North Pacific Fisheries Commission

NPFC-2023-SSC PS12-WP09

2023 updates on Pacific saury stock assessment in the North Pacific Ocean using Bayesian state-space production models (rev)

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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 9th SSC-PS meeting. 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 the process errors in the dynamics 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 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 2023 median depletion level was only 21.0% (80%CI=10.7-34.8%) of the carrying capacity. Furthermore, B-ratio (=B/Bmsy) and F-ratio (=F/Fmsy) in 2022 were 0.337 (80%CI=0.229-0.474) and 0.799 (80%CI=0.517-1.384), respectively. For those three years average values, B-ratio over 2021-2023 and F-ratio over 2020-2022 were respectively 0.336 (80%CI=0.206-0.505) and 1.106 (80%CI=0.750-1.701). In addition, the probability of the stock being in the green Kobe quadrant in 2022 was estimated to be nearly 0%, while the probabilities of being in the yellow and red Kobe quadrants were assessed as 72% and 28%, respectively. On the weight-of-evidence available now, the current Pacific saury stock is determined to be overfished. Note that there is a large difference in the biomass series between the two base cases, while there is little difference in relative quantities such as the B- and F-ratios and depletion level.

Based on the updated results, if we apply the same formula used in TAC calculation in the 2019 Commission meeting, it would be Fmsy*B2023=183,000 (tons). However, considering the current overfished population level and applying a simple discount exploitation rate depending on the current B-ratio, an appropriate catch would be (B2023/Bmsy)*Fmsy*B2023=80,000 (tons).

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 9th SSC-PS meeting, 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.

MATERIALS AND METHODS

Data set

1) time series of total reported catch up to 2022

2) standardized CPUE indices by the following five Members up to 2022

3) fishery-independent survey by Japan from 2003 to 2023

4) joint CPUE from 1994 to 2022

Table 1. Specification of the new stock assessment for the BSSPM.

	Base case (NB1)	**Base case (NB2)**	**Sensitivity case (NS1)**	**Sensitivity case(NS2)**
Initial year	1980	1980	1980	1980
Biomass survey	$I_{t,bio} = q_{bio}\, B_t e^{v_{t,bio}}$ $v_{t,bio} \sim N(0, cv_{t,bio}^2 + \sigma^2)$ $q_{bio} \sim U(0,1)$ (2003-2023)	Same as left	Same as left	Same as left
CPUE	CHN(2013-2022) JPN_late(1994-2022) KOR(2001-2022) RUS(1994-2021) CT(2001-2022) $I_{t,f} = q_f B_t^b e^{v_{t,f}}$ $v_{t,f} \sim N(0, \sigma_f^2)$ $\sigma_f^2 = c \cdot \left(ave\left(cv_{t,bio}^2\right) + \sigma^2\right)$, where $ave(cv_{t,bio}^2)$ is computed except for 2020 survey ($c = 5$)	Joint CPUE (1994-2022) $I_{t,joint} = q_{joint} B_t^b e^{v_{t,joint}}$ $v_{t,joint} \sim N(0, cv_{t,joint}^2 + \sigma^2)$	CHN(2013-2022) JPN_early(1980-1993, time-varying q) JPN_late(1994-2022) KOR(2001-2022) RUS(1994-2021) CT(2001-2022) $I_{t,f} = q_f B_t^b e^{v_{t,f}}$ $v_{t,f} \sim N(0, \sigma_f^2)$ $\sigma_f^2 = c \cdot \left(ave\left(cv_{t,bio}^2\right) + \sigma^2\right)$, where $ave(cv_{t,bio}^2)$ is computed except for 2020 survey ($c = 6$)	JPN_early(1980-1993, time-varying q) $I_{t,JE} = q_{t,JE} B_t^b e^{v_{t,JE}}$ $v_{t,JE} \sim N(0, \sigma_{JE}^2)$ $\sigma_{JE}^2 = c \cdot \left(ave\left(cv_{t,joint}^2\right) + \sigma^2\right)$ Joint CPUE (1994-2022) $I_{t,joint} = q_{joint} B_t^b e^{v_{t,joint}}$ $v_{t,joint} \sim N(0, cv_{t,joint}^2 + \sigma^2)$
Hyper-depletion/ stability	A common parameter for all fisheries with a prior distribution, $b \sim U(0, 1)$	$b \sim U\,(0, 1)$	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]	$b \sim U\,(0, 1)$ for joint CPUE. [b for JPN_early is fixed at 1]
Prior for other than q_{bio}	Own preferred options	Own preferred options	Own preferred options	Own preferred options

Specification of analysis

We basically used the similar statistical models as Chiba and Kitakado (2019) with some amendment by following the PS09 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 2023 median depletion level was only 21.0% (80%CI=10.7-34.8%) of the carrying capacity. Furthermore, B-ratio (=B/Bmsy) and F-ratio (=F/Fmsy) in 2022 were 0.337 (80%CI=0.229-0.474) and 0.799 (80%CI=0.517-1.384), respectively. For those three years average values, B-ratio over 2021-2023 and F-ratio over 2020-2022 were respectively 0.336 (80%CI=0.206-0.505) and 1.106 (80%CI=0.750-1.701).

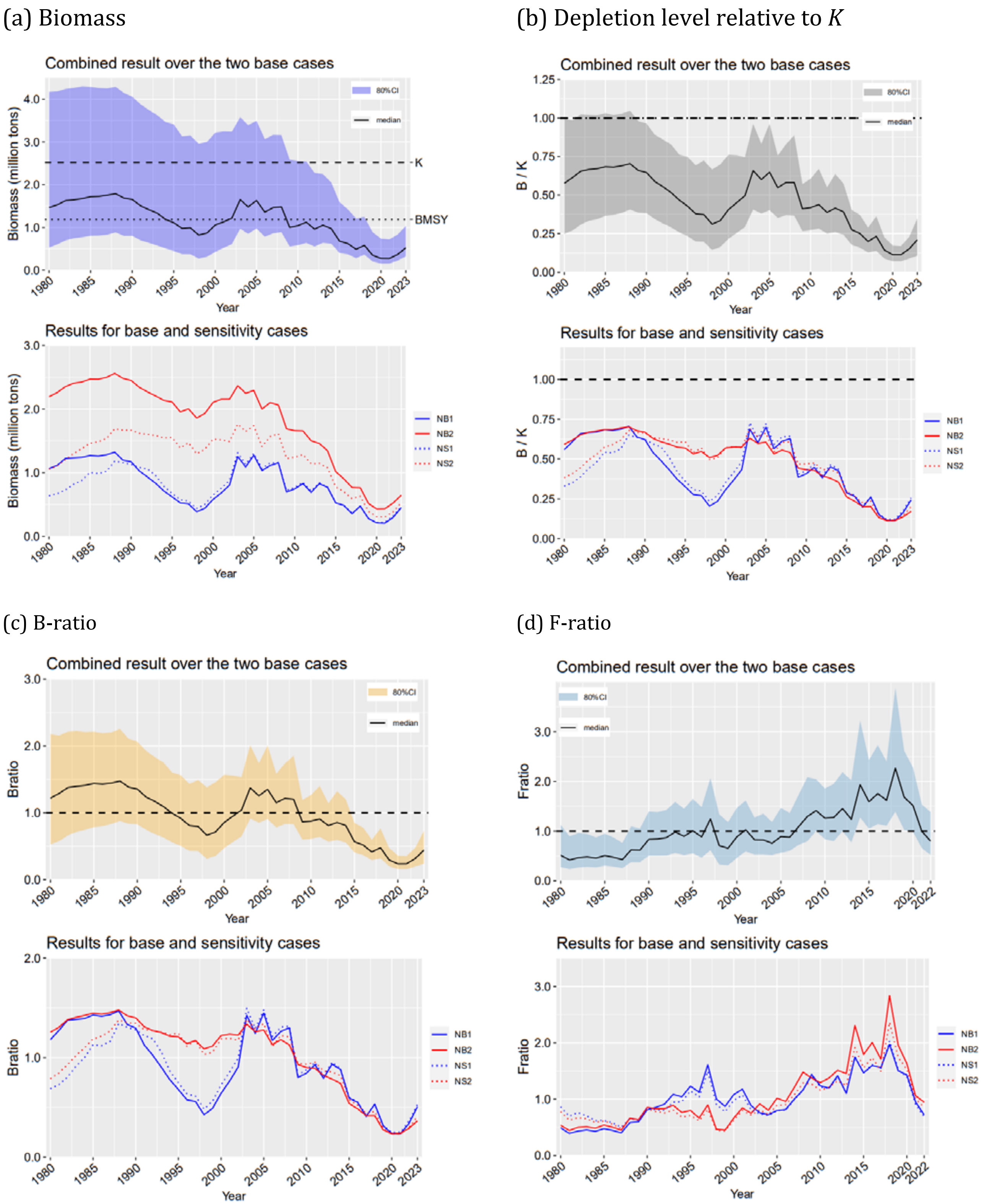


Figure 2. Results of trajectories over the two base cases of (a) biomass, (b) depletion level relative to the carrying capacity, (c) B-ratio and (d) F-ratio.

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

	Mean	Median	Lower10th	Upper10th
C_2022 (million tons)	0.100	0.100	0.100	0.100
AveC_2020_2022	0.111	0.111	0.111	0.111
AveF_2020_2022	0.386	0.376	0.148	0.638
F_2022	0.278	0.270	0.120	0.444
FMSY	0.358	0.350	0.117	0.606
MSY (million tons)	0.403	0.399	0.309	0.496
F_2022/FMSY	0.896	0.799	0.517	1.384
AveF_2020_2022/FMSY	1.186	1.106	0.750	1.701
K (million tons)	3.284	2.518	1.412	6.575
B_2022 (million tons)	0.467	0.371	0.226	0.831
B_2023 (million tons)	0.627	0.523	0.326	1.039
AveB_2021_2023	0.489	0.390	0.245	0.849
BMSY (million tons)	1.513	1.186	0.695	2.905
BMSY/K	0.473	0.469	0.397	0.555
B_2022/K	0.156	0.151	0.088	0.228
B_2023/K	0.222	0.210	0.107	0.348
AveB_2021_2023/K	0.165	0.160	0.092	0.242
B_2022/BMSY	0.347	0.337	0.229	0.474
B_2023/BMSY	0.470	0.441	0.237	0.730
AveB_2021_2023/BMSY	0.350	0.336	0.206	0.505

Evidently, Figure 3, which is the Kobe plot with time series of median B-ratio and F-ratio for 1980-2022, also shows that the probability of the stock being in the green Kobe quadrant in 2022 was estimated to be nearly 0%, while the probabilities of being in the yellow and red Kobe quadrants were assessed as 72% and 28%, respectively. On the weight-of-evidence available now, the current Pacific saury stock is determined not to be overfished and subject to overfishing.

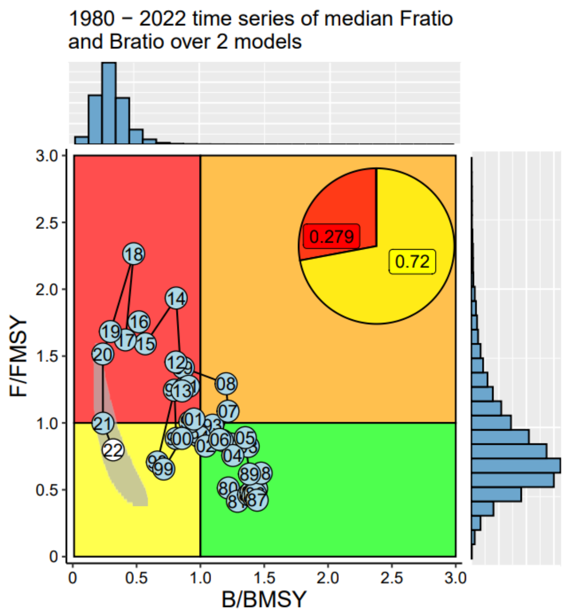


Figure 3. Kobe plot with time series of median B-ratio and F-ratio for 1980-2022.

Conclusion

1) Biomass level: the 2023 median depletion level was only 21.0% (80%CI=10.7-34.8%) of the carrying capacity.

2) Reference points: B-ratio (=B/Bmsy) and F-ratio (=F/Fmsy) in 2022 were 0.337 (80%CI=0.229-0.474) and 0.799 (80%CI=0.517-1.384), respectively. For those three years average values, B-ratio over 2021-2023 and F-ratio over 2020-2022 were respectively 0.336 (80%CI=0.206-0.505) and 1.106 (80%CI=0.750-1.701).

3) The probability of the stock being in the green Kobe quadrant in 2022 was estimated to be nearly 0%, while the probability of being in the yellow or red Kobe quadrant was assessed to be greater than 100%.

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

5) There is a large difference in the biomass series between the two base cases, while there is little difference in relative quantities such as the B-/F-ratios and depletion level.

6) Based on our updated results, if we apply the same formula used in TAC calculation in the 2019 Commission meeting, it would be Fmsy*B2023=0.350*523,000=183,000 (tons).

7) However, considering the current overfished population level and applying a simple discount exploitation rate depending on the current B-ratio, an appropriate catch would be (B2023/Bmsy)*Fmsy*B2023=0.441*0.350*523,000=80,000 (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 (2022) Report of the SSC-PS09.

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-PS09 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-PS09 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 1
(7) Develop retrospective analysis to verify whether any possible systematic inconsistencies exist among model estimates of biomass and fishing mortality	See Appendix 2
(8) Identify final model configuration and model runs for each scenario;	See SSC-PS09 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 1
(10) For each scenario, estimate biological reference points (e.g., MSY, Bmsy, Fmsy) and its associated uncertainty;	See the main text and Appendix 1
(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 1
(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-PS09
(15) Develop alternative ABCs for the projection (e.g., 5-year projection);	See Appendix 1 for the relevant information
(16) Conduct risk analysis for each level of ABC defined in the base-case scenario;	See Appendix 1 for the relevant information
(17) Develop decision tables with alternative state of nature;	See Appendix 1 for the relevant information
(18) Determine optimal ABCs based on decision tables developed in Step (17);	See Appendix 1 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 2.

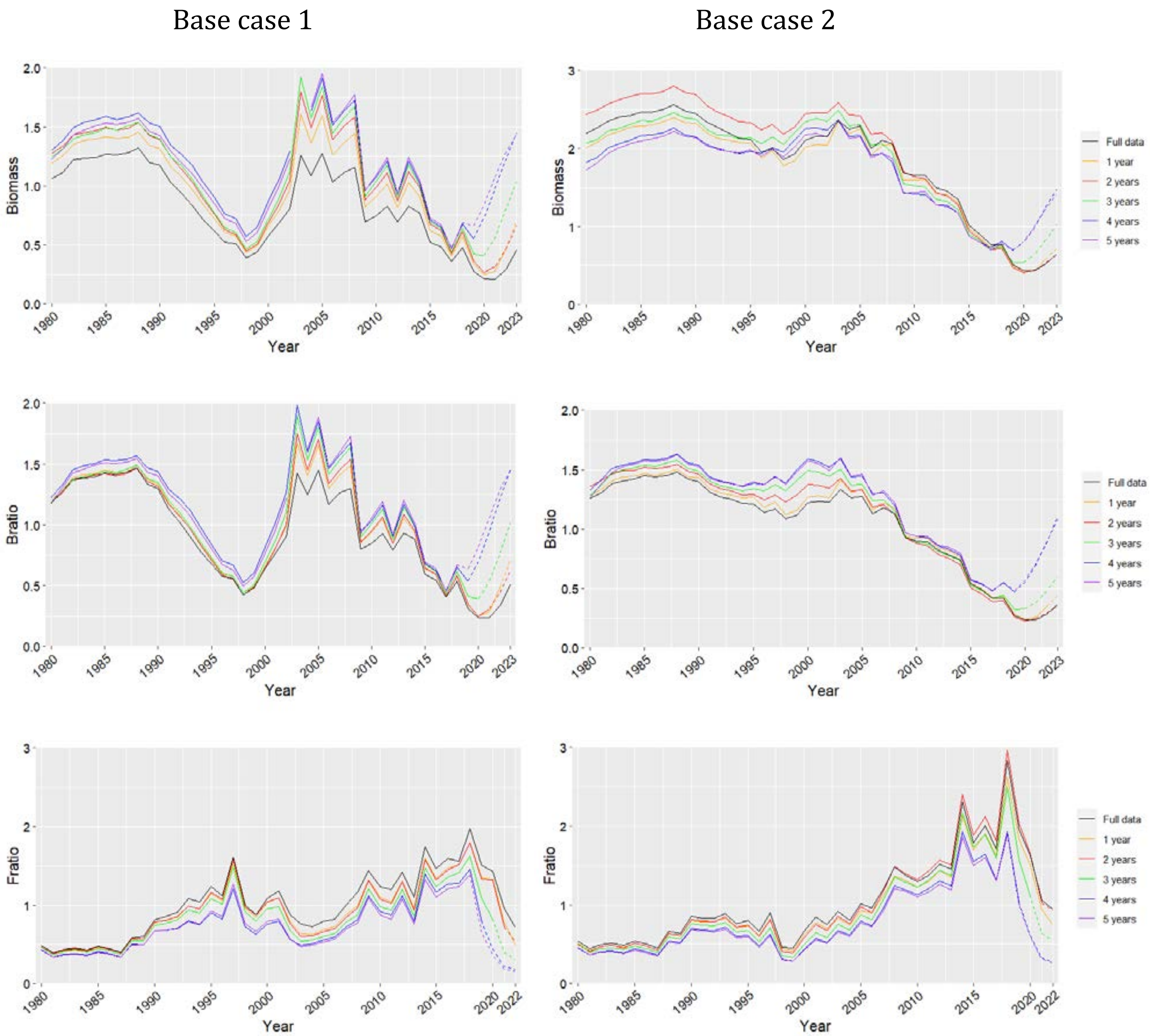


Figure A1. Results of retrospective analysis for Biomass, B-ratio and F-ratio for the two base cases.

