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2022 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 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 2022 median depletion level was only 25.1% (80%CI=14.1-39.4%) of the carrying capacity. Furthermore, B-ratio (=B/Bmsy) and F-ratio (=F/Fmsy) in 2021 were 0.288 (80%CI=0.191-0.406) and 0.740 (80%CI=0.468-1.140), respectively. For those three years average values, B-ratio over 2020-2022 and F-ratio over 2019-2021 were respectively 0.377 (80%CI=0.251-0.558) and 1.169 (80%CI=0.765-1.689). In addition, the probability of the stock being in the green Kobe quadrant in 2021 was estimated to be nearly 0%, while the probability of being in the yellow Kobe quadrant was assessed to be greater than 80%. 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*B2022=229,000 (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 (B2022/Bmsy)*Fmsy*B2022=122,000 (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 2021

2) standardized CPUE indices by the following five Members up to 2021

3) fishery-independent survey by Japan from 2003 to 2022

4) joint CPUE from 1994 to 2021

Table 1. Specification of the new stock assessment for the BSSPM (extracted from SSC-PS09 report).

	Base case (NB1)	**Base case (NB2)**	**Sensitivity case (NS1)**	**Sensitivity case(NS2)**
Initial year	1980	1980	1980	1980
Biomass survey	$I_{t,bio} = q_{bio} B_t e^{v_{t,bio}}$ $v_{t,bio} \sim N(0, cv_{t,bio}^2 + \sigma^2)$ $q_{bio} \sim U(0,1)$ (2003-2022)	Same as left	Same as left	Same as left
CPUE	CHN(2013-2021) JPN_late(1994-2021) KOR(2001-2021) RUS(1994-2021) CT(2001-2021) $I_{t,f} = q_f B_t^b e^{v_{t,f}}$ $v_{t,f} \sim N(0, \sigma_f^2)$ $\sigma_f^2 = c \cdot (ave(cv_{t,bio}^2) + \sigma^2)$, where $ave(cv_{t,bio}^2)$ is computed except for 2020 survey ($c = 5$)	Joint CPUE (1994-2021) $I_{t,joint} = q_{joint} B_t^b e^{v_{t,joint}}$ $v_{t,joint} \sim N(0, cv_{t,joint}^2 + \sigma^2)$	CHN(2013-2021) JPN_early(1980-1993, time-varying q) JPN_late(1994-2021) KOR(2001-2021) RUS(1994-2021) CT(2001-2021) $I_{t,f} = q_f B_t^b e^{v_{t,f}}$ $v_{t,f} \sim N(0, \sigma_f^2)$ $\sigma_f^2 = c \cdot (ave(cv_{t,bio}^2) + \sigma^2)$, where $ave(cv_{t,bio}^2)$ is computed except for 2020 survey ($c = 6$)	JPN_early(1980-1993, time-varying q) $I_{t,JE} = q_{t,JE} B_t^b e^{v_{t,JE}}$ $v_{t,JE} \sim N(0, \sigma_{JE}^2)$ $\sigma_{JE}^2 = c \cdot (ave(cv_{t,joint}^2) + \sigma^2)$ Joint CPUE (1994-2021) $I_{t,joint} = q_{joint} B_t^b e^{v_{t,joint}}$ $v_{t,joint} \sim N(0, cv_{t,joint}^2 + \sigma^2)$
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 2022 median depletion level was only 25.1% (80%CI=14.1-39.4%) of the carrying capacity. Furthermore, B-ratio (=B/Bmsy) and F-ratio (=F/Fmsy) in 2021 were 0.288 (80%CI=0.191-0.406) and 0.740 (80%CI=0.468-1.140), respectively. For those three years average values, B-ratio over 2020-2022 and F-ratio over 2019-2021 were respectively 0.377 (80%CI=0.251-0.558) and 1.169 (80%CI=0.765-1.689).

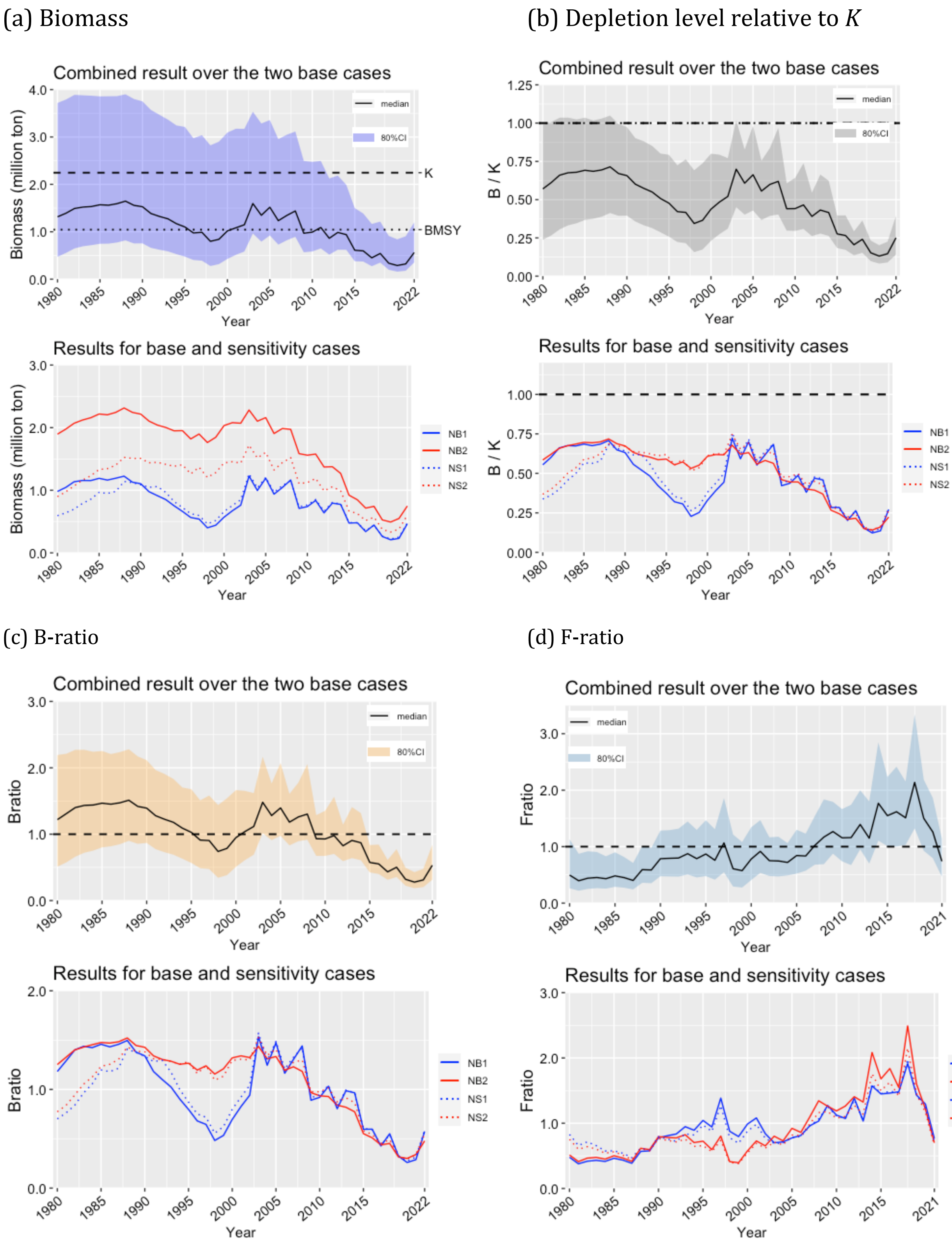


Figure 2. Results of trajectories over the two base cases of (a) biomass, (b) depletion level relative to the carrying capacity, (c) B-ratio and (d) F-ratio.

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

	Mean	Median	Lower10th	Upper10th
C_2021	0.092	0.092	0.092	0.092
AveC_2019_2021	0.141	0.141	0.141	0.141
AveF_2019_2021	0.464	0.456	0.162	0.776
F_2021	0.301	0.287	0.102	0.519
FMSY	0.404	0.407	0.140	0.657
MSY (million ton)	0.416	0.406	0.328	0.506
F_2021/FMSY	0.783	0.740	0.468	1.140
AveF_2019_2021/FMSY	1.211	1.169	0.765	1.689
K (million ton)	2.979	2.246	1.343	5.891
B_2021 (million ton)	0.451	0.321	0.178	0.905
B_2022 (million ton)	0.697	0.563	0.353	1.200
AveB_2020_2022	0.520	0.391	0.238	0.976
BMSY (million ton)	1.360	1.044	0.647	2.601
BMSY/K	0.467	0.460	0.399	0.549
B_2021/K	0.154	0.147	0.090	0.225
B_2022/K	0.262	0.251	0.141	0.394
AveB_2020_2022/K	0.185	0.179	0.112	0.264
B_2021/BMSY	0.295	0.288	0.191	0.406
B_2022/BMSY	0.561	0.532	0.315	0.838
AveB_2020_2022/BMSY	0.397	0.377	0.251	0.558

Evidently, Figure 3, which is the Kobe plot with time series of median B-ratio and F-ratio for 1980-2021, also shows that the probability of the stock being in the green Kobe quadrant in 2021 was estimated to be nearly 0%, while the probability of being in the yellow Kobe quadrant was assessed to be greater than 80%. On the weight-of-evidence available now, the current Pacific saury stock is determined not to be overfished and subject to overfishing.

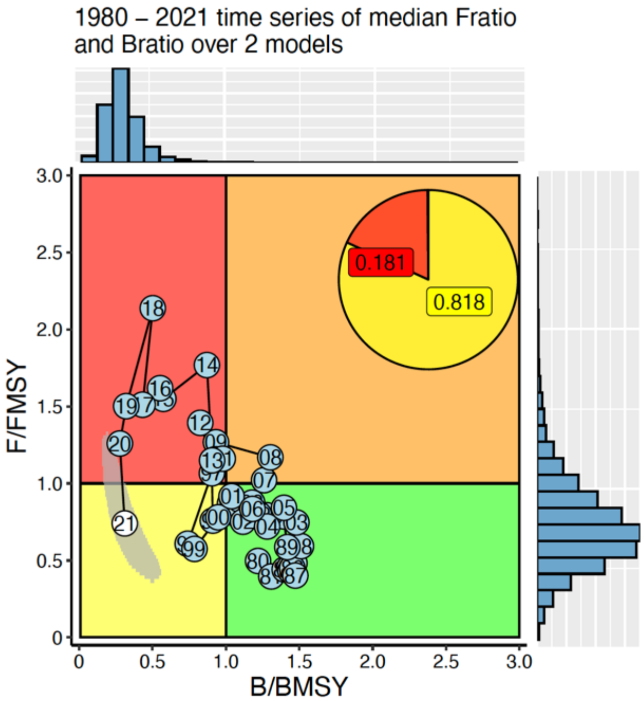


Figure 3. Kobe plot with time series of median B-ratio and F-ratio for 1980-2021.

Future projection and risk analysis

Figure 4 shows the median of biomass trajectory with future projection for different catch levels in 2022-2026 relative to the average catch over 2019-2021. 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.

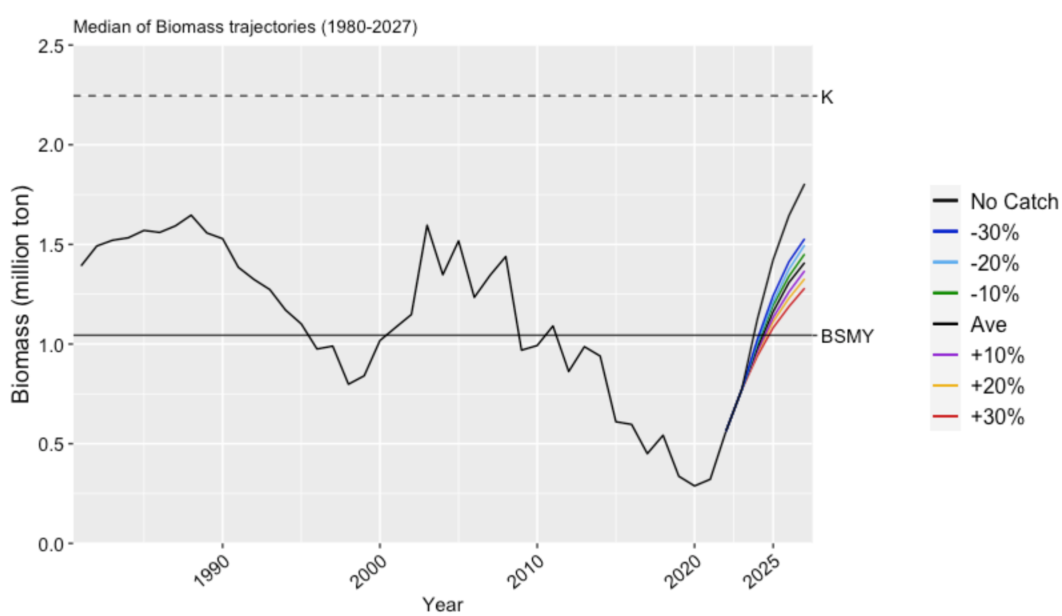


Figure 4. Median of biomass trajectory with future projection under the 8 different catch scenarios.

Table 3. Risk table for different catch levels over next 5 five years relative to 2019-2021 average catch.

	Red	Orange	Yellow	Green	B<BMSY	F>FMSY
+30%	0.159	0	0.220	0.622	0.378	0.159
+20%	0.131	0	0.228	0.641	0.359	0.131
+10%	0.110	0	0.234	0.656	0.343	0.110
±0%	0.090	0	0.233	0.677	0.323	0.090
-10%	0.072	0	0.238	0.689	0.311	0.072
-20%	0.055	0	0.242	0.703	0.297	0.055
-30%	0.042	0	0.243	0.715	0.285	0.042
No Catch	0.000	0	0.209	0.791	0.209	0.000

Conclusion

1) Biomass level: the 2022 median depletion level was only 25.1% (80%CI=14.1-39.4%) 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 2021 were 0.288 (80%CI=0.191-0.406) and 0.740 (80%CI=0.468-1.140), respectively. For those three years average values, B-ratio over 2020-2022 and F-ratio over 2019-2021 were respectively 0.377 (80%CI=0.251-0.558) and 1.169 (80%CI=0.765-1.689).

3) The probability of the stock being in the green Kobe quadrant in 2021 was estimated to be nearly 0%, while the probability of being in the yellow Kobe quadrant was assessed to be greater than 80%.

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*B2022=0.407*563,000=229,000 (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 (B2022/Bmsy)*Fmsy*B2022=0.532*0.407*563,000=122,000 (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).

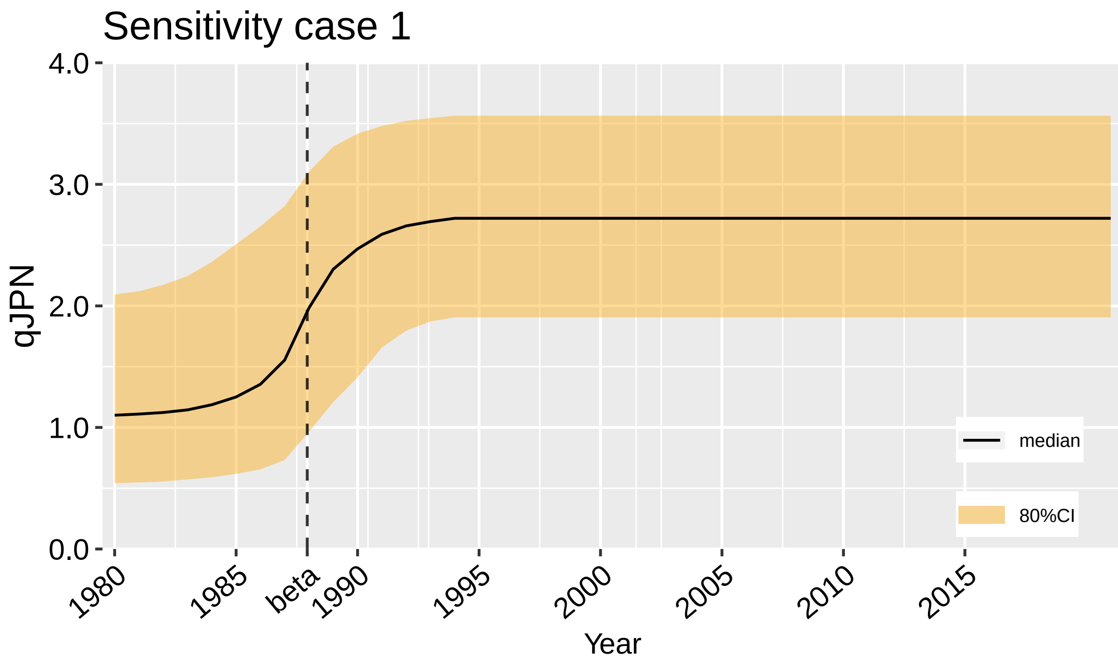
NPFC (2022) Report of the SSC-PS09.

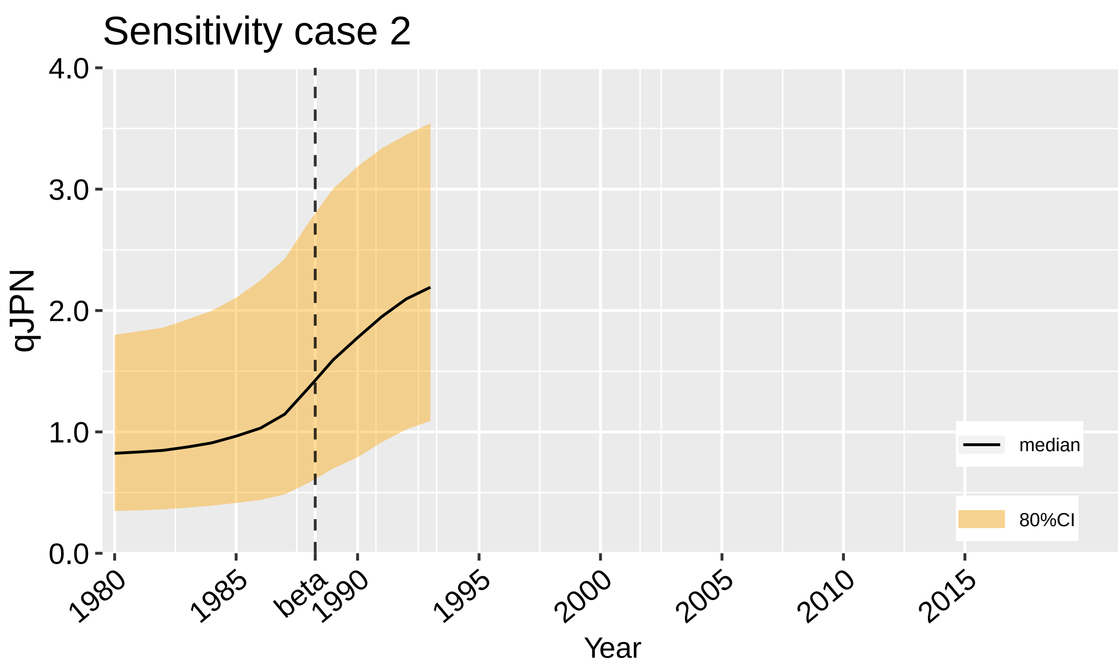
Item	Authors' note
(1) Identify the data that will be available to the stock assessment;	As shown in the main section.
(2) Evaluate data quality and quantity and potential error sources (e.g., sampling errors, measurement errors) and associated statistical properties (e.g., biased or random errors, statistical 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
(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-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
(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-PS09
(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

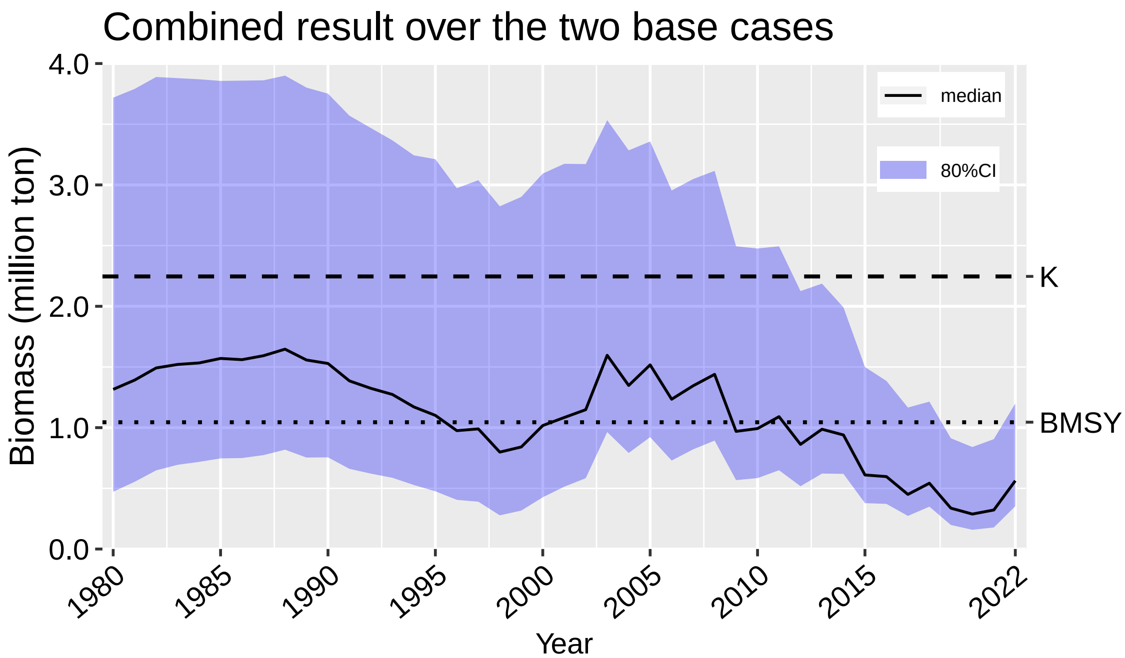
1 Estimated time-varying catchability

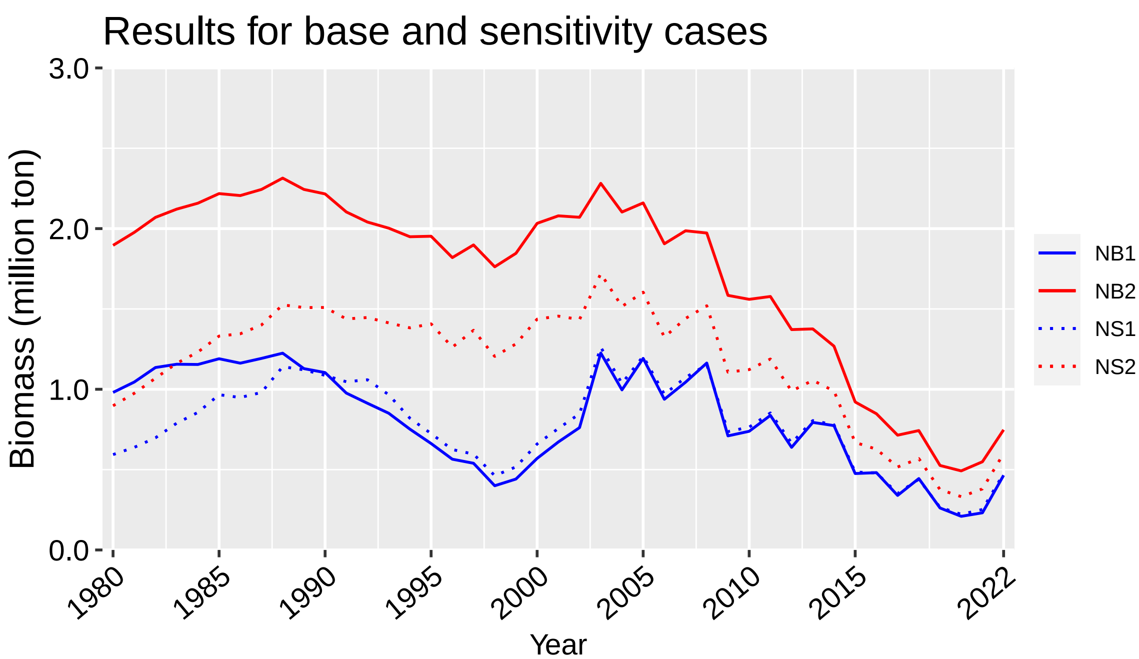


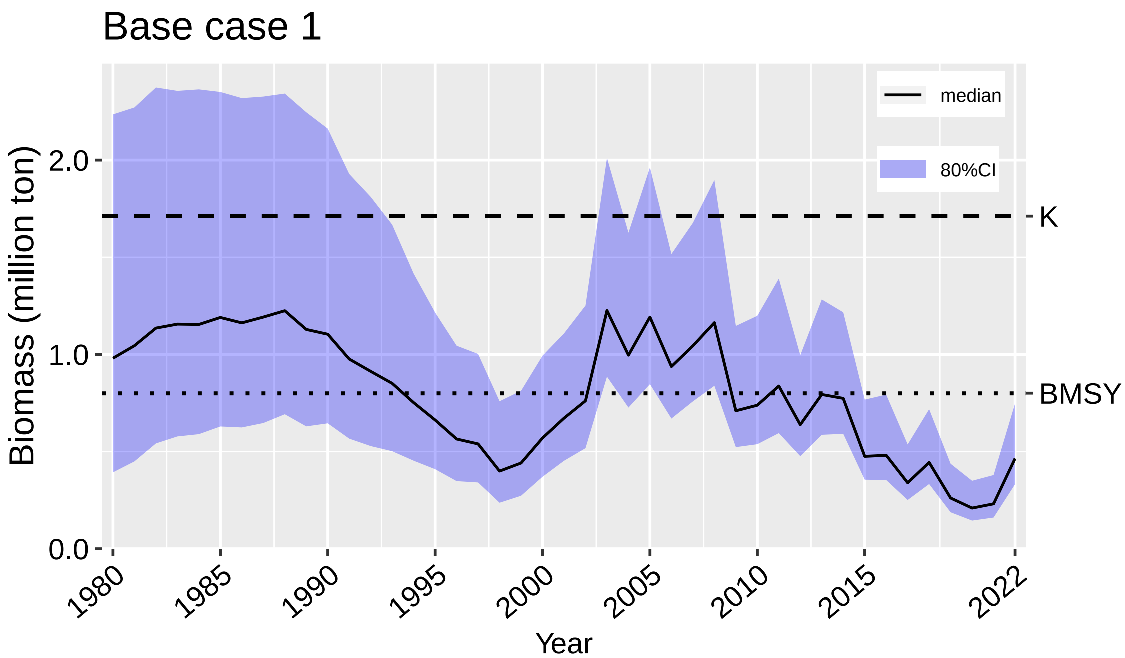


2 Time series plot

2.1 Time series Biomass



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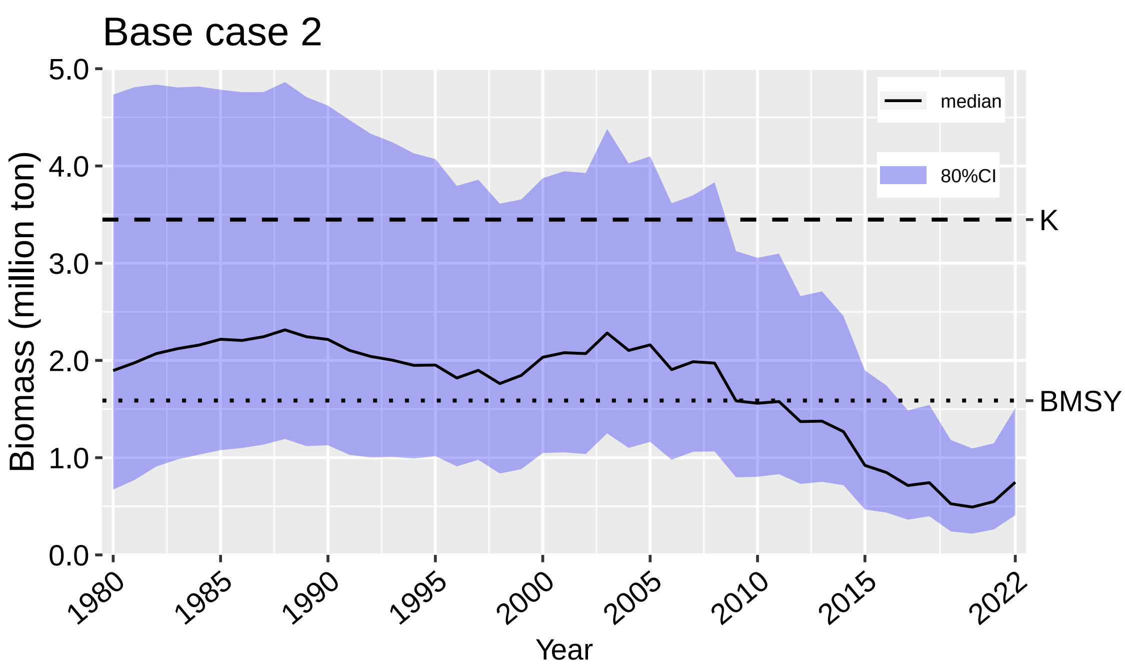
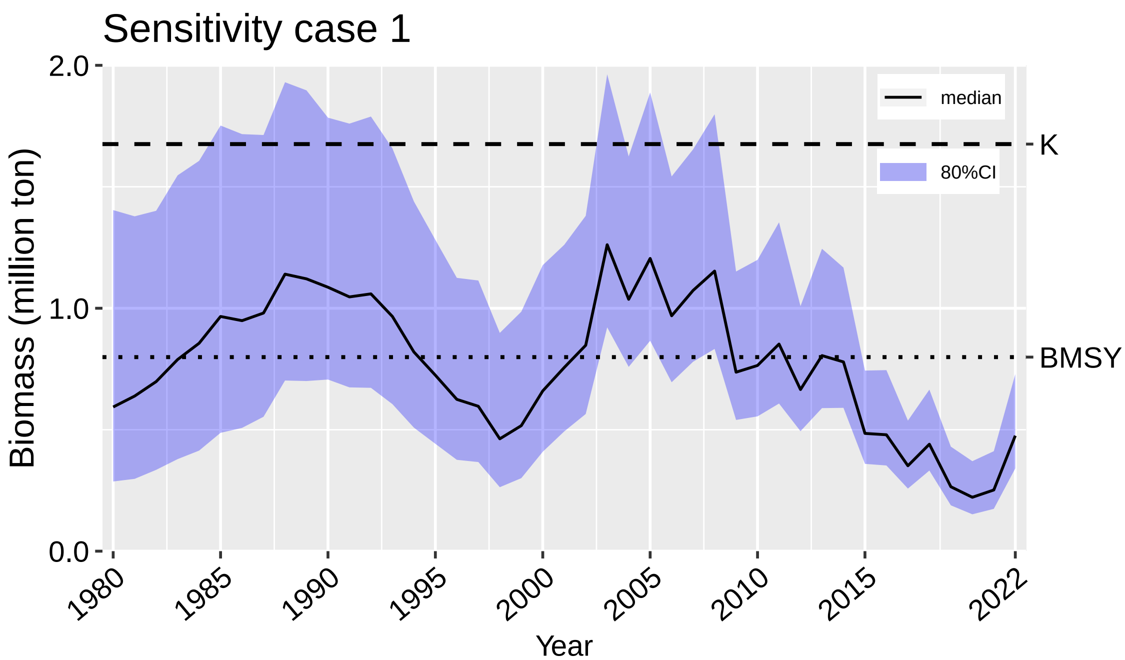
80%CI
K
BMSY
Biomass (million ton)
Year


