2019 updates of stock assessment for Pacific saury in the North Pacific Ocean by using Bayesian state-space production models

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[Note: this document has been revised during the SSC-PS-06 meeting, i.e. AveF_2016_2018 and AveF_2016_2018/Fmsy in table 2, p. 4]

SUMMARY

Stock assessment for the North Pacific saury was conducted based on the new specification (2 base cases and 4 sensitivity cases) agreed in the 5th SSC-PS meeting held in November 2019. The basic model employed in the analysis was the state-space surplus production model as agreed in 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.

As for the base case stock assessment result, the 2019 median depletion level was only 26% of the carrying capacity (80%CI=16.8-37.1%), declined from 33.9% (80%CI=22.2-47.7%) in 2018. Furthermore, B-ratio (=B/Bmsy) in 2019 and F-ratio (=F/Fmsy) in 2018 were 0.574 (80%CI=0.383-0.837) and 1.382 (80%CI=0.901-1.958), respectively. In addition, the probability of the population being in the green Kobe quadrant in 2018 was estimated to be less than 10%, while the probability of being in the red Kobe quadrant was assessed to be greater than 80%, which indicated that the population was overfished and subject to overfishing in 2018.

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 continuation of the current level of catch may cause a further decline in the population size. However, as shown in the retrospective/hindcasting analyses, the estimation for the recent population size tended to depend on the recent data set. Therefore, for providing better management advice, the authors strongly suggest that the analysis should be updated using the most recent abundance indices (including 2020 fishery-independent abundance index and 2019 CPUE indices).

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 5th SSC-PS meeting held in November 2019, the new specification for the BSSPM analysis (2 base cases and 4 sensitivity cases, see Table 1) was agreed. Here, we will report on our updated stock assessment by Japan based on the specification.

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

	New base case (NB1)	**New base case (NB2)**	**Sensitivity case (NS1, NS2)**	**Sensitivity case (NS3, NS4)**
Initial year	1980	1980	1980	1980/2001
Biomass survey	B_obs = B_est*q1 ~ LN(log(q*B), s^2) q~U(0, 1)	Same as left	q~U(0, 2)	q~U(0, 1) 2003-2019
CPUE	CHN(2013-2018) JPN_early(1980-1993) (with time-varying q) JPN_late(1994-2018) KOR(2001-2018) RUS(1994-2018) CT(2001-2018)	CHN(2013-2018) JPN_late(1994-2018) KOR(2001-2018) RUS(1994-2018) CT(2001-2018)	Two sets as on the left for NS1 and NS2 respectively	NS3: Joint CPUE 2001-2019 (no JPN_early) NS4: Joint CPUE 2001-2019 and JPN_early
Variance component	Variances of logCPUEs are assumed to be common and 6 times of that of logbiomass	Variances of logCPUEs are assumed to be common and 5 times of that of logbiomass	Same as base cases 1 and 2, respectively	Same weight between biomass and joint CPUE
Hyper-depletion/ stability	A common parameter for all fisheries but JPN_early, with a prior distribution, b ~ U(0, 1) but [b_JPN_early=1]	A common parameter for all fisheries with a prior distribution, b ~ U(0, 1)	Same as base cases 1 and 2, respectively	b ~ U(0, 1)
Prior for other than q_biomass	Own preferred options	Own preferred options	Own preferred options	Own preferred options

MATERIALS AND METHODS

Data set

1) time series of total reported catch up to 2018 (though 2019 catch does not influence the assessment results)

2) standardized CPUE indices by the following five Members

3) fishery-independent survey by Japan (2003-2019)

4) joint CPUE (2001-2019)Note that we used the joint CPUE for the two sensitivity cases but up to 2017.

Specification of analysis

We basically used the similar statistical models as Chiba and Kitakado (2019) with following the PS06 specification above.

Survey biomass:

$$I_{t,biomass} = q\, B_t e^{v_{t,biomass}}, \quad v_{t,biomass} \sim N(0, \sigma_{biomass}^2)$$

where I_t is the biomass observation in year t, and q and $\sigma_{biomass}$ are respectively the parameters expressing the relative bias in biomass survey and the standard deviation in the biomass survey.

CPUE series:

$$I_{t,f} = q_f B_t^b e^{v_{t,f}}, \quad v_{t,f} \sim N(0, \sigma_f^2)$$

where $I_{t,f}$ is the CPUE observation in year t for fishery f (China, Japan, Korea, Russia, Chinese Taipei), and q_f and σ_f are respectively the catchability coefficient and the standard deviation in CPUE for fishery f, and b is the hyperstability/hyperdepletion parameter. Note that "b" is not assumed for Japanese early CPUE as agreed in TWG03.

Particularly for the Japanese early CPUE, the following functional form was used.

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

Prior distributions:

The prior distributions (except for q for biomass survey) assumed in the BSSPM were as follows:

$$\begin{array}{lll} r \sim U(0.01,3), & K \sim U(0.0001,10), & D1 \sim U(0.01,1), \\ z \sim U(0.01,2), & \tau \sim U(0.01,2), & \sigma_{biomass} \sim U(0.01,1), \\ q_{1980,JPN1} \sim U(0.0001,3), & q_{CHN} \sim U(0.0001,50), & q_{KOR} \sim U(0.0001,30), \\ q_{RUS} \sim U(0.0001,50), & q_{CT} \sim U(0.0001,5), & b \sim U(0,1), \\ \alpha \sim U(0.0001,10), & \beta \sim U(1980,1994), & \delta \sim U(0.0001,3) \end{array}$$

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). Model selection was not conducted formally in this paper. Instead, as a way of model checking, a kind of hindcasting approach (in terms of predictability; e.g. Kell et al. 2016), was used to identify retrospective patterns and predictability in the models. No serious retrospective patterns were observed (see Figure 1; see also Appendix, Section 9.2). However, the hindcasting results warned that the recent population size tended to depend on the recent data set, which also indicated that the model may have less prediction skill.

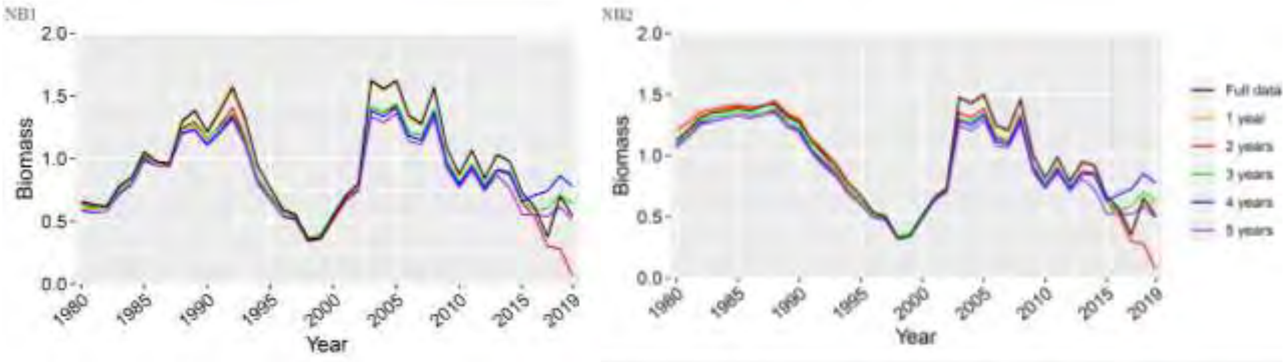


Figure 1. Results of retrospective/hindcasting analyses for the two base cases. The hindcasting (prediction after the retrospective analysis) was carried out using the observed catch records.

Time series and stock status

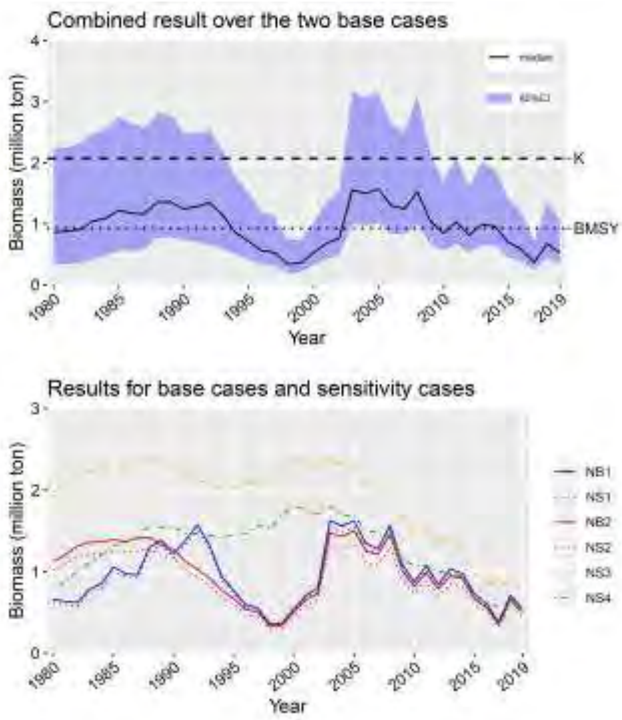
Figure 2 shows the trajectories of biomass, B- and F-ratios and depletion level relative to the carrying capacity over the two base cases (further information including the series of harvest rate is available in Appendix). The result indicated that, although there were long-term fluctuations and interannual 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 base case stock assessment result, the 2019 median depletion level was only 26% of the carrying capacity (80%CI=16.8-37.1%), declined from 33.9% (80%CI=22.2-47.7%) in 2018. In addition, B-ratio (=B/Bmsy) in 2019 and F-ratio (=F/Fmsy) in 2018 were 0.574 (80%CI=0.383-0.837) and 1.382 (80%CI=0.901-1.958), respectively, which clearly indicated that the population status was assessed as overfished and subject to overfishing.

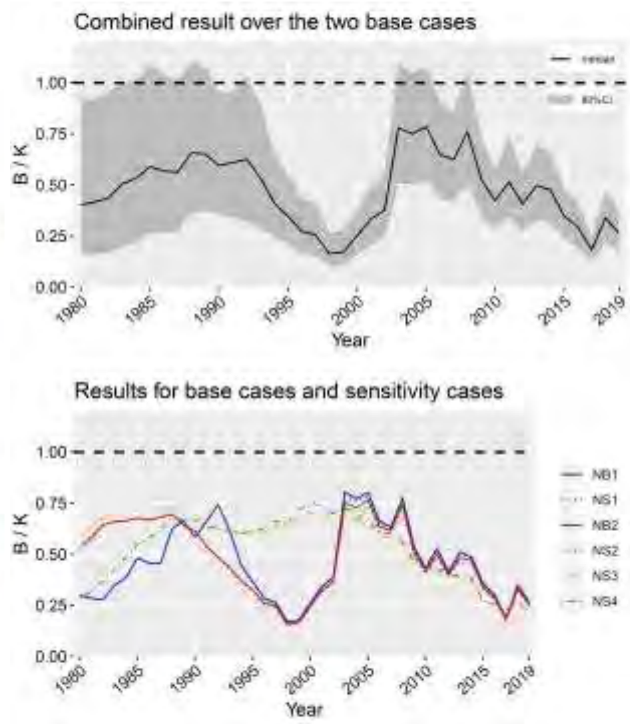
Table 2. Estimates of key reference quantities combined over the two base cases.

	Mean	Median	Lower10th	Upper10th
C_2018	0.439	0.439	0.439	0.439
AveC_2016_2018	0.354	0.354	0.354	0.354
AveF_2016_2018	0.665	0.664	0.336	0.992
F_2018	0.653	0.649	0.322	0.988
FMSY	0.473	0.470	0.269	0.679
MSY (million ton)	0.448	0.435	0.359	0.548
F_2018/FMSY	1.419	1.377	0.905	1.964
AveF_2016_2018/FMSY	1.443	1.412	0.960	1.935
K (million ton)	2.436	2.070	1.398	3.921
B_2018 (million ton)	0.819	0.677	0.444	1.362
B_2019 (million ton)	0.631	0.521	0.334	1.059
AveB_2017_2019	0.650	0.539	0.359	1.073
BMSY (million ton)	1.080	0.924	0.642	1.693
BMSY/K	0.449	0.439	0.401	0.516
B_2018/K	0.346	0.339	0.225	0.473
B_2019/K	0.266	0.260	0.169	0.368
AveB_2017_2019/K	0.275	0.271	0.183	0.368
B_2018/BMSY	0.775	0.745	0.513	1.066
B_2019/BMSY	0.595	0.572	0.384	0.829
AveB_2017_2019/BMSY	0.614	0.594	0.419	0.832

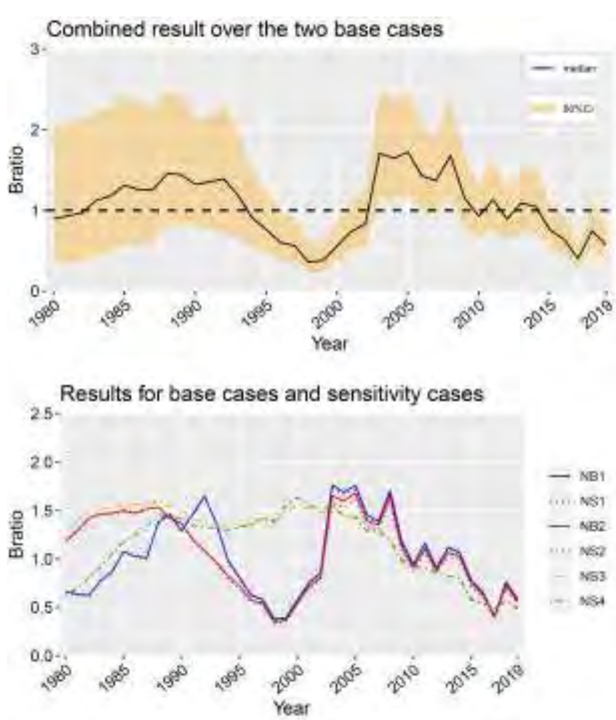
(a) Biomass



(b) Depletion level relative to K



(c) B-ratio



(d) F-ratio

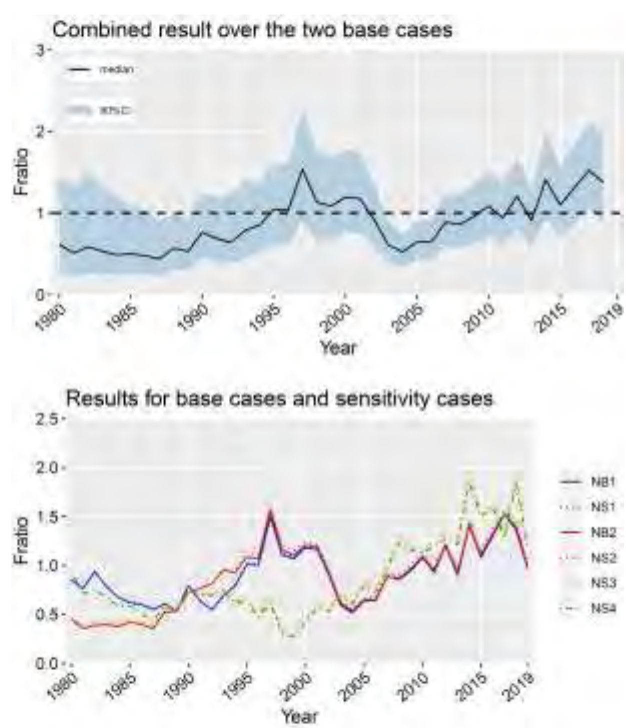


Figure 2. Results of trajectories over the two base cases of (a) biomass, (b) depletion level relative to the carrying capacity, (c) B-ratio and (d) F-ratio.

Evidently, Figure 3, which is the Kobe plot with time series of median B-ratio and F-ratio for 1980-2018, also shows that the probability of population in 2018 being in the green Kobe quadrant is estimated to be less than 10%, while the probability of being in the red Kobe quadrant is estimated to be greater than 80%, which indicates that the population is considered to be overfished and subject to overfishing in 2018.

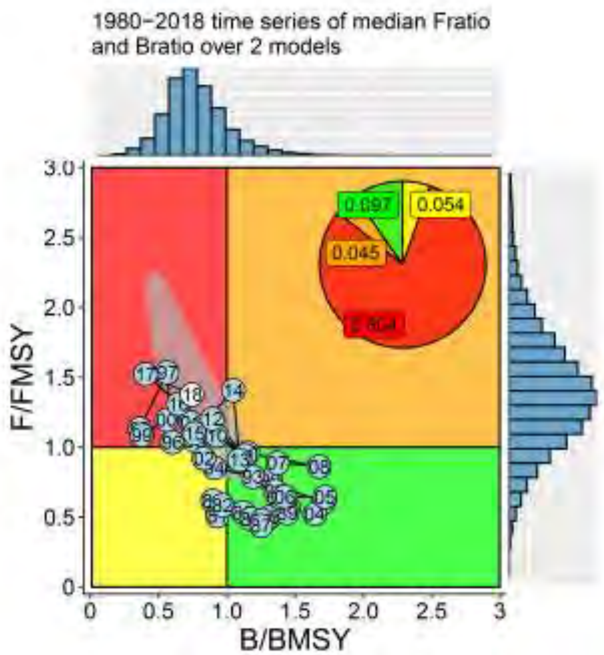


Figure 3. Kobe plot with time series of median B-ratio and F-ratio for 1980-2018.

Future projection and risk analysis

Figure 4 shows the median of biomass trajectory with future projection for different catch levels in 2019-2023 relative to the average catch over 2016-2018 (catch in 2019 is assumed to be the 2016-2018 average). 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.

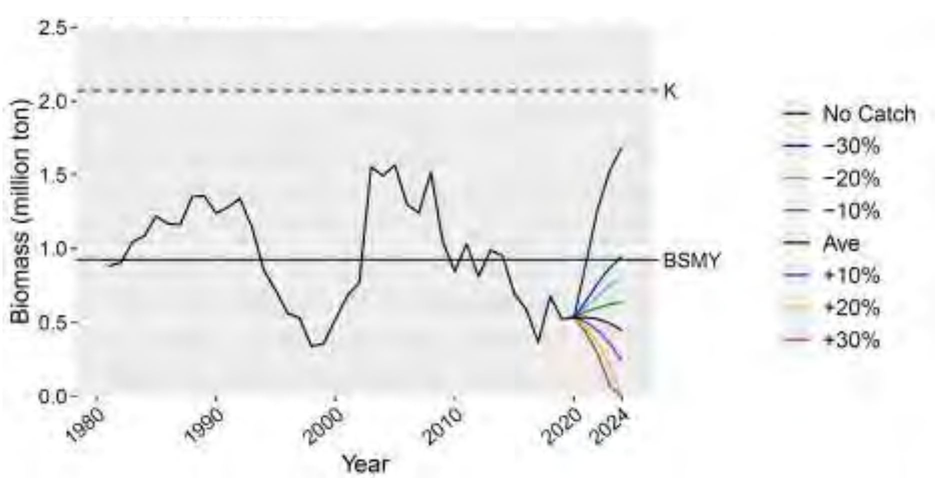


Figure 4. Median of biomass trajectory with future projection under the different catch scenarios.

Table 3. Risk table for different catch levels relative to 2016-2018 average catch.

	Red	Orange	Yellow	Green	B<BMSY	F>FMSY
+30%	0.831	0.012	0.015	0.142	0.846	0.843
+20%	0.784	0.008	0.026	0.182	0.810	0.792
+10%	0.714	0.004	0.045	0.237	0.759	0.718
±0%	0.628	0.002	0.076	0.294	0.704	0.630
-10%	0.524	0.001	0.113	0.362	0.637	0.525
-20%	0.417	0.000	0.148	0.435	0.565	0.417
-30%	0.302	0.000	0.188	0.510	0.490	0.302
No Catch	0.000	0.000	0.137	0.863	0.137	0.000

Conclusion

1) Biomass level: 2019 median depletion level was only 26% of the carrying capacity (80%CI=16.8-37.1%), which was declined from 33.9% (80%CI=22.2-47.7%) in 2018.

2) B-ratio (=B/Bmsy) in 2019 was 0.574 (80%CI=0.383-0.837), and F-ratio (=F/Fmsy) in 2018 was 1.382 (80%CI=0.901-1.958).

3) The probability of population in 2018 being in the green Kobe quadrant was estimated to be less than 10%, while the probability of being in the red Kobe quadrant was assessed to be greater than 80%, which indicated that the population was overfished and subject to overfishing in 2018.

4) The MSY was estimated around 435,000 tons (80%CI=359,000-551,000), which is greater than the current catch level. However, the current biomass level is markedly low, and therefore this amount is not an appropriate level of catch; rather, if applying the same formula used in TAC calculation in 2019, it should be B2019*Fmsy=520,000*0471=244,920 (tons). This figure should be further reduced if we consider the estimation uncertainty as well as biomass estimates in 2020 and 2021, which are to be produced using the most recent data set.

5) As shown in the retrospective/hindcasting analyses, the estimation for the recent population size tended to depend on the recent data set, and therefore for providing with better management advice, the authors strongly suggest that the analysis should be updated using the most recent abundance indices (including 2020 fishery-independent abundance index and 2019 CPUE indices).

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).

Kell, L., A. Kimoto and T. Kitakado (2016) Evaluation of the Prediction Skill of Stock Assessment Using Hindcasting. Fisheries Research, 183, 119-127.

NPFC (2019) Report of the SSC-PS06.

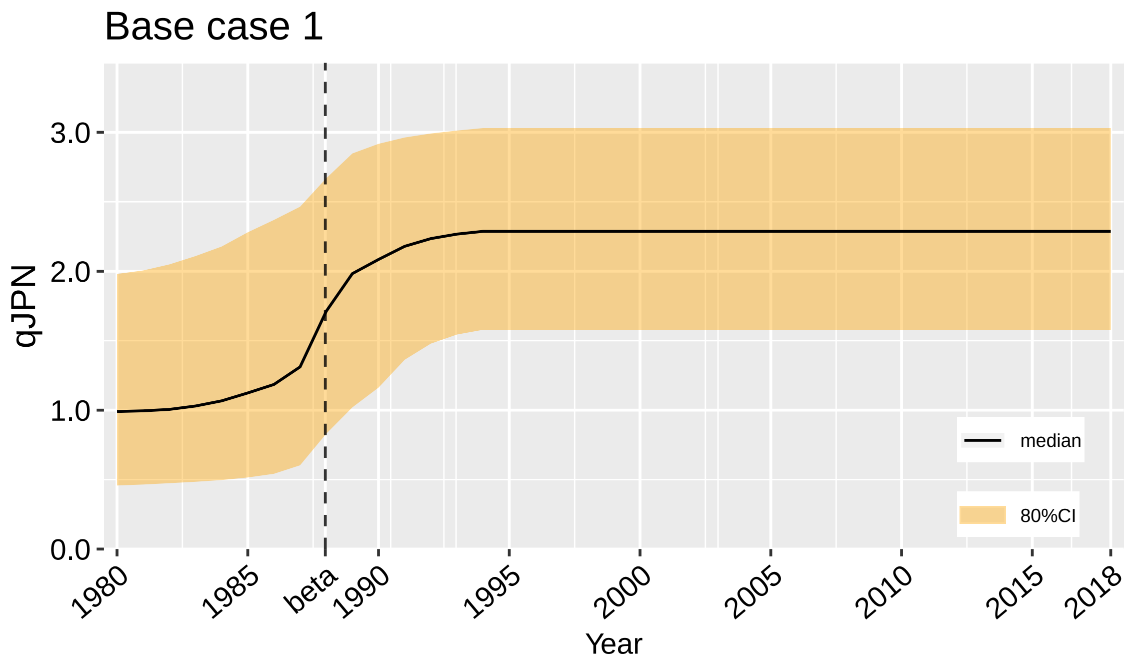
Item	Authors' note
(1) Identify the data that will be available to the stock assessment;	See SSC-PS05 report and table in this document.
(2) Evaluate data quality and quantity and potential error sources (e.g., sampling errors, measurement errors) and associated statistical properties (e.g., biased or random errors, statistical distribution) to ensure that the best available information is used in the assessment;	No errors in catch data. All biomass 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-PS05 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-PS05 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-PS05 report
(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-PS05
(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 the SSC-PS06

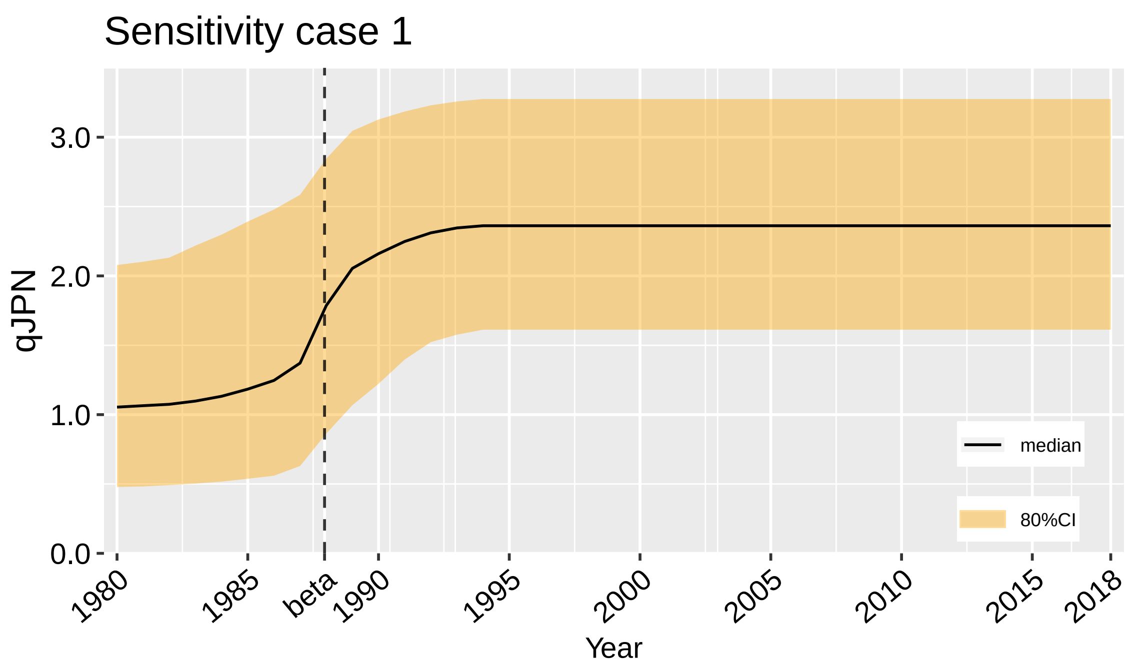
Appendix:

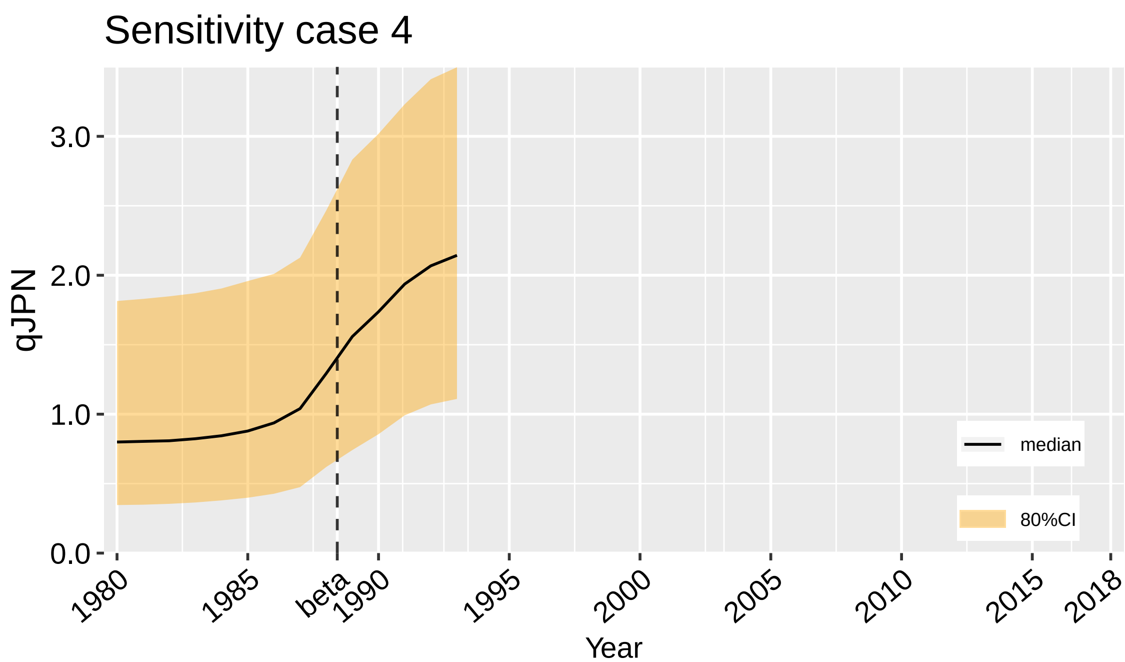
Toshihide Kitakado, Yuki Ueda, Ren Tamura and Nanako Sekiguchi