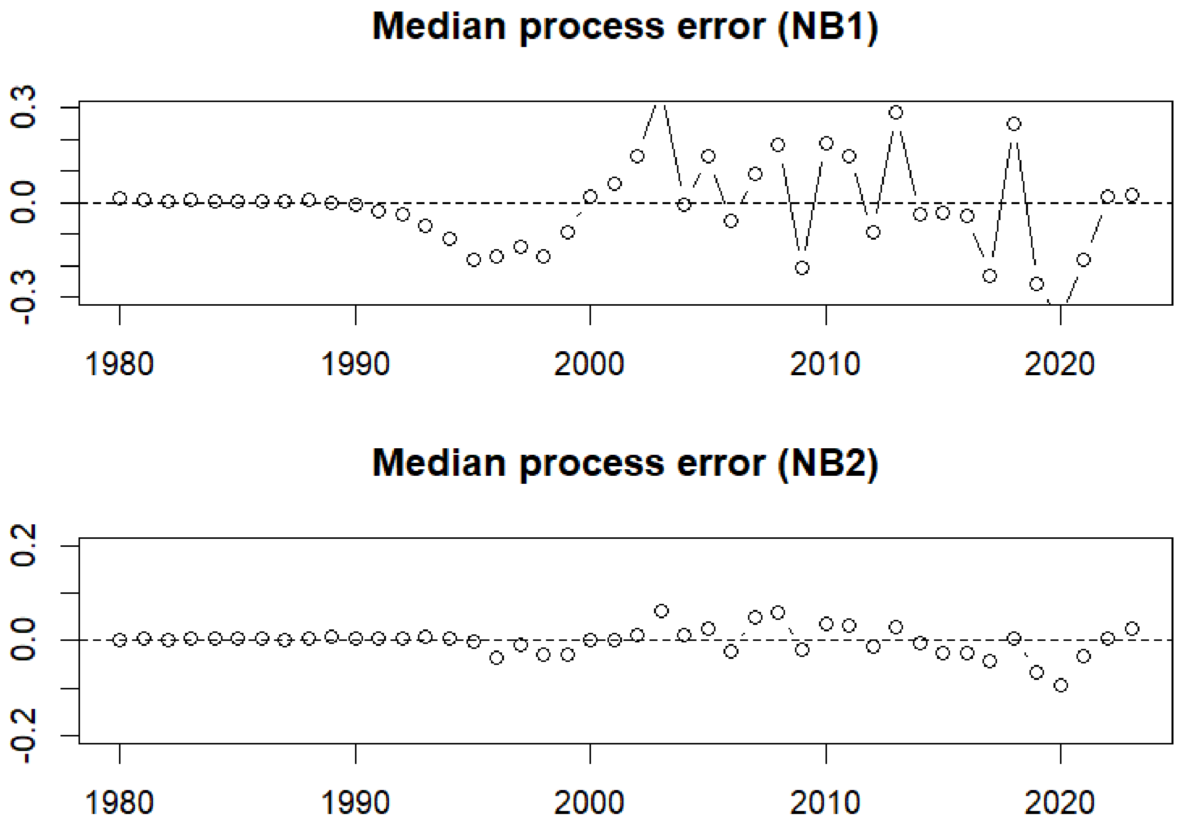
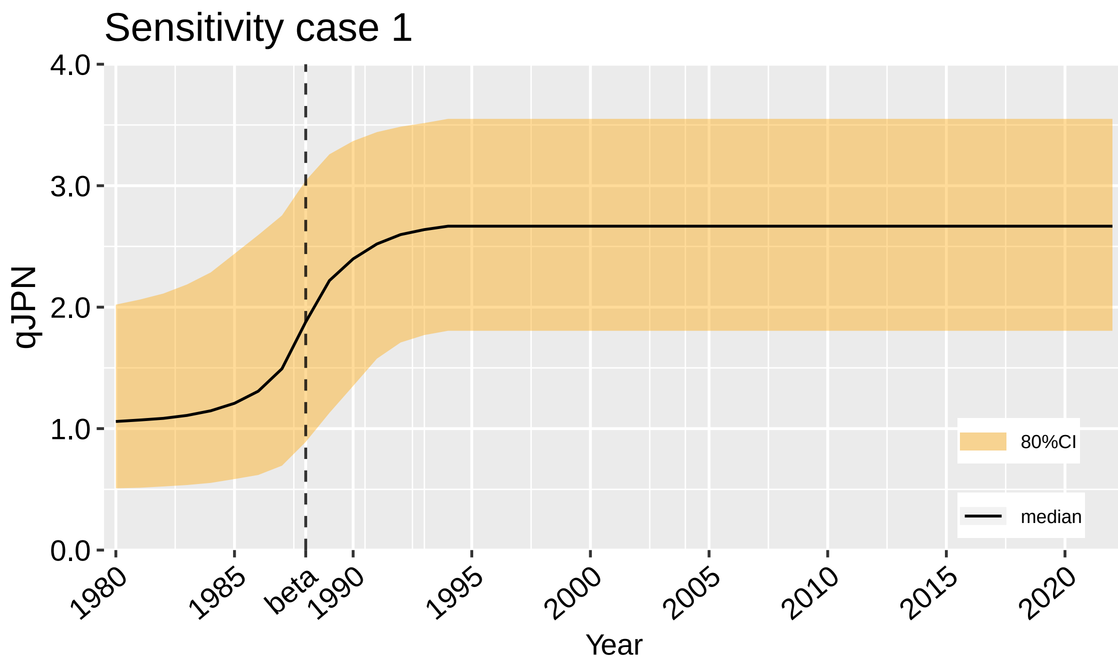


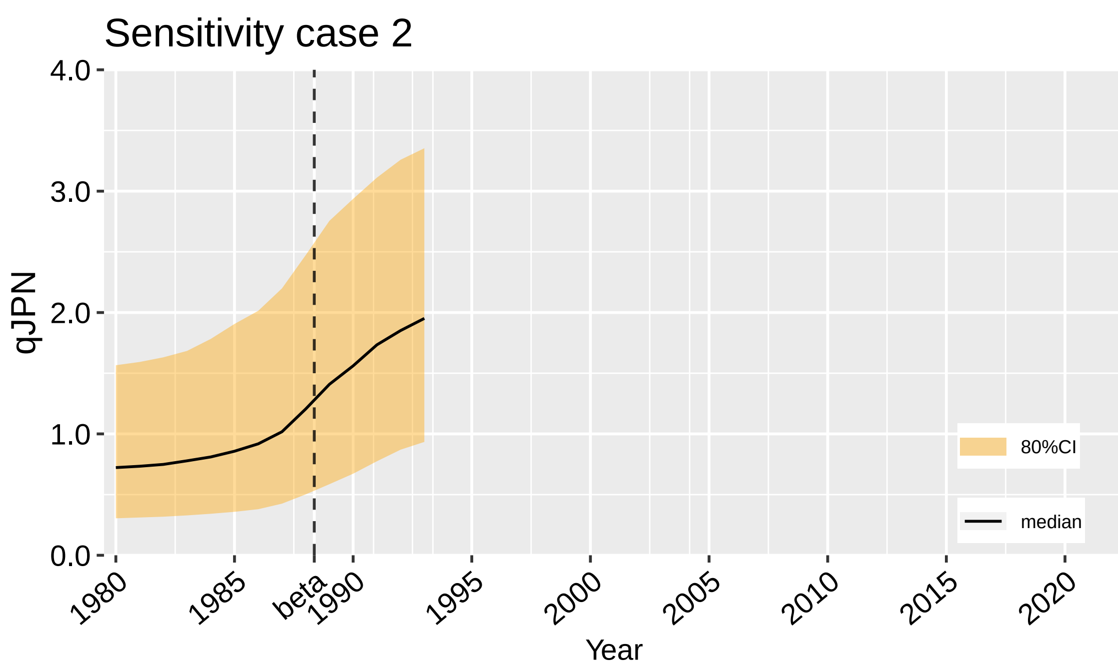
Figure A2. Median time series of process errors in base case models 1 and 2.

Appendix:

Contents

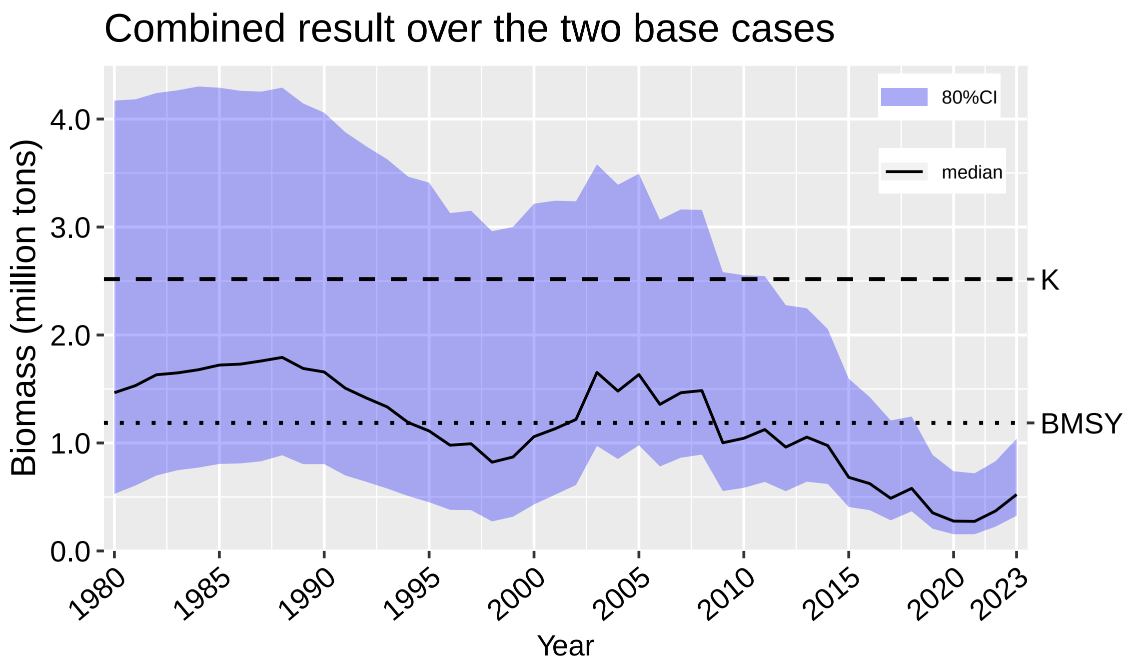
1 Estimated time-varying catchability

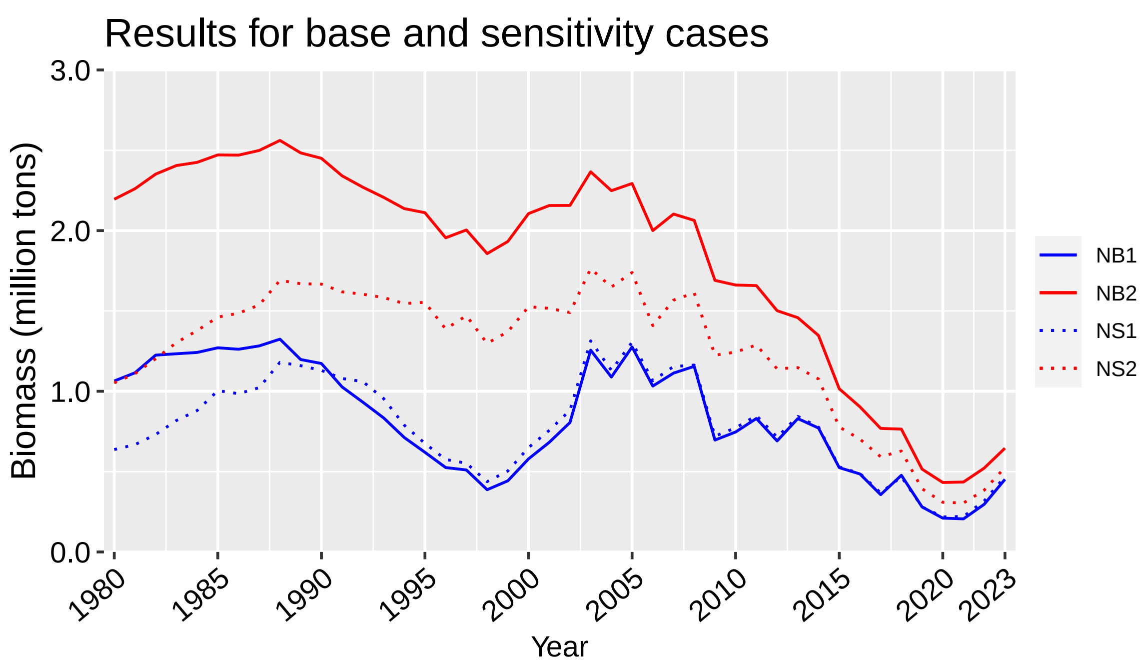


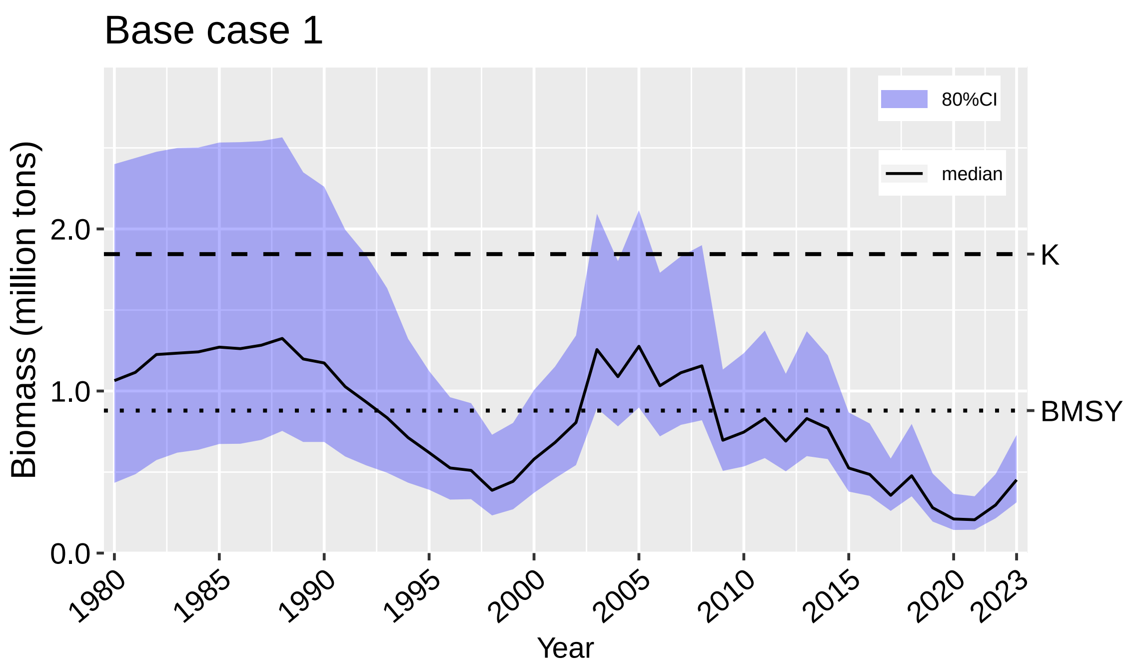


2 Time series plot

2.1 Time series Biomass






Base case 1
80%CI
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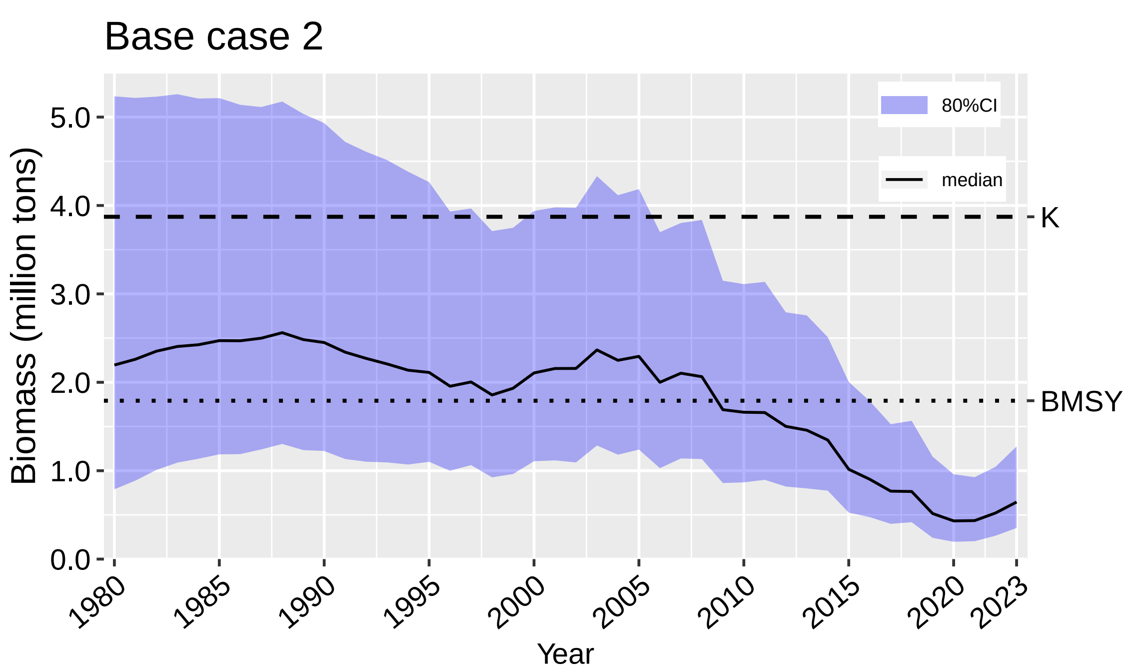
Base case 2
80%CI
median
K
BMSY
Biomass (million tons)
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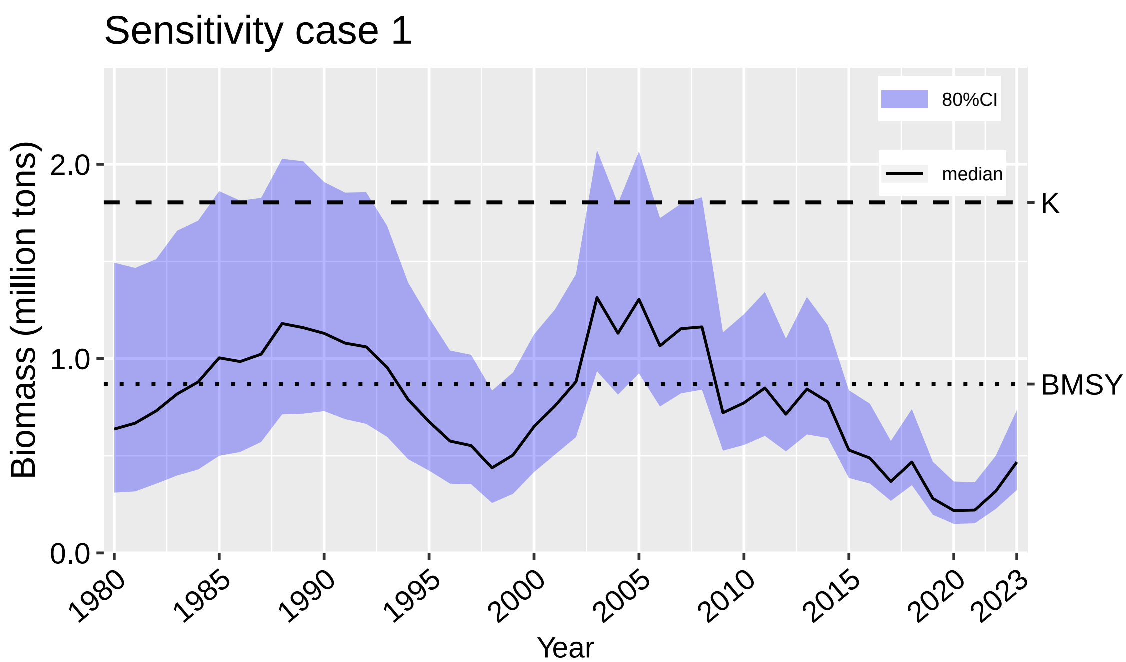
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median
K
BMSY
Biomass (million tons)
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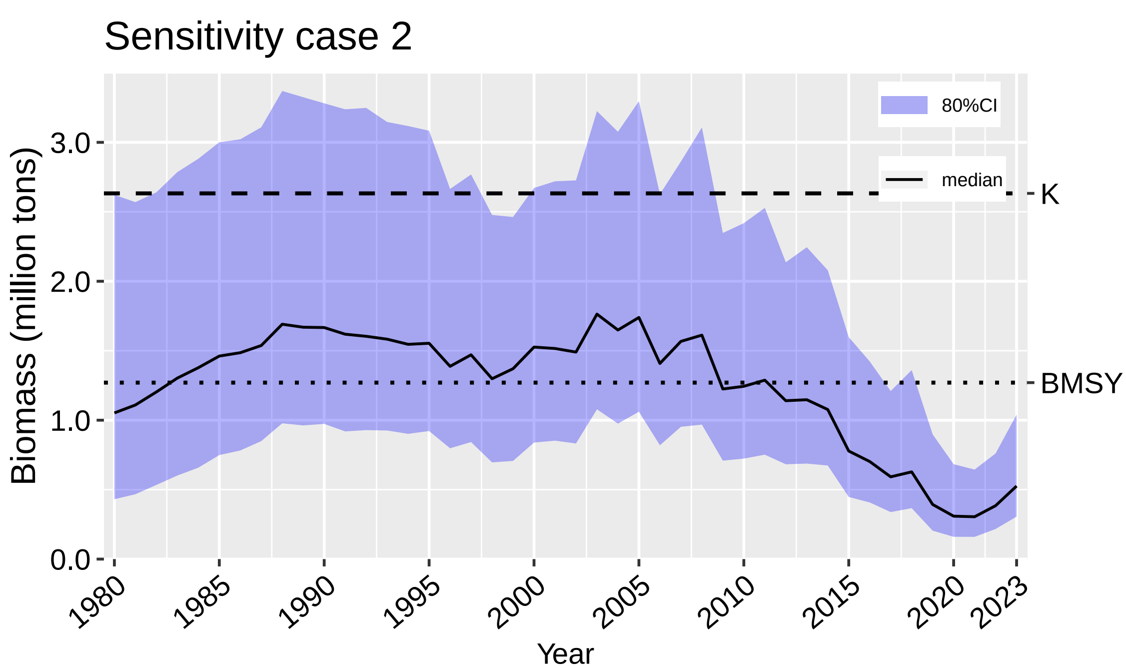
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Biomass (million tons)
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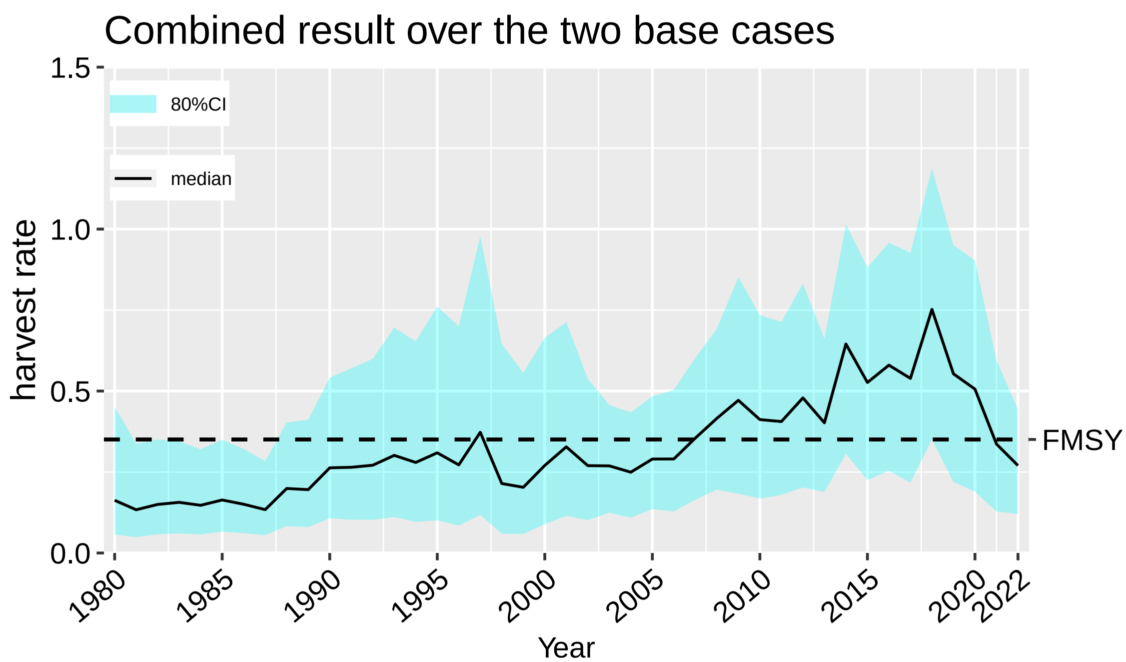
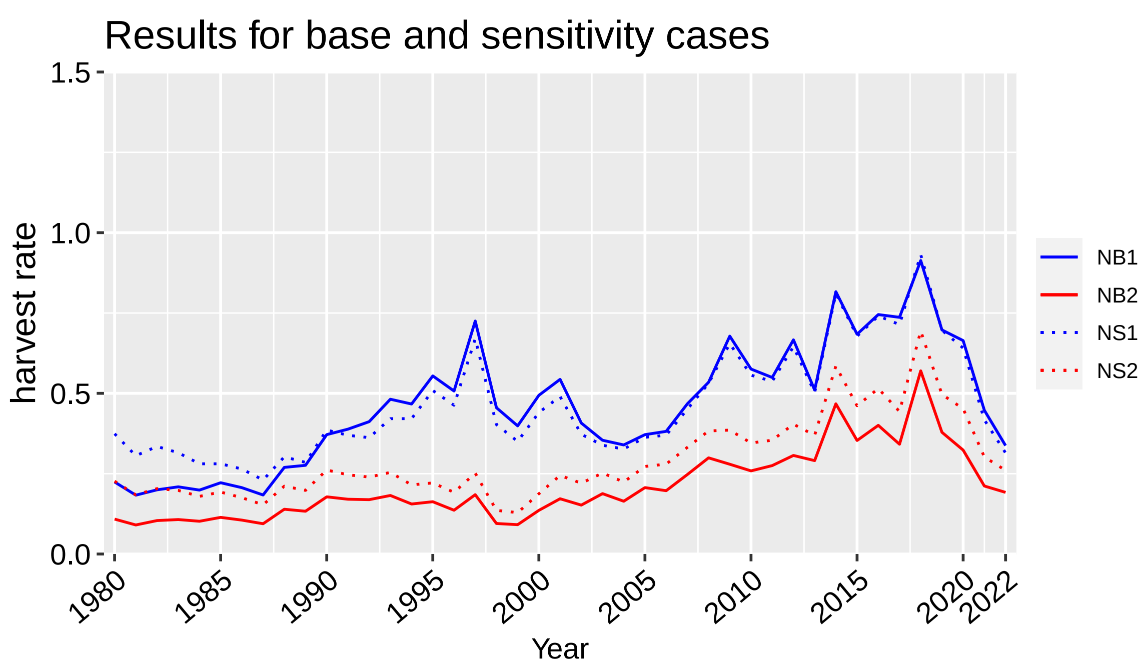
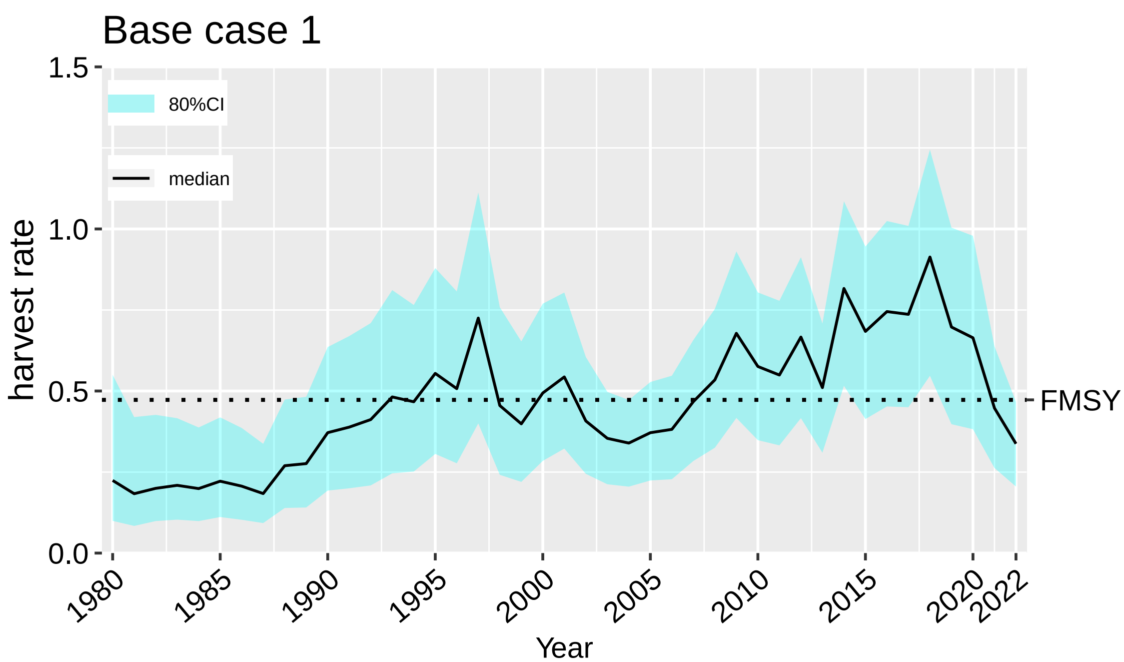
2.2 Time series Harvest rate



