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2021 updates on Pacific saury stock assessment in the North Pacific Ocean using Bayesian state-space production models

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SUMMARY

Stock assessment for the North Pacific saury was updated based on the specification (2 base cases and 2 sensitivity cases) agreed in the 7th SSC-PS meeting held in October 2020. The basic model employed in the analysis was the state-space surplus production model as has been used since the SSC-PS01 as an interim stock assessment model. The model can account for process and observation errors in the abundance indices. Parameters in the models were estimated based on Bayesian framework with a Markov chain Monte Carlo method. The estimation results were diagnosed with respect to shapes of posterior distributions, residual plots, retrospective pattern and predictability of the future population status. The outcomes of stock status and future projection were shown according to the template agreed in the 5th SSC-PS meeting with some modifications to accommodate the data period.

As for the combined base case stock assessment result, the 2021 median depletion level was only 19.5% (80%CI=10.8-31.4%) of the carrying capacity. Furthermore, B-ratio (=B/Bmsy) and F-ratio (=F/Fmsy) in 2020 were 0.339 (80%CI=0.212-0.526) and 1.033 (80%CI=0.641-1.625), respectively. For those three years average values, B-ratio over 2019-2021 and F-ratio over 2018-2020 were respectively 0.378 (80%CI=0.238-0.574) and 1.480 (80%CI=0.973-2.187). In addition, the probability of the stock being in the green Kobe quadrant in 2020 was estimated to be nearly 0%, while the probability of being in the red Kobe quadrant was assessed to be greater than 50%. On the weight-of-evidence available now, the current Pacific saury stock is determined to be overfished and subject to overfishing.

For population outlook, population dynamics were projected for some scenarios with respect to several levels of reduction/increase of catch as well as status quo. The results showed that increased catch compared to the current level may cause a severe decline in the population size.

INTRODUCTION

The Pacific saury is one of the commercially valuable species in the North Pacific, and the North Pacific Fishery Commission (NPFC hereafter) has been the responsible organization for the management of this species since its establishment. The Small Scientific Committee for Pacific saury (SSC-PS) was established under the Scientific Committee (SC) to undertake stock assessment of the Pacific saury.

In the 7th SSC-PS meeting held in October 2021, the new specification for the BSSPM analysis (2 base cases and 2 sensitivity cases, see Table 1) was agreed. Here, we will report on our updated stock assessment based on the specification with additionally available 2019 fishery-dependent indices.

Table 1. Specification of the new stock assessment specification for the BSSPM (extracted from SSC-PS07 report).

	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) $I_{t,joint} = q_{joint} B_t^b e^{v_{t,joint}}$ $v_{t,joint} \sim N(0, \sigma_{joint}^2)$ $\sigma_{joint}^2 = c \cdot (ave(cv_t^2) + \sigma_{bio}^2)$, where $ave(cv_t^2)$ is computed except for 2020 survey	Joint CPUE (2001-2020)
Variance component	Variances of logCPUEs are assumed to be common and 6 times of that of log biomass (c = 6)	Variances of logCPUEs are assumed to be common and 5 times of that of 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, $b \sim U(0, 1)$ [b for JPN_early is fixed at 1]	A common parameter for all fisheries with a prior distribution, $b \sim U(0, 1)$	$b \sim U$ (0, 1)	$b \sim U$ (0, 1)
Prior for other than q_{bio}	Own preferred options	Own preferred options	Own preferred options	Own preferred options

MATERIALS AND METHODS

Data set

1) time series of total reported catch up to 2020

2) standardized CPUE indices by the following five Members up to 2020

3) fishery-independent survey by Japan from 2003 to 2021

4) joint CPUE from 2001 to 2020

Specification of analysis

We basically used the similar statistical models as Chiba and Kitakado (2019) with some amendment by following the PS07 specification described above. Main differences from the models of China and Chinese Taipei were the assumption for the time-varying catchability for the Japanese early CPUE,

$$q_{t,JPN1} = q_{1980,JPN1} + \delta \cdot \frac{1}{1 + e^{\alpha(\beta - t)}}$$

and the prior distributions for the free parameters as follows:

$$\begin{array}{lll} r \sim U(0.01,3), & K \sim U(0.0001,10), & D1 \sim U(0.01,1), \\ z \sim U(0.01,2), & \tau \sim U(0.01,2), & \sigma_{biomass} \sim U(0.01,1), \\ q_{1980,JPN1} \sim U(0.0001,3), & q_{CHN} \sim U(0.0001,100), & q_{KOR} \sim U(0.0001,100), \\ q_{RUS} \sim U(0.0001,100), & q_{CT} \sim U(0.0001,100), & b \sim U(0,1), \\ \alpha \sim U(0.0001,10), & \beta \sim U(1980,1994), & \delta \sim U(0.0001,3) \end{array}$$

RESULTS

Diagnosis

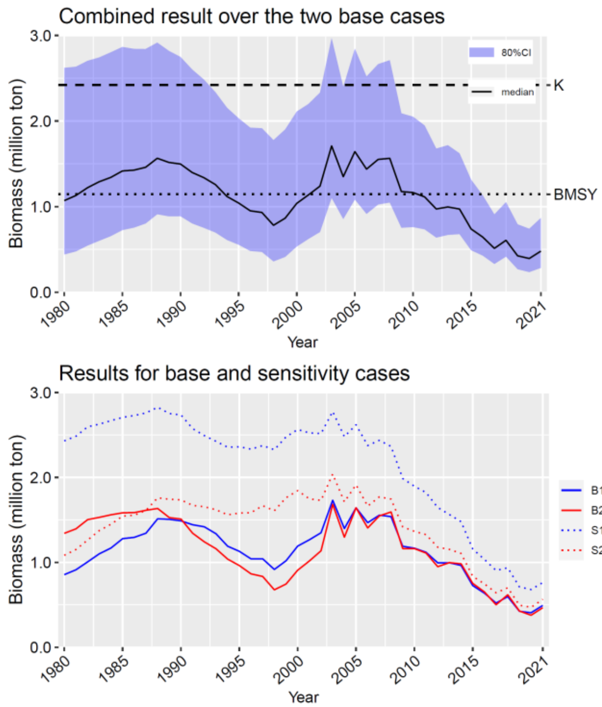
In terms of parameter estimation, shapes of posterior distributions were generally good (see Appendix, Section 6). The results of fitting showed that the estimated population dynamics fitted well to some CPUE series and the biomass indices by Japanese survey (Appendix, Section 9.1).

Time series and stock status

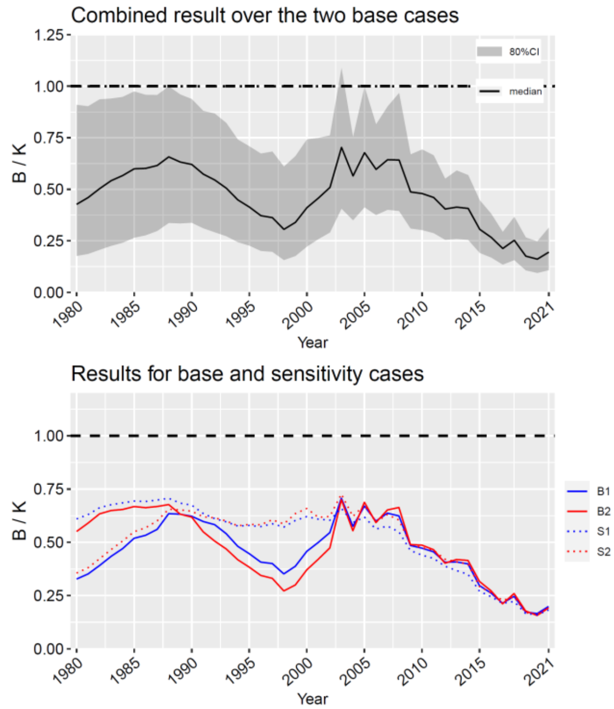
Figure 2 shows the trajectories of biomass, B- and F-ratios and depletion level relative to the carrying capacity over the two base cases (further information including the series of harvest rate is available in Appendix). The result indicated that, although there were long-term fluctuations and interannual variability in the biomass, the stock declined from high abundance period in 2003-2008 to current low levels. The exploitation rates were increasing slowly in 2000's and remained high since 2010.

Table 2 also shows the results of key reference quantities combined over the two base cases. As for the combined base case stock assessment result, the 2021 median depletion level was only 19.5% (80%CI=10.8-31.4%) of the carrying capacity. Furthermore, B-ratio (=B/Bmsy) and F-ratio (=F/Fmsy) in 2020 were 0.339 (80%CI=0.212-0.526) and 1.033 (80%CI=0.641-1.625), respectively. For those three years average values, B-ratio over 2019-2021 and F-ratio over 2018-2020 were respectively 0.378 (80%CI=0.238-0.574) and 1.480 (80%CI=0.973-2.187).

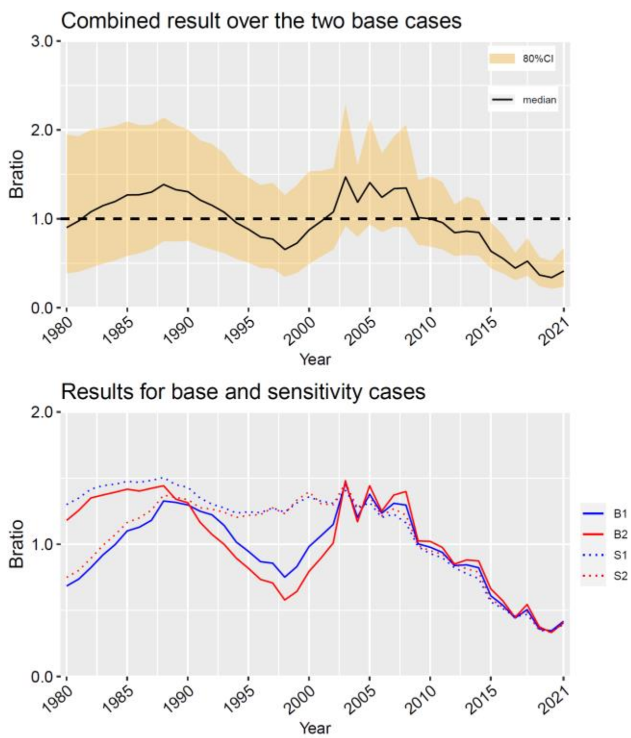
(a) Biomass



(b) Depletion level relative to K



(c) B-ratio



(d) F-ratio

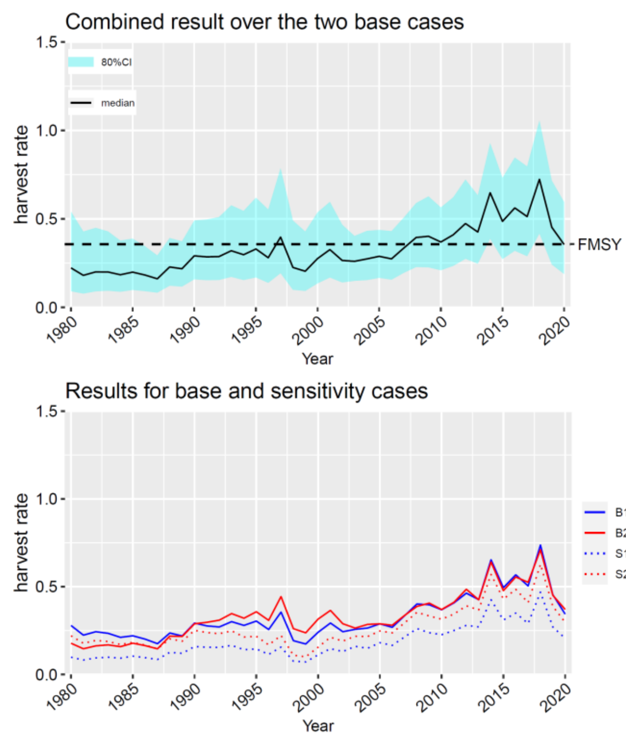


Figure 2. Results of trajectories over the two base cases of (a) biomass, (b) depletion level relative to the carrying capacity, (c) B-ratio and (d) F-ratio.

Table 2. Estimates of key reference quantities combined over the two base cases.

	Mean	Median	Lower10th	Upper10th
C_2020	0.140	0.140	0.140	0.140
AveC_2018_2020	0.257	0.257	0.257	0.257
AveF_2018_2020	0.526	0.515	0.290	0.775
F_2020	0.378	0.355	0.188	0.595
FMSY	0.368	0.357	0.179	0.563
MSY (million ton)	0.415	0.405	0.339	0.498
F_2020/FMSY	1.097	1.033	0.641	1.625
AveF_2018_2020/FMSY	1.543	1.480	0.973	2.187
K (million ton)	2.915	2.421	1.548	4.949
B_2020 (million ton)	0.455	0.393	0.235	0.742
B_2021 (million ton)	0.545	0.480	0.284	0.868
AveB_2019_2021	0.498	0.433	0.274	0.792
BMSY (million ton)	1.336	1.144	0.751	2.189
BMSY/K	0.469	0.463	0.398	0.552
B_2020/K	0.168	0.161	0.094	0.248
B_2021/K	0.205	0.195	0.108	0.314
AveB_2019_2021/K	0.185	0.179	0.106	0.269
B_2020/BMSY	0.358	0.339	0.212	0.526
B_2021/BMSY	0.440	0.412	0.238	0.673
AveB_2019_2021/BMSY	0.396	0.378	0.238	0.574

Evidently, Figure 3, which is the Kobe plot with time series of median B-ratio and F-ratio for 1980-2019, also shows that the probability of the stock being in the green Kobe quadrant in 2020 was estimated to be nearly 0%, while the probability of being in the red Kobe quadrant was assessed to be greater than 50%. On the weight-of-evidence available now, the current Pacific saury stock is determined to be overfished and subject to overfishing.

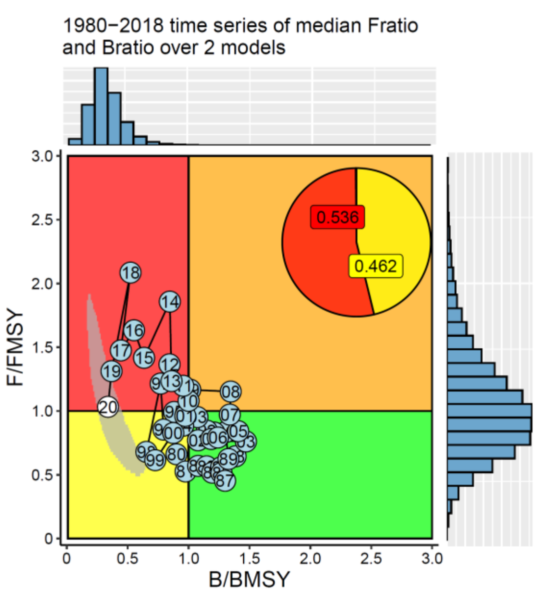


Figure 3. Kobe plot with time series of median B-ratio and F-ratio for 1980-2020.

Future projection and risk analysis

Figure 4 shows the median of biomass trajectory with future projection for different catch levels in 2021-2025 relative to the average catch over 2018-2020. Table 3 is the risk table associated with the projection. The result shows that continuation of the current level would make the probability of Kobe red quadrant remain high while catch reductions are expected to contribute to the recovery of population status.

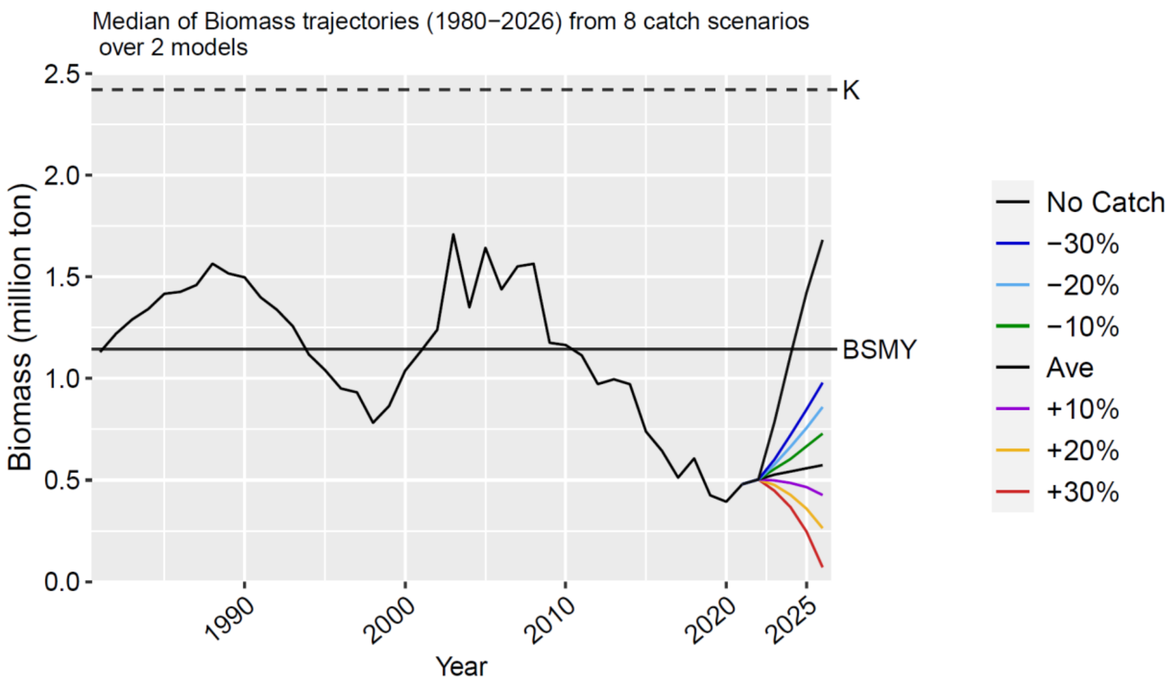


Figure 4. Median of biomass trajectory with future projection under the 8 different catch scenarios.

Table 3. Risk table for different catch levels over next 5 five years relative to 2018-2020 average catch.

	Red	Orange	Yellow	Green	B<BMSY	F>FMSY
+30%	0.784	0.001	0.053	0.162	0.837	0.785
+20%	0.725	0.000	0.080	0.194	0.806	0.726
+10%	0.662	0.000	0.108	0.229	0.771	0.663
±0%	0.587	0.000	0.139	0.274	0.726	0.588
-10%	0.495	0.000	0.181	0.323	0.677	0.495
-20%	0.406	0.000	0.227	0.366	0.634	0.406
-30%	0.315	0.000	0.266	0.419	0.581	0.315
No Catch	0.000	0.000	0.254	0.746	0.254	0.000

Conclusion

1) Biomass level: the 2021 median depletion level was only 19.5% (80%CI=10.8-31.4%) of the carrying capacity, declined from 30.7% (80%CI=20.0-42.0%) in 2018.

2) Reference points: B-ratio (=B/Bmsy) and F-ratio (=F/Fmsy) in 2020 were 0.339 (80%CI=0.212-0.526) and 1.033 (80%CI=0.641-1.625), respectively. For those three years average values, B-ratio over 2019-2021 and F-ratio over 2018-2020 were respectively 0.378 (80%CI=0.238-0.574) and 1.480 (80%CI=0.973-2.187).

3) The probability of the stock being in the green Kobe quadrant in 2020 was estimated to be nearly 0%, while the probability of being in the red Kobe quadrant was assessed to be greater than 50%.

4) On the weight-of-evidence available now, the current Pacific saury stock is determined to be overfished and subject to overfishing.

5) For population outlook, population dynamics were projected for some scenarios with respect to several levels of reduction/increase of catch as well as status quo. The results showed that increased catch compared to the current level may cause a severe decline in the population size.

6) The MSY was estimated around 405,000 tons (80%CI=339,000-498,000), which is greater than the current catch level. However, the current biomass level is markedly low as 480,000 tons (80%CI=284,000-868,000), and therefore the MSY is not an appropriate level of catch; rather, if applying the same formula used in TAC calculation in 2019, it should be X=B2021*Fmsy=480,000*0.357=171,000 (tons).

References

Chiba, N. and T. Kitakado (2019) Outcomes of the stock assessment for the Pacific saury - 2019 update with the BSSPM-. NPFC-2019-TWG PSSA04-WP10 (Rev. 1).

NPFC (2019) Report of the SSC-PS05.

NPFC (2020) Report of the SSC-PS06.