Contents

1 Estimated time-varying catchability



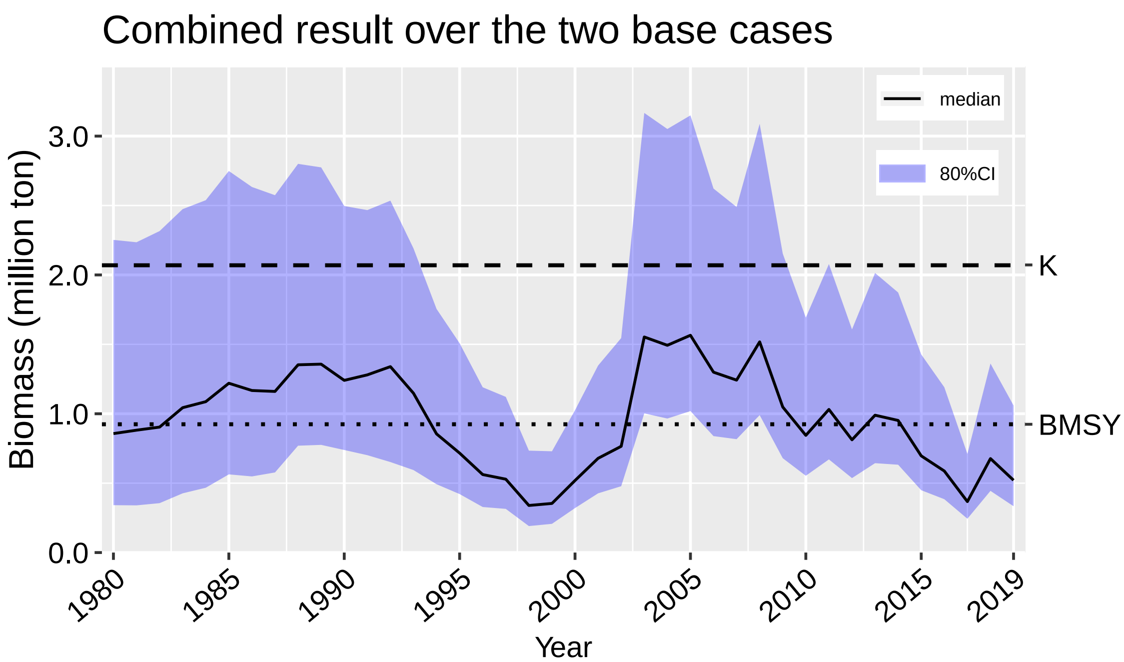


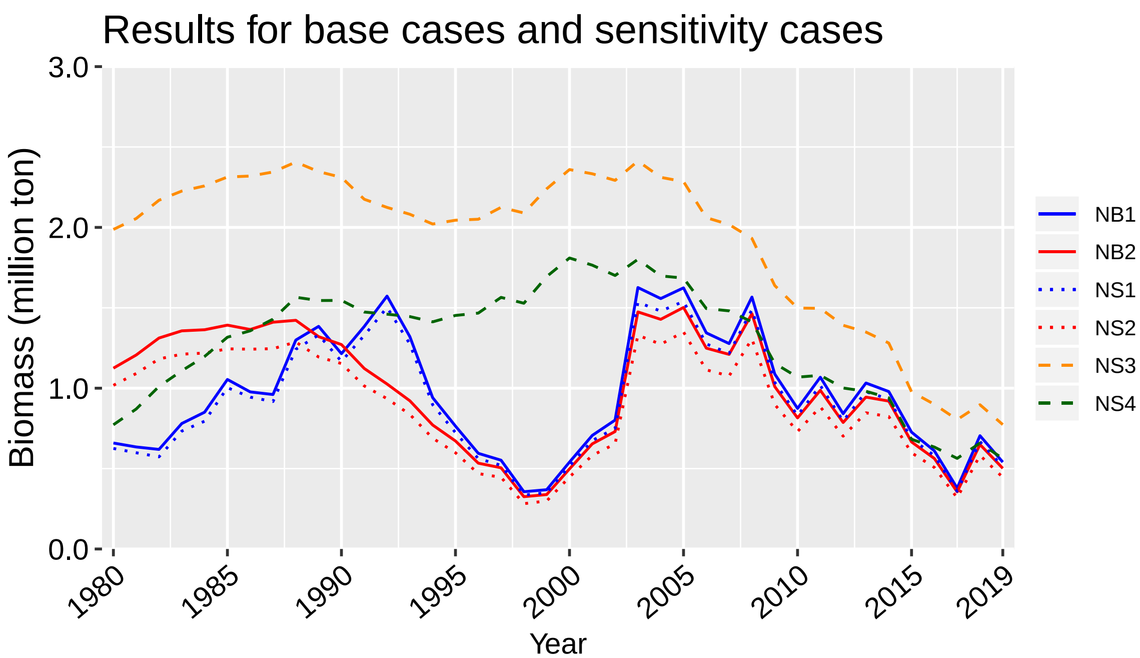


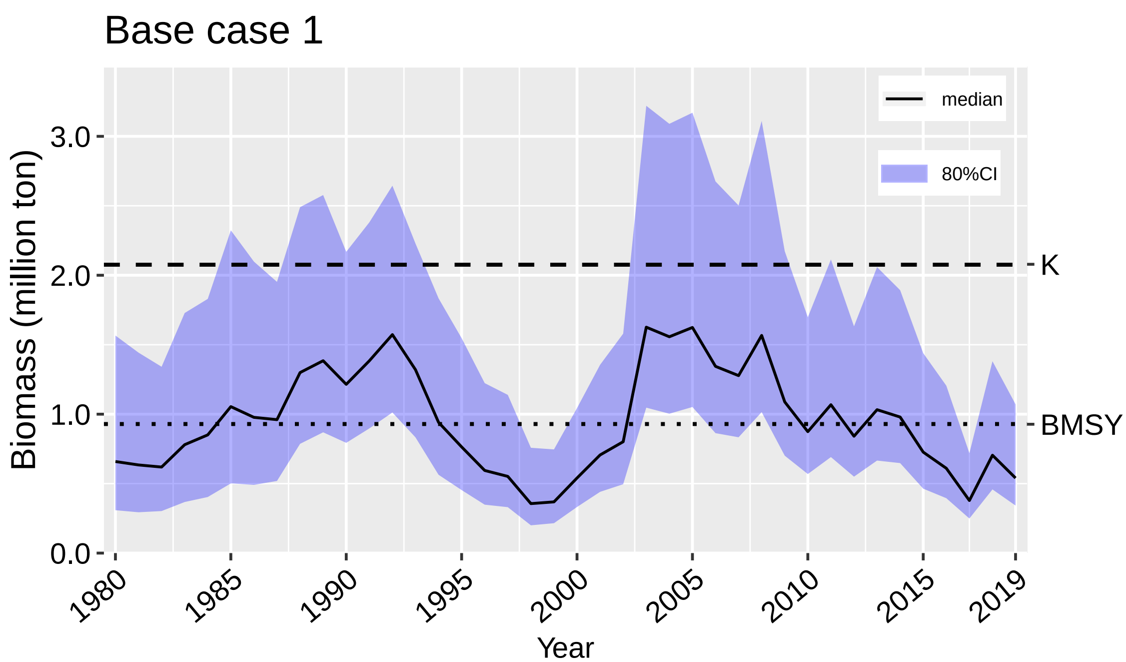
Sensitivity case 4
qJPN
3.0
2.0
1.0
0.0
1980
1985
beta
1990
1995
2000
2005
2010
2015
2018
Year
median
80%CI

2 Time series plot

2.1 Time series Biomass






Base case 1
median
80%CI
K
BMSY
Biomass (million ton)
Year
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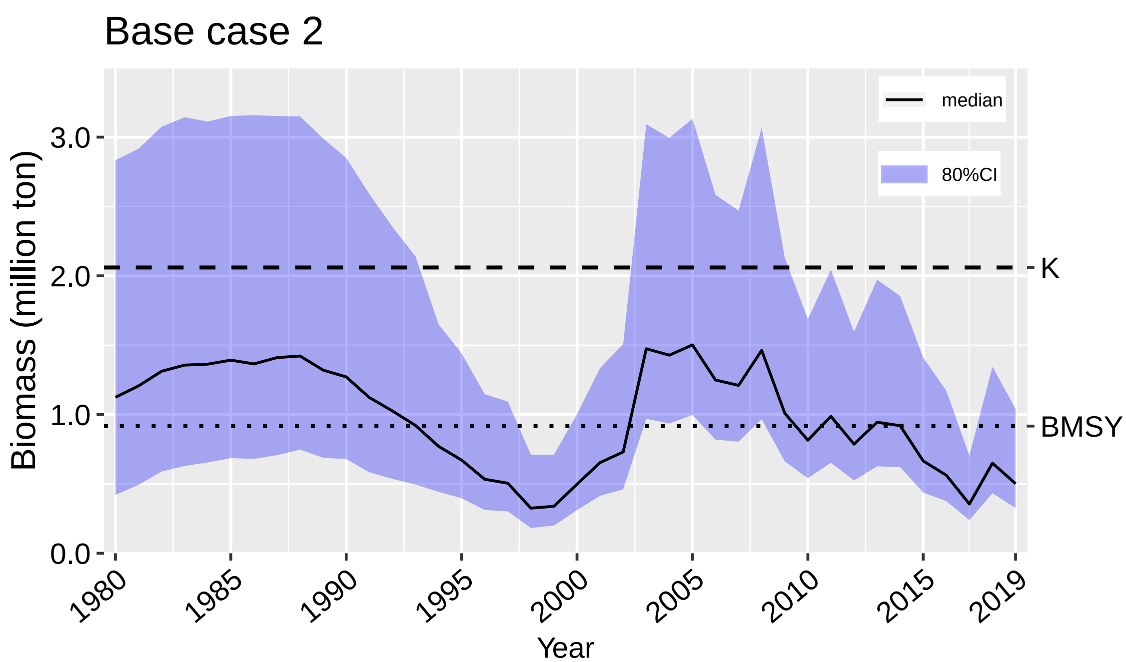
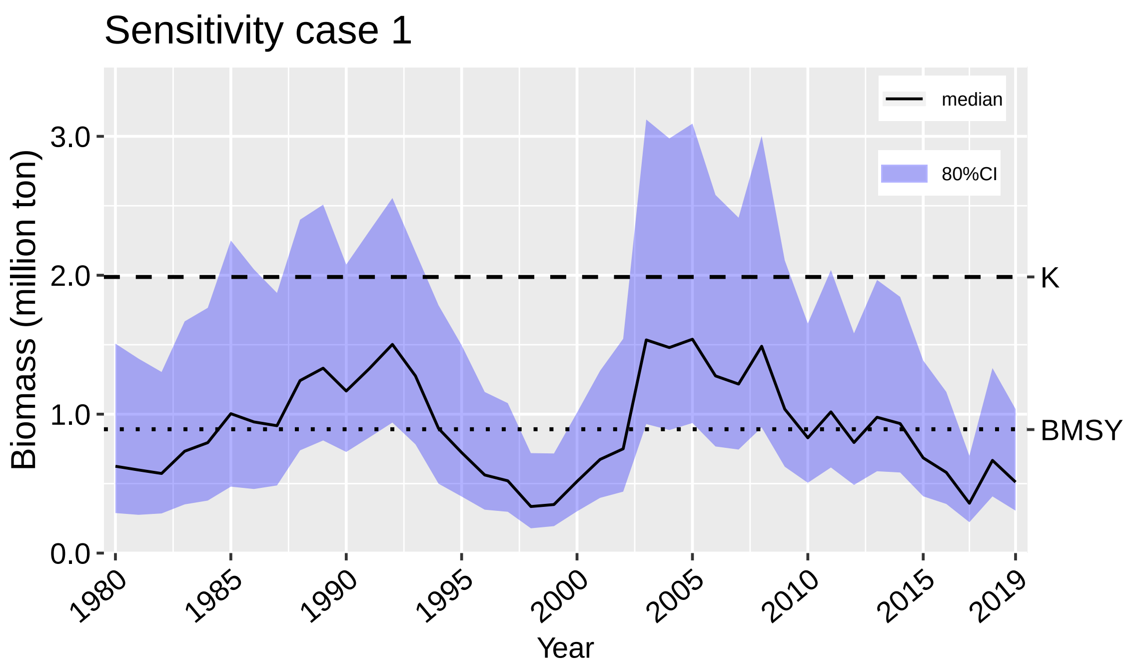
1.0
2.0
3.0
1980
1985
1990
1995
2000
2005
2010
2015
2019


Base case 2
median
80%CI
K
BMSY
Biomass (million ton)
Year
0.0
1.0
2.0
3.0
1980
1985
1990
1995
2000
2005
2010
2015
2019


Sensitivity case 1
median
80%CI
K
BMSY
Biomass (million ton)
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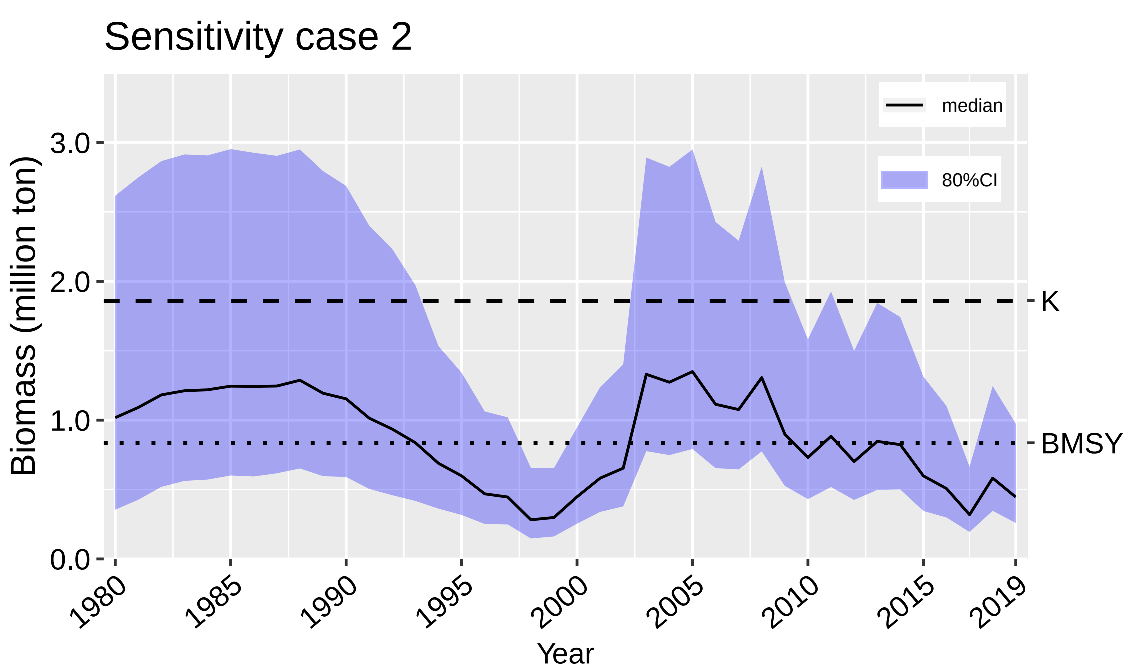
2.0
1.0
0.0
1980
1985
1990
1995
2000
2005
2010
2015
2019
Year


Sensitivity case 2
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80%CI
K
BMSY
Biomass (million ton)
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0.0
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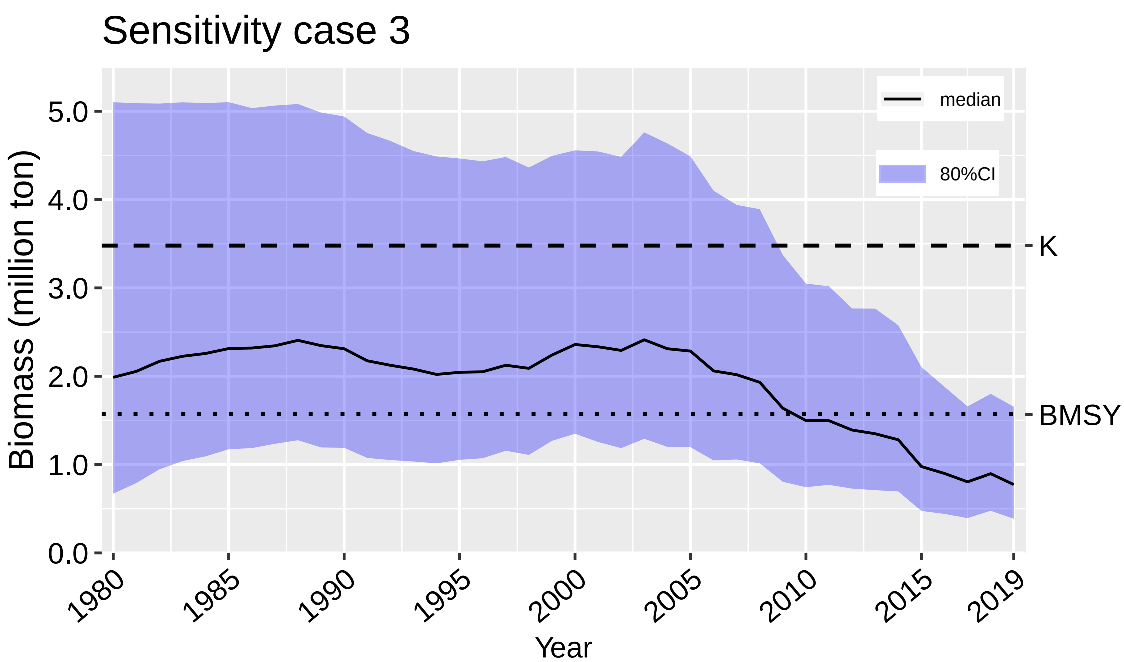
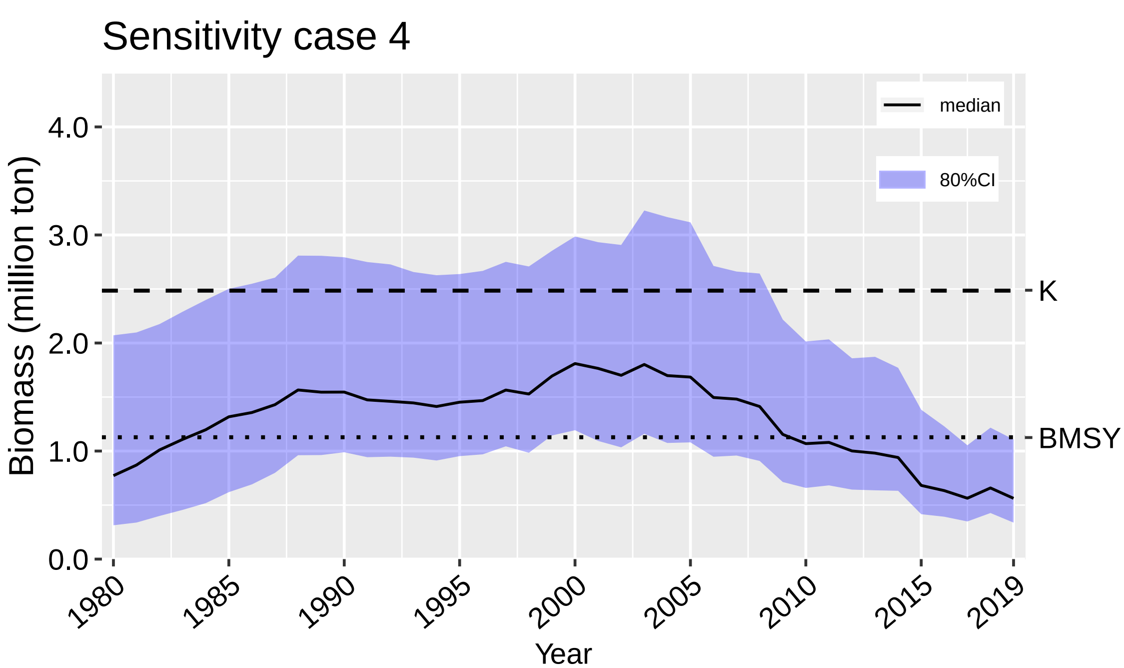
1985
1990
1995
2000
2005
2010
2015
2019
Year


Sensitivity case 3
Biomass (million ton)
0.0
1.0
2.0
3.0
4.0
5.0
1980
1985
1990
1995
2000
2005
2010
2015
2019
Year
median
80%CI
K
BMSY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Biomass (million ton)
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1985
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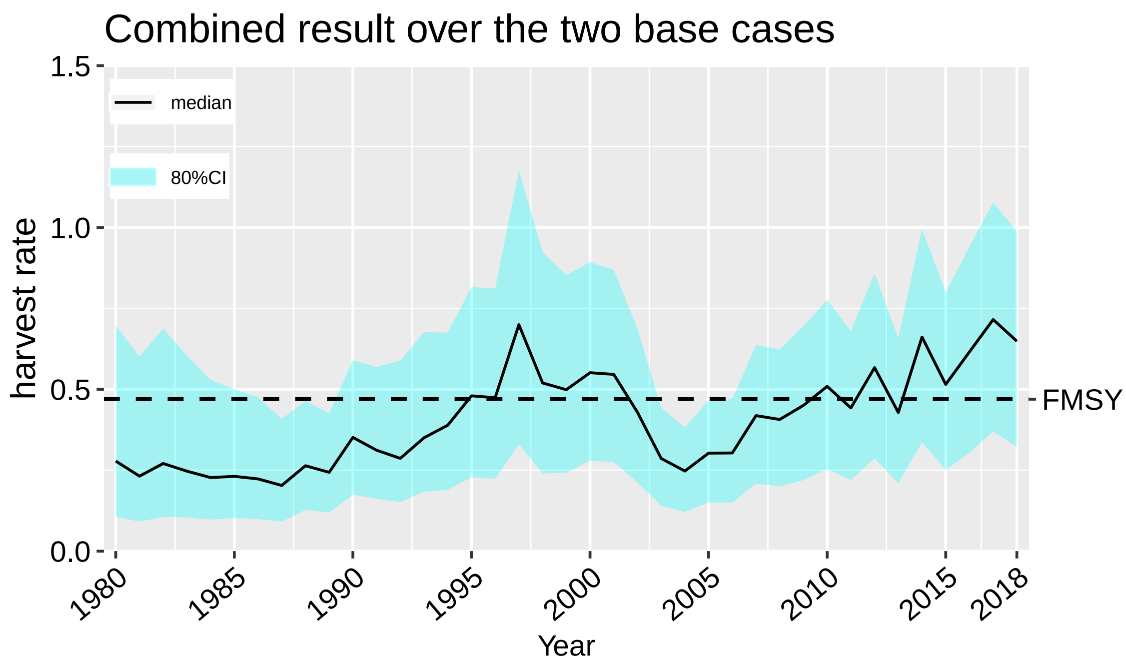
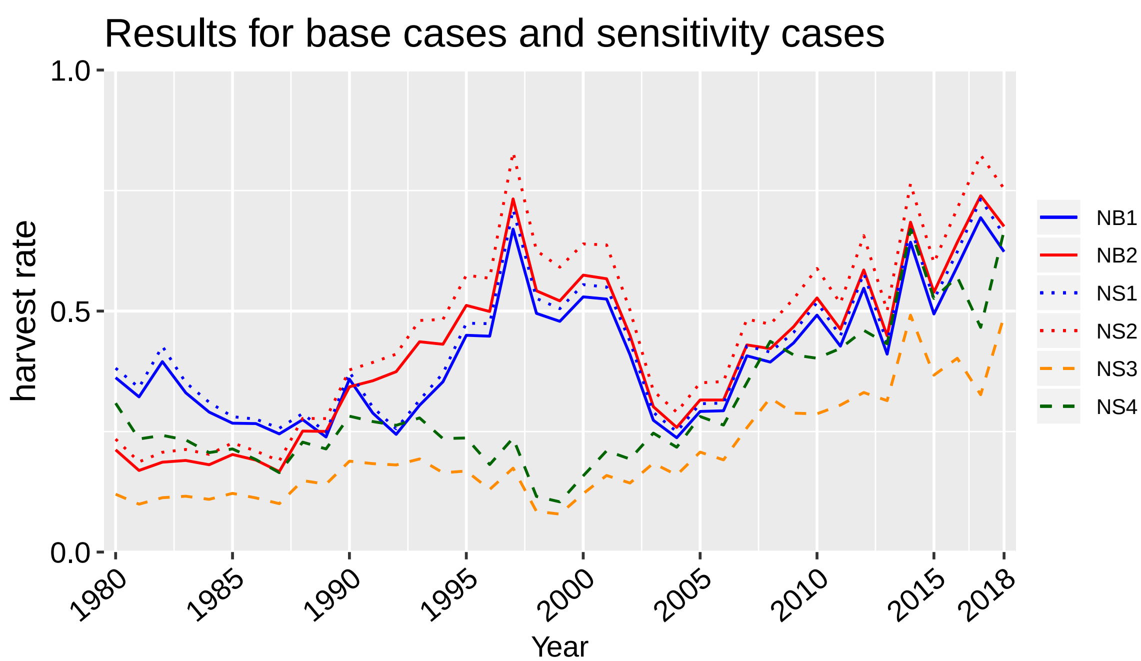
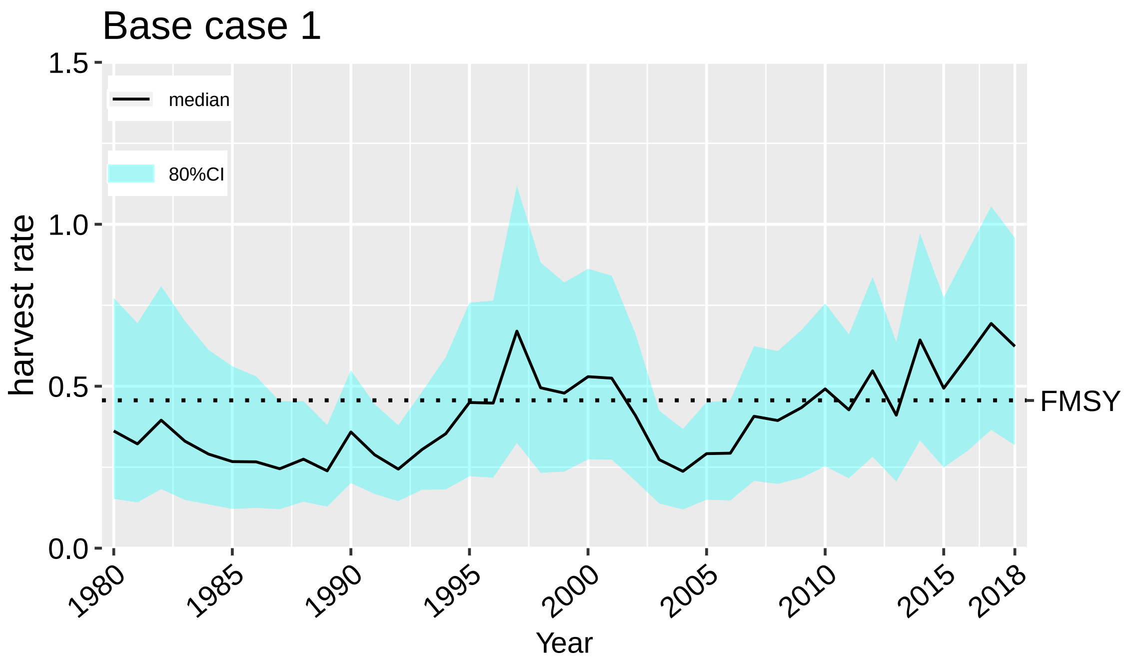
2010
2015
2019
Year
median
80%CI
K
BMSY

2.2 Time series Harvest rate






Base case 1
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80%CI
harvest rate
FMSY
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1.5
1980
1985
1990
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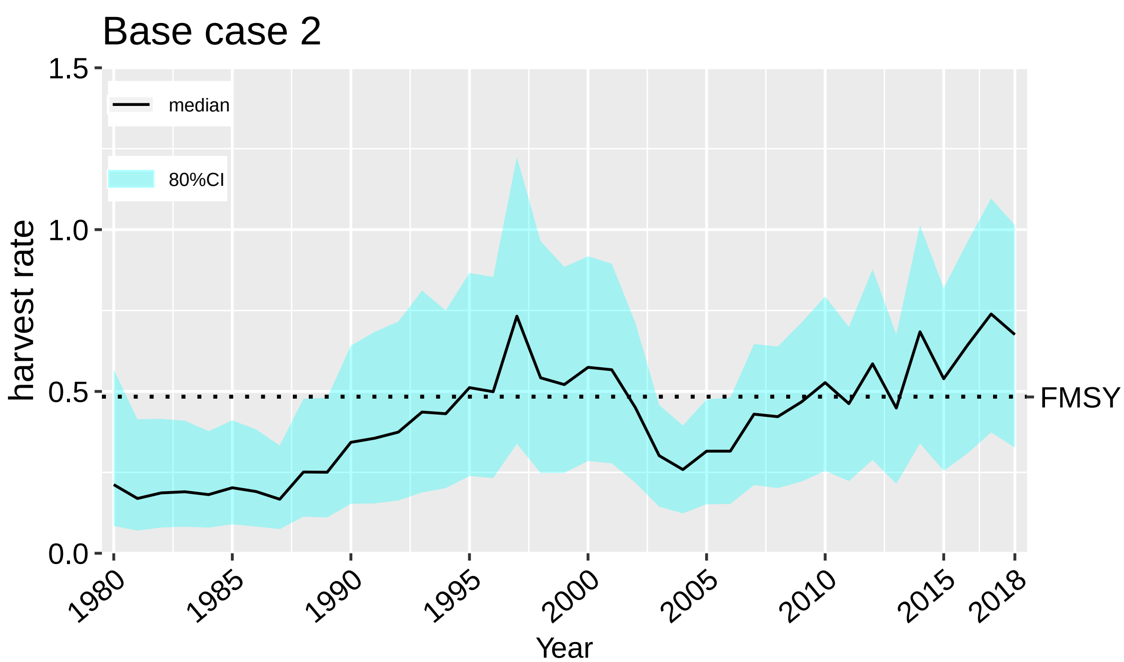
2000
2005
2010
2015
2018


Base case 2
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80%CI
harvest rate
FMSY
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1.5
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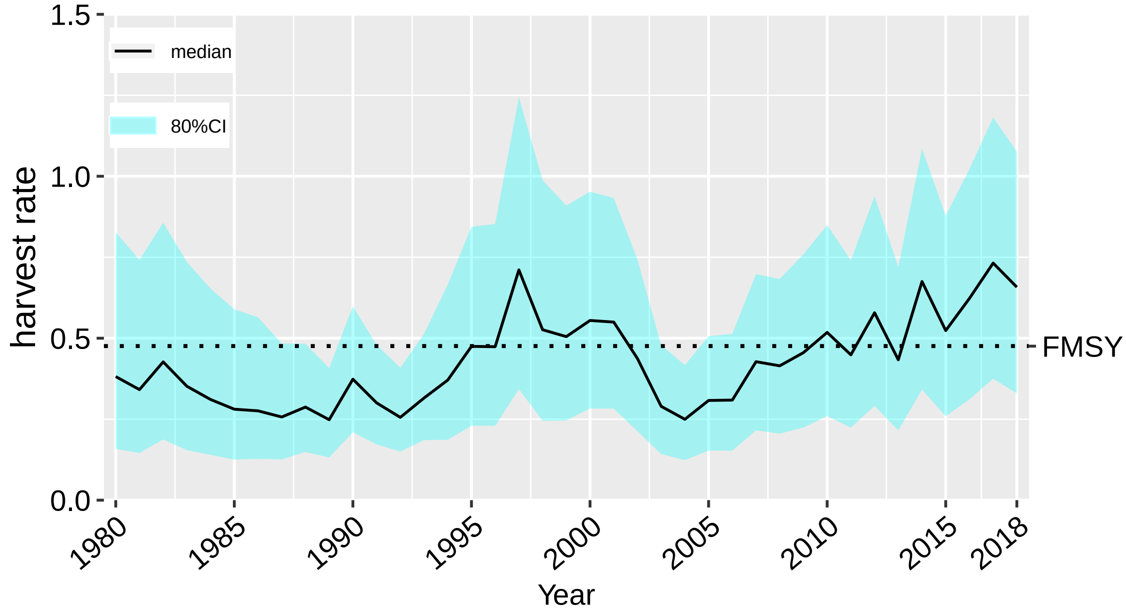
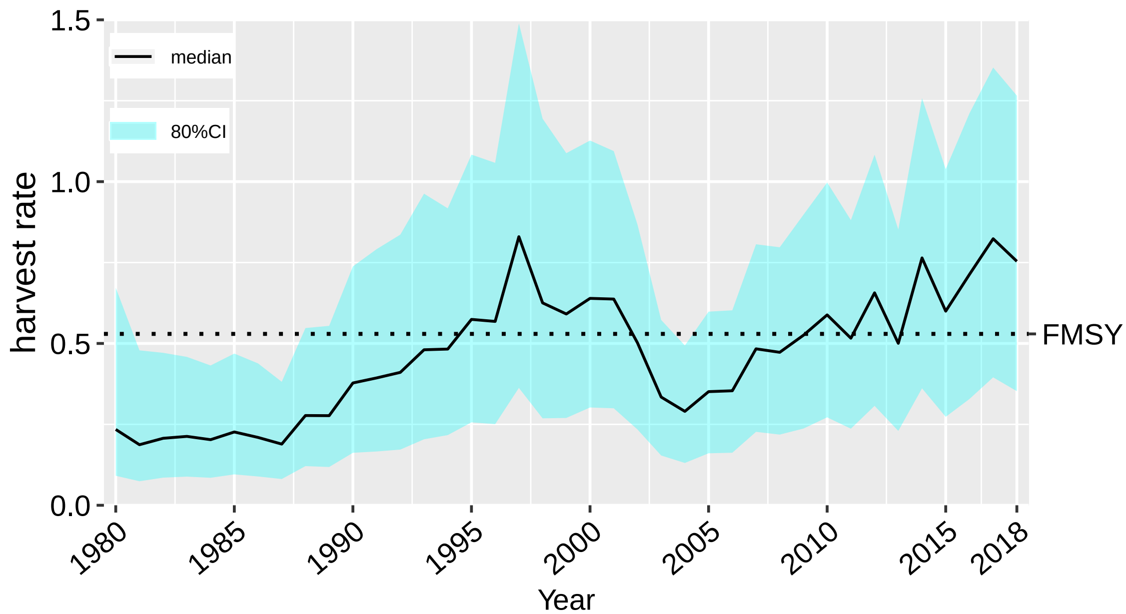
2010
2015
2018