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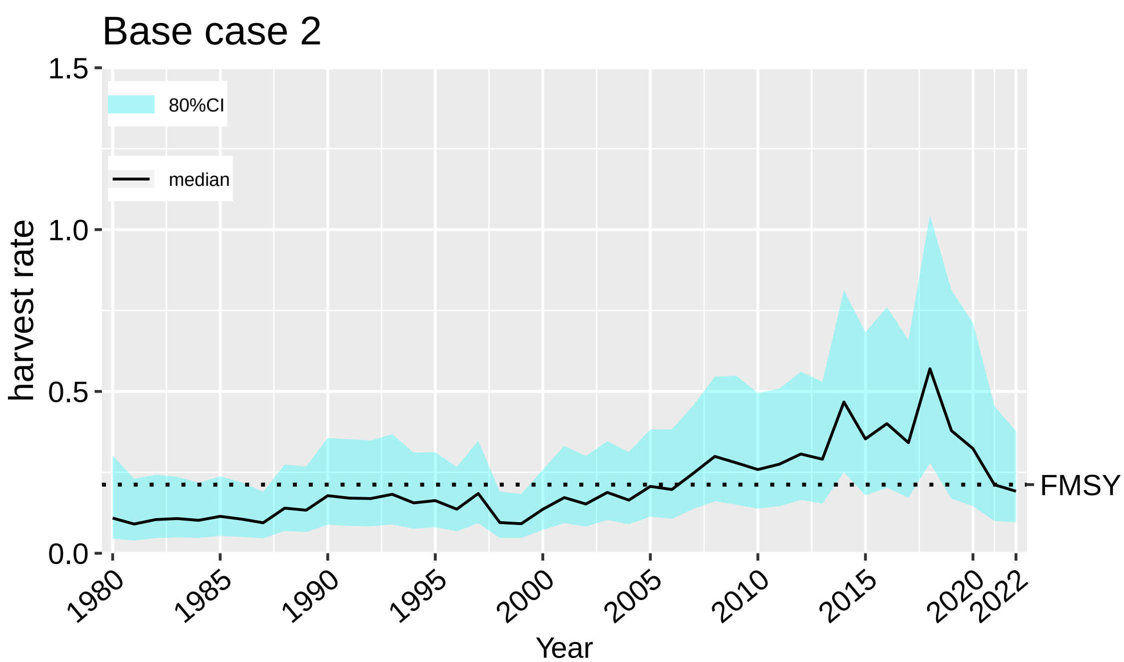
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harvest rate
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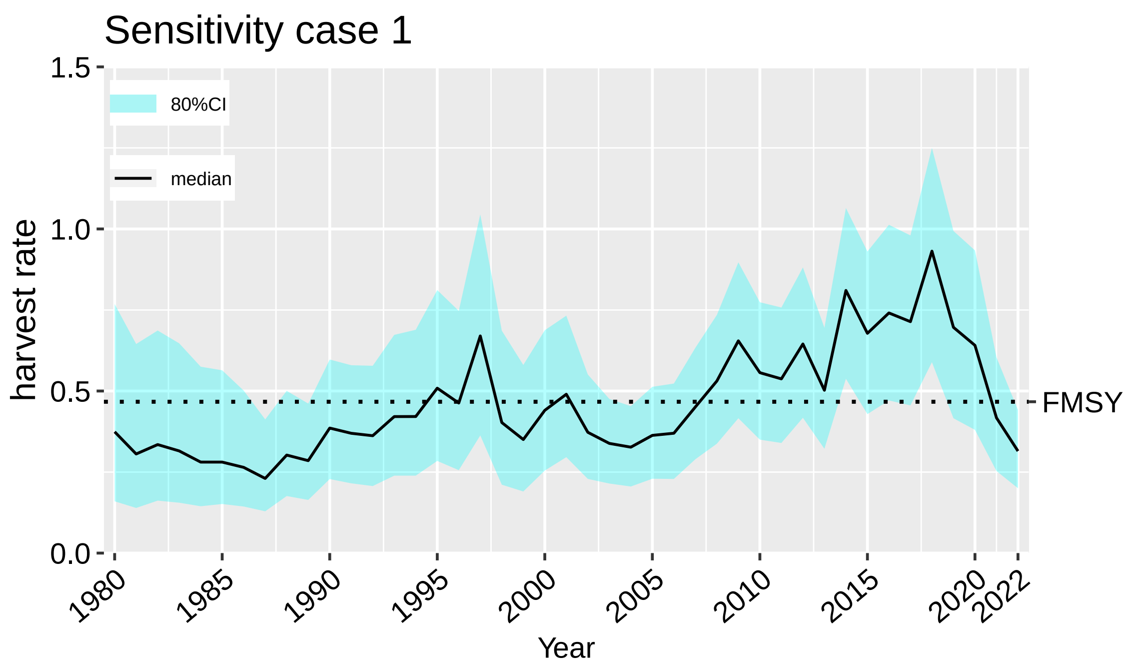
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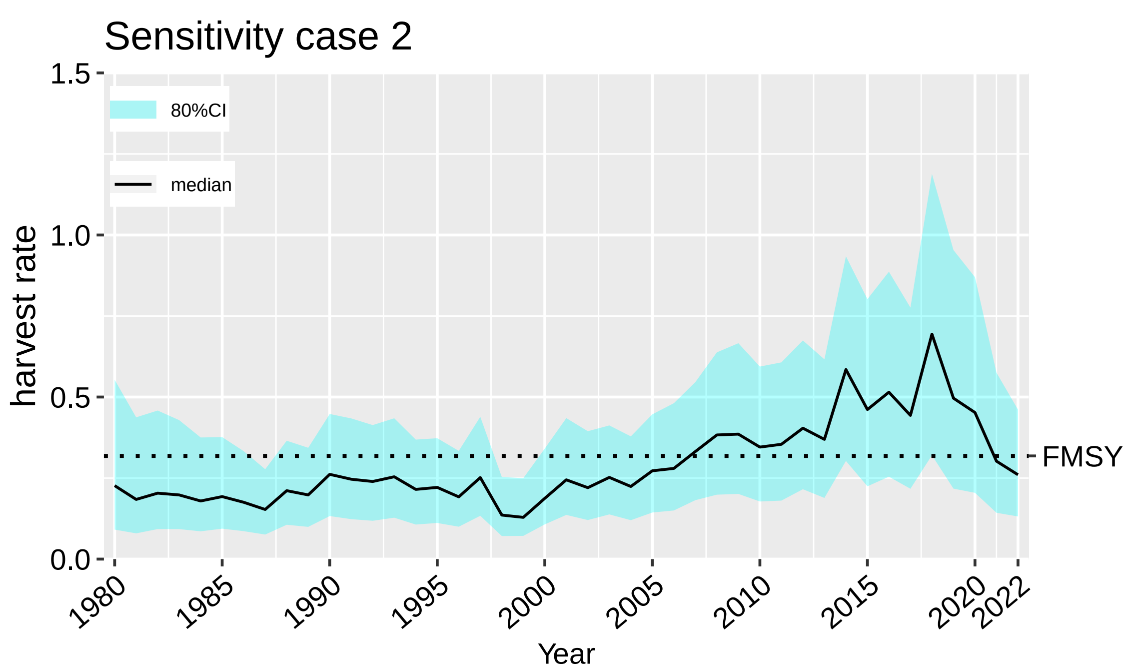
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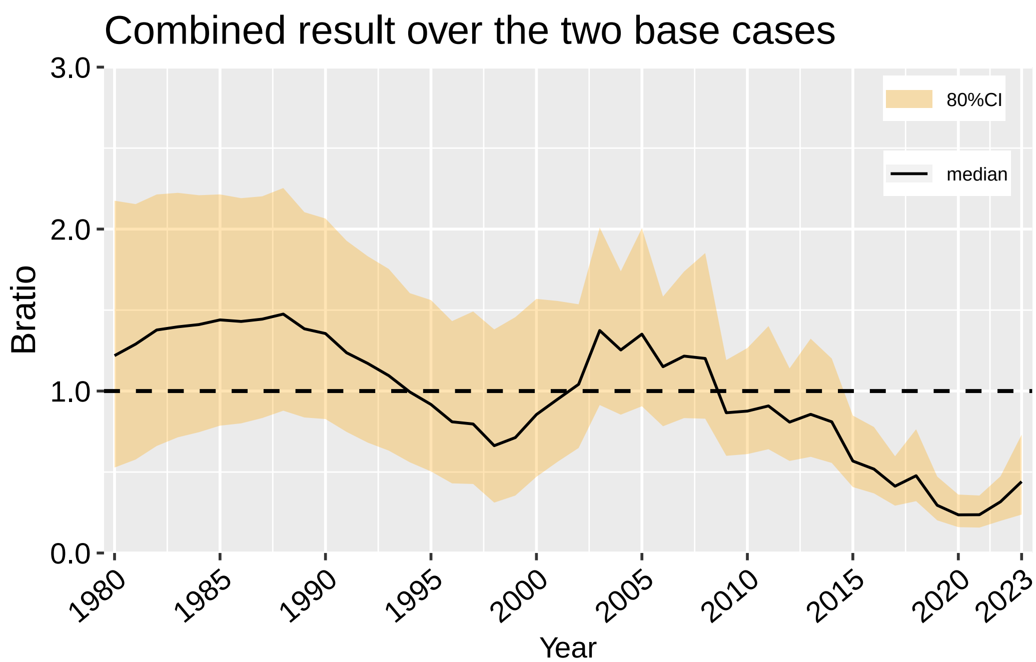