Base case 2
median
80%CI
K
BMSY
Biomass (million ton)
Year


Sensitivity case 1
Biomass (million ton)
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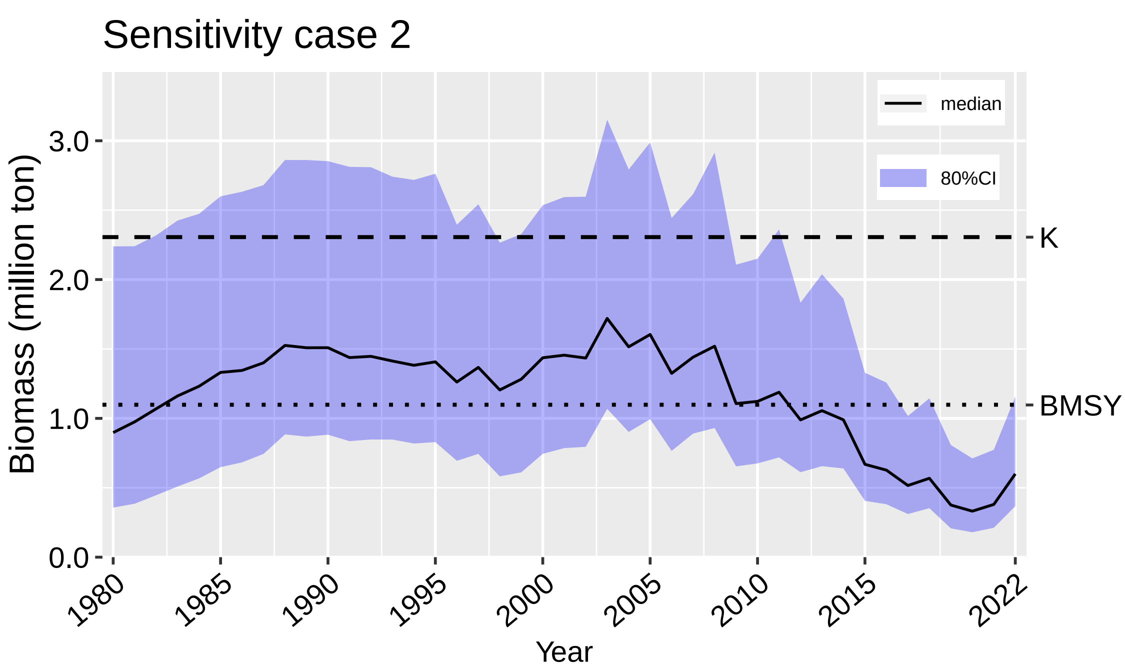
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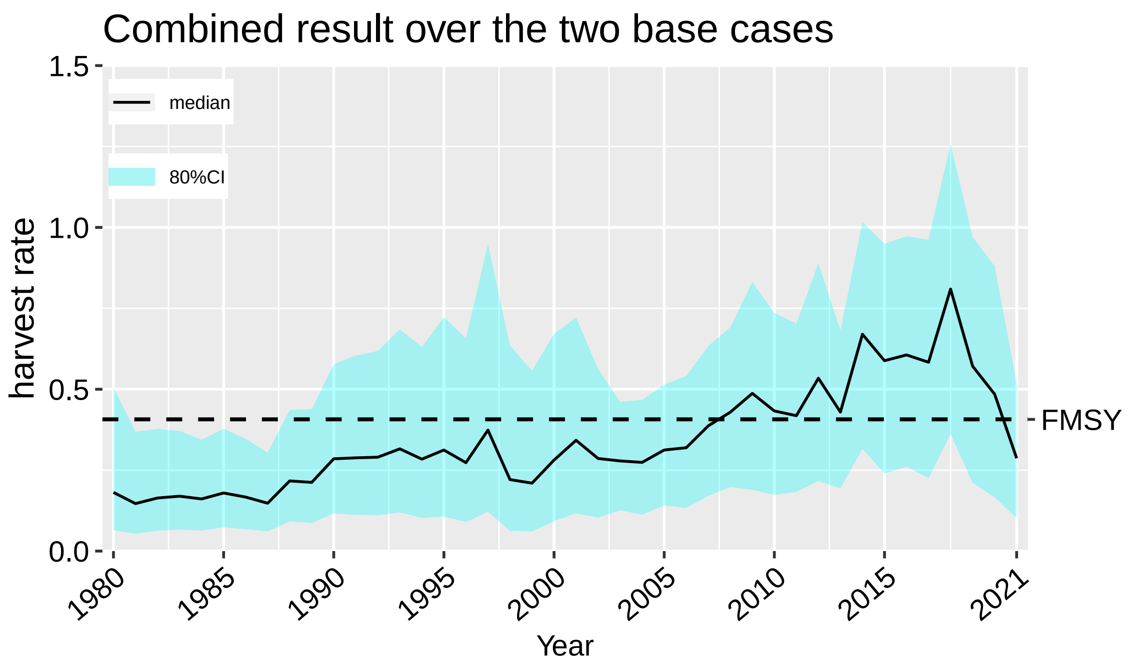
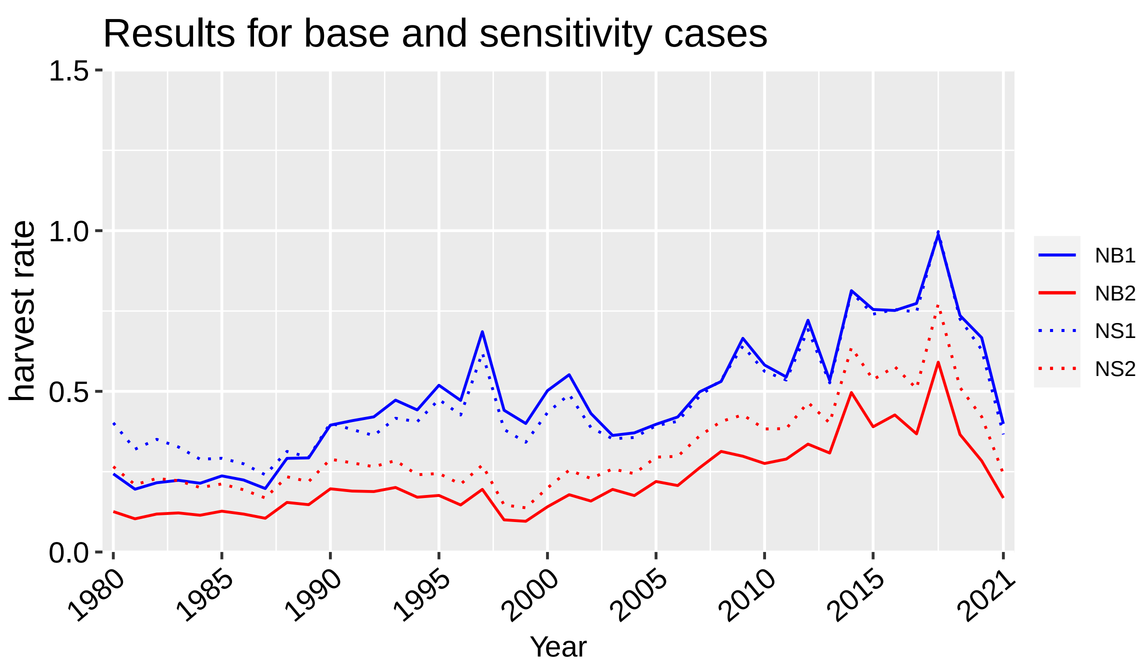
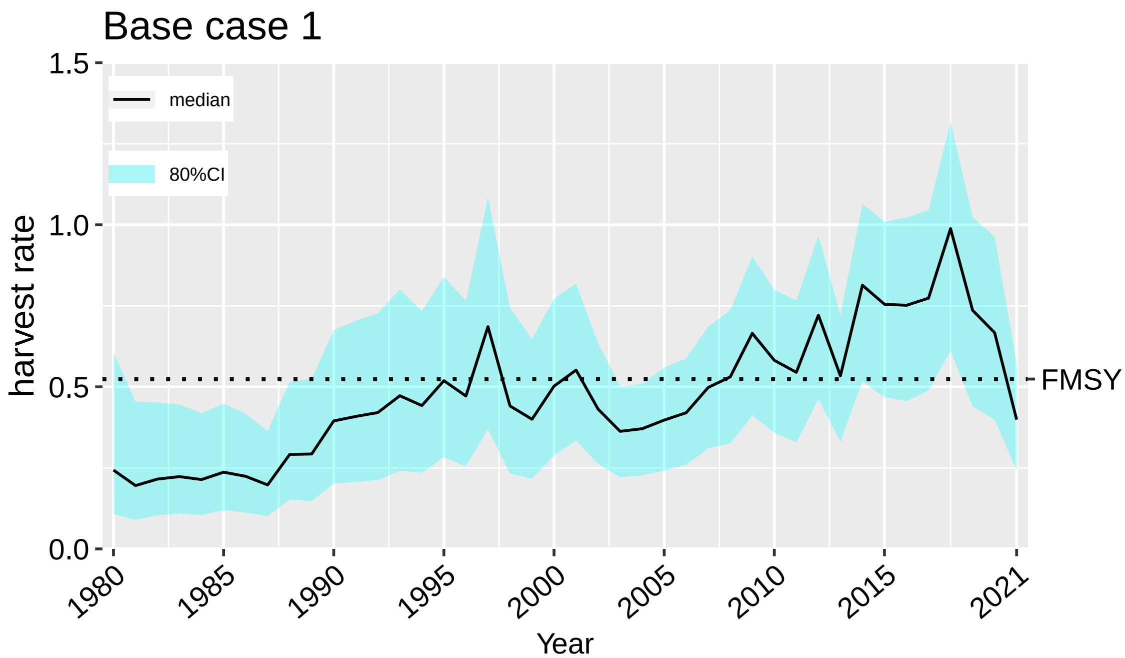
2.2 Time series Harvest rate



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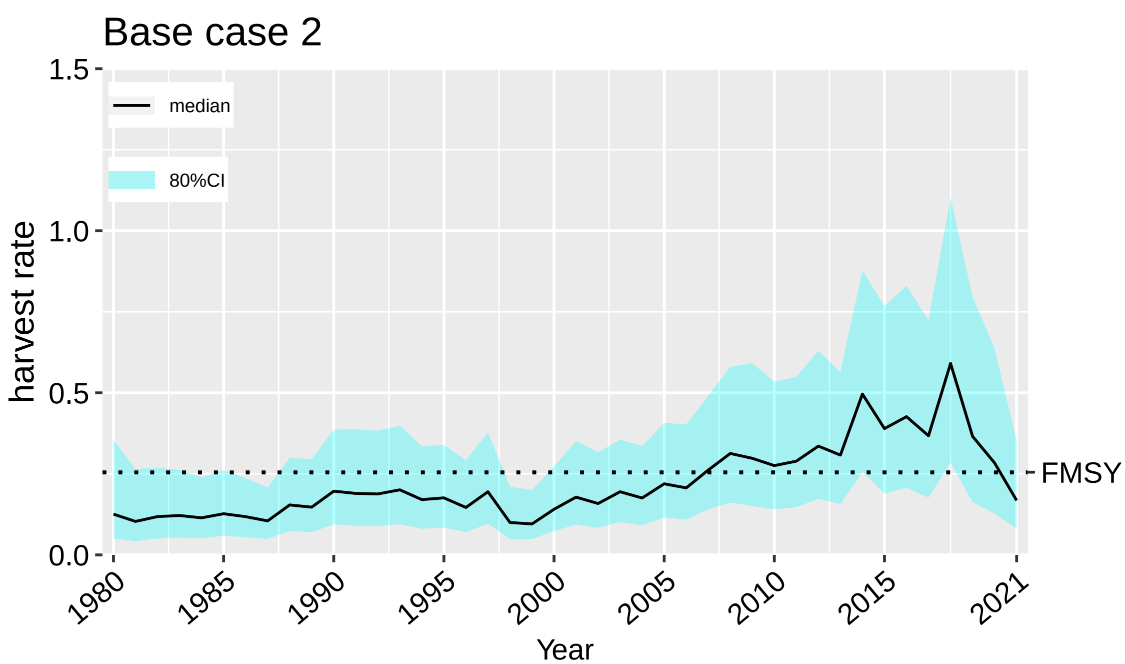
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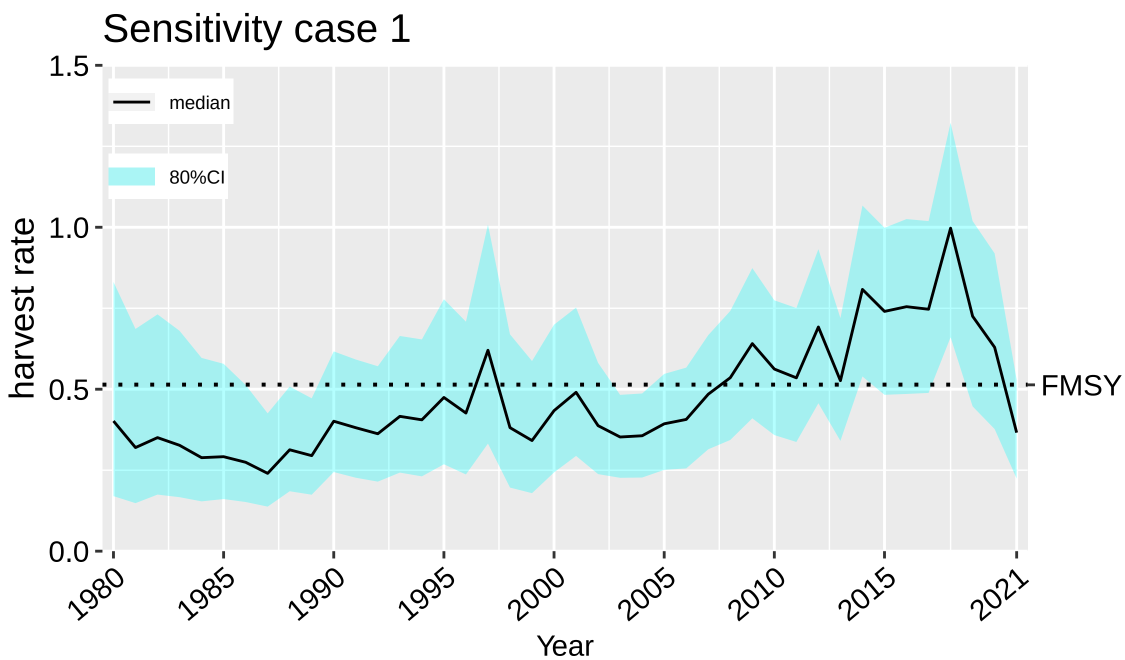

Sensitivity case 1
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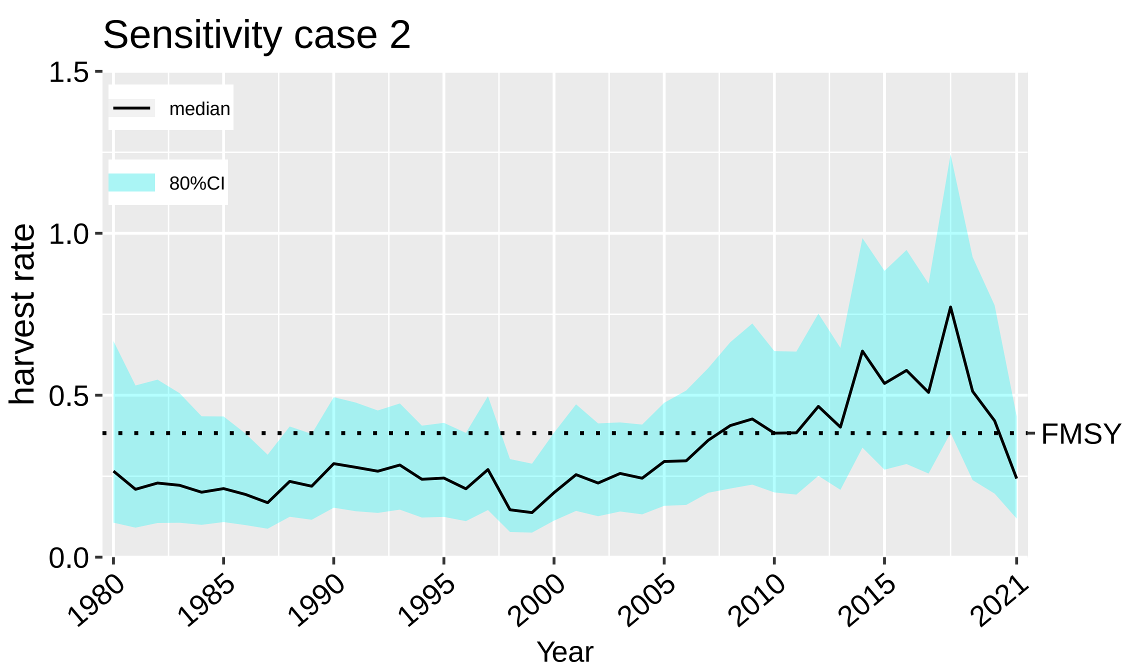

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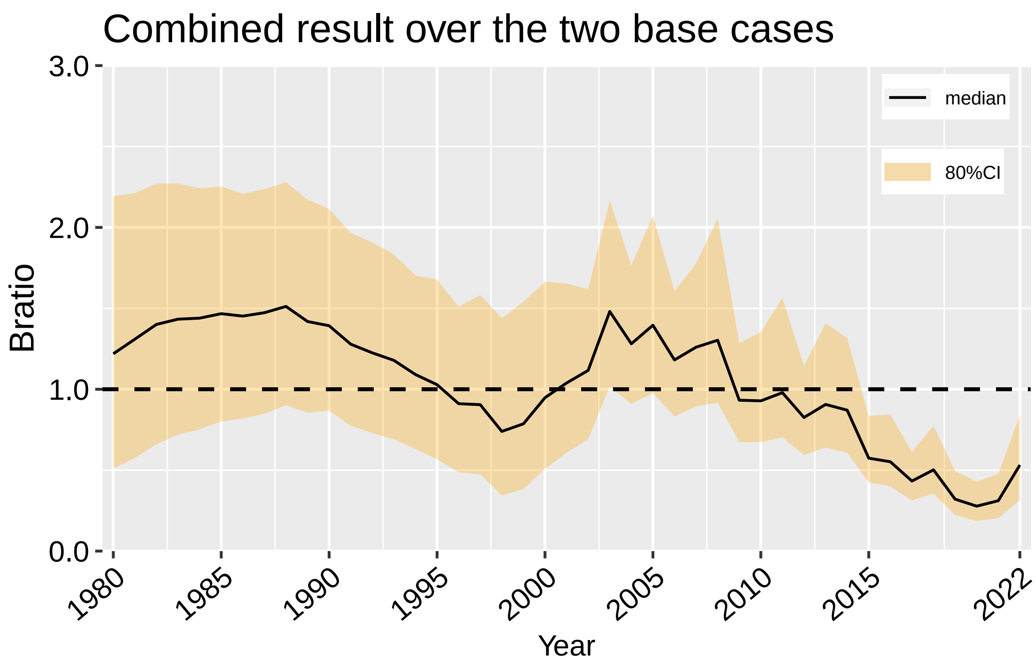

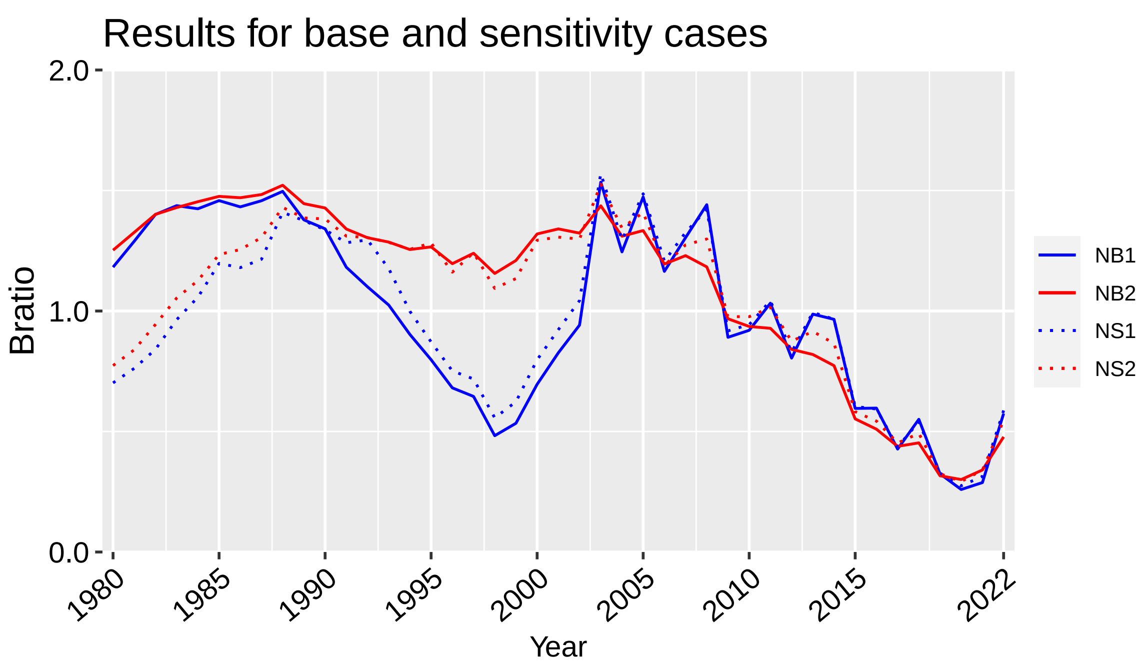

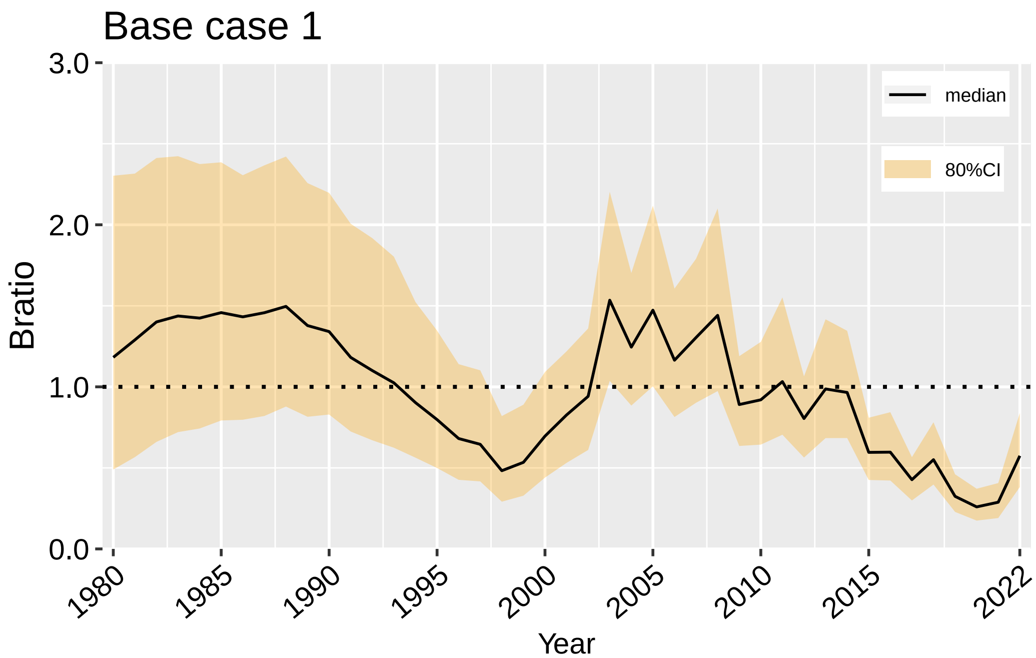
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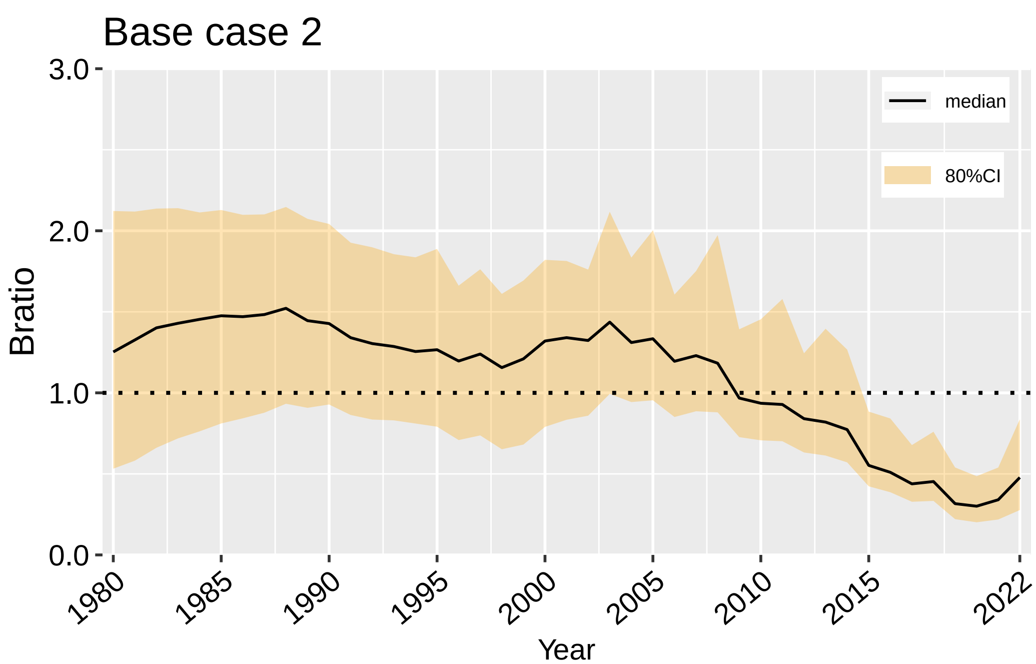
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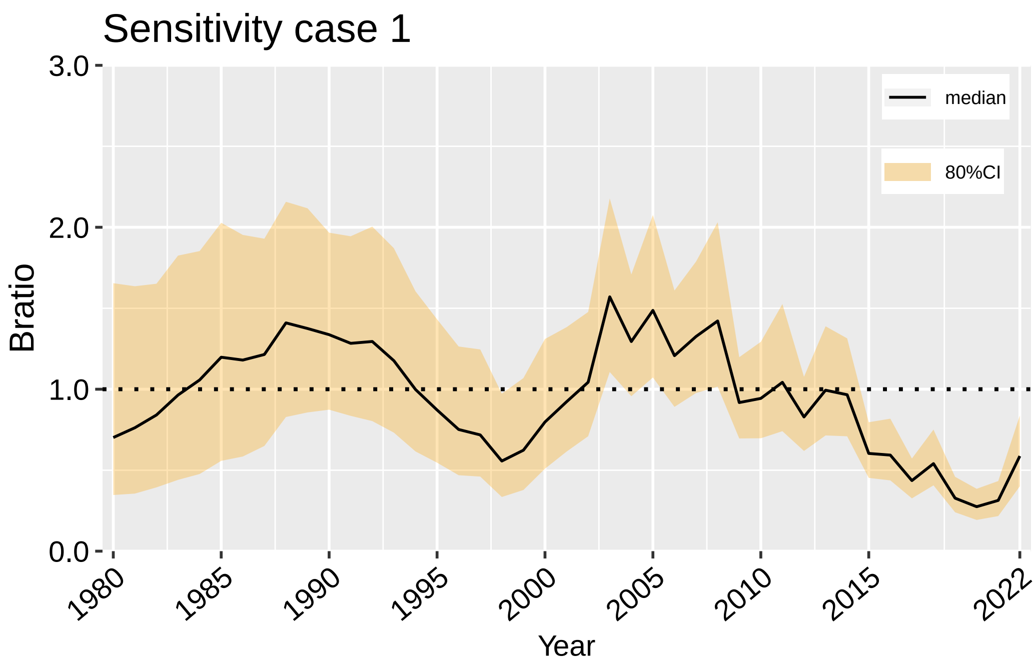
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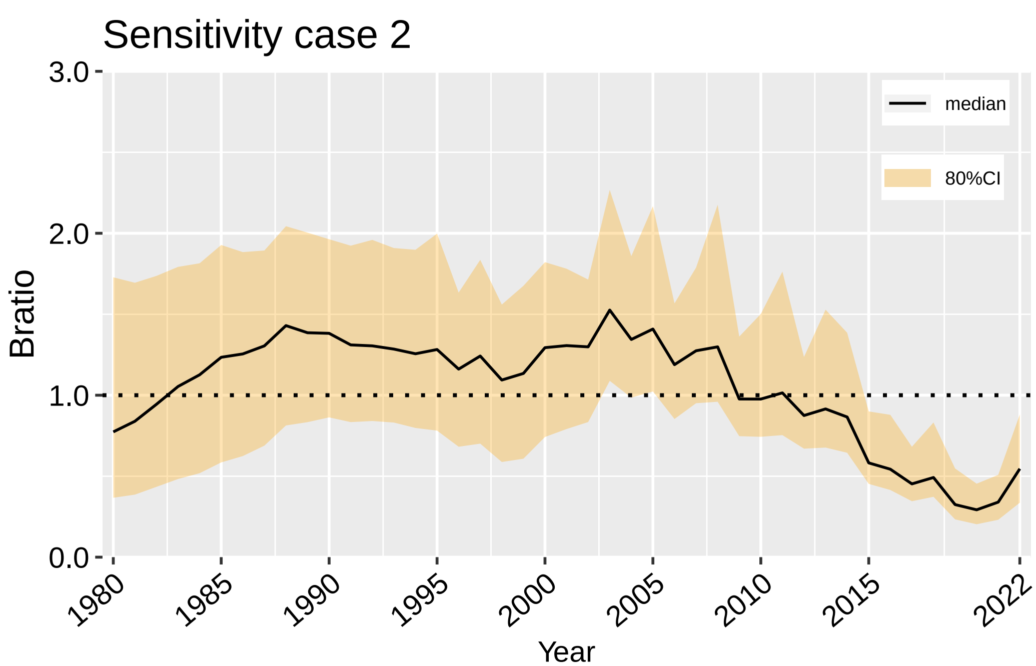
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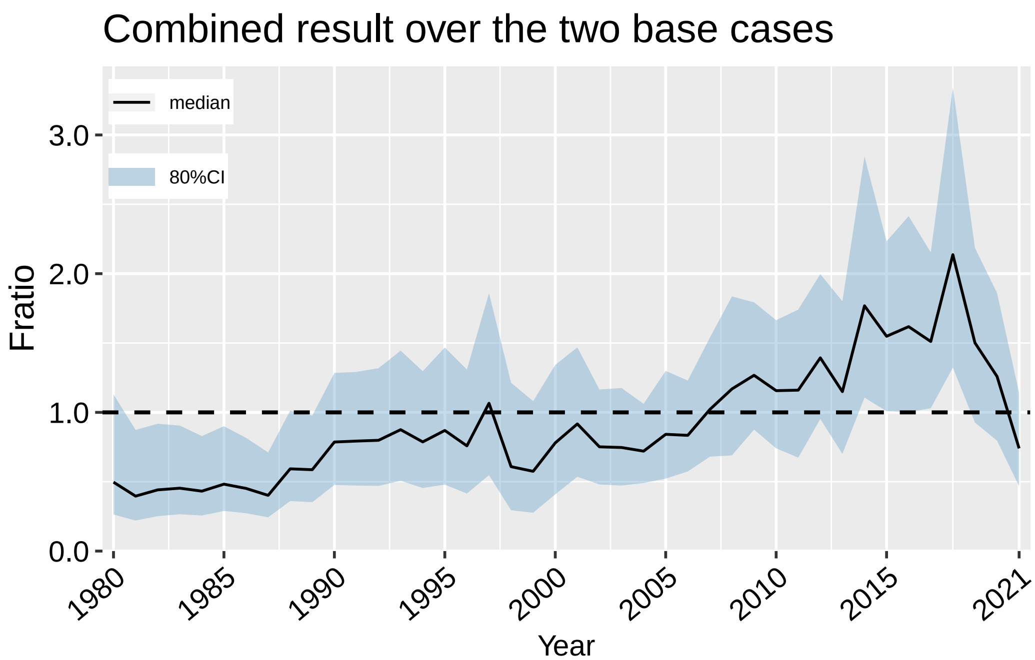