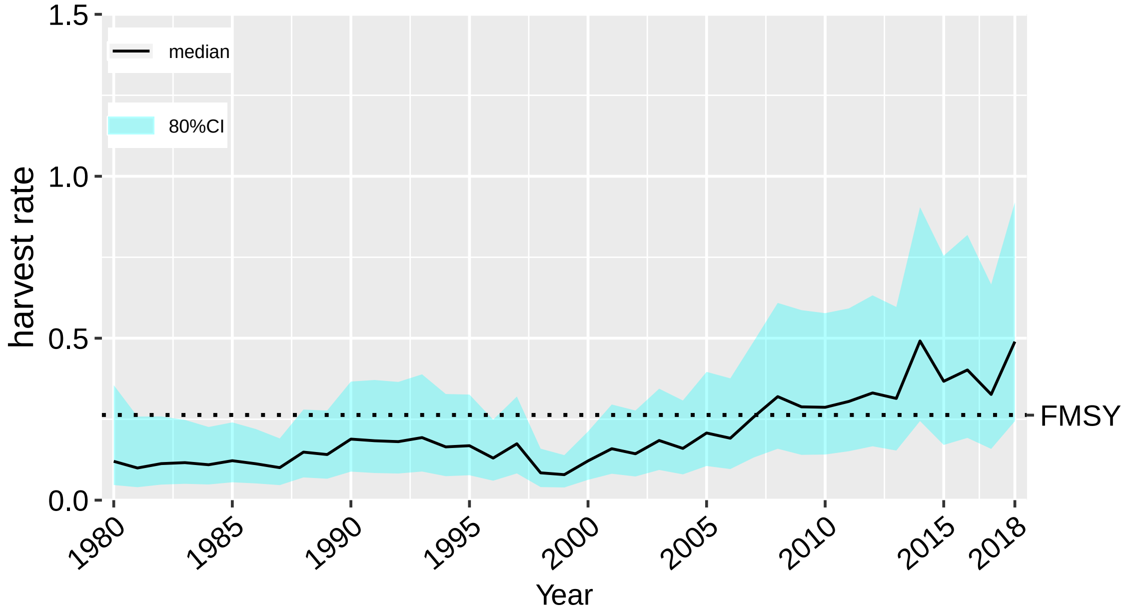
Sensitivity case 1



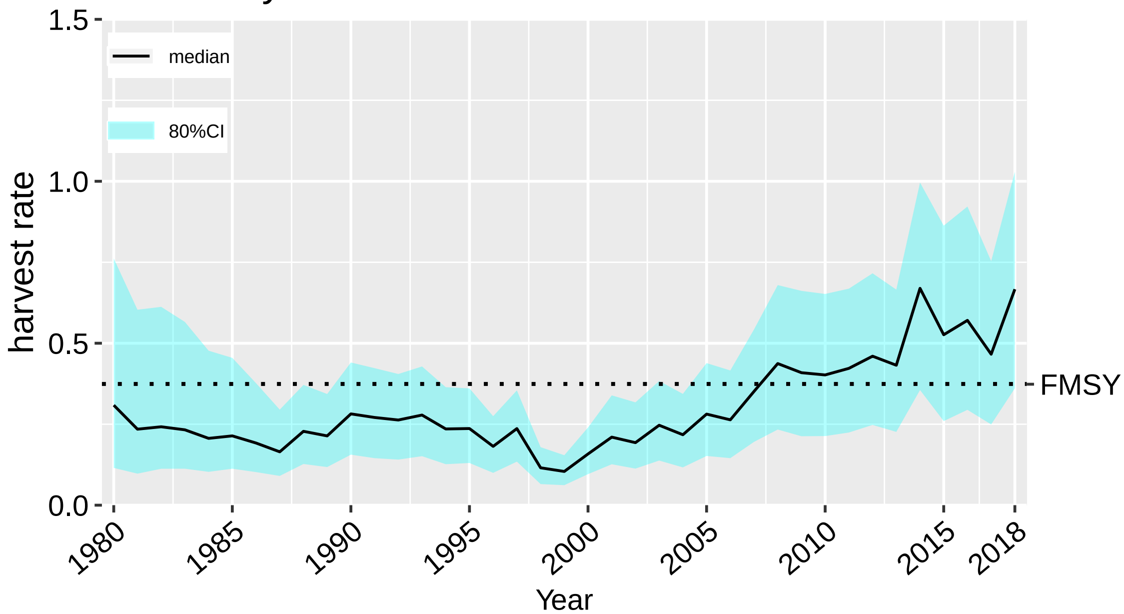
Base case 2



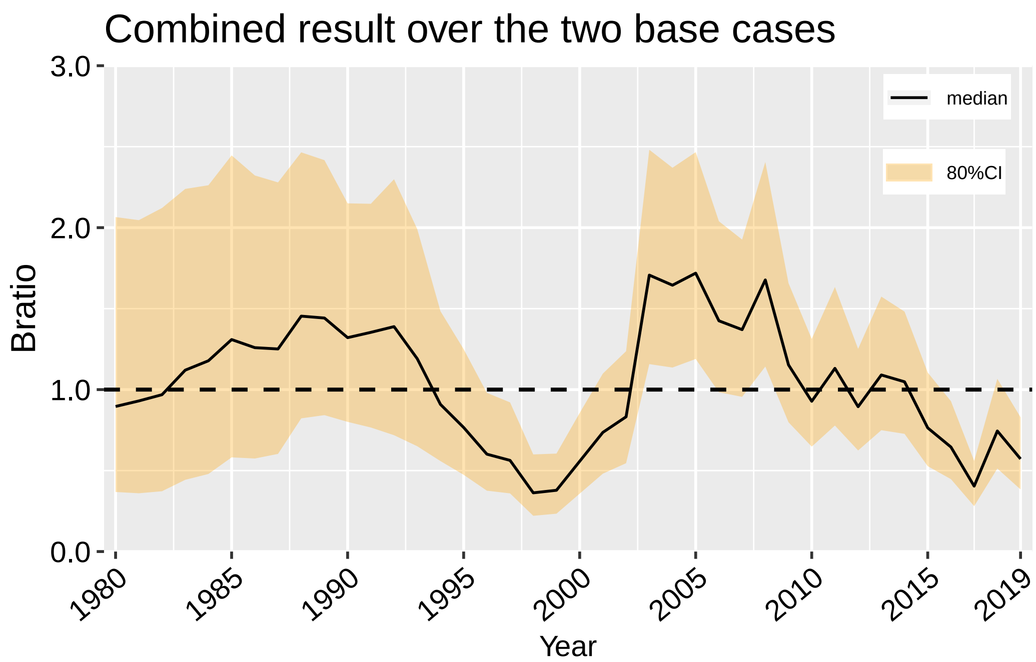
Sensitivity case 3

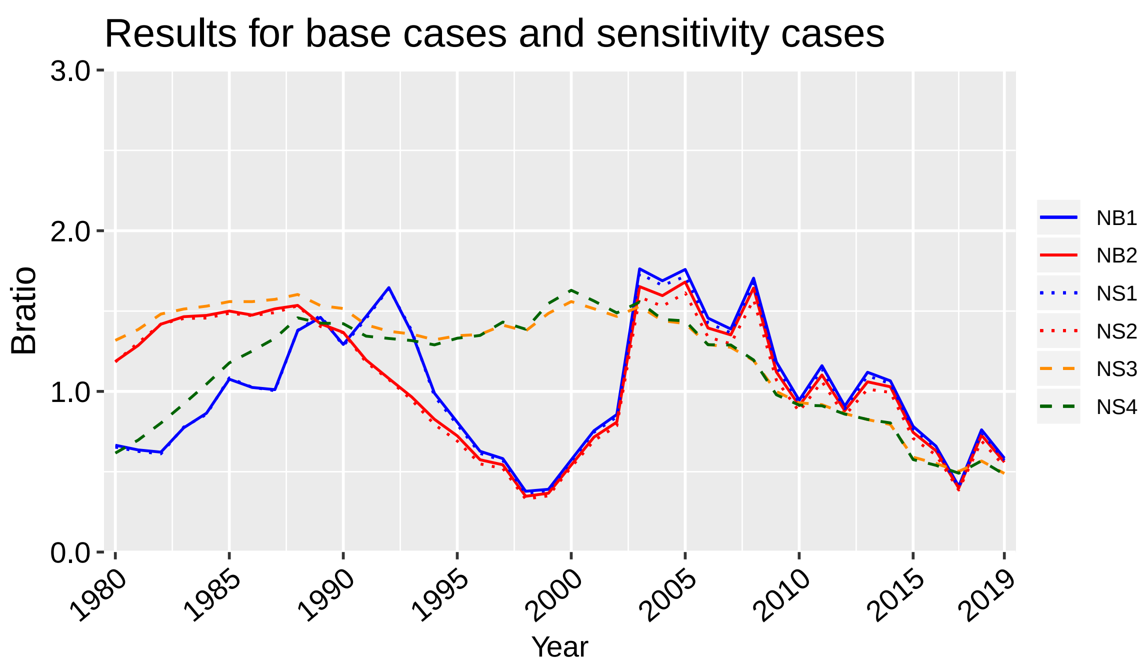


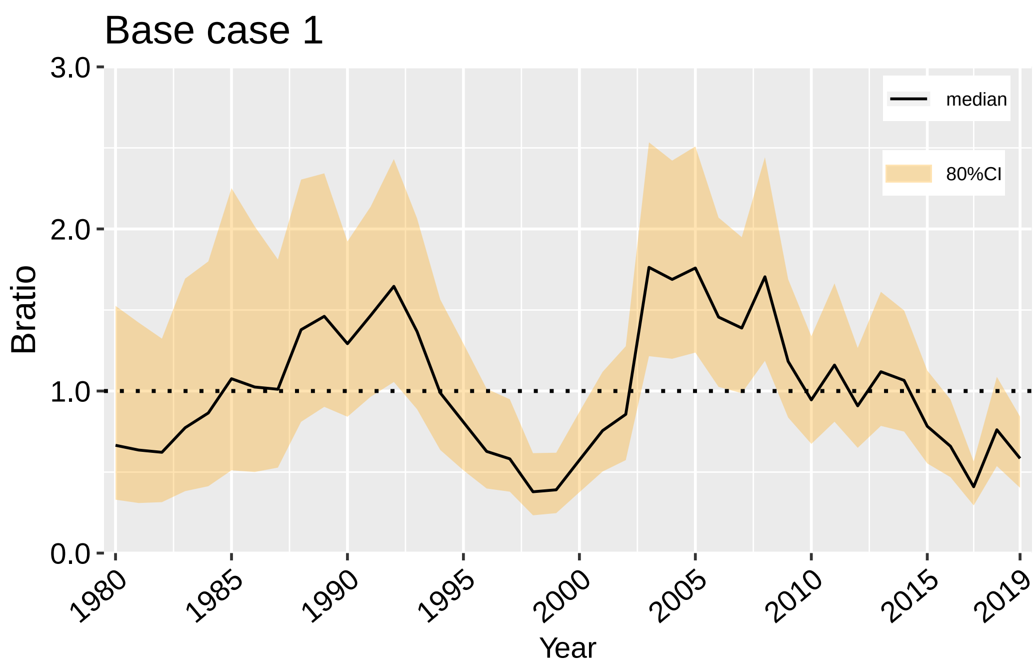
Sensitivity case 4

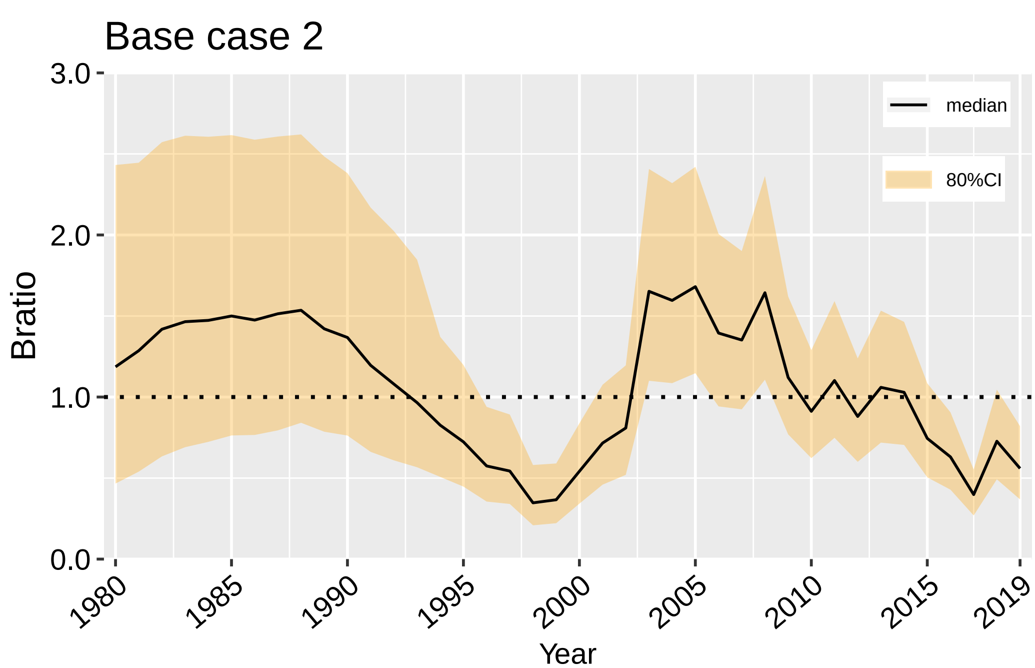


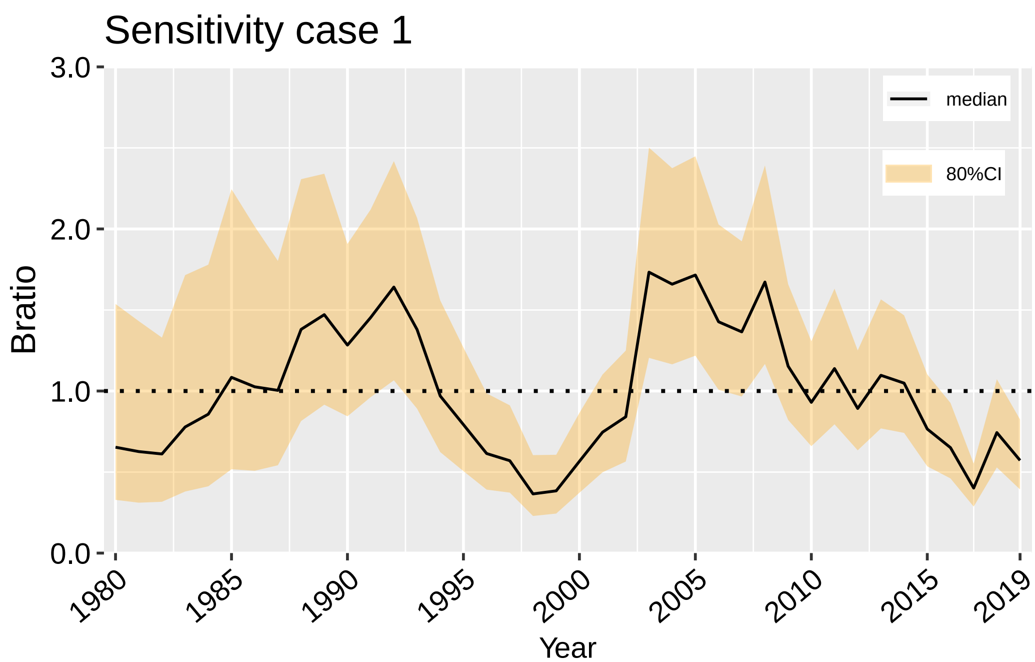
2.3 Time series Bratio

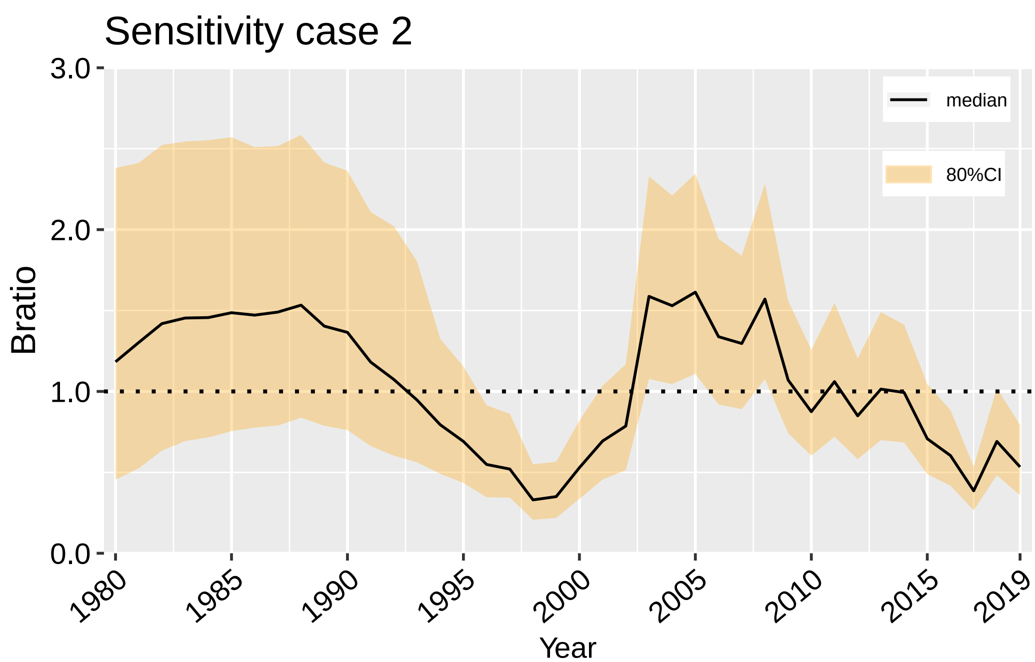


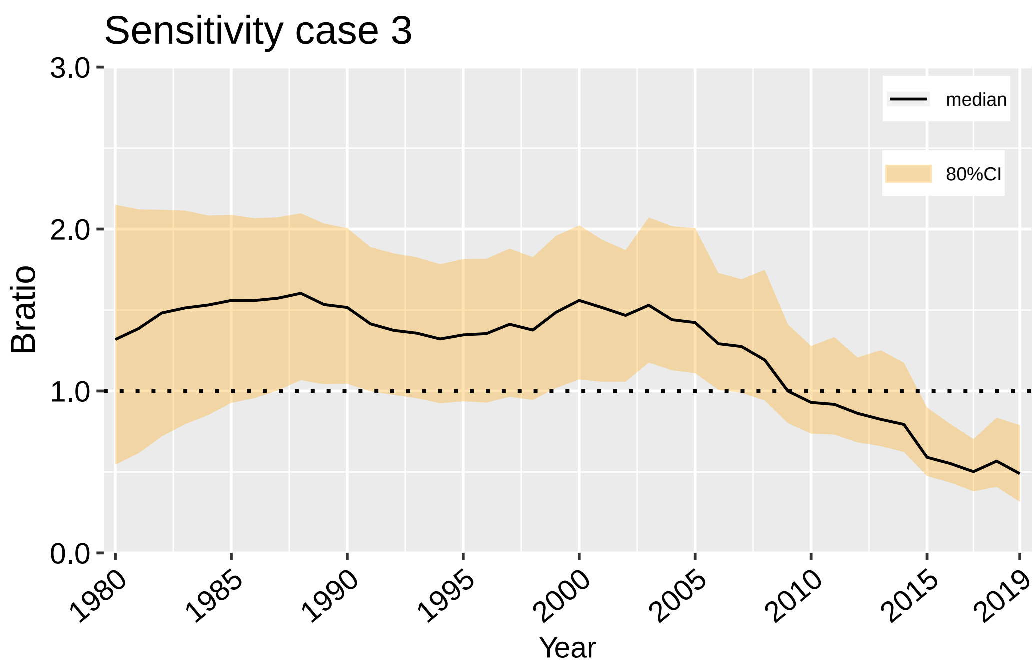


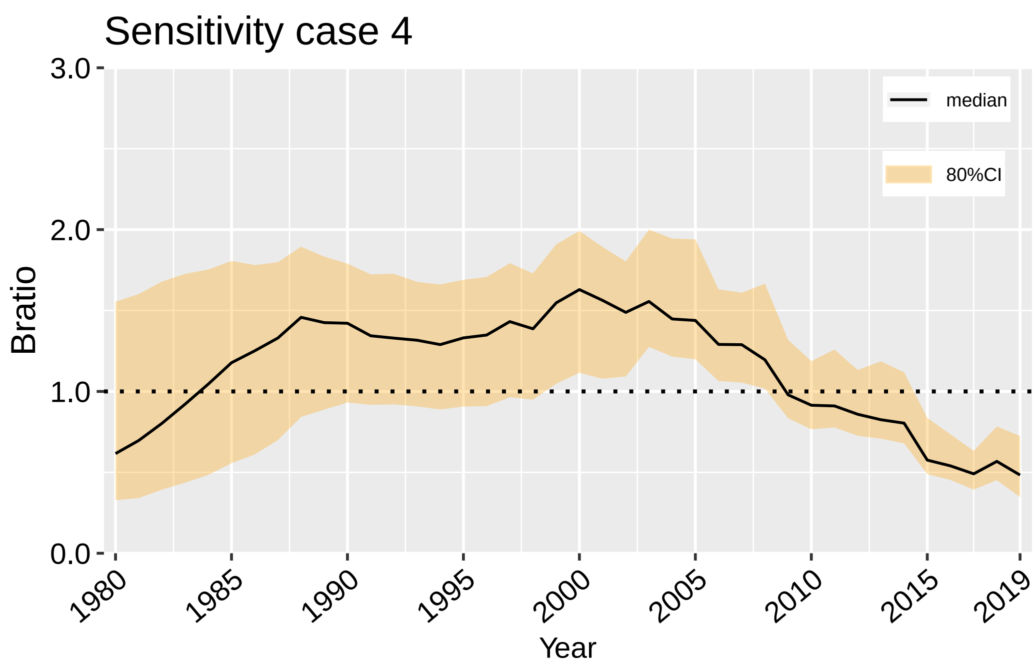

Base case 1
3.0
2.0
1.0
0.0
Bratio
median
80%CI
1980
1985
1990
1995
2000
2005
2010
2015
2019
Year


Base case 2
3.0
2.0
1.0
0.0
Bratio
median
80%CI
1980
1985
1990
1995
2000
2005
2010
2015
2019
Year

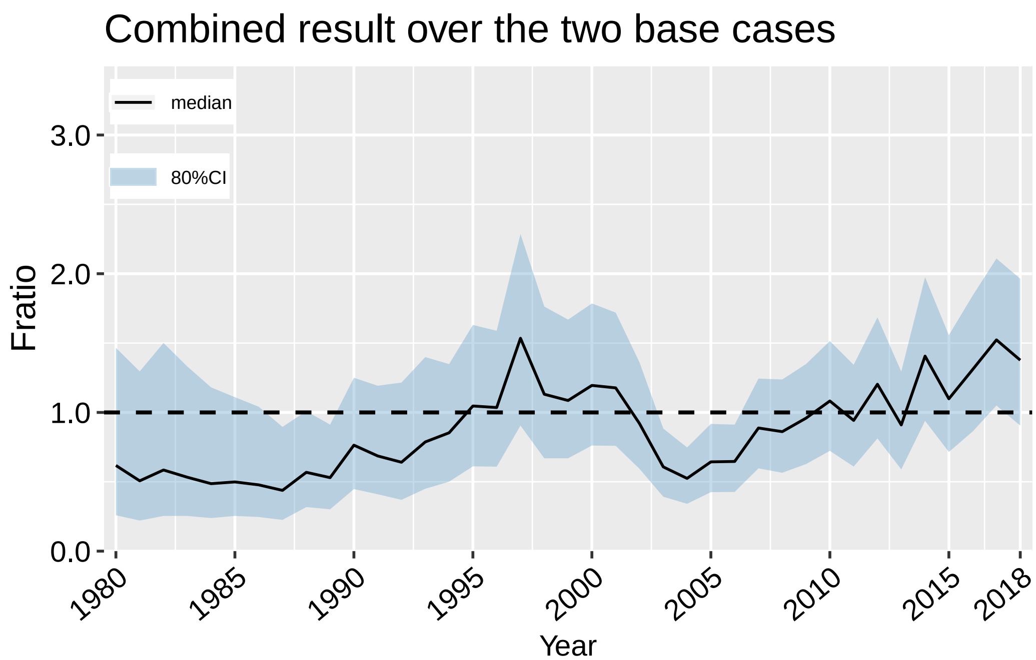

Sensitivity case 1
Bratio
Year
median
80%CI

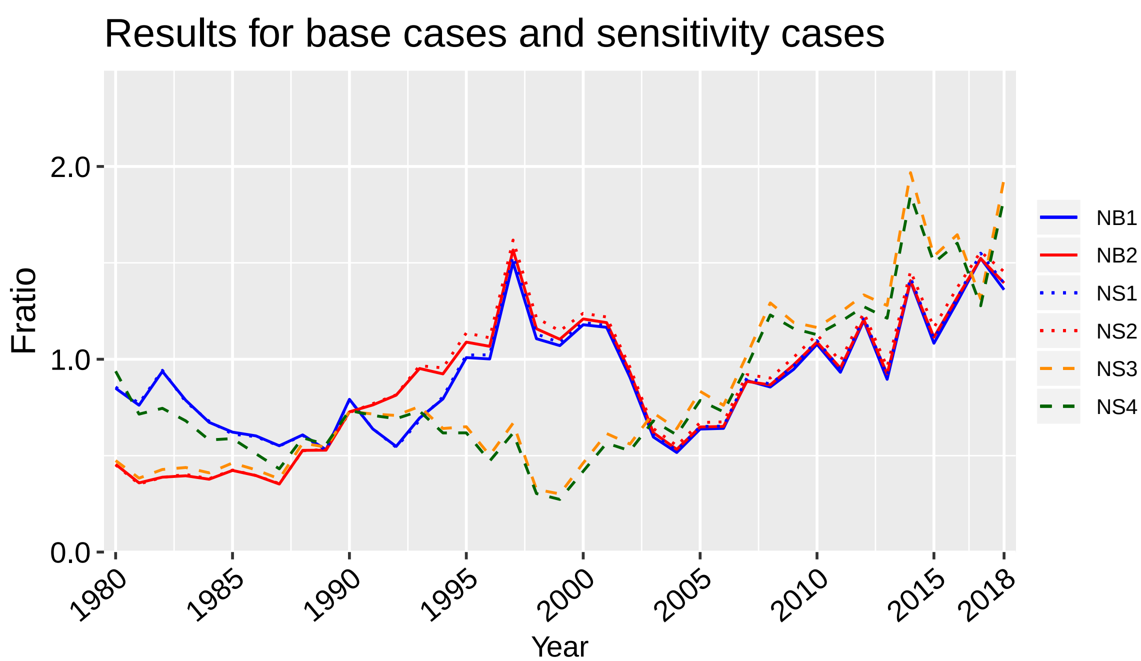

Sensitivity case 2
Bratio
Year
median
80%CI

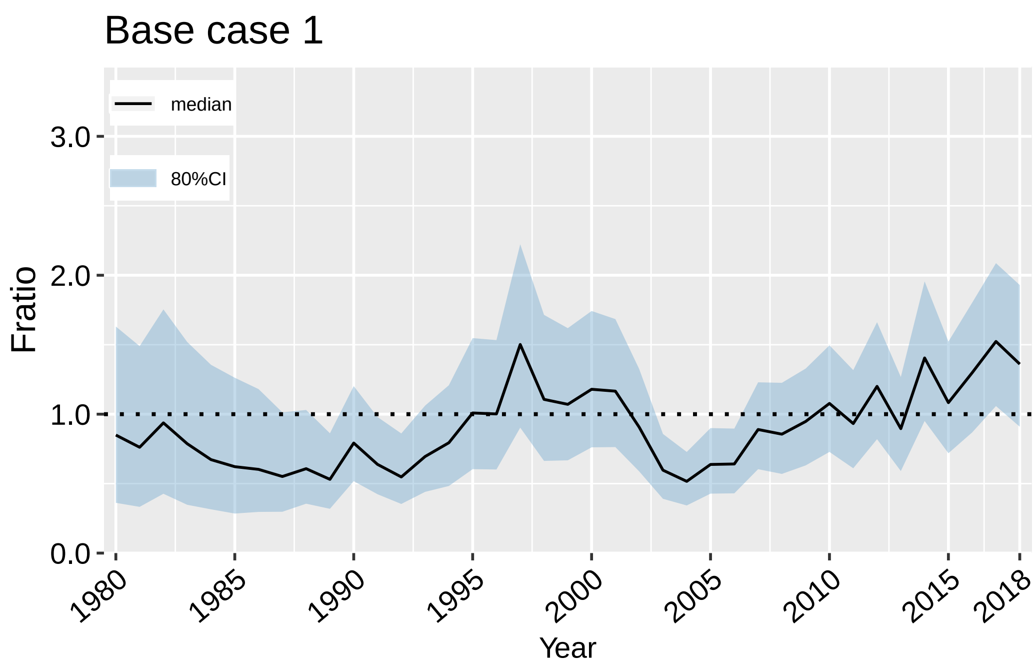

Sensitivity case 3
3.0
2.0
1.0
0.0
Bratio
median
80%CI
1980
1985
1990
1995
2000
2005
2010
2015
2019
Year

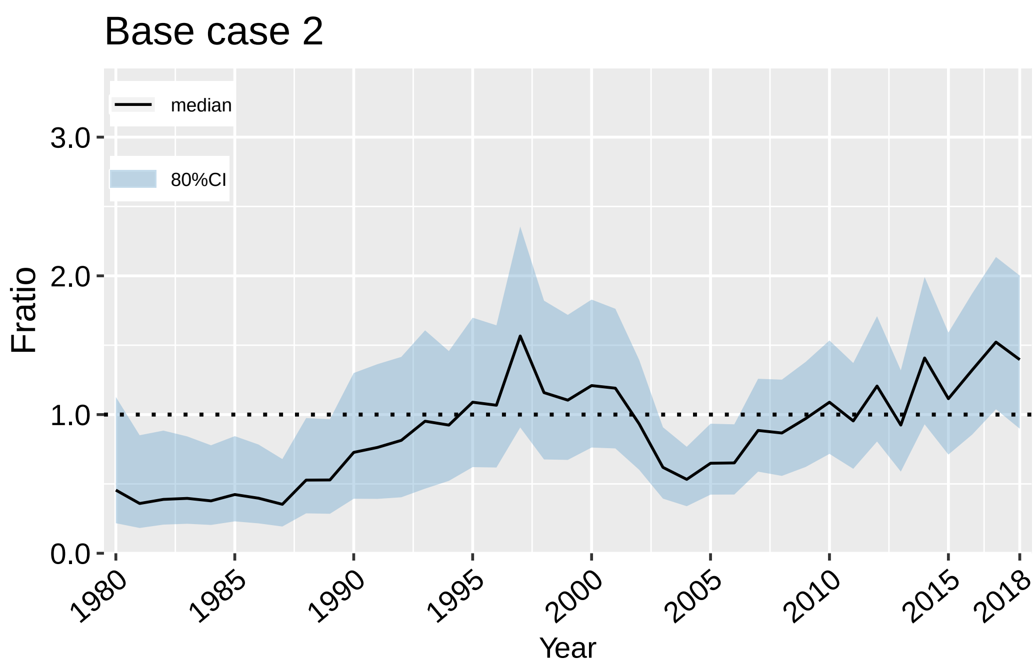

Sensitivity case 4
3.0
2.0
1.0
0.0
Bratio
median
80%CI
1980
1985
1990
1995
2000
2005
2010
2015
2019
Year