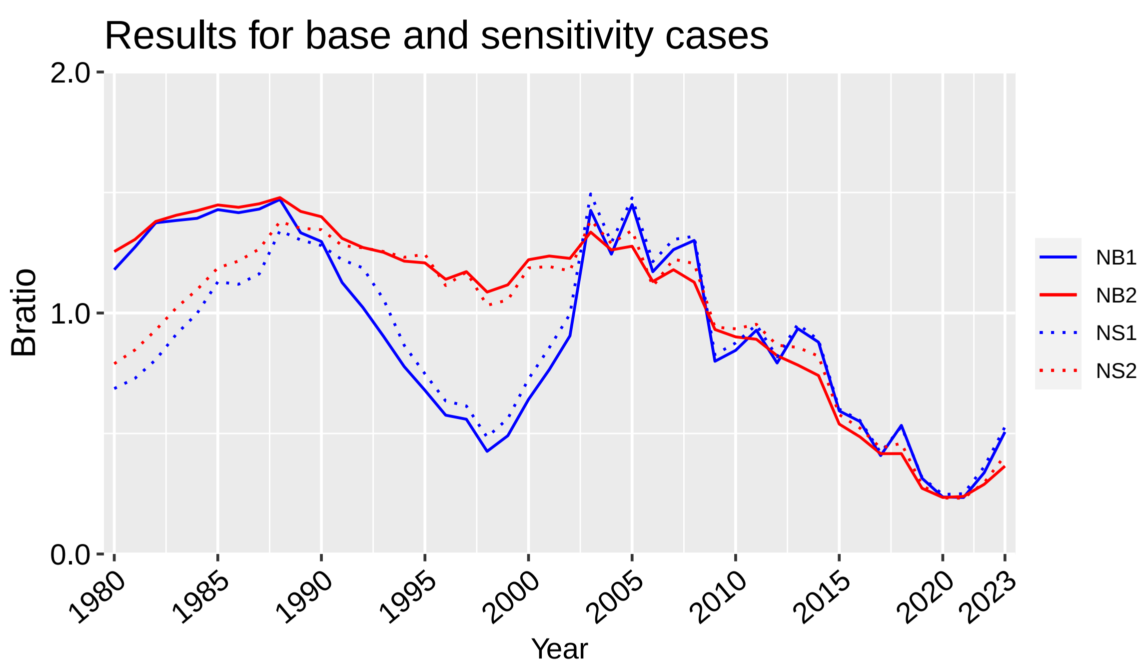

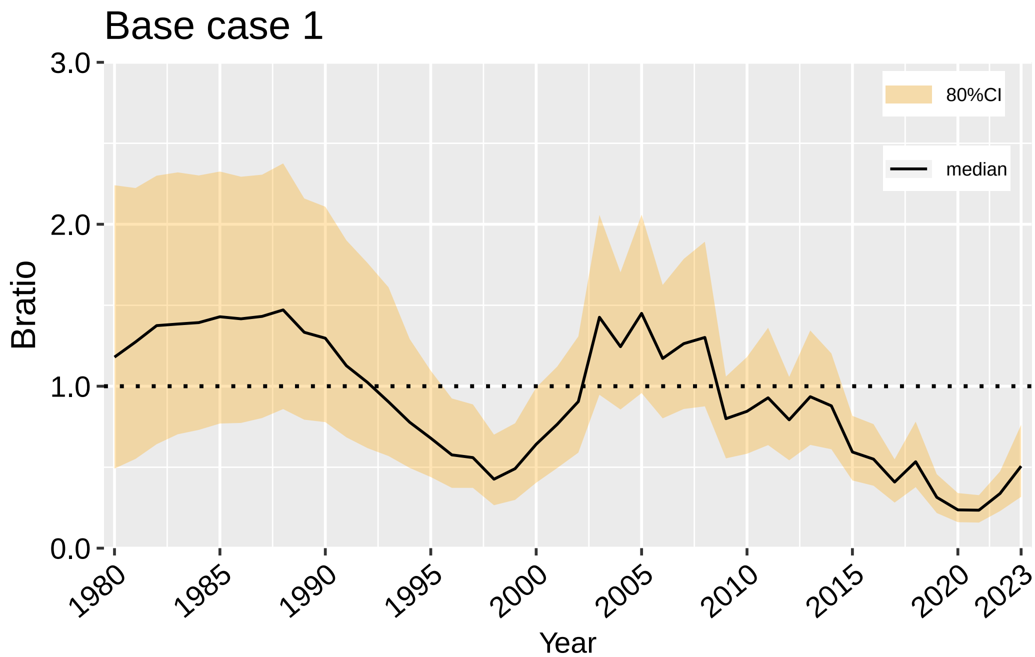
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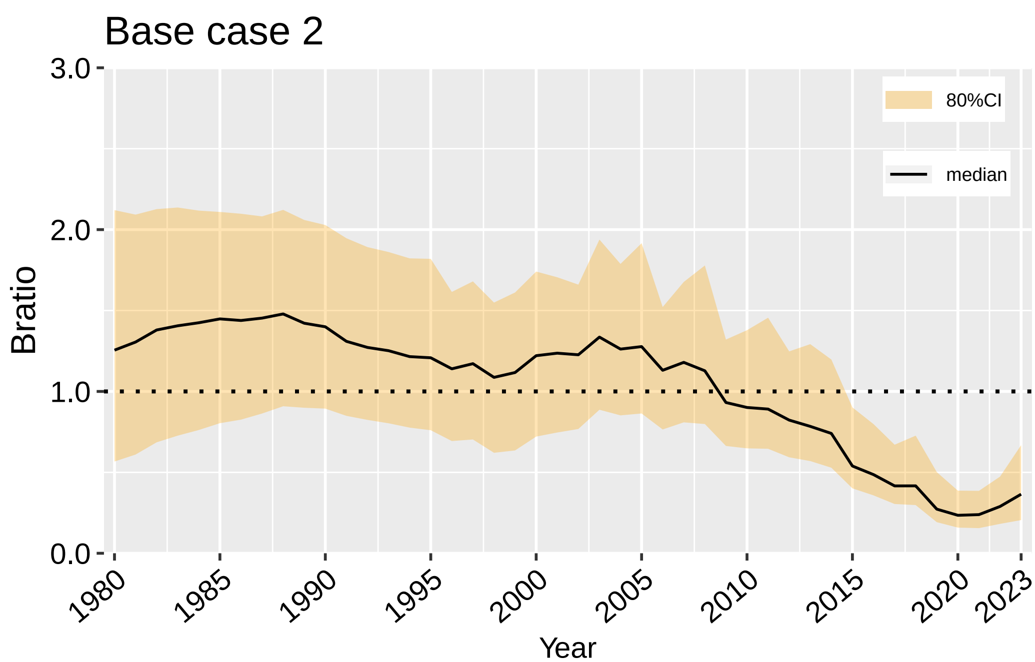
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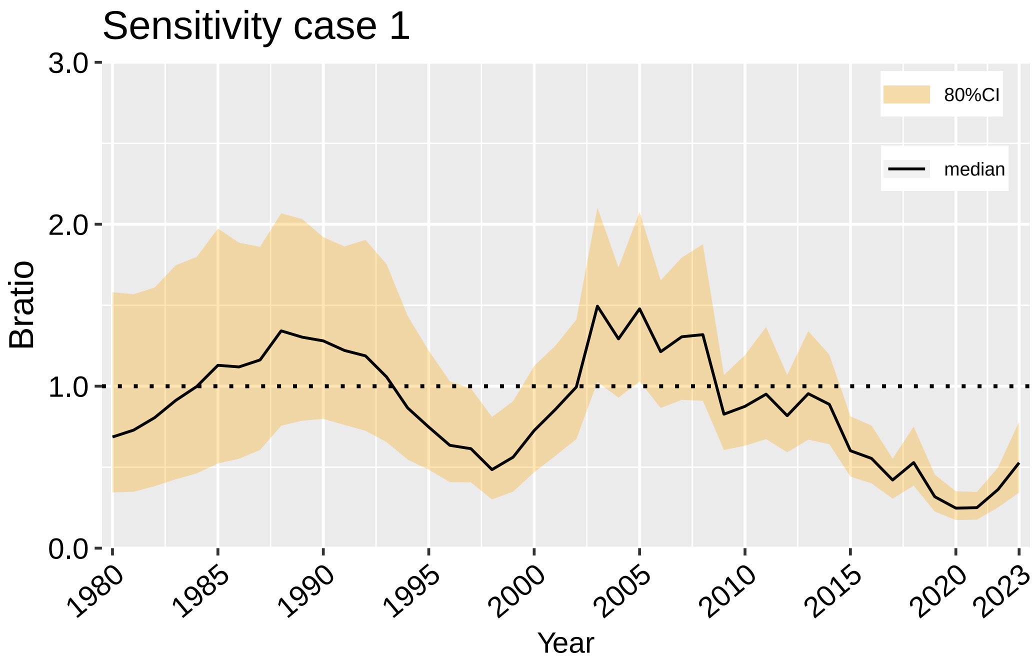
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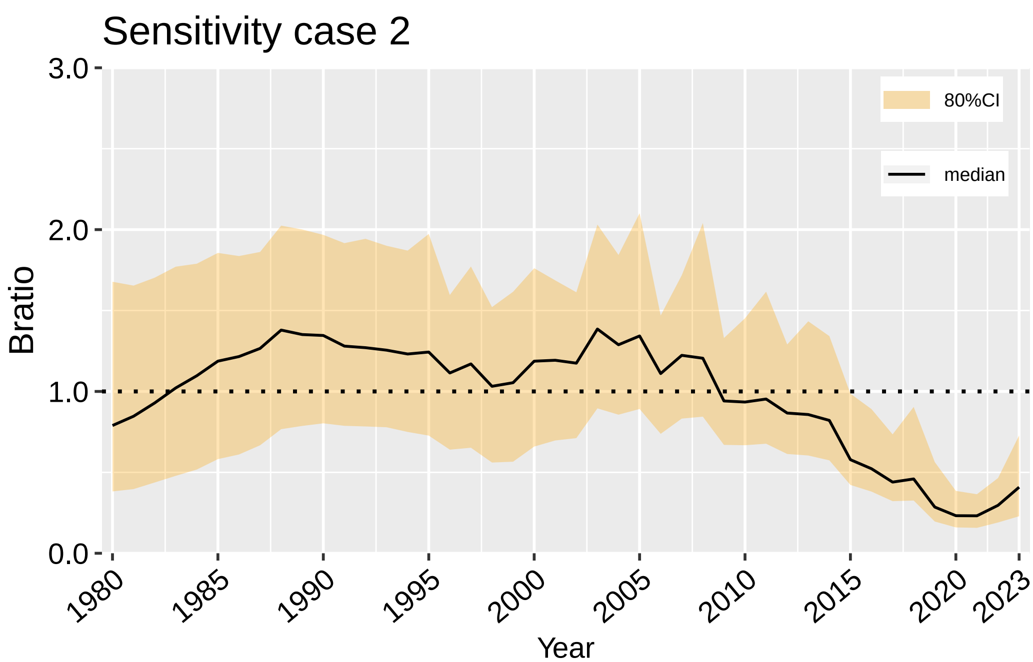
Sensitivity case 2
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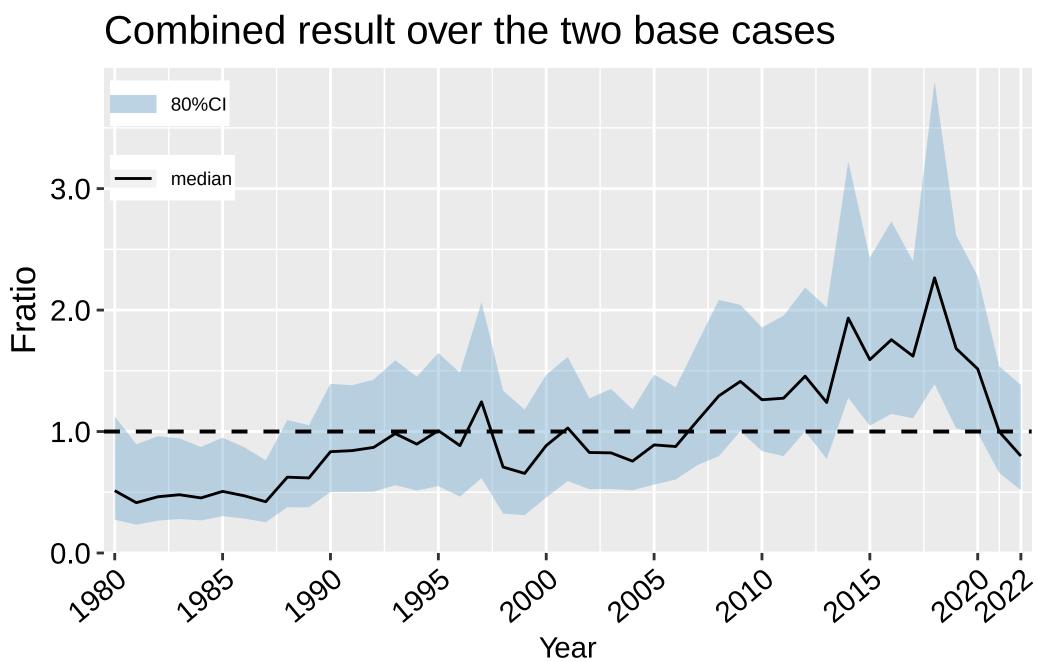
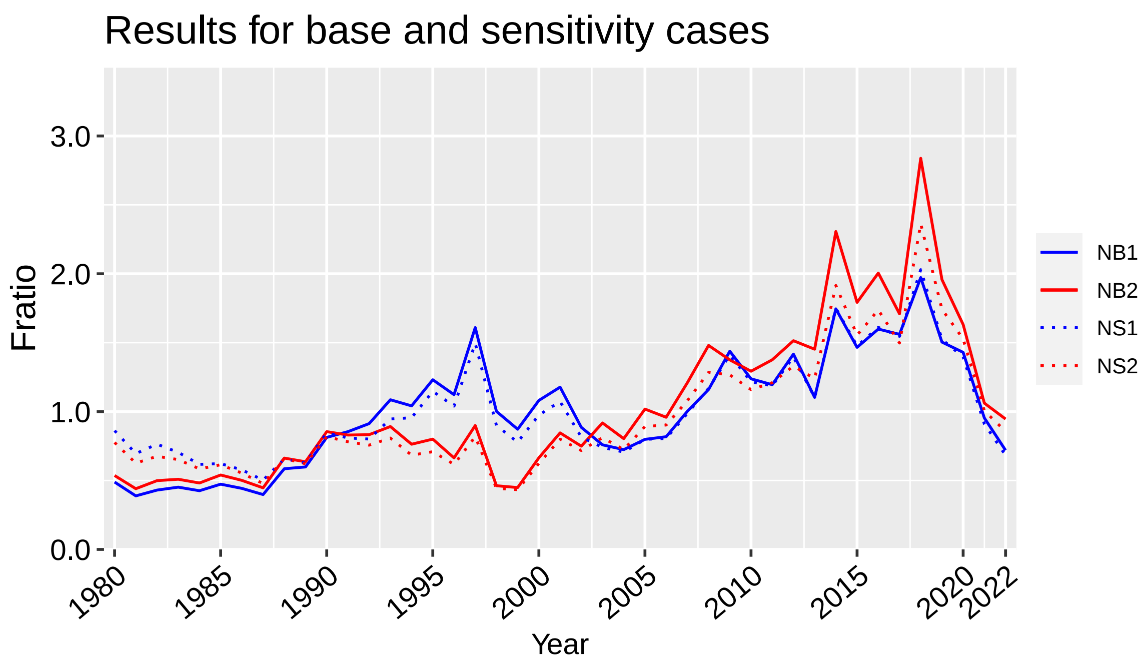
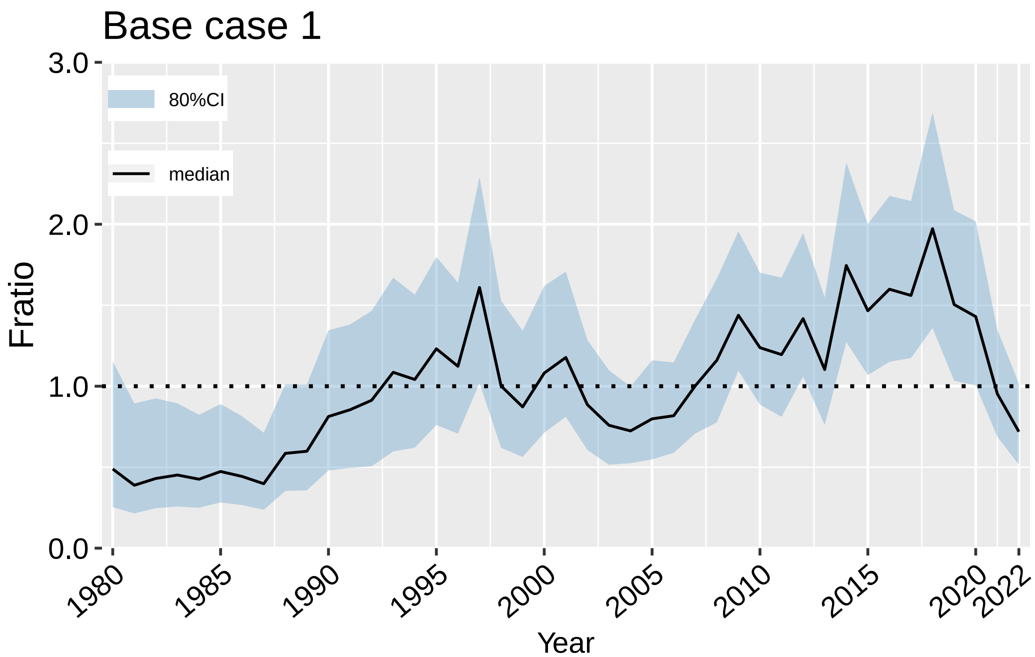
2.4 Time series Fratio



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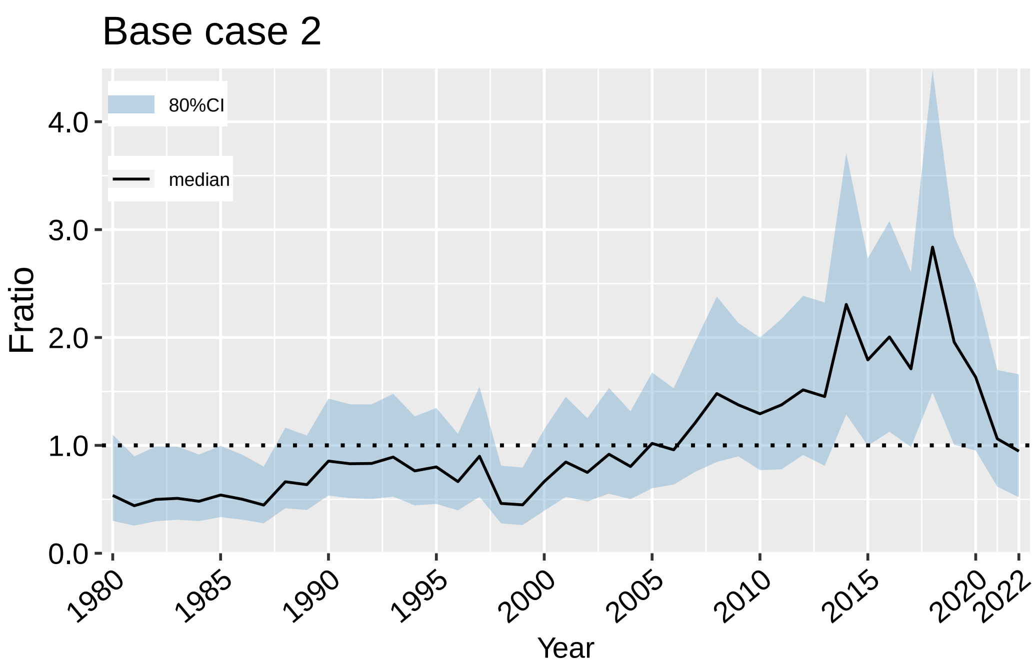
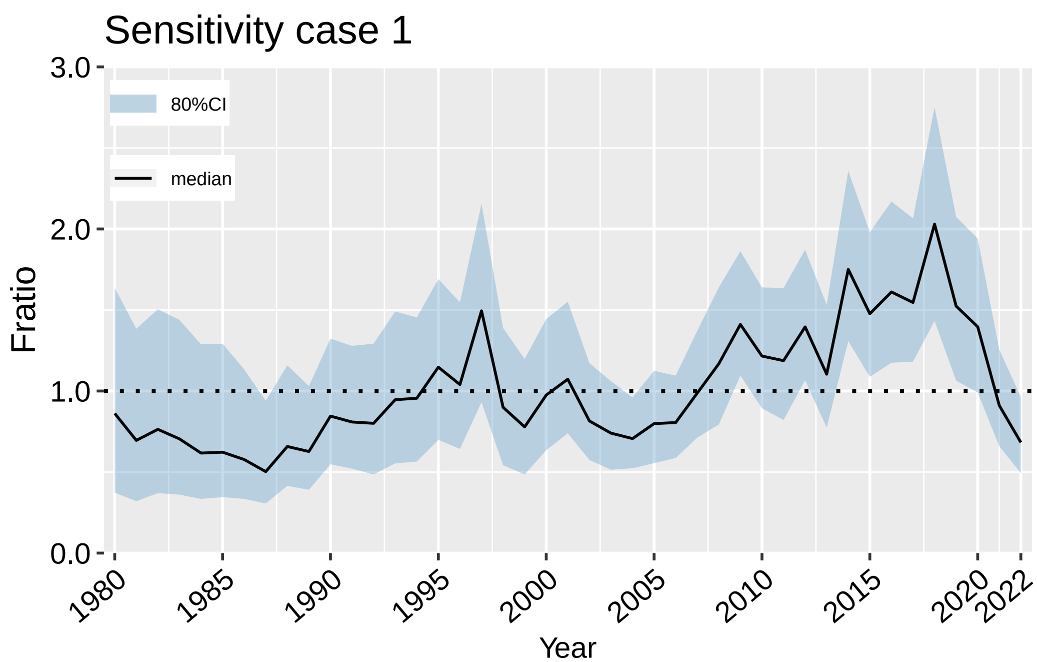
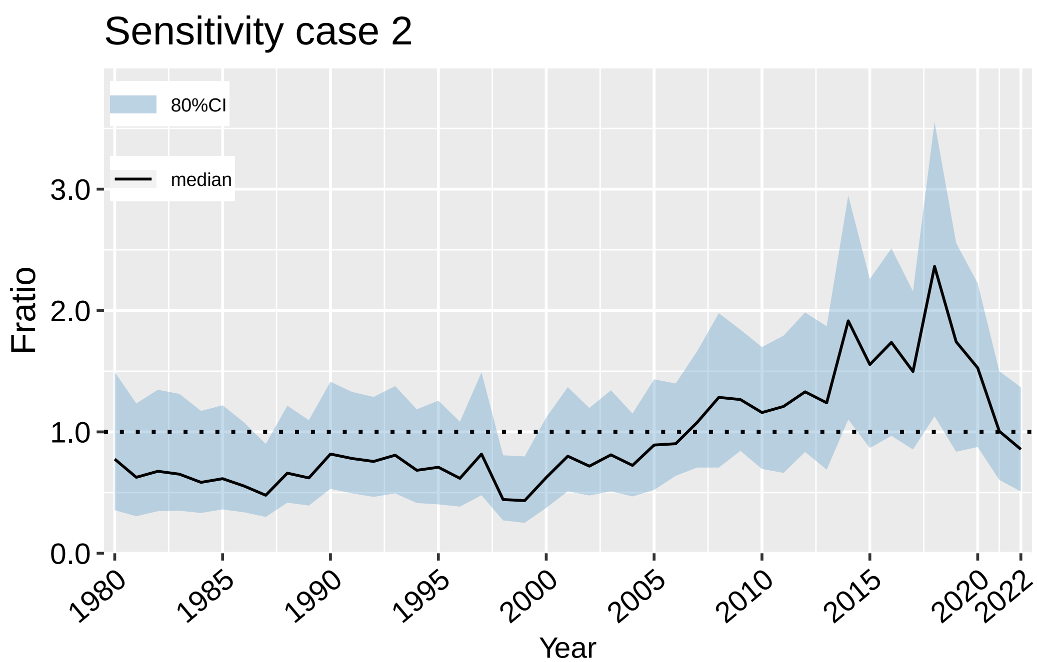
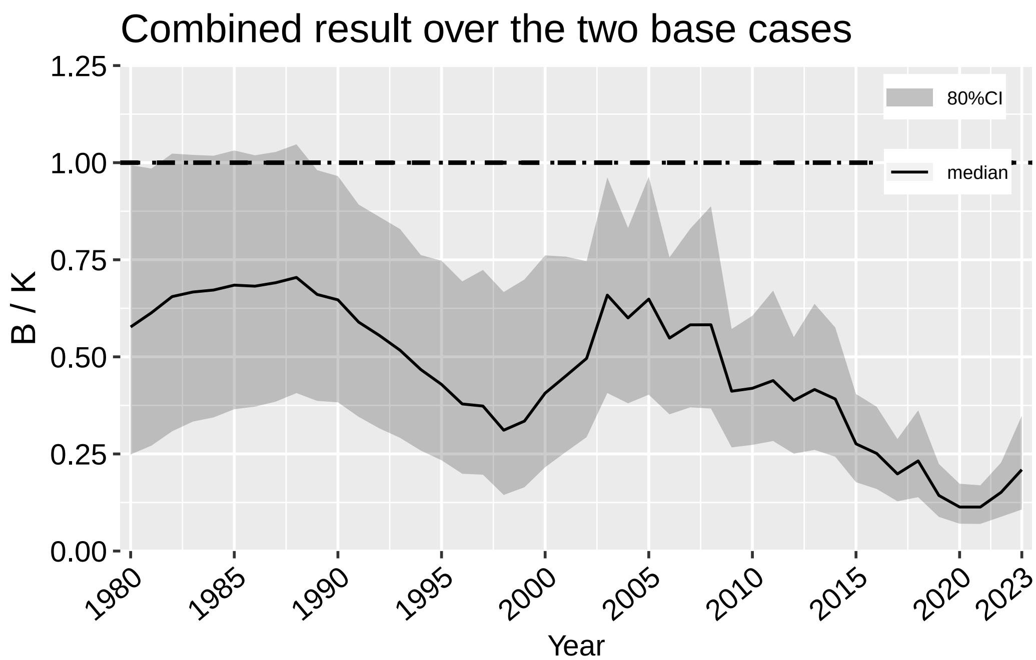
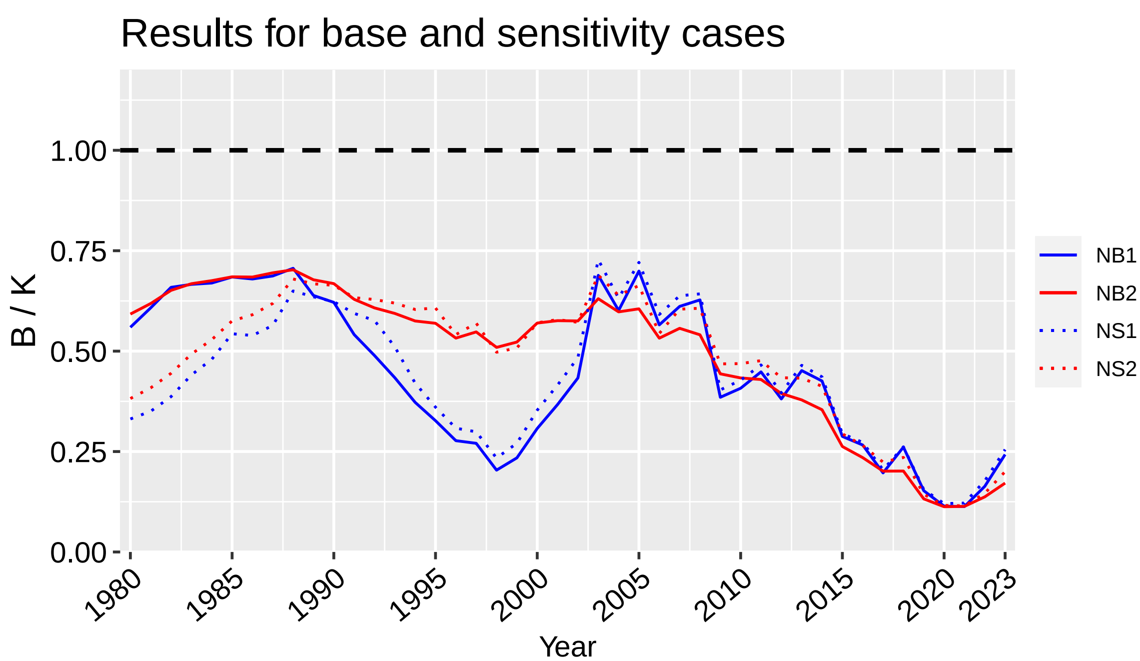