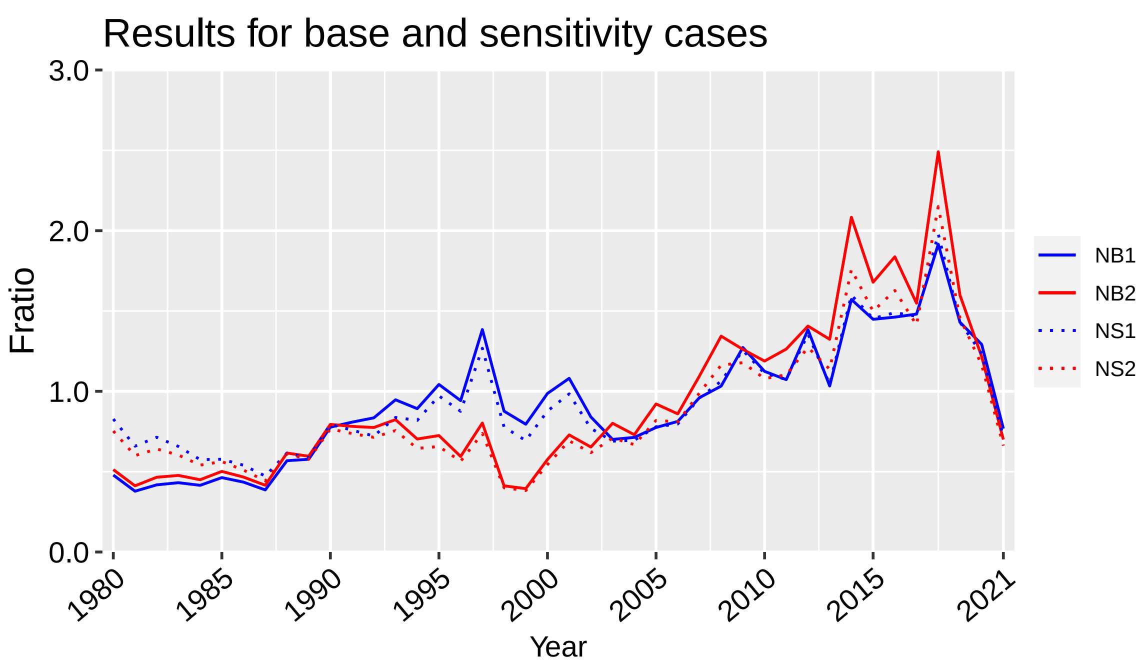

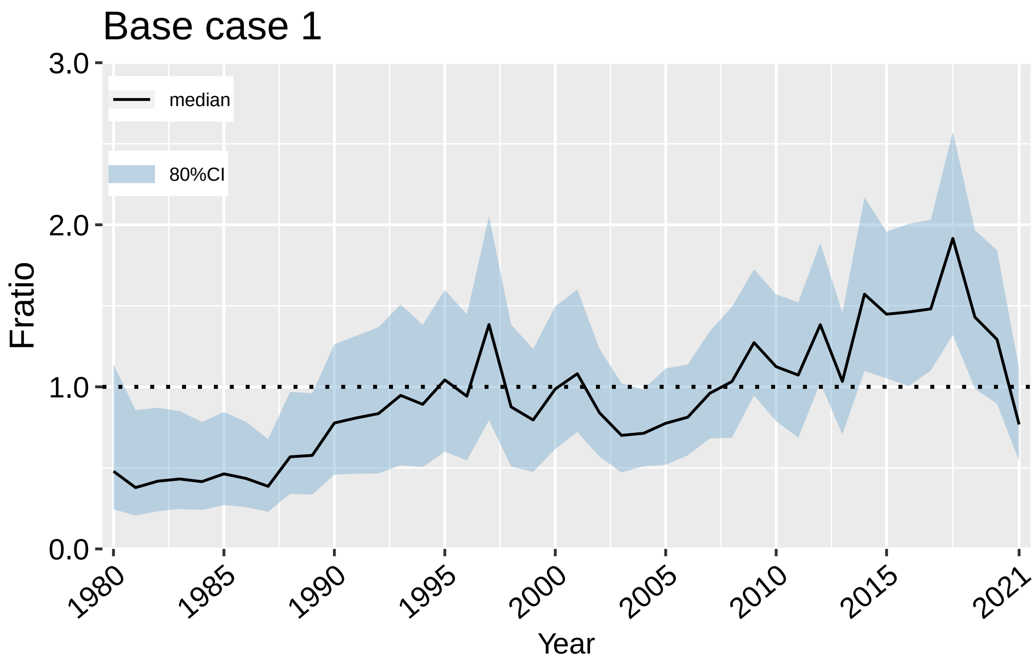
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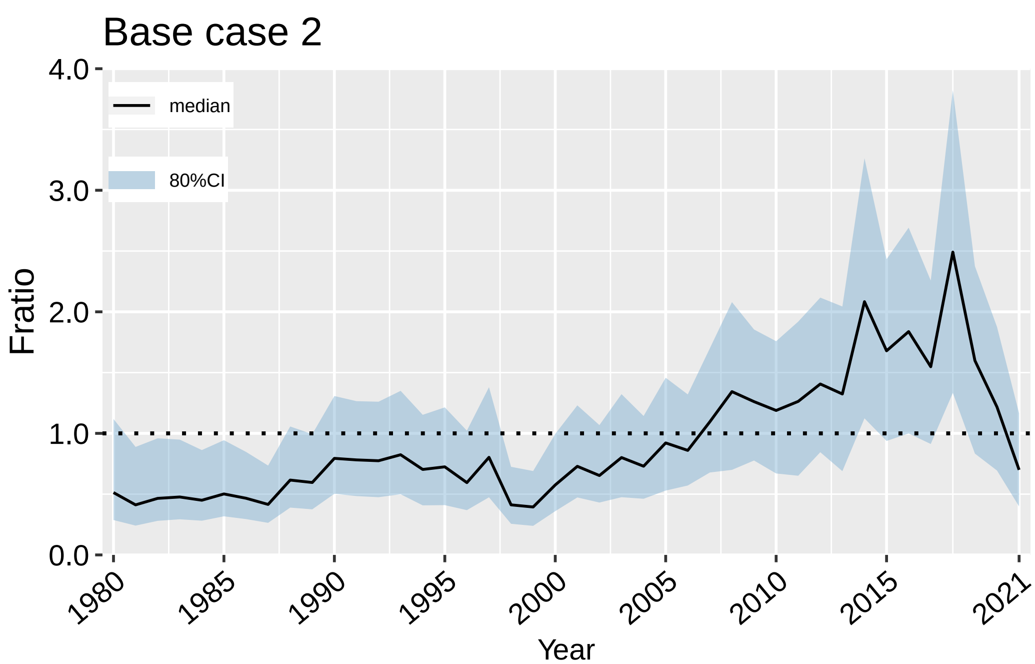
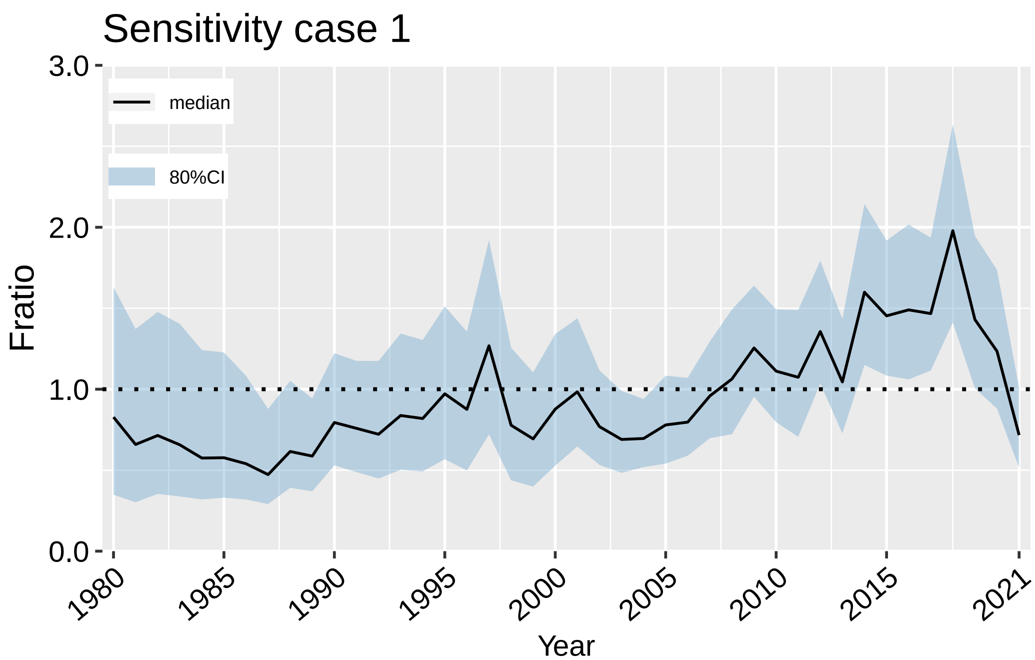
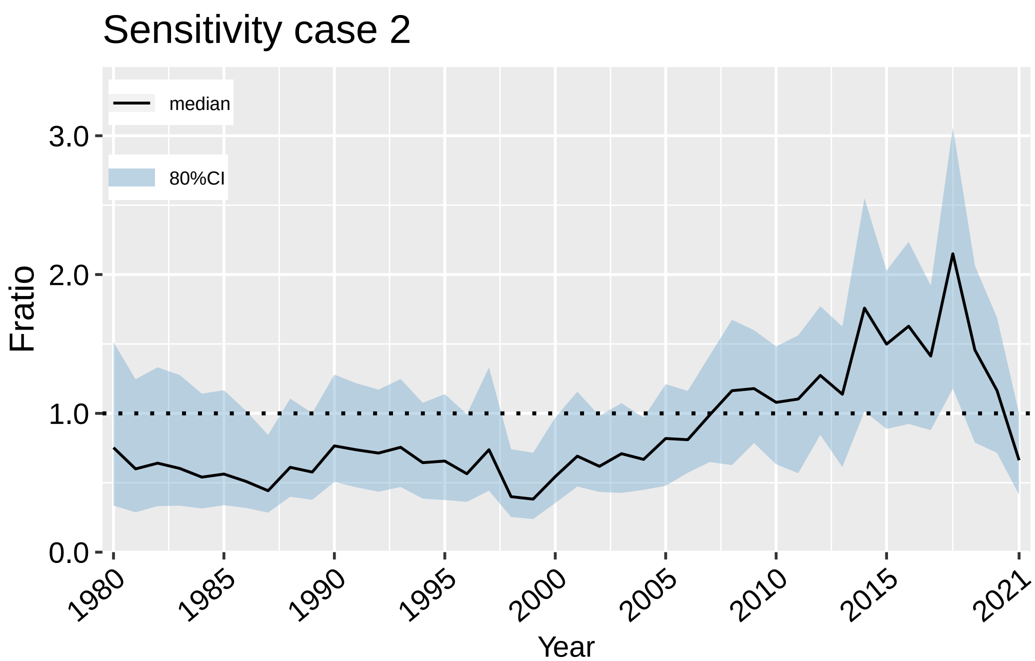
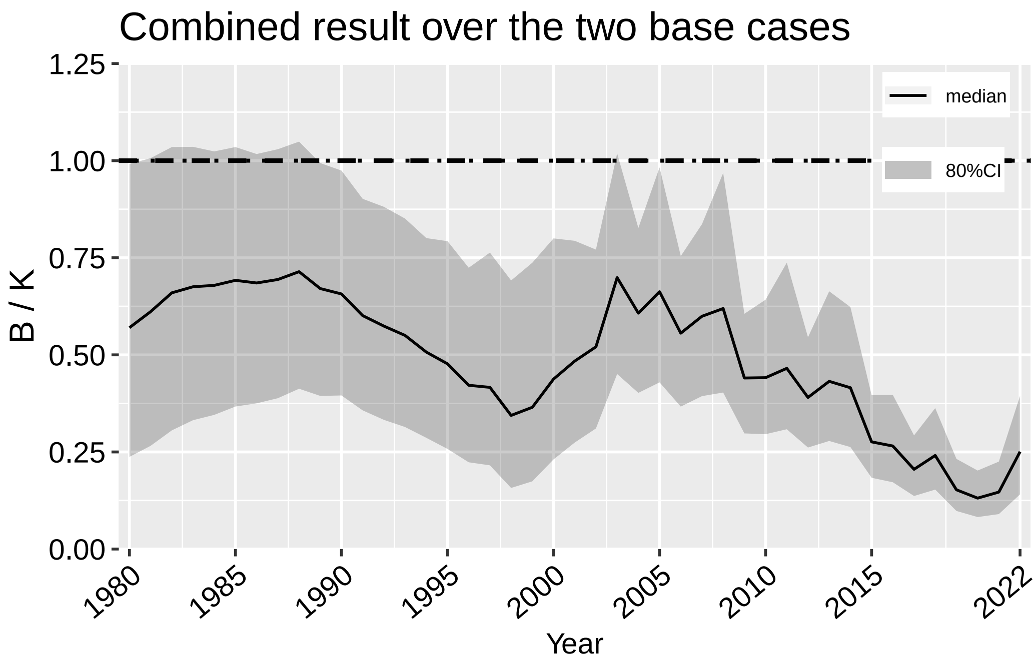
2021
Year

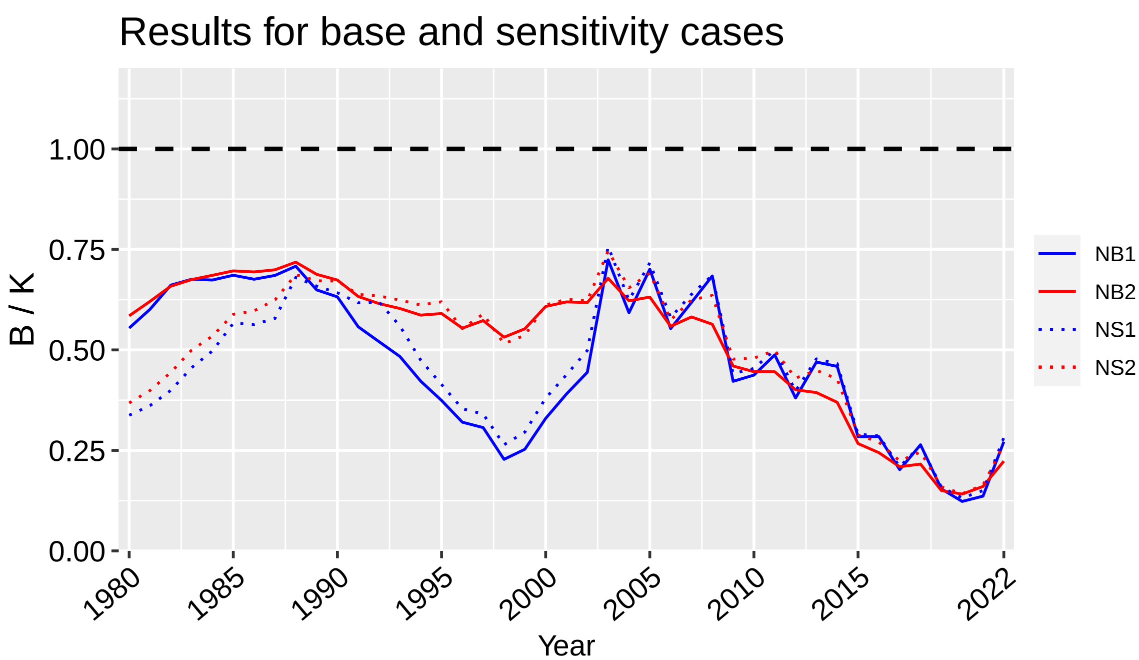

Base case 2
4.0
3.0
2.0
1.0
0.0
median
80%CI
Fratio
1980
1985
1990
1995
2000
2005
2010
2015
2021
Year

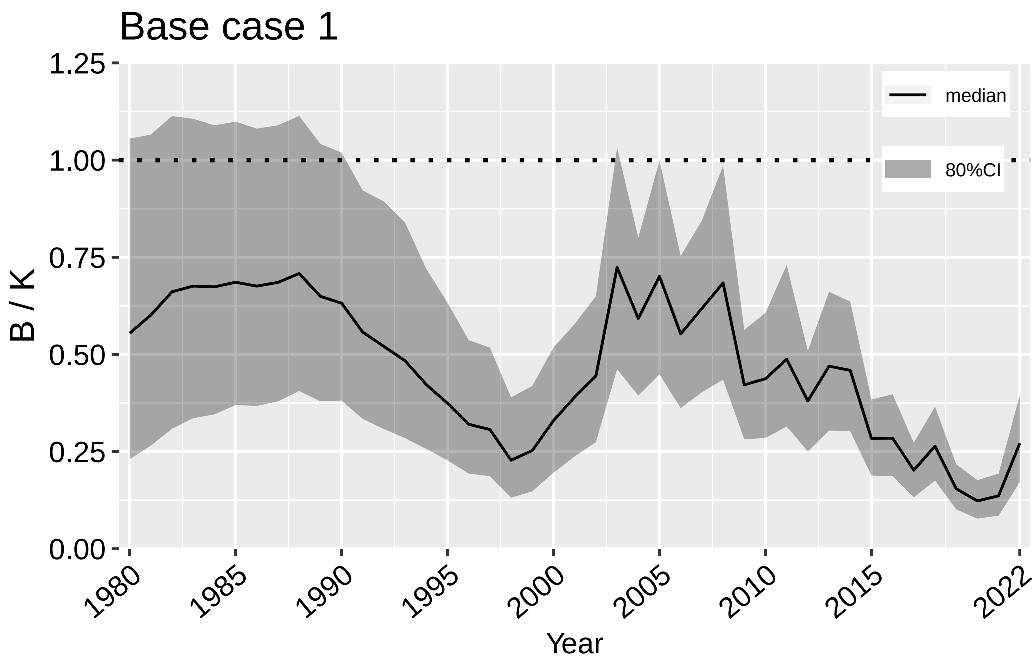

Sensitivity case 1
median
80%CI
Fratio
3.0
2.0
1.0
0.0
1980
1985
1990
1995
2000
2005
2010
2015
2021
Year

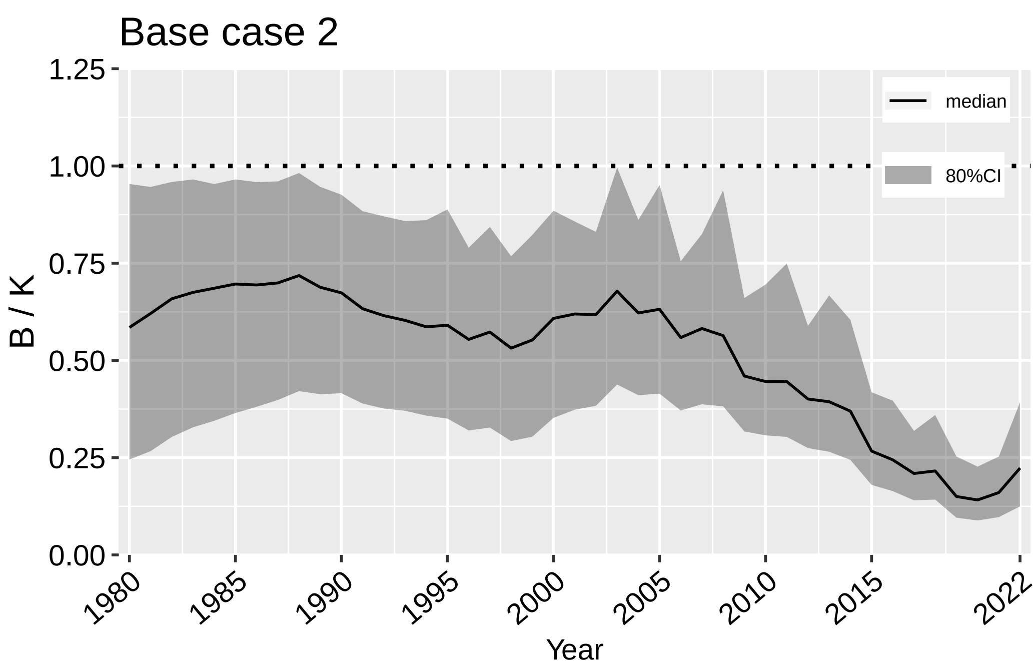

Sensitivity case 2
median
80%CI
Fratio
3.0
2.0
1.0
0.0
1980
1985
1990
1995
2000
2005
2010
2015
2021
Year

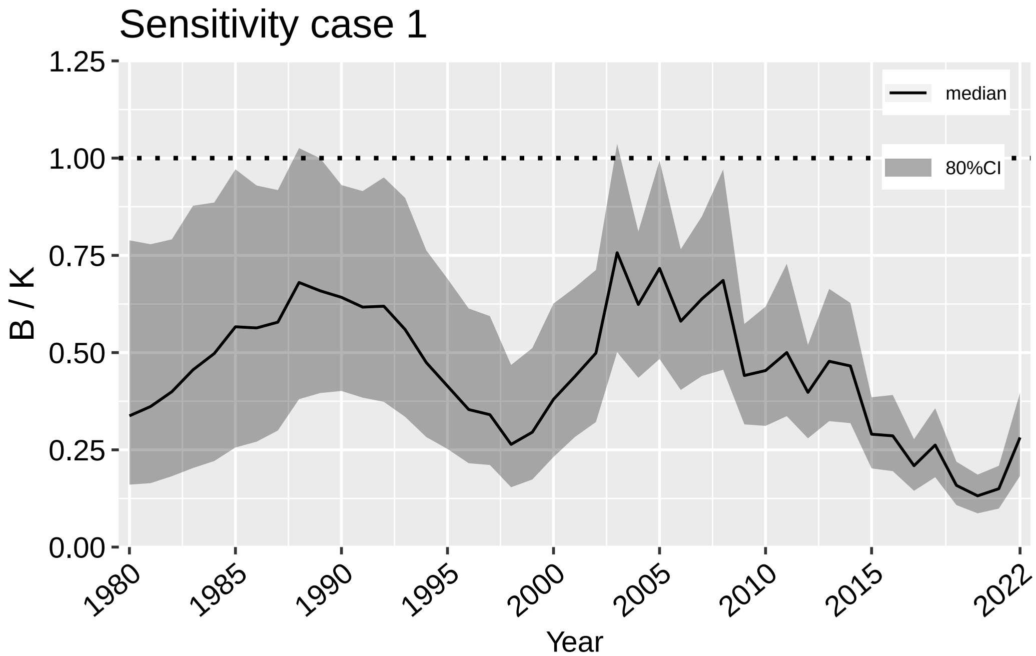
2.5 Time series B/K

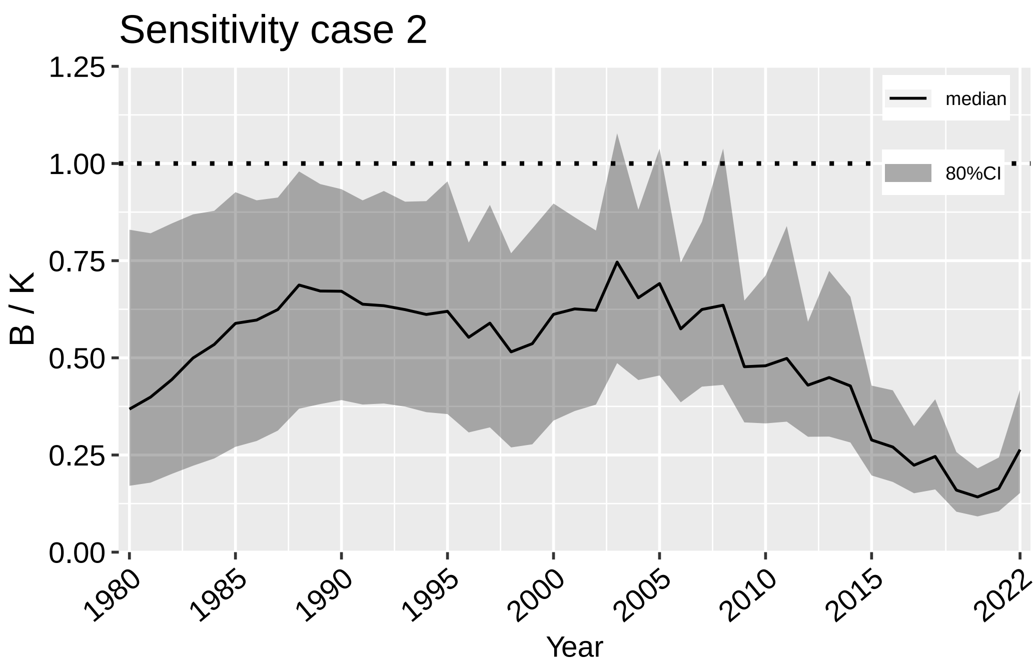




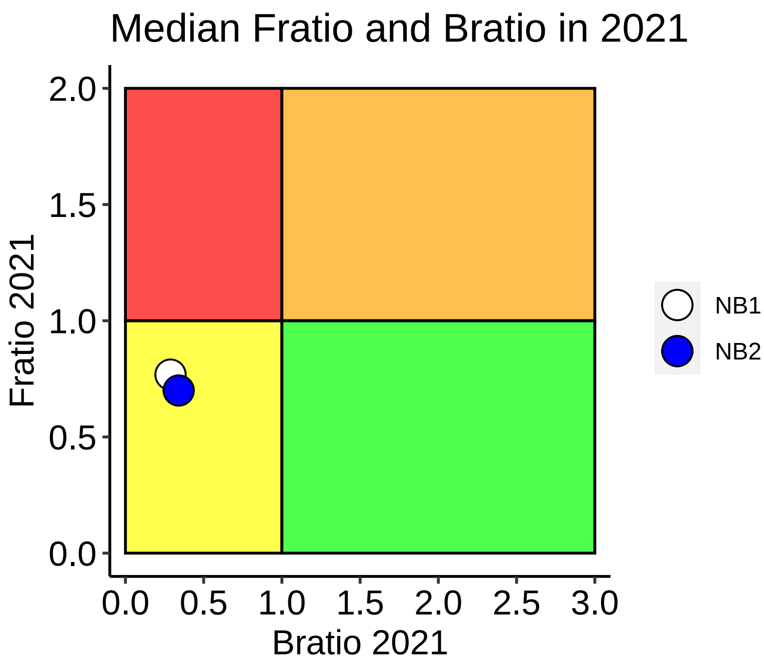

Base case 1
1.25
1.00
0.75
0.50
0.25
0.00
B / K
1980
1985
1990
1995
2000
2005
2010
2015
2022
Year
median
80%CI

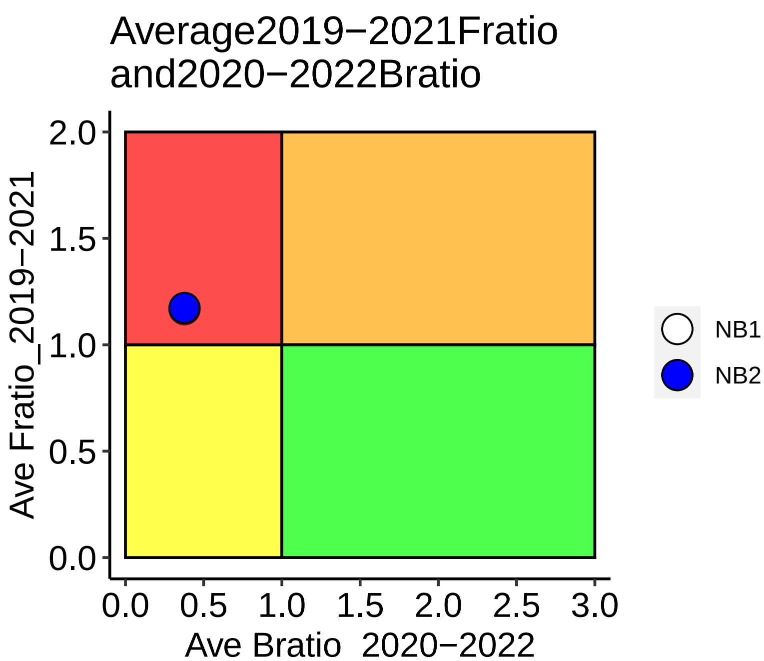

Base case 2
1.25
1.00
0.75
0.50
0.25
0.00
B / K
1980
1985
1990
1995
2000
2005
2010
2015
2022
Year
median
80%CI