2.4 Time series Fratio

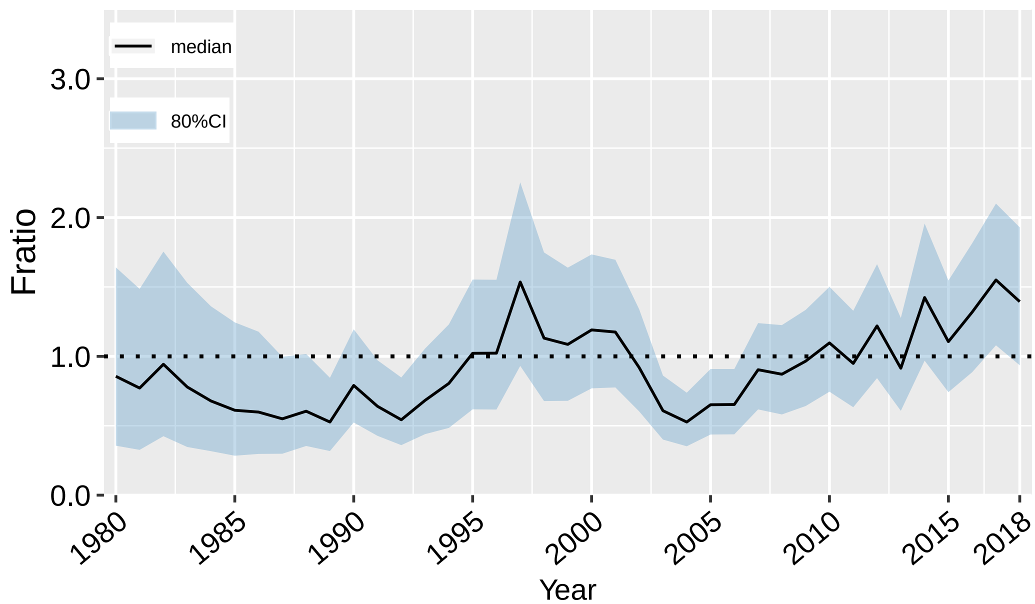




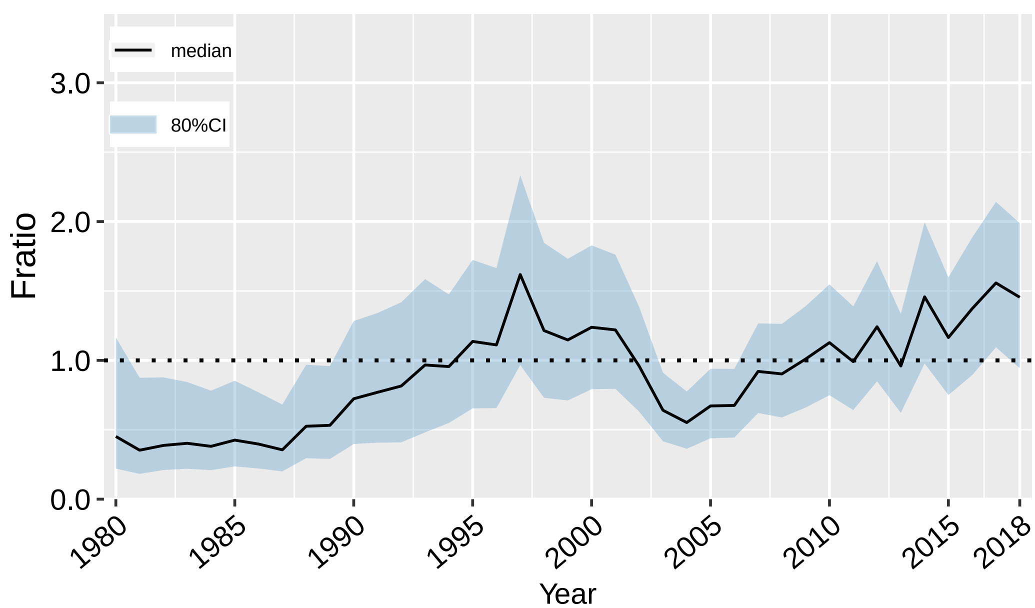

Base case 1
median
80%CI
Fratio
3.0
2.0
1.0
0.0
1980
1985
1990
1995
2000
2005
2010
2015
2018
Year

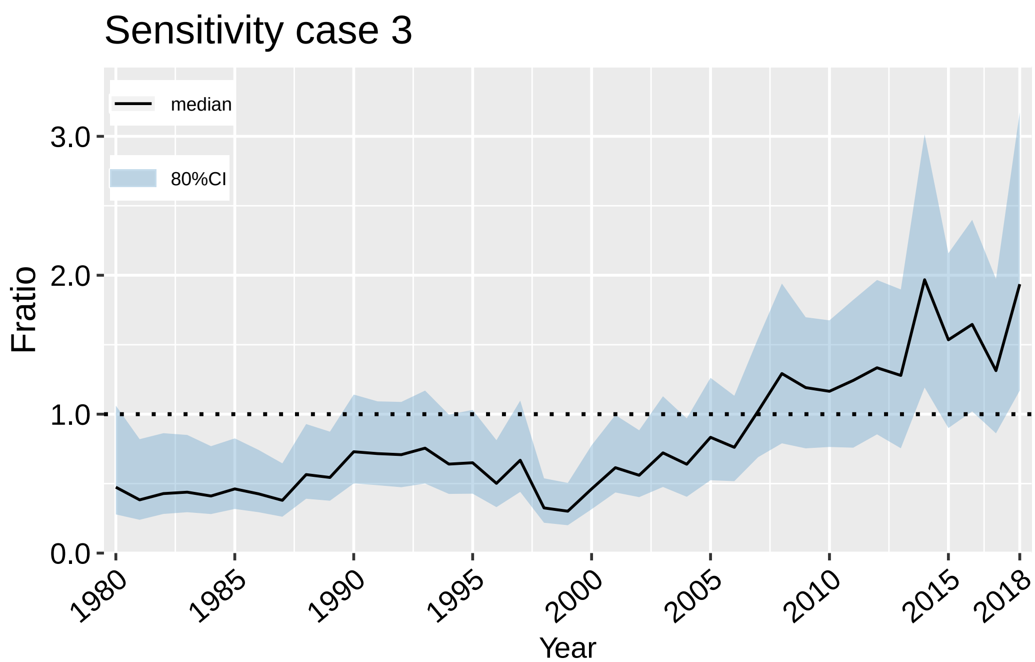

Base case 2
median
80%CI
Fratio
3.0
2.0
1.0
0.0
1980
1985
1990
1995
2000
2005
2010
2015
2018
Year

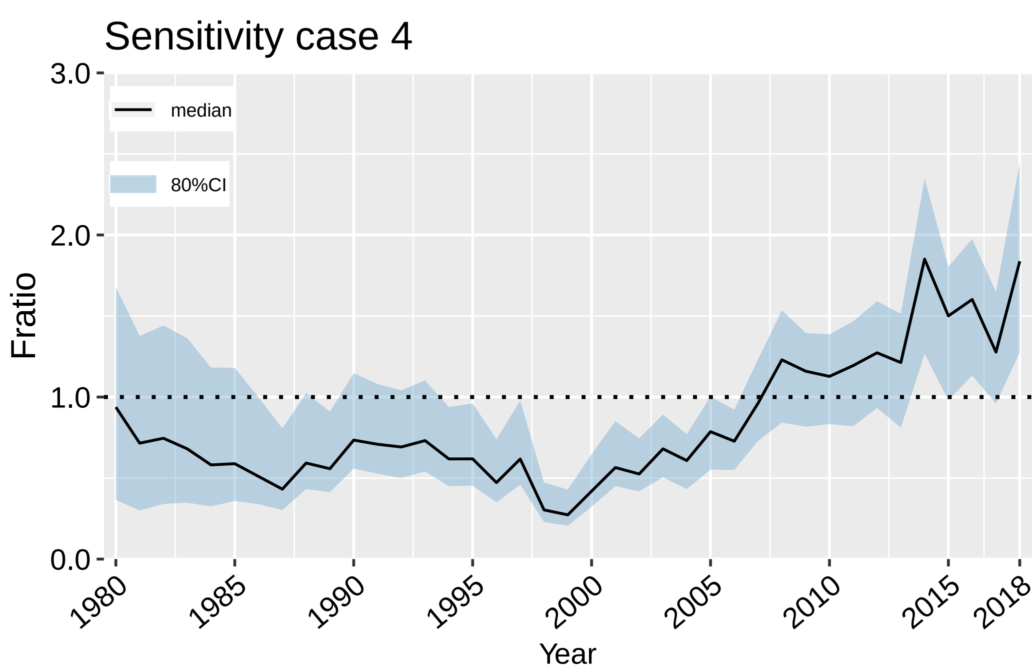
Sensitivity case 1



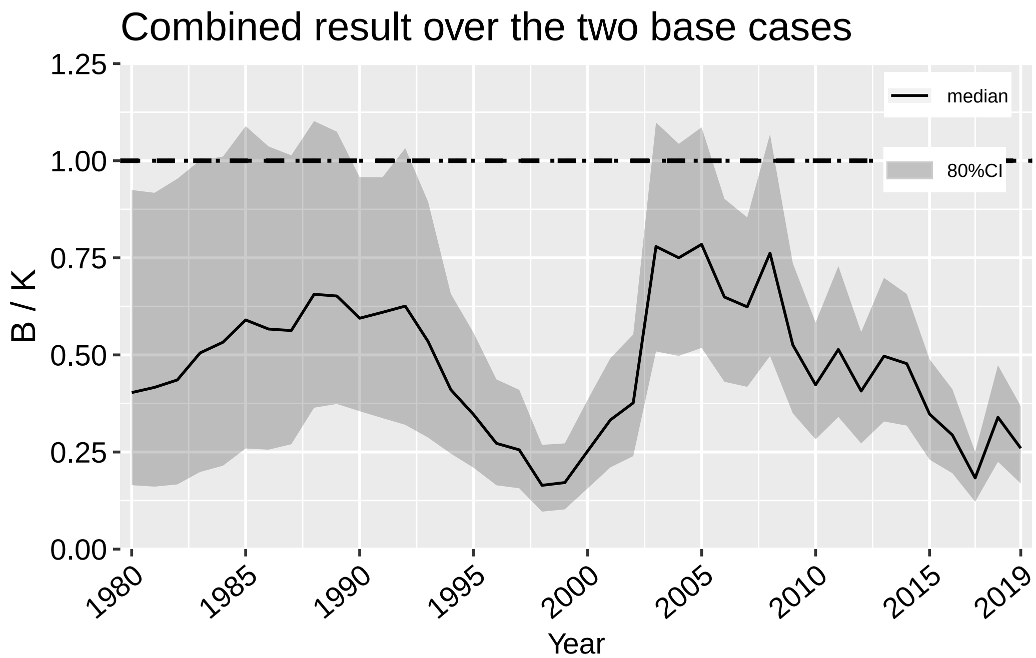
Sensitivity case 2

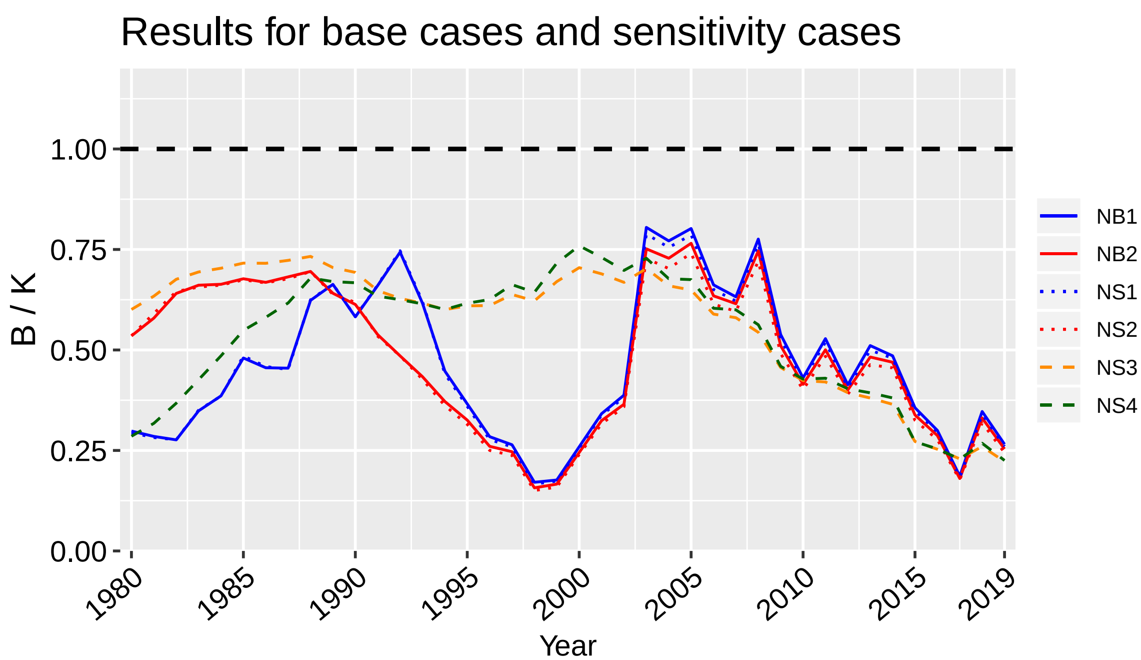


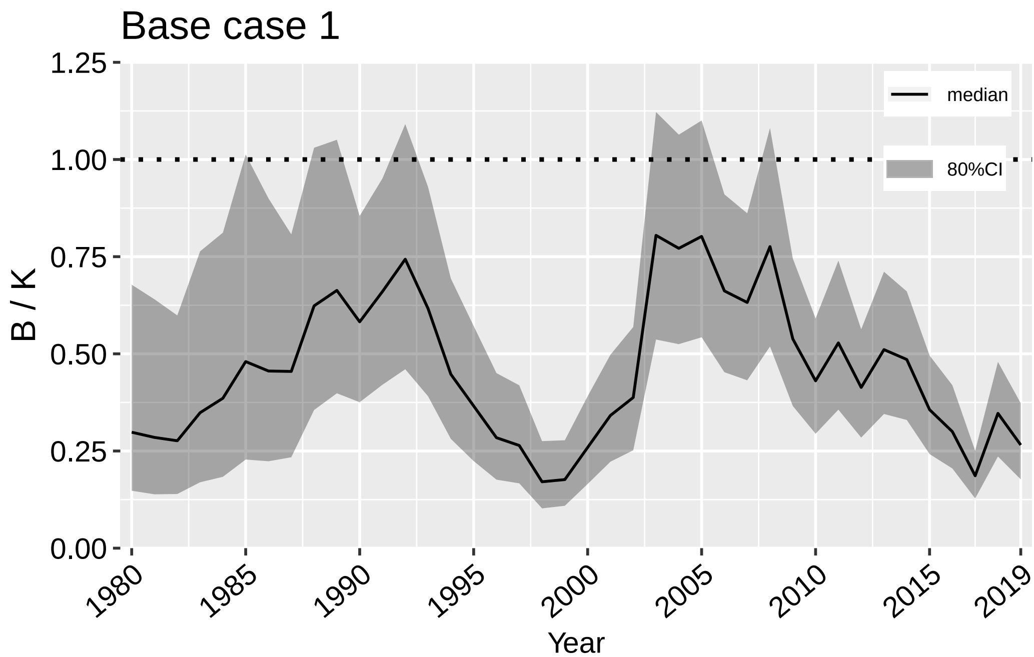

Sensitivity case 3
median
80%CI
3.0
2.0
1.0
0.0
Fratio
1980
1985
1990
1995
2000
2005
2010
2015
2018
Year

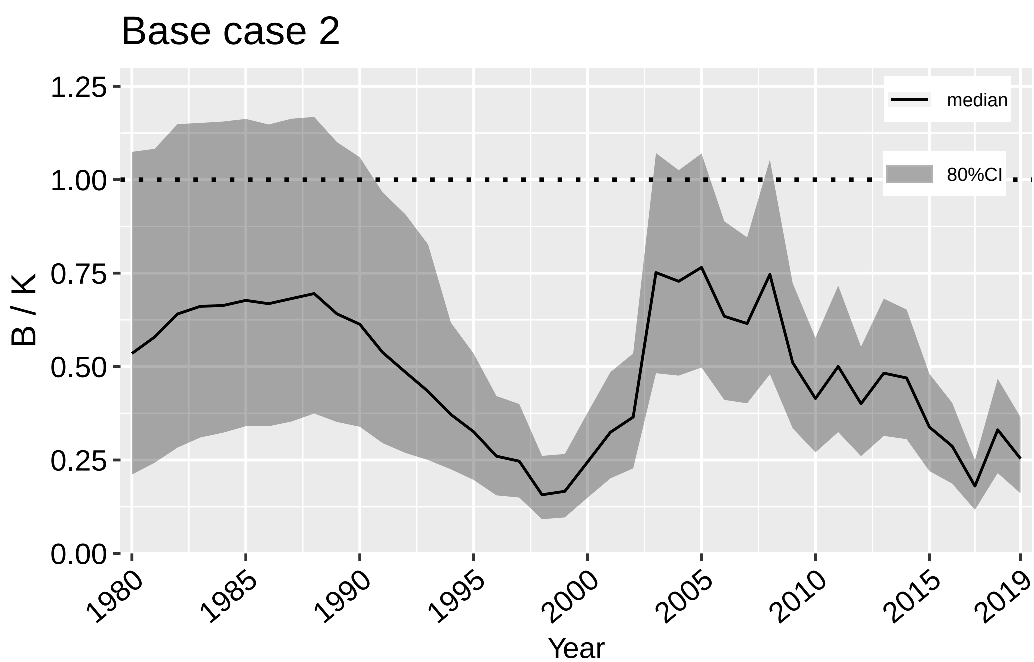

Sensitivity case 4
median
80%CI
3.0
2.0
1.0
0.0
Fratio
1980
1985
1990
1995
2000
2005
2010
2015
2018
Year

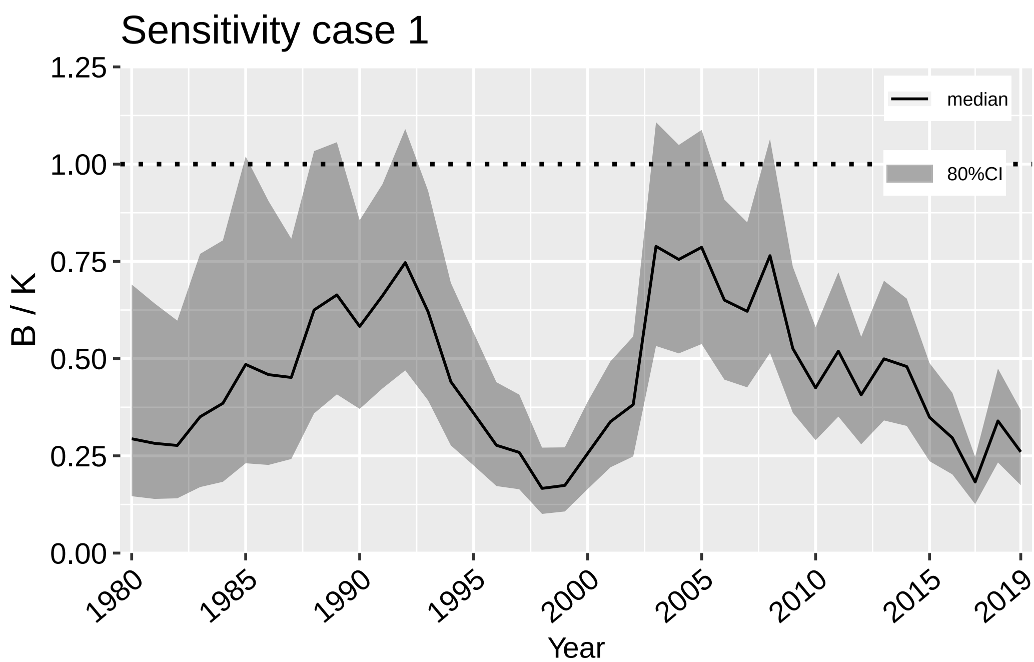
2.5 Time series B/K



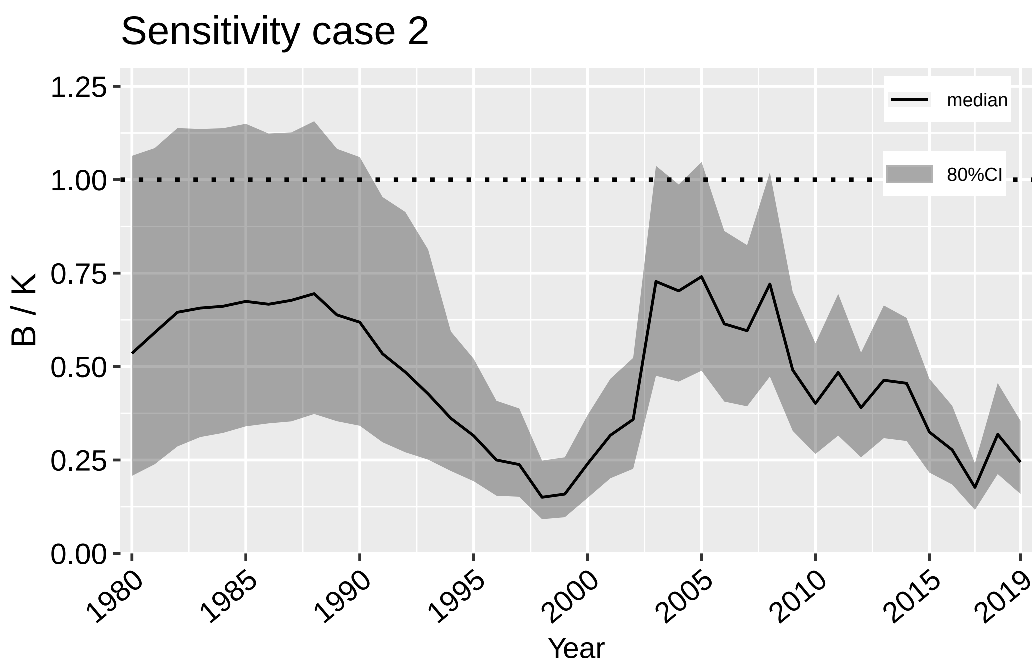



Base case 1
B / K
Year
median
80%CI
1.25
1.00
0.75
0.50
0.25
0.00
1980
1985
1990
1995
2000
2005
2010
2015
2019

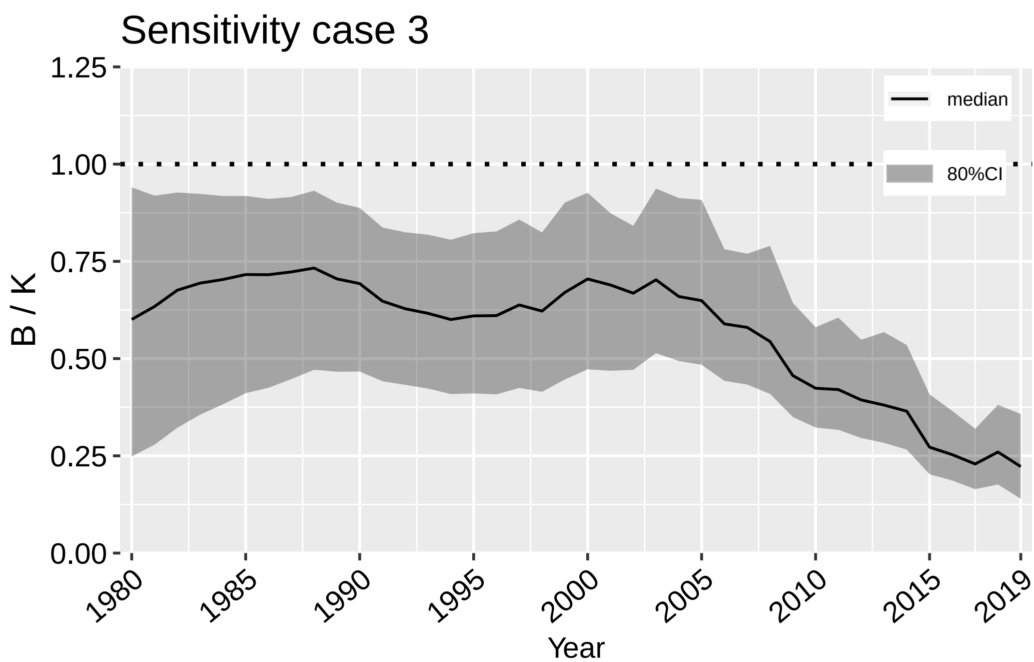

Base case 2
B / K
Year
median
80%CI
1.25
1.00
0.75
0.50
0.25
0.00
1980
1985
1990
1995
2000
2005
2010
2015
2019

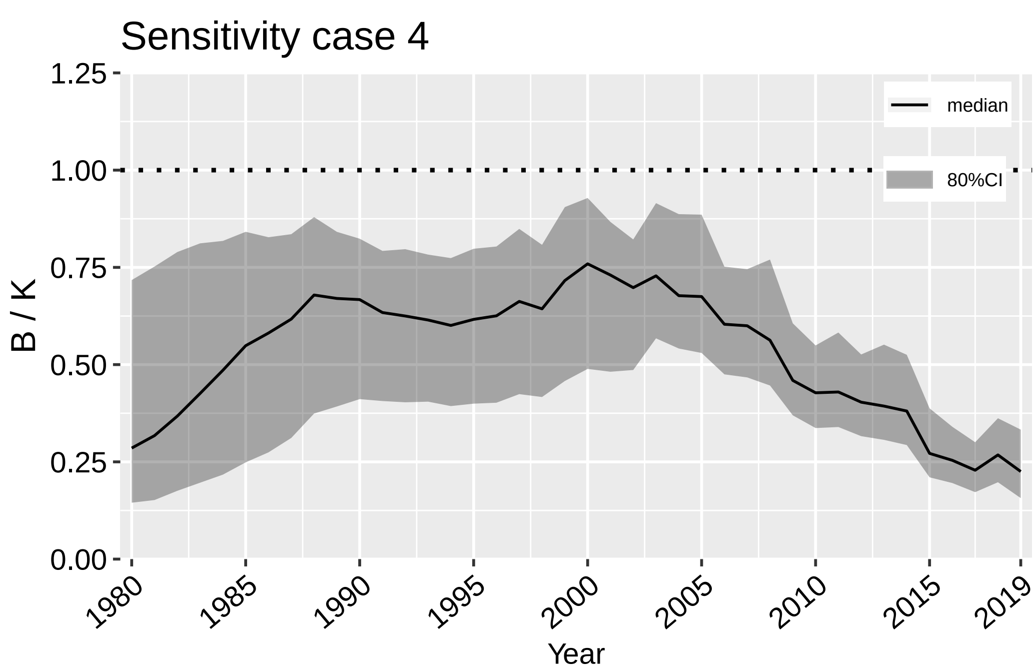


Sensitivity case 1
1.25
1.00
0.75
0.50
0.25
0.00
B / K
median
80%CI
1980
1985
1990
1995
2000
2005
2010
2015
2019
Year

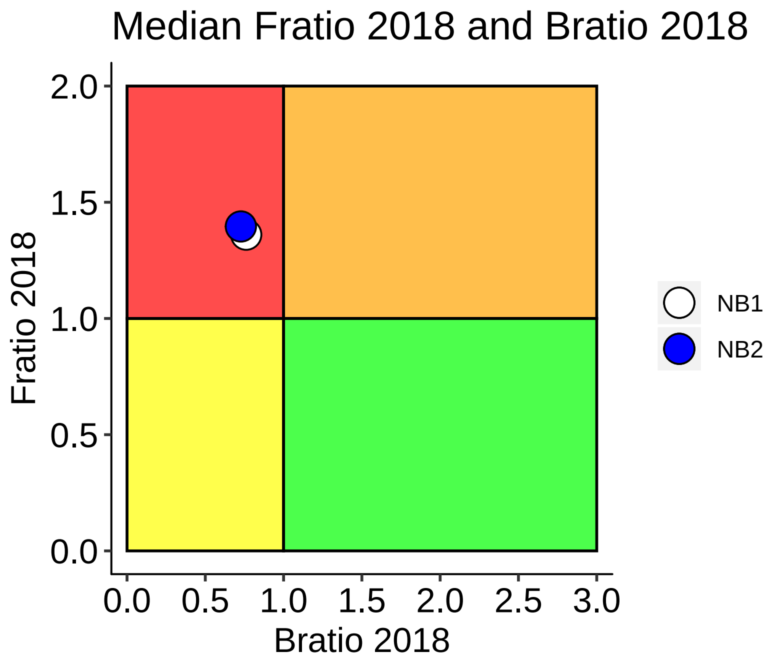


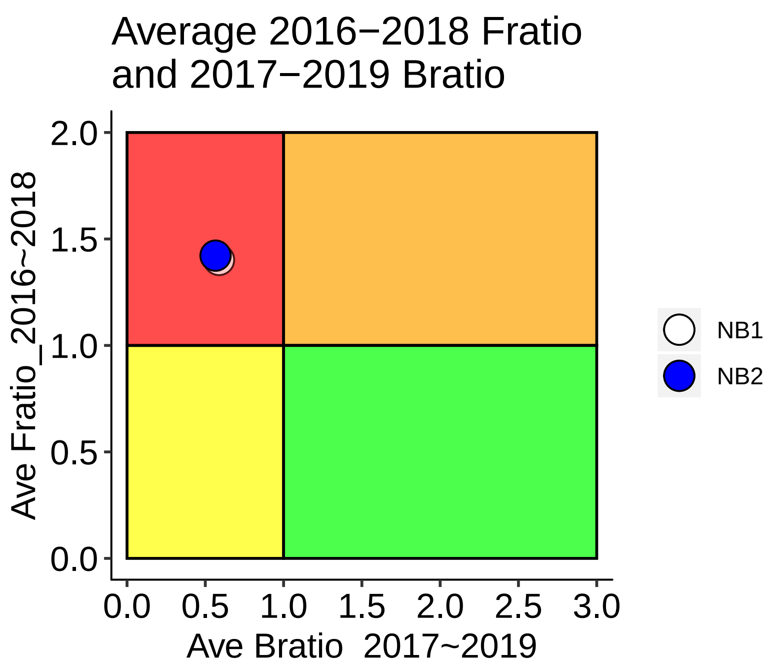
Sensitivity case 2
1.25
1.00
0.75
0.50
0.25
0.00
B / K
median
80%CI
1980
1985
1990
1995
2000
2005
2010
2015
2019
Year


Sensitivity case 3
1.25
1.00
0.75
0.50
0.25
0.00
B / K
median
80%CI
1980
1985
1990
1995
2000
2005
2010
2015
2019
Year