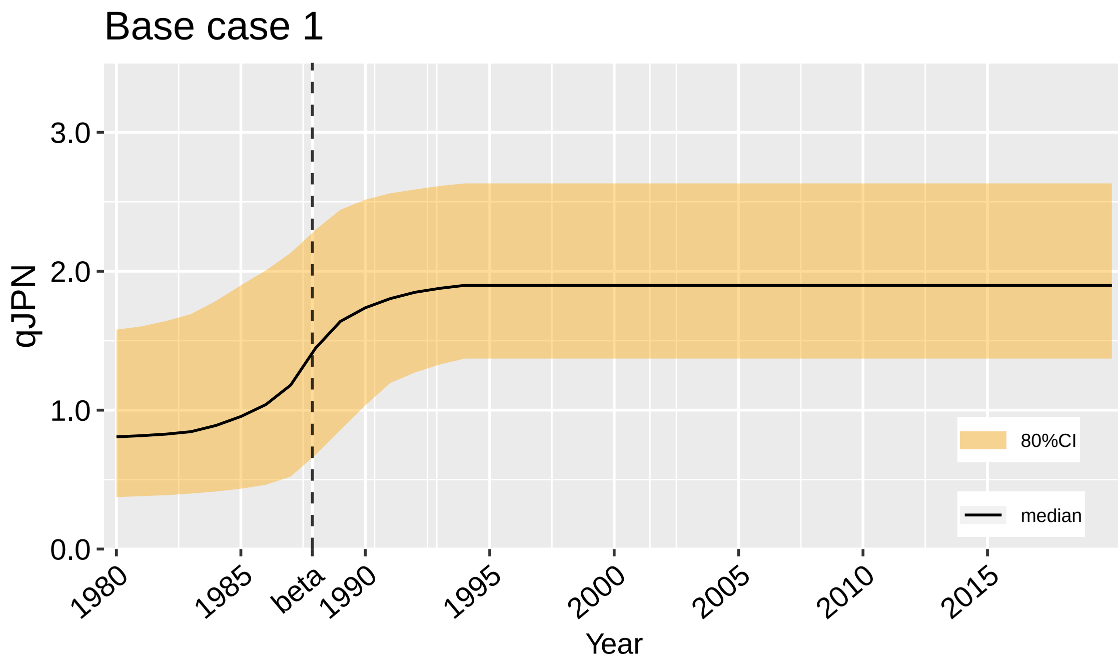
NPFC (2021) Report of the SSC-PS07.

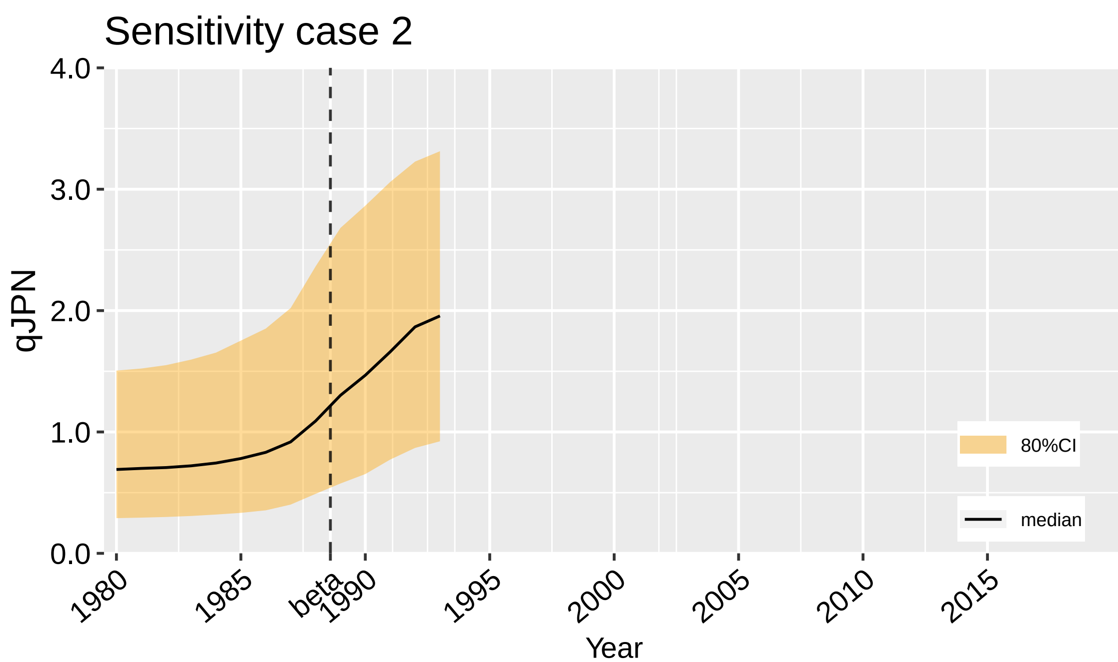
Item	Authors' note
(1) Identify the data that will be available to the stock assessment;	As shown in the main section.
(2) Evaluate data quality and quantity and potential error sources (e.g., sampling errors, measurement errors) and associated statistical properties (e.g., biased or random errors, statistical distribution) to ensure that the best available information is used in the assessment;	No errors in catch data. All abundance indices have estimation errors.
(3) Select population models describing the dynamics of PS stock and observational models linking population variables with the observed variables;	Biomass dynamics models with process & observation errors (see Chiba and Kitakado 2019)
(4) Develop base case scenarios and alternative scenarios for sensitivity analyses;	See SSC-PS07 report and table in this document.
(5) Compile input data and prior distributions for the model parameterization for the base case and alternative scenarios;	See SSC-PS07 report and table in this document.
(6) For each scenario, fit the model to the data, diagnostics of model convergence, plot and evaluate residual patterns, compare prior and posterior distributions for key model parameters, and evaluate biological implications of the estimated parameters;	See Appendix
(7) Develop retrospective analysis to verify whether any possible systematic inconsistencies exist among model estimates of biomass and fishing mortality	See Appendix
(8) Identify final model configuration and model runs for each scenario;	See SSC-PS07 report and table in this document
(9) For each scenario, estimate and plot exploitable stock biomass and fishing mortality (and their relevant credibility distributions) over time;	See Appendix
(10) For each scenario, estimate biological reference points (e.g., MSY, Bmsy, Fmsy) and its associated uncertainty;	See the main text and Appendix
(11) Identify target and limit reference points for stock biomass and fishing mortality;	Should be discussed during the meeting
(12) Have the Kobe plot for each scenario;	See the main text and Appendix
(13) Determine if the stock is "overfished" and "overfishing" occurs for the base and sensitivity scenarios;	See summary
(14) Finalize the base-case scenario;	Has been finalized in the SSC-PS07
(15) Develop alternative ABCs for the projection (e.g., 5-year projection);	See Appendix for the relevant information
(16) Conduct risk analysis for each level of ABC defined in the base-case scenario;	See Appendix for the relevant information
(17) Develop decision tables with alternative state of nature;	See Appendix for the relevant information
(18) Determine optimal ABCs based on decision tables developed in Step (17);	See Appendix for the relevant information
(19) Provide scientific advice on stock status and appropriate catch level to SC through SSC PS.	To be discussed during this meeting

Appendix:

Contents

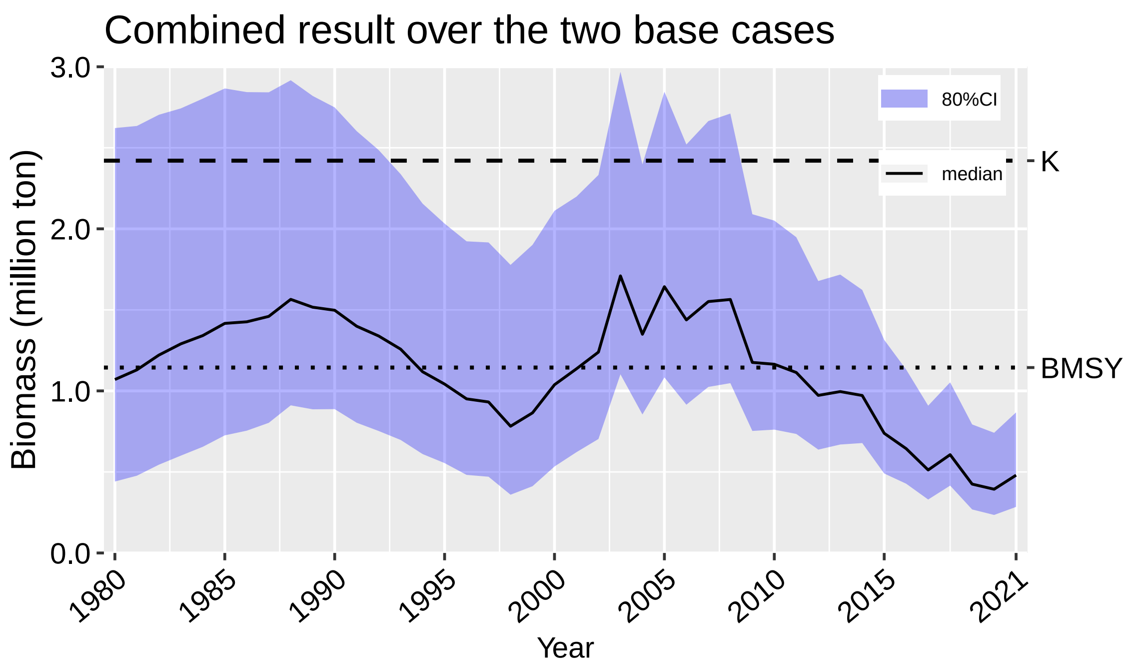
1 Estimated time-varying catchability

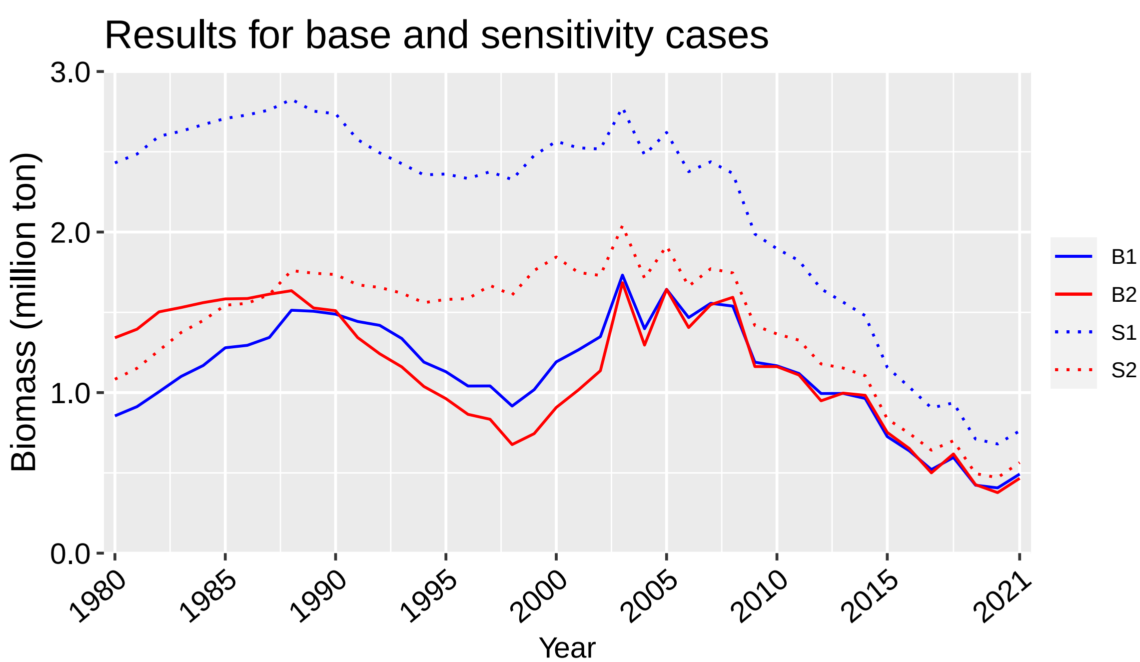




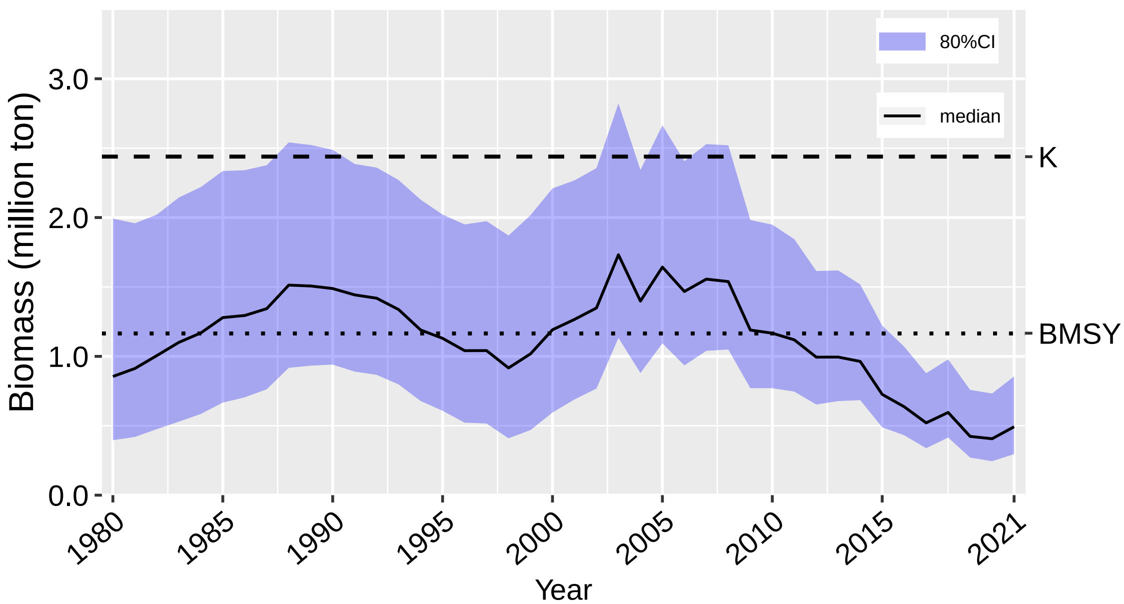
2 Time series plot

2.1 Time series Biomass





Base case 1



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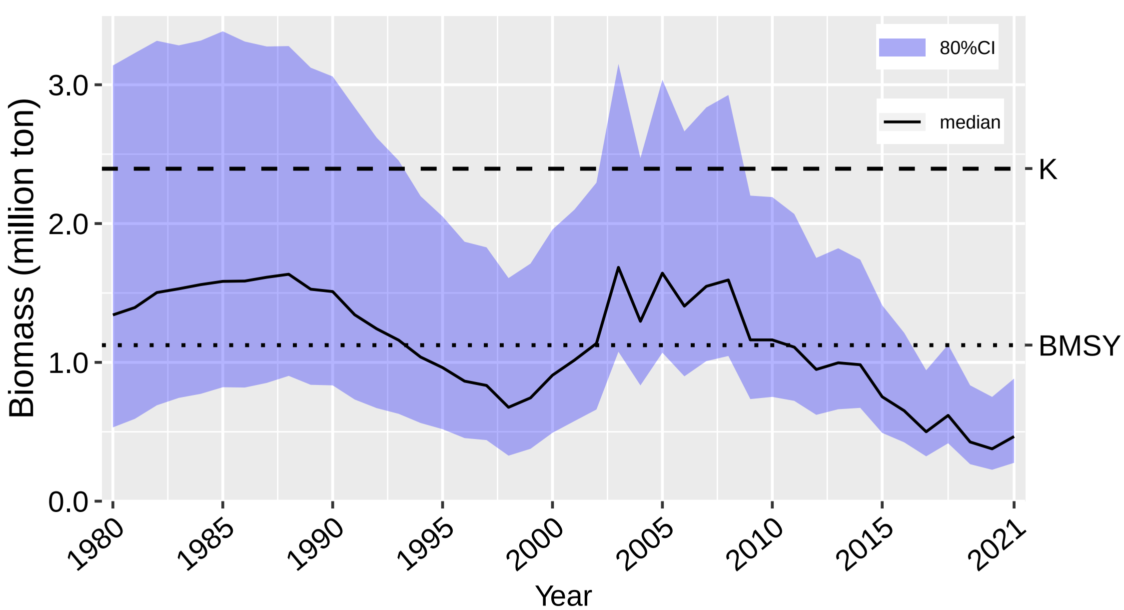