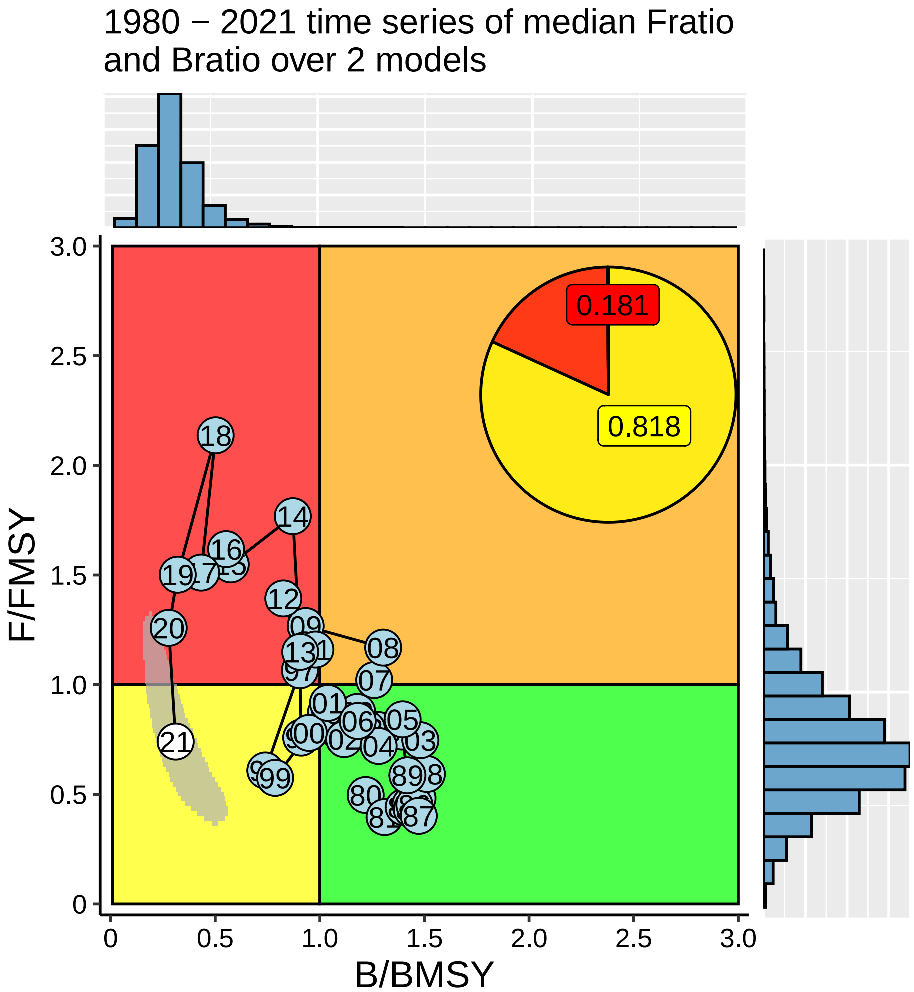

Sensitivity case 1
B / K
1.25
1.00
0.75
0.50
0.25
0.00
median
80%CI
1980
1985
1990
1995
2000
2005
2010
2015
2022
Year


Sensitivity case 2
B / K
1.25
1.00
0.75
0.50
0.25
0.00
median
80%CI
1980
1985
1990
1995
2000
2005
2010
2015
2022
Year

3 Kobe plot


Median Fratio and Bratio in 2021
Fratio 2021
Bratio 2021
0.0
0.5
1.0
1.5
2.0
2.5
3.0
NB1
NB2


Average2019−2021Fratio
and2020−2022Bratio
Ave Fratio_2019−2021
Ave Bratio_2020−2022
0.0
0.5
1.0
1.5
2.0
2.5
3.0
NB1
NB2


1980 − 2021 time series of median Fratio
and Bratio over 2 models
F/FMSY
B/BMSY
0.181
0.818
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

4 Summary of reference points

Over 2 new base case models

	Mean	Median	Lower10th	Upper10th
C_2021	0.092	0.092	0.092	0.092
AveC_2019_2021	0.141	0.141	0.141	0.141
AveF_2019_2021	0.464	0.456	0.162	0.776
F_2021	0.301	0.287	0.102	0.519
FMSY	0.404	0.407	0.140	0.657
MSY (million ton)	0.416	0.406	0.328	0.506
F_2021/FMSY	0.783	0.740	0.468	1.140
AveF_2019_2021/FMSY	1.211	1.169	0.765	1.689
K (million ton)	2.979	2.246	1.343	5.891
B_2021 (million ton)	0.451	0.321	0.178	0.905
B_2022 (million ton)	0.697	0.563	0.353	1.200
AveB_2020_2022	0.520	0.391	0.238	0.976
BMSY (million ton)	1.360	1.044	0.647	2.601
BMSY/K	0.467	0.460	0.399	0.549
B_2021/K	0.154	0.147	0.090	0.225
B_2022/K	0.262	0.251	0.141	0.394
AveB_2020_2022/K	0.185	0.179	0.112	0.264
B_2021/BMSY	0.295	0.288	0.191	0.406
B_2022/BMSY	0.561	0.532	0.315	0.838
AveB_2020_2022/BMSY	0.397	0.377	0.251	0.558

Base case 1

	Mean	Median	Lower10th	Upper10th
C_2021	0.092	0.092	0.092	0.092
AveC_2019_2021	0.141	0.141	0.141	0.141
AveF_2019_2021	0.606	0.609	0.374	0.831
F_2021	0.405	0.399	0.243	0.574
FMSY	0.519	0.524	0.324	0.704
MSY (million ton)	0.429	0.419	0.358	0.508
F_2021/FMSY	0.806	0.768	0.542	1.113
AveF_2019_2021/FMSY	1.205	1.167	0.844	1.596
K (million ton)	1.978	1.712	1.246	2.975
B_2021 (million ton)	0.257	0.231	0.161	0.379
B_2022 (million ton)	0.514	0.465	0.332	0.748
AveB_2020_2022	0.335	0.302	0.224	0.481
BMSY (million ton)	0.908	0.800	0.605	1.309
BMSY/K	0.468	0.460	0.408	0.544
B_2021/K	0.138	0.136	0.085	0.193
B_2022/K	0.279	0.272	0.171	0.396
AveB_2020_2022/K	0.181	0.180	0.117	0.246
B_2021/BMSY	0.295	0.288	0.191	0.406
B_2022/BMSY	0.597	0.575	0.382	0.839
AveB_2019_2021/BMSY	0.387	0.377	0.263	0.518

Base case 2

	Mean	Median	Lower10th	Upper10th
C_2021	0.092	0.092	0.092	0.092
AveC_2019_2021	0.141	0.141	0.141	0.141
AveF_2019_2021	0.322	0.275	0.126	0.589
F_2021	0.196	0.168	0.080	0.352
FMSY	0.288	0.255	0.106	0.525
MSY (million ton)	0.402	0.390	0.302	0.504
F_2021/FMSY	0.759	0.700	0.399	1.165
AveF_2019_2021/FMSY	1.218	1.173	0.664	1.785
K (million ton)	3.980	3.448	1.718	7.268
B_2021 (million ton)	0.646	0.549	0.262	1.148
B_2022 (million ton)	0.879	0.748	0.409	1.510
AveB_2020_2022	0.706	0.602	0.307	1.234
BMSY (million ton)	1.812	1.588	0.839	3.177
BMSY/K	0.466	0.459	0.391	0.553
B_2021/K	0.170	0.160	0.097	0.253
B_2022/K	0.244	0.223	0.125	0.393
AveB_2020_2022/K	0.189	0.178	0.107	0.284
B_2021/BMSY	0.366	0.340	0.219	0.539
B_2022/BMSY	0.526	0.478	0.277	0.837
AveB_2019_2021/BMSY	0.407	0.377	0.242	0.606

Sensitivity case 1

	Mean	Median	Lower10th	Upper10th
C__2021	0.092	0.092	0.092	0.092
AveC__2019__2021	0.141	0.141	0.141	0.141
AveF__2019__2021	0.581	0.579	0.359	0.802
F__2021	0.373	0.366	0.224	0.529
FMSY	0.513	0.514	0.324	0.692
MSY (million ton)	0.418	0.412	0.357	0.483
F__2021/FMSY	0.747	0.717	0.515	1.011
AveF__2019__2021/FMSY	1.163	1.133	0.842	1.516
K (million ton)	1.921	1.676	1.239	2.801
B__2021 (million ton)	0.278	0.252	0.174	0.412
B__2022 (million ton)	0.516	0.475	0.341	0.729
AveB__2020__2022	0.347	0.317	0.234	0.493
BMSY (million ton)	0.892	0.799	0.611	1.264
BMSY/K	0.474	0.469	0.410	0.550
B__2021/K	0.152	0.150	0.099	0.209
B__2022/K	0.287	0.282	0.183	0.397
AveB__2020__2022/K	0.192	0.191	0.129	0.256
B__2021/BMSY	0.322	0.314	0.217	0.433
B__2022/BMSY	0.607	0.587	0.401	0.838
AveB__2019__2021/BMSY	0.405	0.397	0.285	0.533

Sensitivity case 2

	Mean	Median	Lower10th	Upper10th
C__2021	0.092	0.092	0.092	0.092
AveC__2019__2021	0.141	0.141	0.141	0.141
AveF__2019__2021	0.425	0.397	0.189	0.708
F__2021	0.262	0.243	0.119	0.435
FMSY	0.398	0.383	0.187	0.627
MSY (million ton)	0.424	0.413	0.347	0.505
F__2021/FMSY	0.693	0.662	0.414	0.999
AveF__2019__2021/FMSY	1.113	1.095	0.670	1.551
K (million ton)	2.759	2.306	1.405	4.707
B__2021 (million ton)	0.451	0.380	0.212	0.774
B__2022 (million ton)	0.706	0.600	0.368	1.156
AveB__2020__2022	0.520	0.441	0.262	0.874
BMSY (million ton)	1.281	1.098	0.703	2.113
BMSY/K	0.477	0.475	0.402	0.557
B__2021/K	0.171	0.164	0.105	0.244
B__2022/K	0.278	0.264	0.152	0.418
AveB__2020__2022/K	0.200	0.193	0.123	0.284
B__2021/BMSY	0.359	0.340	0.231	0.508
B__2022/BMSY	0.586	0.546	0.336	0.881
AveB__2019__2021/BMSY	0.420	0.398	0.270	0.599

5 Summary of estimates of parameters

Base case 1

	Mean	Median	Lower10th	Upper10th
r	1.517	1.375	0.793	2.513
K (million ton)	1.978	1.712	1.246	2.975
qCHN	18.503	18.040	11.510	26.006
qJPN2	2.853	2.837	1.917	3.792
qKOR	11.651	11.608	7.865	15.470
qRUS	29.194	29.127	19.821	38.714
qCT	2.937	2.935	1.983	3.896
qBio	0.727	0.752	0.476	0.943
Shape	0.756	0.625	0.242	1.512
sigma_com	0.580	0.577	0.574	0.591
sigma	0.036	0.031	0.014	0.065
tau	0.326	0.317	0.215	0.452
FMSY	0.519	0.524	0.324	0.704
BMSY (million ton)	0.908	0.800	0.605	1.309
MSY (million ton)	0.429	0.419	0.358	0.508
b	0.821	0.831	0.667	0.962

Base case 2

	Mean	Median	Lower10th	Upper10th
r	0.998	0.809	0.283	2.090
K (million ton)	3.980	3.448	1.718	7.268
qJOINT	0.797	0.793	0.524	1.074
qBio	0.431	0.392	0.200	0.732
Shape	0.758	0.617	0.132	1.630
sigma	0.258	0.260	0.163	0.351
tau	0.169	0.143	0.036	0.341
FMSY	0.288	0.255	0.106	0.525
BMSY (million ton)	1.812	1.588	0.839	3.177
MSY (million ton)	0.402	0.390	0.302	0.504
b	0.520	0.515	0.278	0.780

Sensitivity case 1

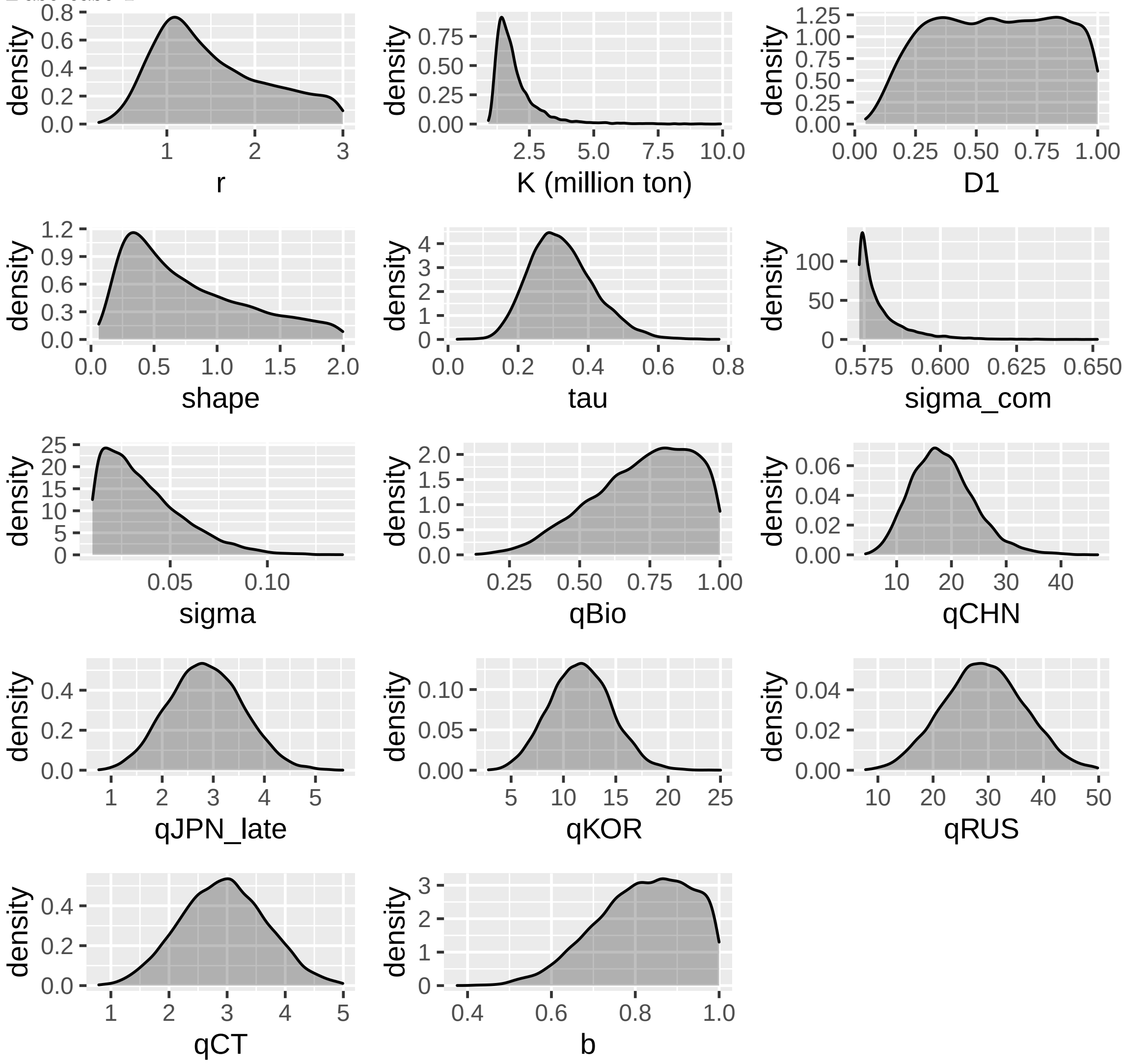
	Mean	Median	Lower10th	Upper10th
r	1.436	1.279	0.764	2.393
K (million ton)	1.921	1.676	1.239	2.801
qCHN	18.178	17.581	11.403	25.719
qJPN1	1.215	1.101	0.542	2.094
qJPN2	2.732	2.721	1.906	3.565
qKOR	11.415	11.268	7.798	15.225
qRUS	27.947	27.629	19.236	37.086
qCT	2.874	2.854	1.975	3.814
qBio	0.717	0.731	0.487	0.933
Shape	0.813	0.700	0.252	1.592
sigma_com	0.634	0.632	0.628	0.644
sigma	0.033	0.029	0.013	0.060
tau	0.285	0.281	0.176	0.402
FMSY	0.513	0.514	0.324	0.692
BMSY (million ton)	0.892	0.799	0.611	1.264
MSY (million ton)	0.418	0.412	0.357	0.483
b	0.808	0.822	0.643	0.957

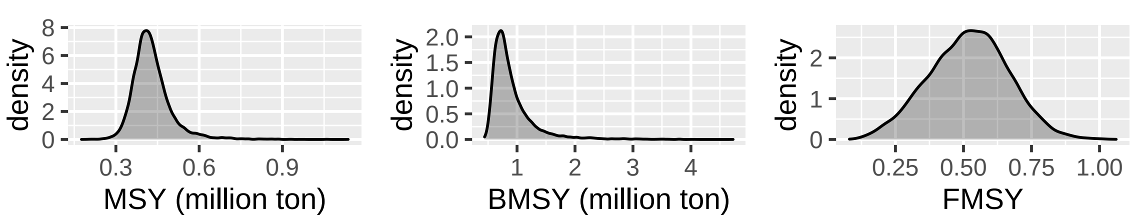
Sensitivity case 2

	Mean	Median	Lower10th	Upper10th
r	1.155	0.994	0.467	2.164
K (million ton)	2.759	2.306	1.405	4.707
qJOINT	0.923	0.918	0.640	1.213
qBio	0.547	0.533	0.283	0.845
Shape	0.852	0.756	0.199	1.690
sigma_JPN_early	0.867	0.858	0.756	0.985
sigma	0.175	0.179	0.068	0.267
tau	0.214	0.202	0.057	0.384
FMSY	0.398	0.383	0.187	0.627
BMSY (million ton)	1.281	1.098	0.703	2.113
MSY (million ton)	0.424	0.413	0.347	0.505
b	0.563	0.559	0.332	0.806

