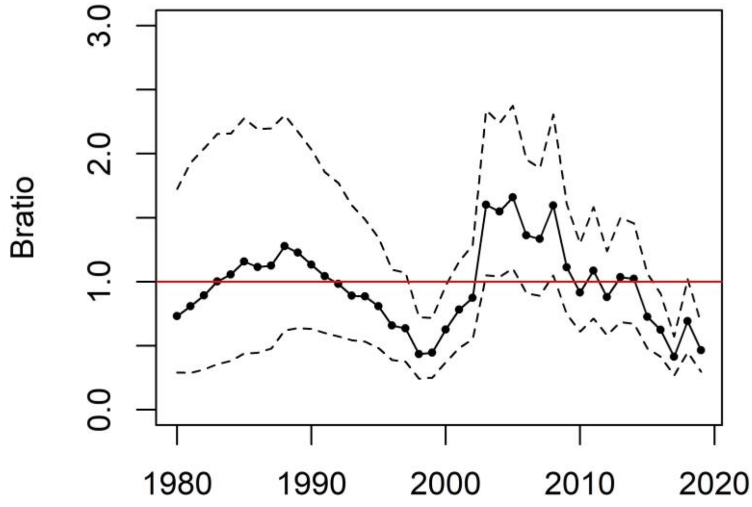


Figure 7. Median Bratio and 80% CI over base case scenarios 1-2.

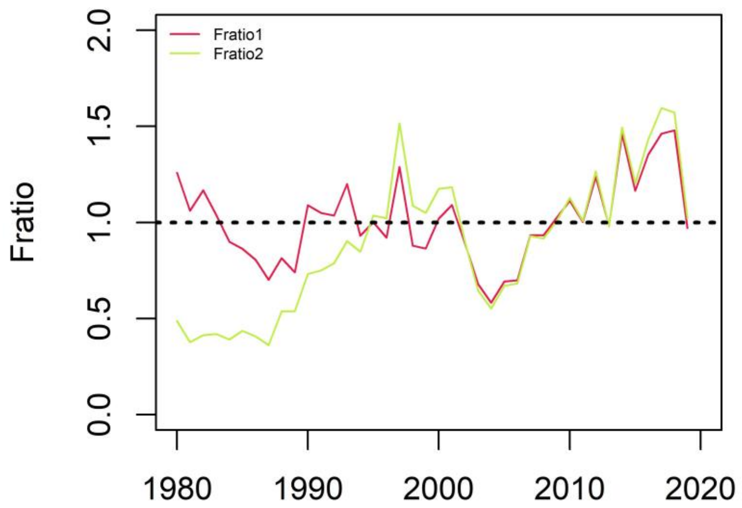


Figure 8. Median Fratio over time from each base case scenario (1-2).

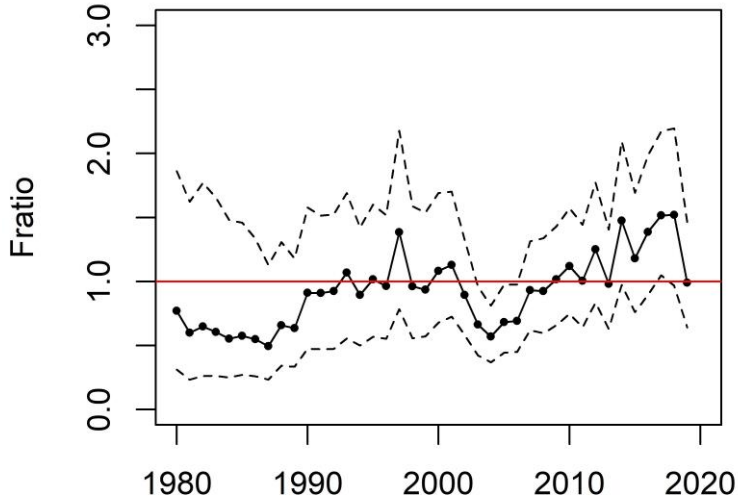


Figure 9. Median Fratio and 80% CI over base case scenarios 1-2.

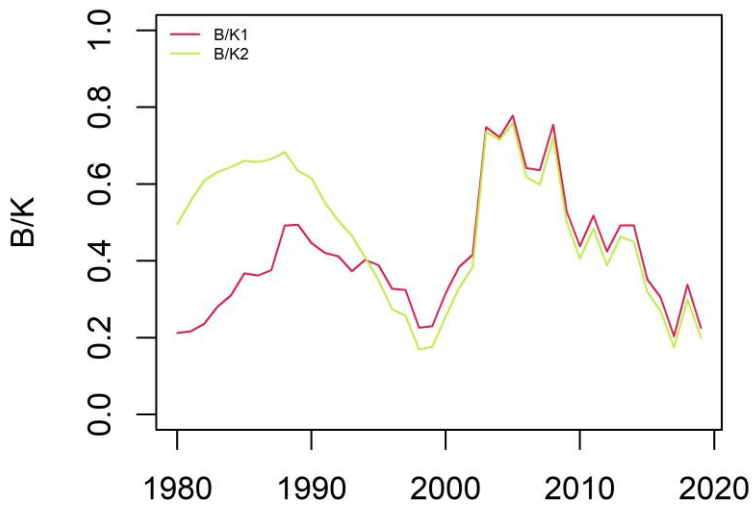


Figure 10. Median B/K over time from each base case scenario (1-2).

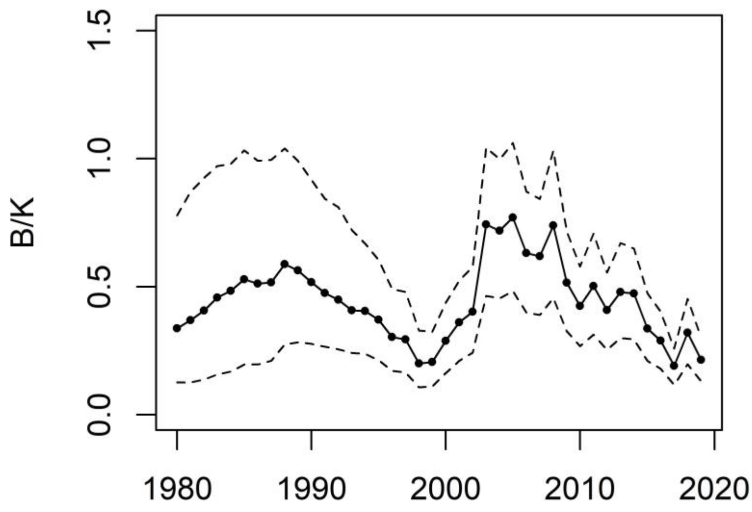


Figure 11. Median B/K and 80% CI over base case scenarios 1-2.

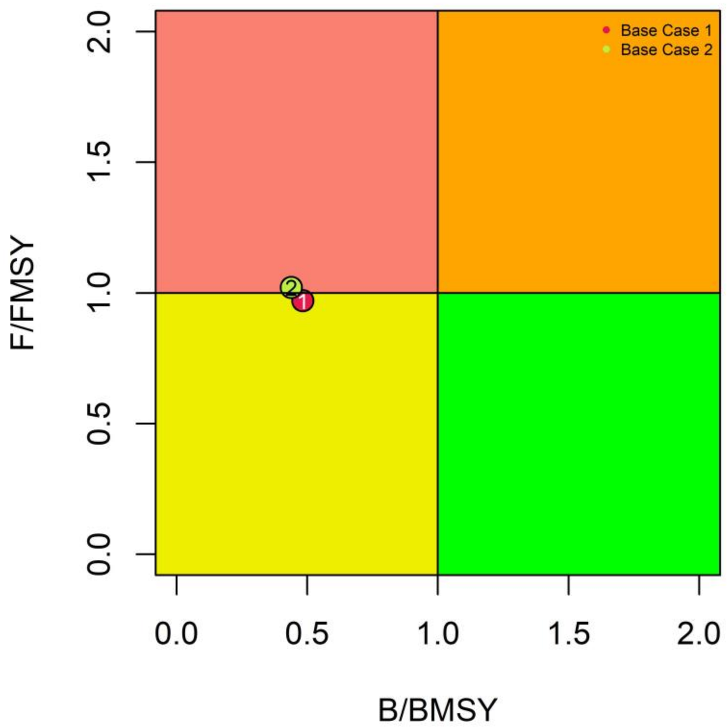


Figure 12. Median Fratio2019 and Bratio2019 calculated from each base case scenario (1-2).

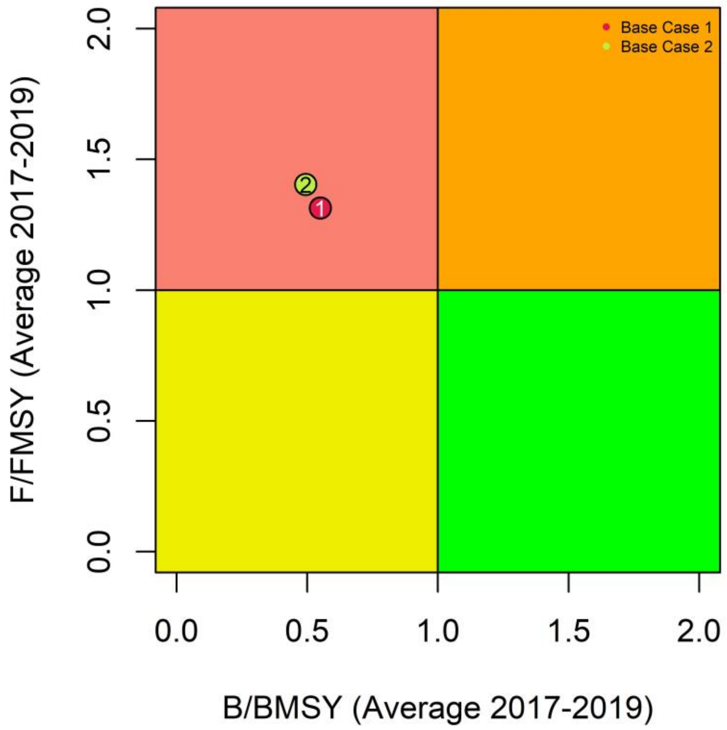


Figure 13. Median Fratio (average from 2017-2019) and Bratio (average from 2017-2019) calculated from each base case scenario (1-2).