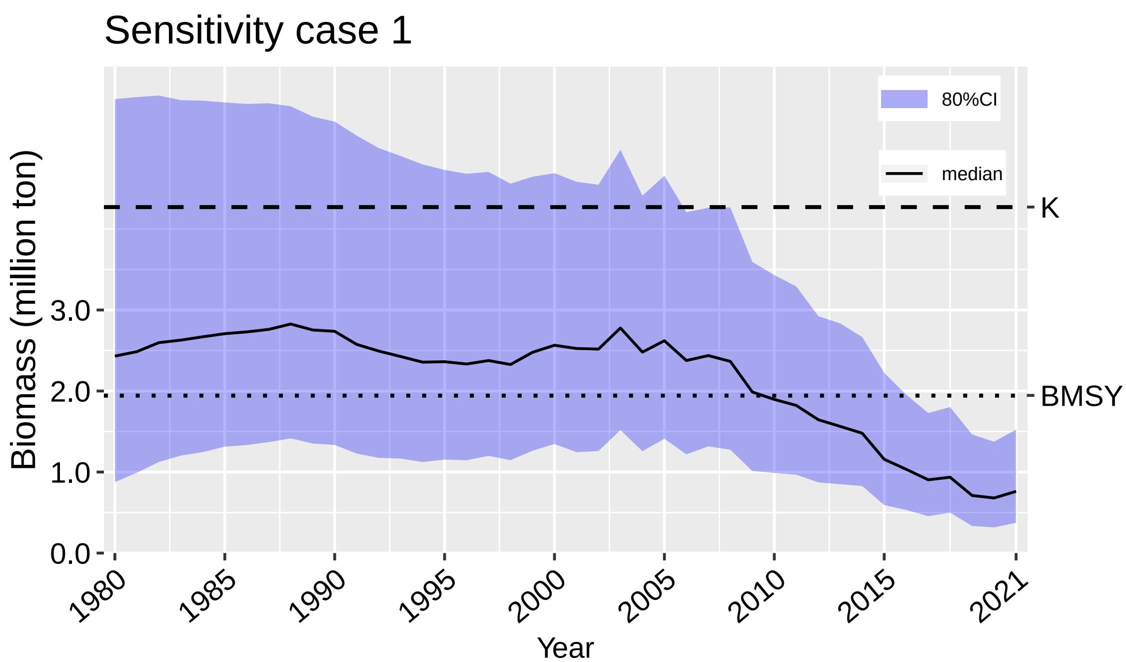
Sensitivity case 1
80%CI
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BMSY
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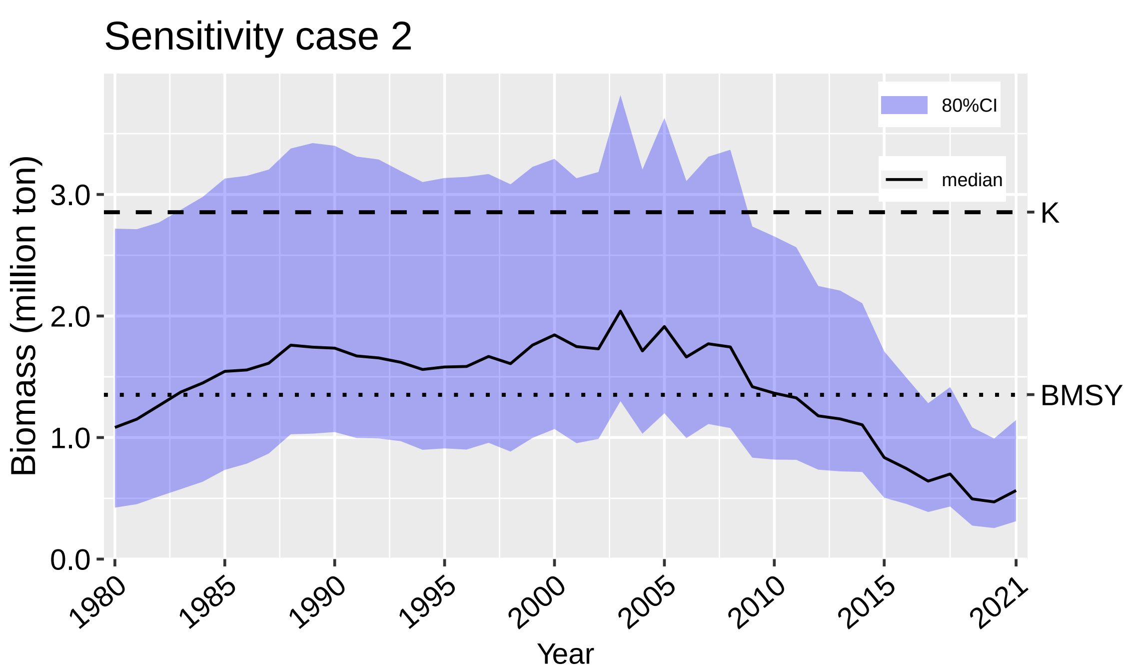
Sensitivity case 2
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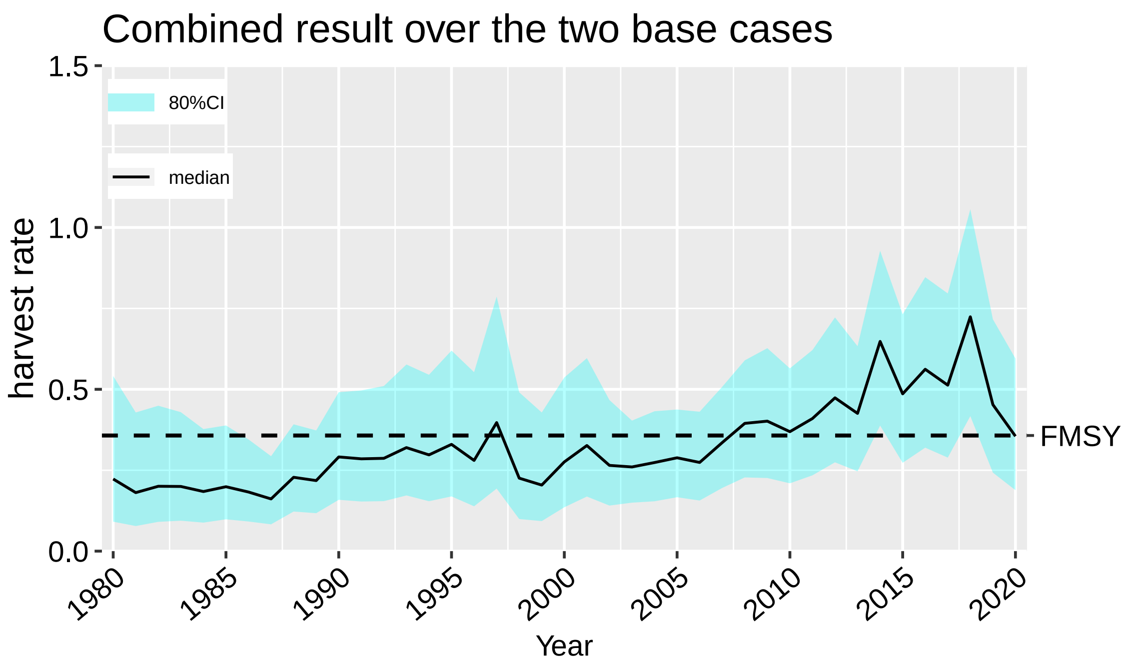
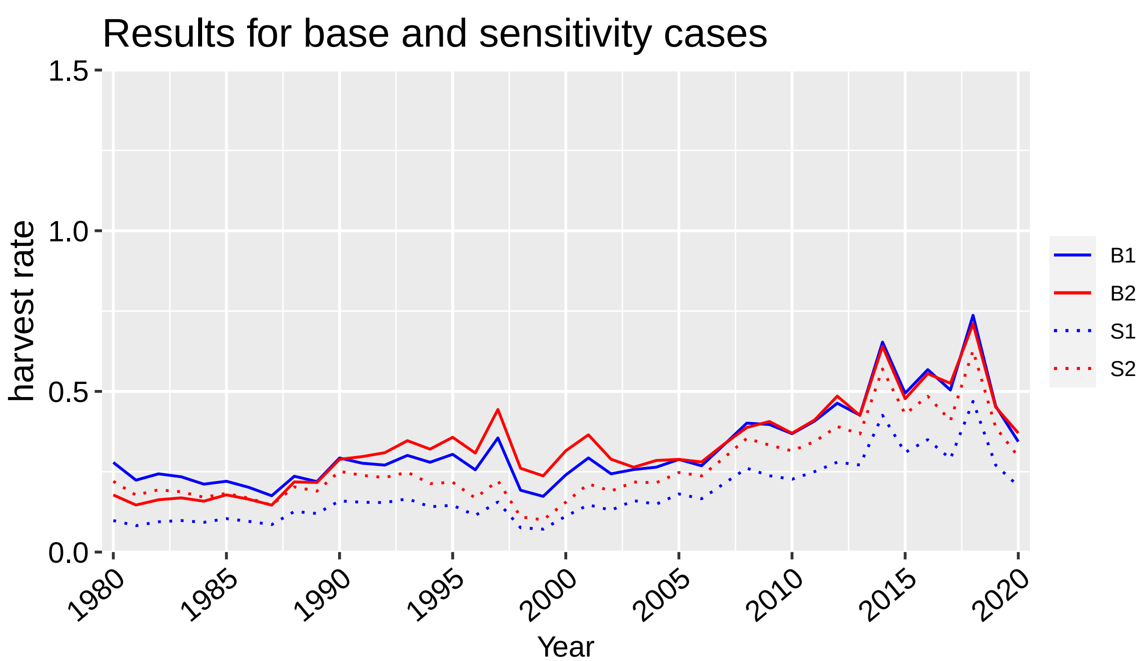
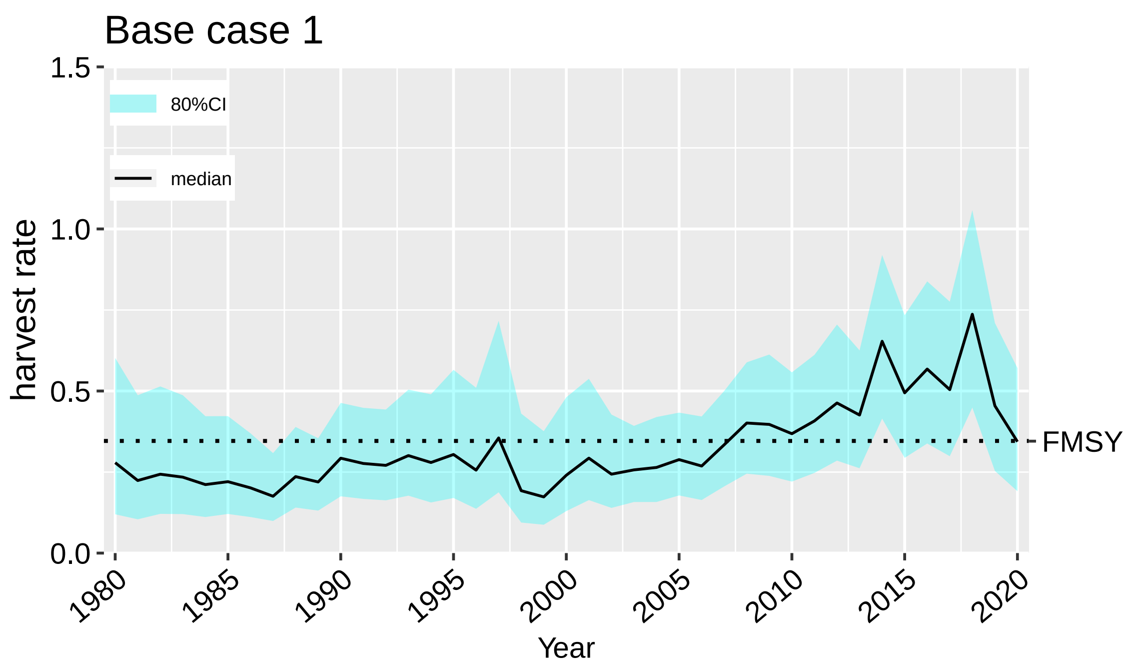
2.2 Time series Harvest rate



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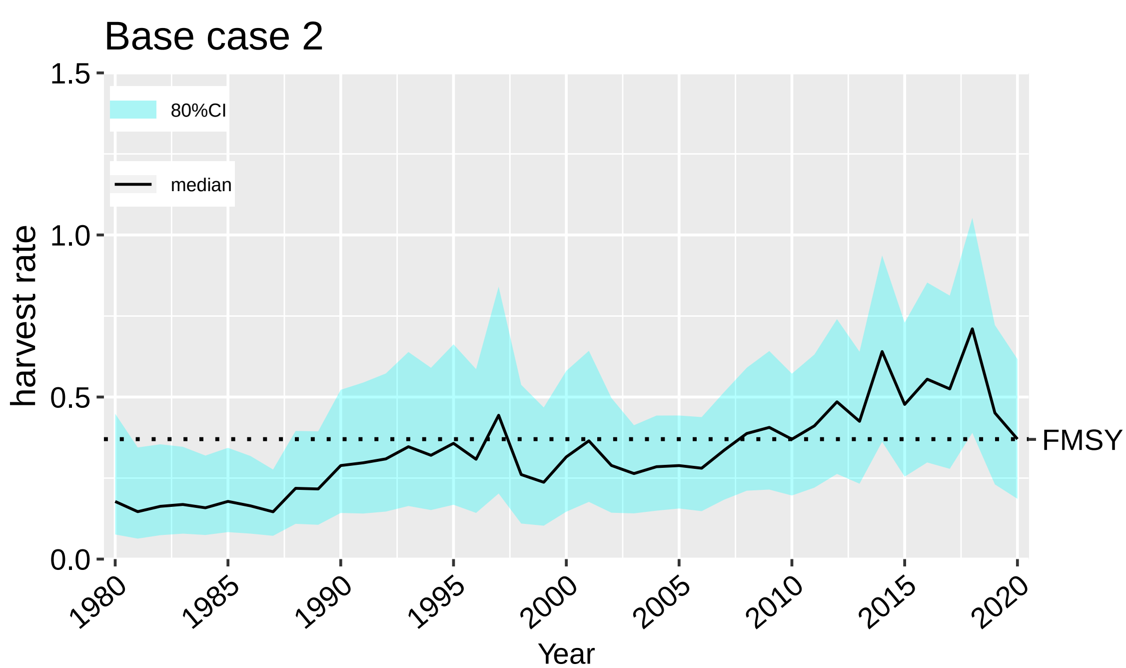
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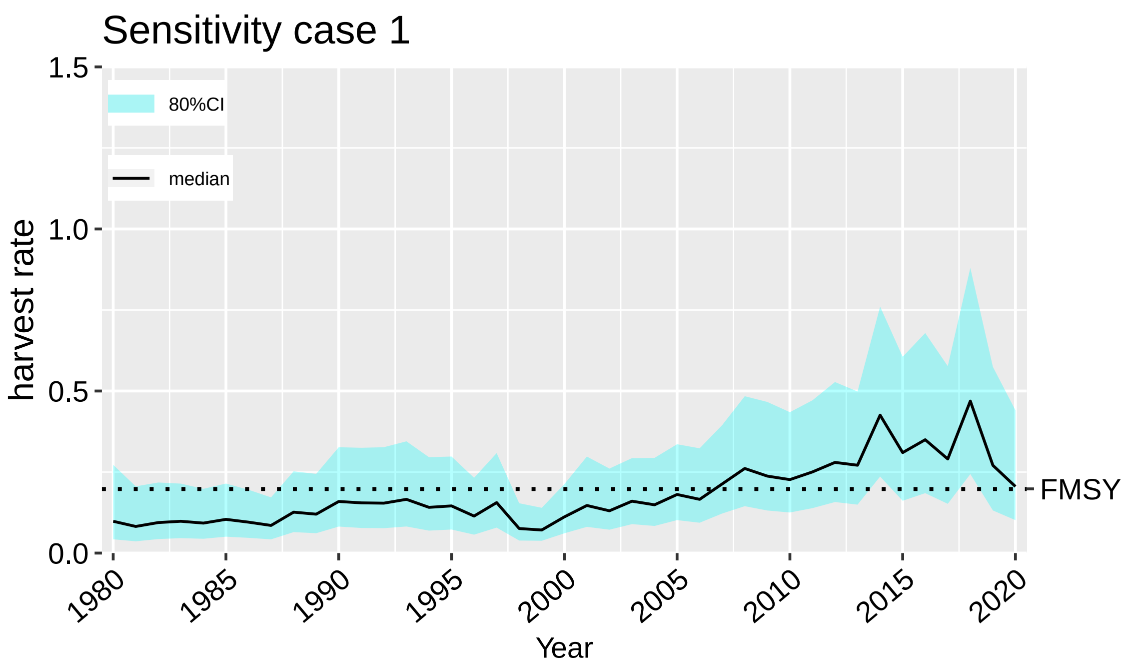
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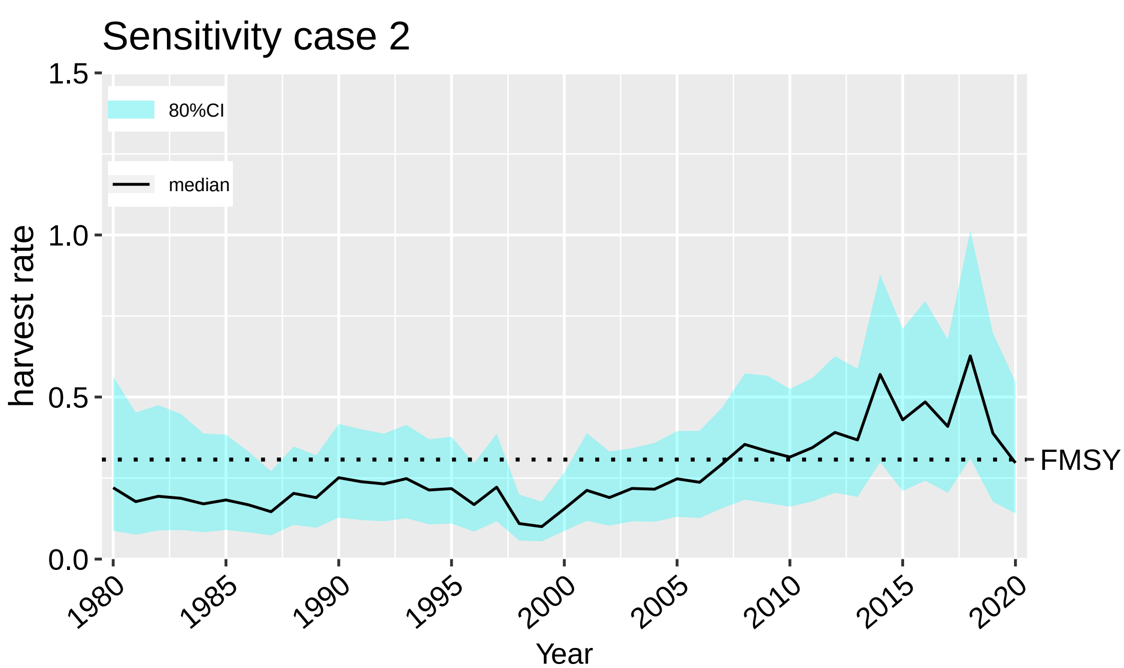
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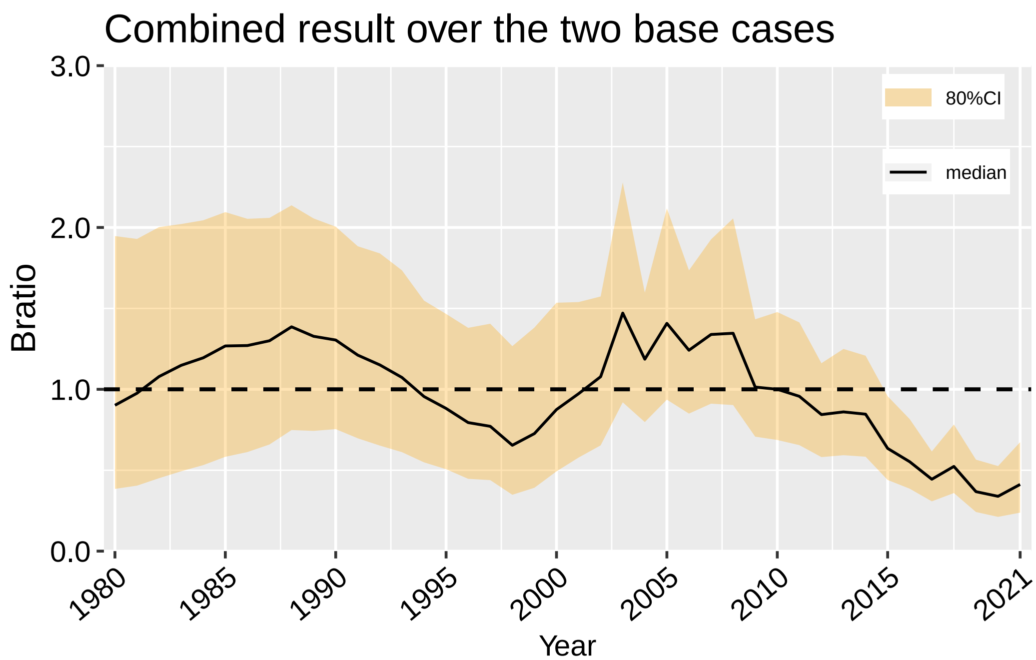