Base case 2
80%CI
median
Fratio
4.0
3.0
2.0
1.0
0.0
1980
1985
1990
1995
2000
2005
2010
2015
2020
2022
Year

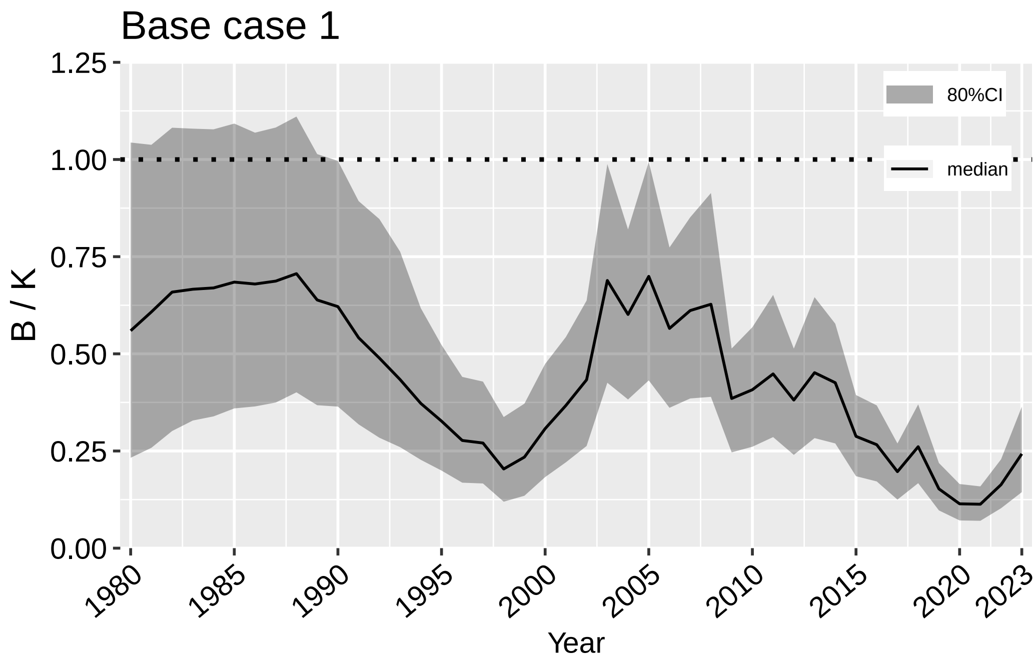

Sensitivity case 1
80%CI
median
Fratio
3.0
2.0
1.0
0.0
1980
1985
1990
1995
2000
2005
2010
2015
2020
2022
Year

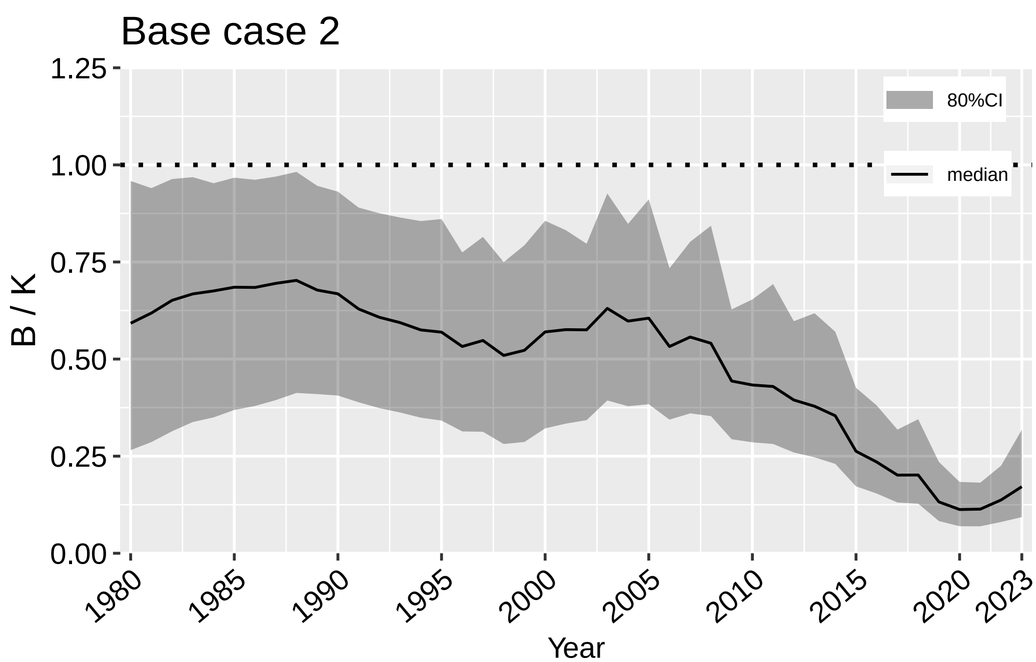

Sensitivity case 2
80%CI
median
Fratio
3.0
2.0
1.0
0.0
1980
1985
1990
1995
2000
2005
2010
2015
2020
2022
Year

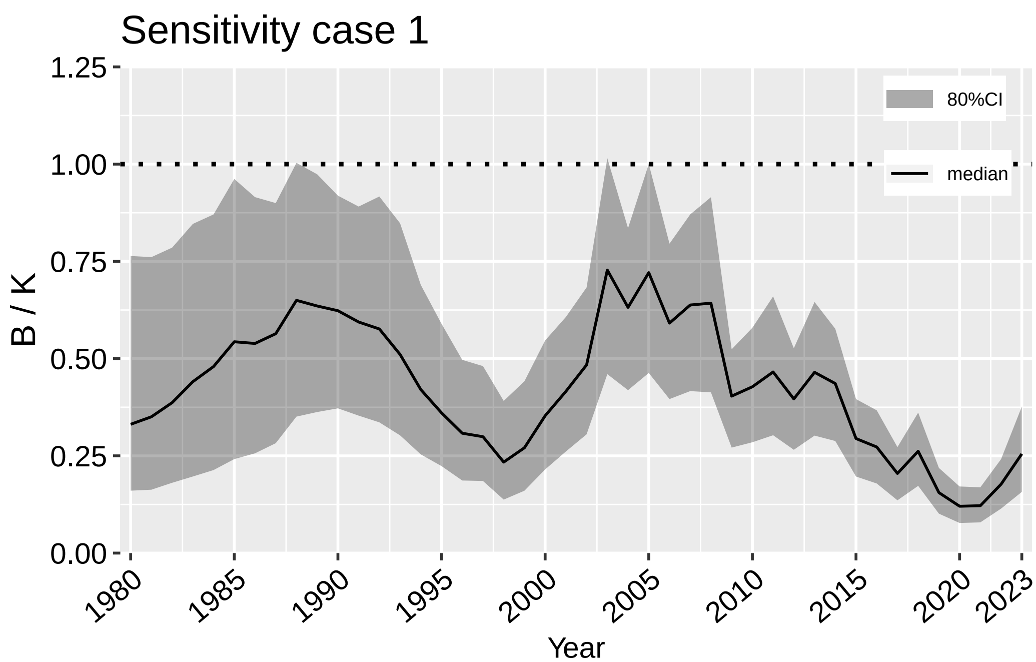
2.5 Time series B/K

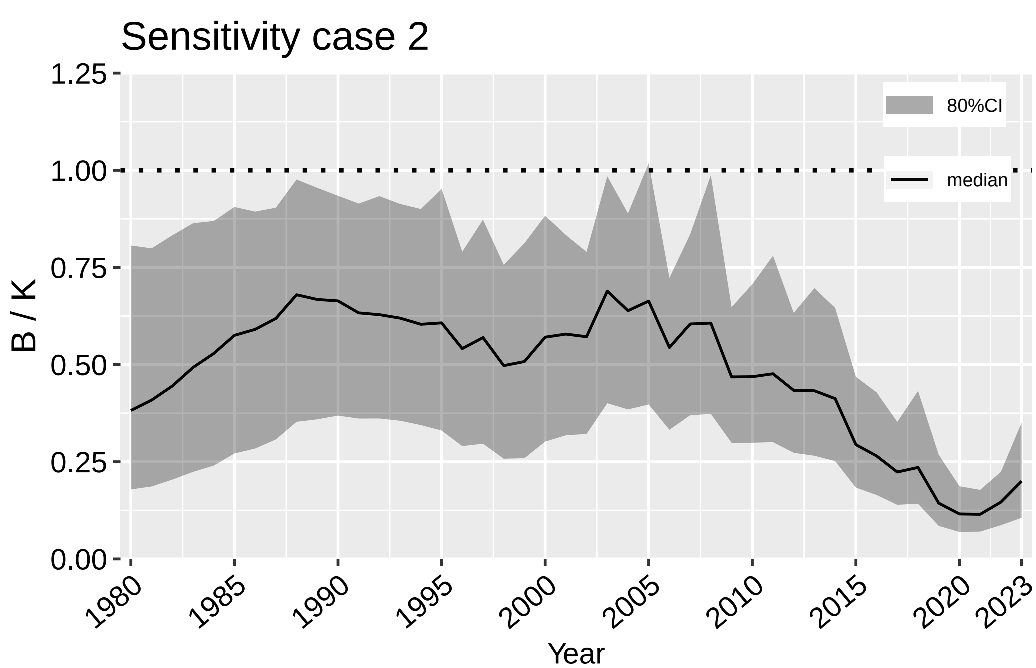




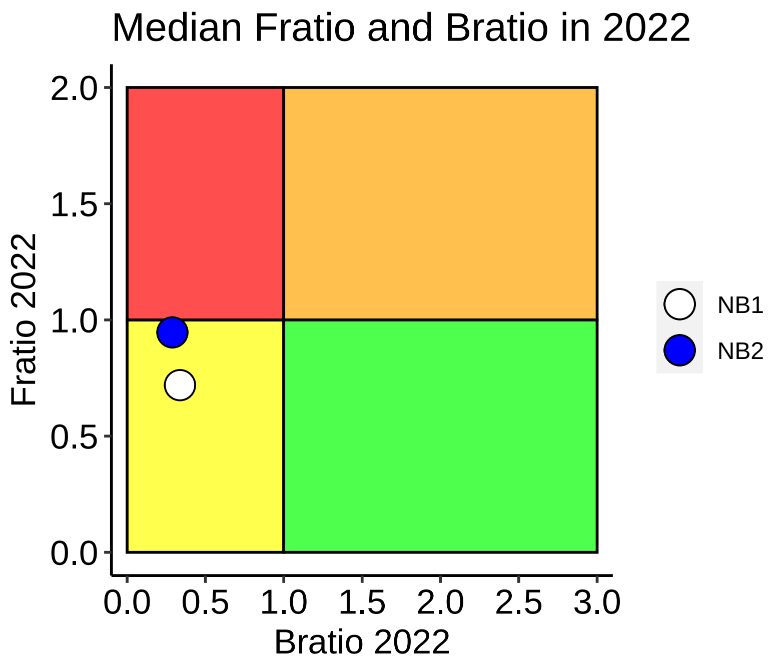

Base case 1
1.25
1.00
0.75
0.50
0.25
0.00
B / K
80%CI
median
1980
1985
1990
1995
2000
2005
2010
2015
2020
2023
Year


Base case 2
1.25
1.00
0.75
0.50
0.25
0.00
B / K
80%CI
median
1980
1985
1990
1995
2000
2005
2010
2015
2020
2023
Year

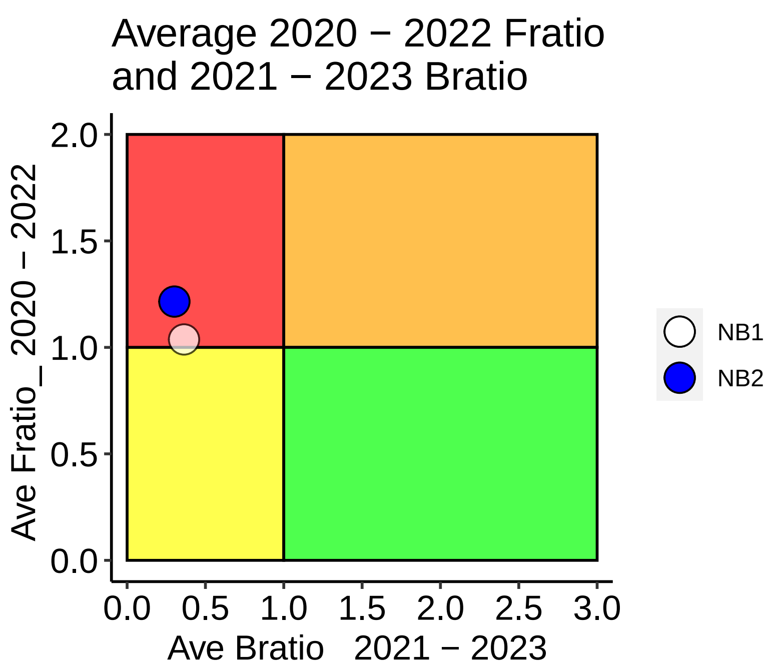

Sensitivity case 1
80%CI
median
B / K
1.25
1.00
0.75
0.50
0.25
0.00
1980
1985
1990
1995
2000
2005
2010
2015
2020
2023
Year


Sensitivity 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
2020
2023
Year

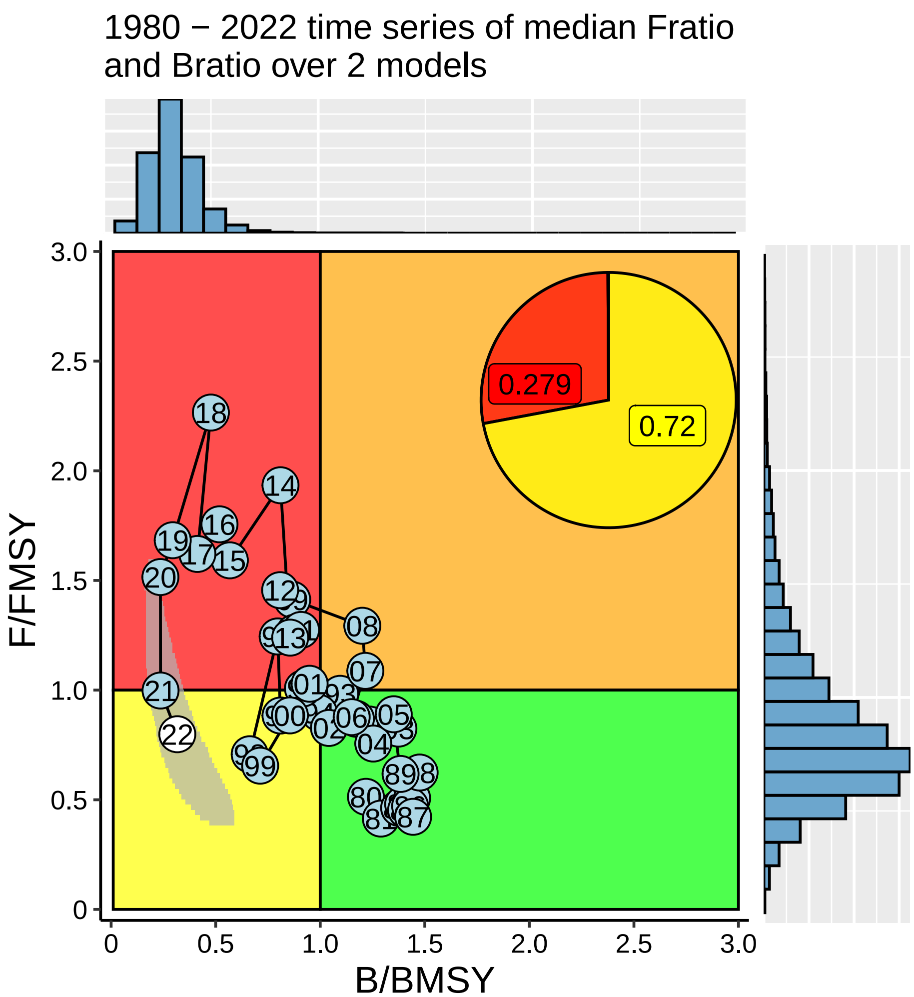
3 Kobe plot



Median Fratio and Bratio in 2022
Fratio 2022
Bratio 2022
2.0
1.5
1.0
0.5
0.0
0.0 0.5 1.0 1.5 2.0 2.5 3.0
NB1
NB2



Average 2020 − 2022 Fratio
and 2021 − 2023 Bratio
Ave Fratio_ 2020 − 2022
Ave Bratio_ 2021 − 2023
2.0
1.5
1.0
0.5
0.0
0.0 0.5 1.0 1.5 2.0 2.5 3.0
NB1
NB2


1980 − 2022 time series of median Fratio
and Bratio over 2 models
F/FMSY
B/BMSY
0.279
0.72
3.0
2.5
2.0
1.5
1.0
0.5
0
0
0.5
1.0
1.5
2.0
2.5
3.0
18
14
16
19
17
15
20
12
08
13
07
21
01
06
05
22
00
04
99
89
80
87

4 Summary of reference points

Over 2 new base case models

	Mean	Median	Lower10th	Upper10th
C_2022 (million tons)	0.100	0.100	0.100	0.100
AveC_2020_2022	0.111	0.111	0.111	0.111
AveF_2020_2022	0.386	0.376	0.148	0.638
F_2022	0.278	0.270	0.120	0.444
FMSY	0.358	0.350	0.117	0.606
MSY (million tons)	0.403	0.399	0.309	0.496
F_2022/FMSY	0.896	0.799	0.517	1.384
AveF_2020_2022/FMSY	1.186	1.106	0.750	1.701
K (million tons)	3.284	2.518	1.412	6.575
B_2022 (million tons)	0.467	0.371	0.226	0.831
B_2023 (million tons)	0.627	0.523	0.326	1.039
AveB_2021_2023	0.489	0.390	0.245	0.849
BMSY (million tons)	1.513	1.186	0.695	2.905
BMSY/K	0.473	0.469	0.397	0.555
B_2022/K	0.156	0.151	0.088	0.228
B_2023/K	0.222	0.210	0.107	0.348
AveB_2021_2023/K	0.165	0.160	0.092	0.242
B_2022/BMSY	0.347	0.337	0.229	0.474
B_2023/BMSY	0.470	0.441	0.237	0.730
AveB_2021_2023/BMSY	0.350	0.336	0.206	0.505