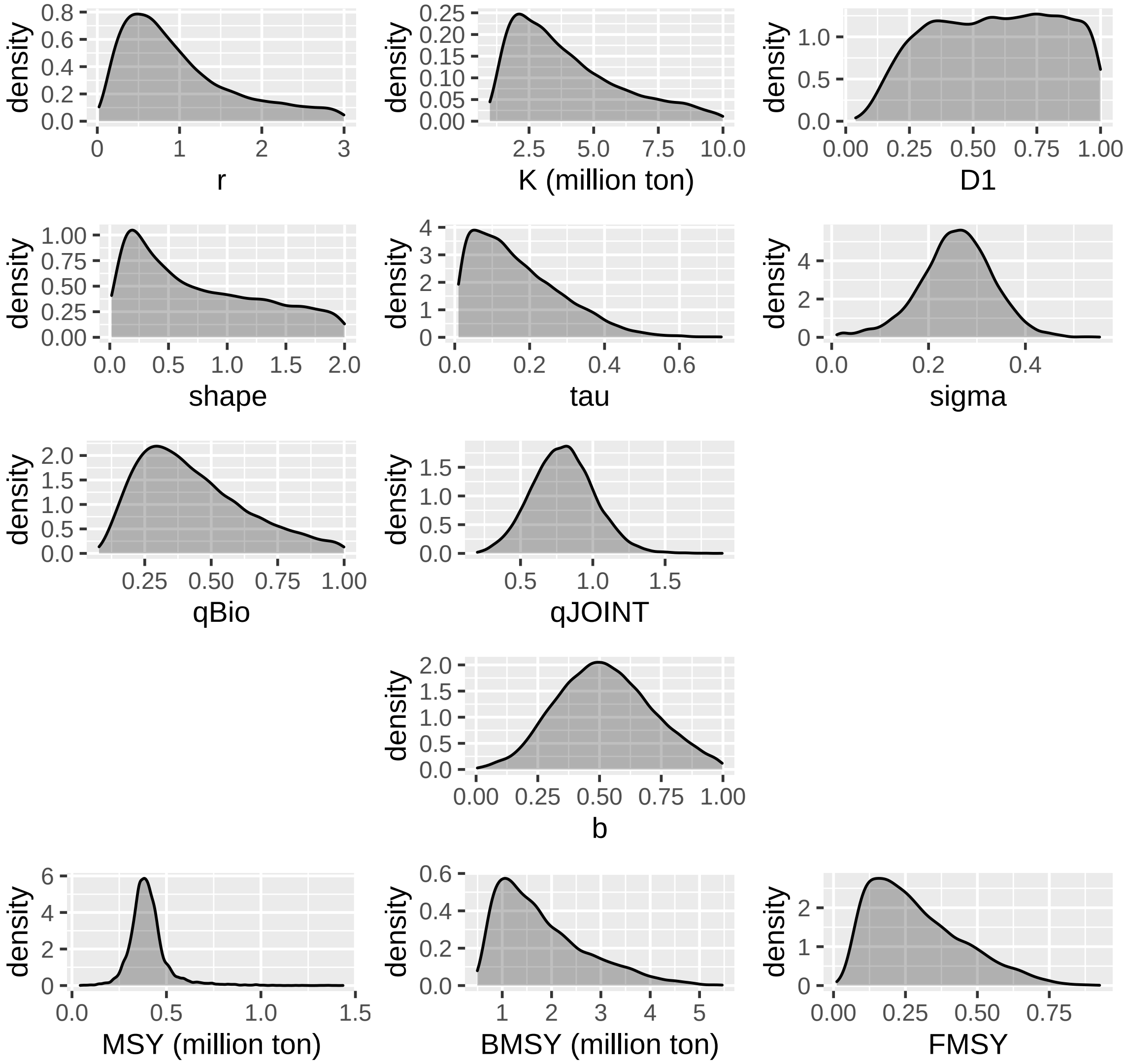
6 Posterior distributions

Base case 1

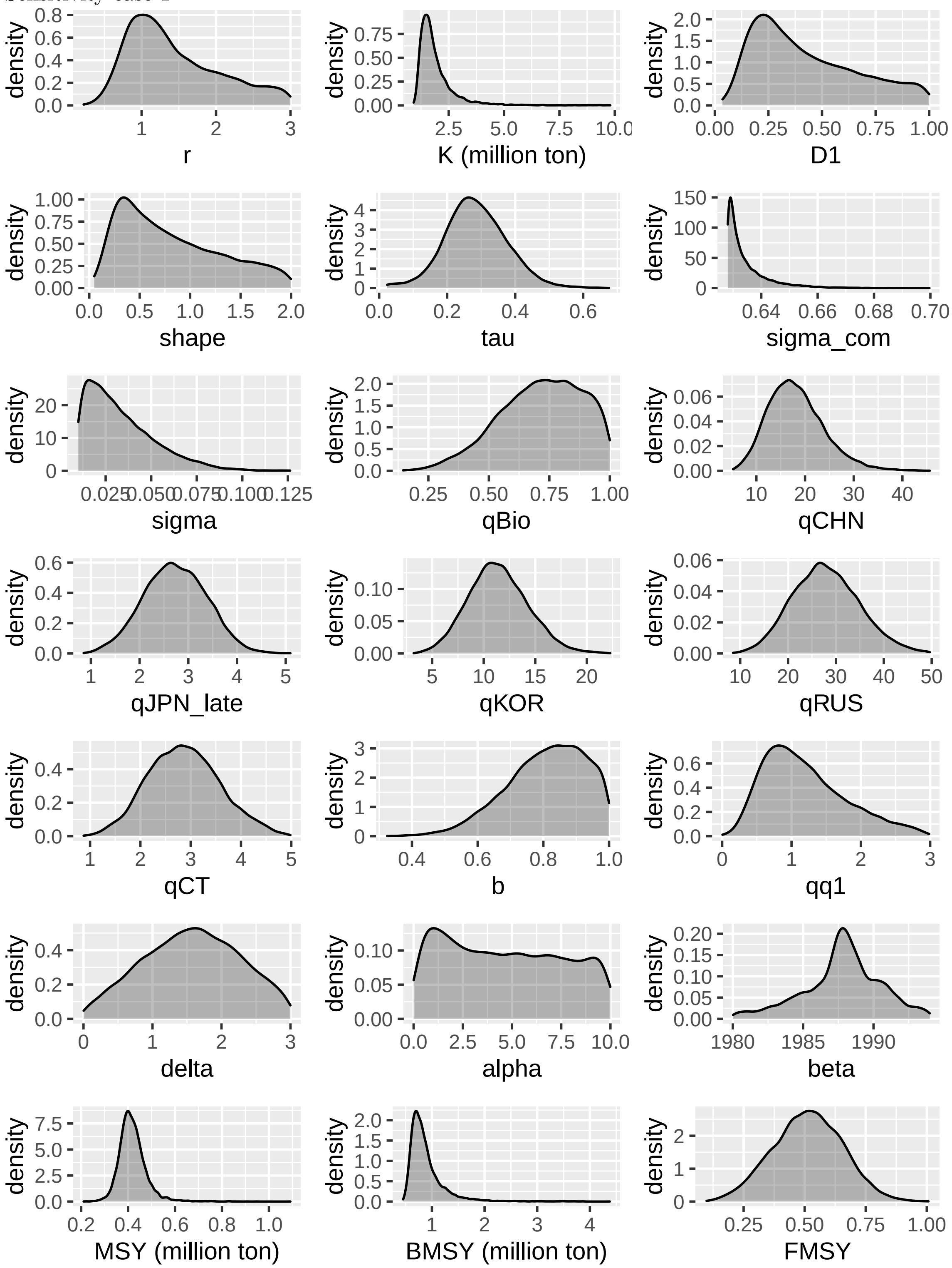




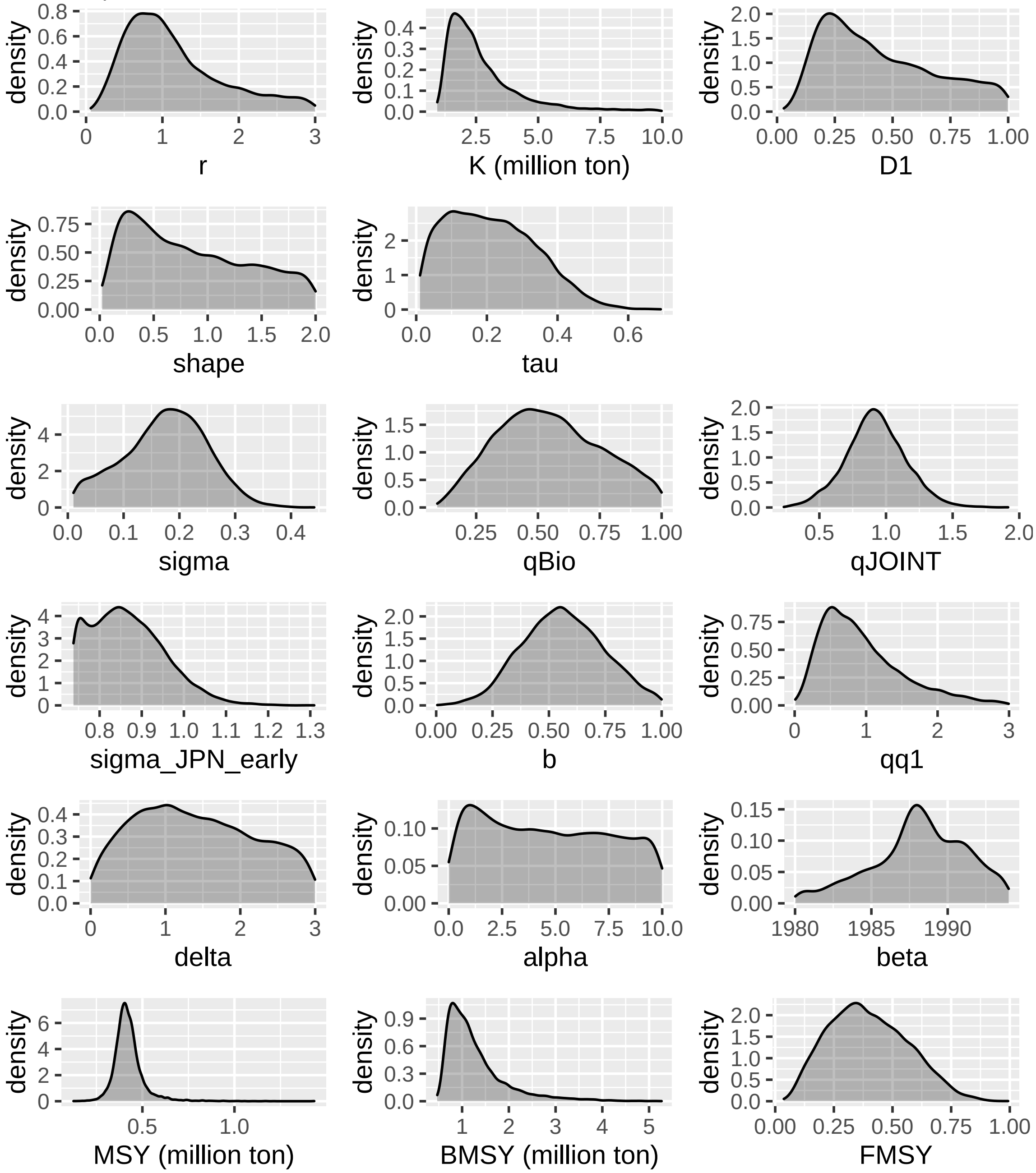
Base case 2


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

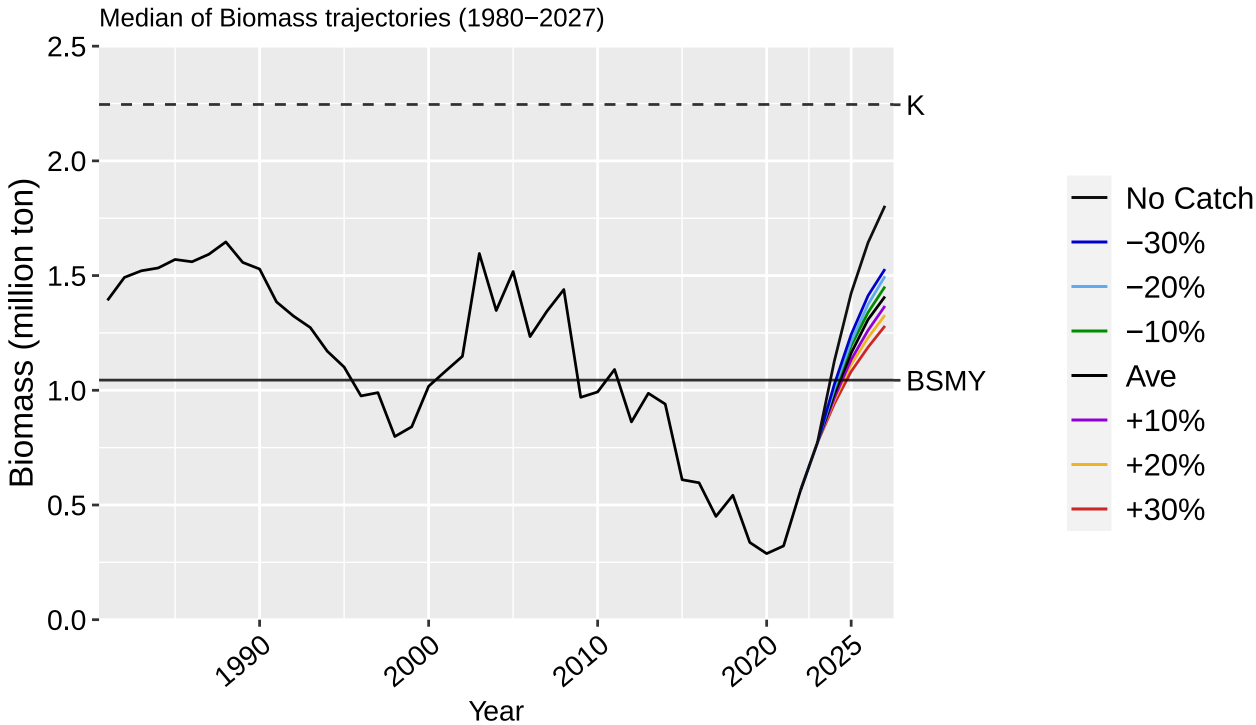
Sensitivity case 1

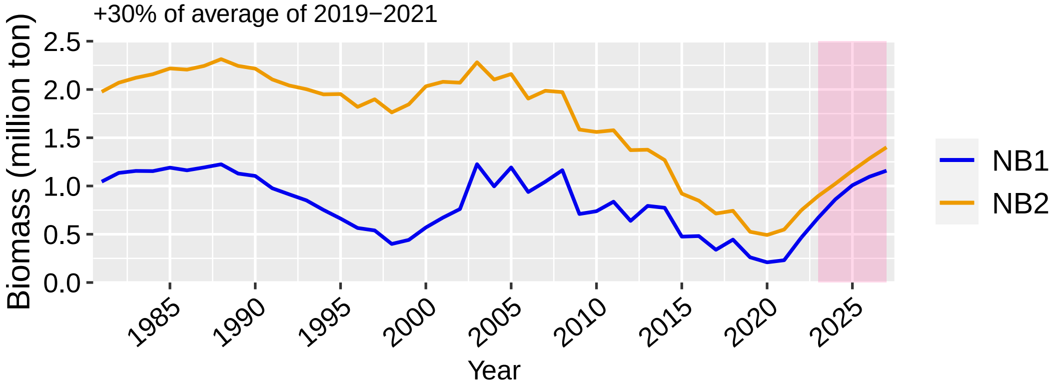


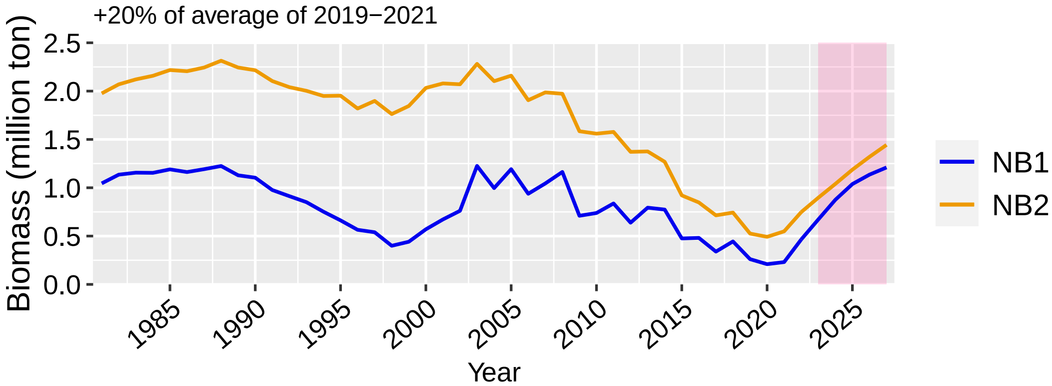
Sensitivity case 2

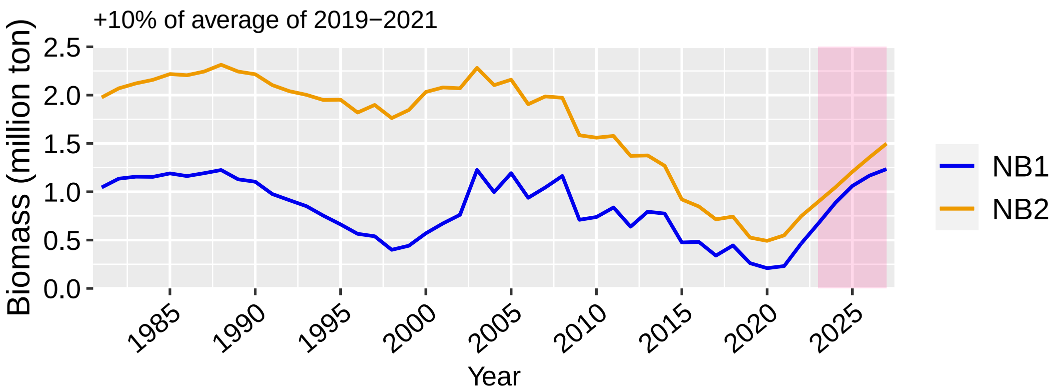


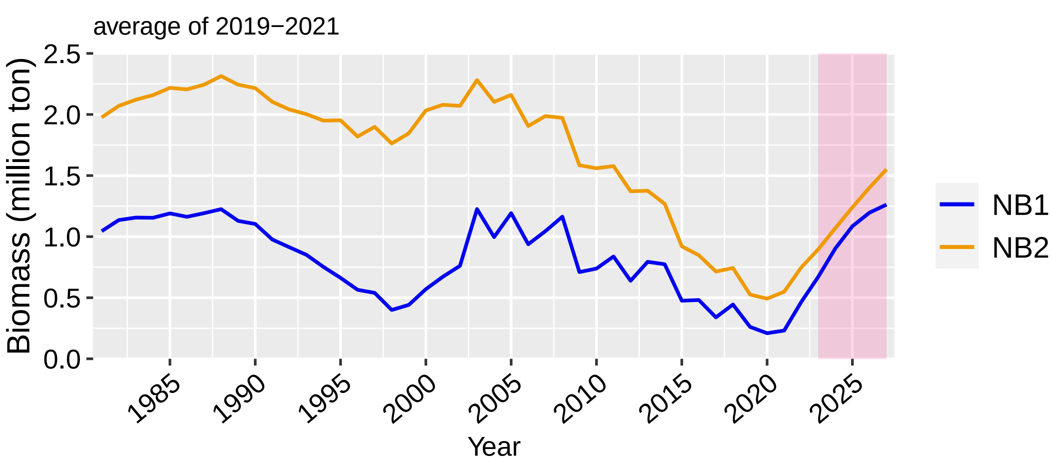
7 Future projection

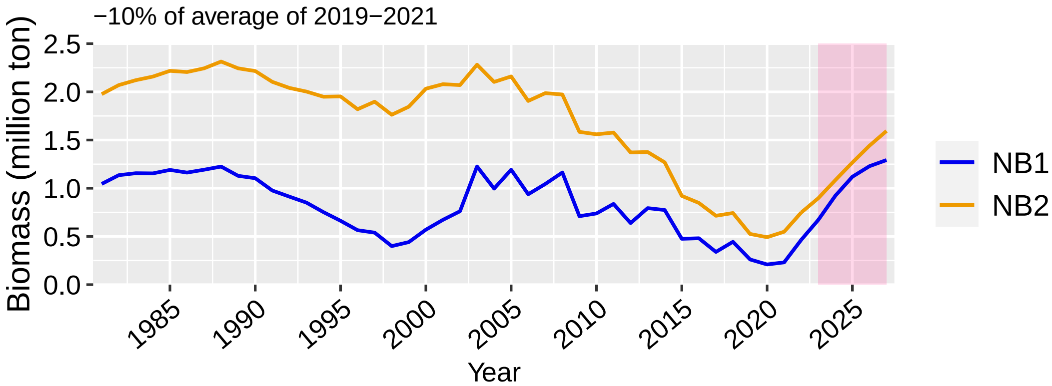


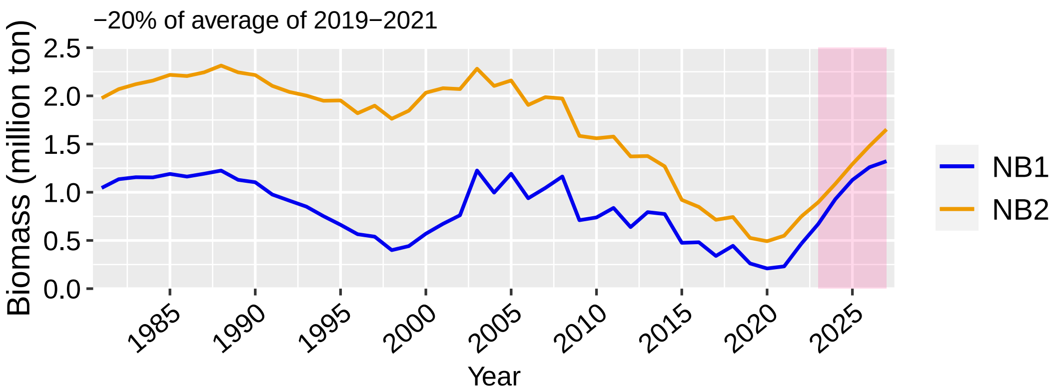

+30% of average of 2019−2021
Biomass (million ton)
2.5
2.0
1.5
1.0
0.5
0.0
1985
1990
1995
2000
2005
2010
2015
2020
2025
Year
NB1
NB2

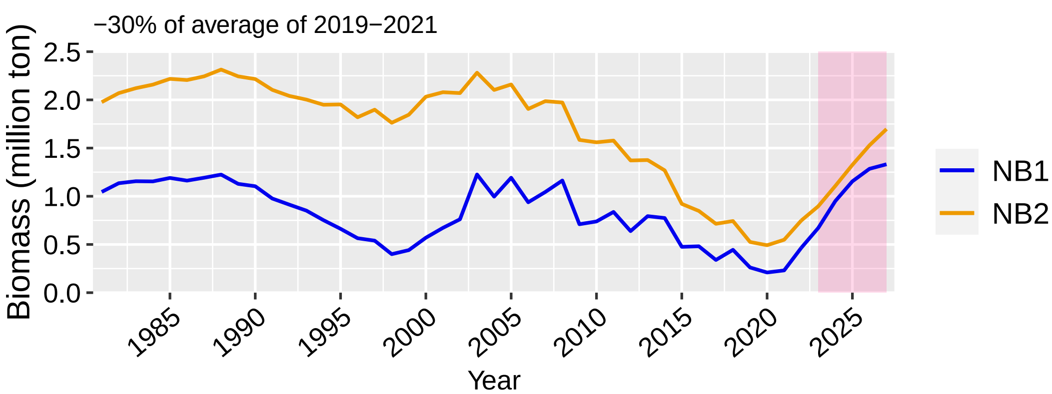

+20% of average of 2019−2021
Biomass (million ton)
2.5
2.0
1.5
1.0
0.5
0.0
1985
1990
1995
2000
2005
2010
2015
2020
2025
Year
NB1
NB2

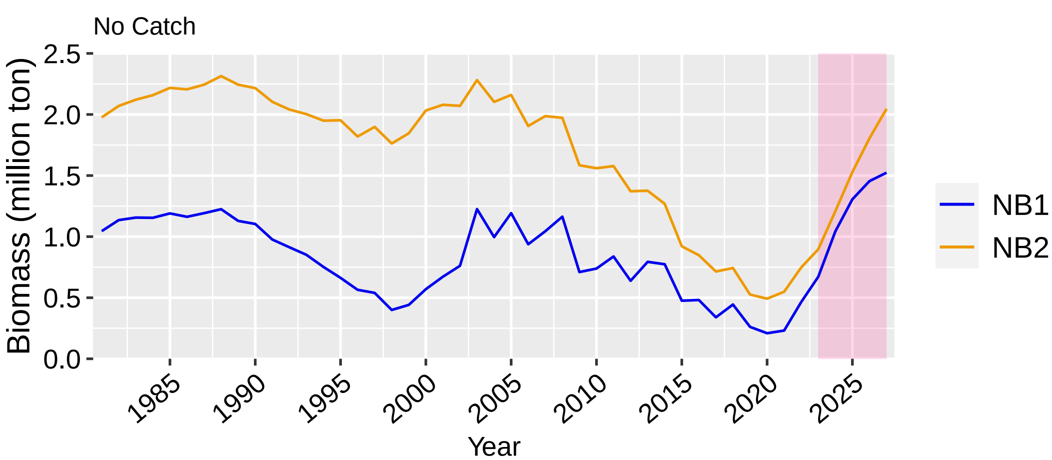

+10% of average of 2019−2021
Biomass (million ton)
2.5
2.0
1.5
1.0
0.5
0.0
1985
1990
1995
2000
2005
2010
2015
2020
2025
Year
NB1
NB2


average of 2019−2021
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
NB1
NB2


−10% of average of 2019−2021
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
NB1
NB2


−20% of average of 2019−2021
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
NB1
NB2


−30% of average of 2019−2021
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
NB1
NB2


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
NB1
NB2

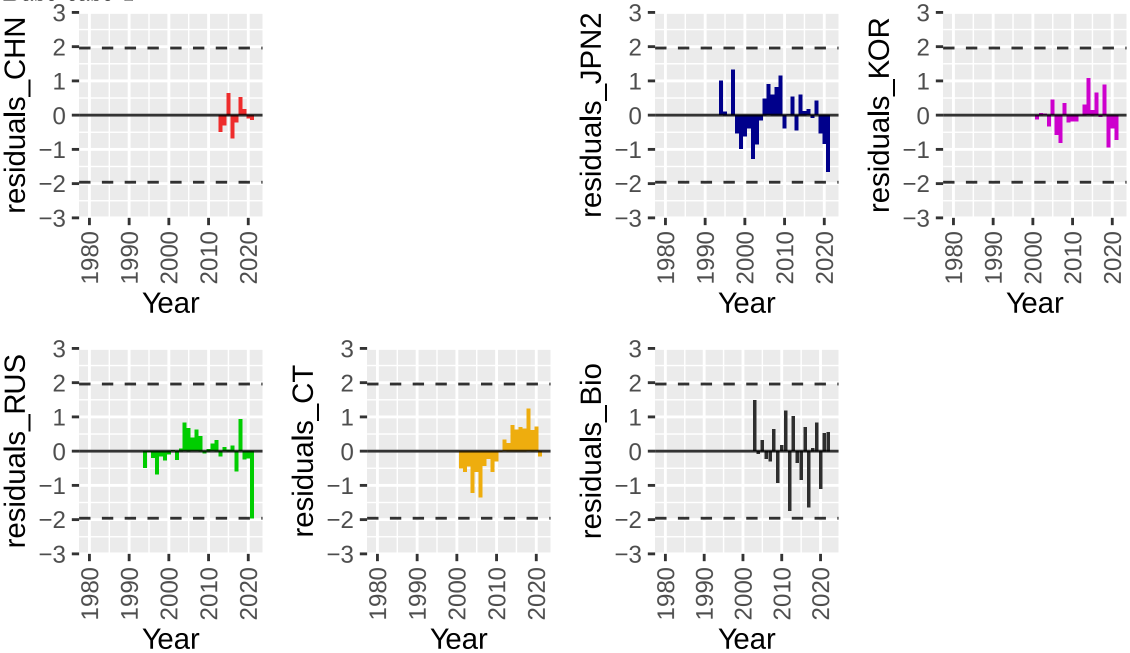
8 Risk table

	Red	Orange	Yellow	Green	B<BMSY	F>FMSY
+30%	0.159	0	0.220	0.622	0.378	0.159
+20%	0.131	0	0.228	0.641	0.359	0.131
+10%	0.110	0	0.234	0.656	0.343	0.110
±0%	0.090	0	0.233	0.677	0.323	0.090
-10%	0.072	0	0.238	0.689	0.311	0.072
-20%	0.055	0	0.242	0.703	0.297	0.055
-30%	0.042	0	0.243	0.715	0.285	0.042
No Catch	0.000	0	0.209	0.791	0.209	0.000