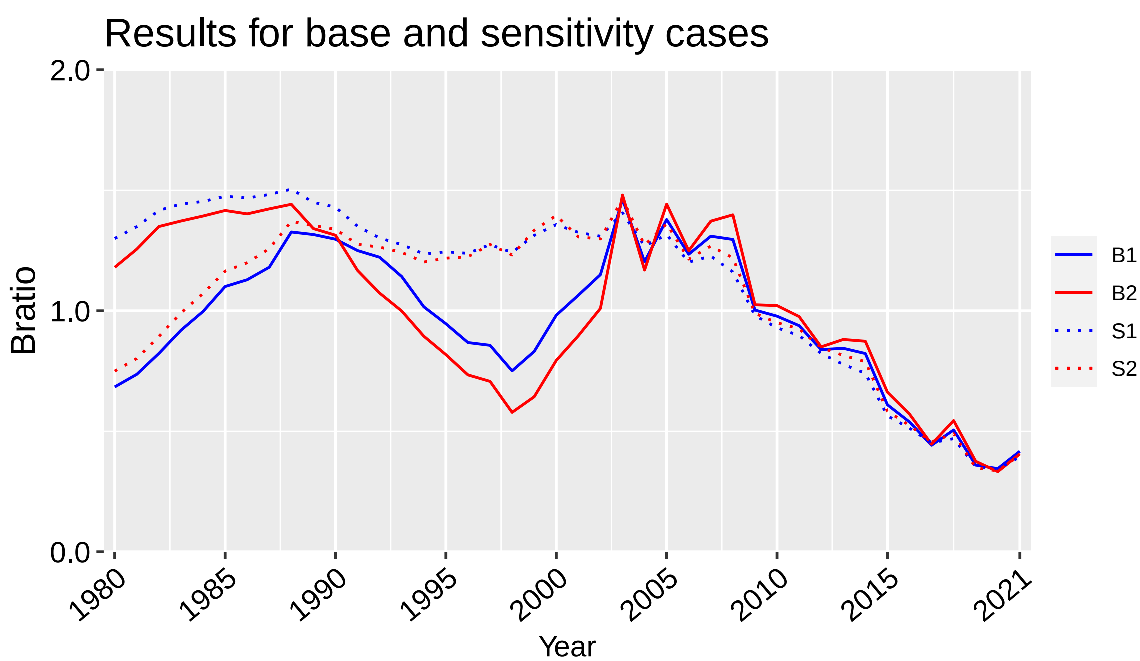

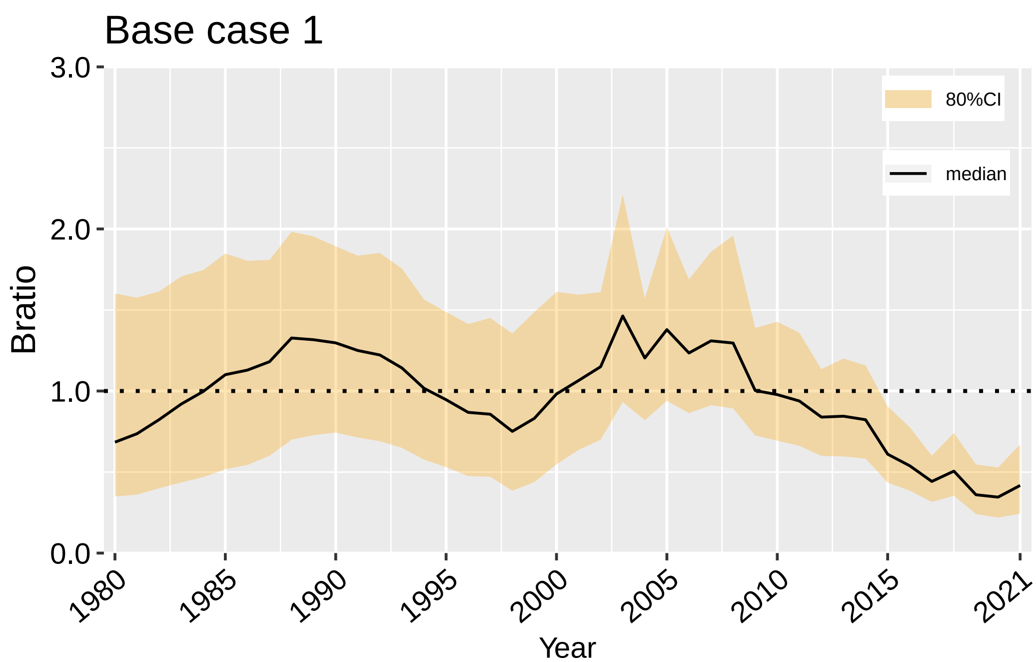
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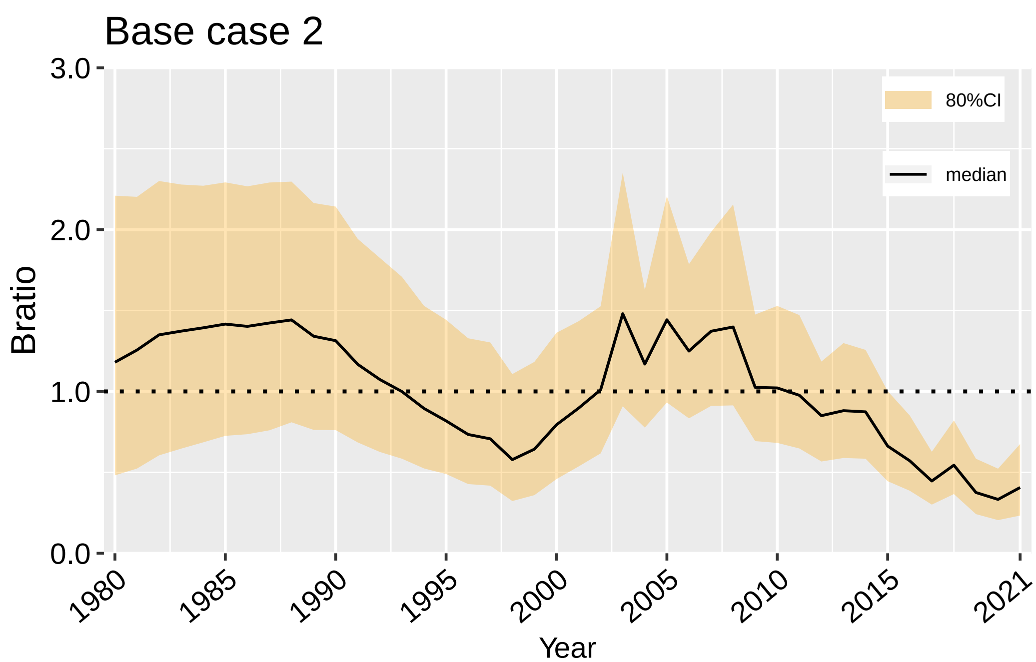
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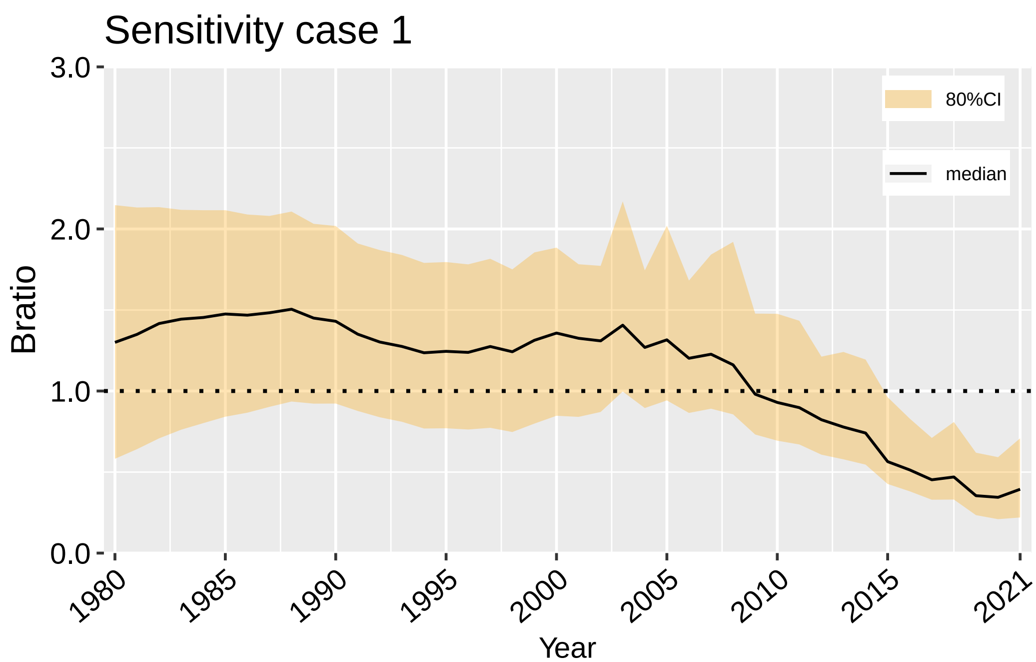
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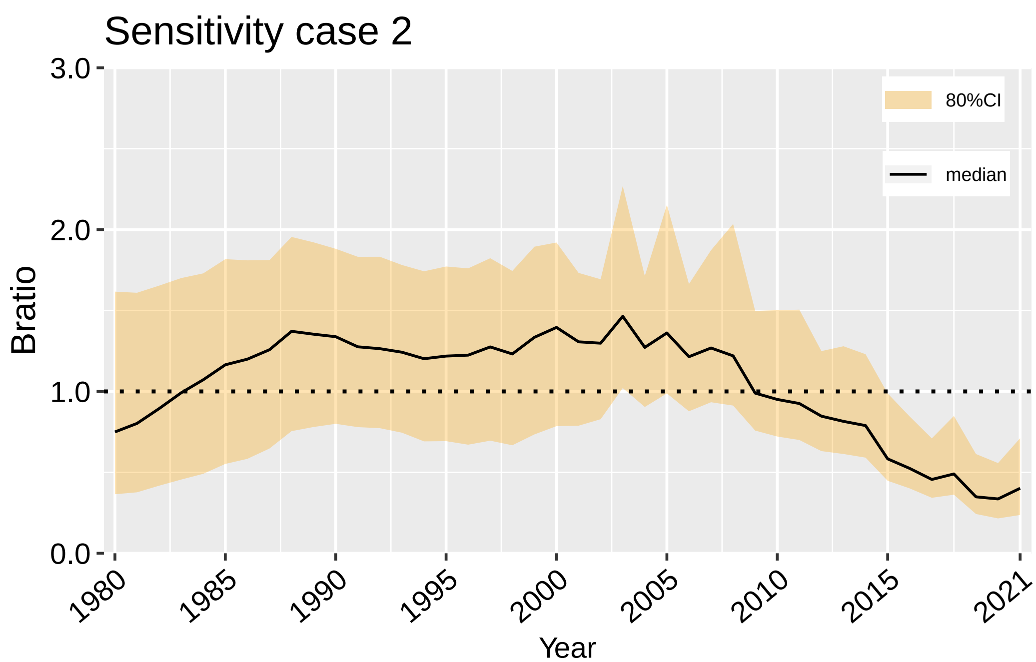
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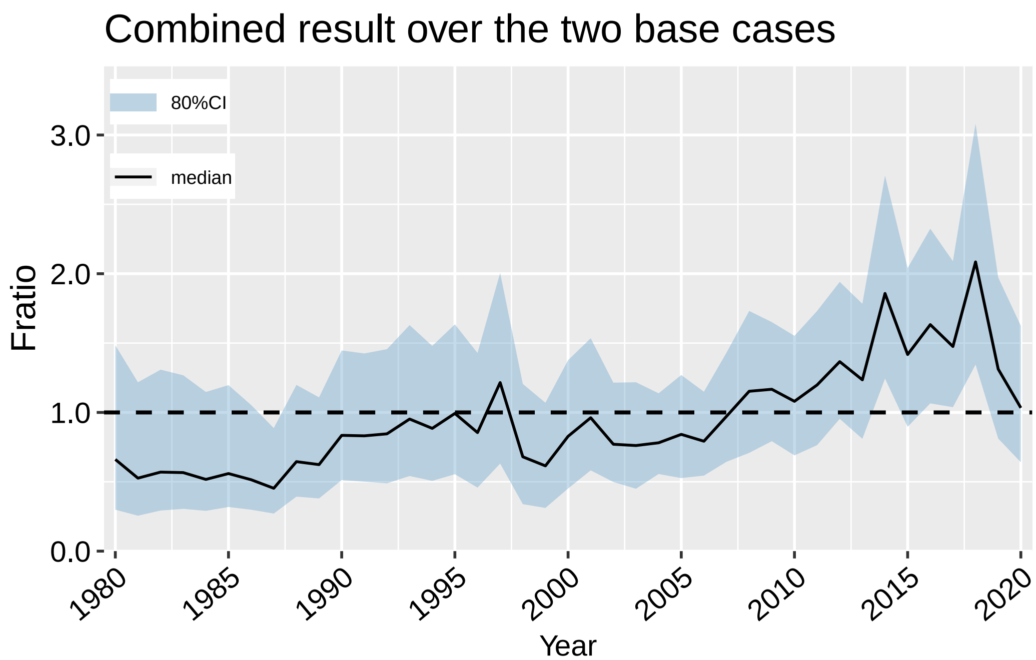
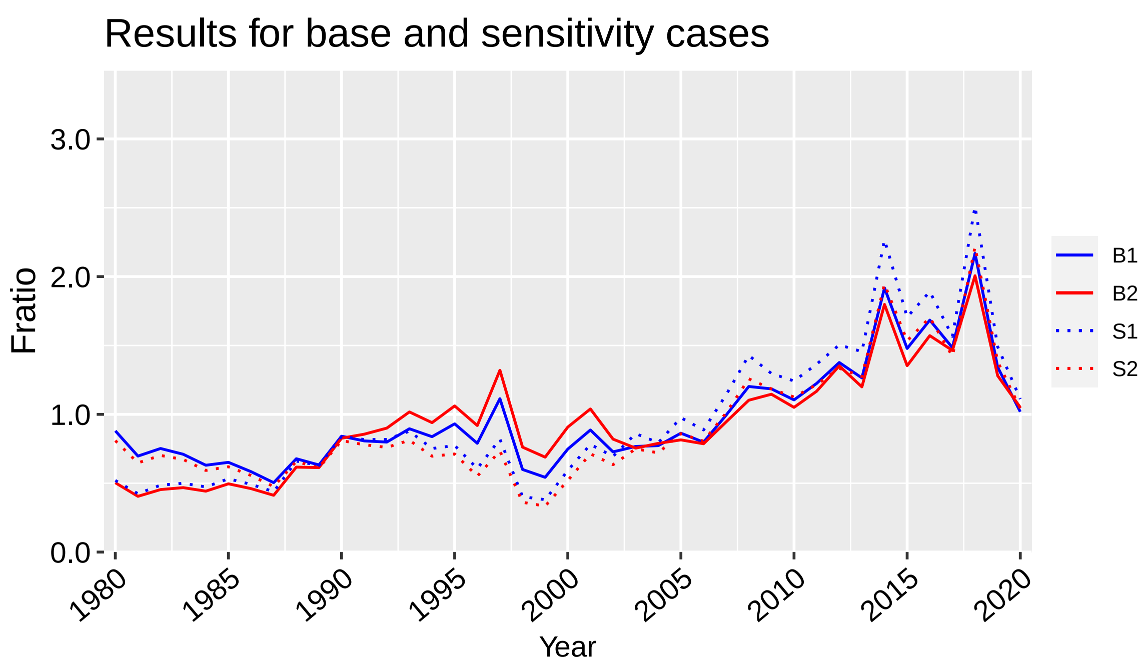
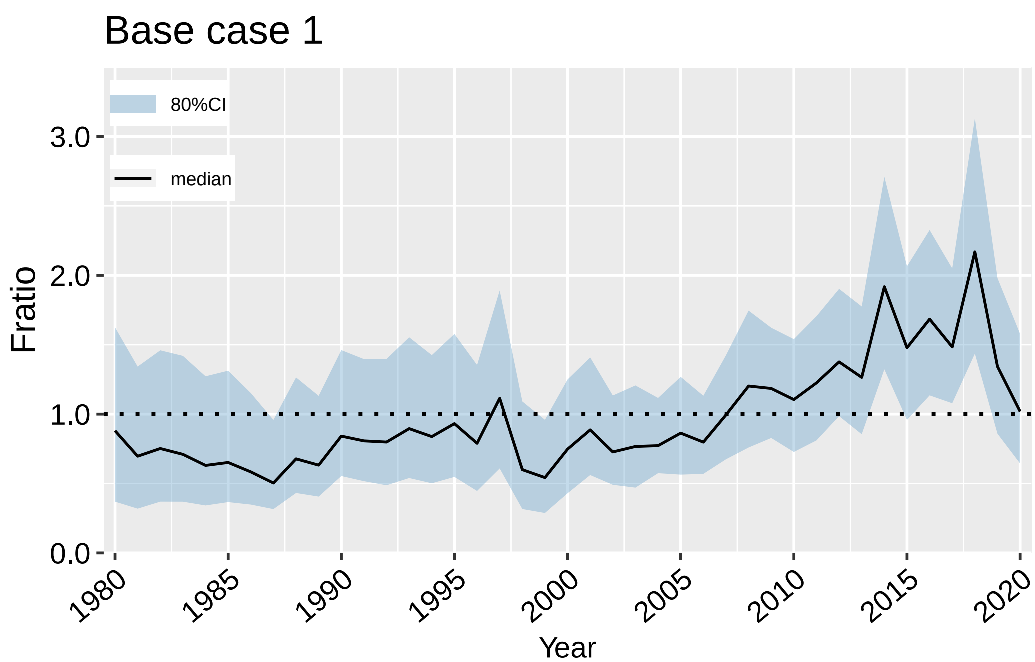
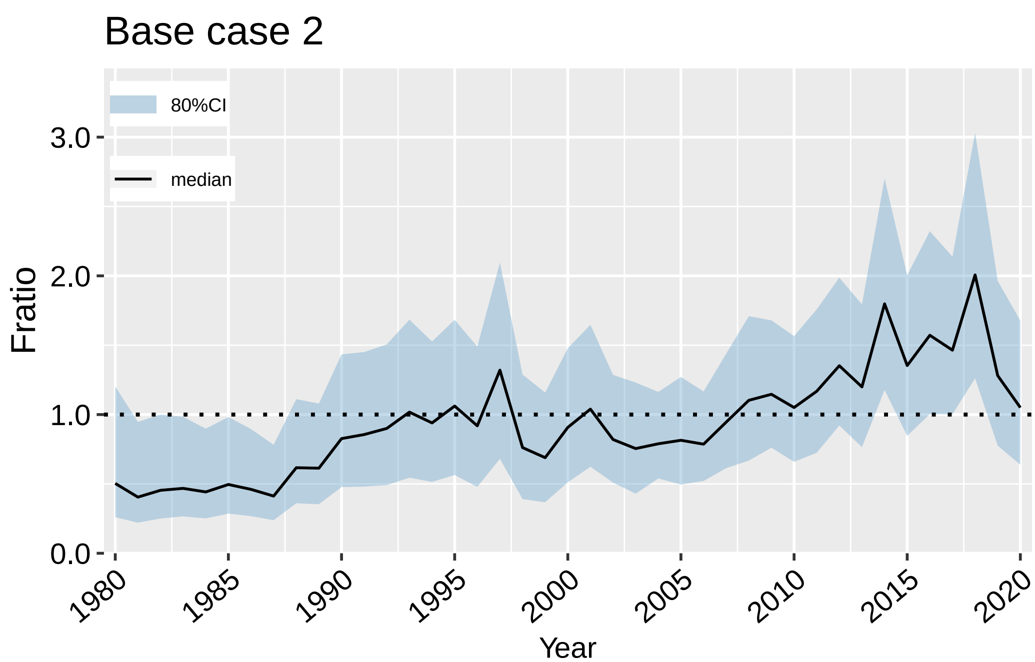


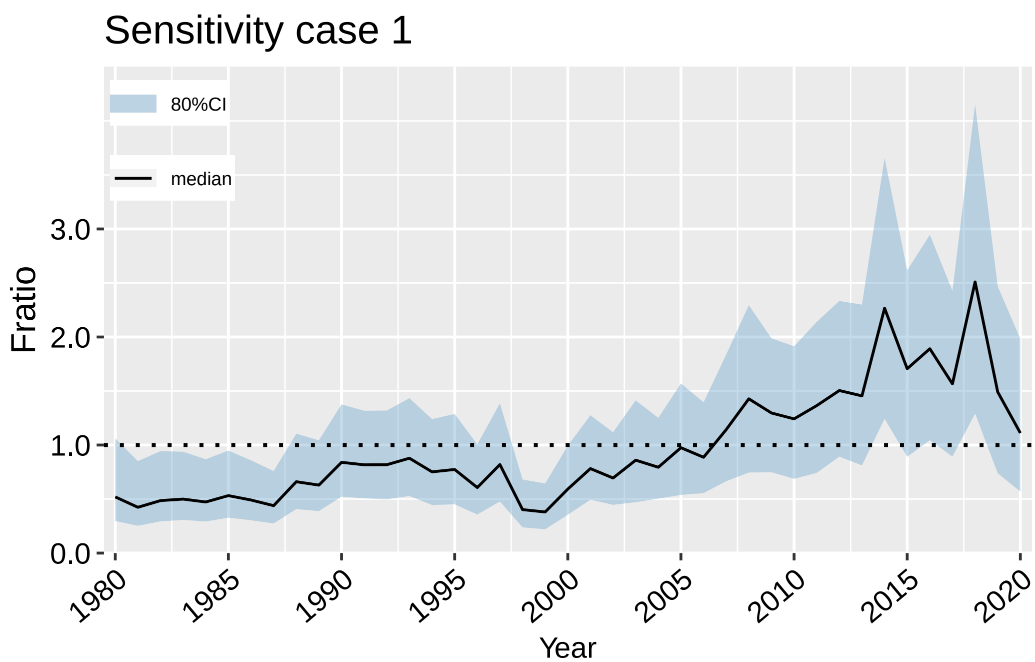


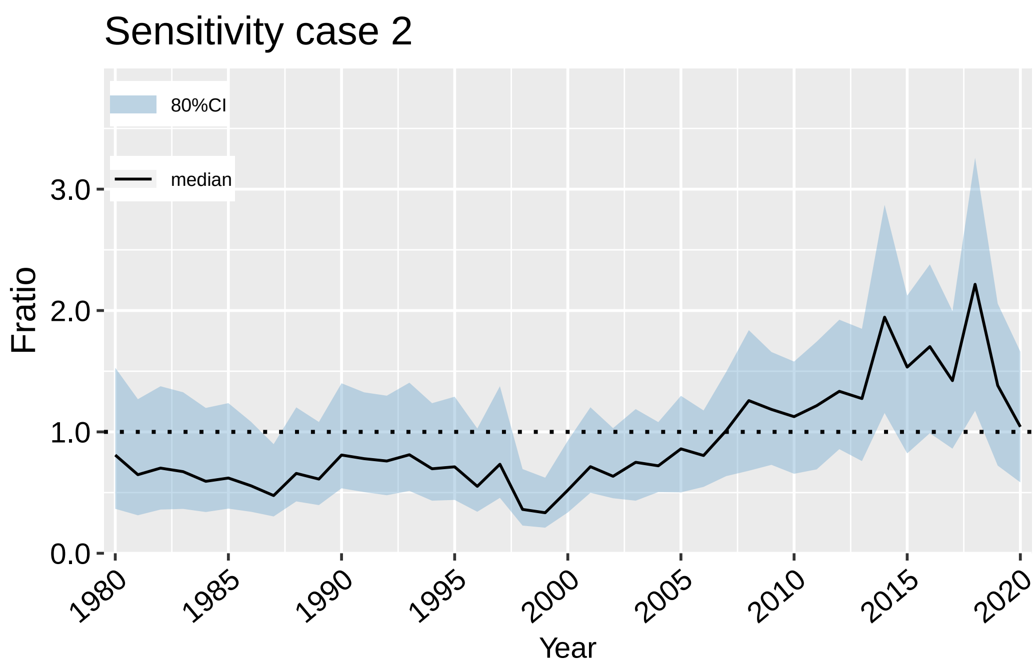


Base case 1
80%CI
median
Fratio
3.0
2.0
1.0
0.0
1980
1985
1990
1995
2000
2005
2010
2015
2020
Year