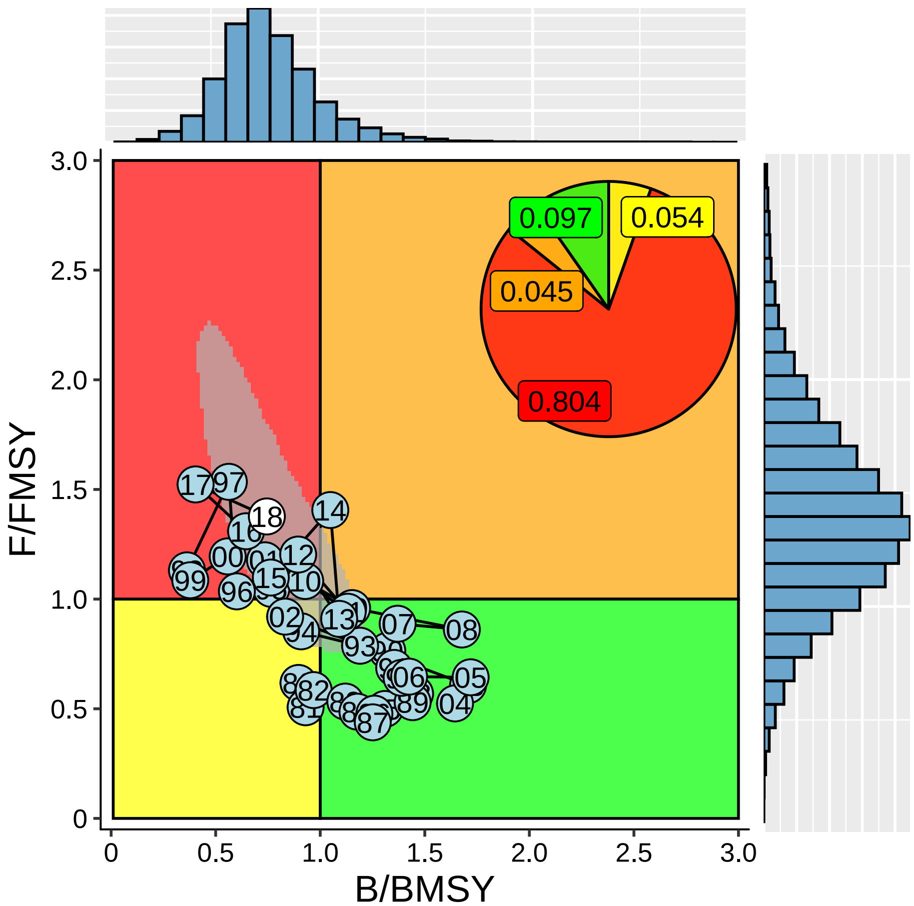

Sensitivity case 4
1.25
1.00
0.75
0.50
0.25
0.00
B / K
median
80%CI
1980
1985
1990
1995
2000
2005
2010
2015
2019
Year

3 Kobe plot


Median Fratio 2018 and Bratio 2018
Fratio 2018
2.0
1.5
1.0
0.5
0.0
0.0 0.5 1.0 1.5 2.0 2.5 3.0
Bratio 2018
NB1
NB2


Average 2016−2018 Fratio
and 2017−2019 Bratio
Ave Fratio_2016~2018
2.0
1.5
1.0
0.5
0.0
0.0 0.5 1.0 1.5 2.0 2.5 3.0
Ave Bratio_2017~2019
NB1
NB2

1980−2018 time series of median Fratio and Bratio over 2 models



4 Summary of reference points

Over 2 new base case models

	Mean	Median	Lower10th	Upper10th
C_2018	0.439	0.439	0.439	0.439
AveC_2016_2018	0.354	0.354	0.354	0.354
AveF_2016_2018	0.665	0.664	0.336	0.992
F_2018	0.653	0.649	0.322	0.988
FMSY	0.473	0.470	0.269	0.679
MSY (million ton)	0.448	0.435	0.359	0.548
F_2018/FMSY	1.419	1.377	0.905	1.964
AveF_2016_2018/FMSY	1.443	1.412	0.960	1.935
K (million ton)	2.436	2.070	1.398	3.921
B_2018 (million ton)	0.819	0.677	0.444	1.362
B_2019 (million ton)	0.631	0.521	0.334	1.059
AveB_2017_2019	0.650	0.539	0.359	1.073
BMSY (million ton)	1.080	0.924	0.642	1.693
BMSY/K	0.449	0.439	0.401	0.516
B_2018/K	0.346	0.339	0.225	0.473
B_2019/K	0.266	0.260	0.169	0.368
AveB_2017_2019/K	0.275	0.271	0.183	0.368
B_2018/BMSY	0.775	0.745	0.513	1.066
B_2019/BMSY	0.595	0.572	0.384	0.829
AveB_2017_2019/BMSY	0.614	0.594	0.419	0.832

Base case 1

	Mean	Median	Lower10th	Upper10th
C_2018	0.439	0.439	0.439	0.439
AveC_2016_2018	0.354	0.354	0.354	0.354
AveF_2016_2018	0.646	0.642	0.332	0.968
F_2018	0.632	0.623	0.318	0.958
FMSY	0.461	0.456	0.268	0.658
MSY (million ton)	0.439	0.429	0.354	0.529
F_2018/FMSY	1.401	1.361	0.910	1.930
AveF_2016_2018/FMSY	1.429	1.402	0.965	1.902
K (million ton)	2.426	2.076	1.424	3.853
B_2018 (million ton)	0.839	0.705	0.458	1.381
B_2019 (million ton)	0.645	0.540	0.342	1.071
AveB_2017_2019	0.665	0.559	0.368	1.088
BMSY (million ton)	1.076	0.929	0.653	1.659
BMSY/K	0.449	0.438	0.400	0.517
B_2018/K	0.354	0.347	0.236	0.479
B_2019/K	0.272	0.265	0.177	0.373
AveB_2017_2019/K	0.281	0.277	0.192	0.372
B_2018/BMSY	0.793	0.761	0.537	1.087
B_2019/BMSY	0.608	0.584	0.403	0.842
AveB_2017_2019/BMSY	0.628	0.606	0.438	0.846

Base case 2

	Mean	Median	Lower10th	Upper10th
C_2018	0.439	0.439	0.439	0.439
AveC_2016_2018	0.354	0.354	0.354	0.354
AveF_2016_2018	0.684	0.690	0.341	1.011
F_2018	0.673	0.676	0.326	1.014
FMSY	0.485	0.484	0.269	0.697
MSY (million ton)	0.458	0.441	0.364	0.566
F_2018/FMSY	1.437	1.396	0.898	2.002
AveF_2016_2018/FMSY	1.457	1.422	0.954	1.962
K (million ton)	2.446	2.060	1.374	4.000
B_2018 (million ton)	0.799	0.650	0.433	1.345
B_2019 (million ton)	0.617	0.502	0.326	1.042
AveB_2017_2019	0.635	0.518	0.352	1.061
BMSY (million ton)	1.085	0.917	0.631	1.730
BMSY/K	0.449	0.439	0.402	0.515
B_2018/K	0.338	0.331	0.215	0.467
B_2019/K	0.261	0.254	0.161	0.365
AveB_2017_2019/K	0.269	0.265	0.174	0.364
B_2018/BMSY	0.756	0.727	0.492	1.046
B_2019/BMSY	0.582	0.560	0.368	0.820
AveB_2017_2019/BMSY	0.600	0.583	0.402	0.815

Sensitivity case 1

	Mean	Median	Lower10th	Upper10th
C_2018	0.439	0.439	0.439	0.439
AveC_2016_2018	0.354	0.354	0.354	0.354
AveF_2016_2018	0.700	0.676	0.344	1.087
F_2018	0.686	0.658	0.330	1.076
FMSY	0.489	0.476	0.273	0.720
MSY (million ton)	0.440	0.429	0.358	0.529
F_2018/FMSY	1.423	1.394	0.935	1.929
AveF_2016_2018/FMSY	1.451	1.428	0.990	1.911
K (million ton)	2.331	1.988	1.318	3.709
B_2018 (million ton)	0.794	0.668	0.408	1.332
B_2019 (million ton)	0.611	0.511	0.305	1.037
AveB_2017_2019	0.630	0.532	0.329	1.050
BMSY (million ton)	1.036	0.891	0.606	1.612
BMSY/K	0.451	0.440	0.402	0.518
B_2018/K	0.348	0.340	0.233	0.474
B_2019/K	0.267	0.260	0.175	0.368
AveB_2017_2019/K	0.276	0.271	0.189	0.368
B_2018/BMSY	0.776	0.744	0.528	1.073
B_2019/BMSY	0.595	0.572	0.393	0.825
AveB_2017_2019/BMSY	0.615	0.594	0.429	0.830

Sensitivity case 2

	Mean	Median	Lower10th	Upper10th
C_2018	0.439	0.439	0.439	0.439
AveC_2016_2018	0.354	0.354	0.354	0.354
AveF_2016_2018	0.797	0.768	0.363	1.264
F_2018	0.788	0.754	0.353	1.266
FMSY	0.545	0.530	0.281	0.827
MSY (million ton)	0.458	0.445	0.370	0.558
F_2018/FMSY	1.474	1.454	0.944	1.989
AveF_2016_2018/FMSY	1.492	1.469	1.003	1.969
K (million ton)	2.247	1.859	1.158	3.756
B_2018 (million ton)	0.716	0.582	0.347	1.246
B_2019 (million ton)	0.554	0.446	0.259	0.975
AveB_2017_2019	0.571	0.465	0.280	0.993
BMSY (million ton)	1.002	0.836	0.541	1.655
BMSY/K	0.453	0.444	0.405	0.516
B_2018/K	0.328	0.319	0.212	0.456
B_2019/K	0.252	0.244	0.159	0.355
AveB_2017_2019/K	0.261	0.256	0.172	0.354
B_2018/BMSY	0.728	0.691	0.483	1.021
B_2019/BMSY	0.560	0.534	0.359	0.793
AveB_2017_2019/BMSY	0.579	0.557	0.393	0.793

Sensitivity case 3

	Mean	Median	Lower10th	Upper10th
C_2018	0.439	0.439	0.439	0.439
AveC_2016_2018	0.354	0.354	0.354	0.354
AveF_2016_2018	0.455	0.408	0.199	0.796
F_2018	0.537	0.489	0.244	0.920
FMSY	0.296	0.263	0.106	0.545
MSY (million ton)	0.408	0.402	0.312	0.493
F_2018/FMSY	2.095	1.936	1.170	3.175
AveF_2016_2018/FMSY	1.728	1.629	1.042	2.497
K (million ton)	4.064	3.479	1.751	7.392
B_2018 (million ton)	1.051	0.897	0.478	1.801
B_2019 (million ton)	0.929	0.774	0.387	1.655
AveB_2017_2019	0.996	0.845	0.431	1.745
BMSY (million ton)	1.811	1.570	0.826	3.206
BMSY/K	0.454	0.441	0.389	0.543
B_2018/K	0.272	0.260	0.176	0.381
B_2019/K	0.239	0.222	0.140	0.358
AveB_2017_2019/K	0.254	0.242	0.170	0.351
B_2018/BMSY	0.602	0.567	0.407	0.835
B_2019/BMSY	0.529	0.489	0.315	0.789
AveB_2017_2019/BMSY	0.562	0.529	0.393	0.771

Sensitivity case 4

	Mean	Median	Lower10th	Upper10th
C_2018	0.439	0.439	0.439	0.439
AveC_2016_2018	0.354	0.354	0.354	0.354
AveF_2016_2018	0.587	0.569	0.305	0.897
F_2018	0.682	0.667	0.361	1.030
FMSY	0.385	0.374	0.195	0.597
MSY (million ton)	0.425	0.420	0.368	0.483
F_2018/FMSY	1.864	1.838	1.275	2.447
AveF_2016_2018/FMSY	1.583	1.573	1.149	1.999
K (million ton)	2.881	2.485	1.562	4.709
B_2018 (million ton)	0.771	0.658	0.426	1.216
B_2019 (million ton)	0.669	0.562	0.338	1.107
AveB_2017_2019	0.712	0.607	0.382	1.142
BMSY (million ton)	1.306	1.128	0.749	2.057
BMSY/K	0.462	0.452	0.398	0.546
B_2018/K	0.277	0.268	0.198	0.362
B_2019/K	0.238	0.225	0.157	0.333
AveB_2017_2019/K	0.253	0.245	0.185	0.329
B_2018/BMSY	0.601	0.568	0.452	0.784
B_2019/BMSY	0.517	0.483	0.347	0.724
AveB_2017_2019/BMSY	0.549	0.523	0.420	0.708

5 Summary of estimates of parameters

Base case 1

	Mean	Median	Lower10th	Upper10th
r	1.609	1.538	0.733	2.631
K (million ton)	2.426	2.076	1.424	3.853
qCHN	16.644	16.419	10.905	22.622
qJPN1	1.119	0.990	0.458	1.980
qJPN2	2.298	2.287	1.579	3.030
qKOR	10.039	10.044	6.905	13.187
qRUS	24.984	24.863	17.136	32.790
qCT	2.261	2.256	1.559	2.969
qBio	0.570	0.565	0.292	0.858
Shape	0.581	0.448	0.190	1.188
sigma_com	0.322	0.320	0.290	0.355
sigma_Bio	0.131	0.131	0.118	0.145
tau	0.341	0.335	0.258	0.433
FMSY	0.461	0.456	0.268	0.658
BMSY (million ton)	1.076	0.929	0.653	1.659
MSY (million ton)	0.439	0.429	0.354	0.529
b	0.590	0.585	0.462	0.725

Base case 2

	Mean	Median	Lower10th	Upper10th
r	1.658	1.610	0.762	2.668
K (million ton)	2.446	2.060	1.374	4.000
qCHN	17.209	16.962	11.134	23.541
qJPN1				
qJPN2	2.383	2.397	1.621	3.114
qKOR	10.392	10.433	7.063	13.582
qRUS	26.006	26.195	17.652	33.959
qCT	2.342	2.356	1.586	3.071
qBio	0.605	0.613	0.298	0.903
Shape	0.580	0.462	0.200	1.160
sigma_com	0.326	0.324	0.293	0.360
sigma_Bio	0.146	0.145	0.131	0.161
tau	0.356	0.348	0.256	0.466
FMSY	0.485	0.484	0.269	0.697
BMSY (million ton)	1.085	0.917	0.631	1.730
MSY (million ton)	0.458	0.441	0.364	0.566
b	0.585	0.579	0.454	0.726

Sensitivity case 1

	Mean	Median	Lower10th	Upper10th
r	1.650	1.585	0.760	2.655
K (million ton)	2.331	1.988	1.318	3.709
qCHN	17.443	16.936	11.167	24.432
qJPN1	1.176	1.054	0.479	2.078
qJPN2	2.409	2.362	1.612	3.275
qKOR	10.519	10.337	7.054	14.250
qRUS	26.164	25.570	17.517	35.469
qCT	2.372	2.332	1.588	3.210
qBio	0.620	0.599	0.301	0.966
Shape	0.591	0.467	0.202	1.197
sigma_com	0.322	0.320	0.291	0.355
sigma_Bio	0.131	0.131	0.119	0.145
tau	0.343	0.338	0.259	0.433
FMSY	0.489	0.476	0.273	0.720
BMSY (million ton)	1.036	0.891	0.606	1.612
MSY (million ton)	0.440	0.429	0.358	0.529
b	0.592	0.586	0.464	0.728

Sensitivity case 2

	Mean	Median	Lower10th	Upper10th
r	1.741	1.735	0.802	2.714
K (million ton)	2.247	1.859	1.158	3.756
qCHN	18.889	18.380	11.591	26.975
qJPN1				
qJPN2	2.607	2.553	1.670	3.622
qKOR	11.371	11.121	7.329	15.746
qRUS	28.512	27.984	18.273	39.610
qCT	2.559	2.510	1.637	3.541
qBio	0.710	0.683	0.318	1.137
Shape	0.606	0.499	0.217	1.176
sigma_com	0.326	0.324	0.293	0.361
sigma_Bio	0.146	0.145	0.131	0.161
tau	0.356	0.348	0.258	0.466
FMSY	0.545	0.530	0.281	0.827
BMSY (million ton)	1.002	0.836	0.541	1.655
MSY (million ton)	0.458	0.445	0.370	0.558
b	0.590	0.585	0.459	0.730

Sensitivity case 3

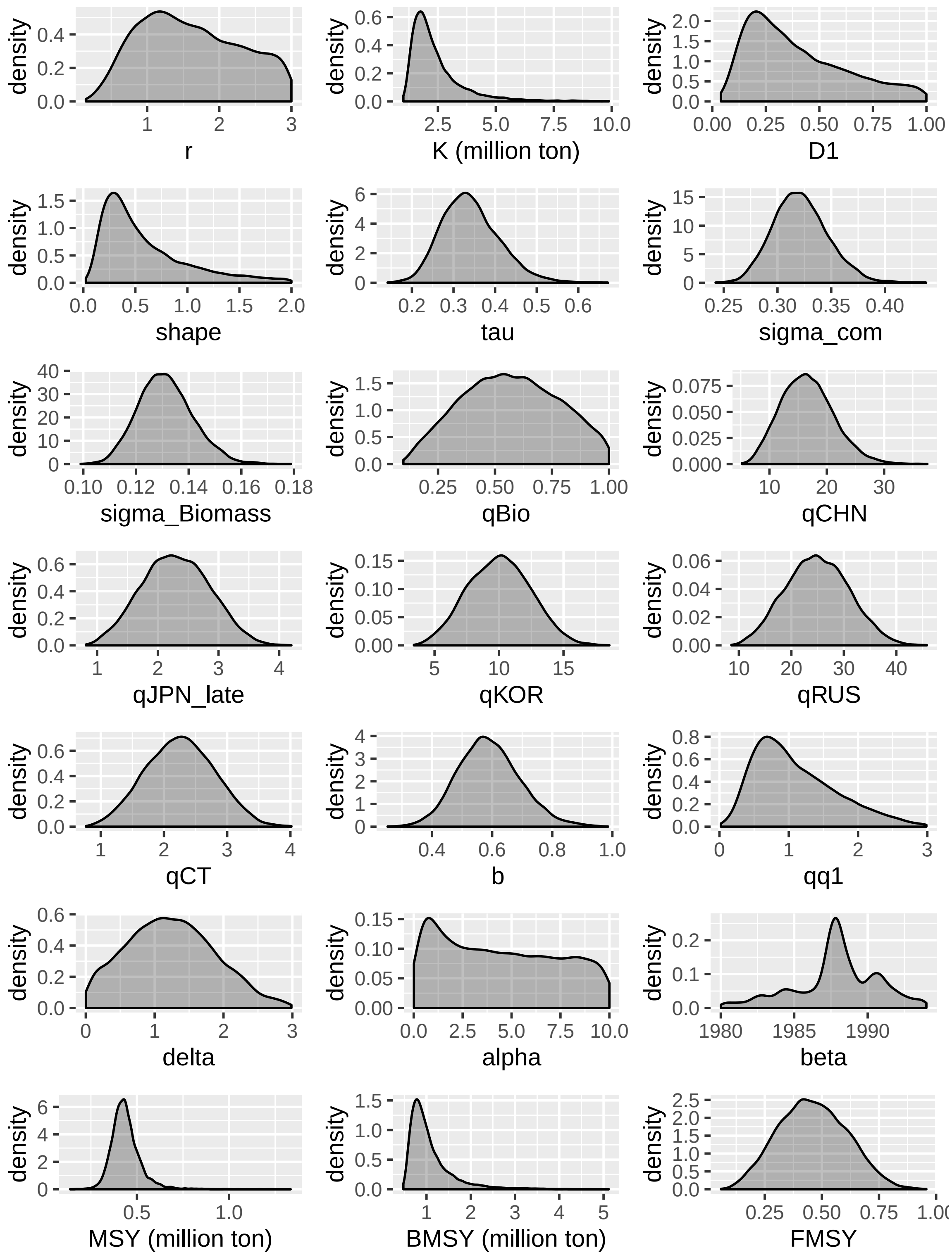
	Mean	Median	Lower10th	Upper10th
r	1.145	0.963	0.297	2.347
K (million ton)	4.064	3.479	1.751	7.392
qJOINT	0.882	0.900	0.699	1.034
qBio	0.426	0.384	0.191	0.746
Shape	0.644	0.473	0.120	1.496
sigma_Joint	0.264	0.260	0.218	0.313
sigma_Bio	0.264	0.260	0.218	0.313
tau	0.122	0.098	0.029	0.249
FMSY	0.296	0.263	0.106	0.545
BMSY (million ton)	1.811	1.570	0.826	3.206
MSY (million ton)	0.408	0.402	0.312	0.493
b	0.213	0.178	0.038	0.432

Sensitivity case 4

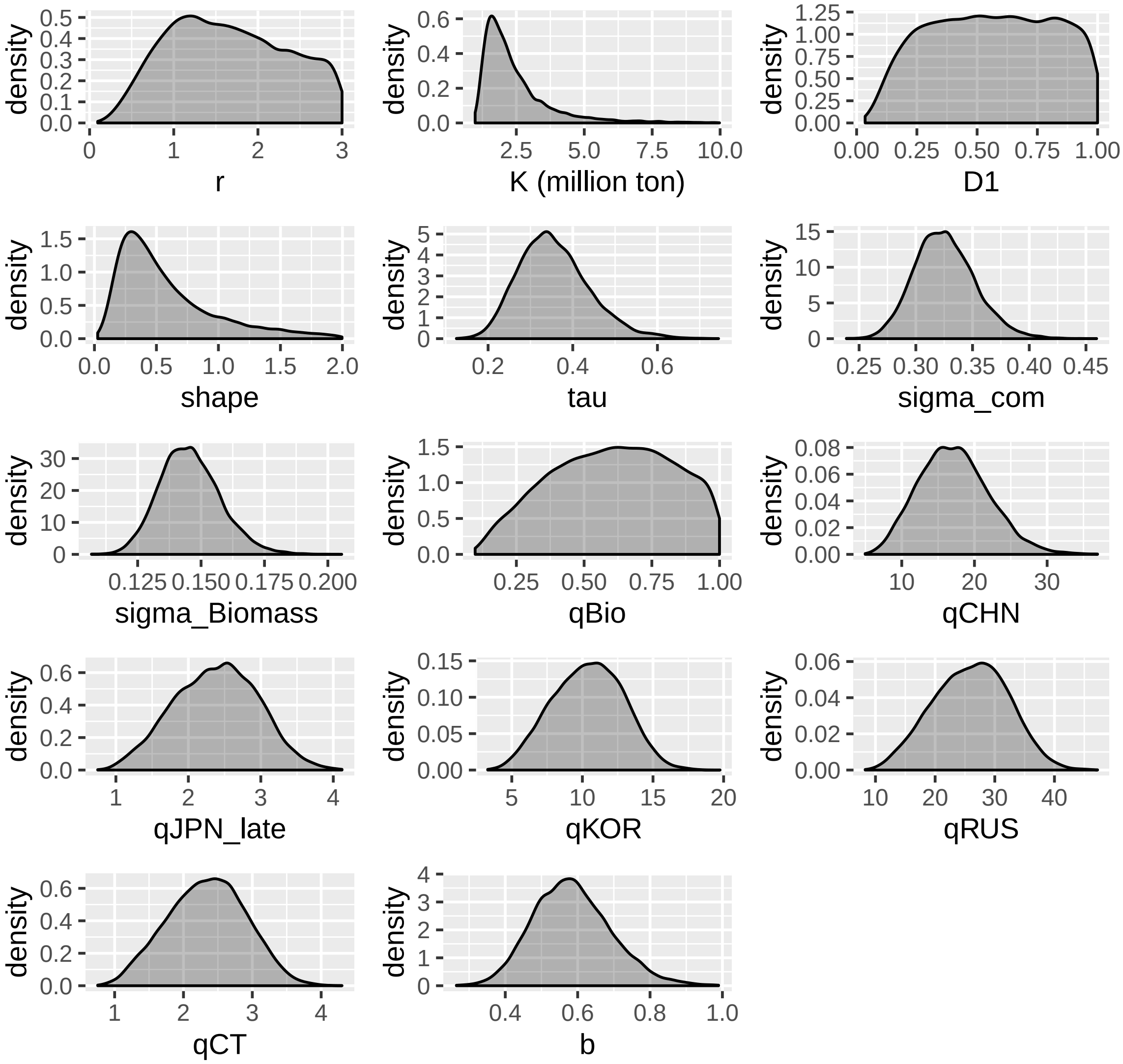
	Mean	Median	Lower10th	Upper10th
r	1.278	1.116	0.485	2.357
K (million ton)	2.881	2.485	1.562	4.709
qJOINT	0.929	0.943	0.797	1.046
qBio	0.545	0.531	0.285	0.827
Shape	0.712	0.560	0.177	1.543
sigma_Joint	0.230	0.229	0.195	0.266
sigma_JPN_early	0.562	0.560	0.478	0.651
sigma_Bio	0.230	0.229	0.195	0.266
tau	0.116	0.094	0.025	0.238
FMSY	0.385	0.374	0.195	0.597
BMSY (million ton)	1.306	1.128	0.749	2.057
MSY (million ton)	0.425	0.420	0.368	0.483
b	0.204	0.175	0.040	0.408

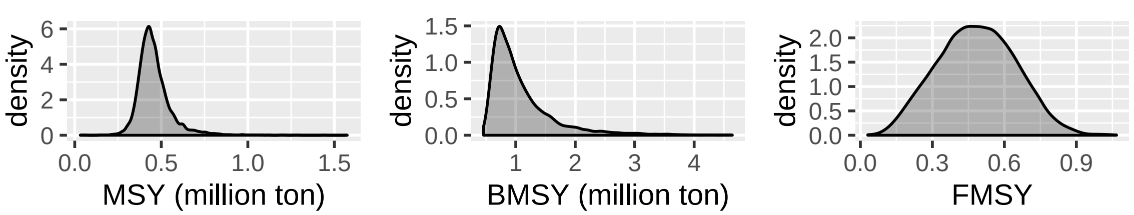
6 Posterior distributions

Base case 1

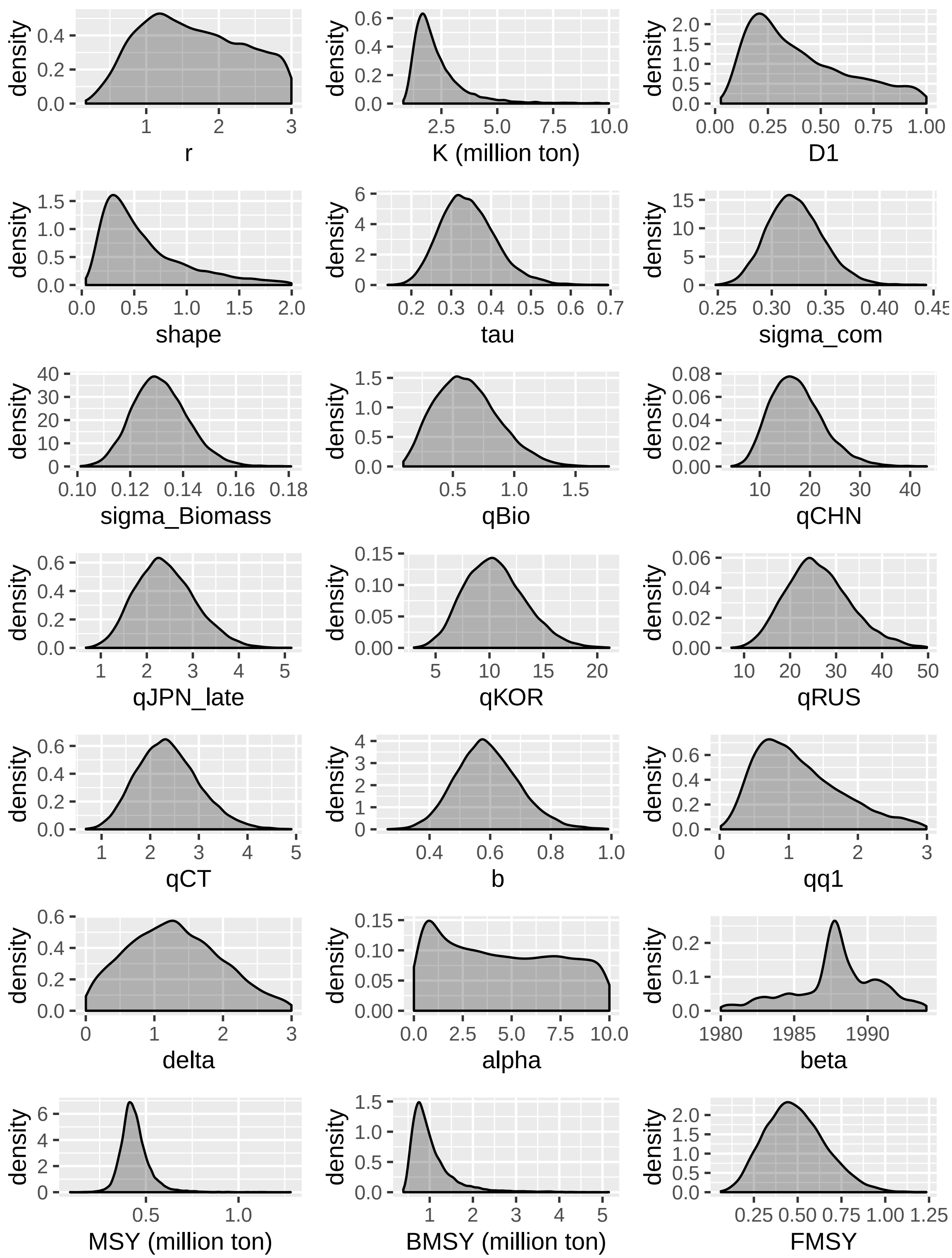


Base case 2

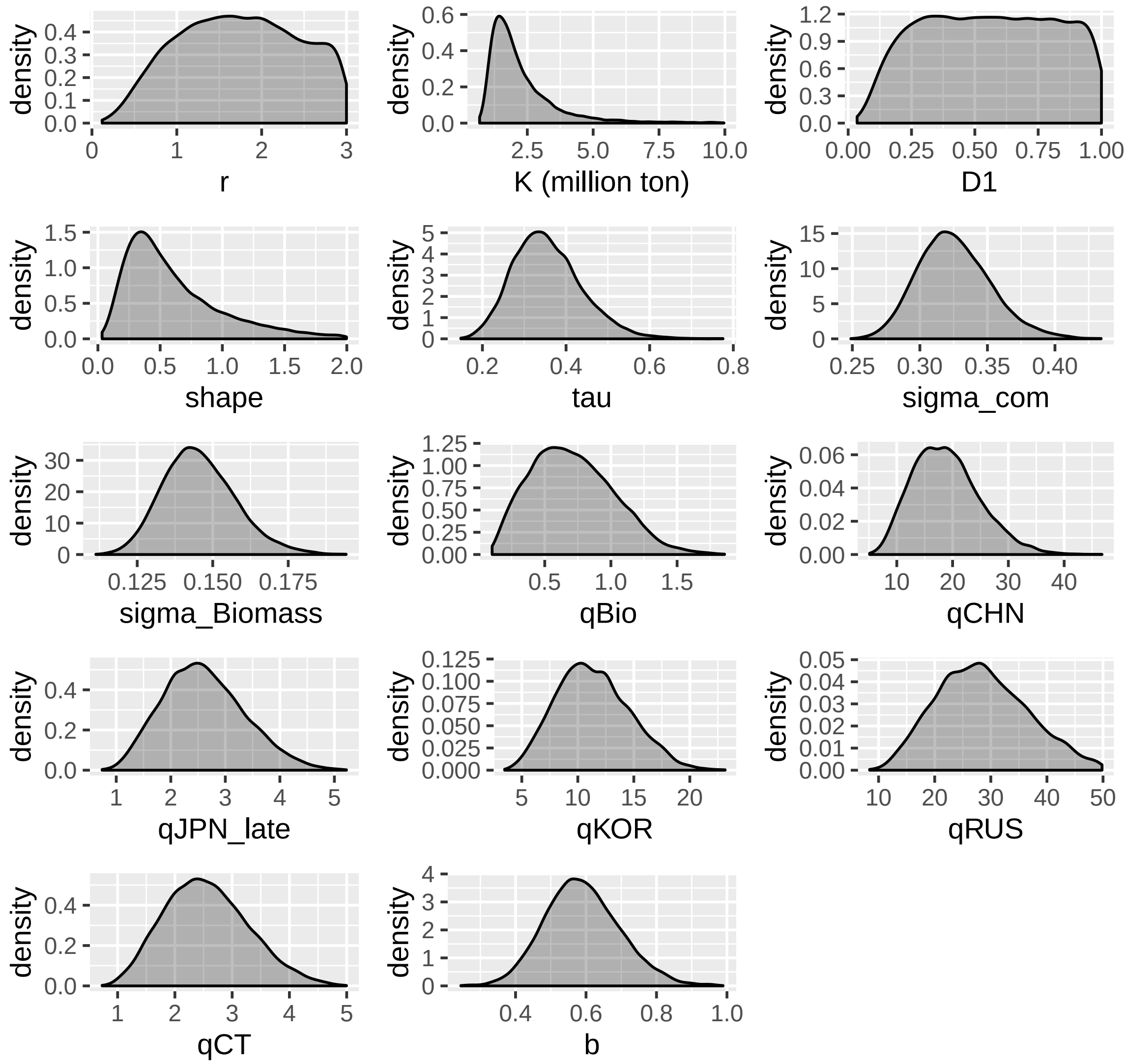

density
r
K (million ton)
D1
shape
tau
sigma_com
sigma_Biomass
qBio
qCHN
qJPN_late
qKOR
qRUS
qCT
b