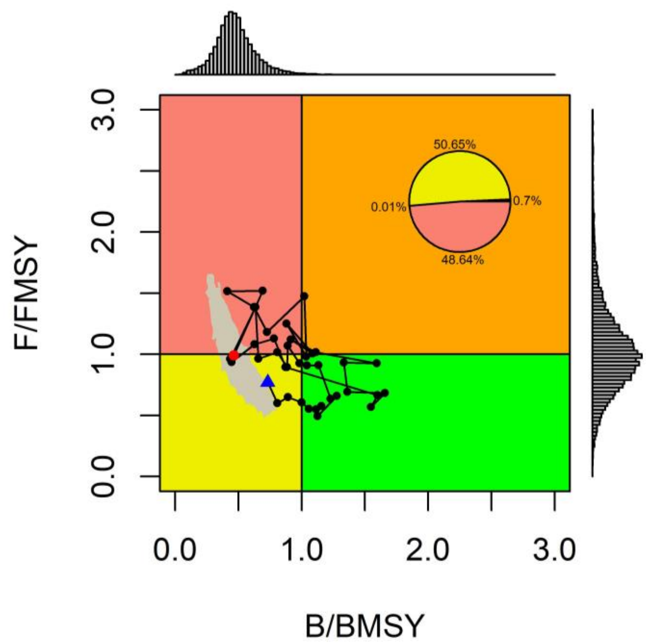


Figure 14. Kobe plot with time series median Fratio and Bratio from 1980 to 2019 over base case scenarios 1-2. The blue dot represents initial year 1980 and the red dot represents the terminal year 2019.

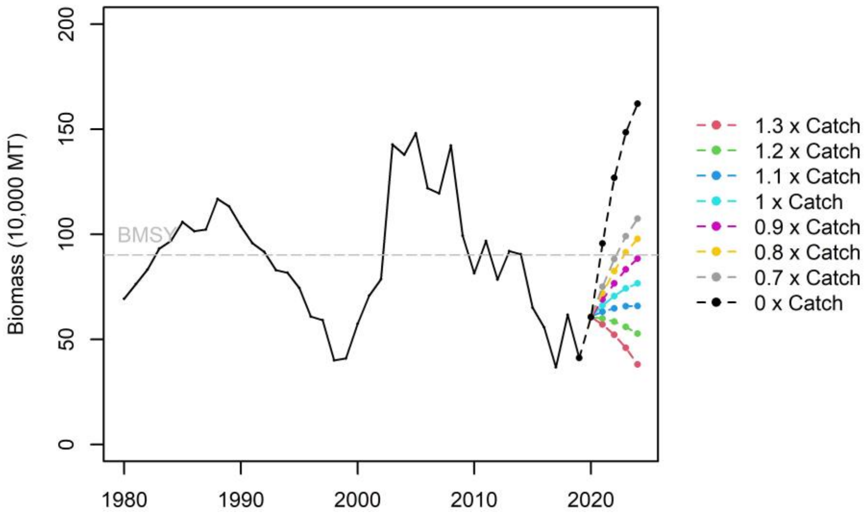


Figure 15. Median biomass trajectories (1980-2024) from 8 catch scenarios over two base case models.

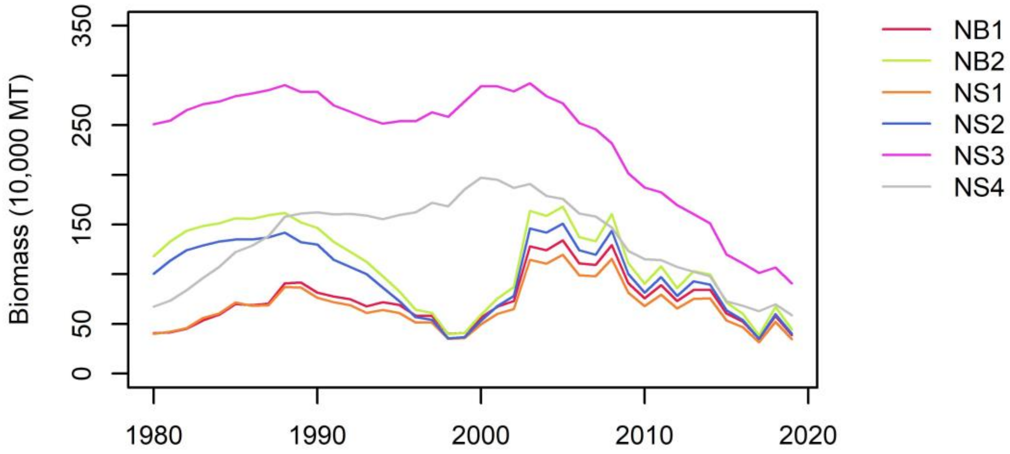


Figure 16. Median biomass over time from each case scenario.

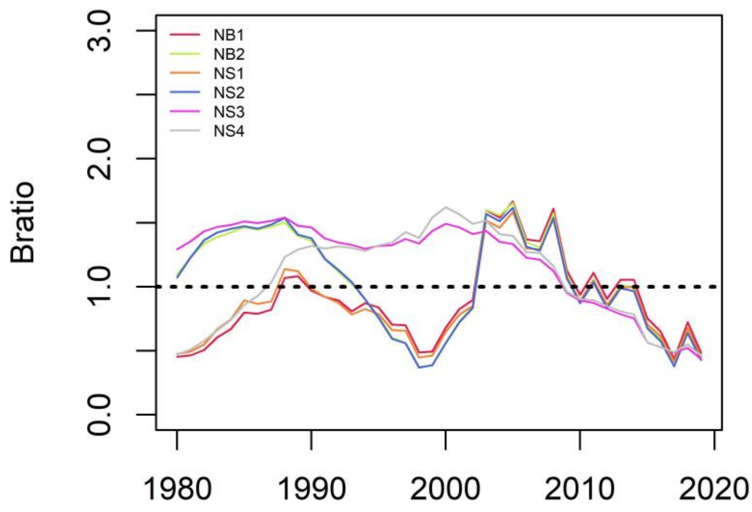


Figure 17. Median Bratio over time from each case scenario.

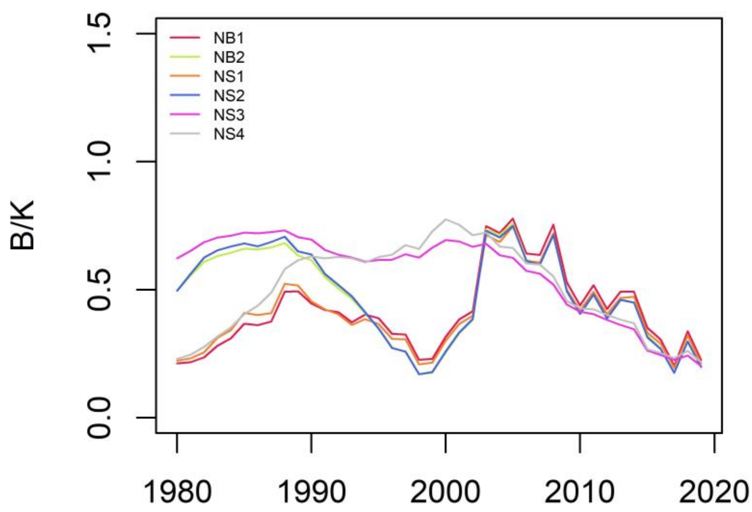


Figure 18. Median B/K over time from each case scenario.

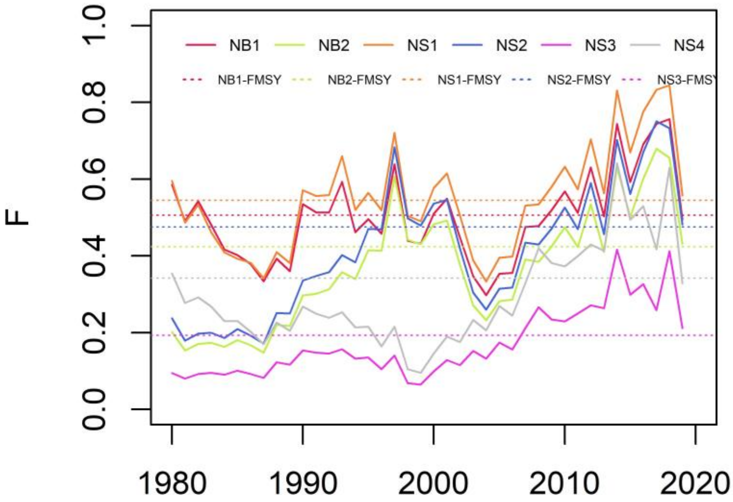


Figure 19. Median F over time from each case scenario.