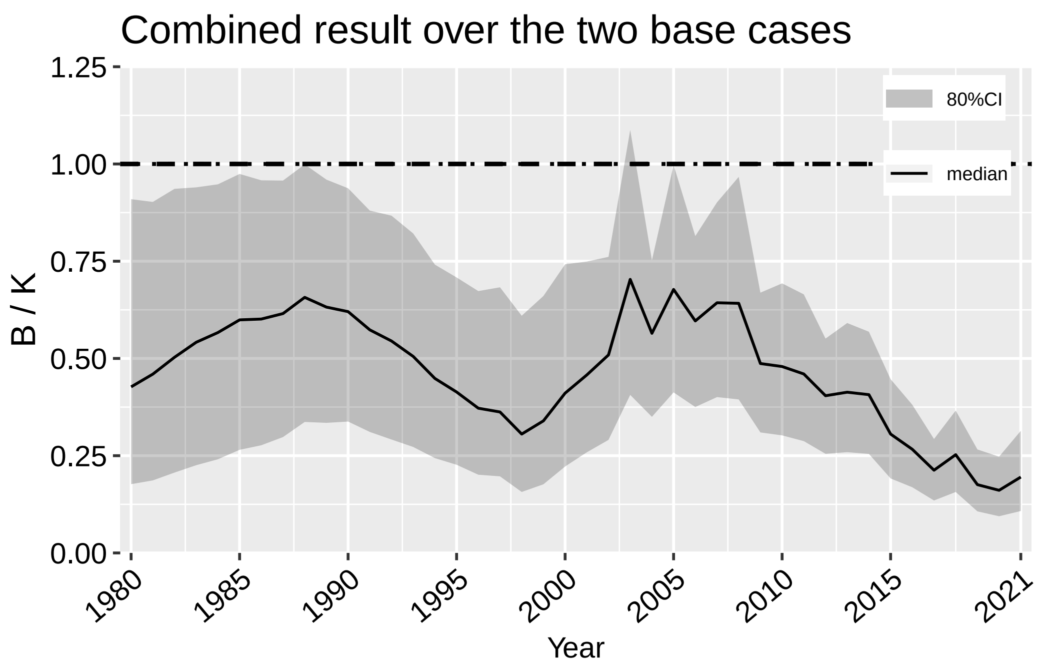


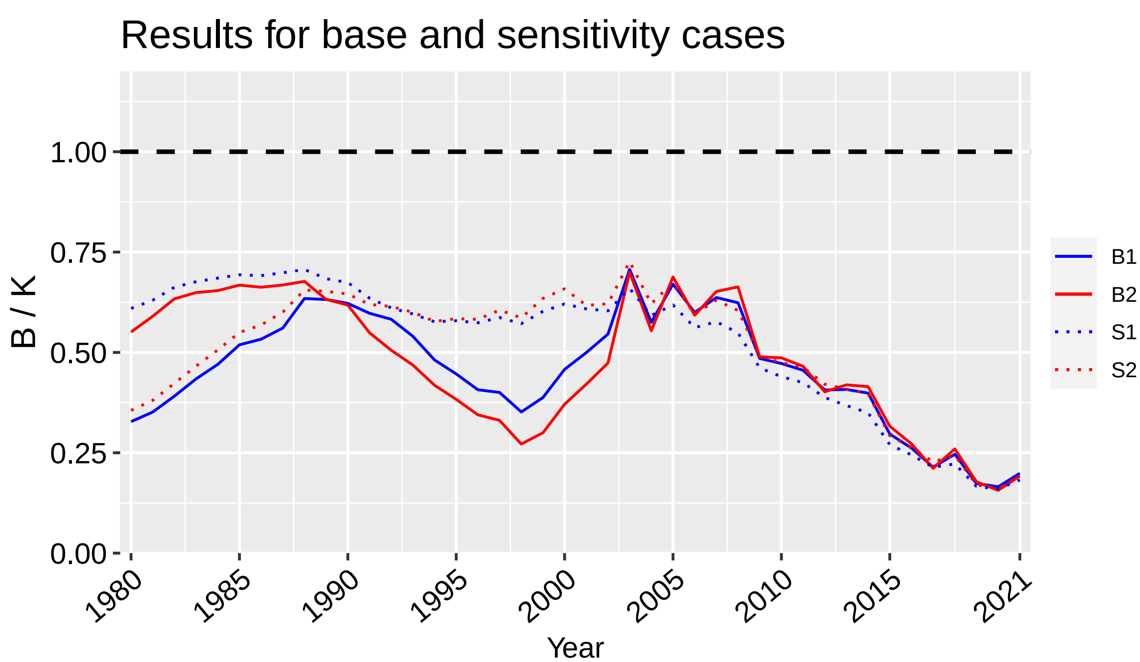
Base case 2
80%CI
median
Fratio
3.0
2.0
1.0
0.0
1980
1985
1990
1995
2000
2005
2010
2015
2020
Year

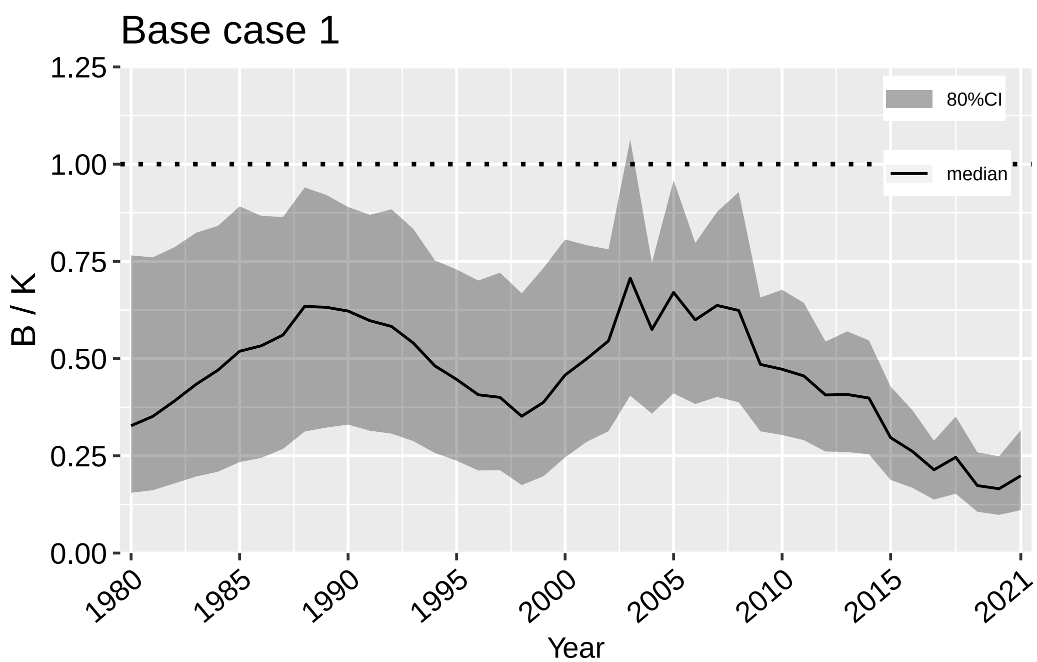

Sensitivity case 1
80%CI
median
Fratio
3.0
2.0
1.0
0.0
1980
1985
1990
1995
2000
2005
2010
2015
2020
Year

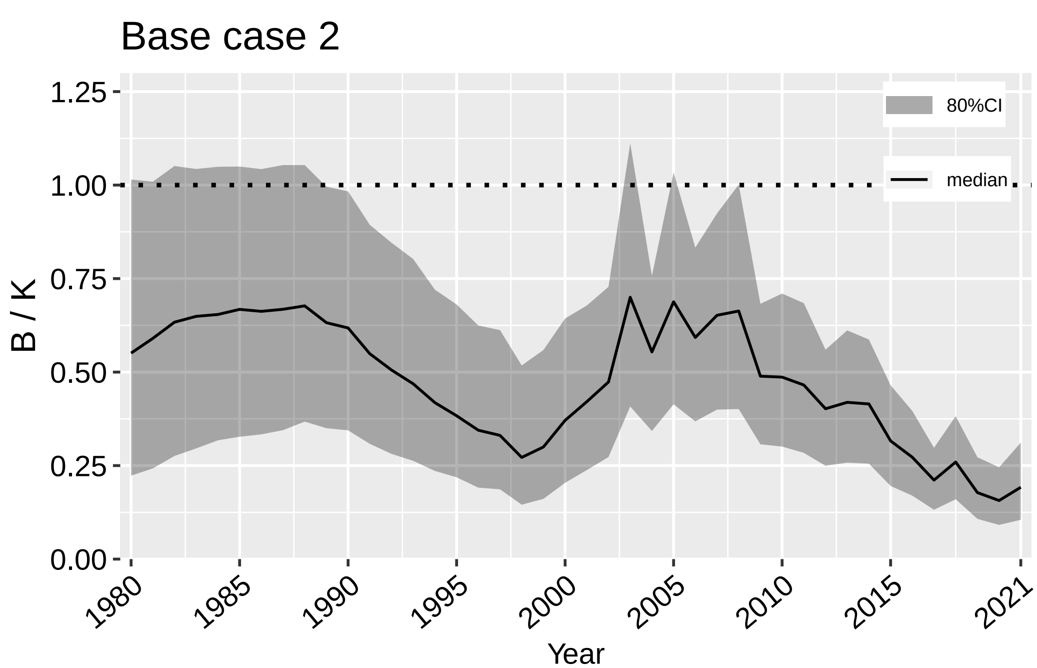

Sensitivity case 2
80%CI
median
Fratio
3.0
2.0
1.0
0.0
1980
1985
1990
1995
2000
2005
2010
2015
2020
Year

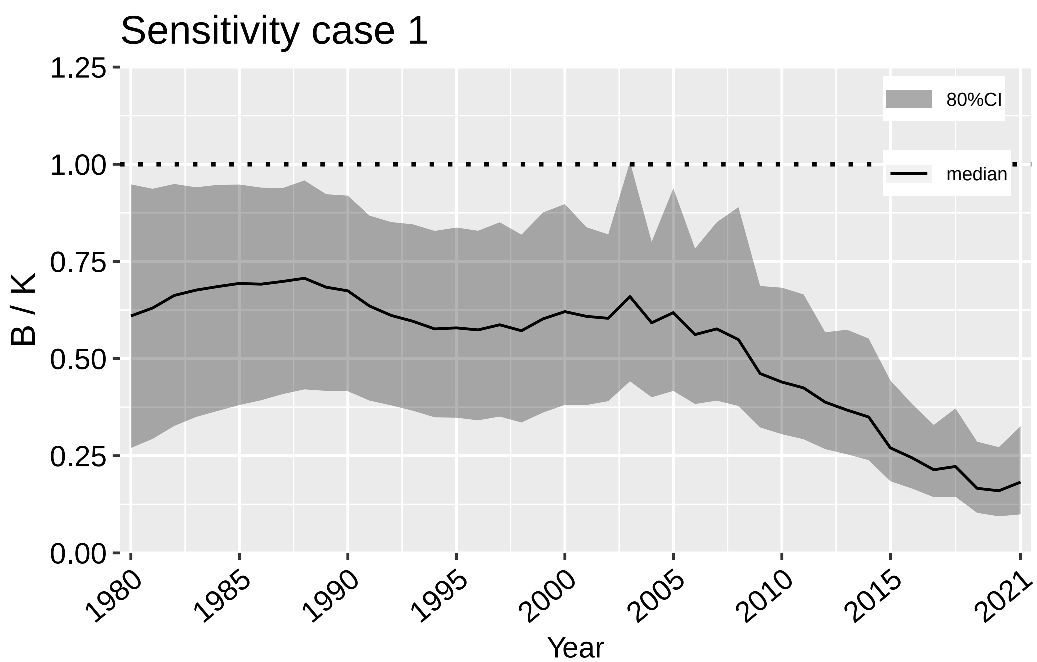
2.5 Time series B/K



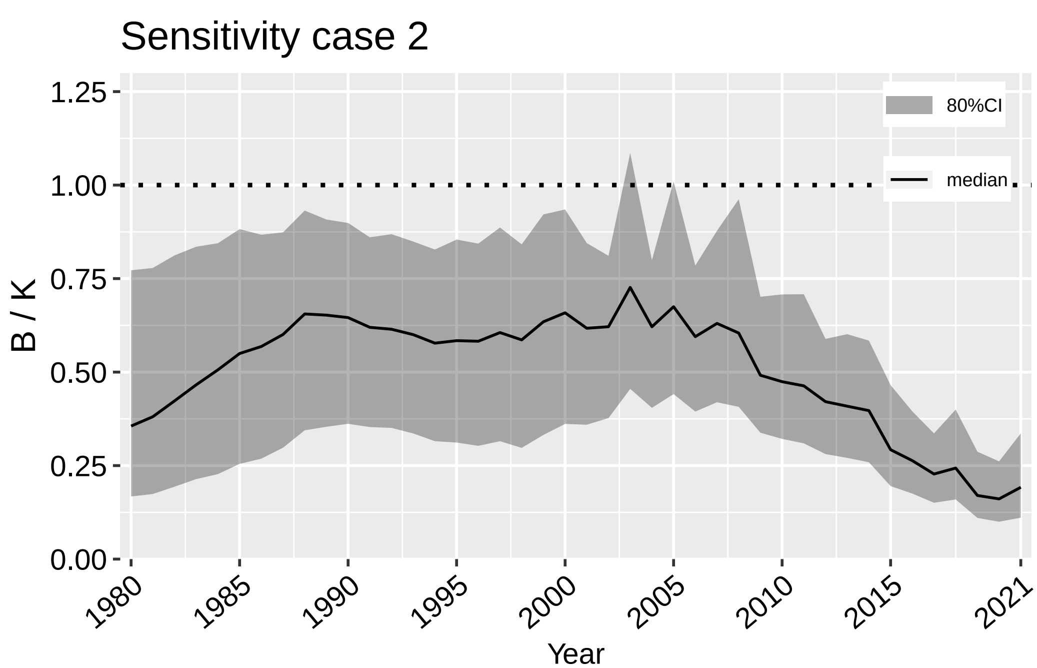



Base case 1
80%CI
median
B / K
1.25
1.00
0.75
0.50
0.25
0.00
1980
1985
1990
1995
2000
2005
2010
2015
2021
Year


Base case 2
80%CI
median
B / K
1.25
1.00
0.75
0.50
0.25
0.00
1980
1985
1990
1995
2000
2005
2010
2015
2021
Year

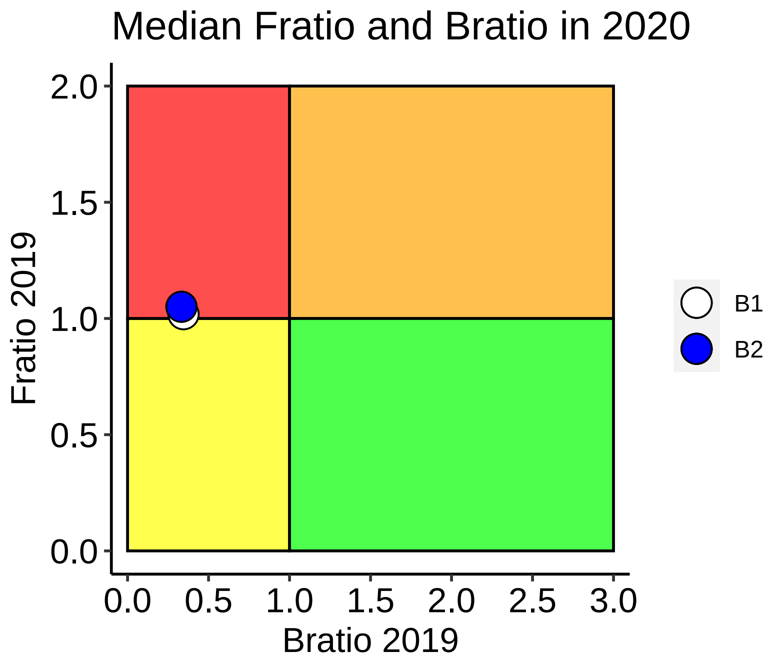


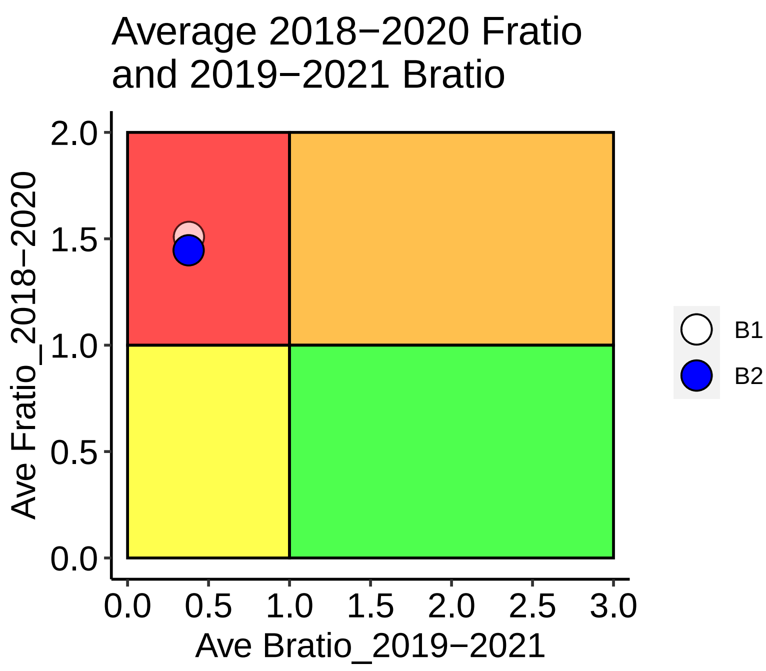
Sensitivity case 1
B / K
1.25
1.00
0.75
0.50
0.25
0.00
1980
1985
1990
1995
2000
2005
2010
2015
2021
Year
80%CI
median