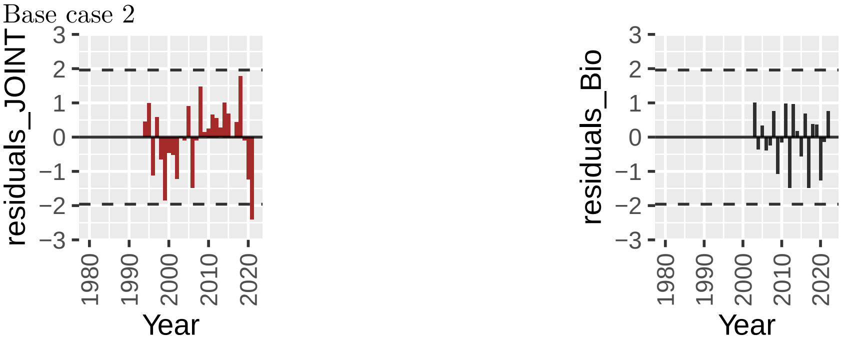
9 Diagnosis

9.1 Standardized residuals plot

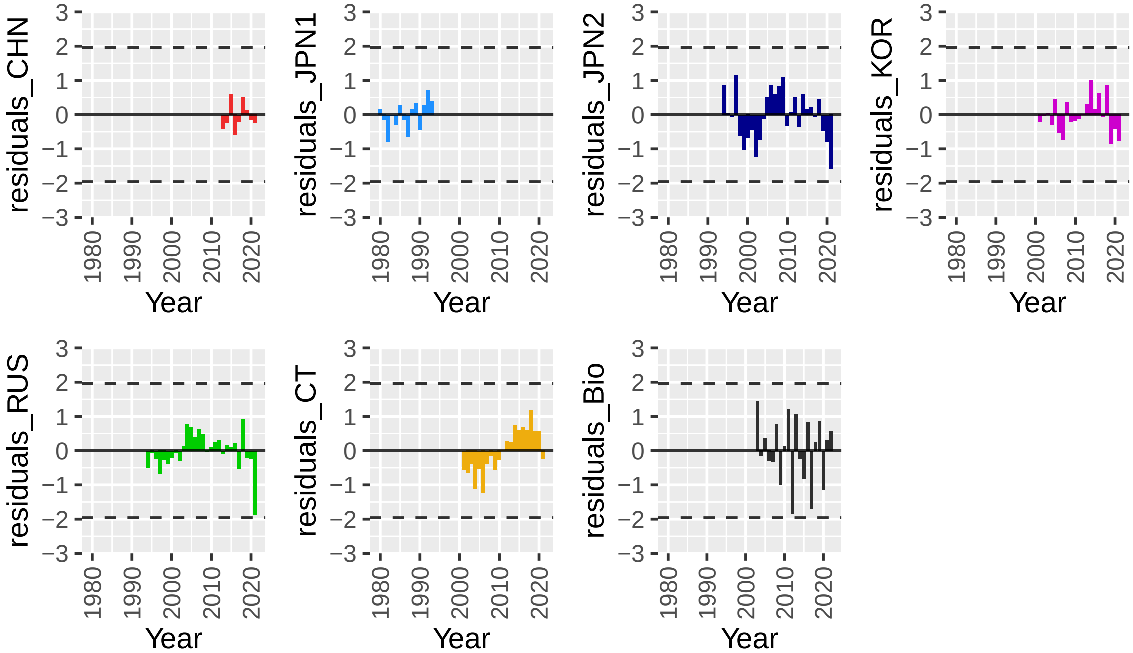
Base case 1



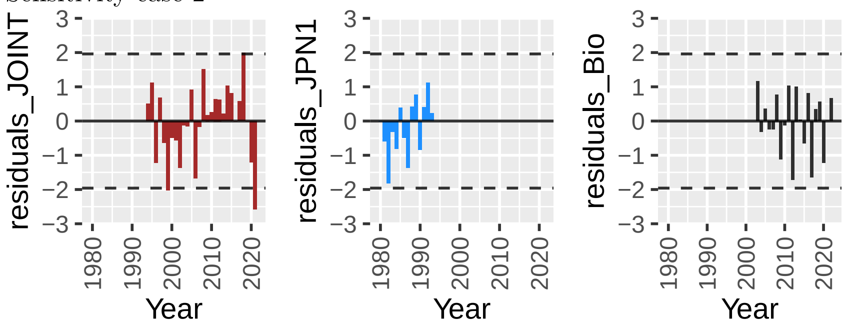
Base case 2



Sensitivity case 1



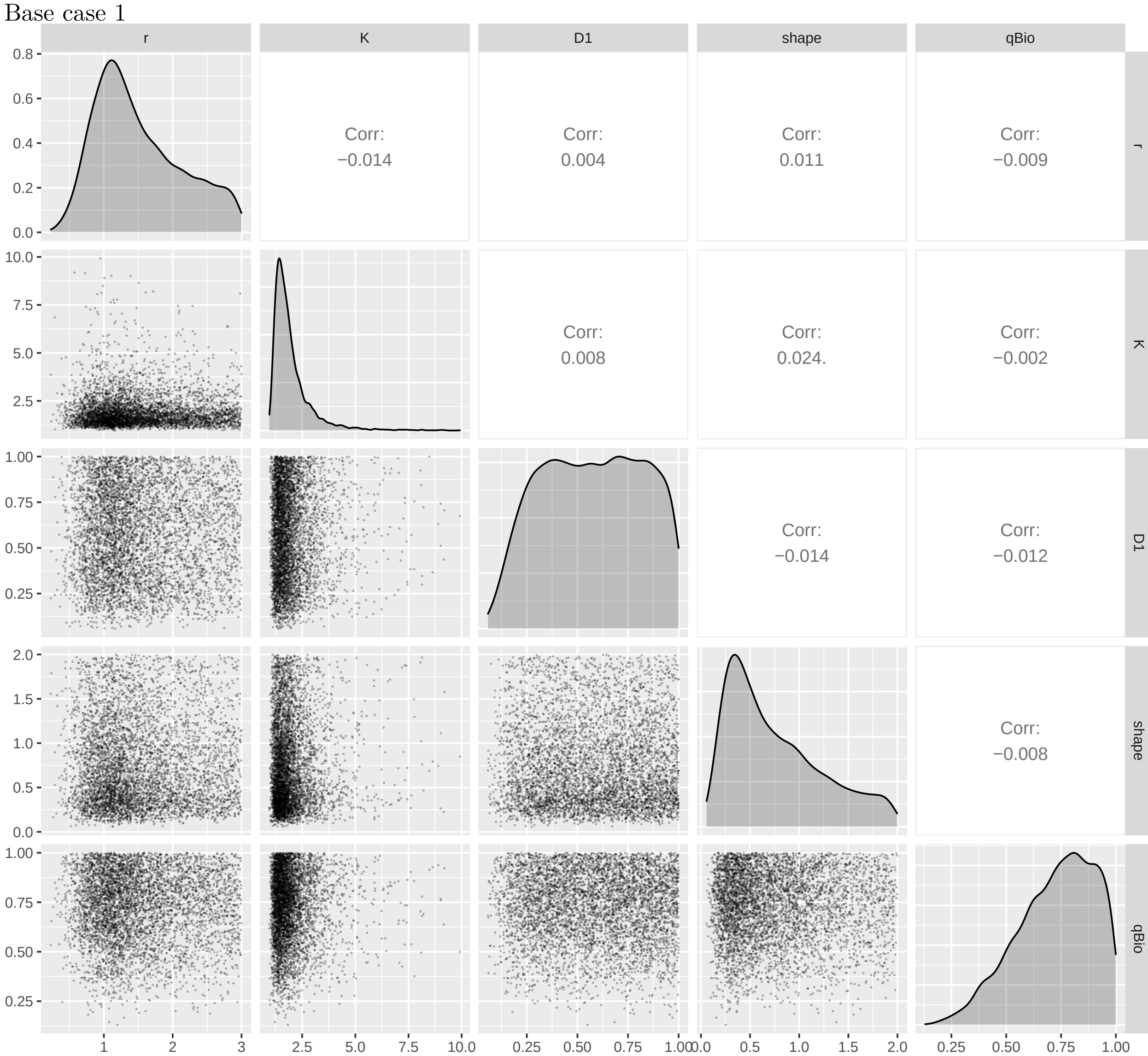
Sensitivity case 2



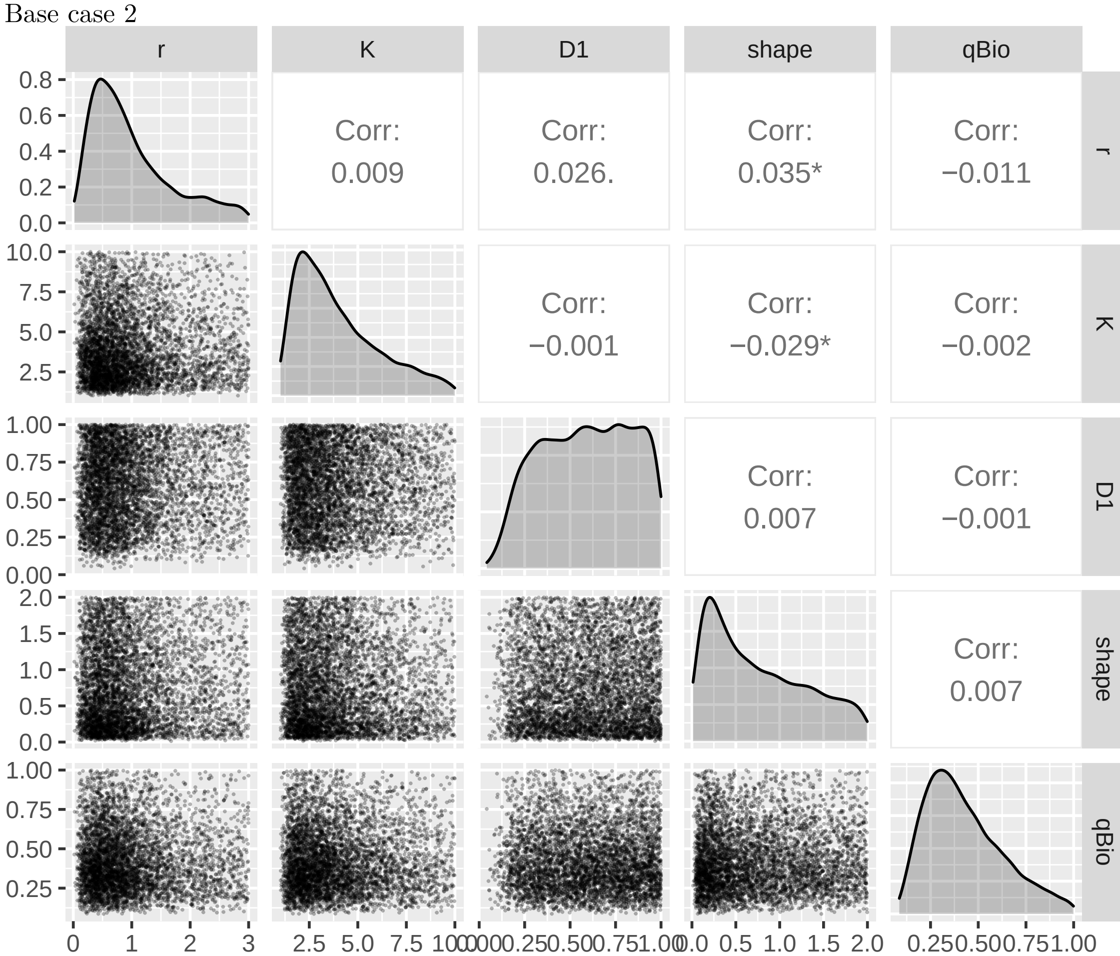
9.2 Correlation

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

Base case 1

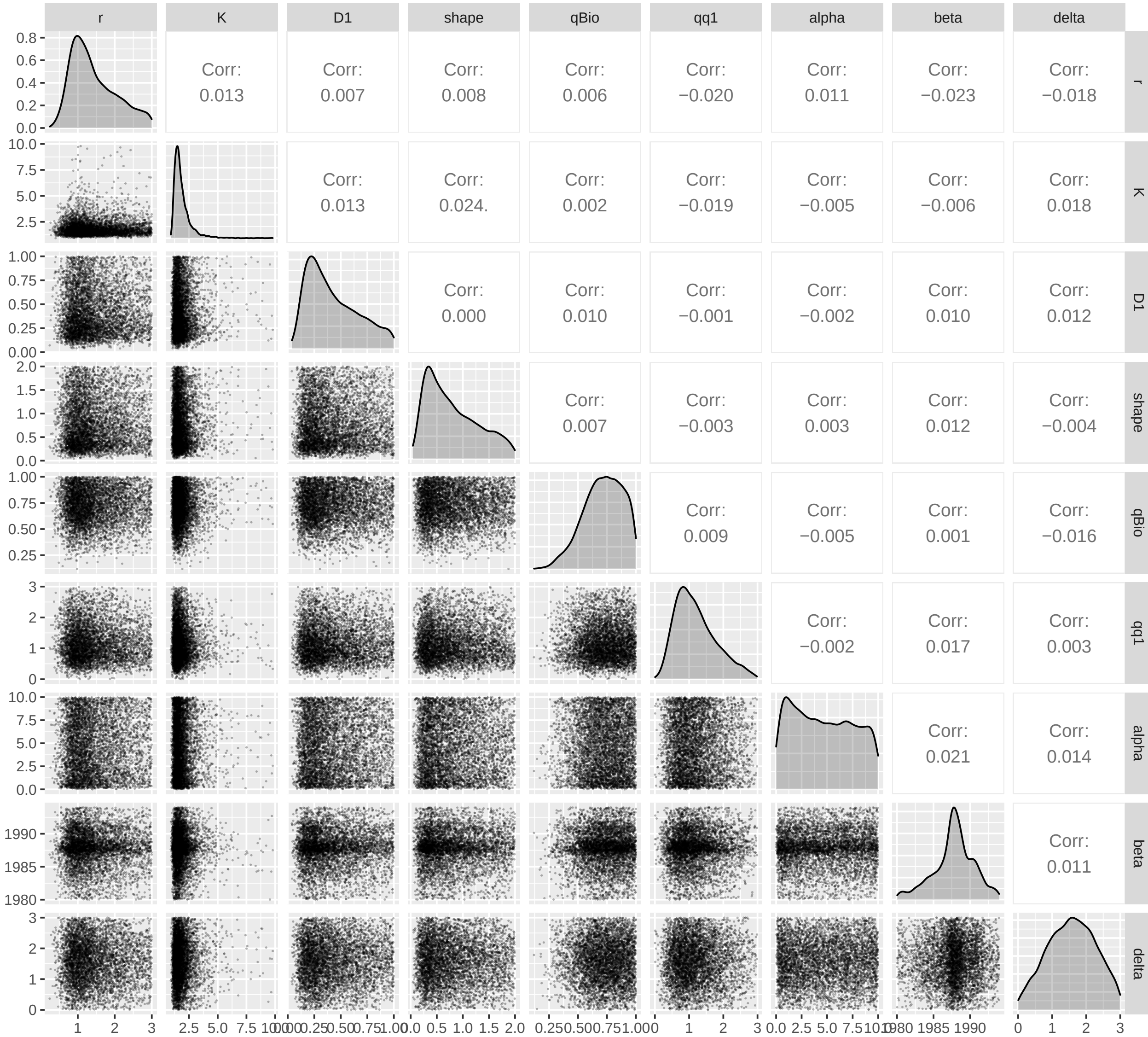


Base case 2

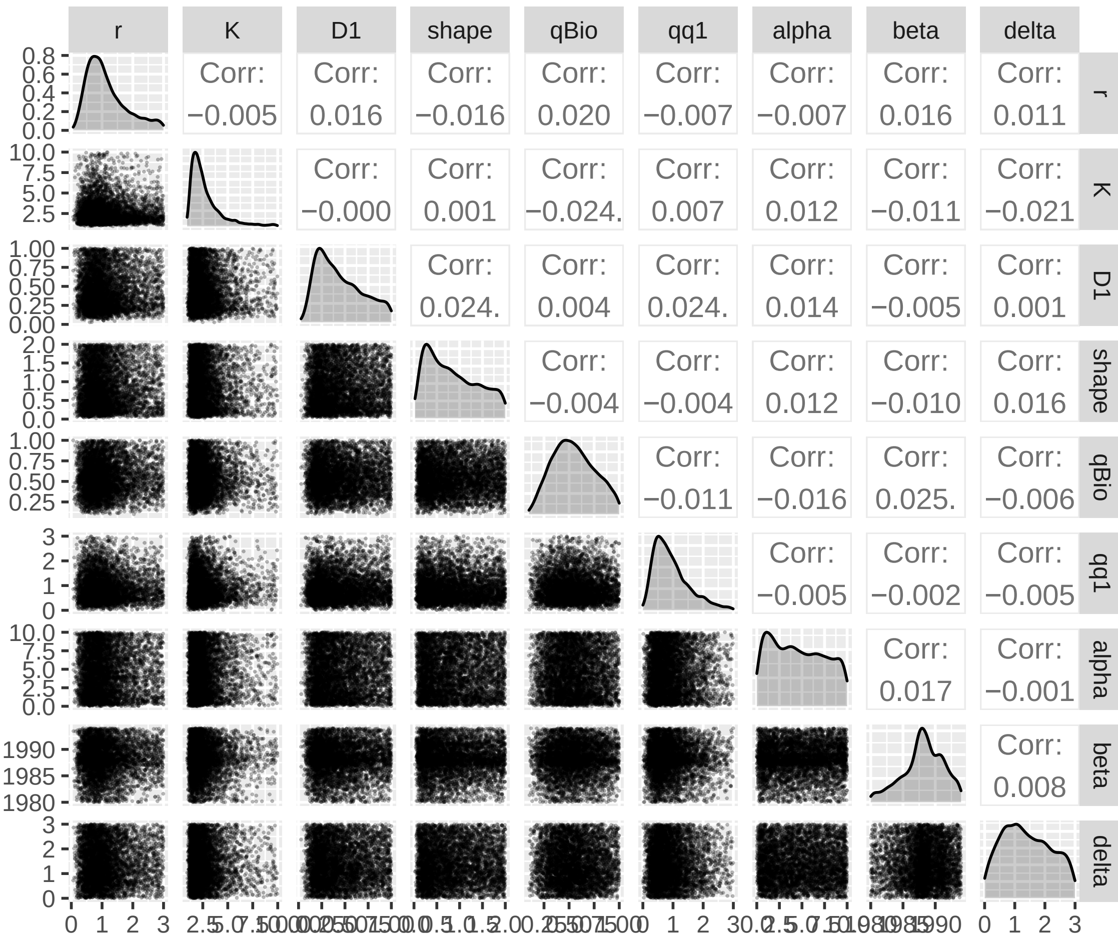


r
K
D1
shape
qBio
Corr:
0.009
Corr:
0.026.
Corr:
0.035*
Corr:
−0.011
Corr:
−0.001
Corr:
−0.029*
Corr:
−0.002
Corr:
0.007
Corr:
−0.001
Corr:
0.007

Sensitivity case 1



Sensitivity case 2


r
K
D1
shape
qBio
qq1
alpha
beta
delta
Corr: −0.005
Corr: 0.016
Corr: −0.016
Corr: 0.020
Corr: −0.007
Corr: −0.007
Corr: 0.016
Corr: 0.011
Corr: −0.000
Corr: 0.001
Corr: −0.024.
Corr: 0.007
Corr: 0.012
Corr: −0.011
Corr: −0.021
Corr: 0.024.
Corr: 0.004
Corr: 0.024.
Corr: 0.014
Corr: −0.005
Corr: 0.001
Corr: −0.004
Corr: −0.004
Corr: 0.012
Corr: −0.010
Corr: 0.016
Corr: −0.011
Corr: −0.016
Corr: 0.025.
Corr: −0.006
Corr: −0.005
Corr: −0.002
Corr: −0.005
Corr: 0.017
Corr: −0.001
Corr: 0.008

Appendix2:

Retrospective analysis and hindcasting

Contents

Hindcasting

MSE estimate

$$MSE_{estimate} = \frac{1}{n} \sum_{t=\text{last year}-\text{n}+1}^{\text{last year}} \left\{ \log I_t - \log \widehat{qB_t} \right\}^2$$

n : Number of hinded years
I_t : the biomass index in year t
$\widehat{qB_t}$: the estimated value of biomass index in year t

	1year		2year		3years		4year		5years	
	NB1	NB2	NB1	NB2	NB1	NB2	NB1	NB2	NB1	NB2
MSE_CHN	0.315		0.551		0.618		0.400		0.173	
MSE_JPN	2.196		2.225		2.304		1.614		0.863	
MSE_KOR	0.932		1.209		1.750		1.205		0.655	
MSE_RUS	2.875		2.253		2.094		1.515		0.909	
MSE_CT	0.394		0.402		0.459		0.390		0.219	
MSE_JOINT		1.562		1.501		1.232		0.897		0.561
MSE_Bio	0.071	0.143	0.086	0.056	1.501	1.269	1.258	1.046	0.444	0.467
ave(CPUE)	1.342	1.562	1.328	1.501	1.445	1.232	1.025	0.897	0.564	0.561
(MSE_Bio+ave(CPUE))/2	0.707	0.853	0.707	0.778	1.473	1.250	1.141	0.972	0.504	0.514

MSE MCMC sample mean

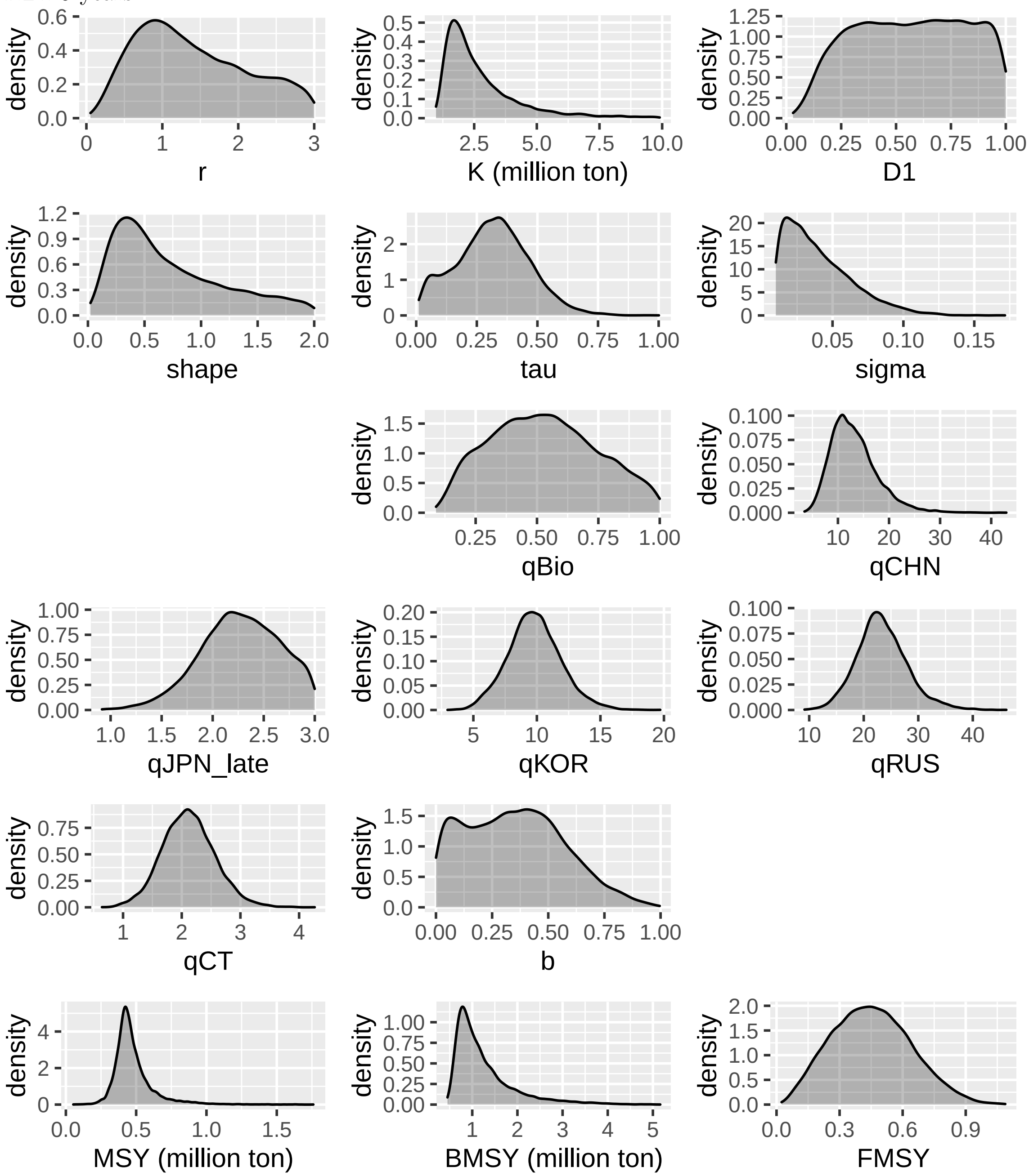
$$MSE_{mean} = \frac{1}{10000} \sum_{i=1}^{10000} \frac{1}{n} \sum_{t=\text{last year}-\text{n}+1}^{\text{last year}} \left\{ \log I_t - \log (q_i B_{ti}) \right\}^2$$

n : Number of hinded years
I_t : the biomass index in year t
q_i : the MCMC sample of catchability coefficient
B_{ti} : the MCMC sample of biomass in year t

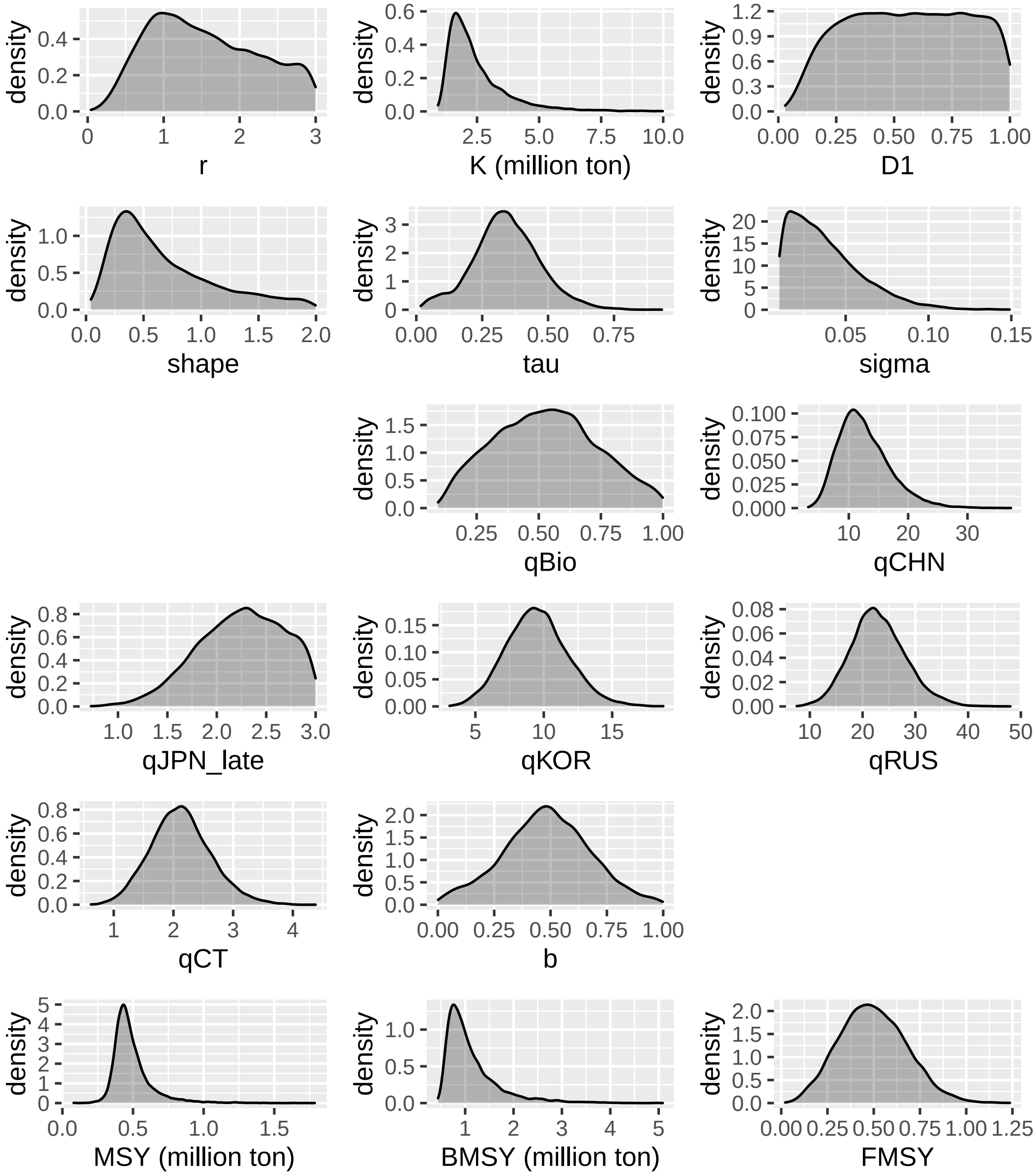
	1year		2year		3years		4year		5years	
	NB1	NB2	NB1	NB2	NB1	NB2	NB1	NB2	NB1	NB2
MSE_CHN	0.461		0.811		0.750		1.252		2.697	
MSE_JPN	2.316		2.426		2.372		2.187		2.793	
MSE_KOR	1.043		1.414		1.820		1.870		2.757	
MSE_RUS	2.991		2.447		2.204		2.127		2.950	
MSE_CT	0.500		0.648		0.549		1.261		2.969	
MSE_Bio		1.568		1.513		1.258		1.010		1.145
sum(CPUE)/5	0.302	0.321	0.842	0.646	1.911	1.567	4.310	4.004	15.132	13.818
(MSE_Bio+sum(CPUE)/5)/2	1.462	1.568	1.549	1.513	1.539	1.258	1.739	1.010	2.833	1.145
	0.882	0.945	1.196	1.079	1.725	1.412	3.025	2.507	8.983	7.482

Posterior distributions

NB1 5 years

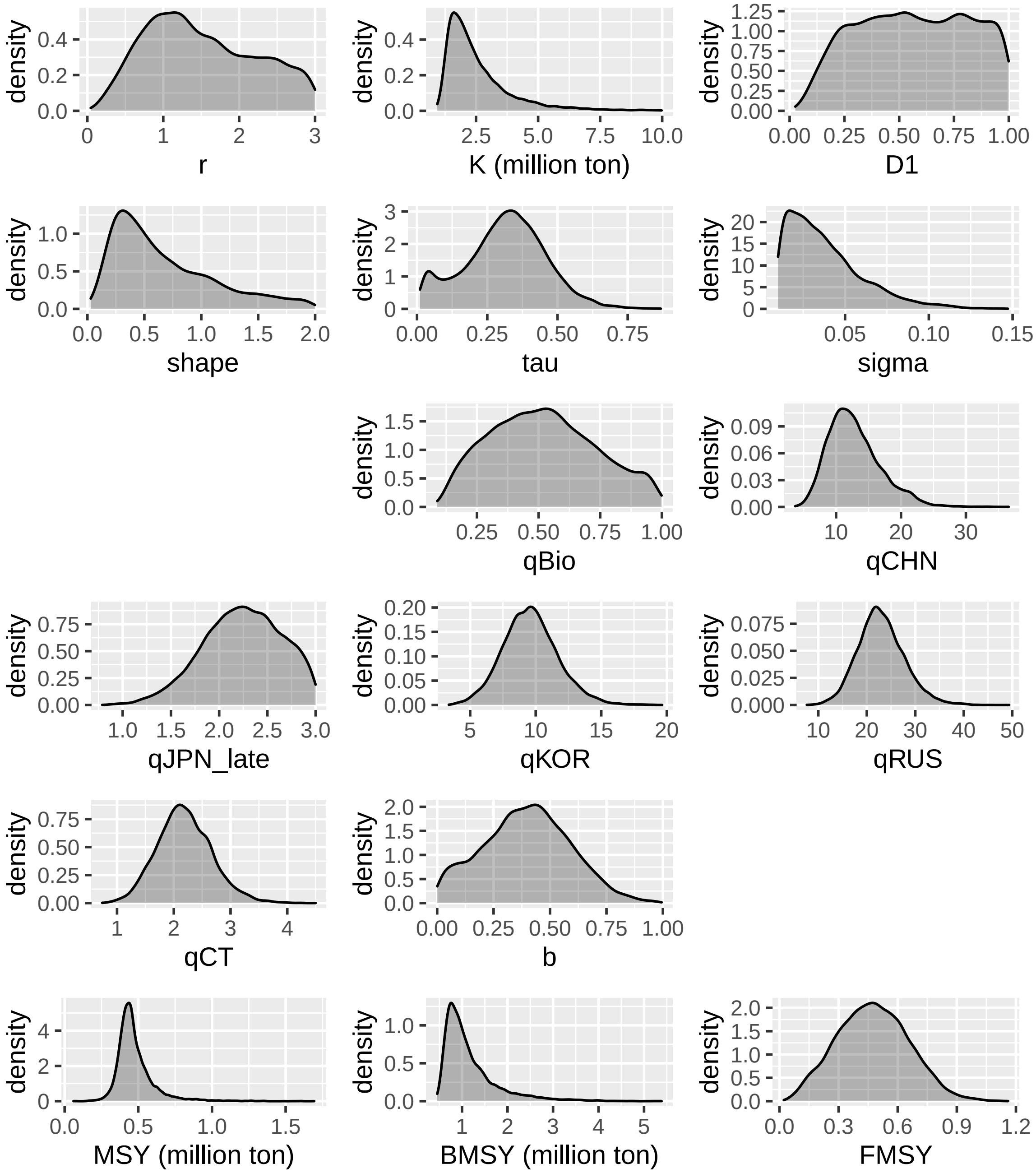


NB1 4 years

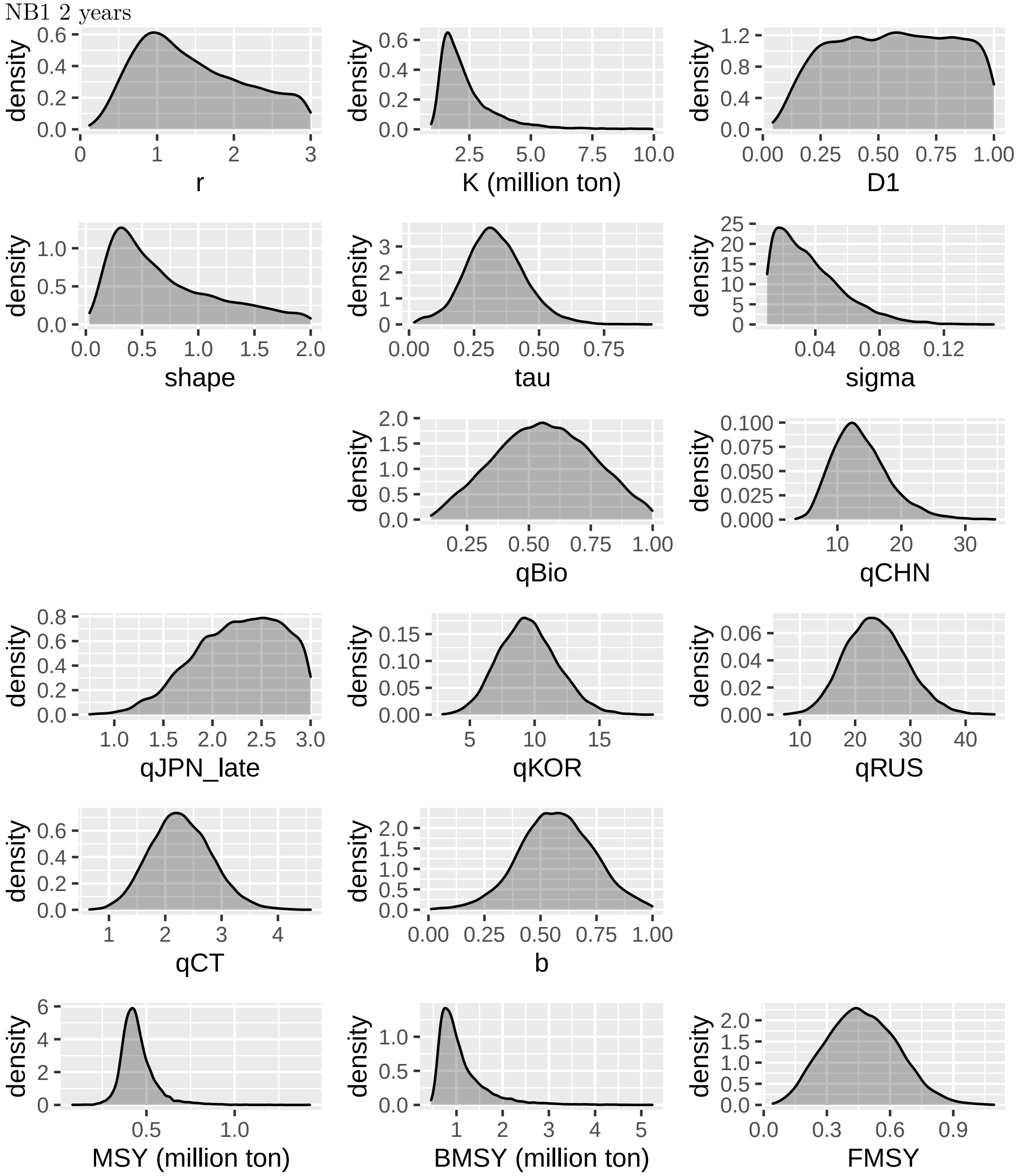


density
r
K (million ton)
D1
shape
tau
sigma
qBio
qCHN
qJPN_late
qKOR
qRUS
qCT
b
MSY (million ton)
BMSY (million ton)
FMSY

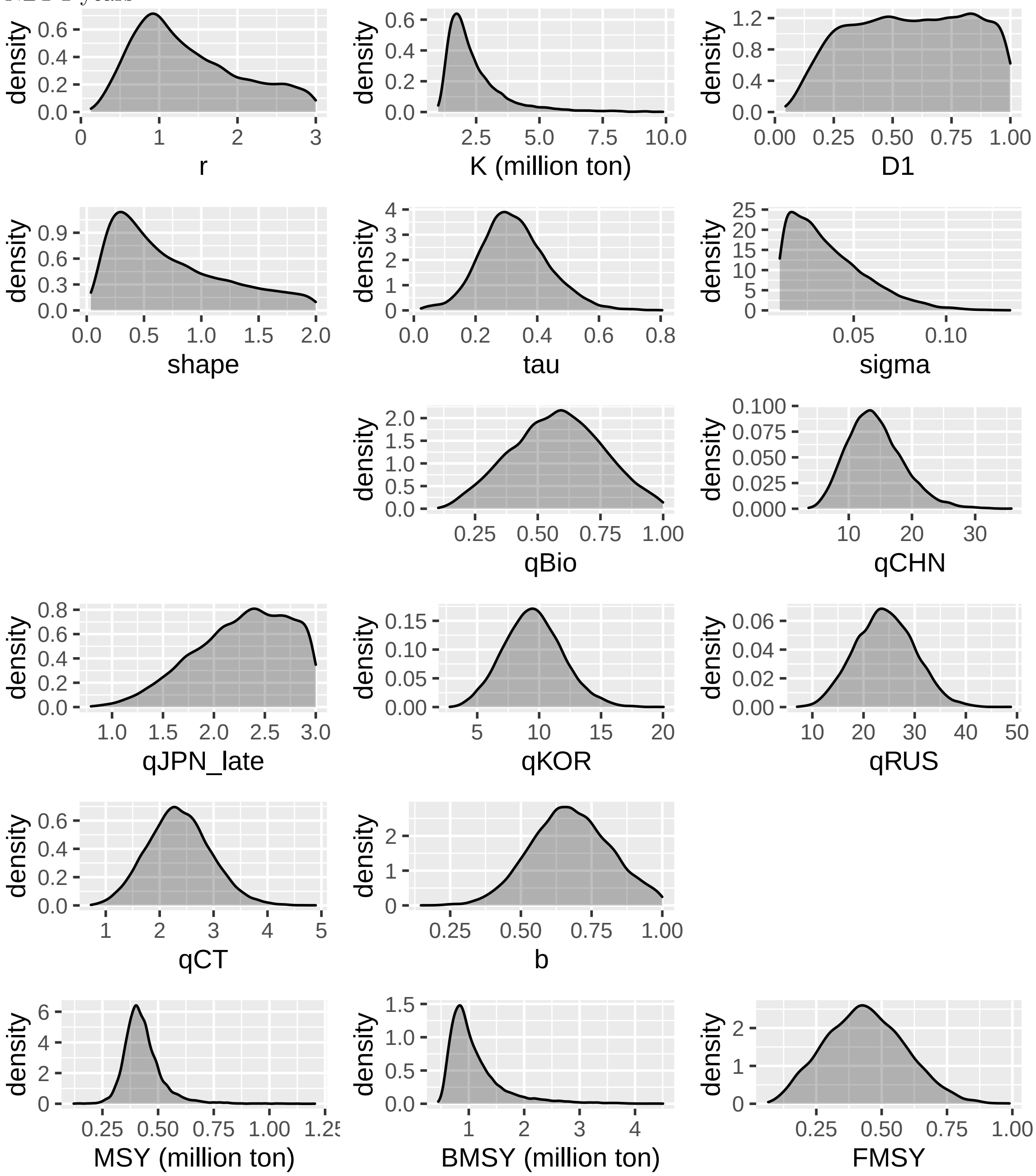
NB1 3 years


density
r
K (million ton)
D1
shape
tau
sigma
qBio
qCHN
qJPN_late
qKOR
qRUS
qCT
b
MSY (million ton)
BMSY (million ton)
FMSY

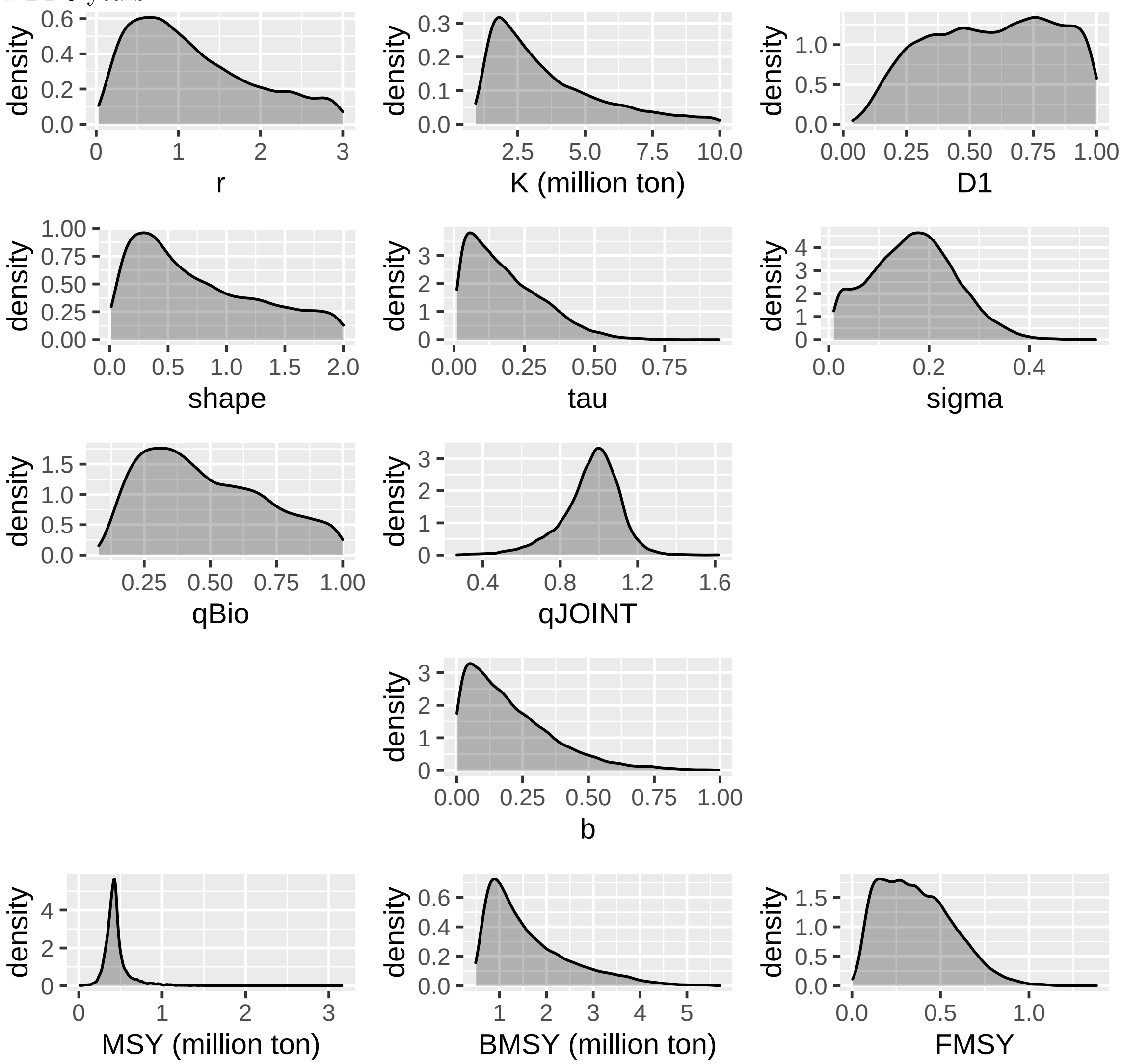
NB1 2 years


density
r
K (million ton)
D1
shape
tau
sigma
qBio
qCHN
qJPN_late
qKOR
qRUS
qCT
b
MSY (million ton)
BMSY (million ton)
FMSY