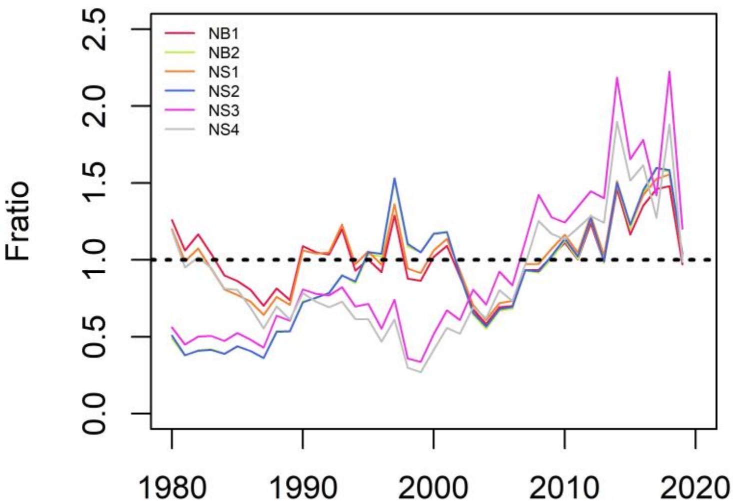
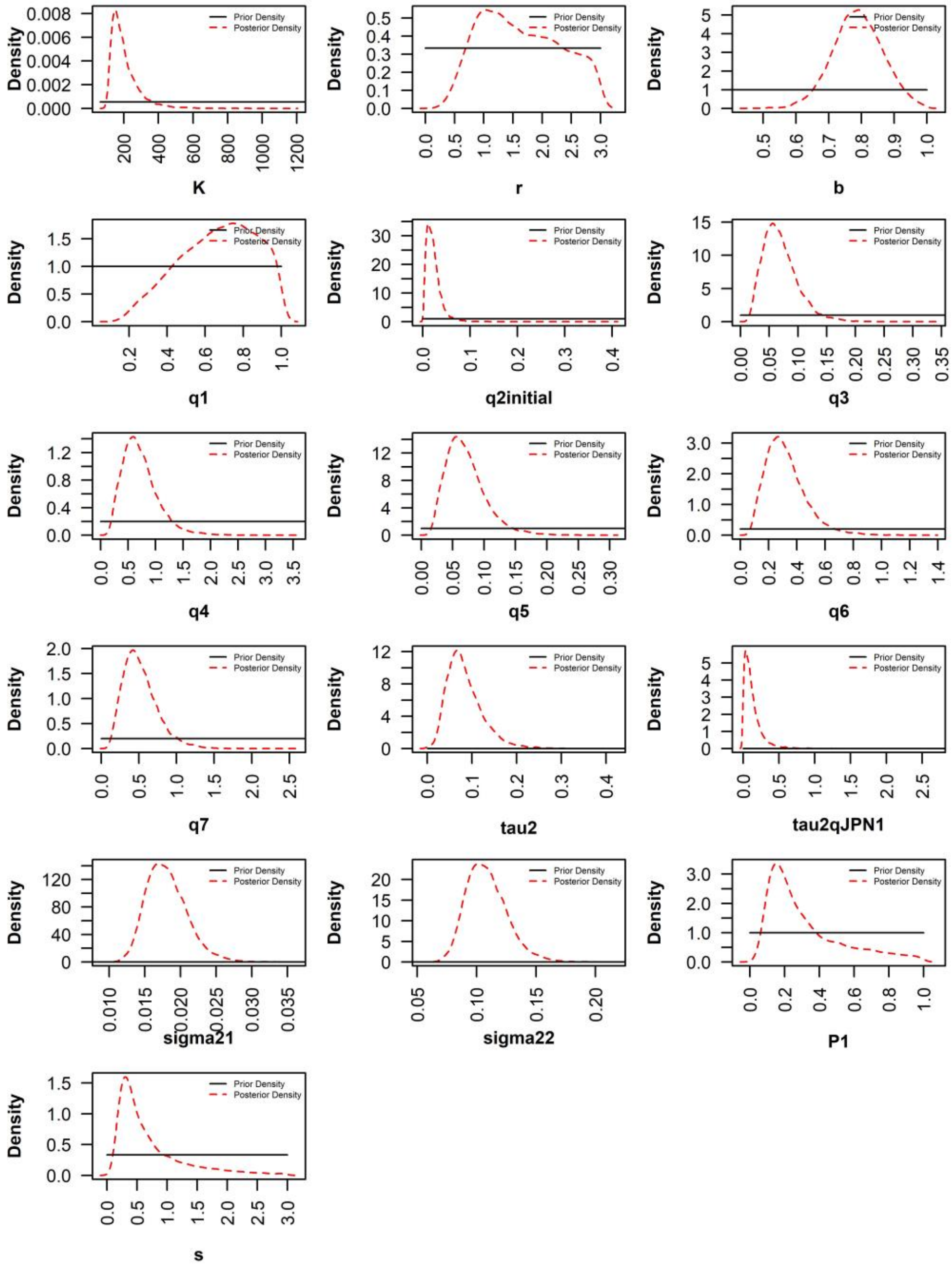
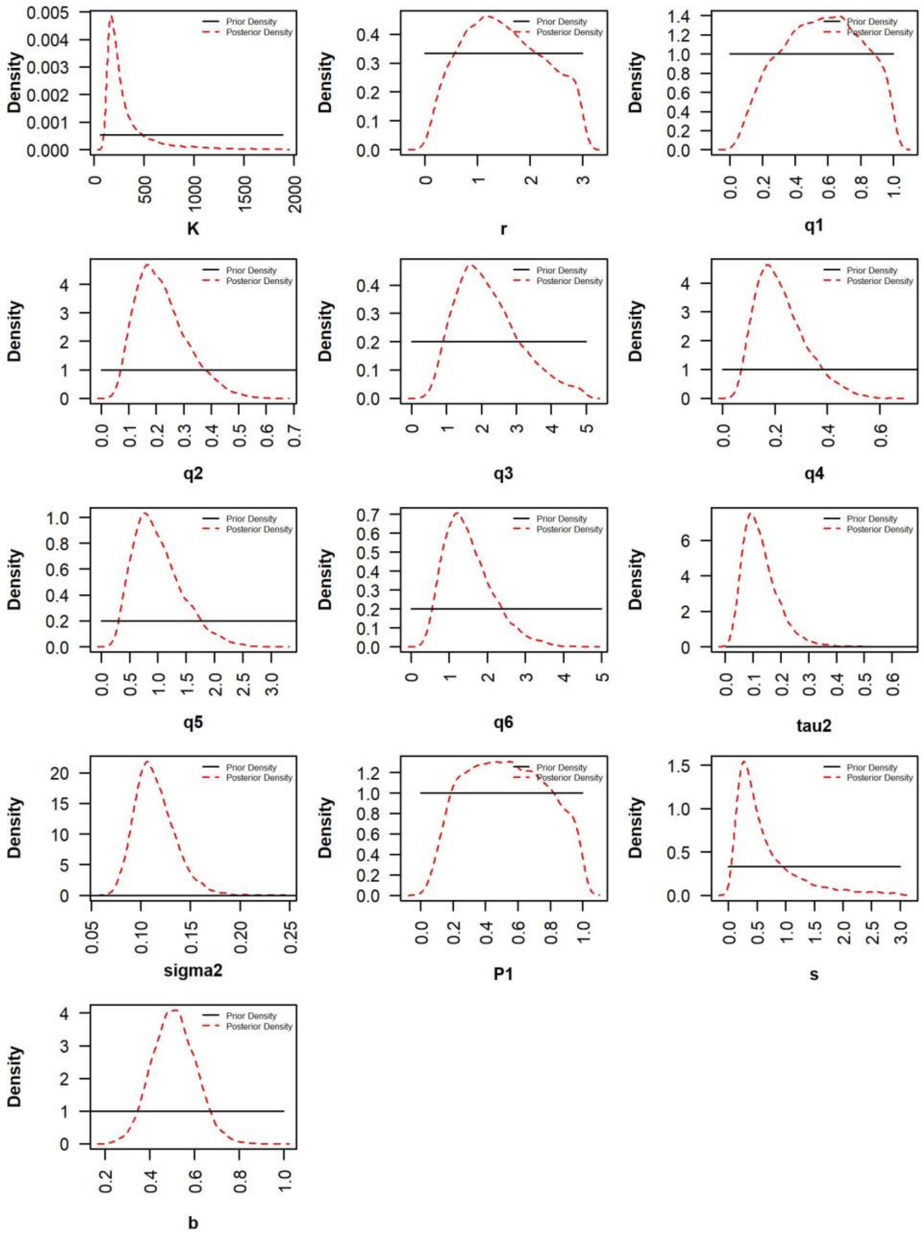


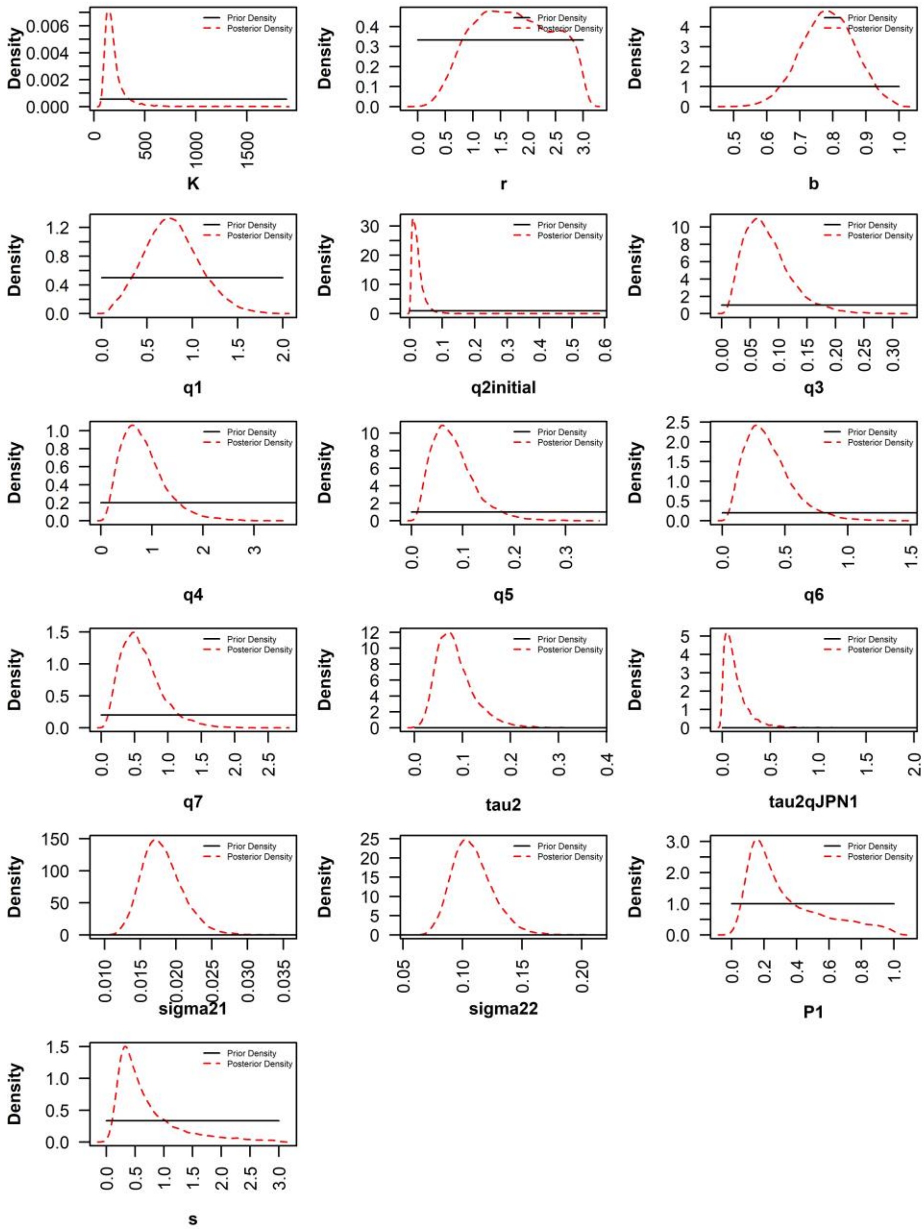
Figure 20. Median Fratio over time from each case scenario.