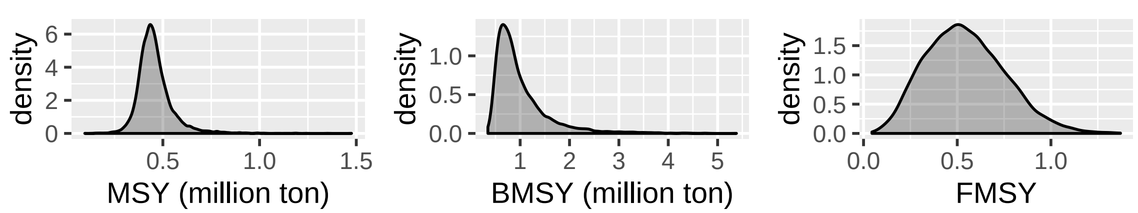

density
MSY (million ton)
BMSY (million ton)
FMSY

Sensitivity case 1

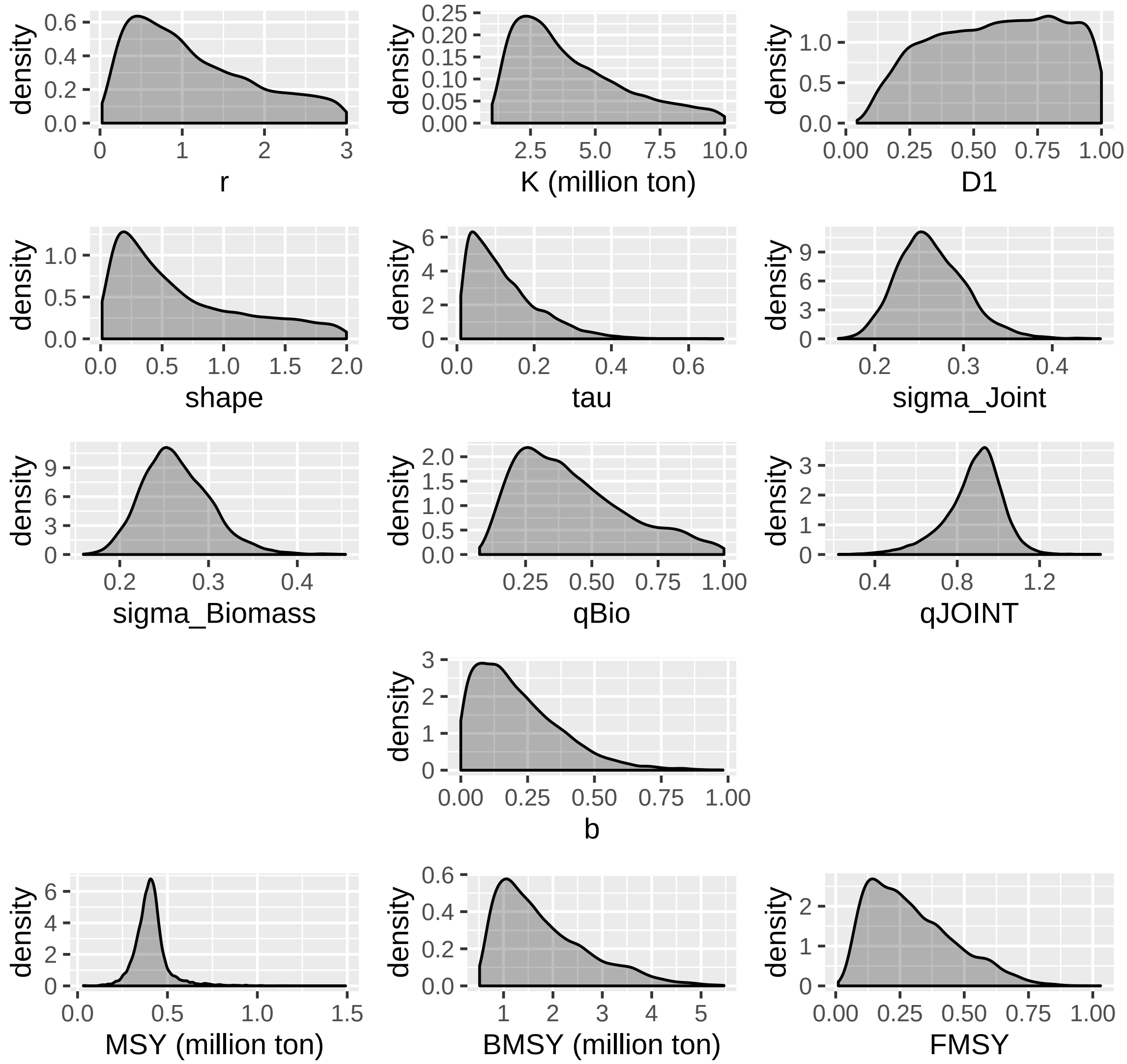


Sensitivity case 2

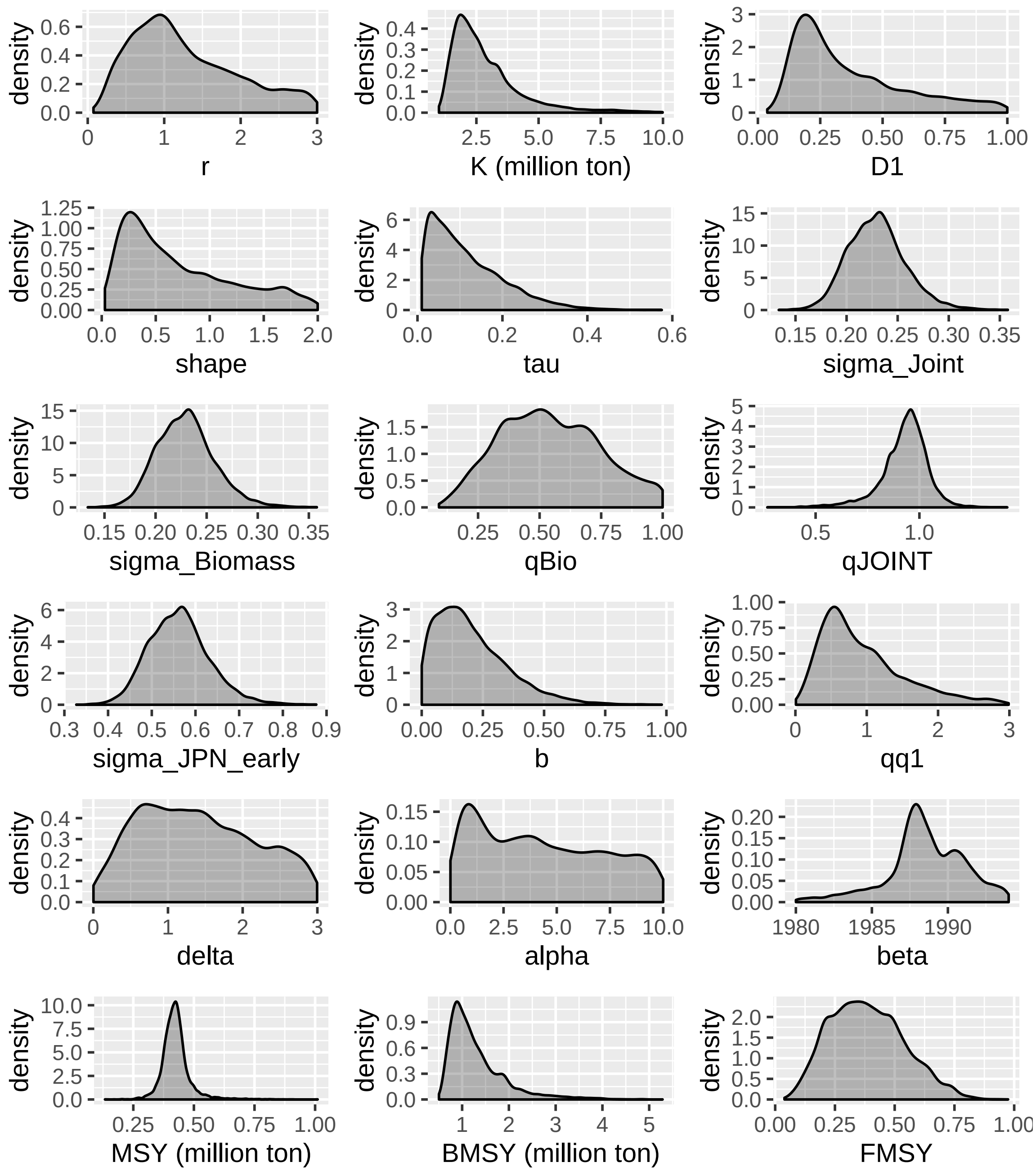




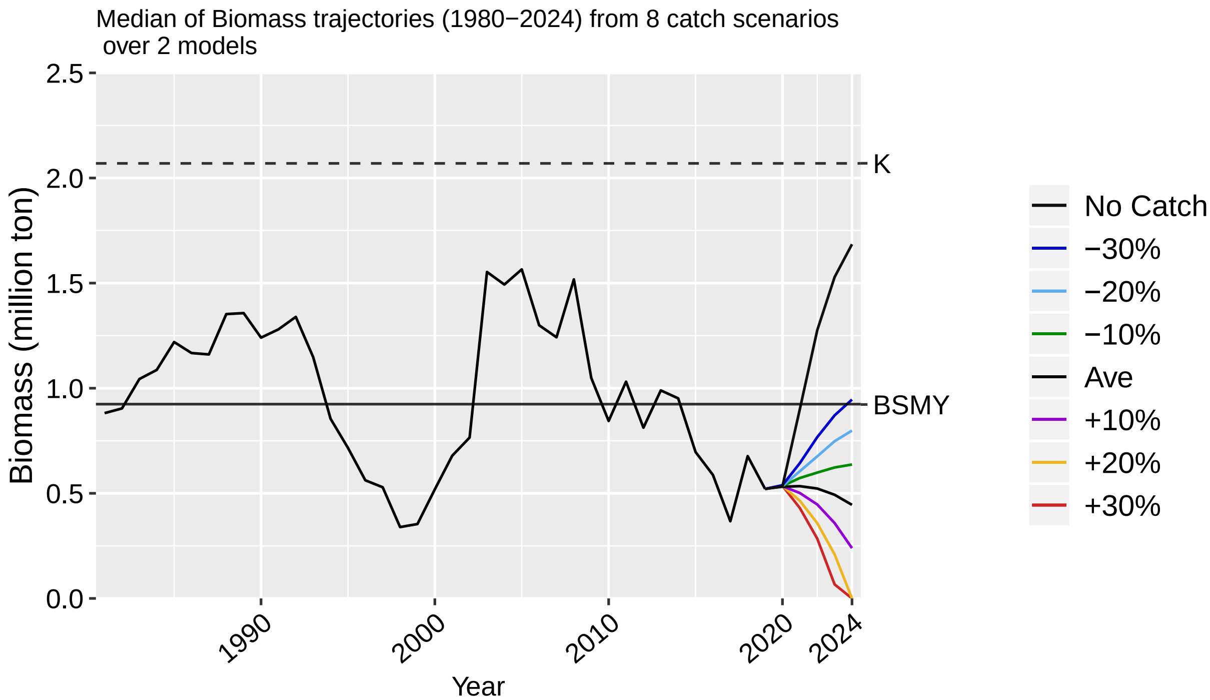
Sensitivity case 3

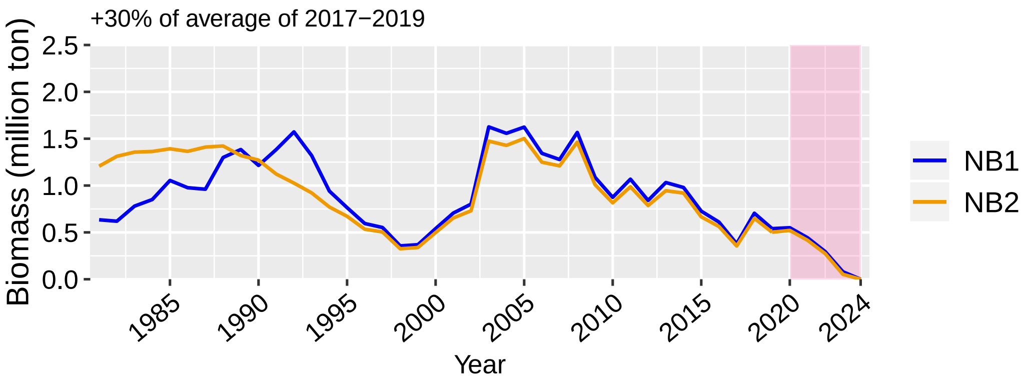


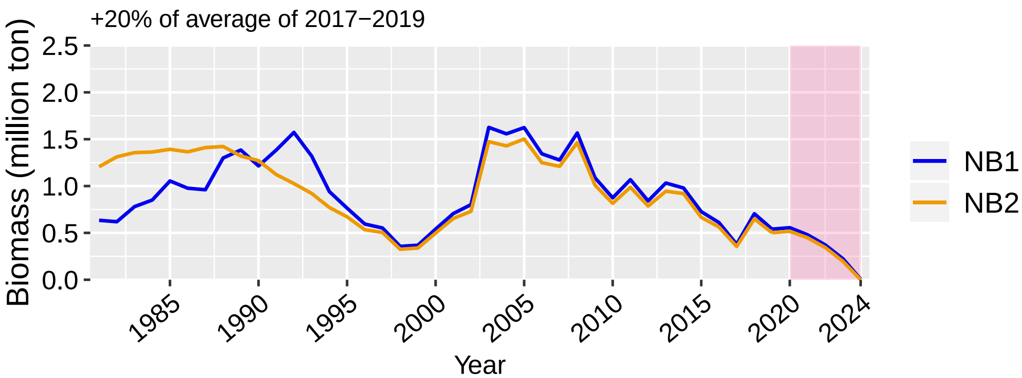
Sensitivity case 4

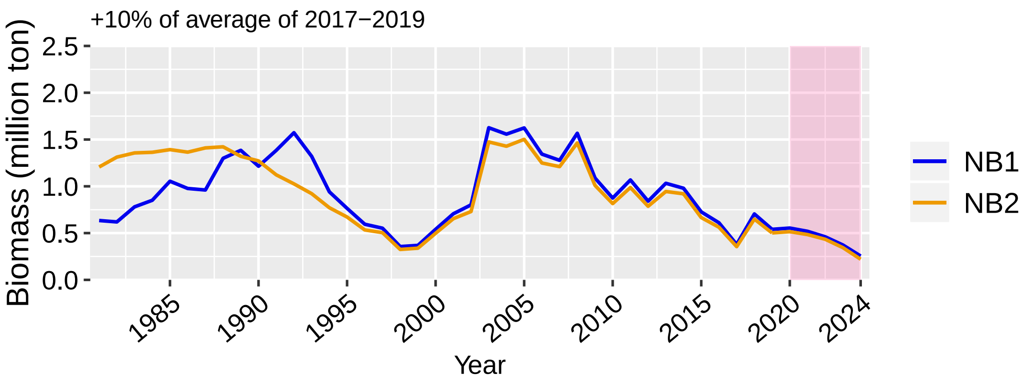


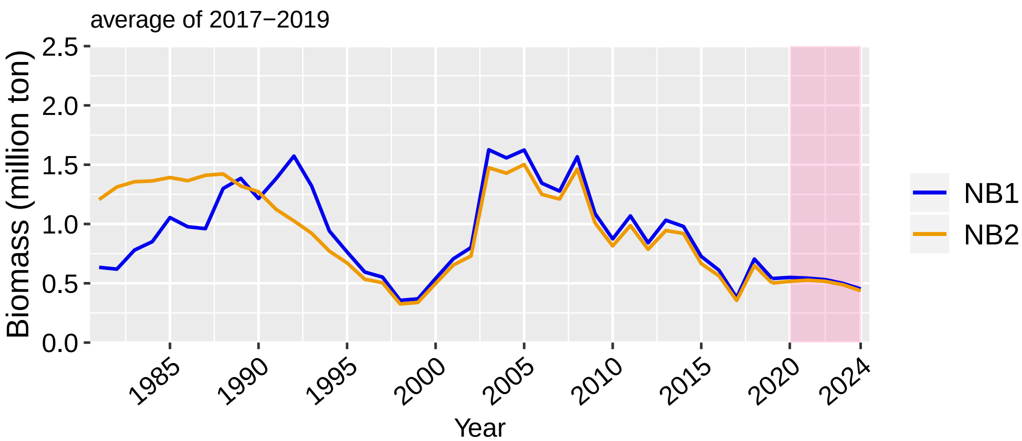
7 Future projection

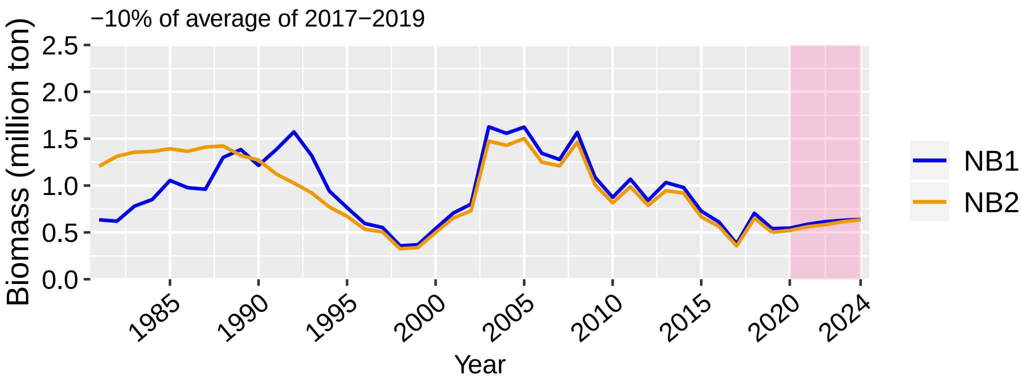


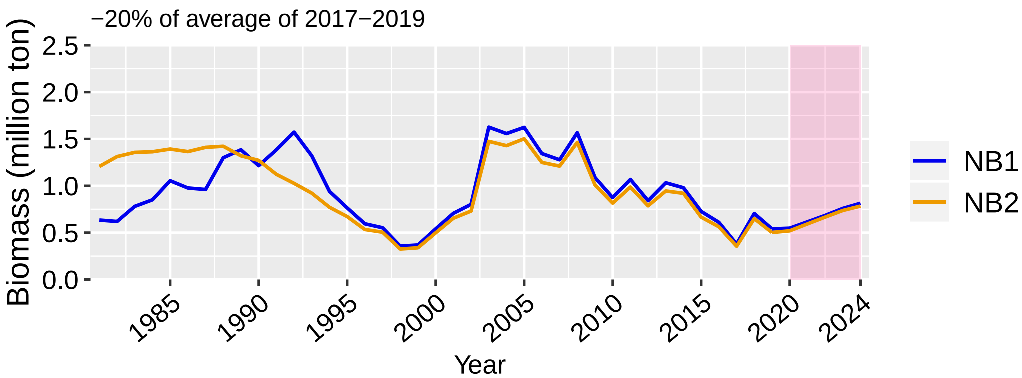

+30% of average of 2017−2019
Biomass (million ton)
Year
NB1
NB2

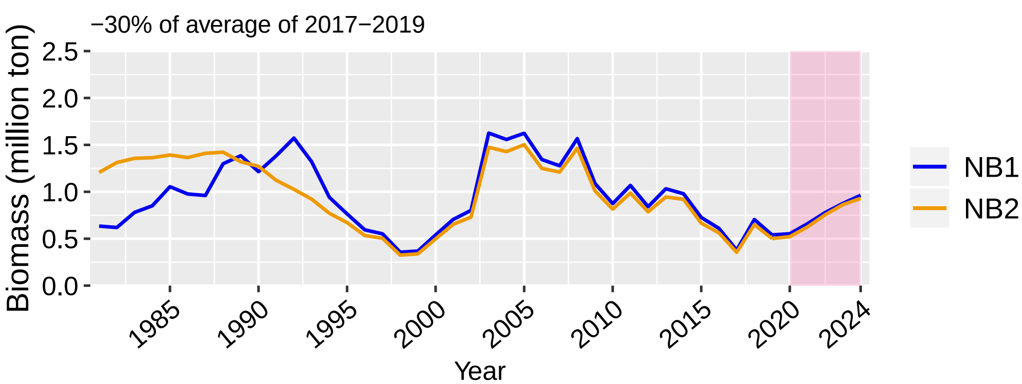

+20% of average of 2017−2019
Biomass (million ton)
Year
NB1
NB2

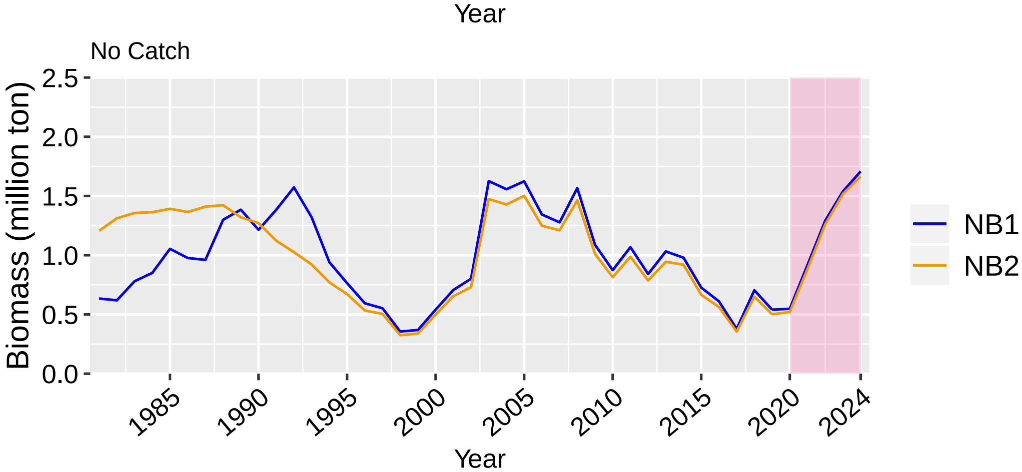

+10% of average of 2017−2019
Biomass (million ton)
Year
NB1
NB2


average of 2017−2019
Biomass (million ton)
Year
NB1
NB2


−10% of average of 2017−2019
Biomass (million ton)
0.0
0.5
1.0
1.5
2.0
2.5
1985
1990
1995
2000
2005
2010
2015
2020
2024
Year
NB1
NB2


−20% of average of 2017−2019
Biomass (million ton)
0.0
0.5
1.0
1.5
2.0
2.5
1985
1990
1995
2000
2005
2010
2015
2020
2024
Year
NB1
NB2


−30% of average of 2017−2019
Biomass (million ton)
0.0
0.5
1.0
1.5
2.0
2.5
1985
1990
1995
2000
2005
2010
2015
2020
2024
Year
NB1
NB2


No Catch
Biomass (million ton)
0.0
0.5
1.0
1.5
2.0
2.5
1985
1990
1995
2000
2005
2010
2015
2020
2024
Year
NB1
NB2

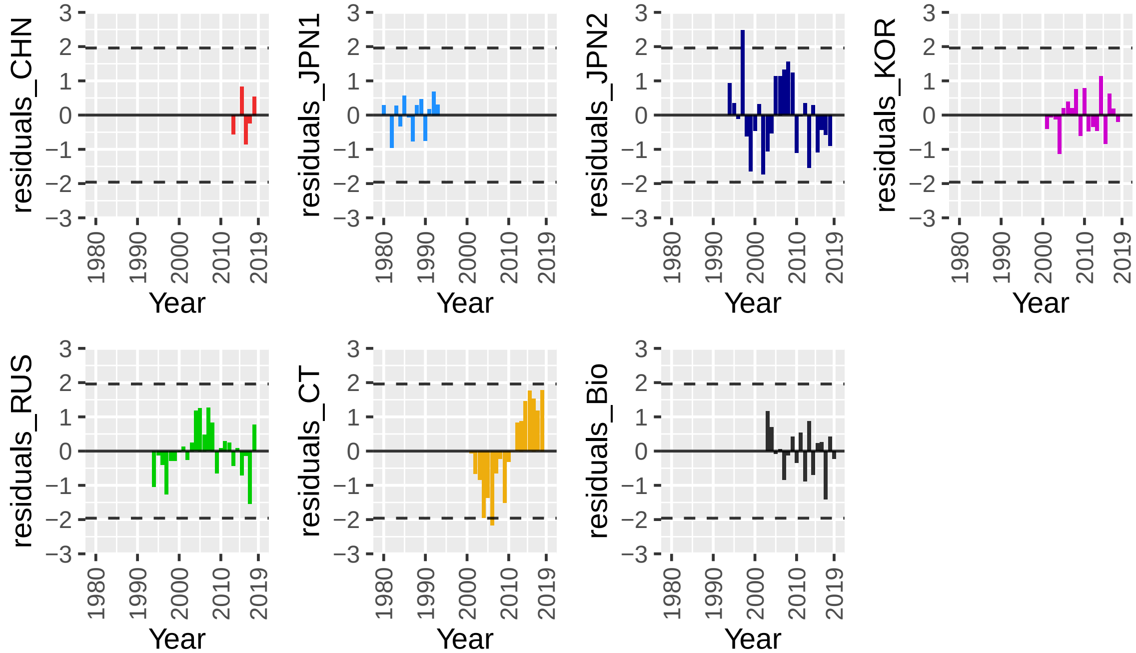
8 Risk table

	Red	Orange	Yellow	Green	B<BMSY	F>FMSY
+30%	0.831	0.012	0.015	0.142	0.846	0.843
+20%	0.784	0.008	0.026	0.182	0.810	0.792
+10%	0.714	0.004	0.045	0.237	0.759	0.718
±0%	0.628	0.002	0.076	0.294	0.704	0.630
-10%	0.524	0.001	0.113	0.362	0.637	0.525
-20%	0.417	0.000	0.148	0.435	0.565	0.417
-30%	0.302	0.000	0.188	0.510	0.490	0.302
No Catch	0.000	0.000	0.137	0.863	0.137	0.000