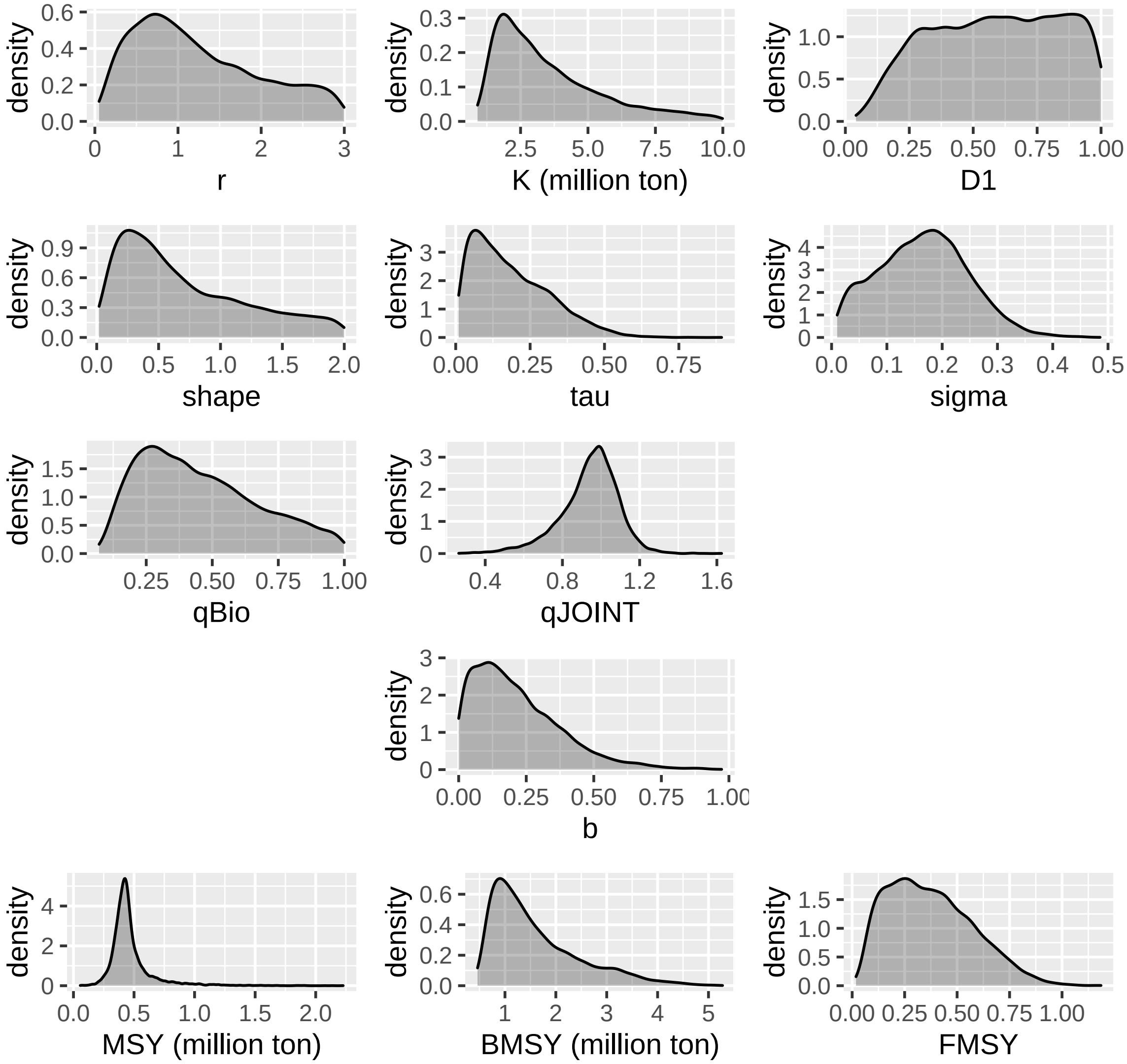
NB1 1 years


density
r
K (million ton)
D1
shape
tau
sigma
qBio
qCHN
qJPN_late
qKOR
qRUS
qCT
b
MSY (million ton)
BMSY (million ton)
FMSY

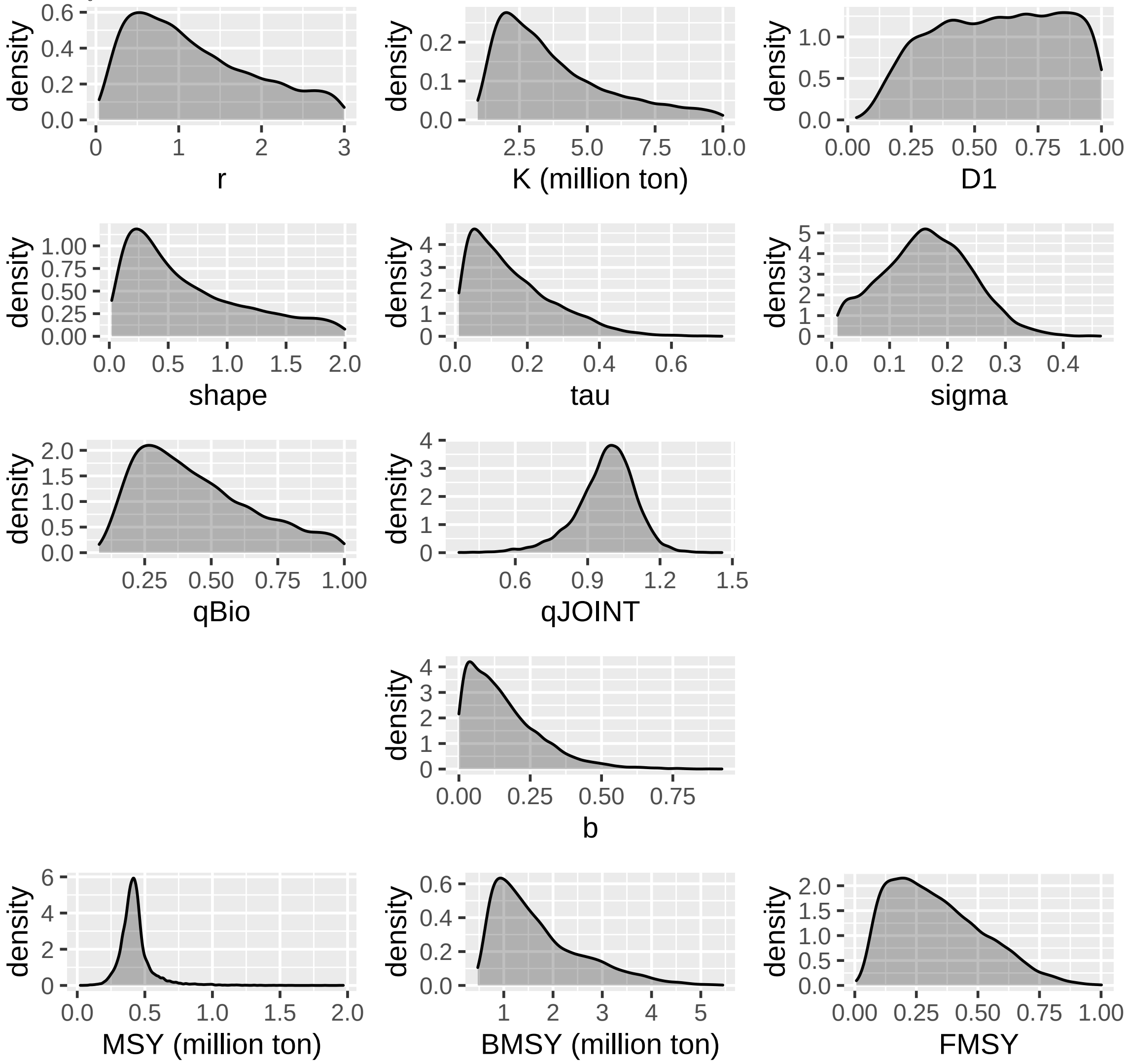
NB2 5 years


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

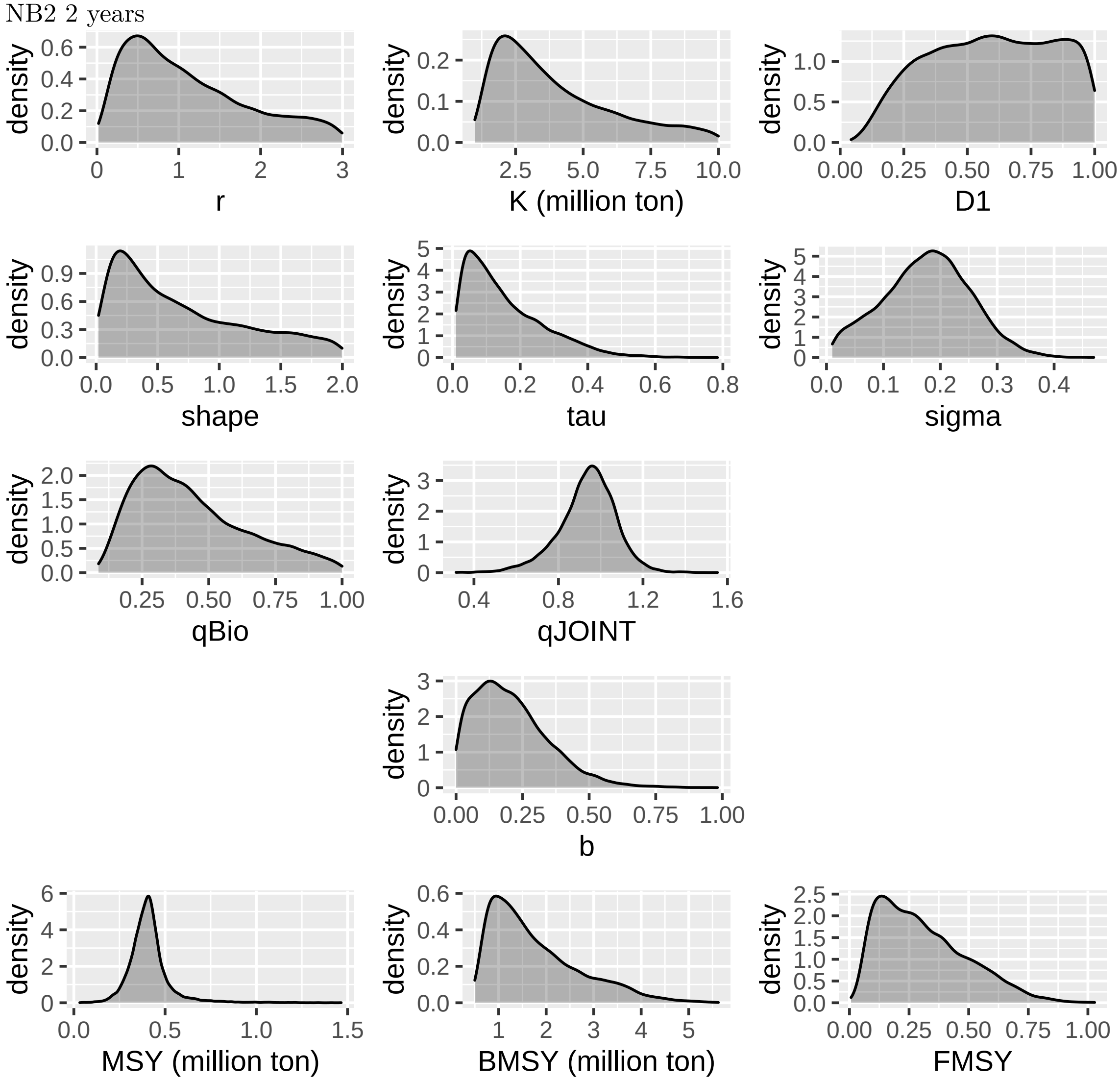
NB2 4 years


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

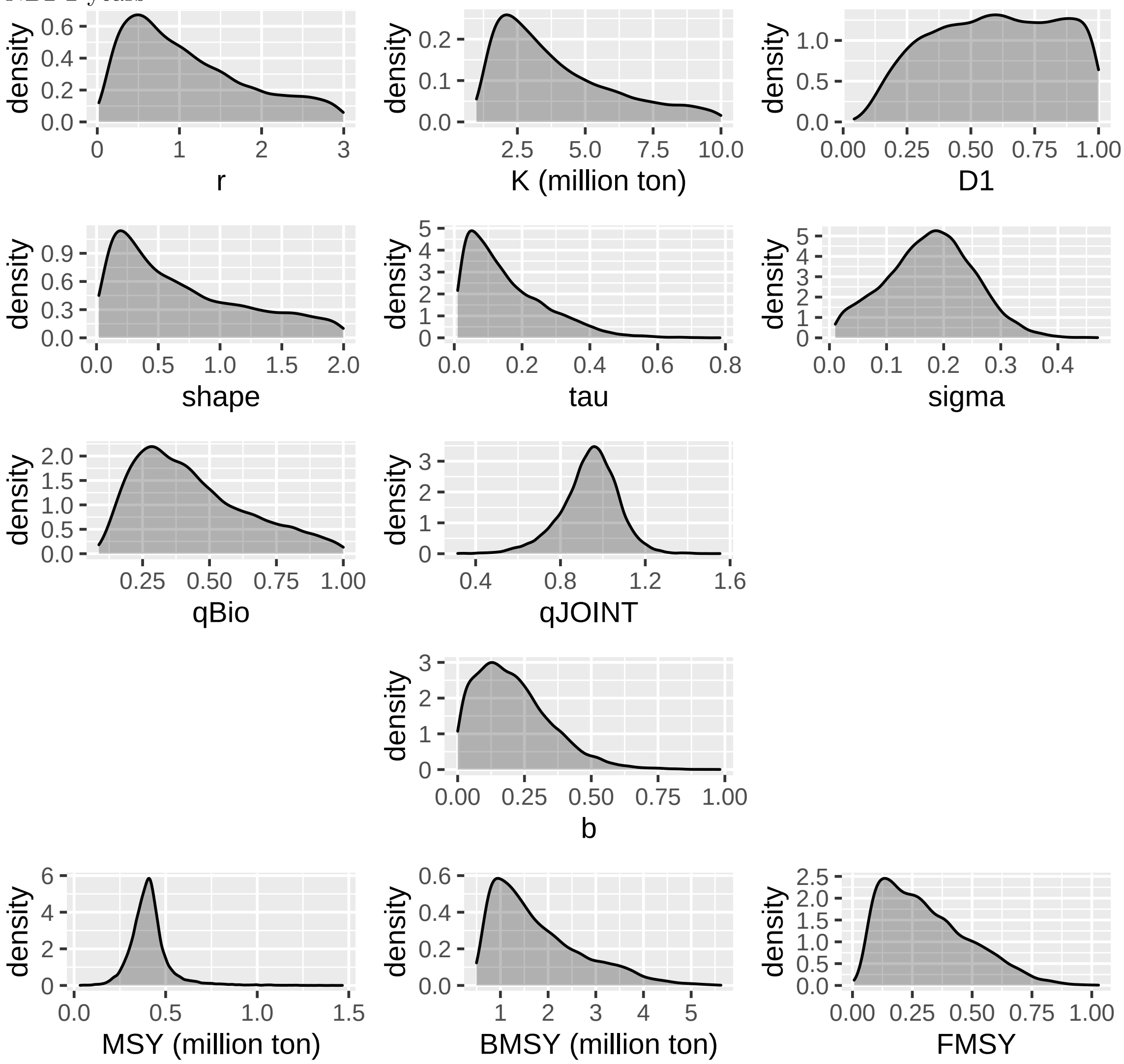
NB2 3 years


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

NB2 2 years

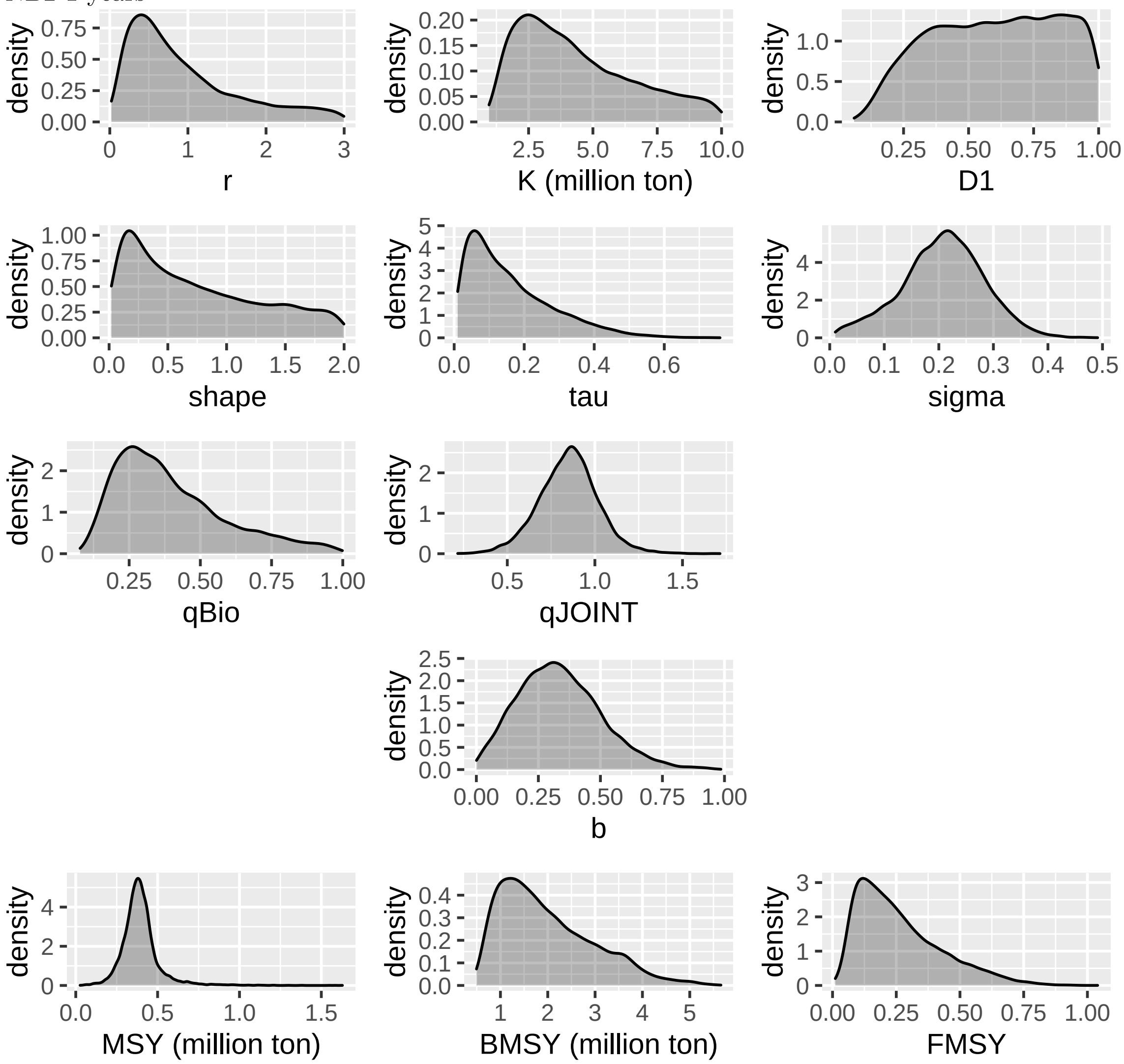

density
r
K (million ton)
D1
shape
tau
sigma
qBio
qJOINT
b
MSY (million ton)
BMSY (million ton)
FMSY

NB2 2 years



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

NB2 1 years

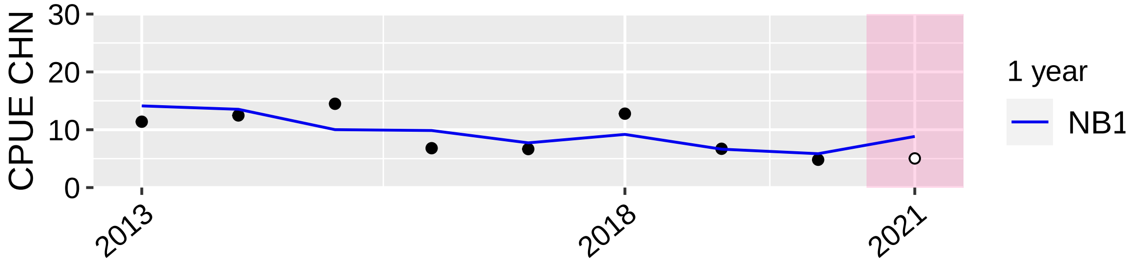

density
0.00
0.25
0.50
0.75
0
1
2
3
r
0.00
0.05
0.10
0.15
0.20
2.5
5.0
7.5
10.0
K (million ton)
0.0
0.5
1.0
0.25
0.50
0.75
1.00
D1
1.00
0.0
0.5
1.0
1.5
2.0
shape
0
1
2
3
4
5
0.2
0.4
0.6
tau
0.1
0.2
0.3
0.4
0.5
sigma
qBio
qJOINT
2.5
b
MSY (million ton)
BMSY (million ton)
FMSY

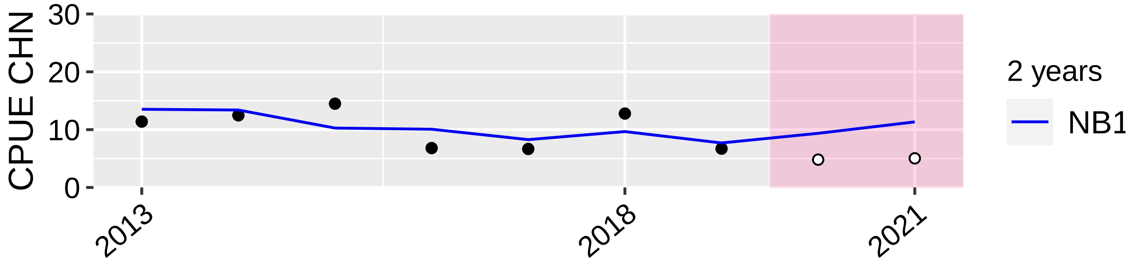
Results of parameters

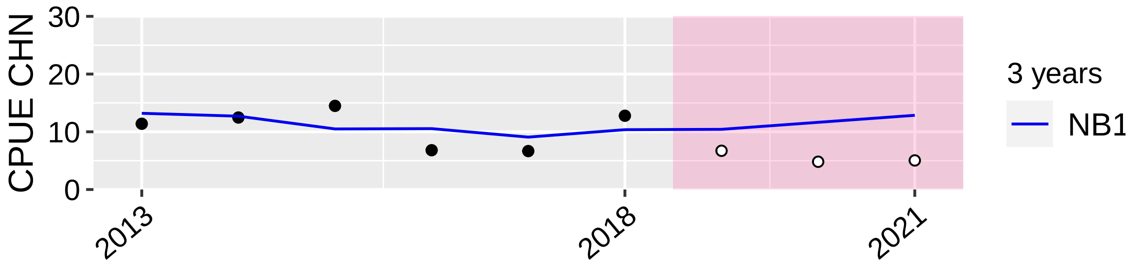
	1year		2years		3years		4years		5years	
	NB1	NB2	NB1	NB2	NB1	NB2	NB1	NB2	NB1	NB2
r	1.220	0.732	1.341	0.937	1.404	1.026	1.460	1.085	1.275	1.006
K (million ton)	2.077	3.869	2.047	3.328	2.163	3.182	2.109	2.955	2.249	2.910
qCHN	13.798		13.156		12.205		11.978		12.501	
qJPN2	2.330		2.312		2.255		2.274		2.278	
qKOR	9.466		9.414		9.514		9.429		9.732	
qRUS	24.157		23.595		22.663		22.667		23.062	
qCT	2.340		2.259		2.166		2.109		2.103	
qJOINT		0.854		0.948		0.989		0.958		0.979
qBio	0.581	0.351	0.561	0.394	0.513	0.397	0.528	0.413	0.521	0.439
Shape	0.593	0.616	0.565	0.550	0.543	0.512	0.550	0.557	0.585	0.622
sigma	0.031	0.210	0.032	0.179	0.033	0.165	0.033	0.167	0.035	0.170
tau	0.318	0.127	0.326	0.122	0.321	0.130	0.340	0.159	0.317	0.154
FMSY	0.434	0.224	0.462	0.275	0.472	0.304	0.489	0.351	0.447	0.344
BMSY (million ton)	0.963	1.766	0.943	1.518	0.984	1.439	0.963	1.343	1.044	1.337
MSY (million ton)	0.417	0.383	0.433	0.401	0.448	0.414	0.459	0.430	0.446	0.423
b	0.674	0.322	0.571	0.187	0.399	0.127	0.482	0.180	0.344	0.163