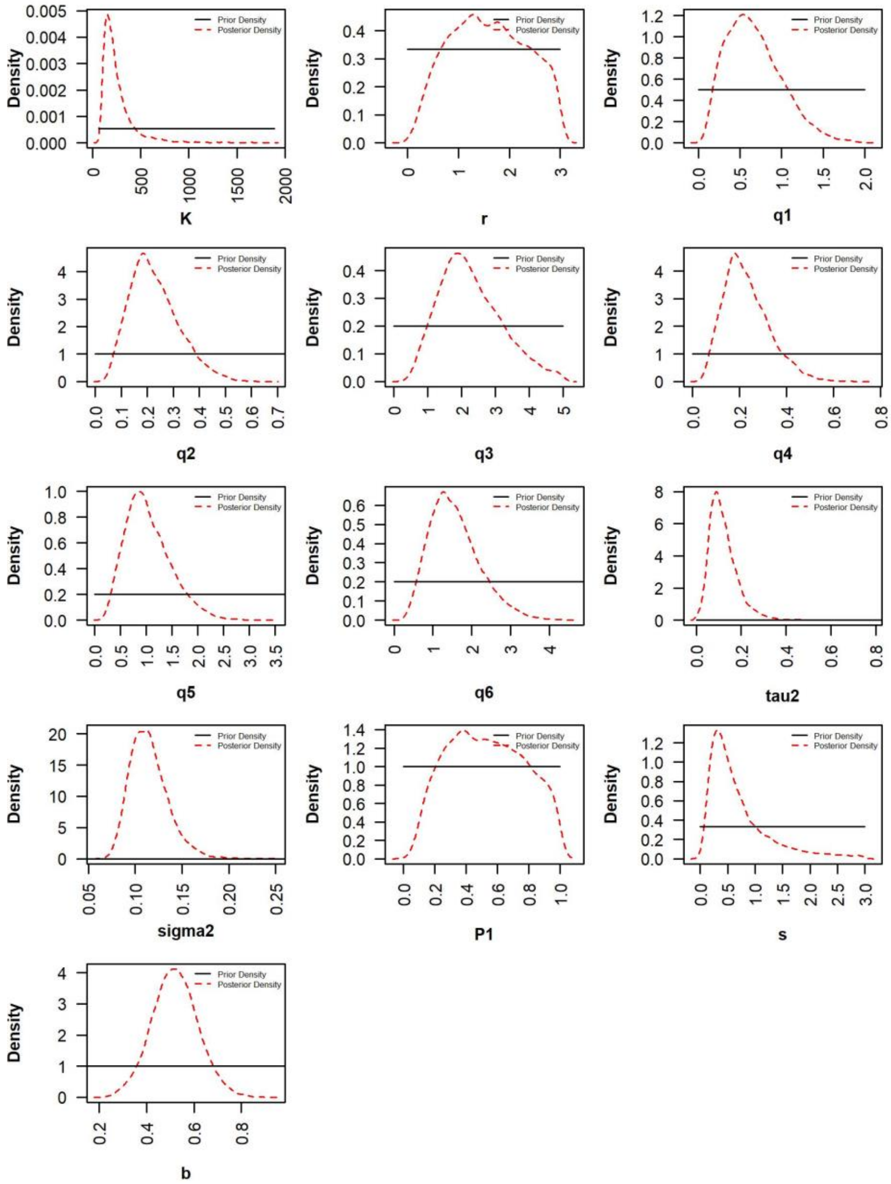
Appendix Figure 1. Prior and posterior distributions of parameters from base case scenario 1. q1 to q7 represent catchability of fishery-independent survey biomass index, Japanese early CPUE, Japanese late CPUE, Russian CPUE, Chinese Taipei CPUE, Korean CPUE, and Chinese CPUE respectively. q2initial 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.



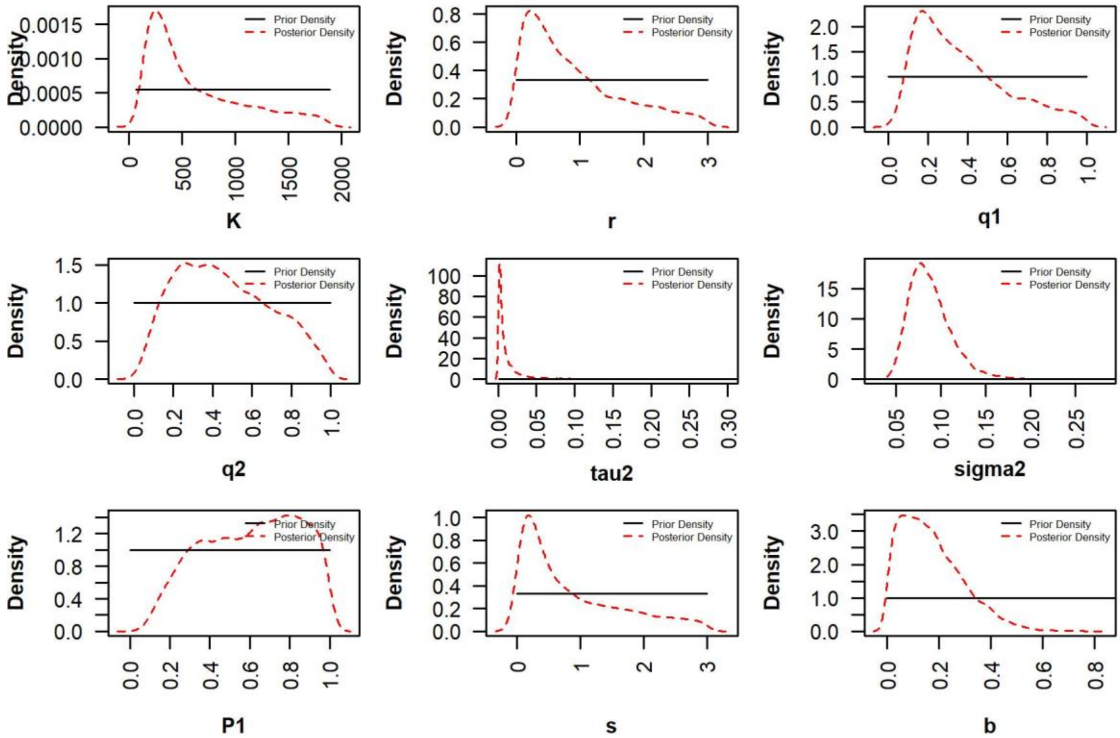
Appendix Figure 2. Prior and posterior distributions of parameters from base case scenario 2. q1 to q6 represent catchability of fishery-independent survey biomass index, Japanese late CPUE, Russian CPUE, Chinese Taipei CPUE, Korean CPUE, and Chinese CPUE respectively. tau2 represents process error variance,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



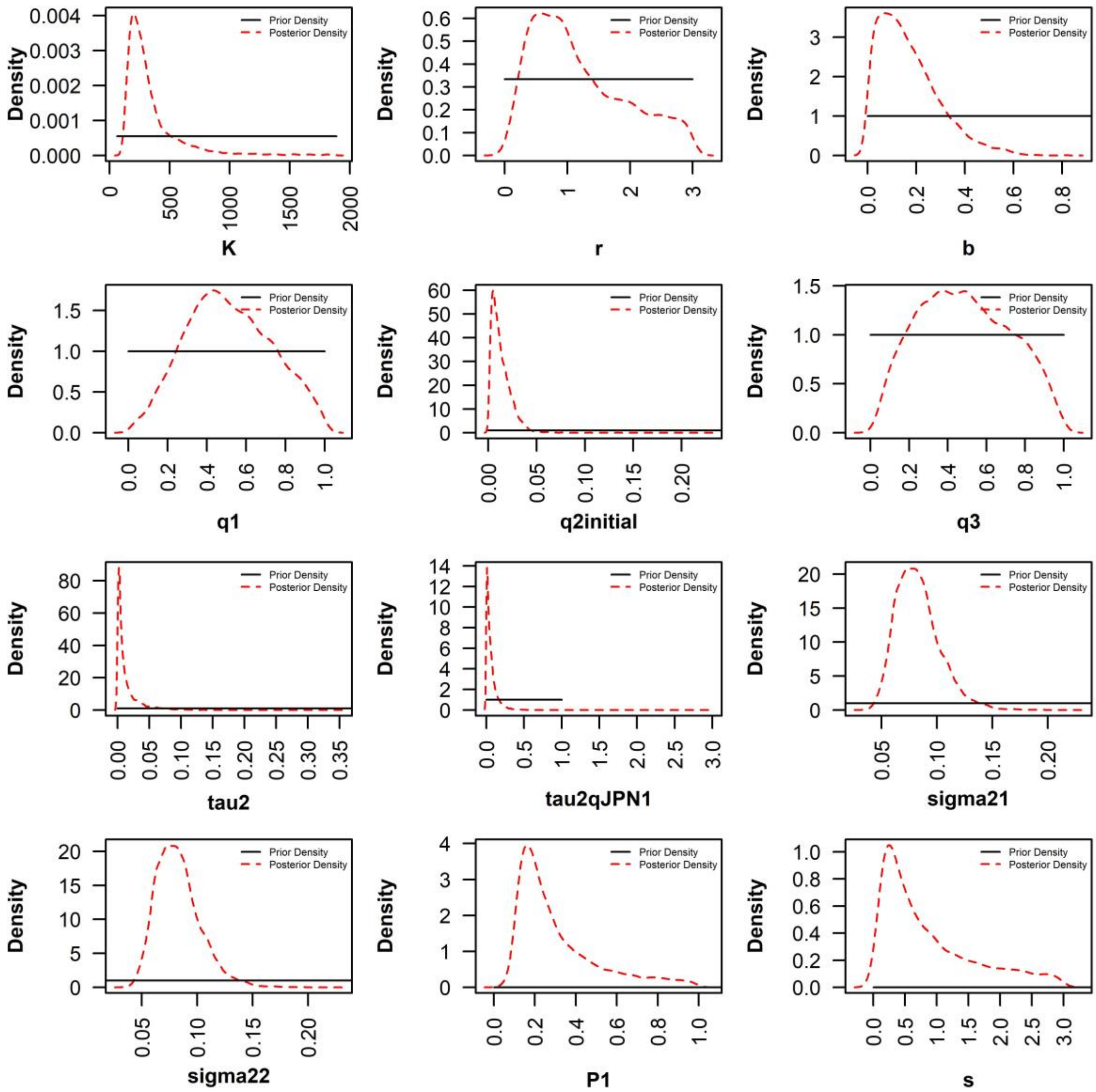
Appendix Figure 3. Prior and posterior distributions of parameters from sensitivity case scenario 1. q1 to q7 represent catchability of fishery-independent survey biomass index, Japanese early CPUE, Japanese late CPUE, Russian CPUE, Chinese Taipei CPUE, Korean CPUE, and Chinese CPUE respectively. q2initial 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.