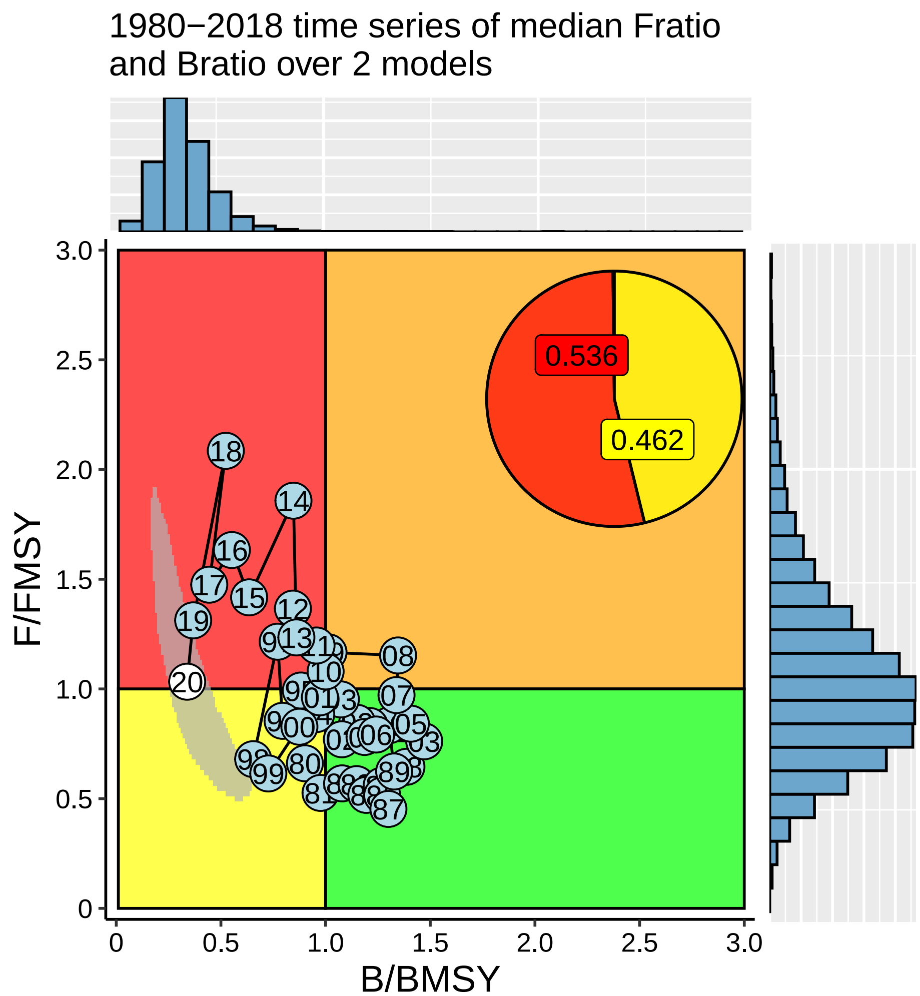


Sensitivity case 2
B / K
1.25
1.00
0.75
0.50
0.25
0.00
1980
1985
1990
1995
2000
2005
2010
2015
2021
Year
80%CI
median

3 Kobe plot


Median Fratio and Bratio in 2020
Fratio 2019
Bratio 2019
2.0
1.5
1.0
0.5
0.0
0.0 0.5 1.0 1.5 2.0 2.5 3.0
B1
B2


Average 2018−2020 Fratio
and 2019−2021 Bratio
Ave Fratio_2018−2020
Ave Bratio_2019−2021
2.0
1.5
1.0
0.5
0.0
0.0 0.5 1.0 1.5 2.0 2.5 3.0
B1
B2


1980−2018 time series of median Fratio
and Bratio over 2 models
F/FMSY
B/BMSY
0.536
0.462
18
14
16
17
15
12
19
13
08
20
10
07
05
06
00
80
99
87
89
0
0.5
1.0
1.5
2.0
2.5
3.0

4 Summary of reference points

Over 2 new base case models

	Mean	Median	Lower10th	Upper10th
C_2020	0.140	0.140	0.140	0.140
AveC_2018_2020	0.257	0.257	0.257	0.257
AveF_2018_2020	0.526	0.515	0.290	0.775
F_2020	0.378	0.355	0.188	0.595
FMSY	0.368	0.357	0.179	0.563
MSY (million ton)	0.415	0.405	0.339	0.498
F_2020/FMSY	1.097	1.033	0.641	1.625
AveF_2018_2020/FMSY	1.543	1.480	0.973	2.187
K (million ton)	2.915	2.421	1.548	4.949
B_2020 (million ton)	0.455	0.393	0.235	0.742
B_2021 (million ton)	0.545	0.480	0.284	0.868
AveB_2019_2021	0.498	0.433	0.274	0.792
BMSY (million ton)	1.336	1.144	0.751	2.189
BMSY/K	0.469	0.463	0.398	0.552
B_2020/K	0.168	0.161	0.094	0.248
B_2021/K	0.205	0.195	0.108	0.314
AveB_2019_2021/K	0.185	0.179	0.106	0.269
B_2020/BMSY	0.358	0.339	0.212	0.526
B_2021/BMSY	0.440	0.412	0.238	0.673
AveB_2019_2021/BMSY	0.396	0.378	0.238	0.574

Base case 1

	Mean	Median	Lower10th	Upper10th
C_2020	0.140	0.140	0.140	0.140
AveC_2018_2020	0.257	0.257	0.257	0.257
AveF_2018_2020	0.527	0.516	0.304	0.766
F_2020	0.366	0.344	0.191	0.571
FMSY	0.360	0.346	0.182	0.551
MSY (million ton)	0.411	0.403	0.343	0.483
F_2020/FMSY	1.076	1.019	0.644	1.577
AveF_2018_2020/FMSY	1.567	1.509	1.020	2.191
K (million ton)	2.908	2.439	1.561	4.855
B_2020 (million ton)	0.461	0.406	0.245	0.732
B_2021 (million ton)	0.550	0.493	0.296	0.855
AveB_2019_2021	0.498	0.442	0.281	0.773
BMSY (million ton)	1.339	1.165	0.763	2.150
BMSY/K	0.472	0.467	0.399	0.554
B_2020/K	0.171	0.165	0.098	0.249
B_2021/K	0.208	0.199	0.110	0.316
AveB_2019_2021/K	0.186	0.181	0.108	0.269
B_2020/BMSY	0.363	0.345	0.219	0.529
B_2021/BMSY	0.443	0.417	0.243	0.670
AveB_2019_2021/BMSY	0.396	0.379	0.241	0.569

Base case 2

	Mean	Median	Lower10th	Upper10th
C_2020	0.140	0.140	0.140	0.140
AveC_2018_2020	0.257	0.257	0.257	0.257
AveF_2018_2020	0.526	0.515	0.275	0.782
F_2020	0.391	0.370	0.186	0.617
FMSY	0.375	0.370	0.176	0.574
MSY (million ton)	0.418	0.408	0.333	0.514
F_2020/FMSY	1.118	1.050	0.638	1.677
AveF_2018_2020/FMSY	1.519	1.446	0.931	2.185
K (million ton)	2.921	2.395	1.534	5.027
B_2020 (million ton)	0.449	0.377	0.226	0.751
B_2021 (million ton)	0.541	0.466	0.276	0.883
AveB_2019_2021	0.499	0.424	0.267	0.821
BMSY (million ton)	1.333	1.124	0.739	2.245
BMSY/K	0.466	0.459	0.398	0.550
B_2020/K	0.164	0.157	0.091	0.246
B_2021/K	0.203	0.192	0.105	0.311
AveB_2019_2021/K	0.184	0.178	0.105	0.269
B_2020/BMSY	0.354	0.333	0.205	0.523
B_2021/BMSY	0.437	0.406	0.233	0.675
AveB_2019_2021/BMSY	0.397	0.377	0.235	0.579

Sensitivity case 1

	Mean	Median	Lower10th	Upper10th
C_2020	0.140	0.140	0.140	0.140
AveC_2018_2020	0.257	0.257	0.257	0.257
AveF_2018_2020	0.359	0.317	0.162	0.627
F_2020	0.244	0.205	0.102	0.441
FMSY	0.232	0.198	0.084	0.435
MSY (million ton)	0.385	0.374	0.276	0.497
F_2020/FMSY	1.225	1.111	0.570	1.983
AveF_2018_2020/FMSY	1.826	1.711	0.895	2.844
K (million ton)	4.719	4.270	2.072	8.220
B_2020 (million ton)	0.786	0.680	0.317	1.375
B_2021 (million ton)	0.877	0.762	0.374	1.524
AveB_2019_2021	0.831	0.718	0.350	1.448
BMSY (million ton)	2.145	1.943	1.004	3.564
BMSY/K	0.464	0.457	0.387	0.553
B_2020/K	0.175	0.160	0.094	0.272
B_2021/K	0.201	0.182	0.099	0.326
AveB_2019_2021/K	0.187	0.172	0.101	0.291
B_2020/BMSY	0.380	0.344	0.209	0.592
B_2021/BMSY	0.438	0.394	0.220	0.708
AveB_2019_2021/BMSY	0.406	0.367	0.224	0.636

Sensitivity case 2

	Mean	Median	Lower10th	Upper10th
C_2020	0.140	0.140	0.140	0.140
AveC_2018_2020	0.257	0.257	0.257	0.257
AveF_2018_2020	0.466	0.442	0.214	0.744
F_2020	0.328	0.297	0.141	0.547
FMSY	0.321	0.307	0.142	0.519
MSY (million ton)	0.415	0.408	0.332	0.504
F_2020/FMSY	1.099	1.042	0.584	1.661
AveF_2018_2020/FMSY	1.583	1.551	0.871	2.291
K (million ton)	3.391	2.854	1.702	5.968
B_2020 (million ton)	0.564	0.471	0.255	0.992
B_2021 (million ton)	0.664	0.564	0.312	1.144
AveB_2019_2021	0.612	0.513	0.289	1.064
BMSY (million ton)	1.577	1.351	0.849	2.683
BMSY/K	0.477	0.477	0.397	0.558
B_2020/K	0.174	0.161	0.100	0.261
B_2021/K	0.211	0.192	0.111	0.336
AveB_2019_2021/K	0.191	0.176	0.110	0.288
B_2020/BMSY	0.368	0.336	0.215	0.557
B_2021/BMSY	0.445	0.402	0.237	0.711
AveB_2019_2021/BMSY	0.403	0.366	0.237	0.613

5 Summary of estimates of parameters

Base case 1

	Mean	Median	Lower10th	Upper10th
r	1.122	0.936	0.452	2.168
K (million ton)	2.908	2.439	1.561	4.855
qCHN	16.148	15.194	9.954	23.680
qJPN1	0.904	0.808	0.374	1.579
qJPN2	1.957	1.898	1.371	2.632
qKOR	5.407	5.255	3.794	7.231
qRUS	21.775	20.993	15.282	29.293
qCT	2.208	2.145	1.531	2.962
qBio	0.617	0.612	0.375	0.881
Shape	0.803	0.685	0.182	1.646
sigma_com	0.671	0.669	0.666	0.681
sigma_Bio	0.034	0.030	0.013	0.060
tau	0.199	0.195	0.057	0.339
FMSY	0.360	0.346	0.182	0.551
BMSY (million ton)	1.339	1.165	0.763	2.150
MSY (million ton)	0.411	0.403	0.343	0.483
b	0.614	0.621	0.346	0.876

Base case 2

	Mean	Median	Lower10th	Upper10th
r	1.215	1.034	0.466	2.325
K (million ton)	2.921	2.395	1.534	5.027
qCHN	16.265	15.530	9.725	23.772
qJPN1				
qJPN2	1.995	1.949	1.309	2.748
qKOR	5.432	5.332	3.571	7.424
qRUS	22.535	21.920	14.791	31.001
qCT	2.220	2.167	1.458	3.039
qBio	0.616	0.616	0.334	0.898
Shape	0.754	0.615	0.175	1.591
sigma_com	0.614	0.611	0.608	0.624
sigma_Bio	0.036	0.031	0.014	0.065
tau	0.265	0.257	0.133	0.404
FMSY	0.375	0.370	0.176	0.574
BMSY (million ton)	1.333	1.124	0.739	2.245
MSY (million ton)	0.418	0.408	0.333	0.514
b	0.671	0.679	0.442	0.899

Sensitivity case 1

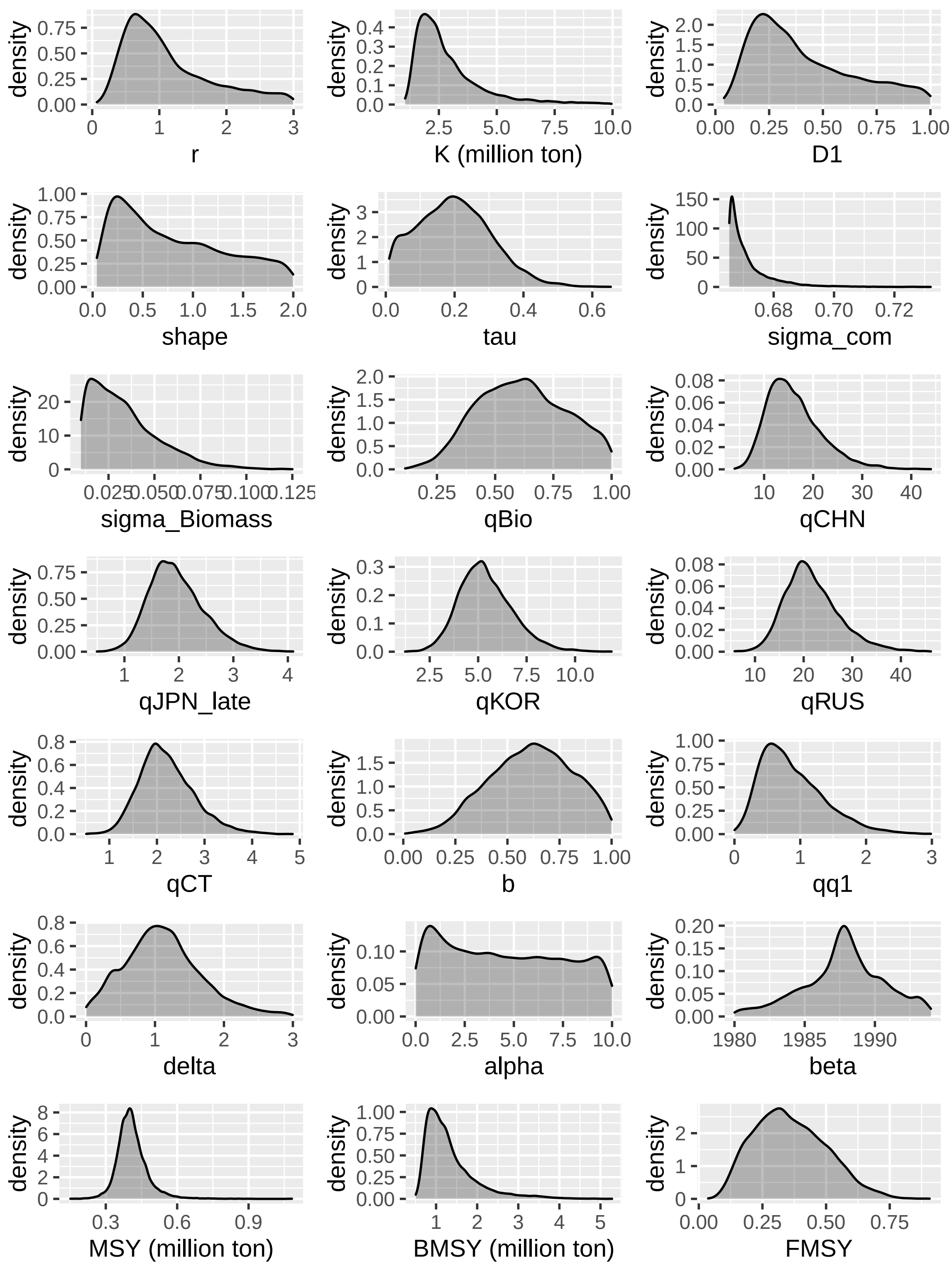
	Mean	Median	Lower10th	Upper10th
r	0.876	0.654	0.214	1.991
K (million ton)	4.719	4.270	2.072	8.220
qJOINT	0.764	0.764	0.519	1.008
qBio	0.421	0.377	0.208	0.717
Shape	0.747	0.600	0.111	1.641
sigma_Joint	0.348	0.343	0.287	0.413
sigma_Bio	0.206	0.209	0.093	0.311
tau	0.149	0.121	0.033	0.309
FMSY	0.232	0.198	0.084	0.435
BMSY (million ton)	2.145	1.943	1.004	3.564
MSY (million ton)	0.385	0.374	0.276	0.497
b	0.476	0.470	0.224	0.742

Sensitivity case 2

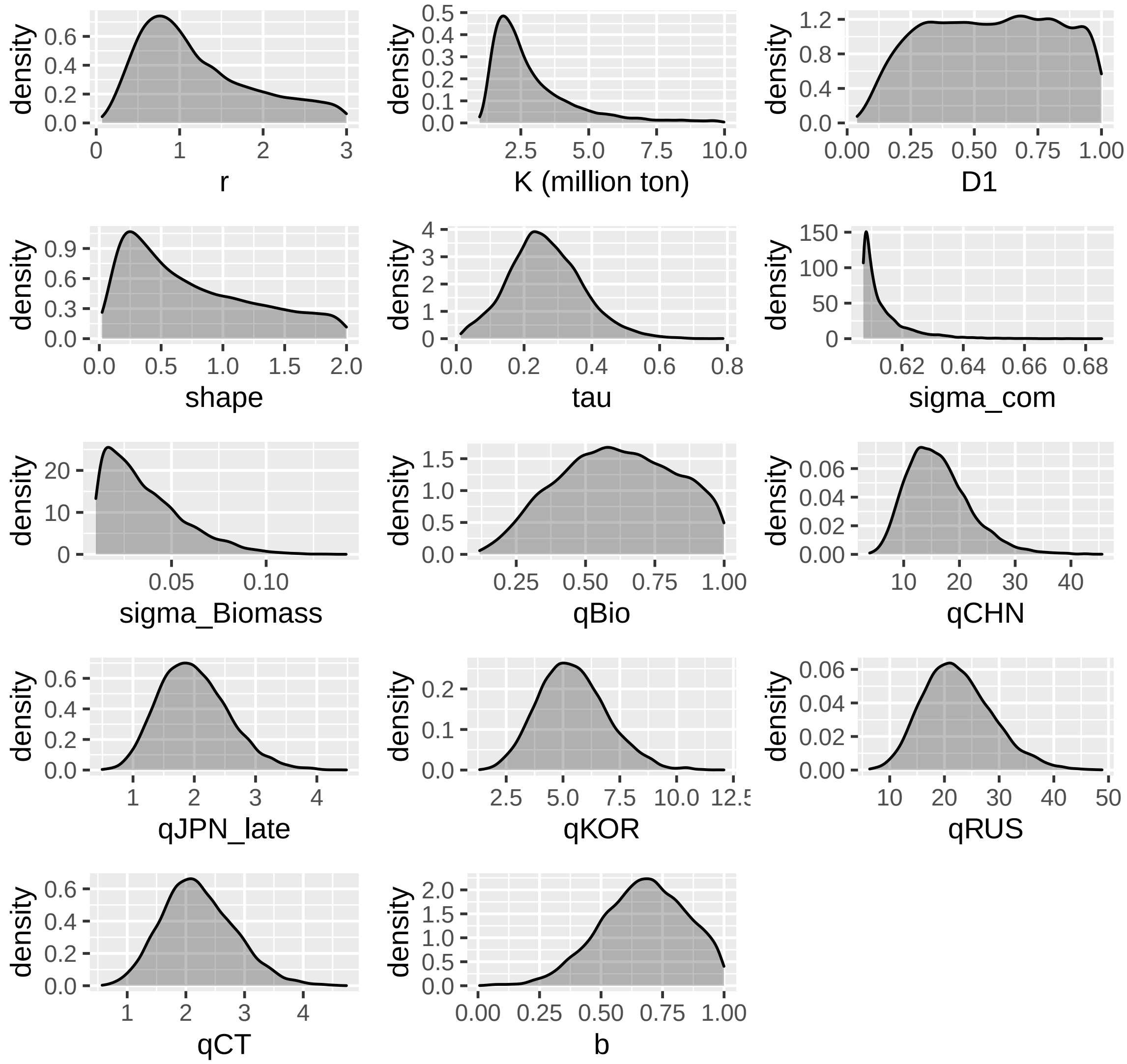
	Mean	Median	Lower10th	Upper10th
r	0.981	0.794	0.346	1.960
K (million ton)	3.391	2.854	1.702	5.968
qJOINT	0.859	0.867	0.598	1.107
qBio	0.539	0.519	0.273	0.834
Shape	0.865	0.778	0.172	1.713
sigma_Joint	0.307	0.300	0.274	0.351
sigma_JPN_early	0.753	0.735	0.671	0.859
sigma_Bio	0.130	0.128	0.037	0.222
tau	0.171	0.150	0.037	0.334
FMSY	0.321	0.307	0.142	0.519
BMSY (million ton)	1.577	1.351	0.849	2.683
MSY (million ton)	0.415	0.408	0.332	0.504
b	0.517	0.505	0.288	0.769