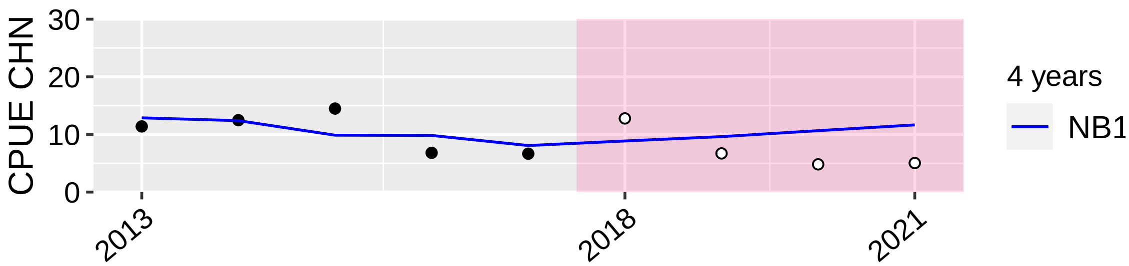
CPUE

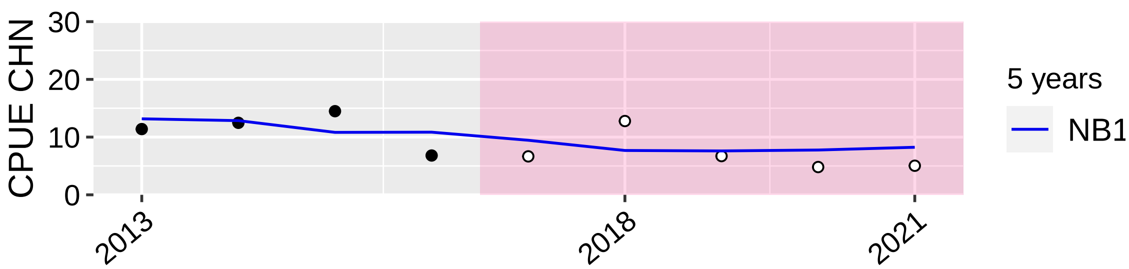
CPUE CHN

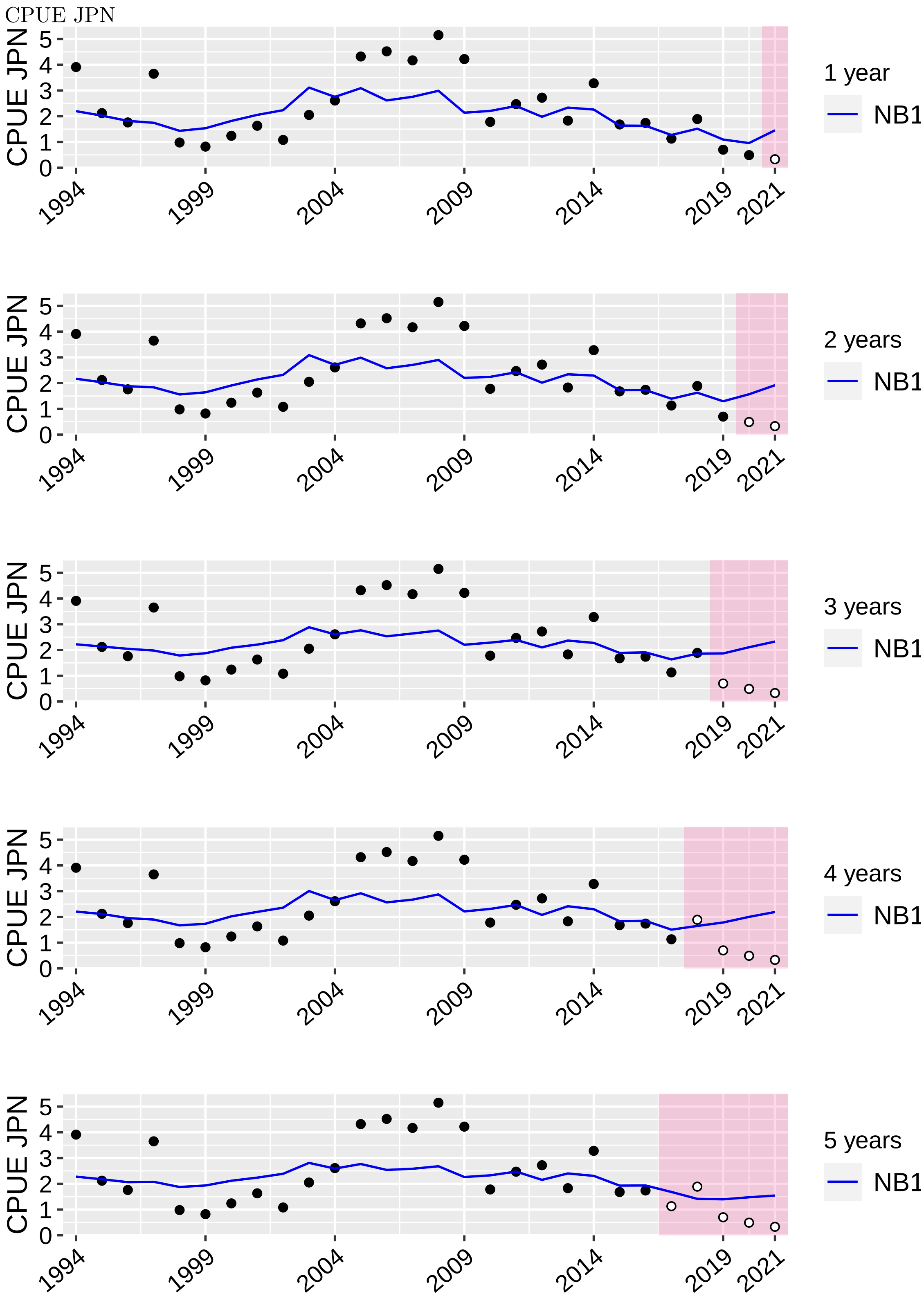




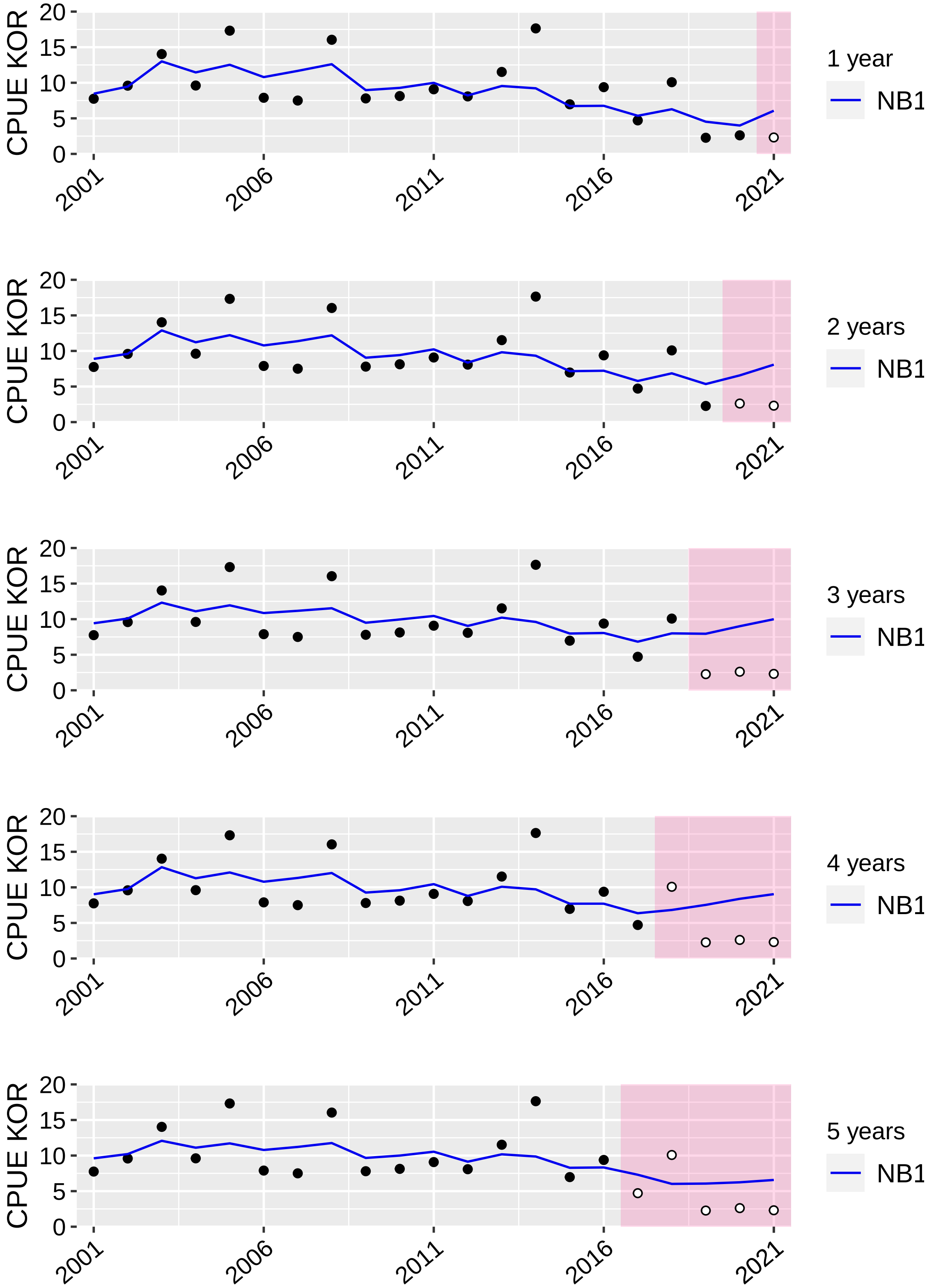




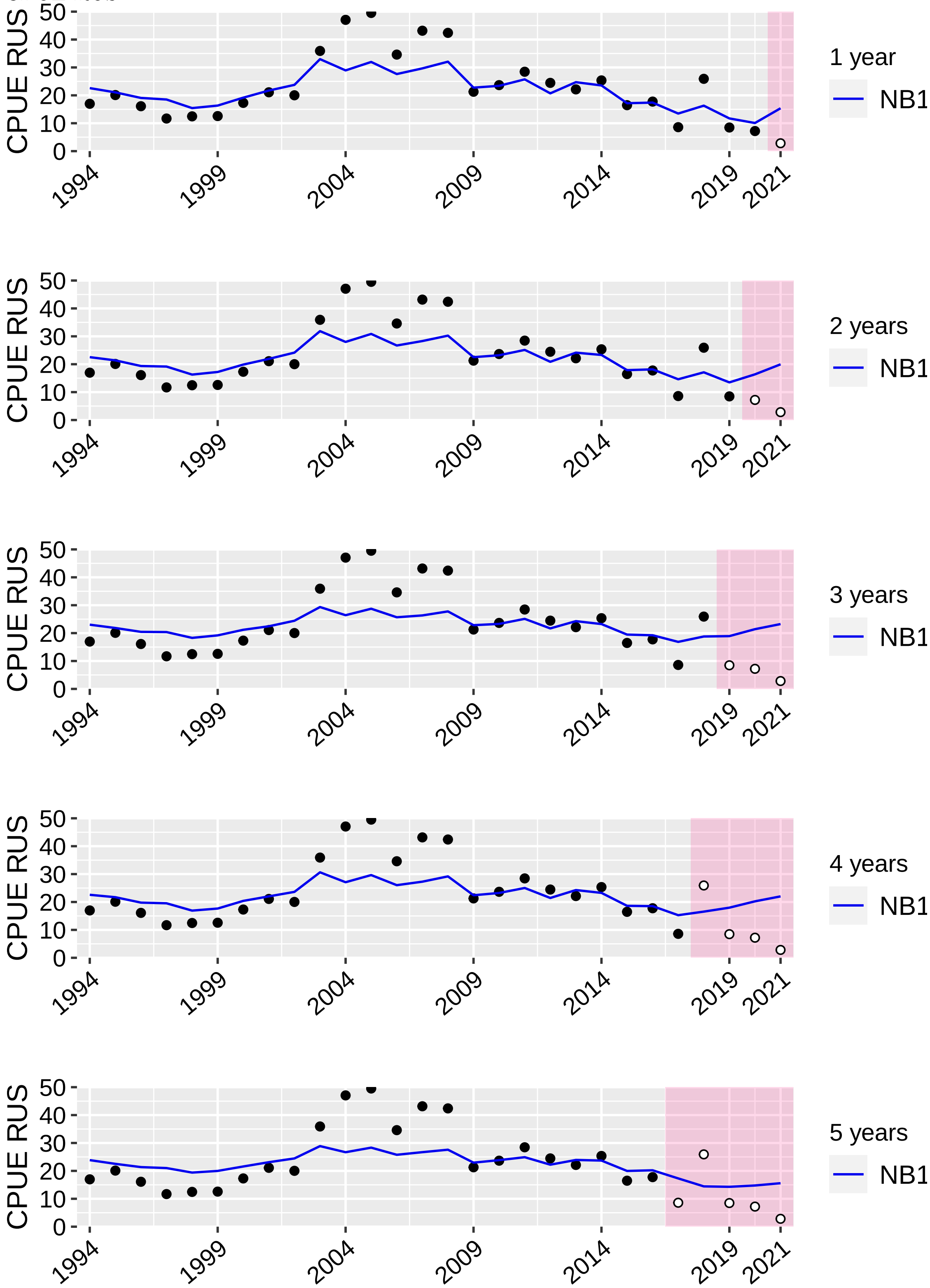



CPUE JPN
CPUE JPN
1994
1999
2004
2009
2014
2019
2021
1 year
NB1
2 years
NB1
3 years
NB1
4 years
NB1
5 years
NB1

CPUE KOR

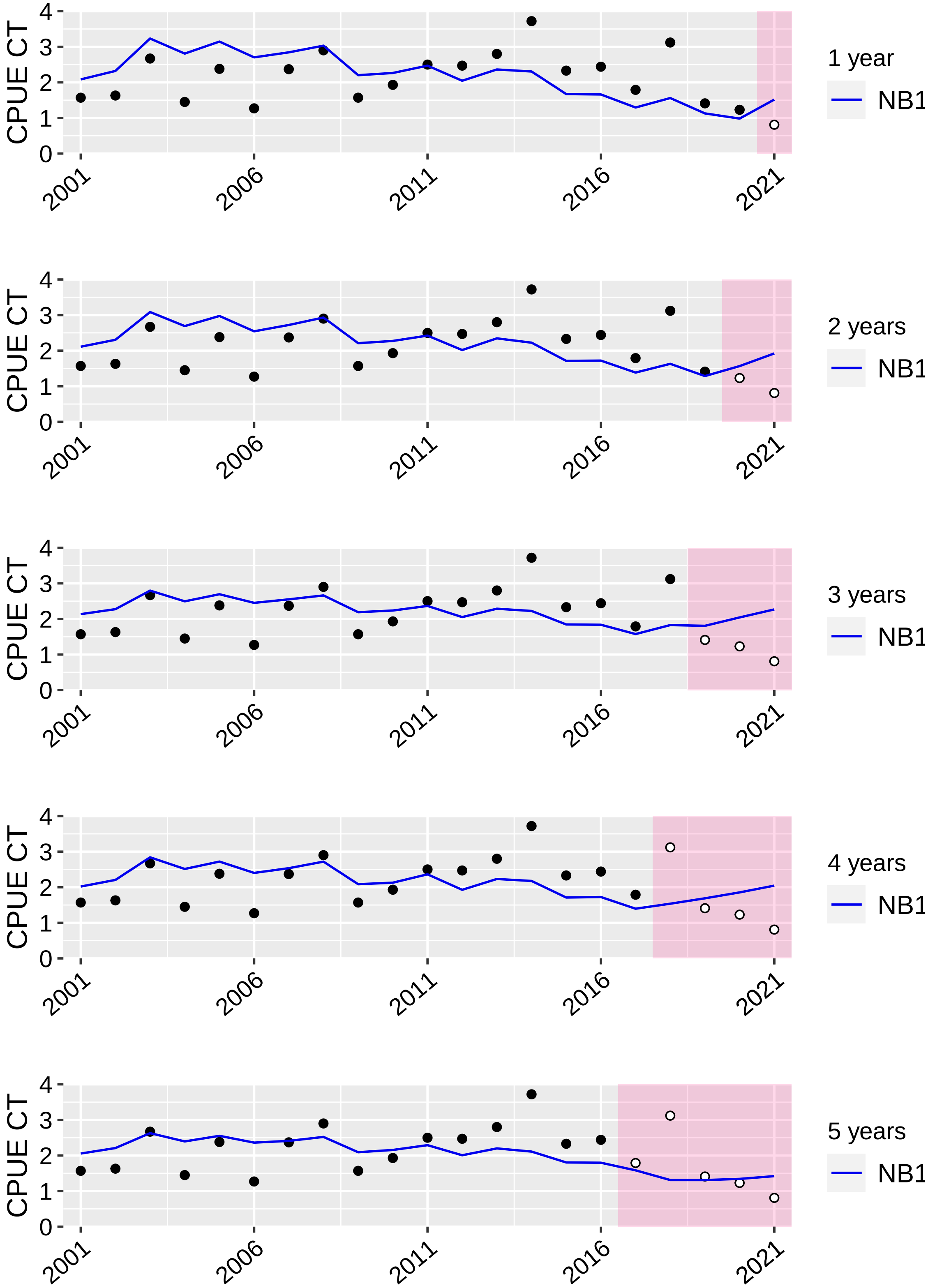

CPUE KOR
20
15
10
5
0
2001
2006
2011
2016
2021
1 year
NB1
2 years
NB1
3 years
NB1
4 years
NB1
5 years
NB1

CPUE RUS



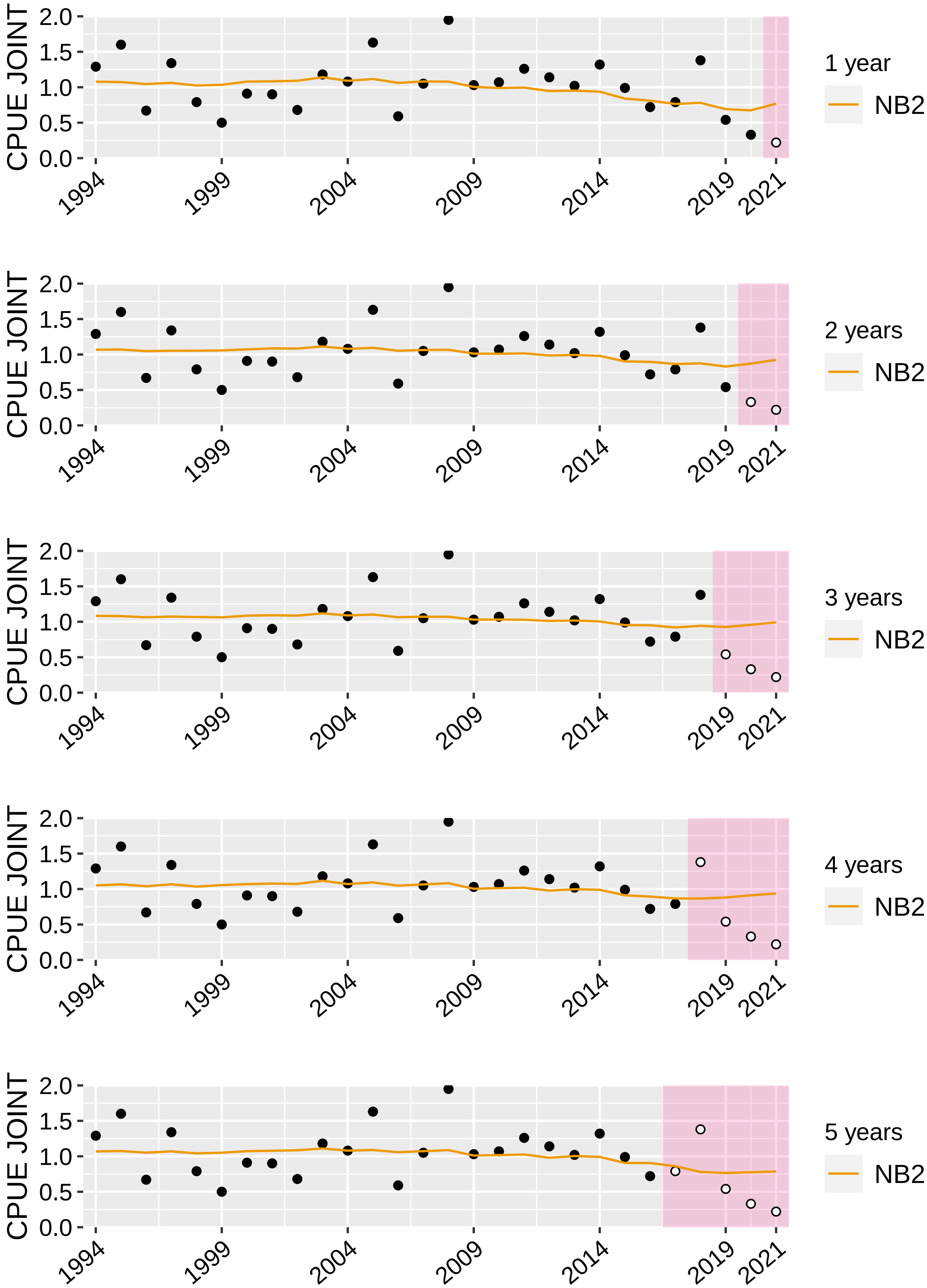
CPUE RUS
50
40
30
20
10
0
1994
1999
2004
2009
2014
2019
2021
1 year
NB1
2 years
NB1
3 years
NB1
4 years
NB1
5 years
NB1

CPUE CT



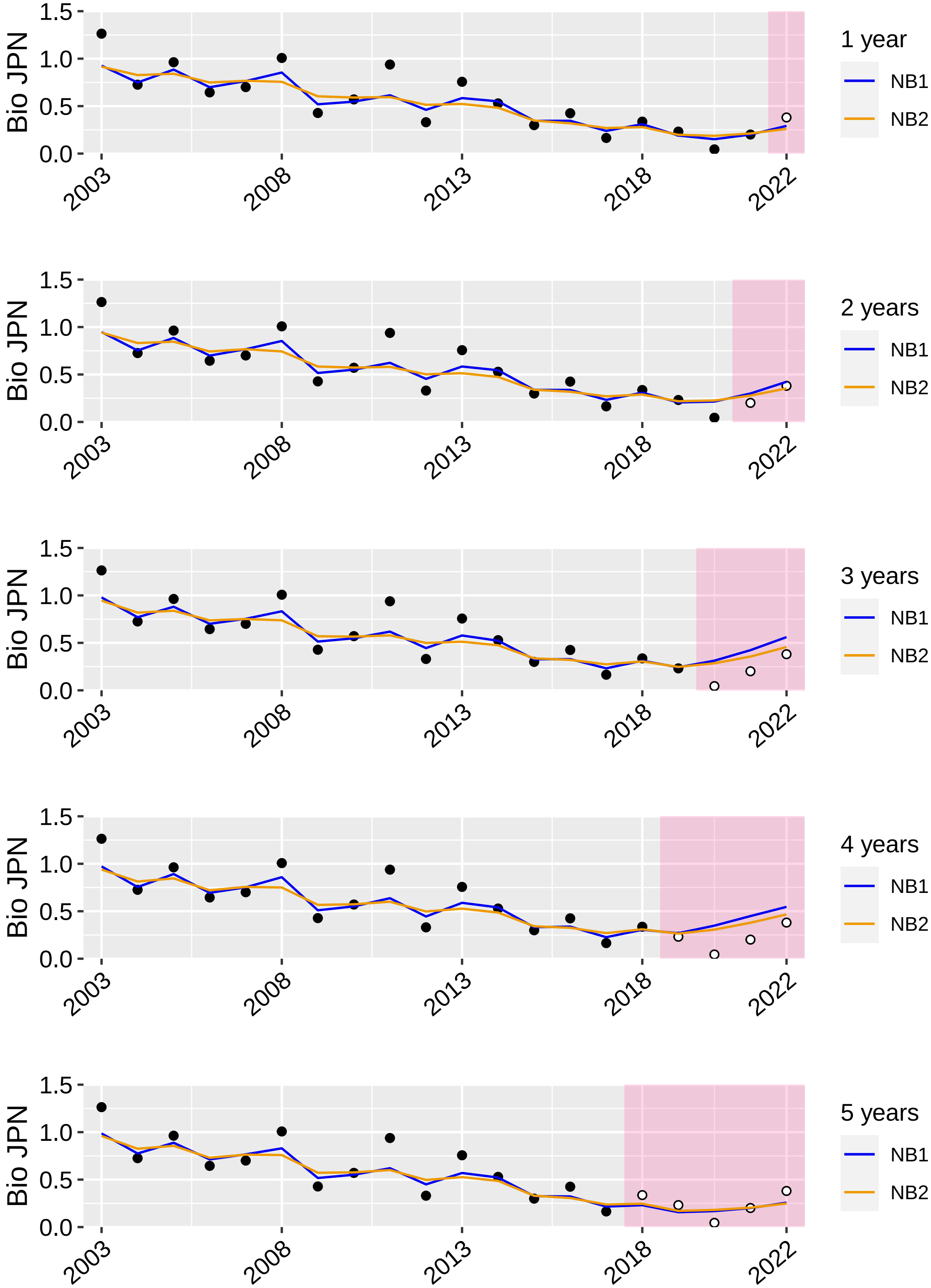
CPUE CT
0
1
2
3
4
2001
2006
2011
2016
2021
1 year
NB1
2 years
NB1
3 years
NB1
4 years
NB1
5 years
NB1

CPUE JOINT



CPUE JOINT
2.0
1.5
1.0
0.5
0.0
1994
1999
2004
2009
2014
2019
2021
1 year
NB2
2 years
NB2
3 years
NB2
4 years
NB2
5 years
NB2

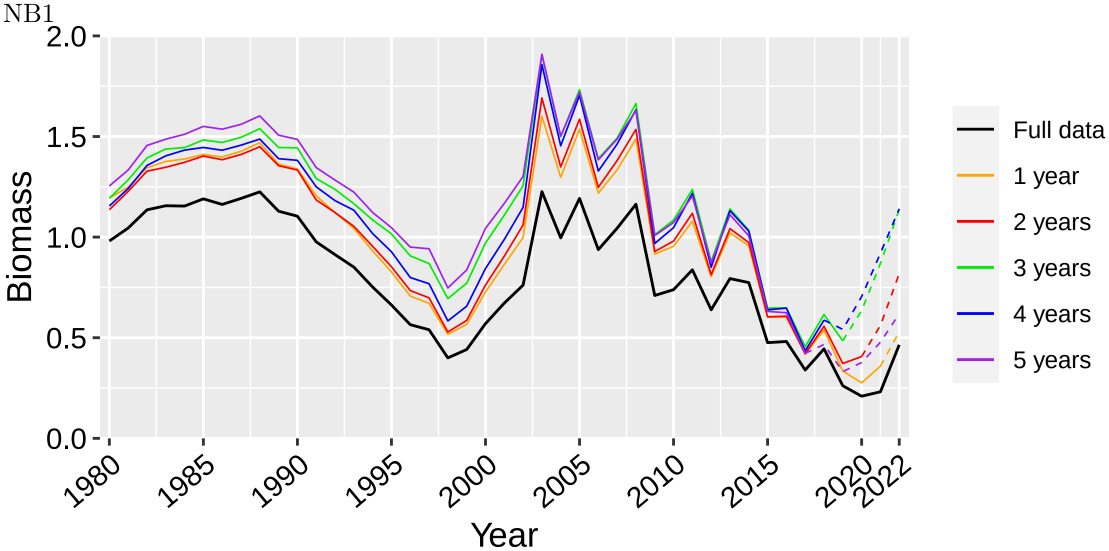
Biomass JPN



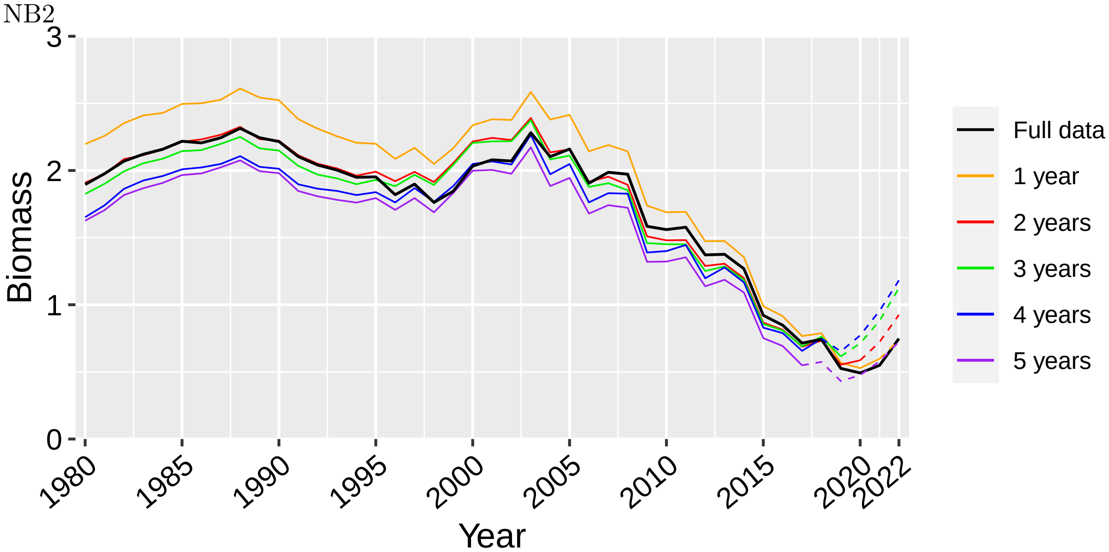
Bio JPN
1.5
1.0
0.5
0.0
2003
2008
2013
2018
2022
1 year
2 years
3 years
4 years
5 years
NB1
NB2

Biomass

NB1

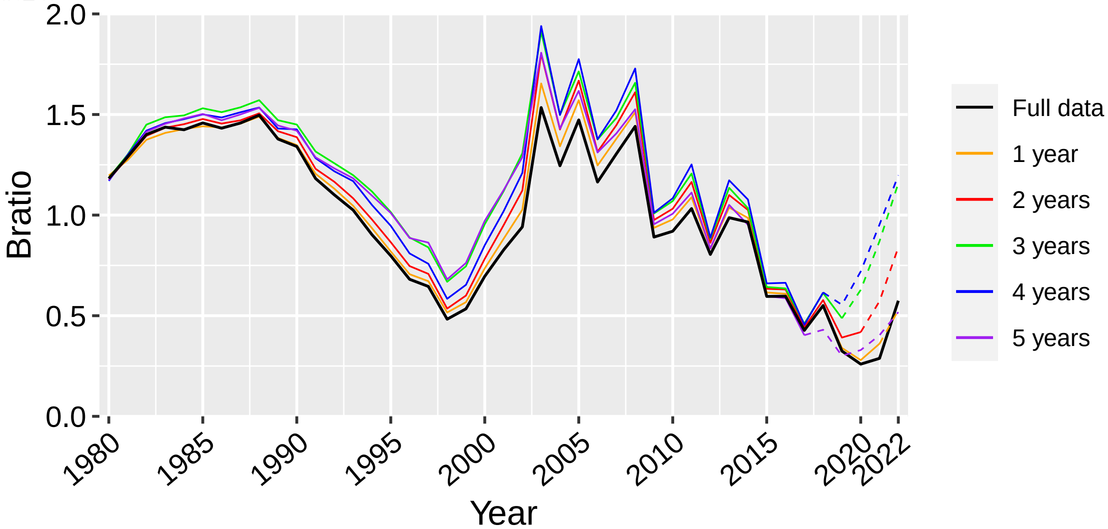


NB2

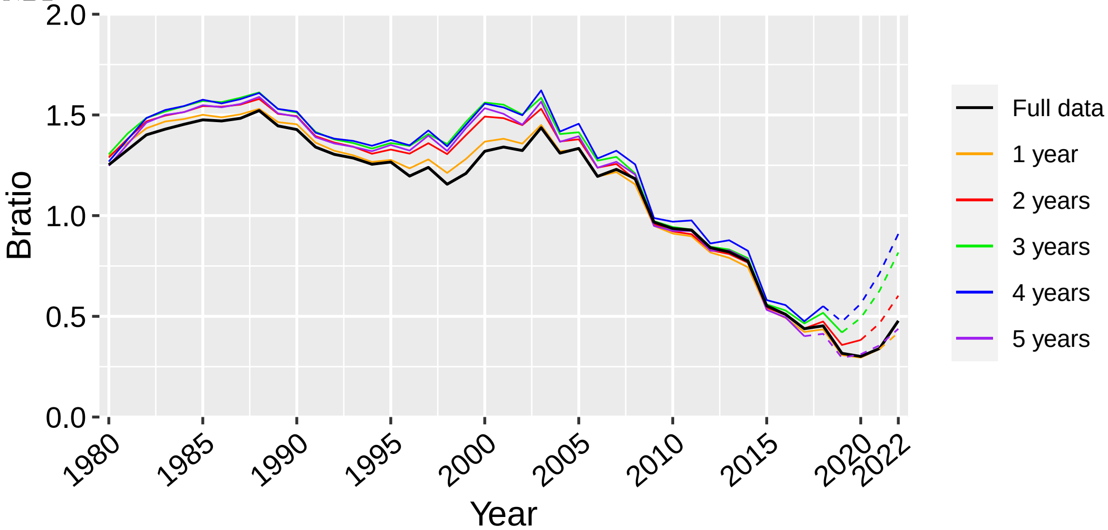


Bratio

NB1

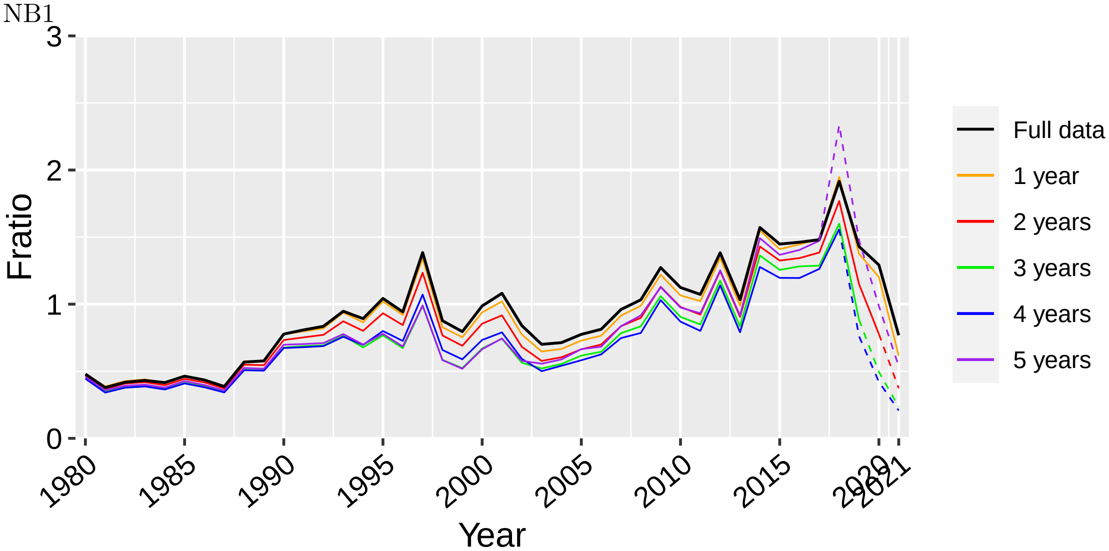


NB2



Fratio

NB1



NB2