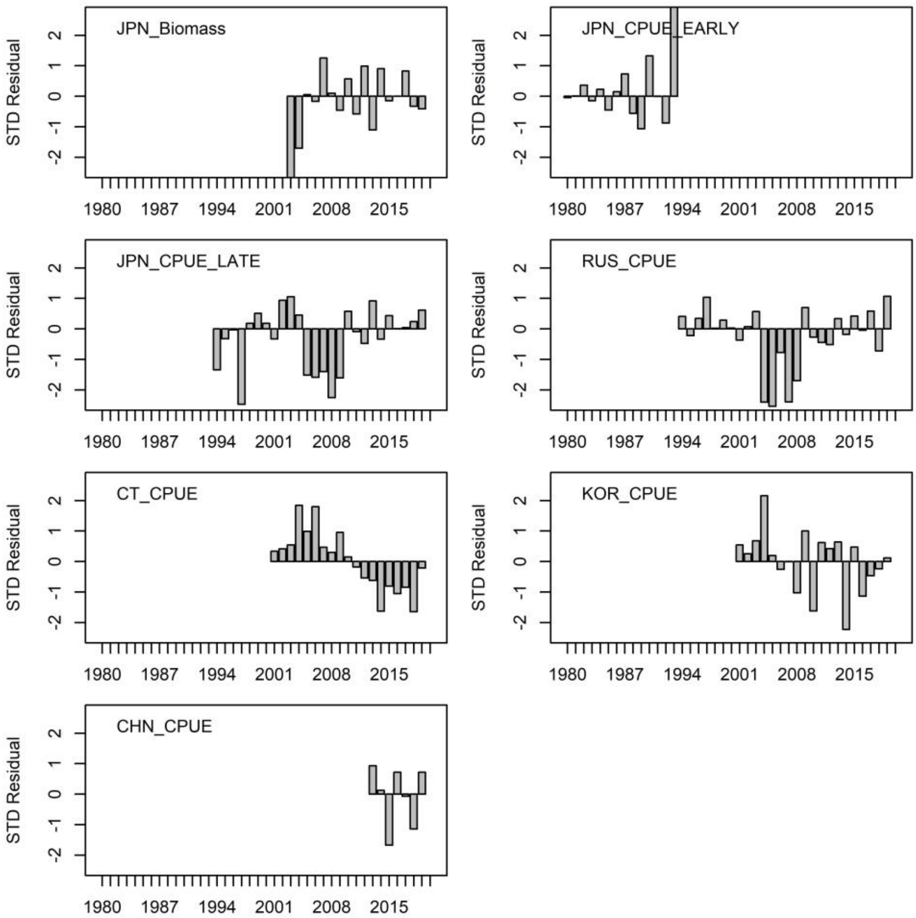
Appendix Figure 4. Prior and posterior distributions of parameters from sensitivity case scenario 2. q1 to q6 represent catchability of fishery-independent survey biomass index, Japanese late CPUE, Russian CPUE, Chinese Taipei CPUE, Korean CPUE, and Chinese CPUE respectively. tau2 represents process error variance, sigma2 represents common observation variance of CPUE. P1 represents B1980/K and s represents shape.



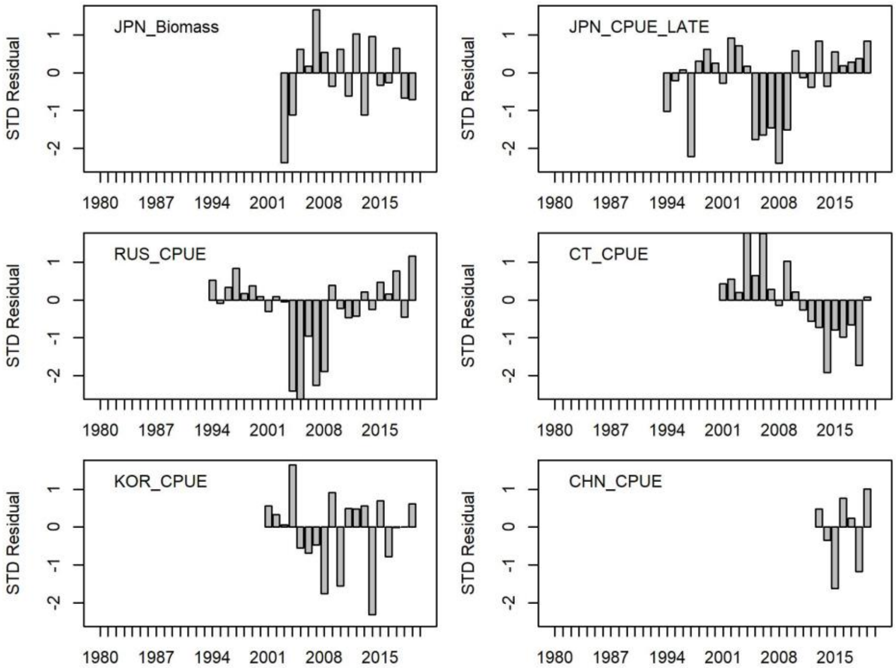
Appendix Figure 5. Prior and posterior distributions of parameters from sensitivity case scenario 3. q1 and q2 represent catchability of fishery-independent survey biomass index and joint CPUE respectively. tau2 represents process error variance, sigma2 represents common observation variance of CPUE. P1 represents B1980/K and s represents shape.



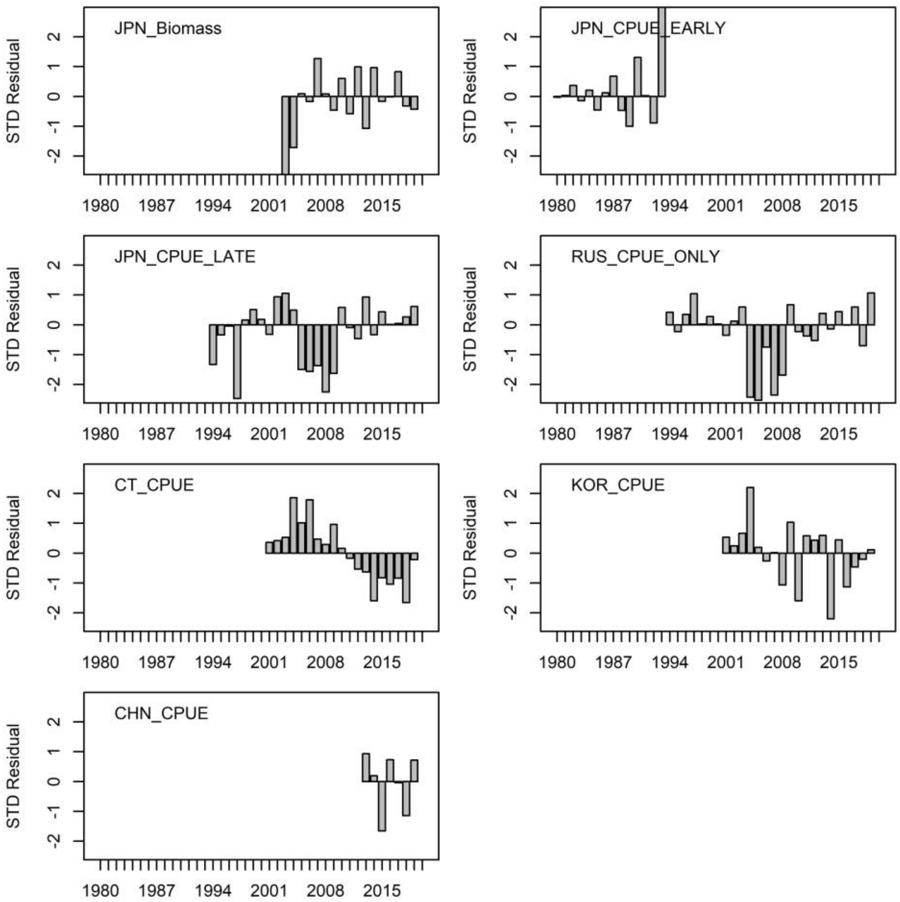
Appendix Figure 6. Prior and posterior distributions of parameters from sensitivity case scenario 4. q1 to q3 represent catchability of fishery-independent survey biomass index, Japanese early CPUE, and joint CPUE respectively. q2initial represents q1980. tau2 represents process error variance, tau2qJPN1 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.



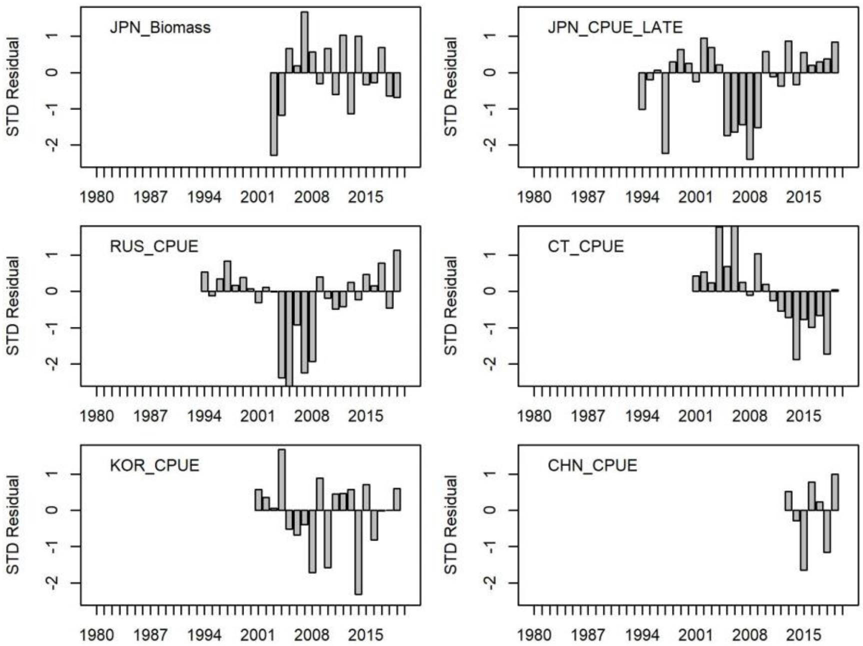
Appendix Figure 7. Standardized residuals between predicted and observed indices from base case scenario 1.