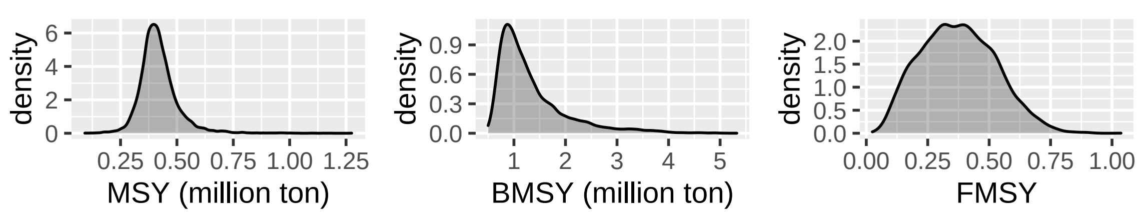
6 Posterior distributions

Base case 1

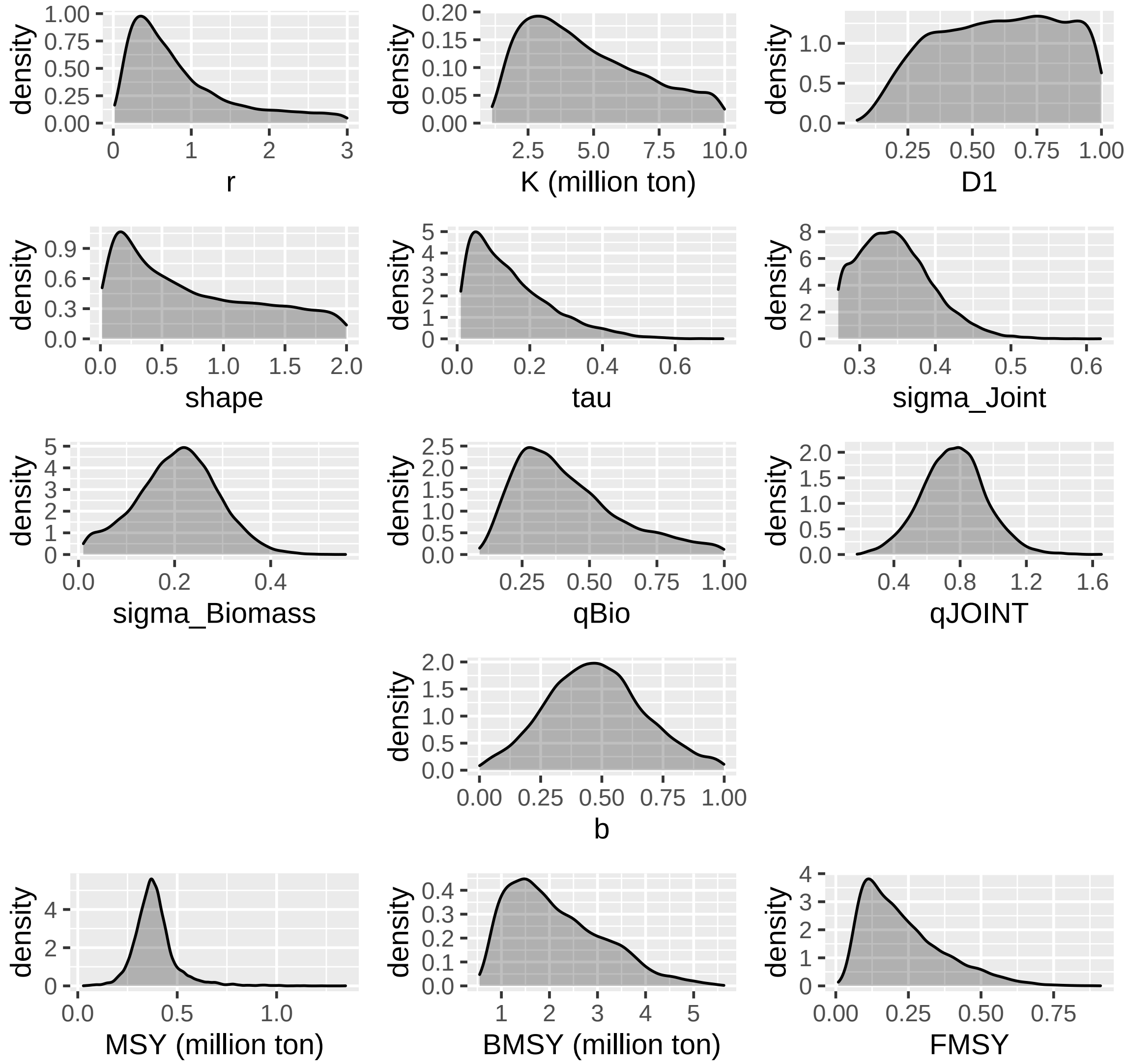


Base case 2

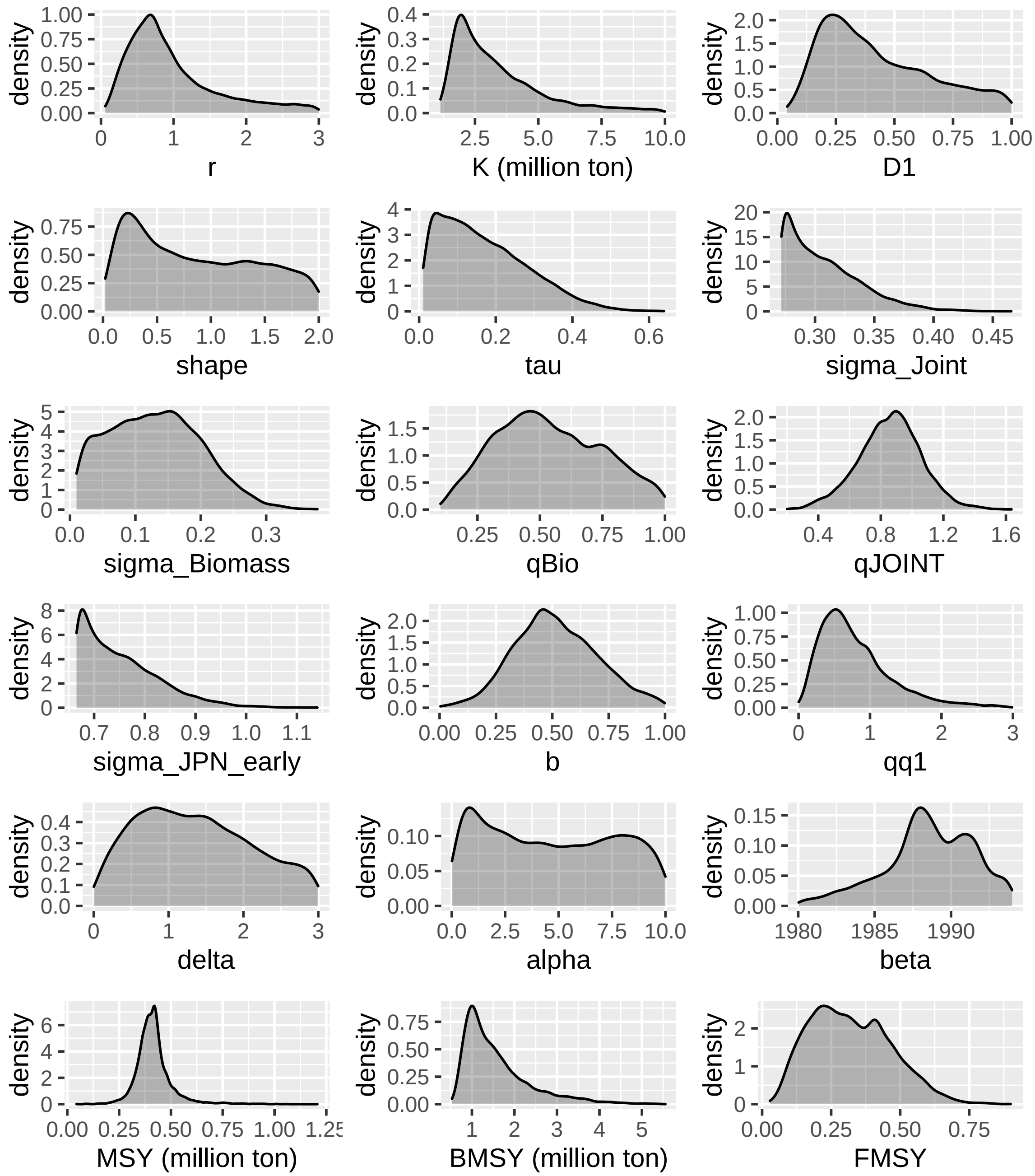

density
r
K (million ton)
D1
shape
tau
sigma_com
sigma_Biomass
qBio
qCHN
qJPN_late
qKOR
qRUS
qCT
b


density
MSY (million ton)
BMSY (million ton)
FMSY

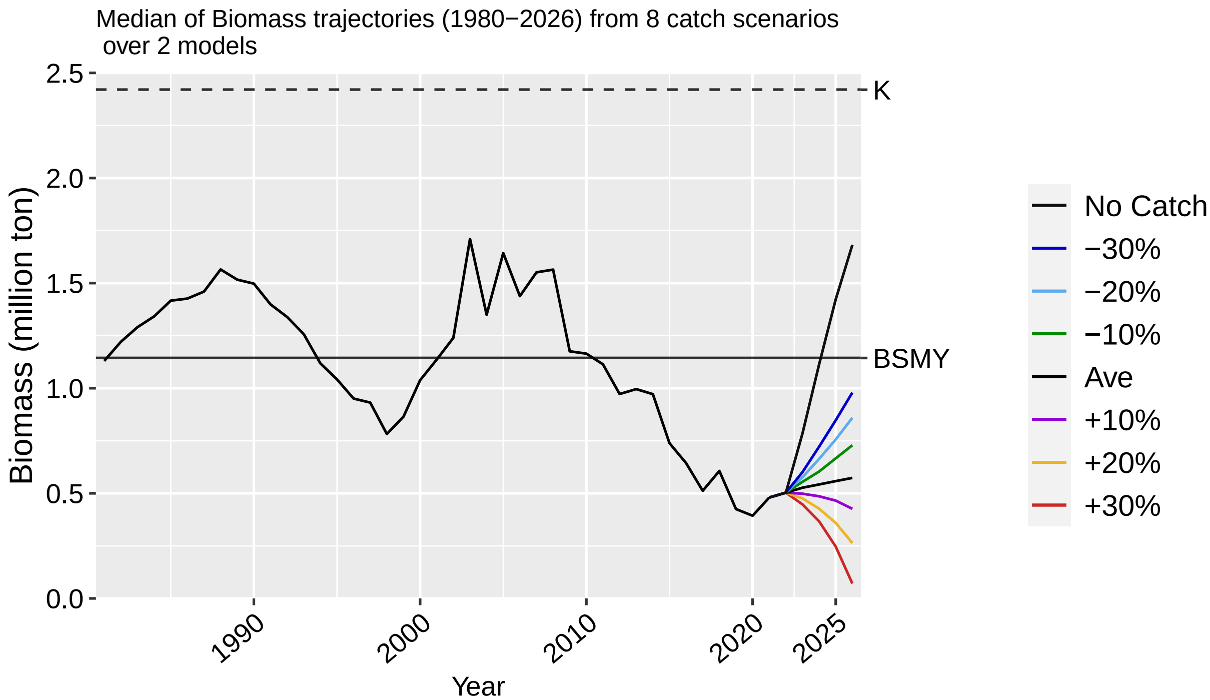
Sensitivity case 1

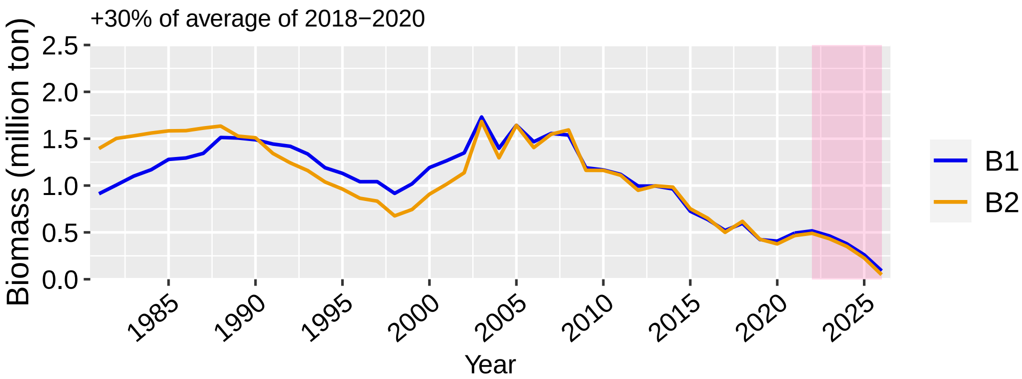


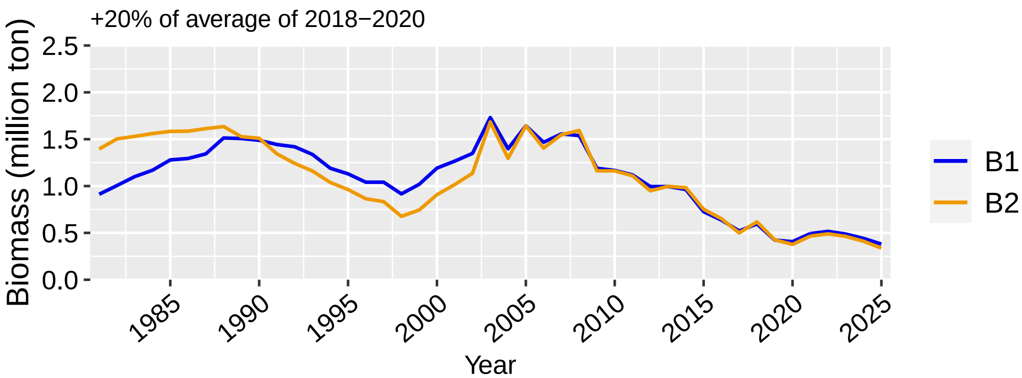
Sensitivity case 2

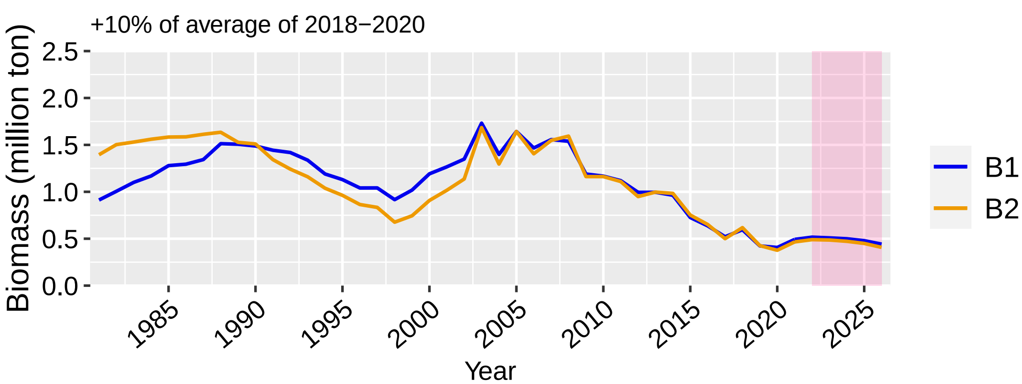


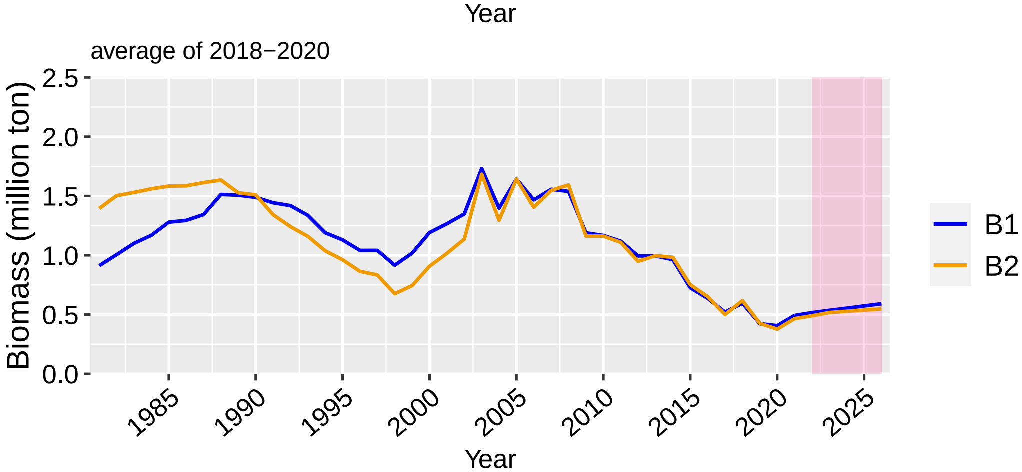
7 Future projection

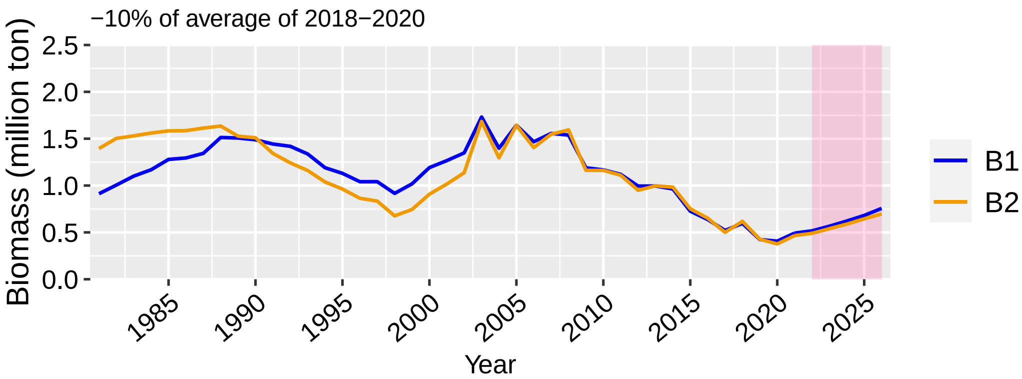


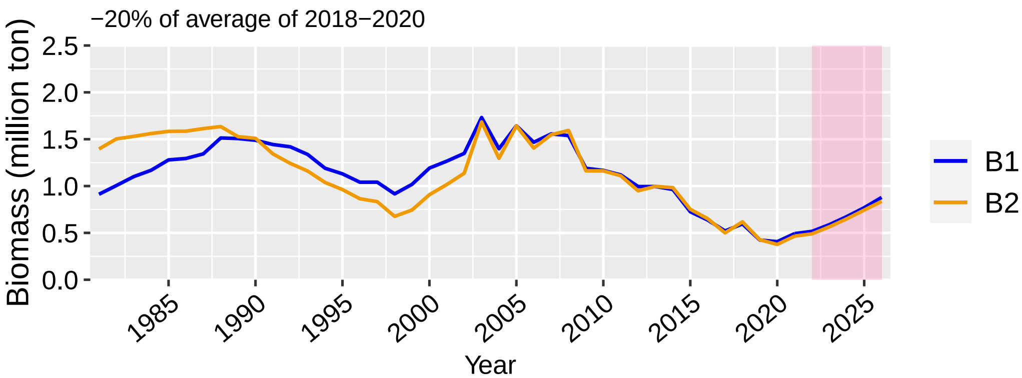

+30% of average of 2018−2020
Biomass (million ton)
2.5
2.0
1.5
1.0
0.5
0.0
1985
1990
1995
2000
2005
2010
2015
2020
2025
Year
B1
B2

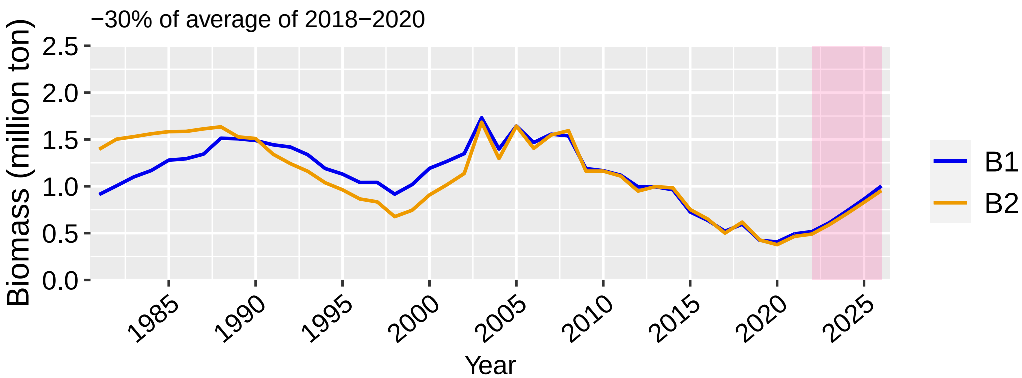

+20% of average of 2018−2020
Biomass (million ton)
2.5
2.0
1.5
1.0
0.5
0.0
1985
1990
1995
2000
2005
2010
2015
2020
2025
Year
B1
B2