Base case 1

	Mean	Median	Lower10th	Upper10th
C_2022 (million tons)	0.100	0.100	0.100	0.100
AveC_2020_2022	0.111	0.111	0.111	0.111
AveF_2020_2022	0.488	0.488	0.290	0.677
F_2022	0.337	0.337	0.205	0.466
FMSY	0.470	0.473	0.280	0.653
MSY (million tons)	0.425	0.416	0.351	0.503
F_2022/FMSY	0.749	0.719	0.515	1.017
AveF_2020_2022/FMSY	1.076	1.037	0.769	1.429
K (million tons)	2.178	1.845	1.304	3.389
B_2022 (million tons)	0.332	0.297	0.215	0.488
B_2023 (million tons)	0.497	0.452	0.313	0.729
AveB_2021_2023	0.353	0.319	0.234	0.516
BMSY (million tons)	1.010	0.879	0.645	1.515
BMSY/K	0.475	0.471	0.407	0.553
B_2022/K	0.165	0.163	0.103	0.229
B_2023/K	0.250	0.243	0.144	0.364
AveB_2021_2023/K	0.176	0.176	0.110	0.243
B_2022/BMSY	0.347	0.337	0.229	0.474
B_2023/BMSY	0.527	0.506	0.317	0.762
AveB_2021_2023/BMSY	0.372	0.363	0.245	0.506

Base case 2

	Mean	Median	Lower10th	Upper10th
C_2022 (million tons)	0.100	0.100	0.100	0.100
AveC_2020_2022	0.111	0.111	0.111	0.111
AveF_2020_2022	0.284	0.244	0.116	0.509
F_2022	0.219	0.192	0.096	0.377
FMSY	0.246	0.212	0.089	0.463
MSY (million tons)	0.382	0.374	0.276	0.484
F_2022/FMSY	1.044	0.946	0.520	1.659
AveF_2020_2022/FMSY	1.296	1.215	0.716	1.942
K (million tons)	4.390	3.872	1.881	7.835
B_2022 (million tons)	0.603	0.522	0.265	1.044
B_2023 (million tons)	0.757	0.646	0.352	1.275
AveB_2021_2023	0.625	0.541	0.284	1.076
BMSY (million tons)	2.016	1.792	0.927	3.434
BMSY/K	0.470	0.468	0.389	0.558
B_2022/K	0.147	0.137	0.081	0.226
B_2023/K	0.194	0.171	0.093	0.318
AveB_2021_2023/K	0.154	0.143	0.084	0.239
B_2022/BMSY	0.314	0.289	0.182	0.474
B_2023/BMSY	0.413	0.365	0.205	0.668
AveB_2021_2023/BMSY	0.329	0.302	0.187	0.502

Sensitivity case 1

	Mean	Median	Lower10th	Upper10th
C_2022 (million tons)	0.100	0.100	0.100	0.100
AveC_2020_2022	0.111	0.111	0.111	0.111
AveF_2020_2022	0.466	0.463	0.284	0.645
F_2022	0.318	0.315	0.200	0.442
FMSY	0.465	0.467	0.282	0.641
MSY (million tons)	0.414	0.408	0.350	0.482
F_2022/FMSY	0.712	0.683	0.494	0.964
AveF_2020_2022/FMSY	1.032	1.000	0.747	1.351
K (million tons)	2.107	1.804	1.305	3.204
B_2022 (million tons)	0.348	0.318	0.227	0.500
B_2023 (million tons)	0.508	0.468	0.324	0.735
AveB_2021_2023	0.367	0.336	0.245	0.520
BMSY (million tons)	0.986	0.869	0.652	1.433
BMSY/K	0.480	0.478	0.408	0.556
B_2022/K	0.178	0.177	0.114	0.242
B_2023/K	0.263	0.255	0.157	0.376
AveB_2021_2023/K	0.188	0.188	0.122	0.254
B_2022/BMSY	0.371	0.362	0.252	0.498
B_2023/BMSY	0.548	0.527	0.343	0.782
AveB_2021_2023/BMSY	0.392	0.384	0.269	0.525

Sensitivity case 2

	Mean	Median	Lower10th	Upper10th
C_2022 (million tons)	0.100	0.100	0.100	0.100
AveC_2020_2022	0.111	0.111	0.111	0.111
AveF_2020_2022	0.370	0.340	0.163	0.628
F_2022	0.280	0.260	0.132	0.461
FMSY	0.337	0.318	0.144	0.555
MSY (million tons)	0.411	0.403	0.323	0.501
F_2022/FMSY	0.911	0.857	0.509	1.368
AveF_2020_2022/FMSY	1.170	1.136	0.688	1.673
K (million tons)	3.201	2.633	1.524	5.822
B_2022 (million tons)	0.453	0.385	0.217	0.761
B_2023 (million tons)	0.624	0.526	0.306	1.040
AveB_2021_2023	0.481	0.409	0.237	0.806
BMSY (million tons)	1.504	1.271	0.775	2.595
BMSY/K	0.484	0.487	0.400	0.562
B_2022/K	0.153	0.146	0.087	0.224
B_2023/K	0.218	0.200	0.106	0.350
AveB_2021_2023/K	0.164	0.156	0.091	0.246
B_2022/BMSY	0.317	0.296	0.190	0.465
B_2023/BMSY	0.453	0.408	0.229	0.728
AveB_2021_2023/BMSY	0.340	0.316	0.199	0.510

5 Summary of estimates of parameters

Base case 1

	Mean	Median	Lower10th	Upper10th
r	1.329	1.163	0.672	2.296
K (million tons)	2.178	1.845	1.304	3.389
qCHN	19.822	19.366	12.055	28.189
qJPN2	2.789	2.776	1.808	3.775
qKOR	12.735	12.666	8.245	17.235
qRUS	1.539	1.533	0.997	2.075
qCT	2.865	2.847	1.874	3.887
qBio	0.704	0.721	0.447	0.936
Shape	0.828	0.721	0.232	1.635
sigma_com	0.598	0.594	0.590	0.612
sigma	0.040	0.035	0.014	0.074
tau	0.305	0.297	0.201	0.418
FMSY	0.470	0.473	0.280	0.653
BMSY (million tons)	1.010	0.879	0.645	1.515
MSY (million tons)	0.425	0.416	0.351	0.503
b	0.863	0.878	0.730	0.976

Base case 2

	Mean	Median	Lower10th	Upper10th
r	0.853	0.651	0.224	1.860
K (million tons)	4.390	3.872	1.881	7.835
qJOINT	0.743	0.724	0.447	1.063
qBio	0.415	0.377	0.198	0.696
Shape	0.804	0.692	0.123	1.701
sigma	0.354	0.351	0.278	0.433
tau	0.170	0.149	0.040	0.328
FMSY	0.246	0.212	0.089	0.463
BMSY (million tons)	2.016	1.792	0.927	3.434
MSY (million tons)	0.382	0.374	0.276	0.484
b	0.662	0.662	0.435	0.901

Sensitivity case 1

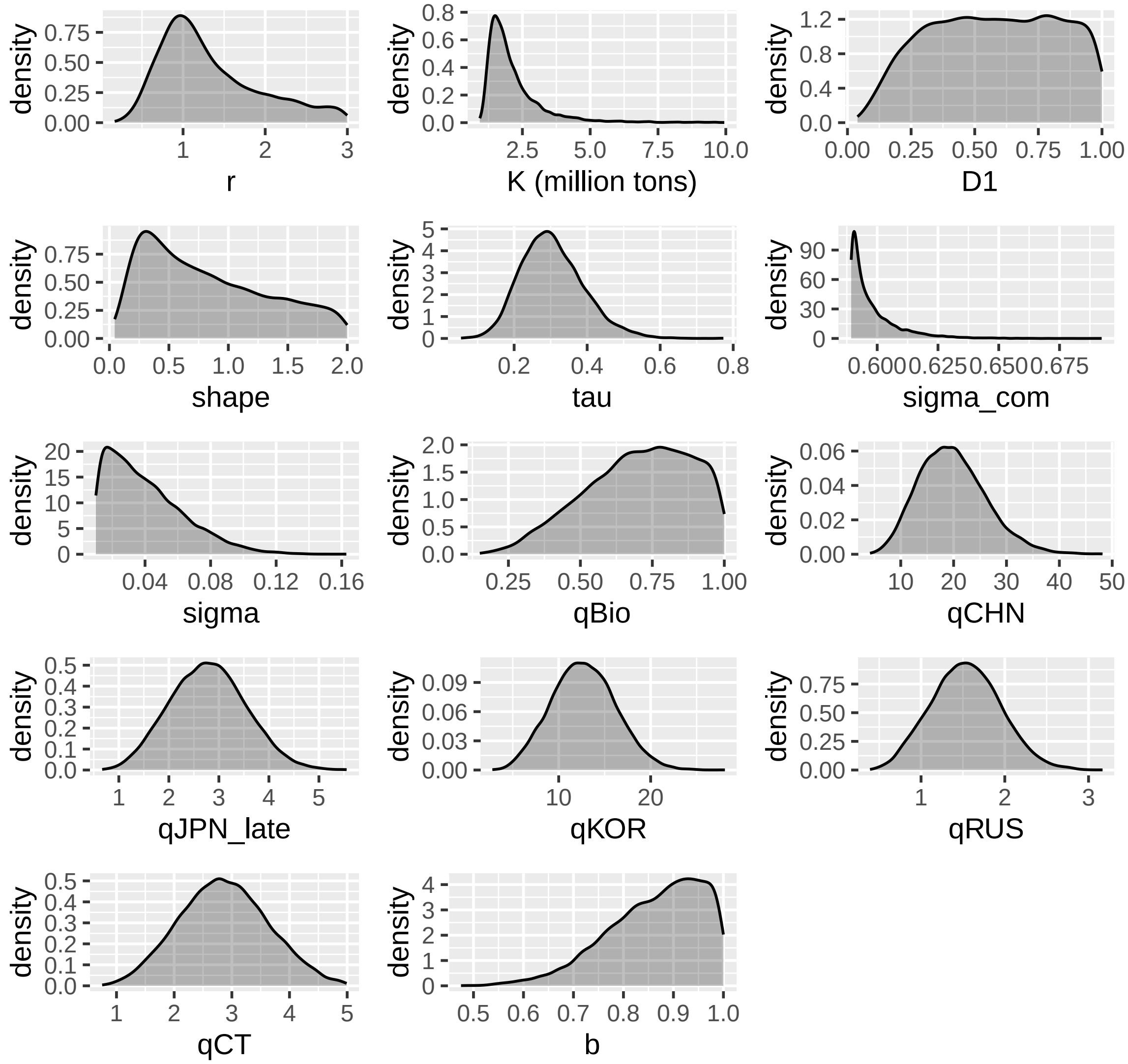
	Mean	Median	Lower10th	Upper10th
r	1.276	1.106	0.663	2.217
K (million tons)	2.107	1.804	1.305	3.204
qCHN	19.511	18.863	12.063	27.897
qJPN1	1.171	1.059	0.509	2.021
qJPN2	2.676	2.667	1.806	3.550
qKOR	12.386	12.230	8.291	16.637
qRUS	1.482	1.465	0.992	1.998
qCT	2.795	2.766	1.871	3.754
qBio	0.690	0.701	0.456	0.912
Shape	0.873	0.781	0.238	1.678
sigma_com	0.653	0.650	0.646	0.664
sigma	0.036	0.031	0.014	0.064
tau	0.276	0.270	0.175	0.384
FMSY	0.465	0.467	0.282	0.641
BMSY (million tons)	0.986	0.869	0.652	1.433
MSY (million tons)	0.414	0.408	0.350	0.482
b	0.847	0.862	0.704	0.972

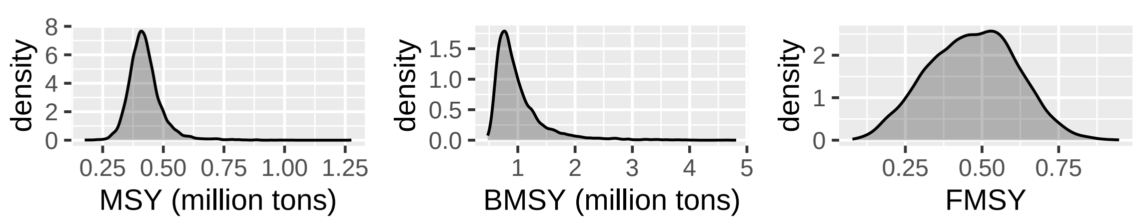
Sensitivity case 2

	Mean	Median	Lower10th	Upper10th
r	0.964	0.794	0.352	1.929
K (million tons)	3.201	2.633	1.524	5.822
qJOINT	0.876	0.869	0.535	1.223
qBio	0.518	0.497	0.257	0.828
Shape	0.926	0.874	0.188	1.761
sigma_JPN_early	0.883	0.880	0.750	1.017
sigma	0.289	0.289	0.220	0.356
tau	0.204	0.198	0.053	0.361
FMSY	0.337	0.318	0.144	0.555
BMSY (million tons)	1.504	1.271	0.775	2.595
MSY (million tons)	0.411	0.403	0.323	0.501
b	0.715	0.721	0.496	0.928