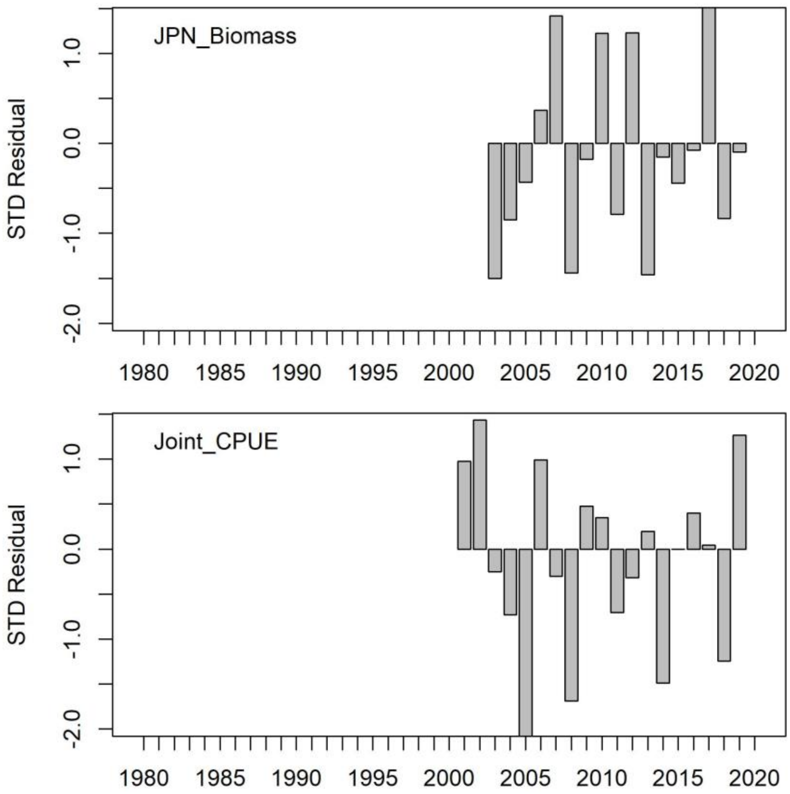
Appendix Figure 8. Standardized residuals between predicted and observed indices from base case scenario 2.



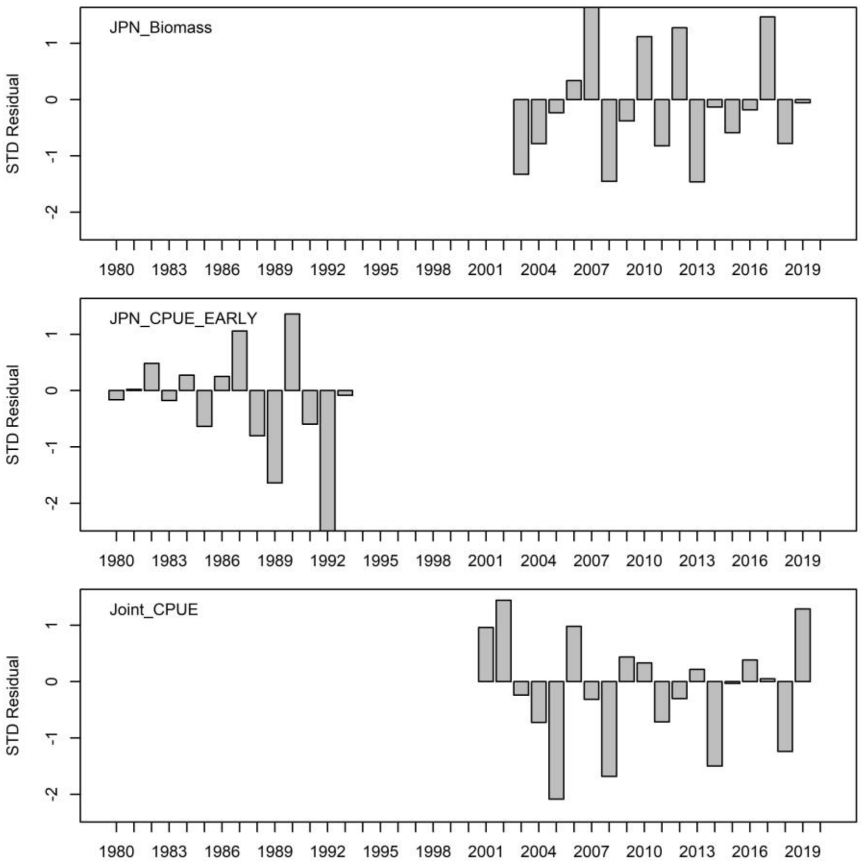
Appendix Figure 9. Standardized residuals between predicted and observed indices from sensitivity case scenario 1.



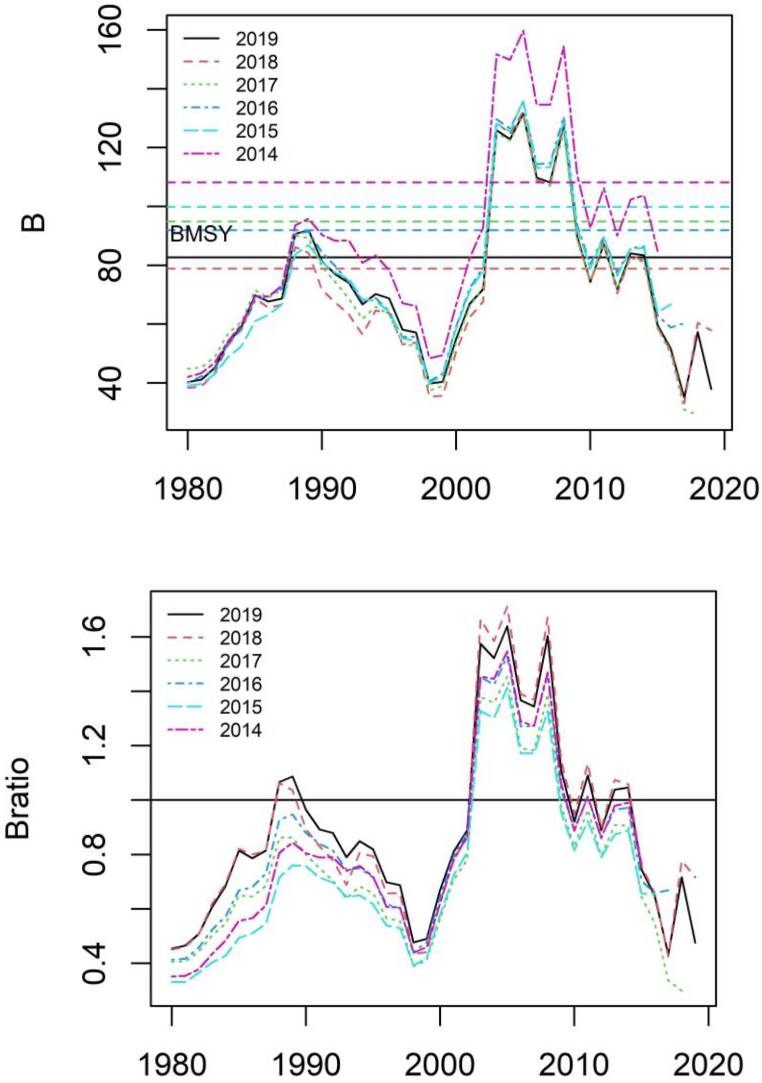
Appendix Figure 10. Standardized residuals between predicted and observed indices from sensitivity case scenario 2.



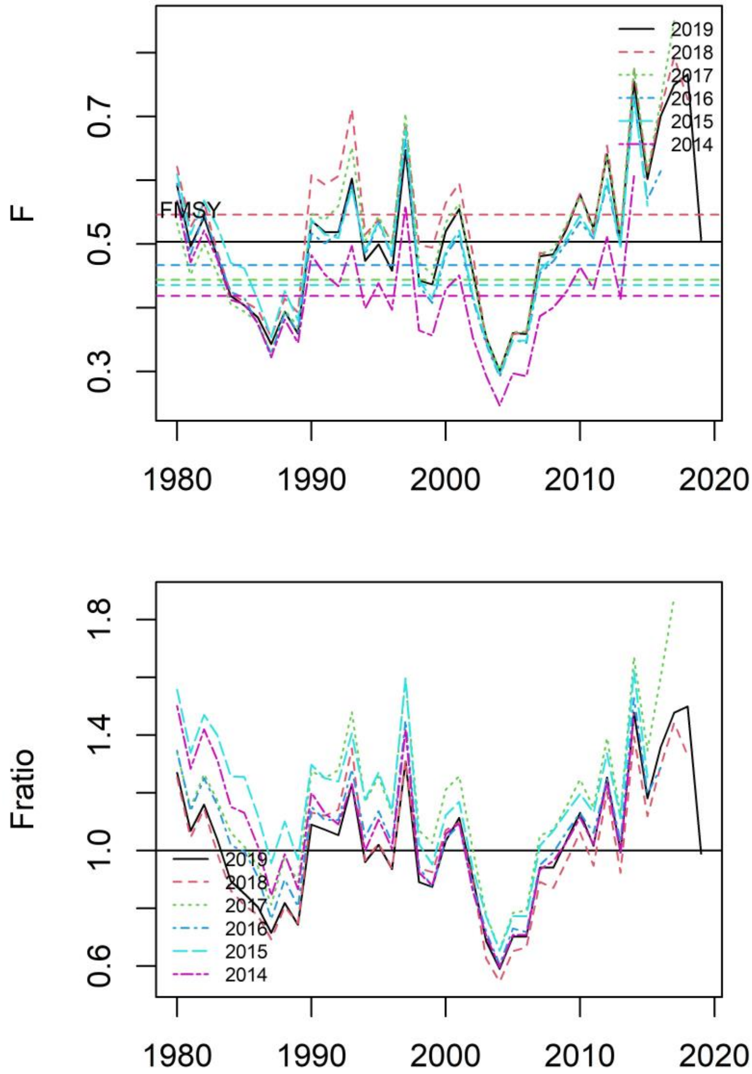
Appendix Figure 11. Standardized residuals between predicted and observed indices from sensitivity case scenario 3.