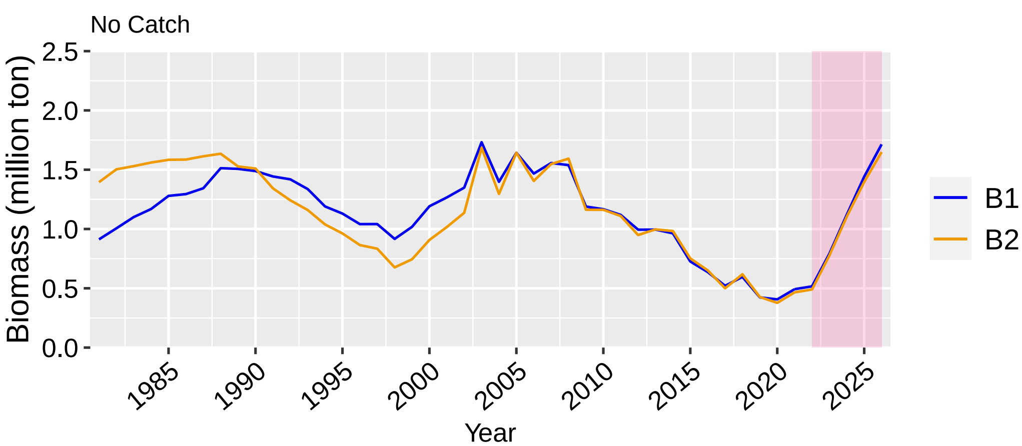

+10% of average of 2018−2020
Biomass (million ton)
2.5
2.0
1.5
1.0
0.5
0.0
1985
1990
1995
2000
2005
2010
2015
2020
2025
Year
B1
B2


average of 2018−2020
Biomass (million ton)
2.5
2.0
1.5
1.0
0.5
0.0
1985
1990
1995
2000
2005
2010
2015
2020
2025
Year
B1
B2


−10% of average of 2018−2020
Biomass (million ton)
2.5
2.0
1.5
1.0
0.5
0.0
1985
1990
1995
2000
2005
2010
2015
2020
2025
Year
B1
B2


−20% of average of 2018−2020
Biomass (million ton)
2.5
2.0
1.5
1.0
0.5
0.0
1985
1990
1995
2000
2005
2010
2015
2020
2025
Year
B1
B2


−30% of average of 2018−2020
Biomass (million ton)
2.5
2.0
1.5
1.0
0.5
0.0
1985
1990
1995
2000
2005
2010
2015
2020
2025
Year
B1
B2


No Catch
Biomass (million ton)
2.5
2.0
1.5
1.0
0.5
0.0
1985
1990
1995
2000
2005
2010
2015
2020
2025
Year
B1
B2

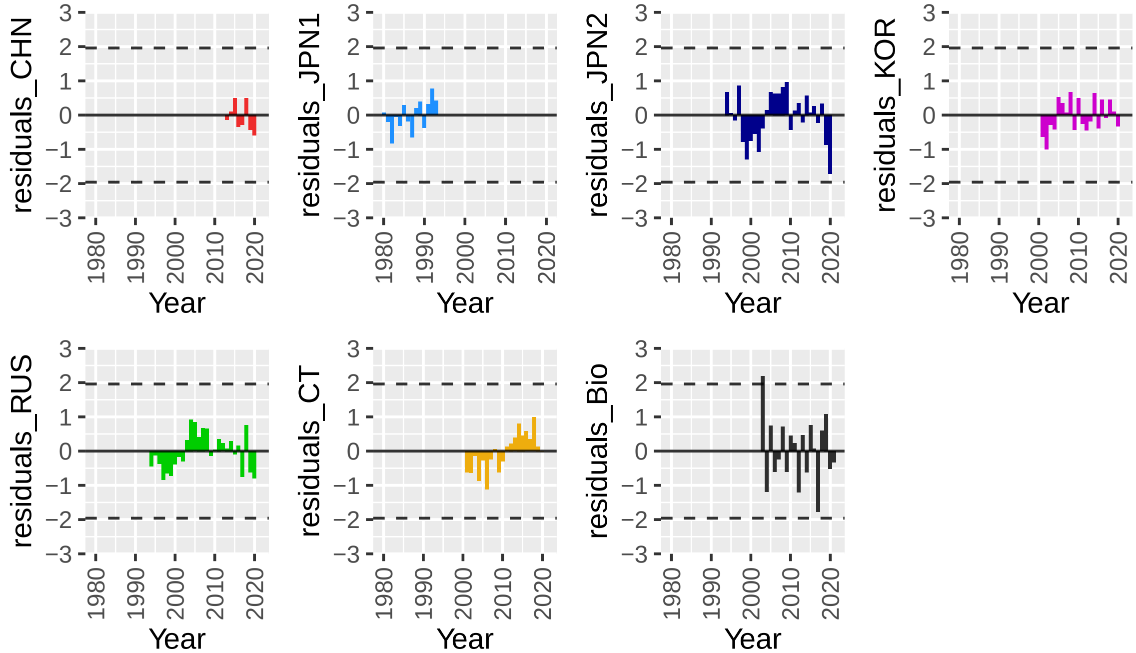
8 Risk table

	Red	Orange	Yellow	Green	B<BMSY	F>FMSY
+30%	0.784	0.001	0.053	0.162	0.837	0.785
+20%	0.725	0.000	0.080	0.194	0.806	0.726
+10%	0.662	0.000	0.108	0.229	0.771	0.663
±0%	0.587	0.000	0.139	0.274	0.726	0.588
-10%	0.495	0.000	0.181	0.323	0.677	0.495
-20%	0.406	0.000	0.227	0.366	0.634	0.406
-30%	0.315	0.000	0.266	0.419	0.581	0.315
No Catch	0.000	0.000	0.254	0.746	0.254	0.000

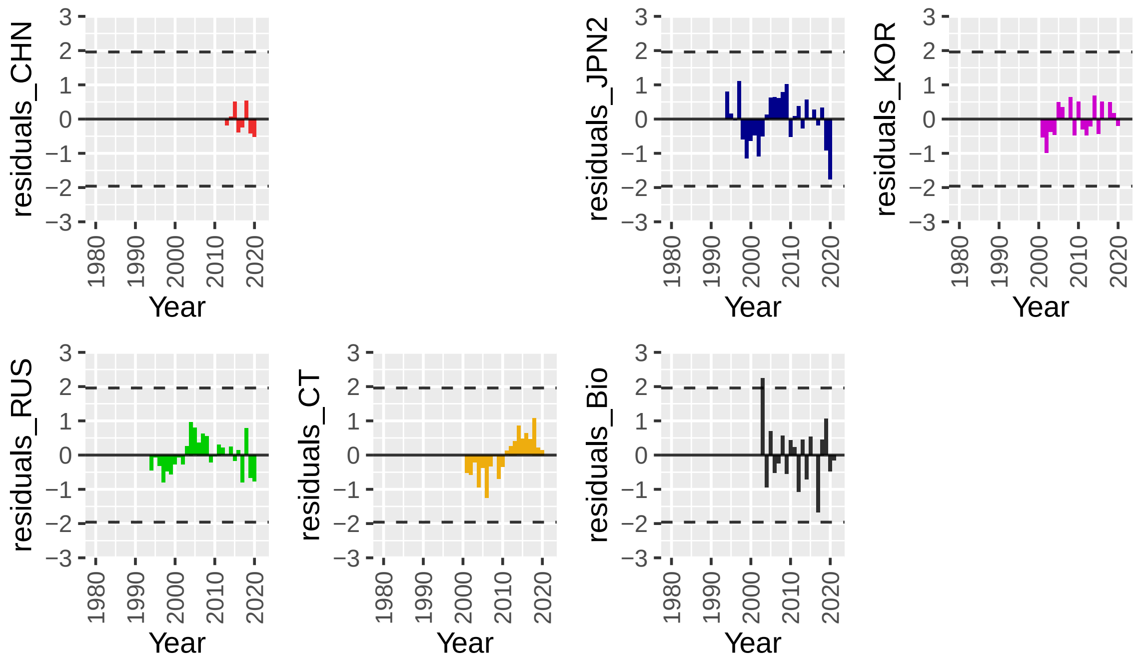
9 Diagnosis

9.1 Standardized residuals plot

Base case 1

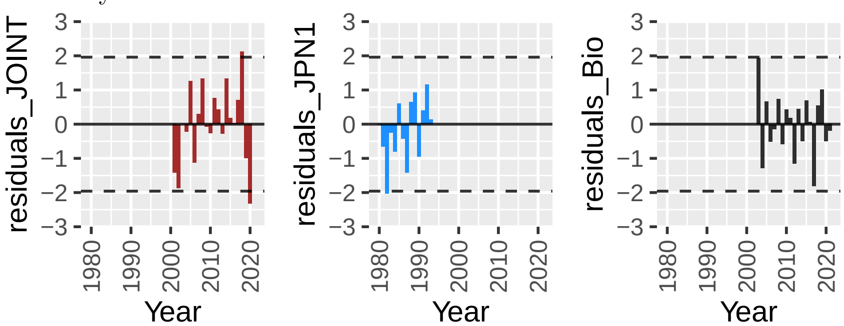


Base case 2



Sensitivity case 1

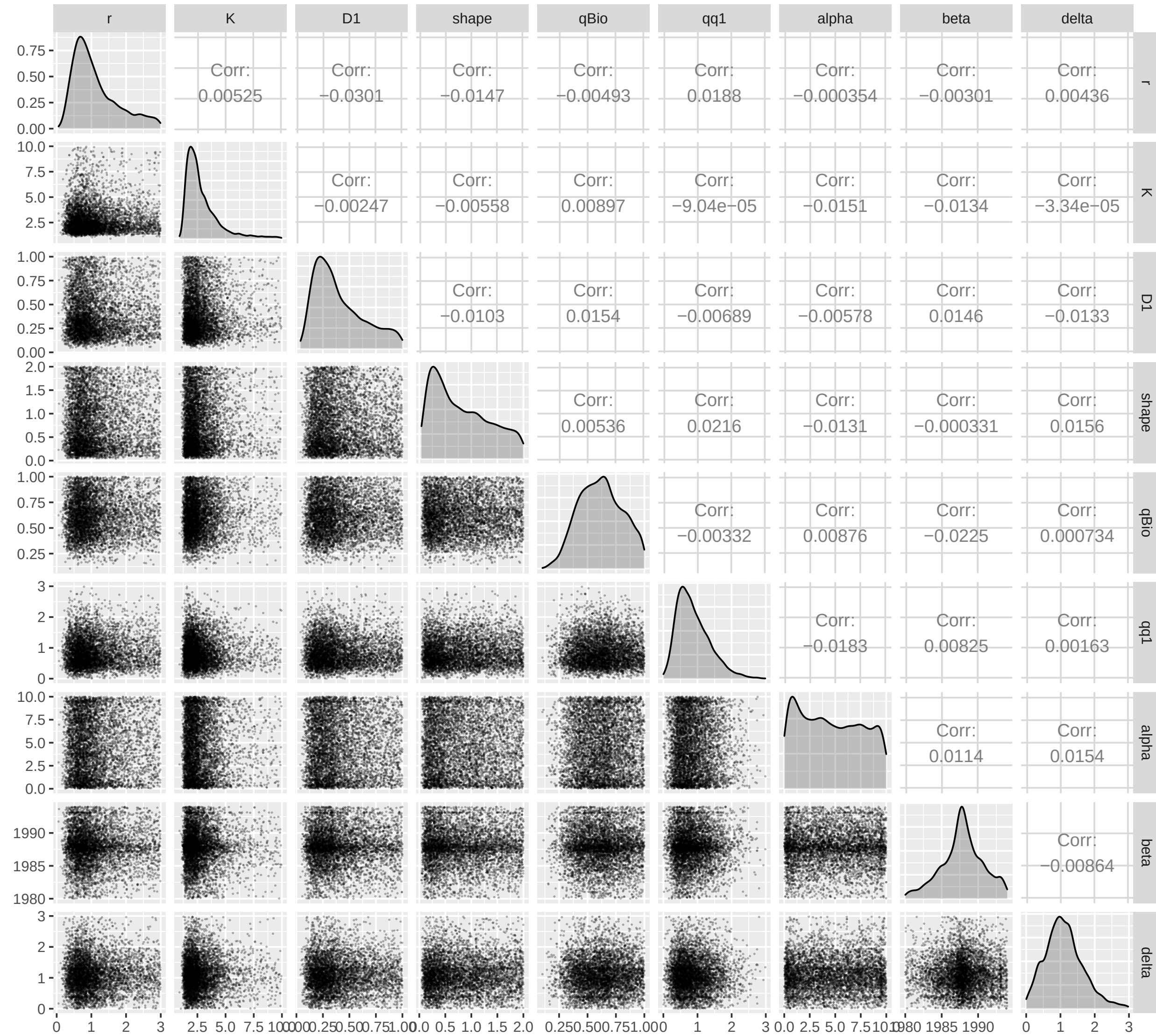
Sensitivity case 2



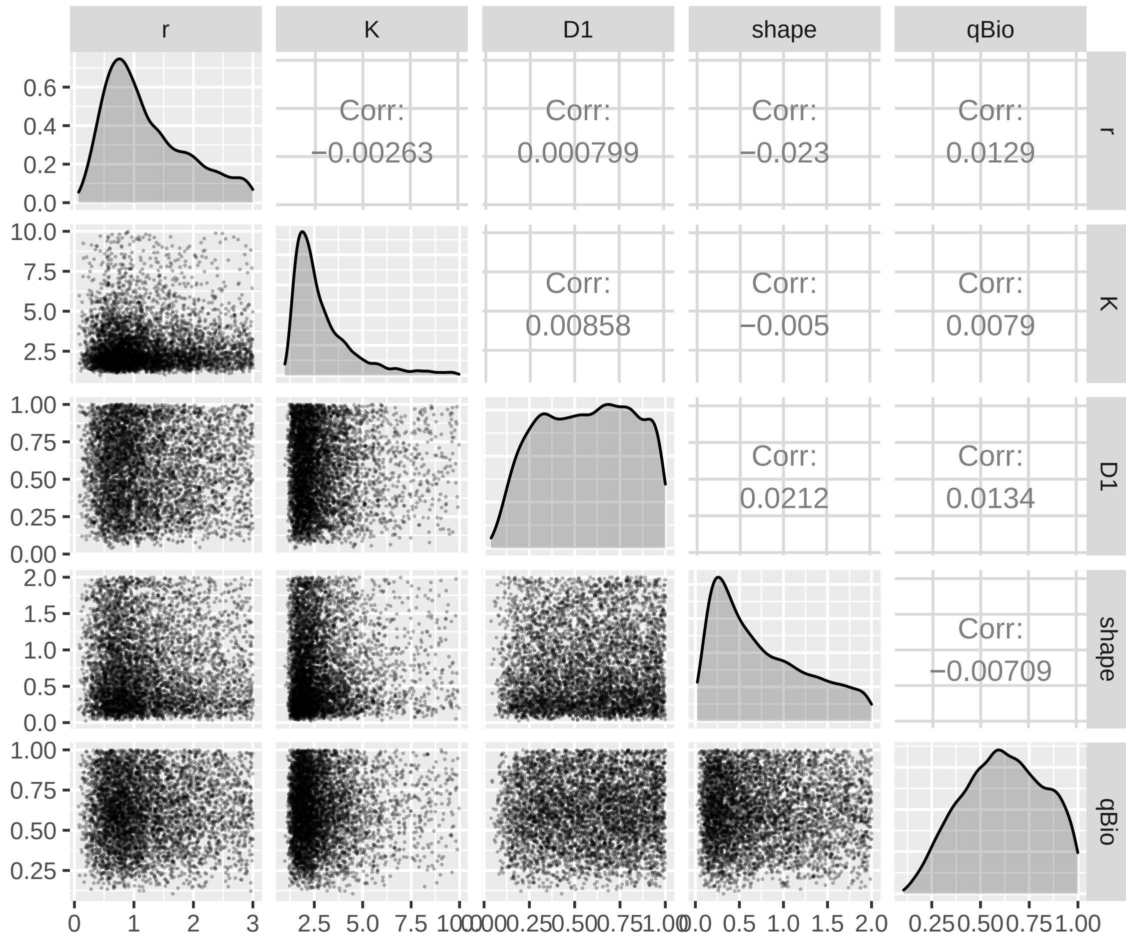
9.2 Correlation

1,000 MCMCsamples from a total of 10,000 samples

Base case 1

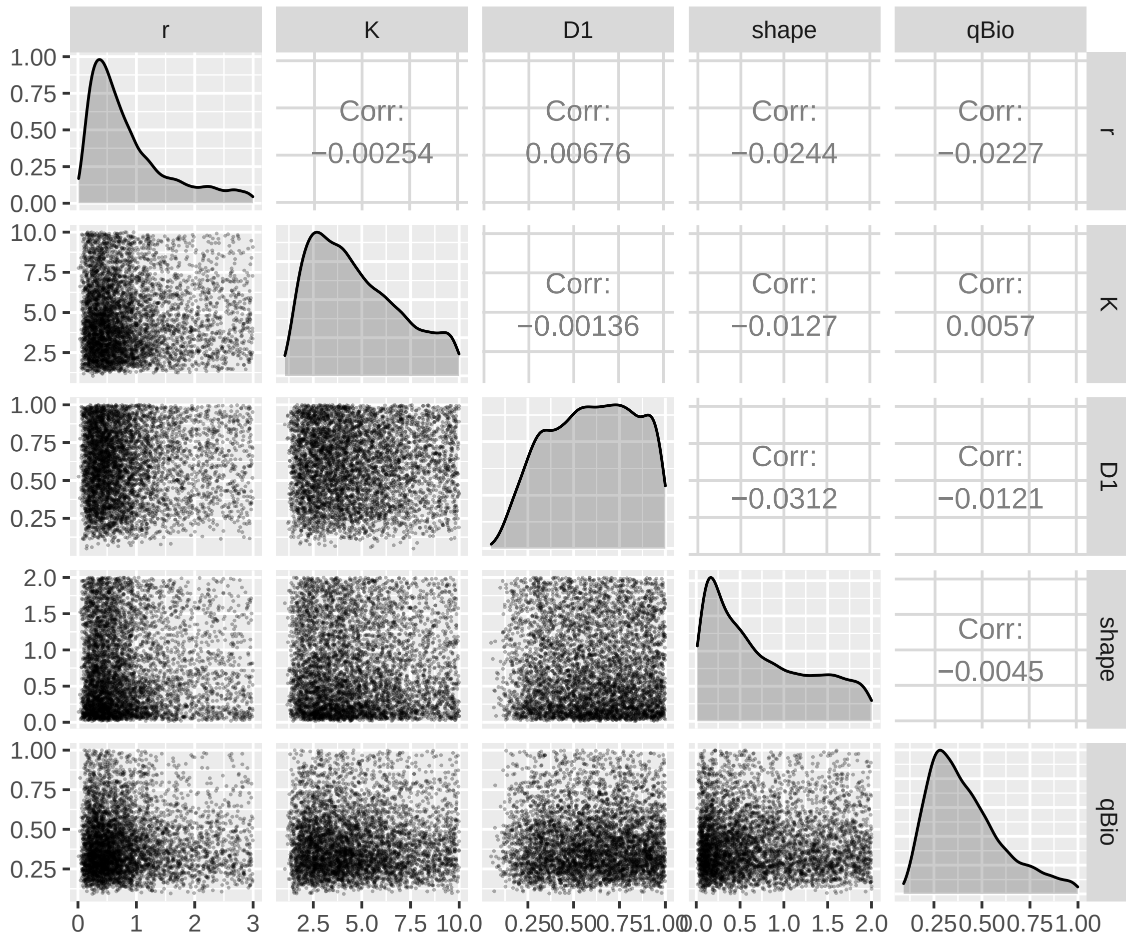


Base case 2



r
K
D1
shape
qBio
Corr:
−0.00263
Corr:
0.000799
Corr:
−0.023
Corr:
0.0129
Corr:
0.00858
Corr:
−0.005
Corr:
0.0079
Corr:
0.0212
Corr:
0.0134
Corr:
−0.00709

Sensitivity case 1



Sensitivity case 2