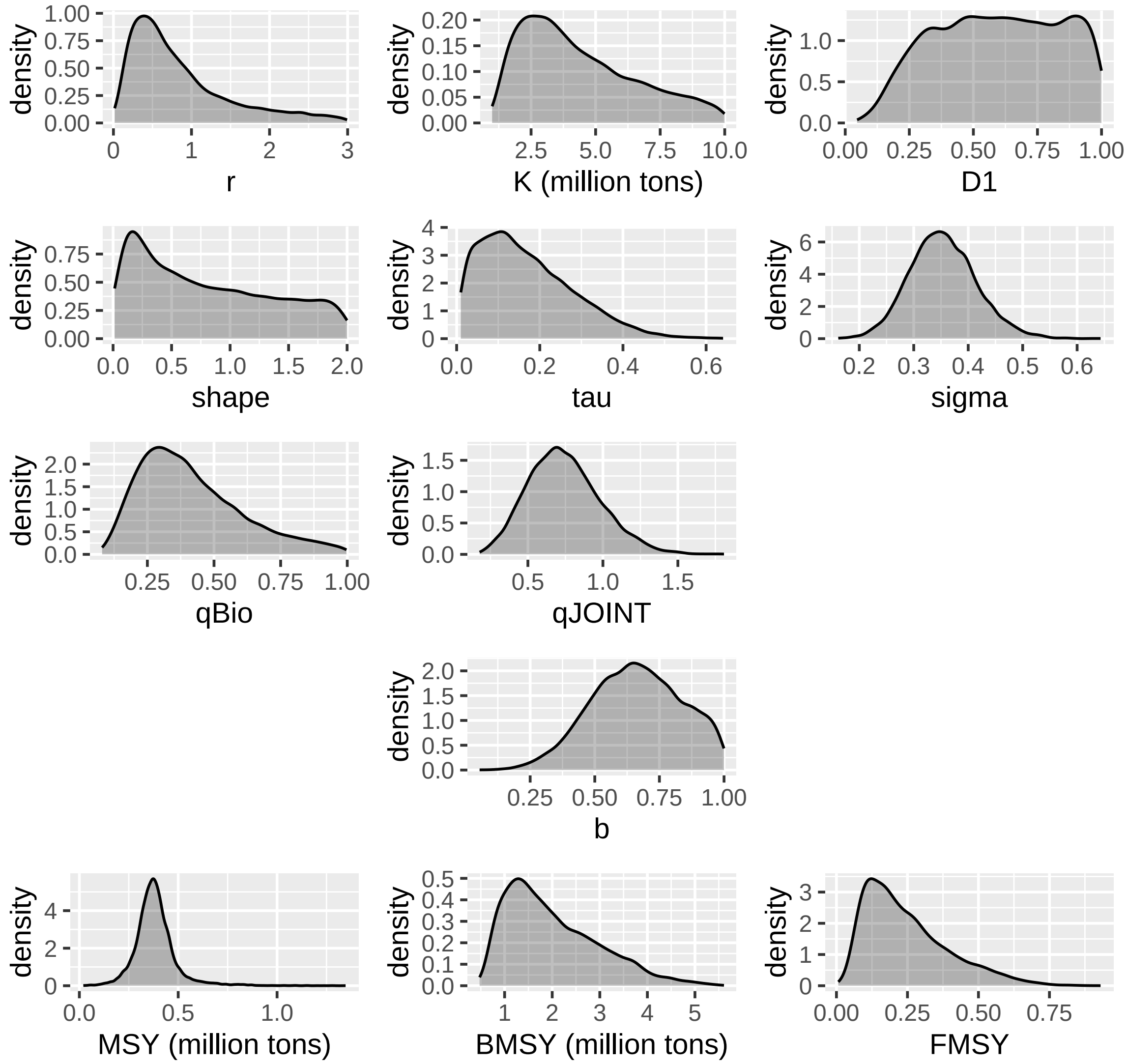
6 Posterior distributions

Base case 1

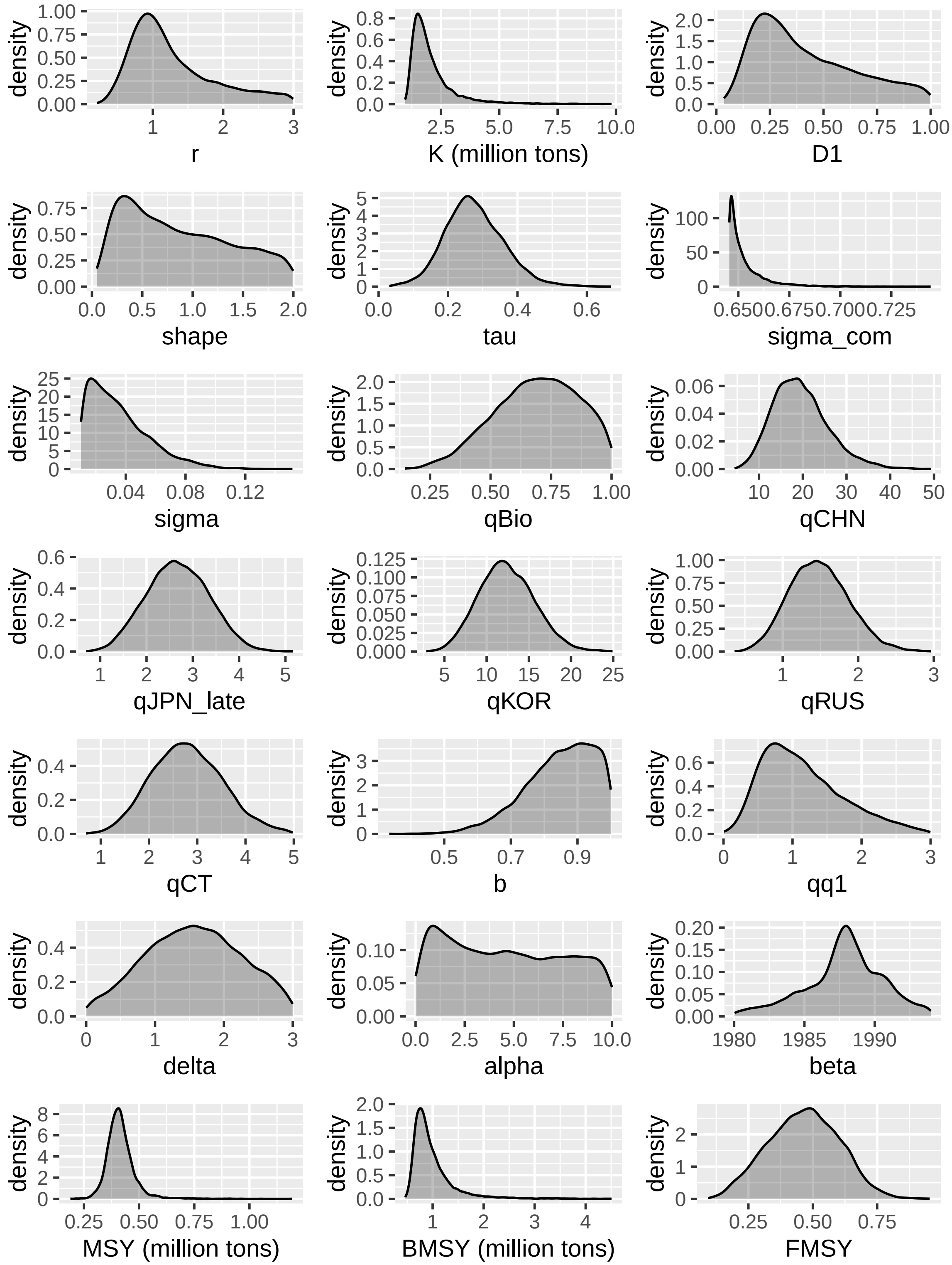




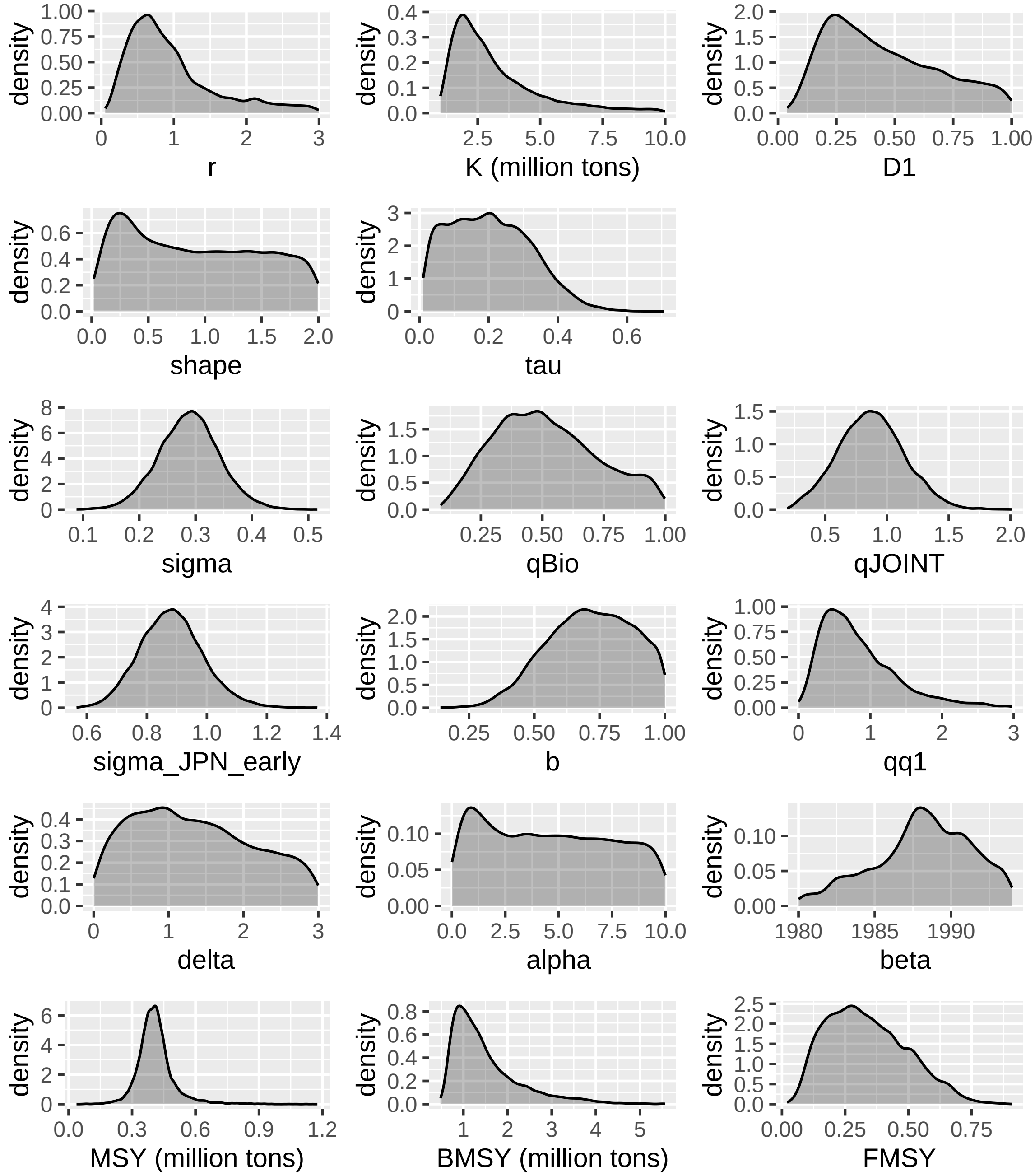
Base case 2


density
r
K (million tons)
D1
shape
tau
sigma
qBio
qJOINT
b
MSY (million tons)
BMSY (million tons)
FMSY

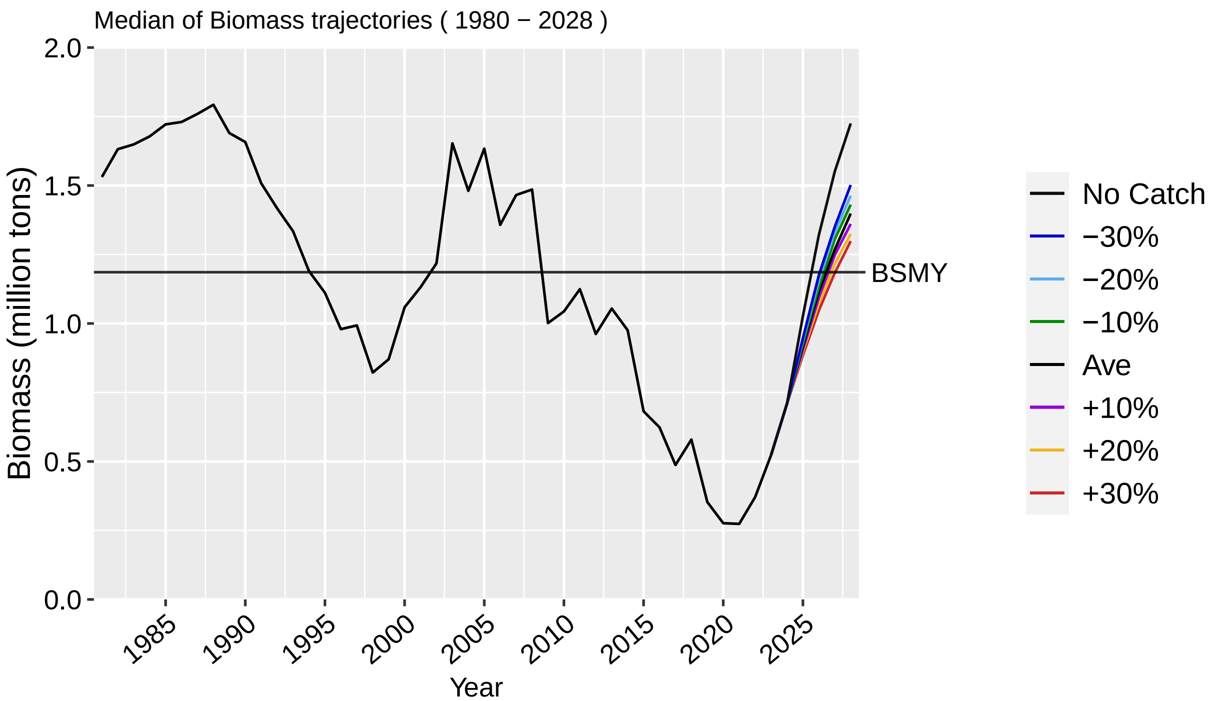
Sensitivity case 1

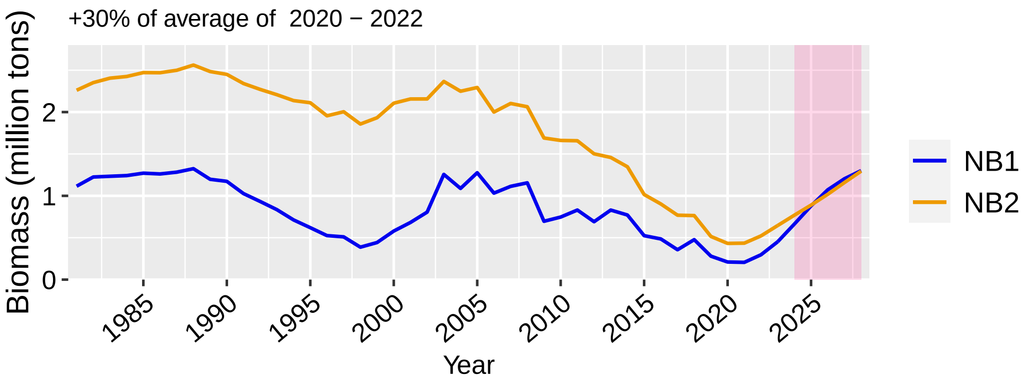


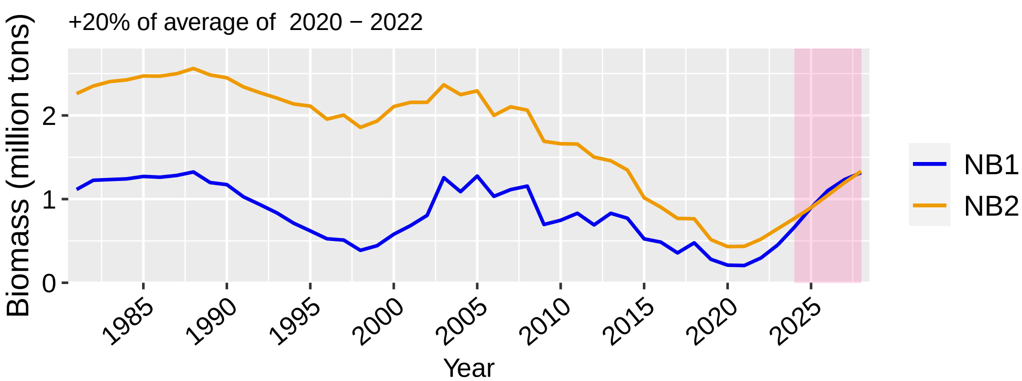
Sensitivity case 2

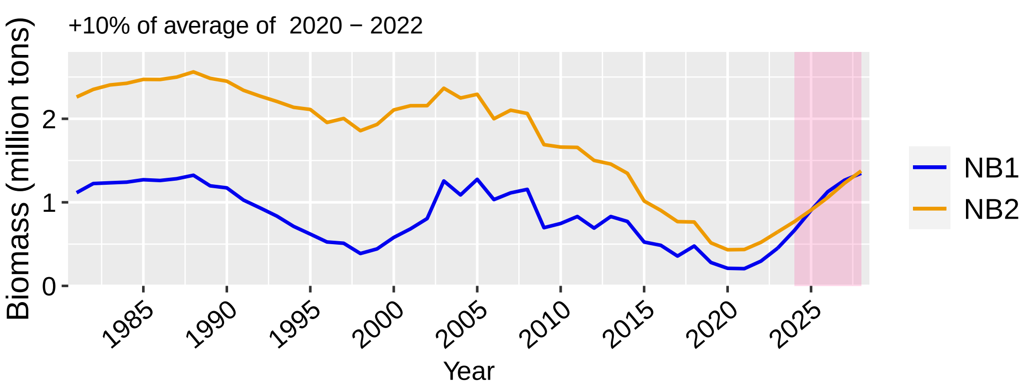


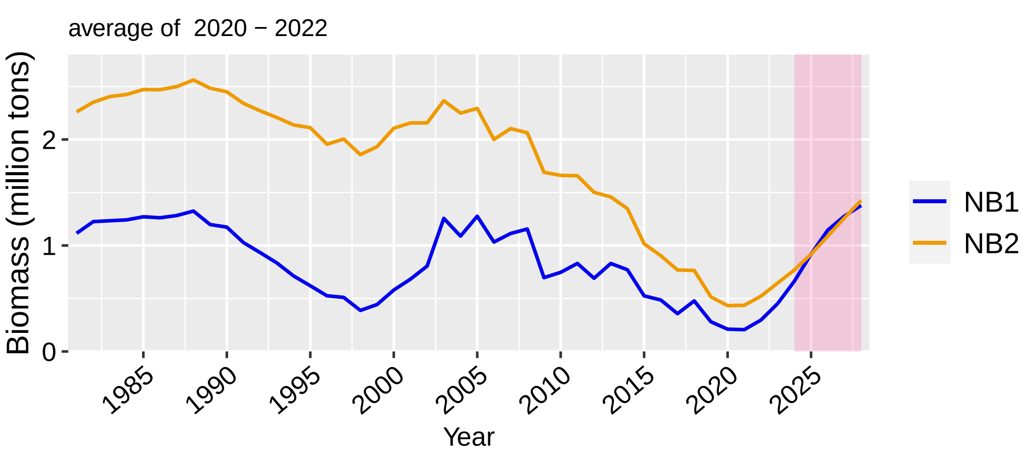
7 Future projection

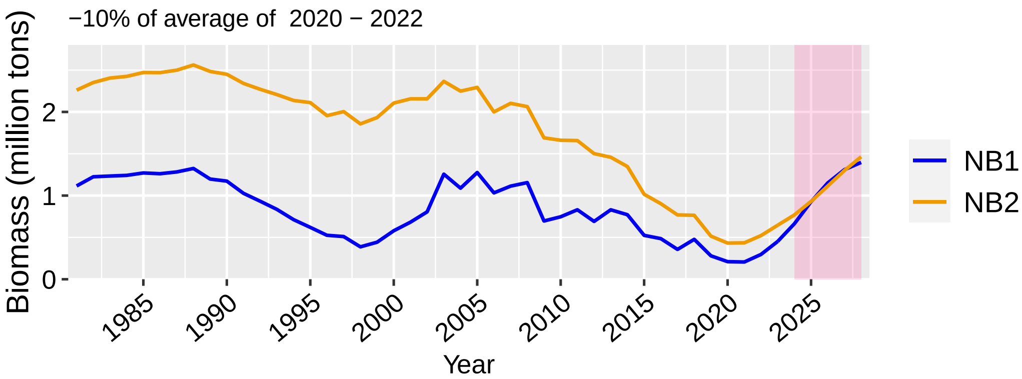


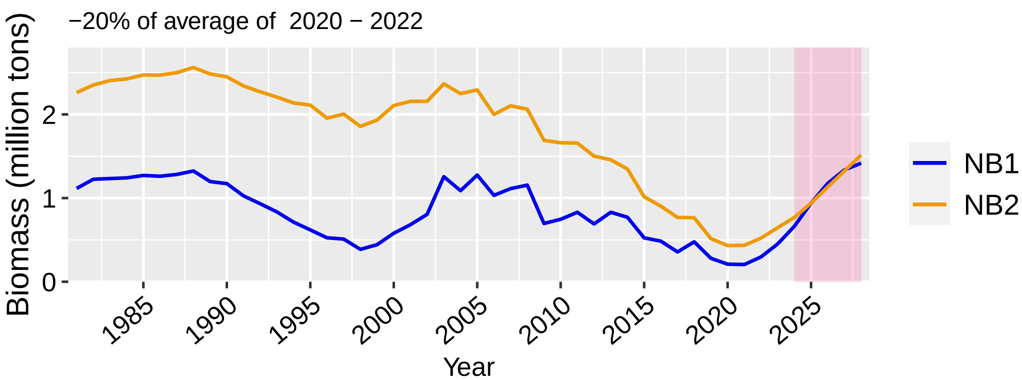

+30% of average of 2020 − 2022
Biomass (million tons)
0
1
2
1985
1990
1995
2000
2005
2010
2015
2020
2025
Year
NB1
NB2

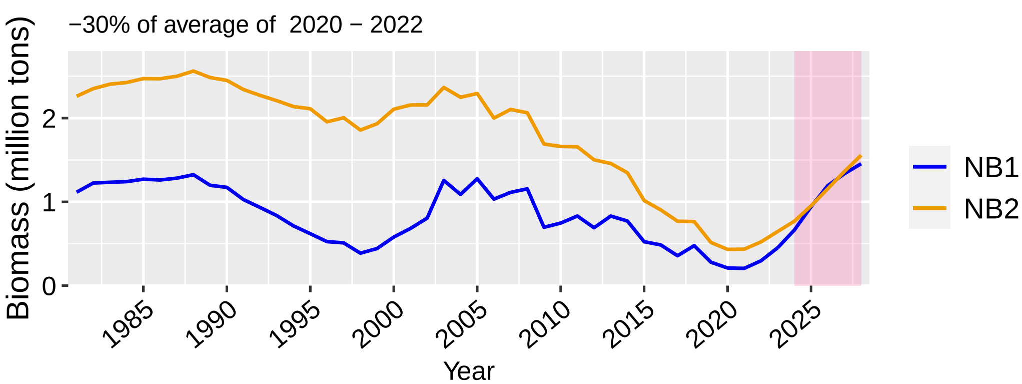

+20% of average of 2020 − 2022
Biomass (million tons)
0
1
2
1985
1990
1995
2000
2005
2010
2015
2020
2025
Year
NB1
NB2

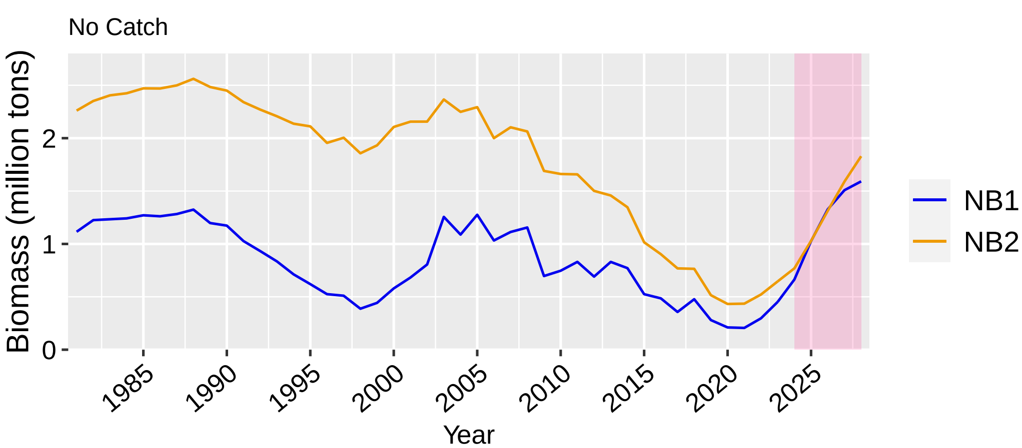

+10% of average of 2020 − 2022
Biomass (million tons)
0
1
2
1985
1990
1995
2000
2005
2010
2015
2020
2025
Year
NB1
NB2


average of 2020 − 2022
Biomass (million tons)
0
1
2
1985
1990
1995
2000
2005
2010
2015
2020
2025
Year
NB1
NB2


−10% of average of 2020 − 2022
Biomass (million tons)
0
1
2
1985
1990
1995
2000
2005
2010
2015
2020
2025
Year
NB1
NB2


−20% of average of 2020 − 2022
Biomass (million tons)
0
1
2
1985
1990
1995
2000
2005
2010
2015
2020
2025
Year
NB1
NB2


−30% of average of 2020 − 2022
Biomass (million tons)
0
1
2
1985
1990
1995
2000
2005
2010
2015
2020
2025
Year
NB1
NB2


No Catch
Biomass (million tons)
0
1
2
1985
1990
1995
2000
2005
2010
2015
2020
2025
Year
NB1
NB2

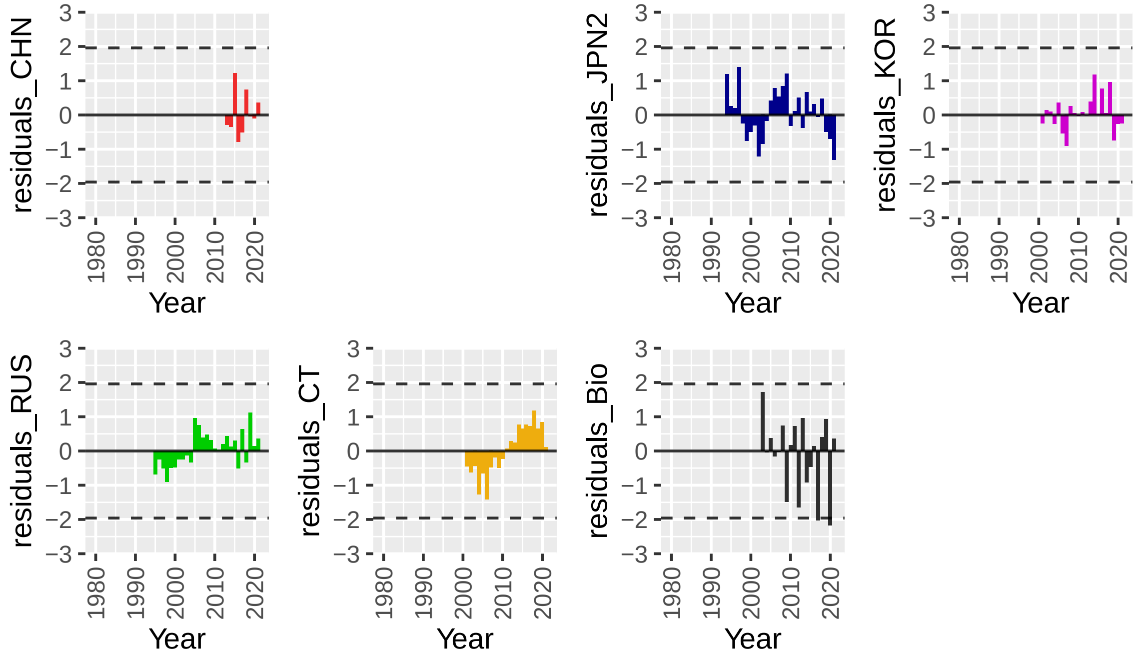
8 Risk table

	Red	Orange	Yellow	Green	B<BMSY	F>FMSY
+30%	0.170	0	0.261	0.569	0.431	0.170
+20%	0.147	0	0.272	0.581	0.419	0.147
+10%	0.125	0	0.280	0.595	0.405	0.125
±0%	0.104	0	0.281	0.615	0.385	0.104
-10%	0.083	0	0.294	0.623	0.377	0.083
-20%	0.064	0	0.298	0.637	0.363	0.064
-30%	0.051	0	0.304	0.645	0.355	0.051
No Catch	0.000	0	0.284	0.716	0.284	0.000