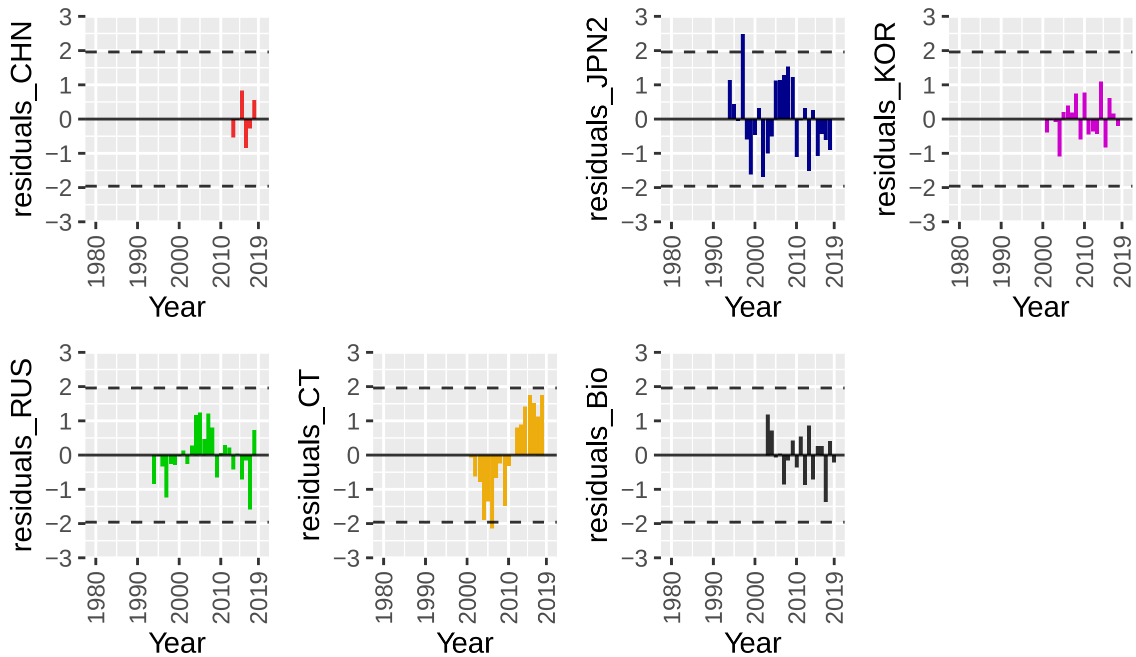
9 Diagnosis

9.1 Standardized residuals plot

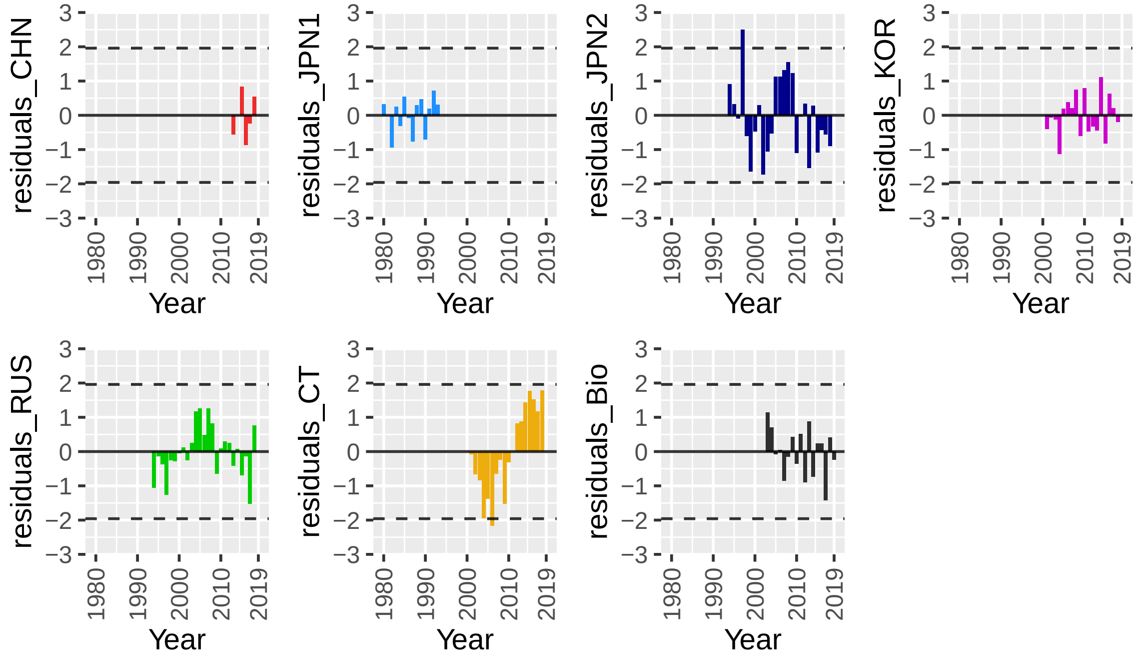
Base case 1



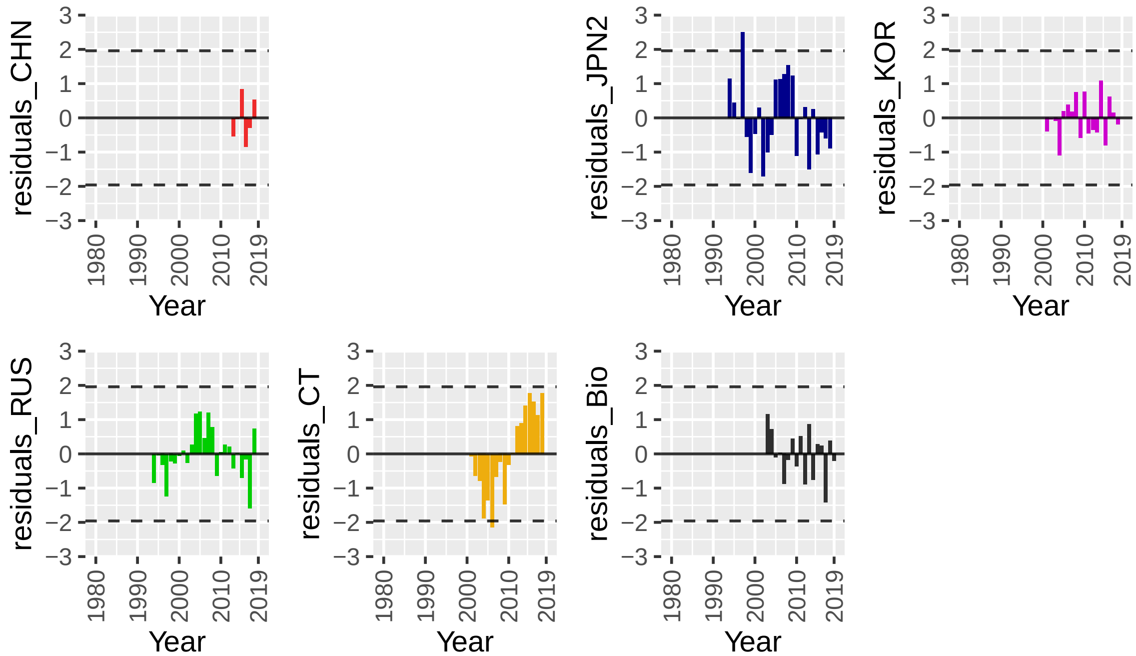
Base case 2



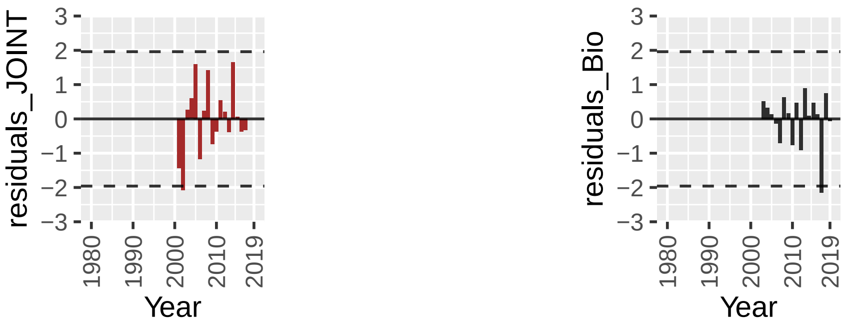
Sensitivity case 1



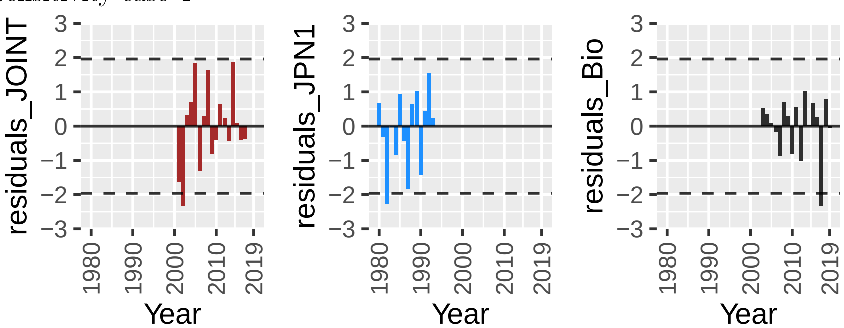
Sensitivity case 2



Sensitivity case 3



Sensitivity case 4



9.2 Hind casting

9.2.1 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	0.053	0.053	0.271	0.247	0.101	0.105	0.102	0.109	0.105	0.101
MSE_JPN	0.073	0.072	0.030	0.028	0.106	0.120	0.205	0.220	0.044	0.046
MSE_KOR	0.002	0.001	0.134	0.120	0.030	0.031	0.049	0.055	0.078	0.076
MSE_RUS	0.077	0.077	0.383	0.372	0.216	0.229	0.233	0.246	0.117	0.122
MSE_CT	0.407	0.413	0.843	0.803	0.308	0.285	0.317	0.301	0.661	0.641
MSE_Bio	0.038	0.030	2.427	2.343	0.203	0.226	0.307	0.327	0.091	0.091
sum(CPUE)/5	0.122	0.123	0.332	0.314	0.152	0.154	0.181	0.186	0.201	0.197
(MSE_Bio+sum(CPUE)/5)/2	0.080	0.077	1.379	1.328	0.178	0.190	0.244	0.256	0.146	0.144

9.2.2 MSE MCMC sample mean

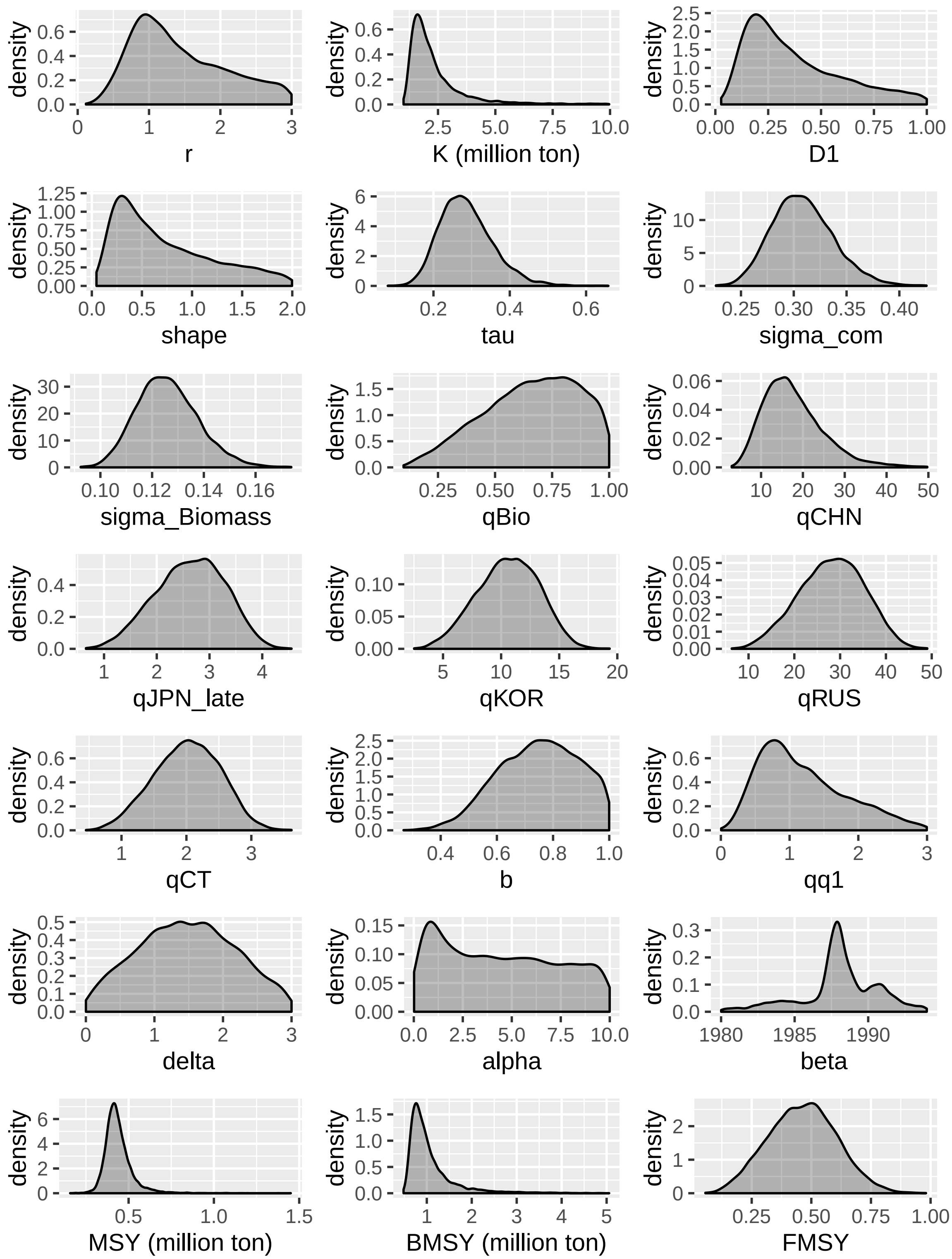
$$MSE_{mean} = \frac{1}{10000} \sum_{i=1}^{10000} \frac{1}{n} \sum_{t=\text{last year}-\text{n}+1}^{\text{last year}} \left\{ \log I_t - \log (q_i B_{ti}) \right\}^2$$

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

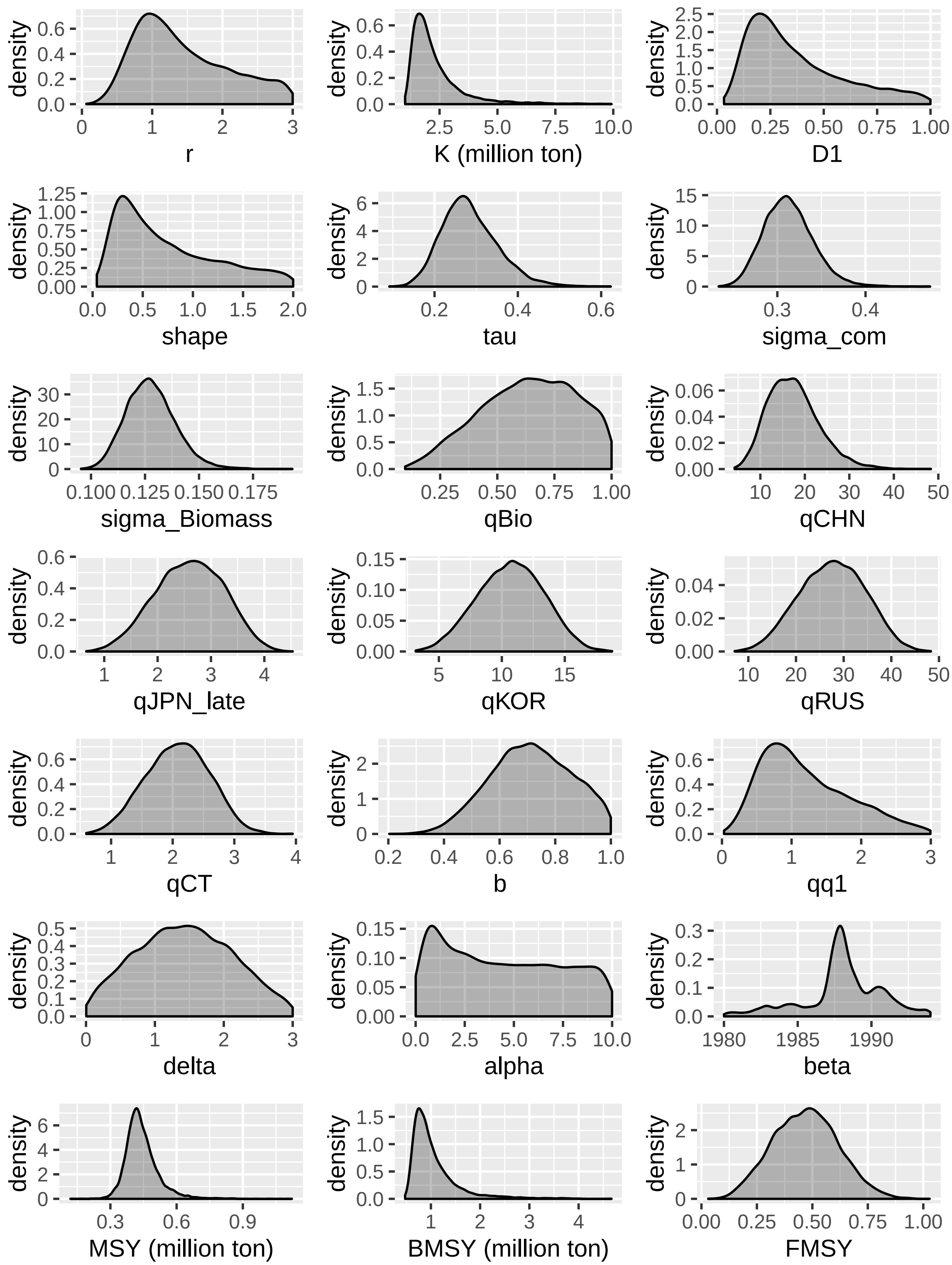
	1year		2year		3years		4year		5years	
	NB1	NB2	NB1	NB2	NB1	NB2	NB1	NB2	NB1	NB2
MSE_CHN	0.083	0.087	0.379	0.373	0.230	0.259	0.457	0.509	4.083	4.262
MSE_JPN	0.087	0.089	0.121	0.128	0.201	0.239	0.470	0.528	3.577	3.736
MSE_KOR	0.017	0.018	0.231	0.225	0.133	0.158	0.345	0.394	3.942	4.118
MSE_RUS	0.096	0.096	0.485	0.482	0.319	0.356	0.534	0.593	3.855	4.013
MSE_CT	0.420	0.426	0.959	0.929	0.428	0.435	0.678	0.714	5.189	5.379
MSE_Bio	0.209	0.229	14.871	14.827	1.727	2.035	2.214	2.421	10.088	10.773
sum(CPUE)/5	0.140	0.143	0.435	0.427	0.262	0.289	0.496	0.548	4.129	4.302
(MSE_Bio+sum(CPUE)/5)/2	0.175	0.186	7.653	7.627	0.995	1.162	1.355	1.484	7.109	7.538

9.2.3 Posterior distributions

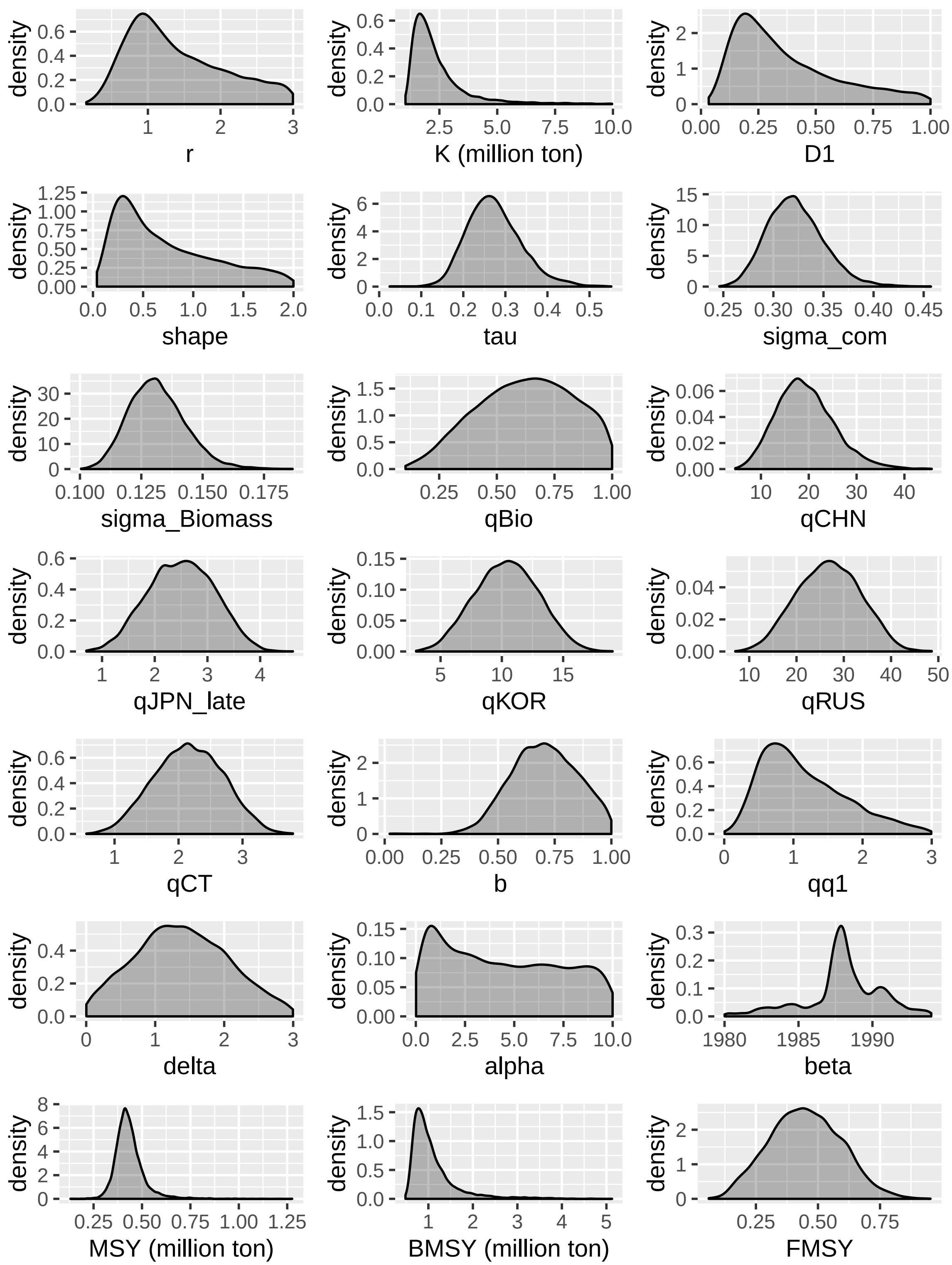
NB1 5 years



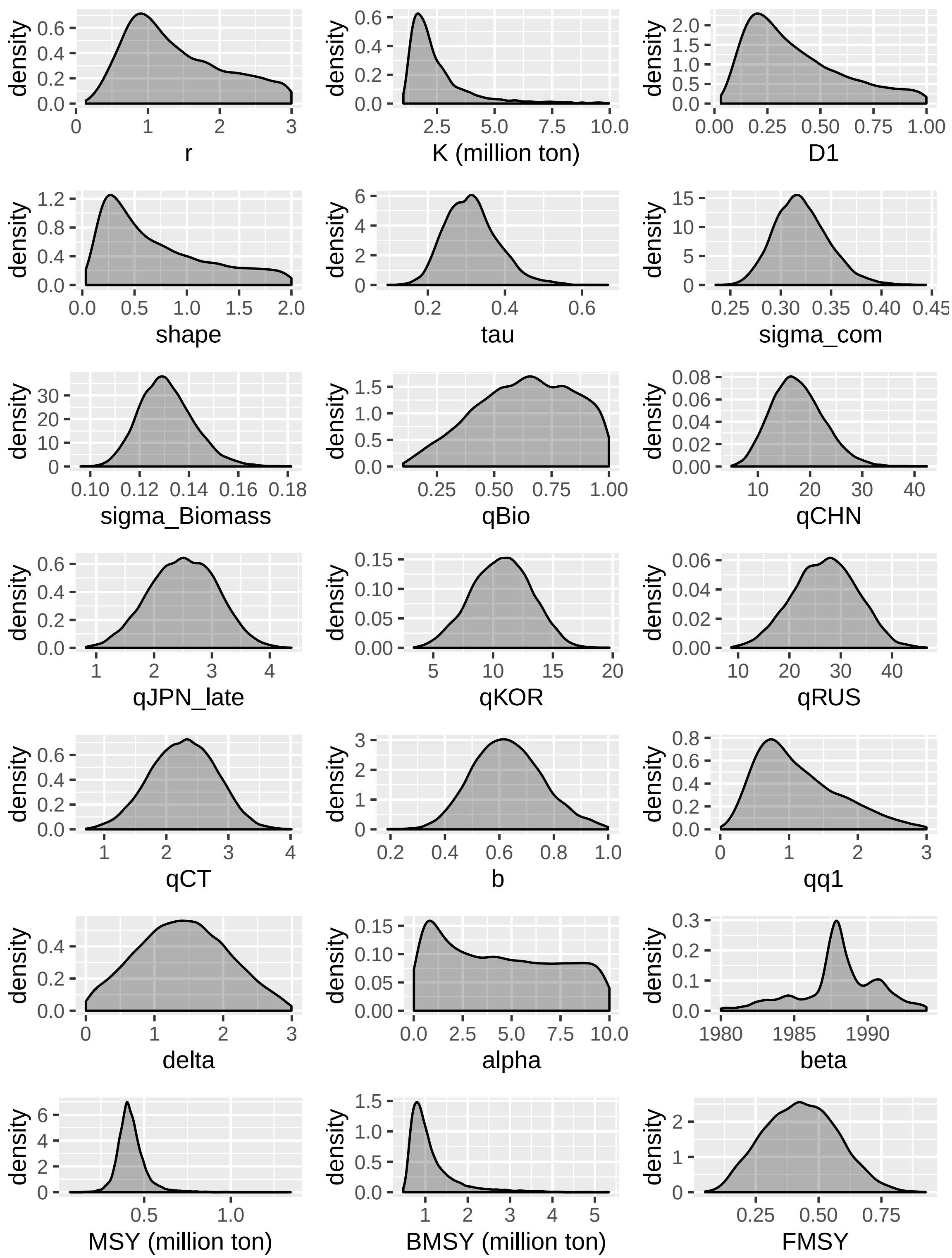
NB1 4 years


density
r
K (million ton)
D1
shape
tau
sigma_com
sigma_Biomass
qBio
qCHN
qJPN_late
qKOR
qRUS
qCT
b
qq1
delta
alpha
beta
MSY (million ton)
BMSY (million ton)
FMSY

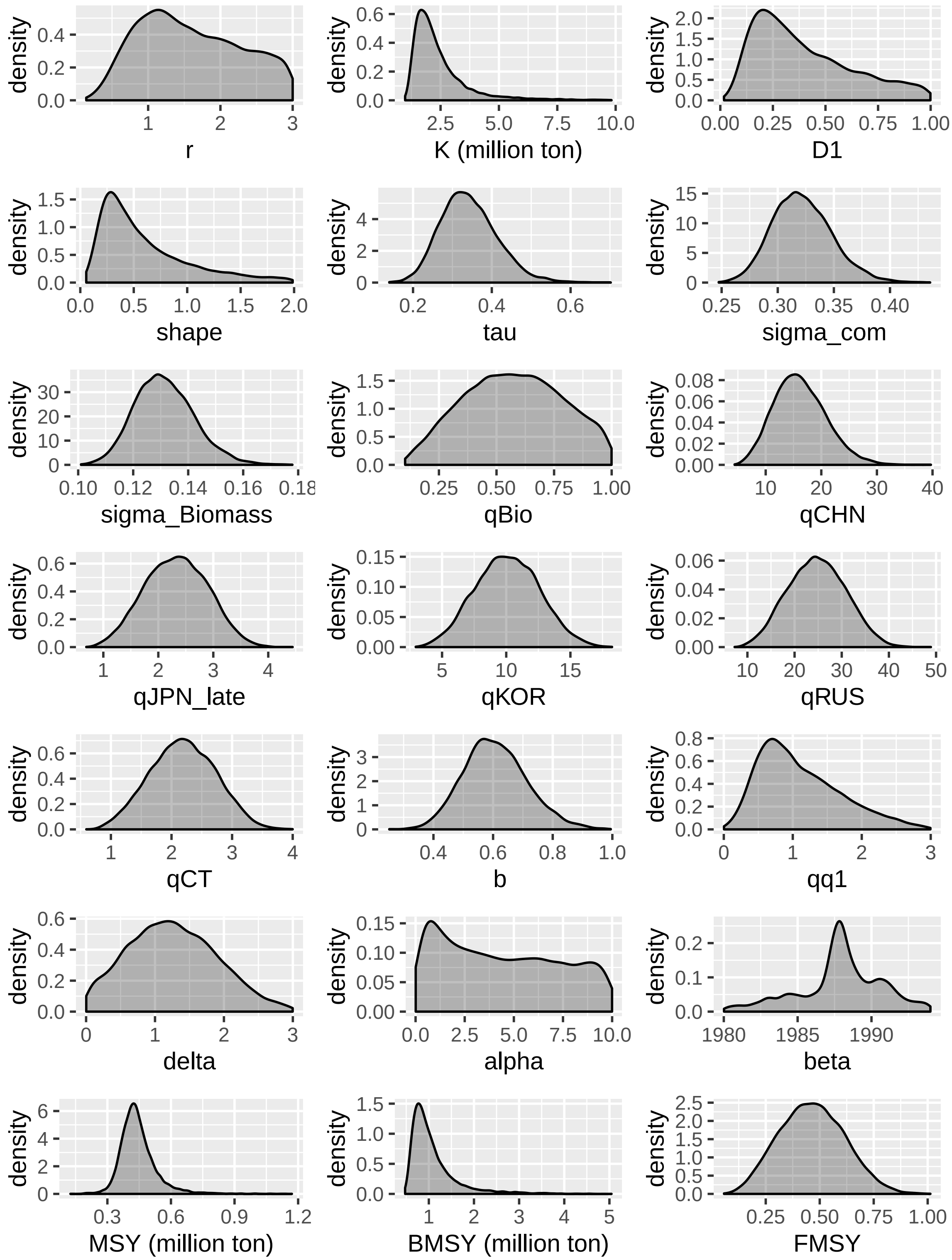
NB1 3 years


density
r
K (million ton)
D1
shape
tau
sigma_com
sigma_Biomass
qBio
qCHN
qJPN_late
qKOR
qRUS
qCT
b
qq1
delta
alpha
beta
MSY (million ton)
BMSY (million ton)
FMSY

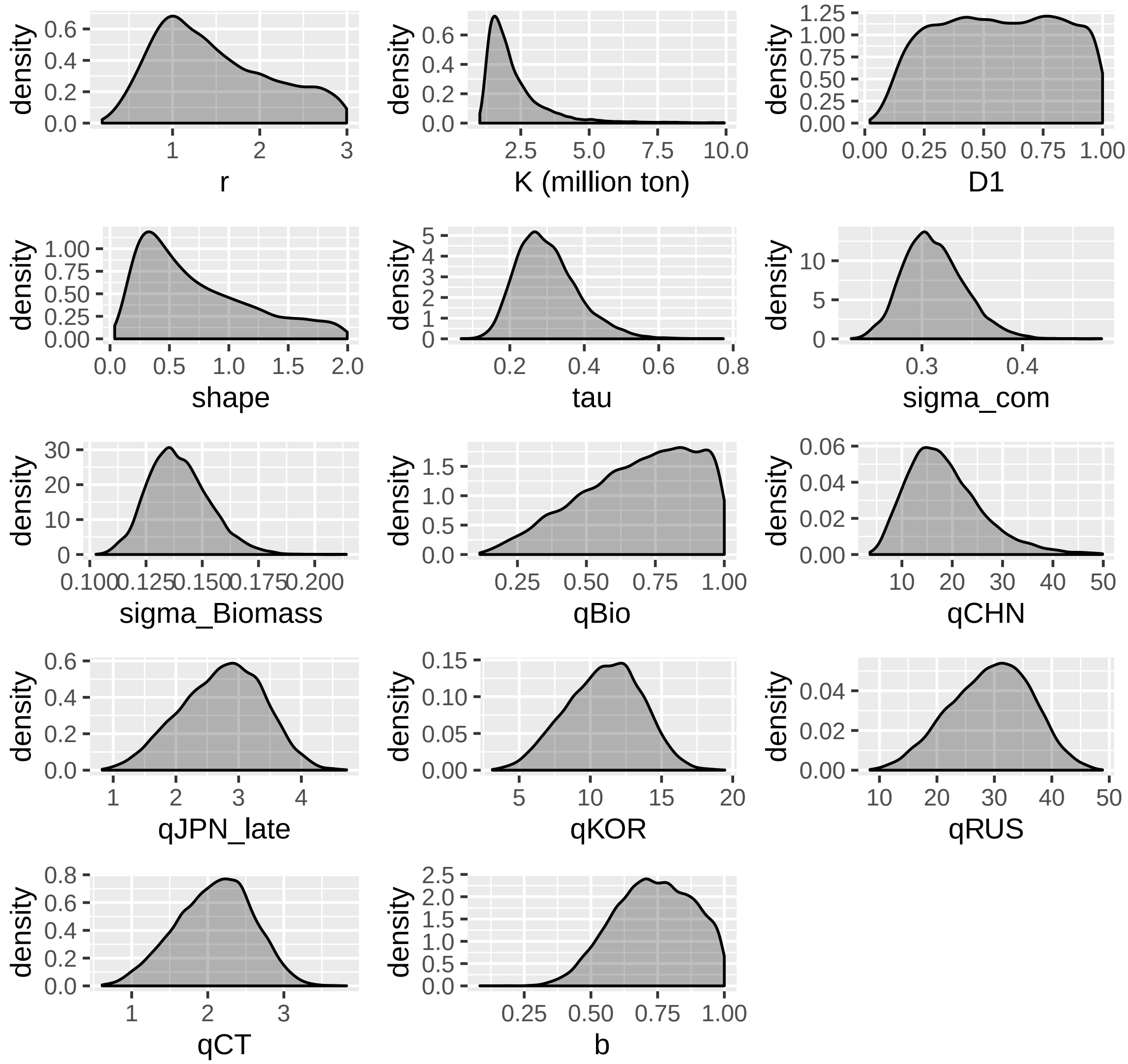
NB1 2 years

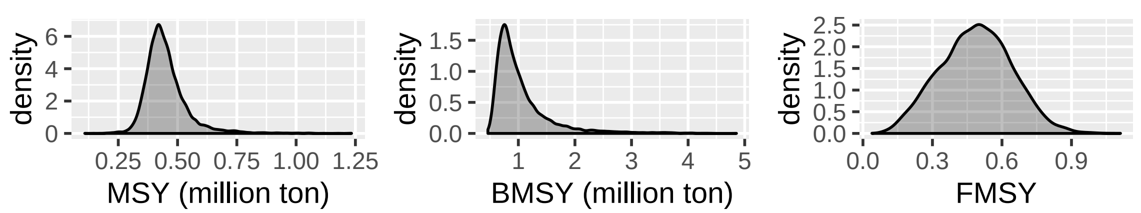

density
r
K (million ton)
D1
shape
tau
sigma_com
sigma_Biomass
qBio
qCHN
qJPN_late
qKOR
qRUS
qCT
b
qq1
delta
alpha
beta
MSY (million ton)
BMSY (million ton)
FMSY