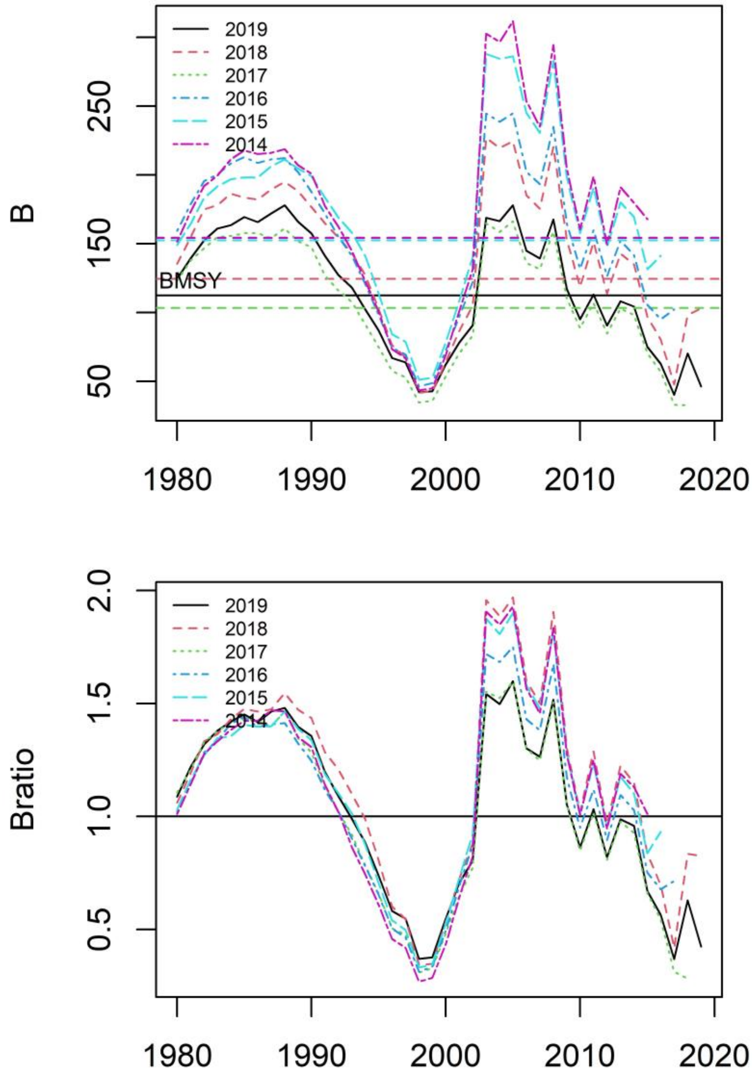
Appendix Figure 12. Standardized residuals between predicted and observed indices from sensitivity case scenario 4.



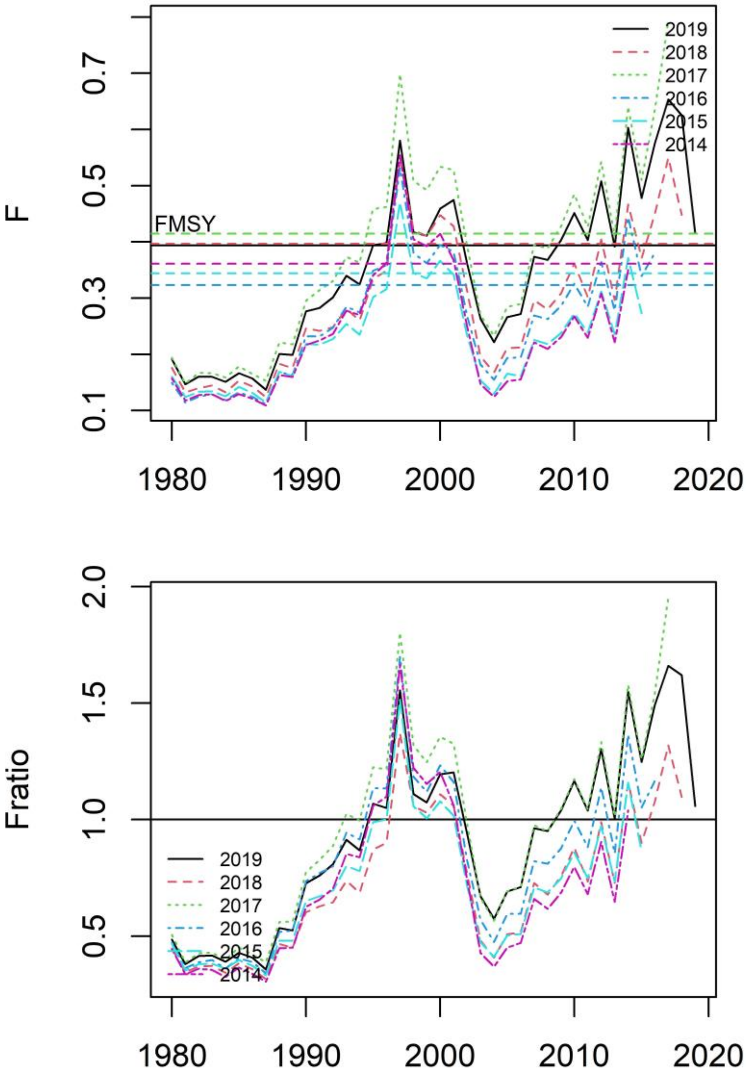
Appendix Figure 13. Time trajectories of biomass and Bratio from a retrospective analysis of base case scenario 1.



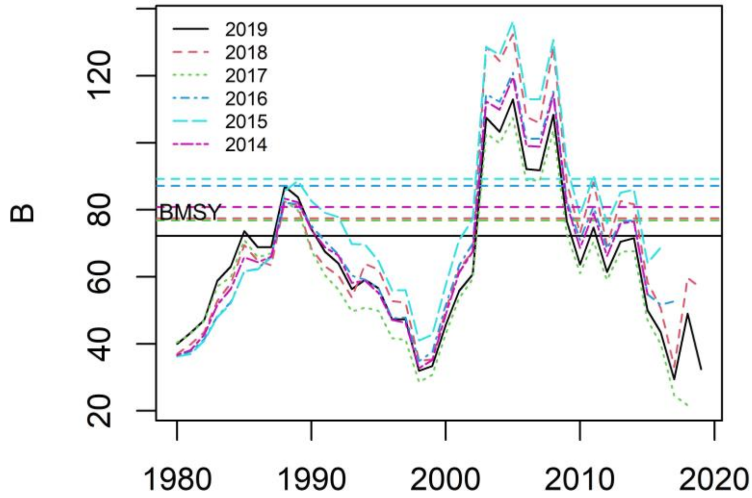
Appendix Figure 14. Time trajectories of fishing mortality and Fratio from retrospective analysis of base case scenario 1.

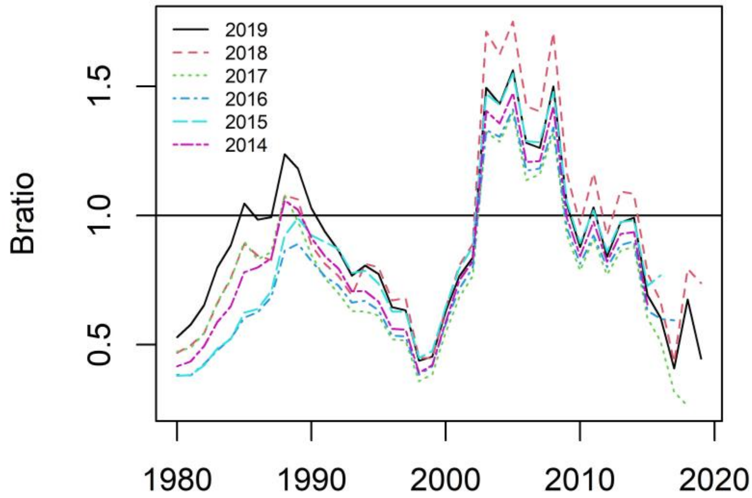


Appendix Figure 15. Time trajectories of biomass and Bratio from a retrospective analysis of base case scenario 2.

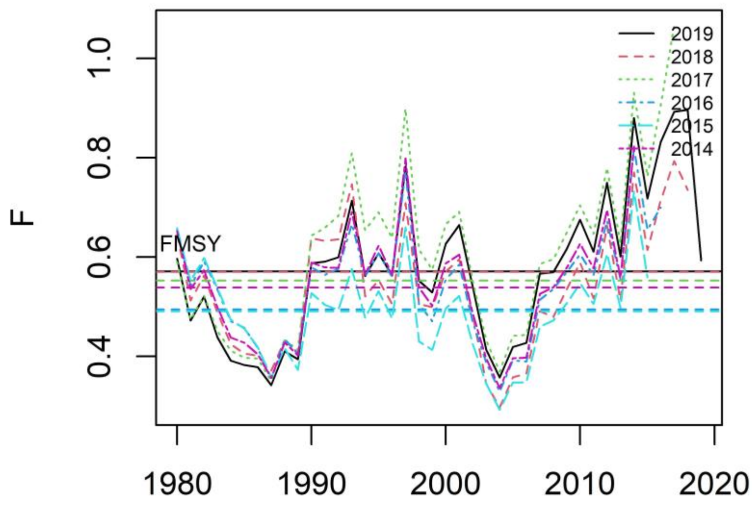


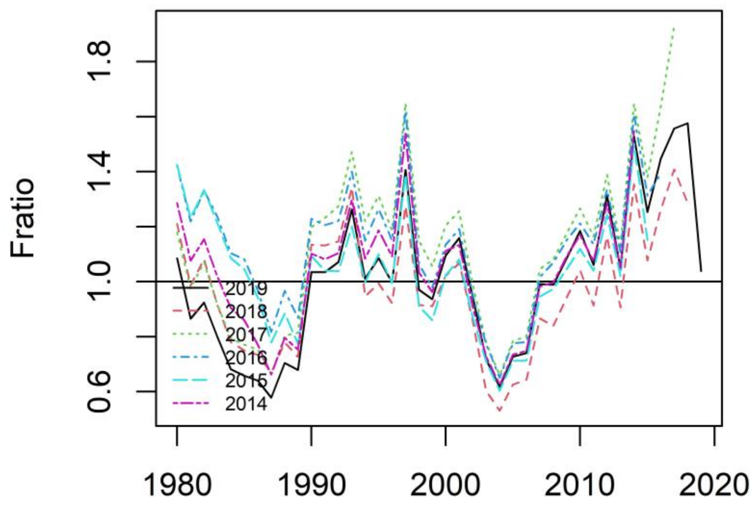
Appendix Figure 16. Time trajectories of fishing mortality and Fratio from retrospective analysis of base case scenario 2.