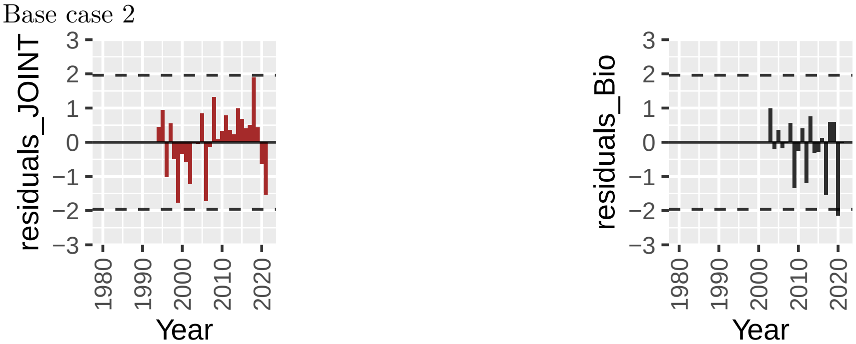
9 Diagnosis

9.1 Standardized residuals plot

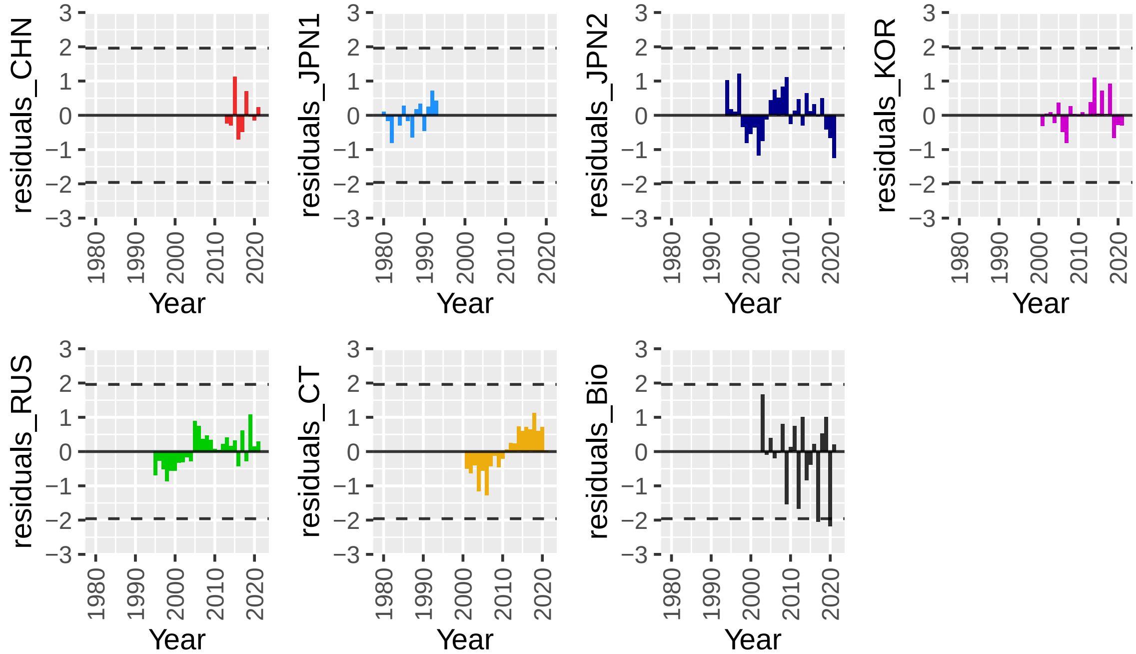
Base case 1



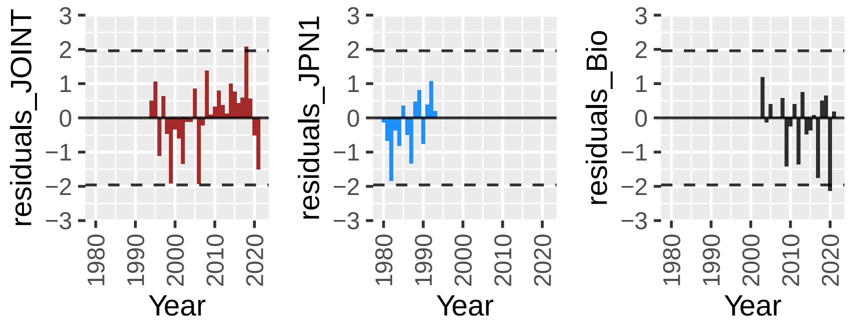
Base case 2



Sensitivity case 1



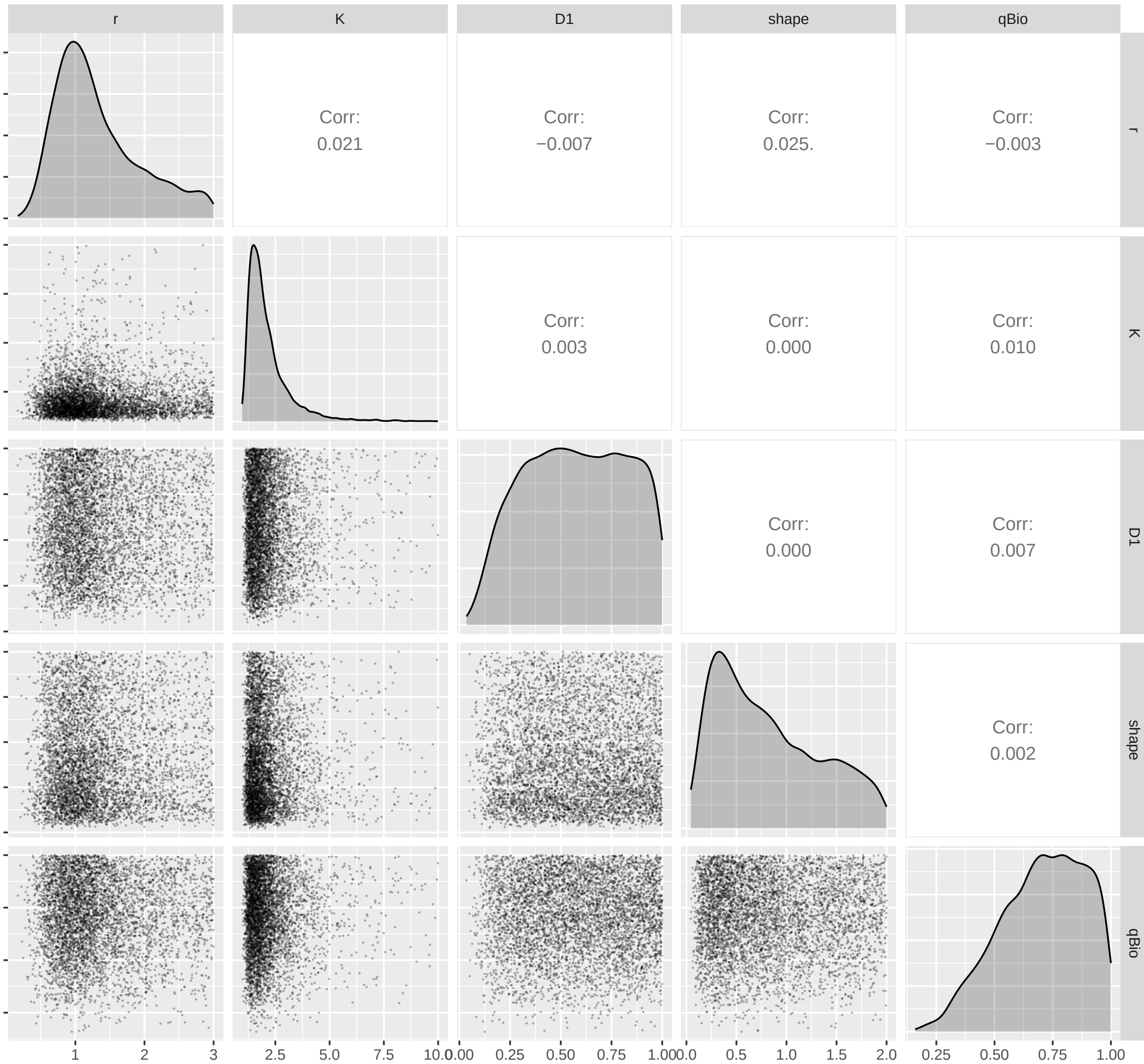
Sensitivity case 2



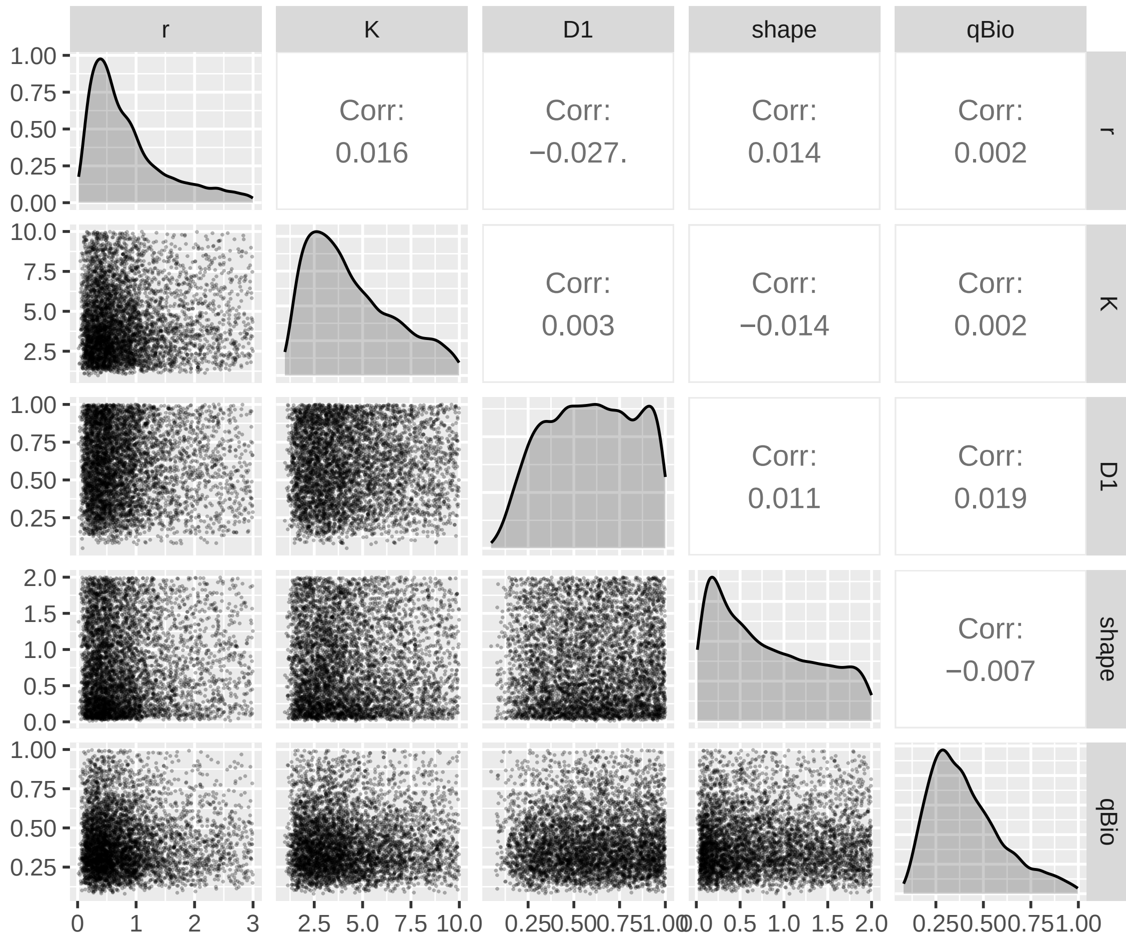
9.2 Correlation

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

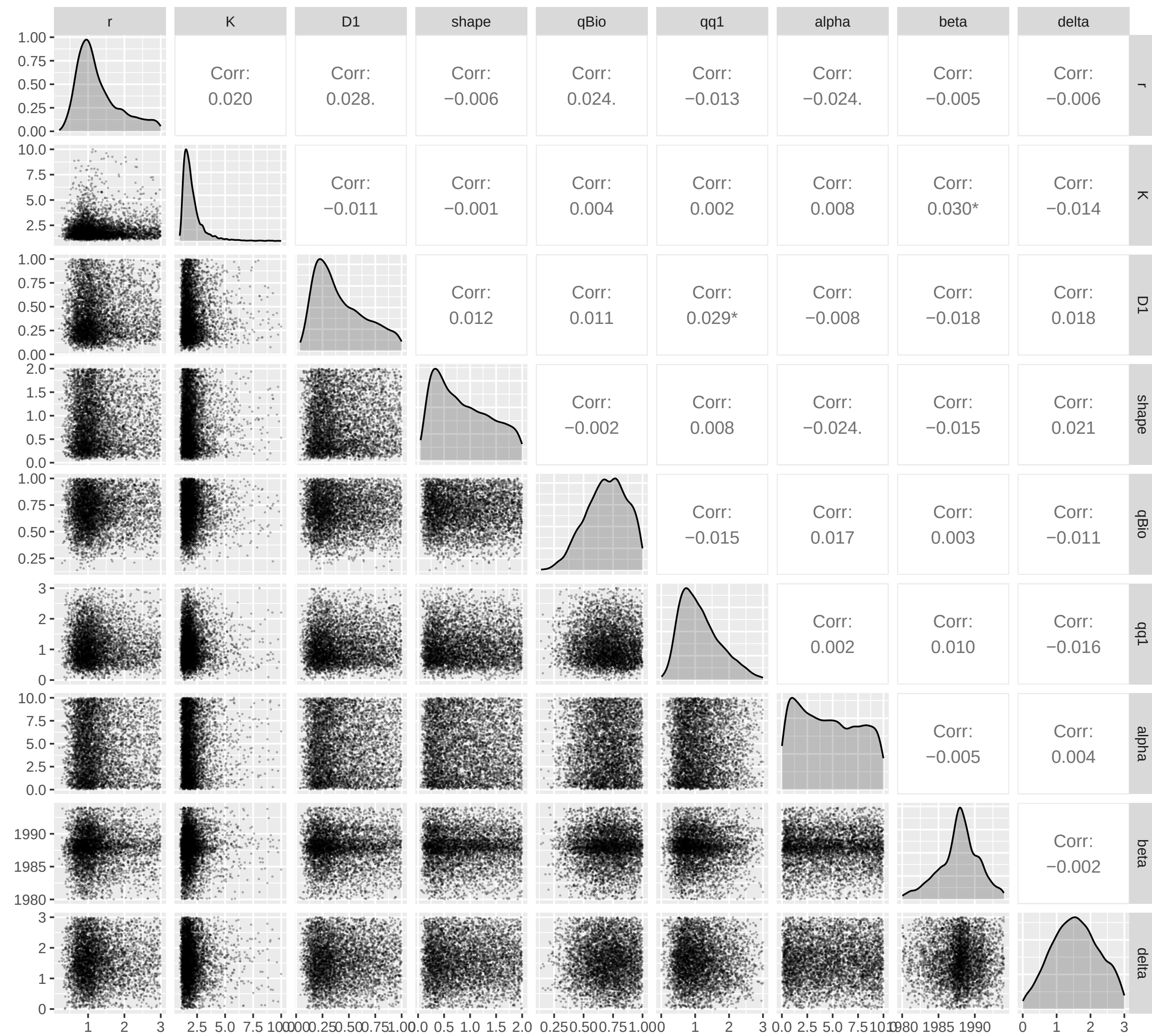
Base case 1



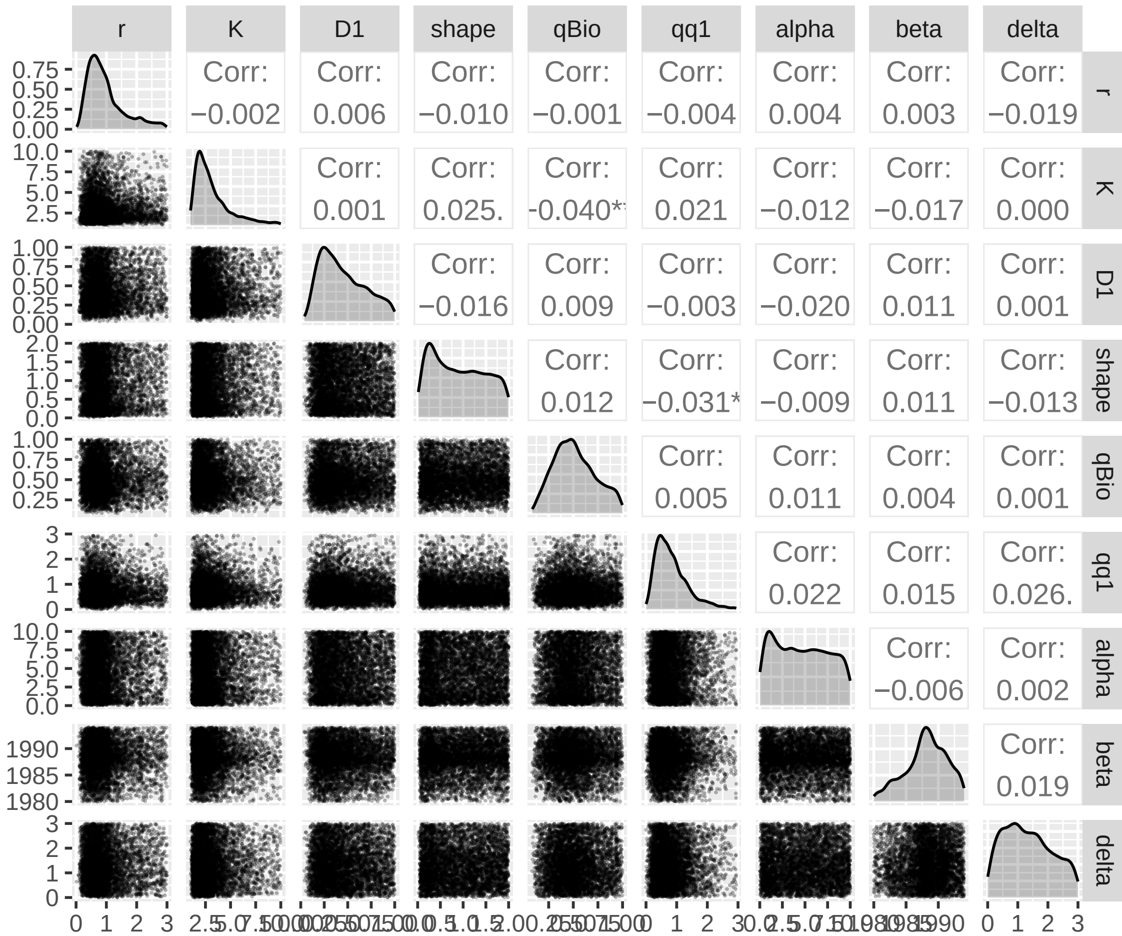
Base case 2


r
K
D1
shape
qBio
Corr:
0.016
Corr:
−0.027.
Corr:
0.014
Corr:
0.002
Corr:
0.003
Corr:
−0.014
Corr:
0.002
Corr:
0.011
Corr:
0.019
Corr:
−0.007

Sensitivity case 1



Sensitivity case 2


r
K
D1
shape
qBio
qq1
alpha
beta
delta
Corr: −0.002
Corr: 0.006
Corr: −0.010
Corr: −0.001
Corr: −0.004
Corr: 0.004
Corr: 0.003
Corr: −0.019
Corr: 0.001
Corr: 0.025.
Corr: -0.040**
Corr: 0.021
Corr: −0.012
Corr: −0.017
Corr: 0.000
Corr: −0.016
Corr: 0.009
Corr: −0.003
Corr: −0.020
Corr: 0.011
Corr: 0.001
Corr: 0.012
Corr: −0.031*
Corr: −0.009
Corr: 0.011
Corr: −0.013
Corr: 0.005
Corr: 0.011
Corr: 0.004
Corr: 0.001
Corr: 0.022
Corr: 0.015
Corr: 0.026.
Corr: −0.006
Corr: 0.002
Corr: 0.019