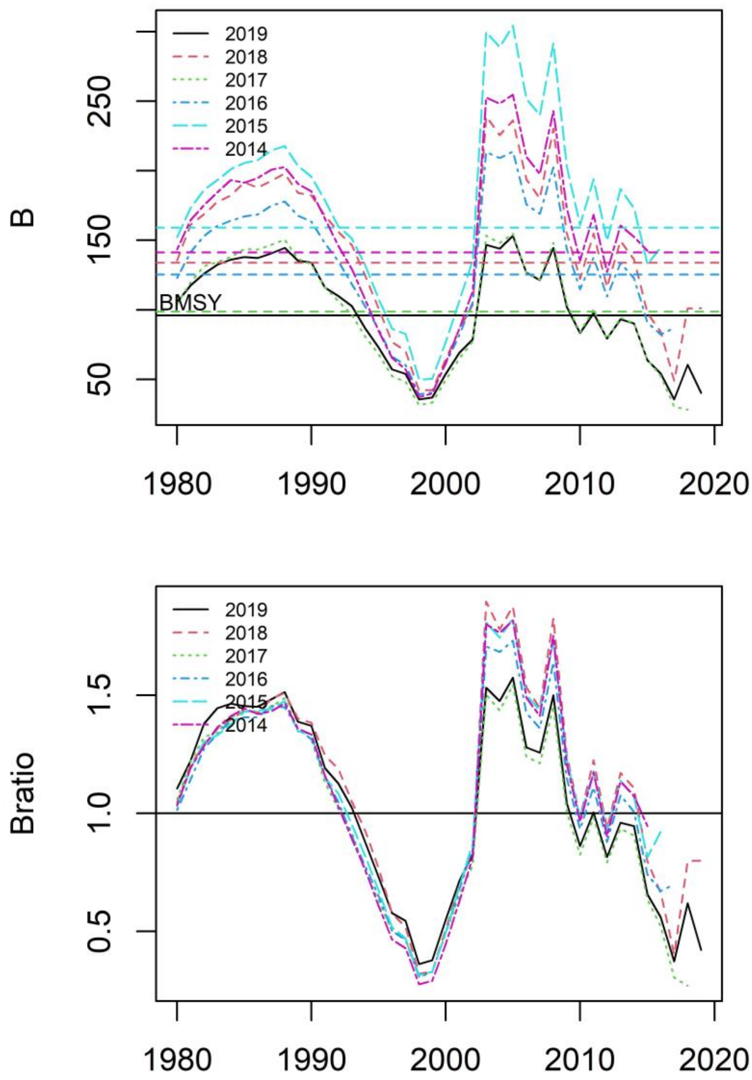


Appendix Figure 17. Time trajectories of biomass and Bratio from a retrospective analysis of sensitivity case scenario 1.

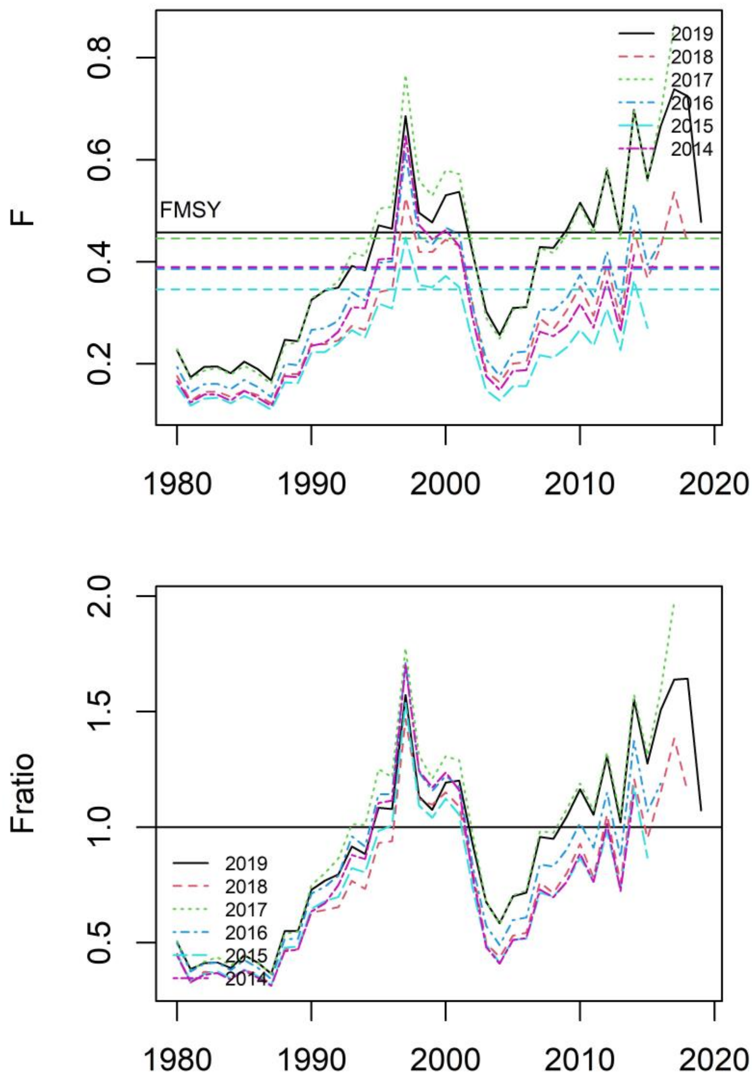




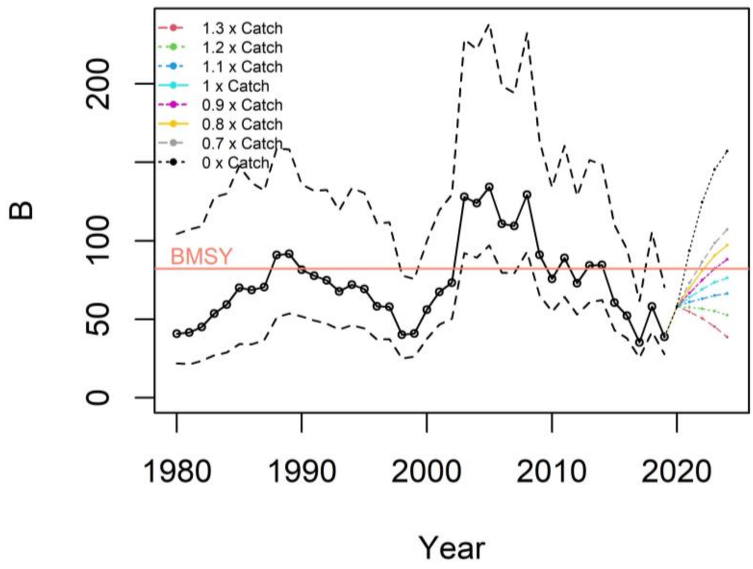
Appendix Figure 18. Time trajectories of fishing mortality and Fratio from retrospective analysis of sensitivity case scenario 1.



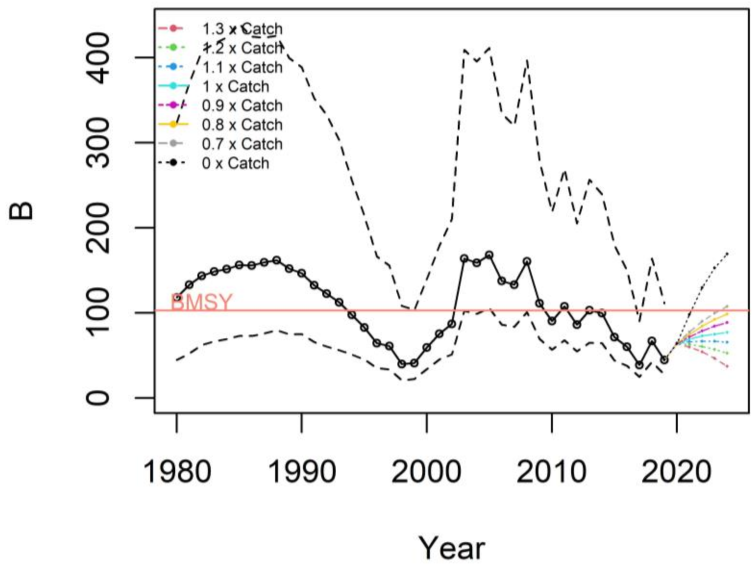
Appendix Figure 19. Time trajectories of biomass and Bratio from a retrospective analysis of sensitivity case scenario 2.



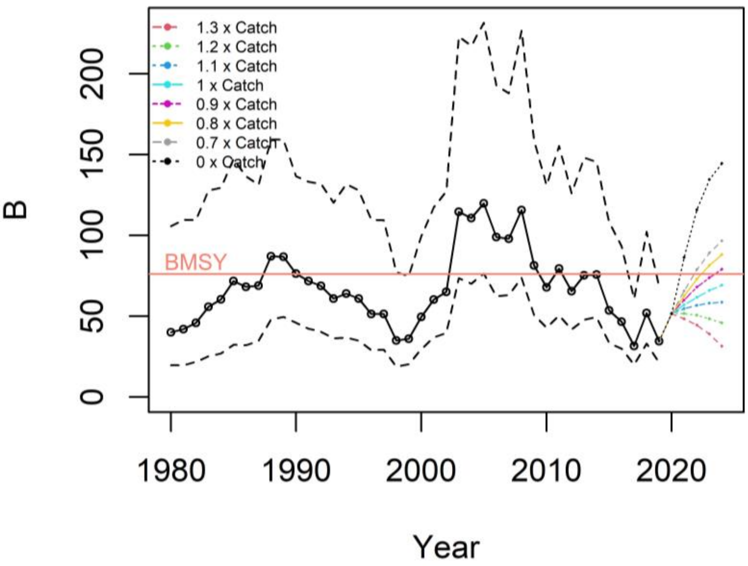
Appendix Figure 20. Time trajectories of fishing mortality and Fratio from retrospective analysis of sensitivity case scenario 2.



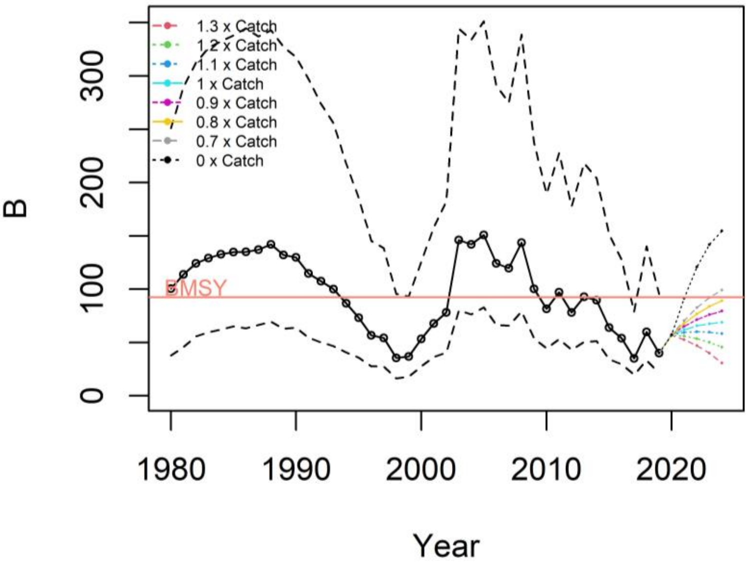
Appendix Figure 21. Biomass projection from base case scenario 1.



Appendix Figure 22. Biomass projection from base case scenario 2.



Appendix Figure 23. Biomass projection from sensitivity case scenario 1.



Appendix Figure 24. Biomass projection from sensitivity case scenario 2.