NB1 1 years

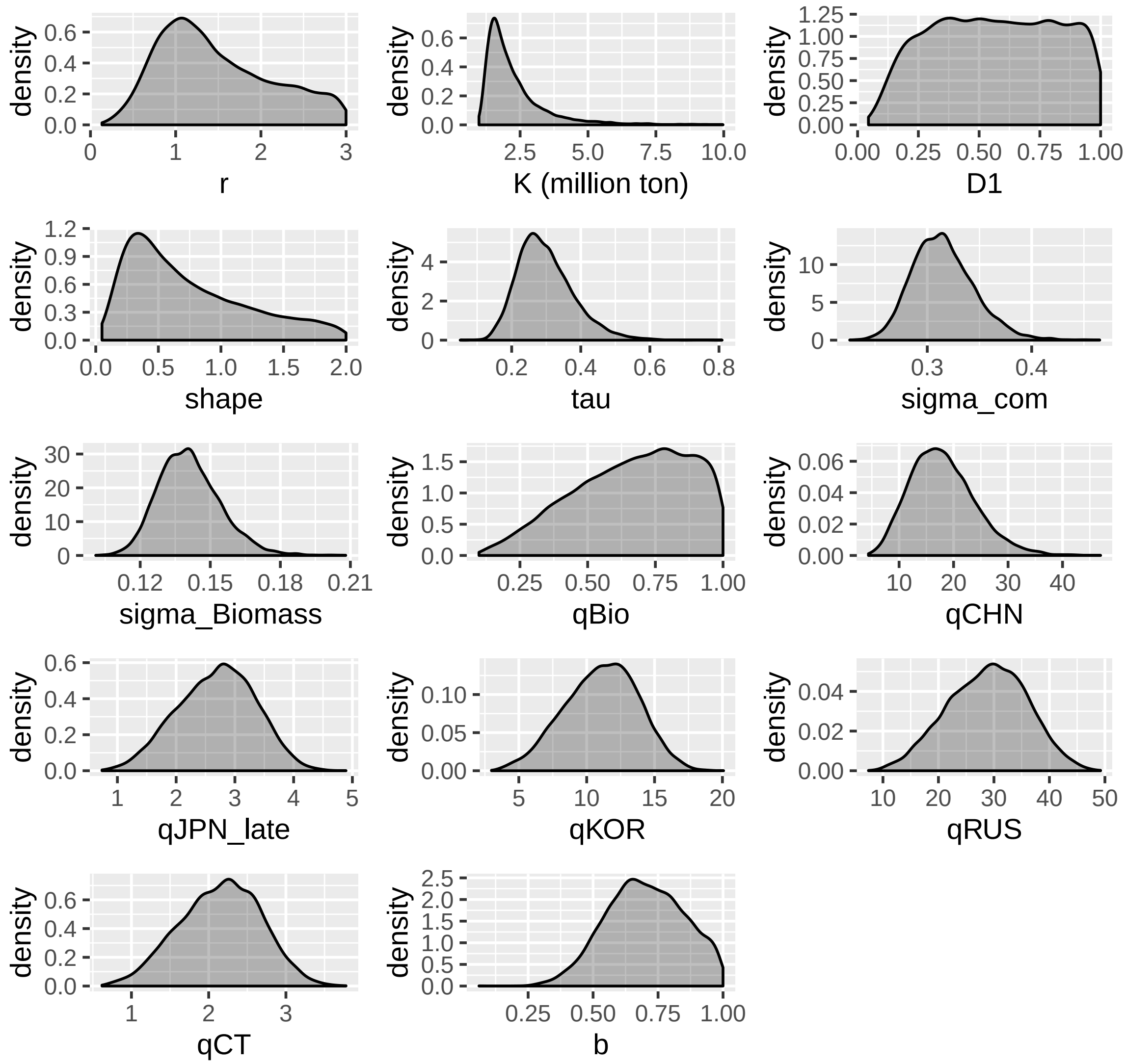

density
r
K (million ton)
D1
shape
tau
sigma_com
sigma_Biomass
qBio
qCHN
qJPN_late
qKOR
qRUS
qCT
b
qq1
delta
alpha
beta
MSY (million ton)
BMSY (million ton)
FMSY

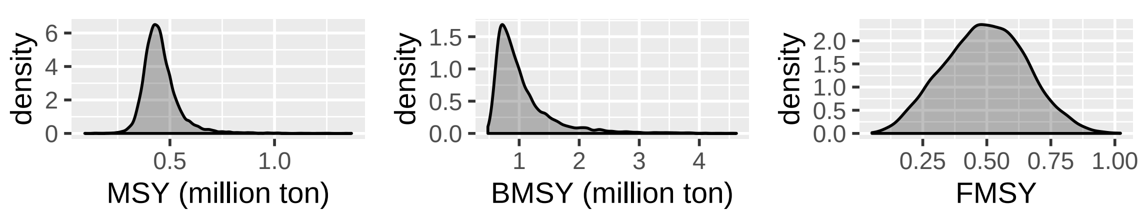
NB2 5 years


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

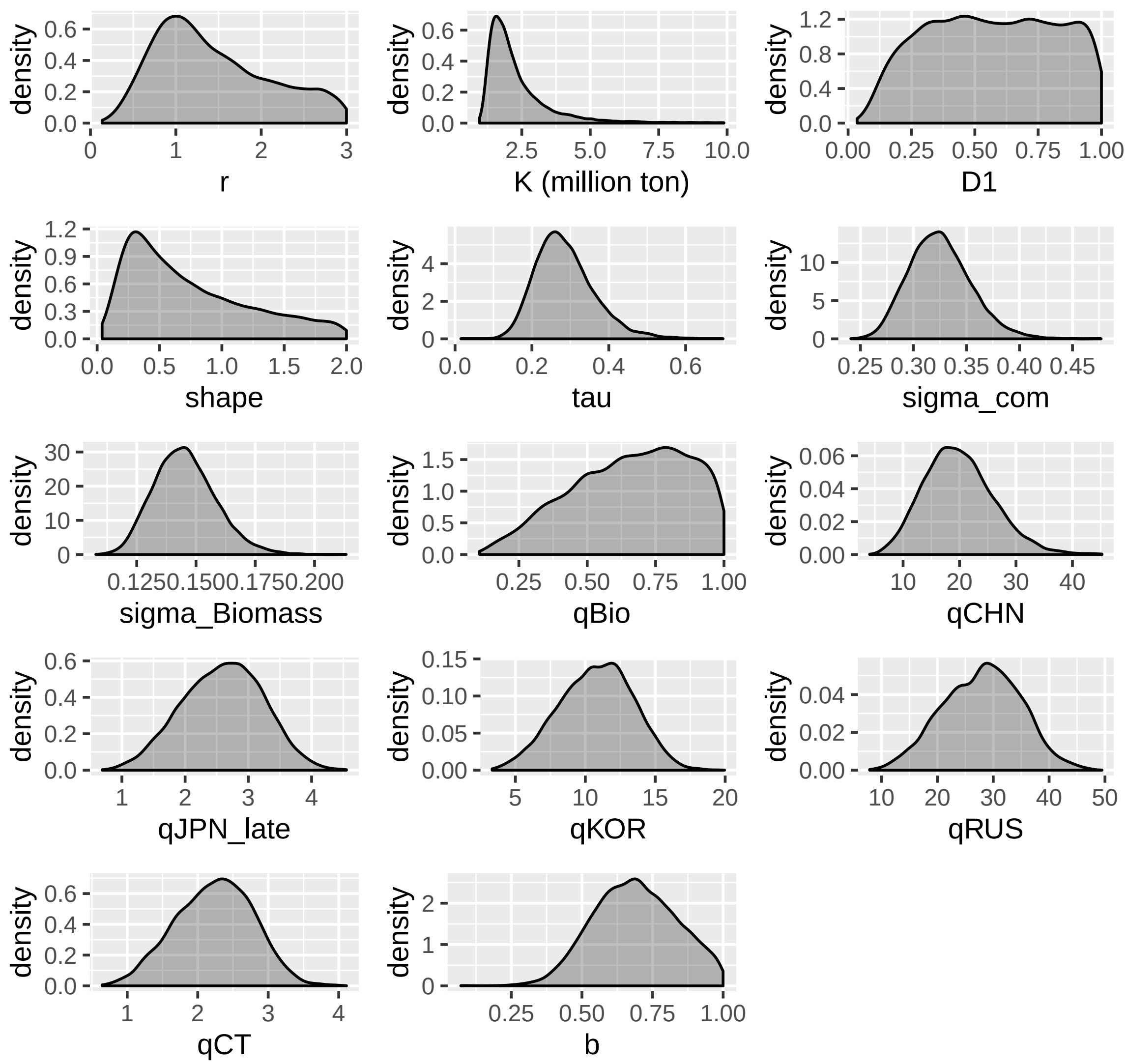

density
MSY (million ton)
BMSY (million ton)
FMSY

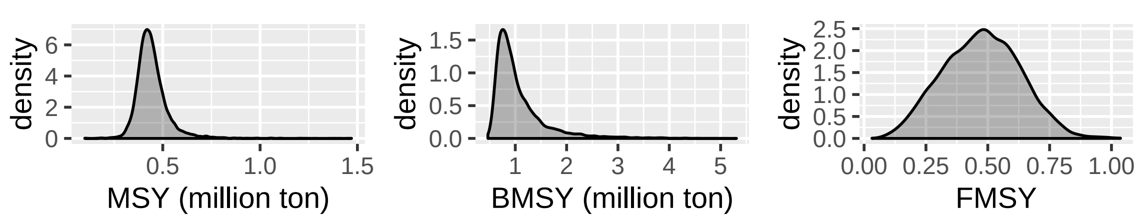
NB2 4 years


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

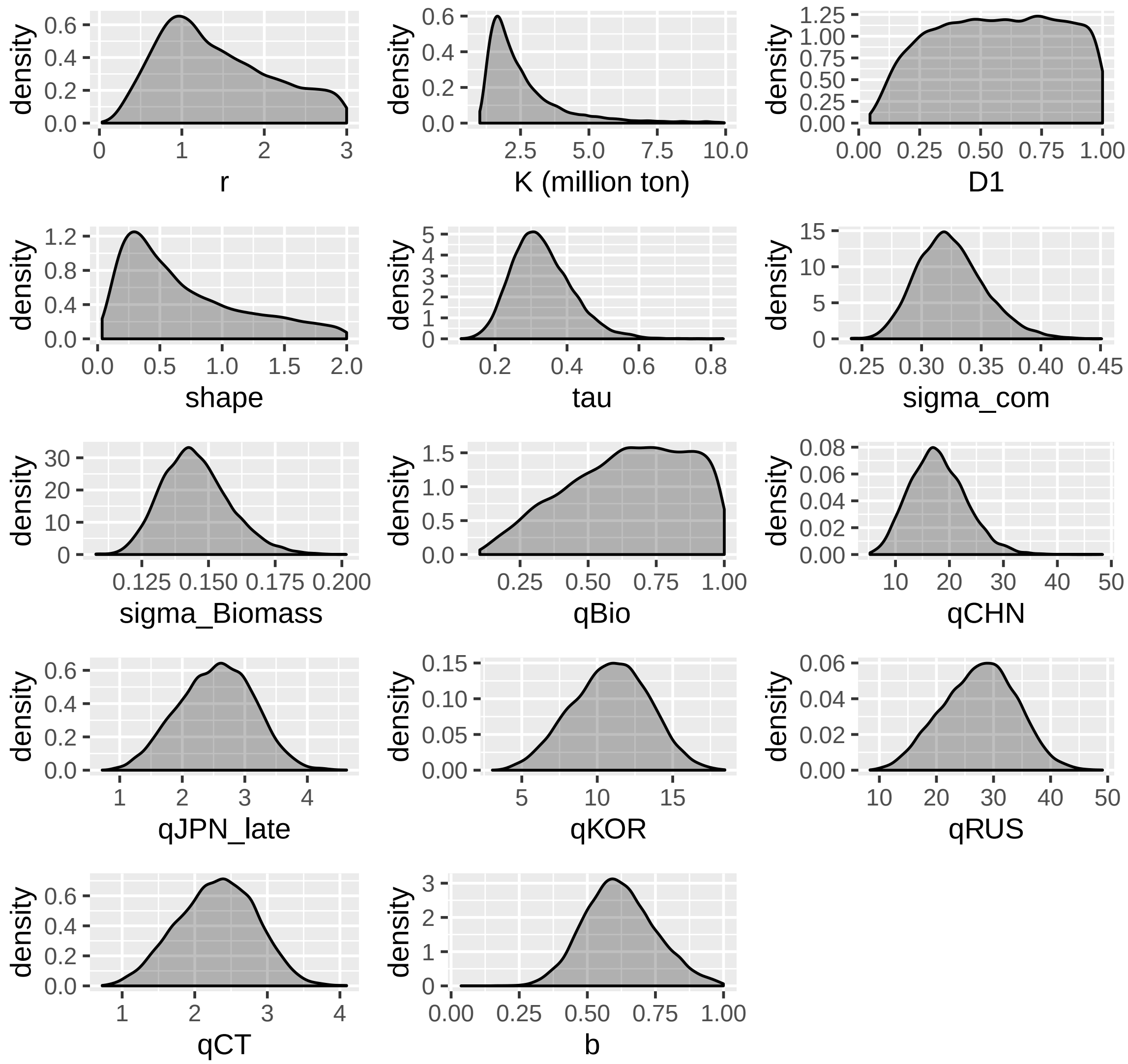

density
MSY (million ton)
BMSY (million ton)
FMSY

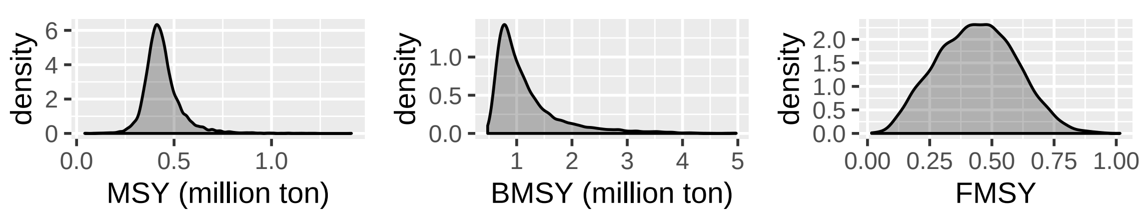
NB2 3 years


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

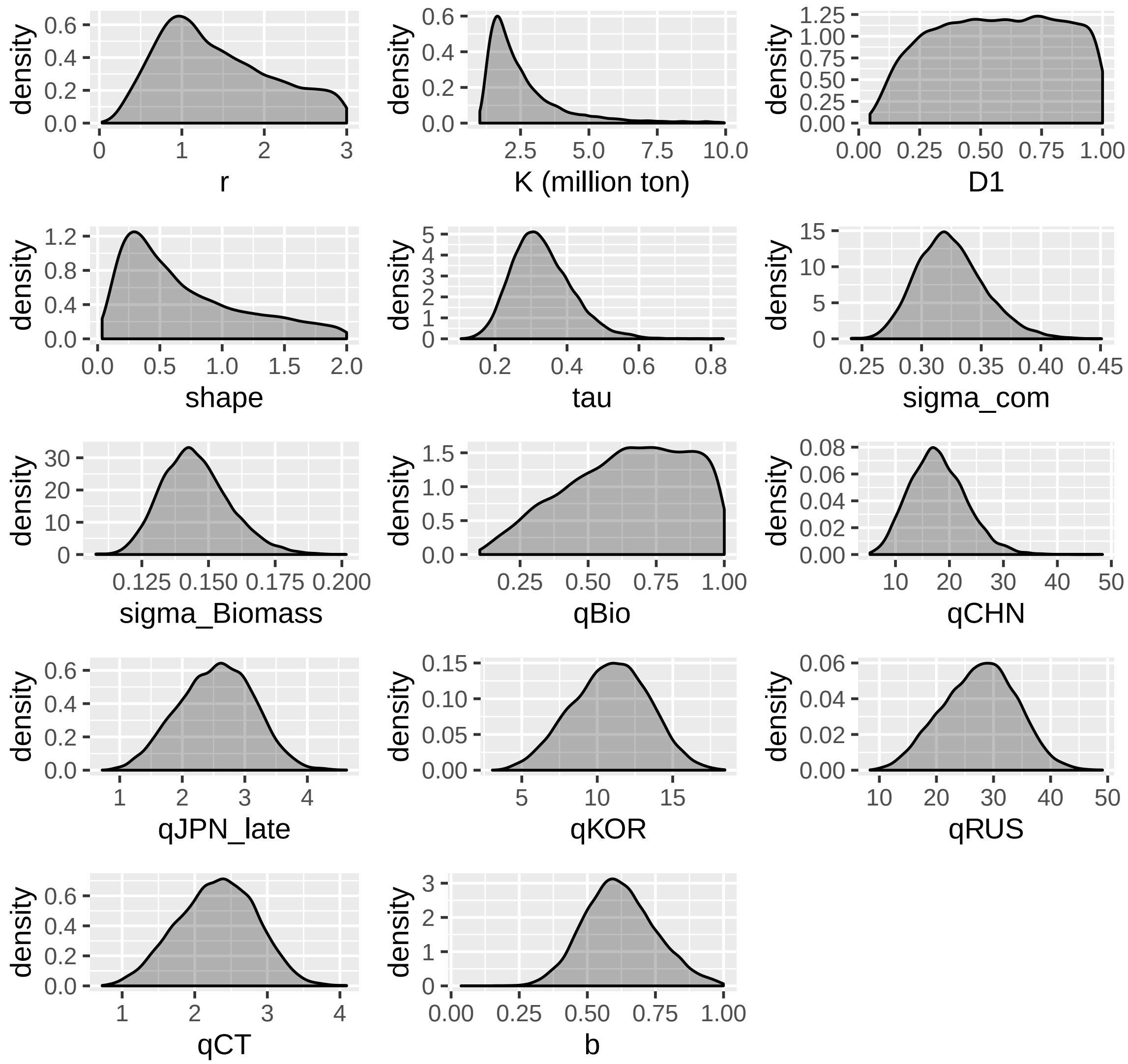

density
MSY (million ton)
BMSY (million ton)
FMSY

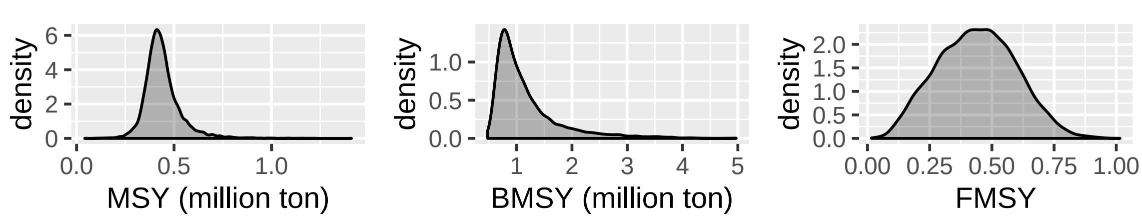
NB2 2 years


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

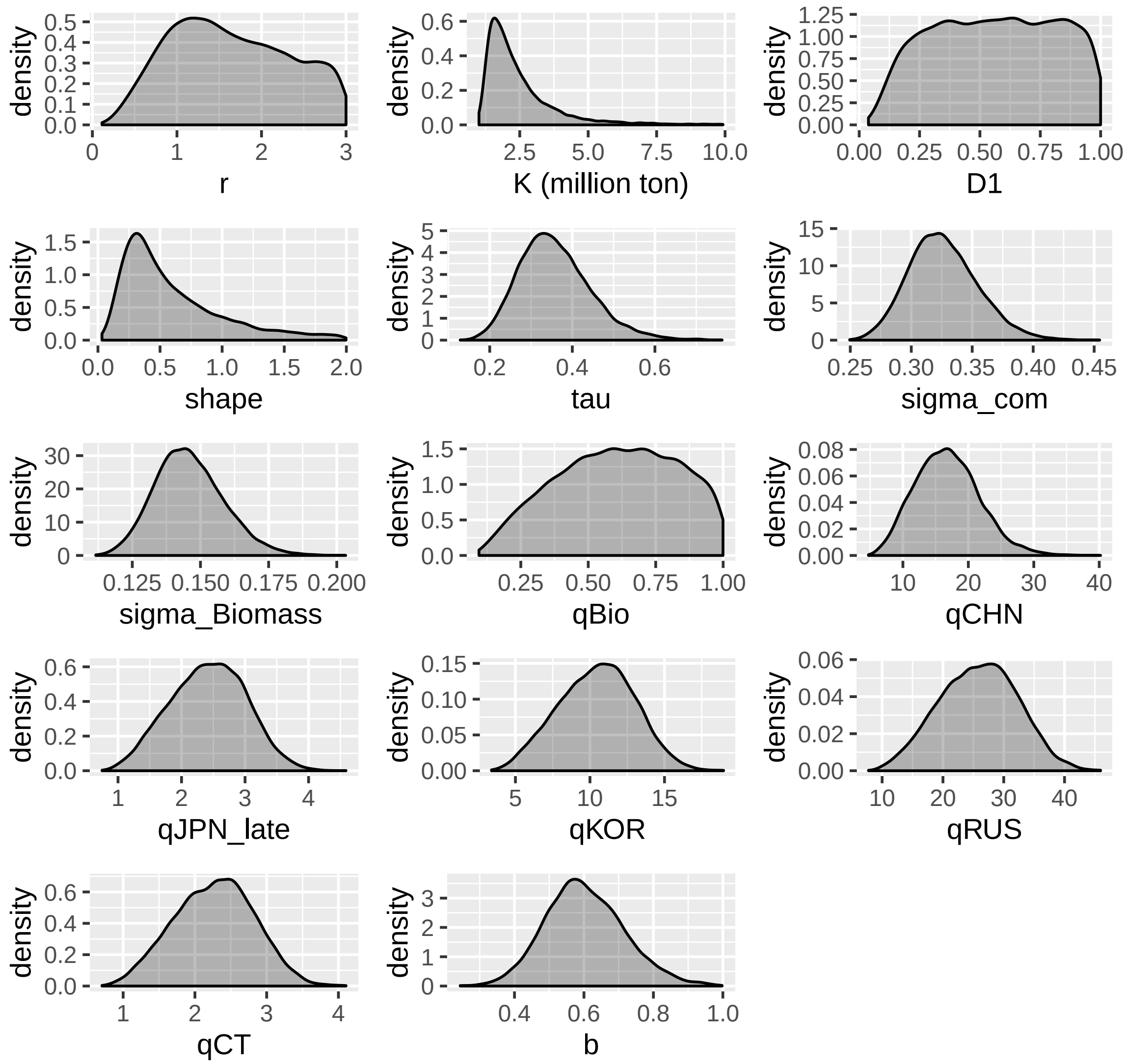

density
MSY (million ton)
BMSY (million ton)
FMSY

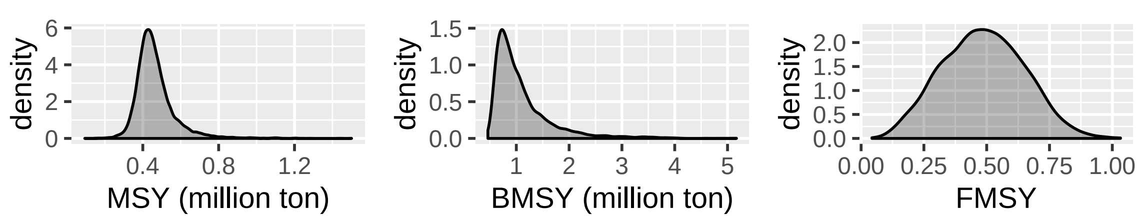
NB2 2 years


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

NB2 1 years


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

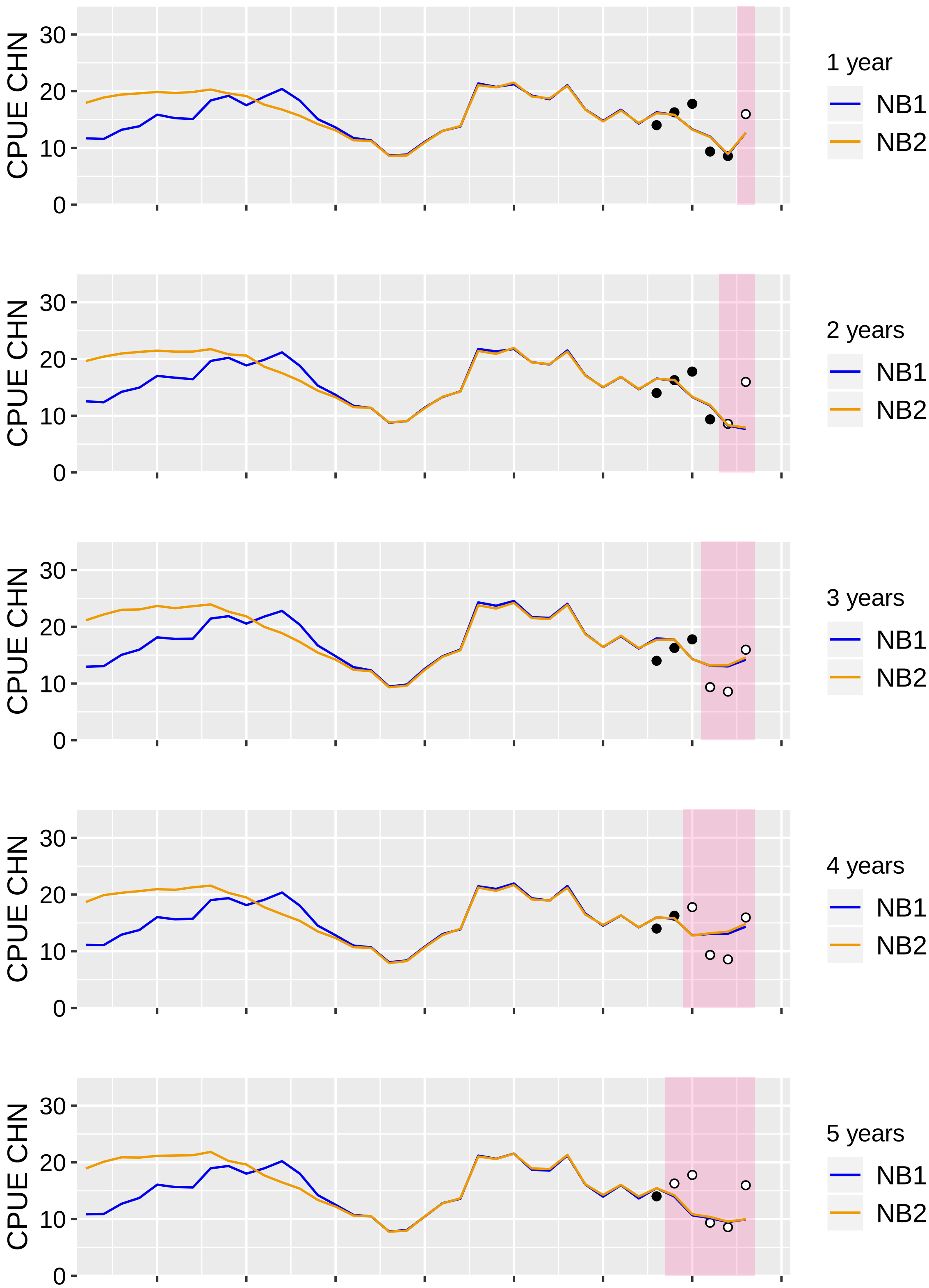

density
MSY (million ton)
BMSY (million ton)
FMSY

9.2.4 Results of parameters

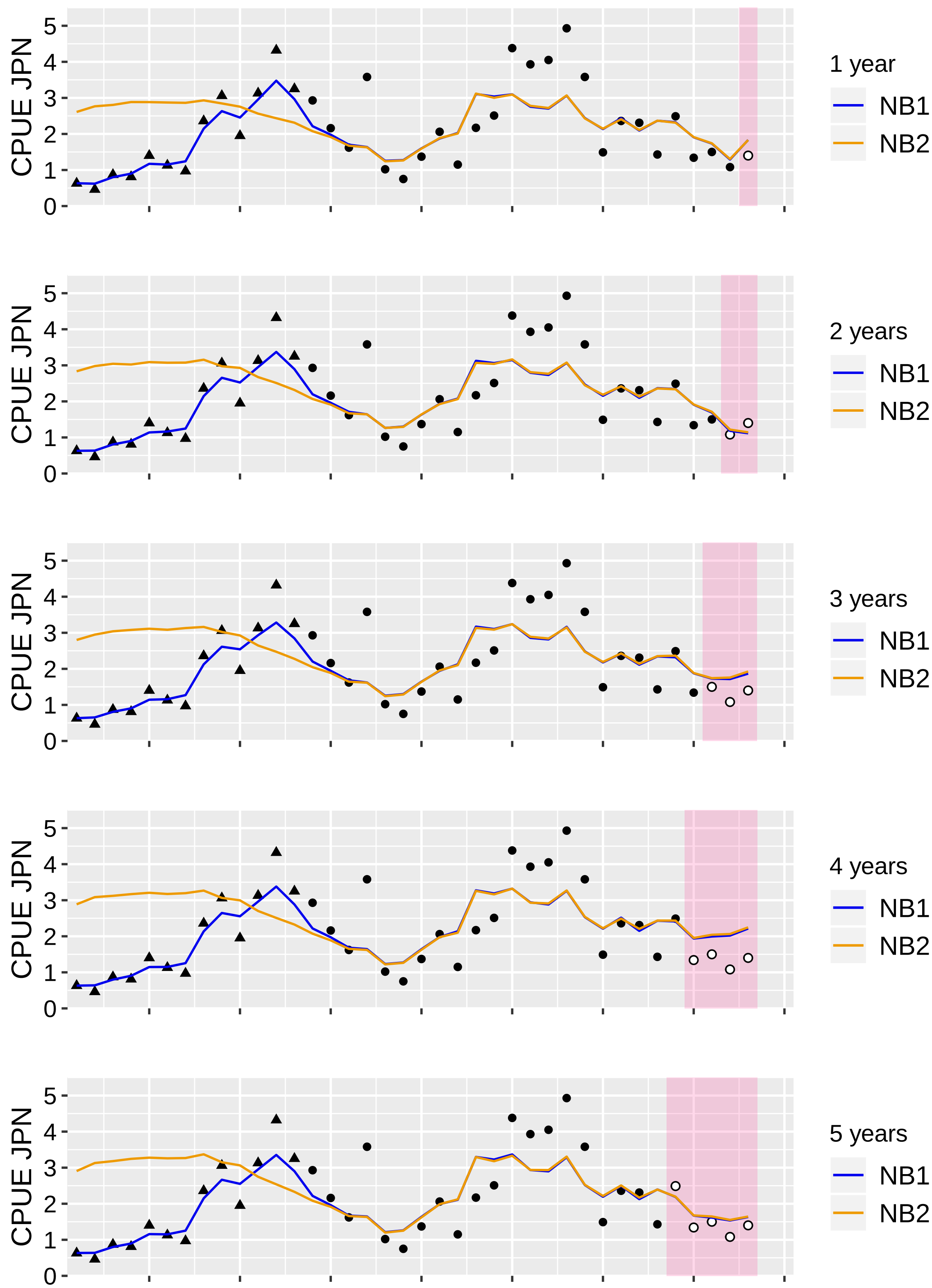
	1year		2years		3years		4years		5years	
	NB1	NB2	NB1	NB2	NB1	NB2	NB1	NB2	NB1	NB2
r	1.512	1.570	1.234	1.298	1.243	1.302	1.281	1.339	1.275	1.345
K (million ton)	2.079	2.060	2.071	2.126	2.035	1.957	1.962	1.919	1.960	1.921
qCHN	15.853	16.576	17.303	17.558	18.800	19.443	16.930	17.440	16.581	17.444
qJPN1	0.999		1.021		1.038		1.086		1.079	
qJPN2	2.332	2.432	2.513	2.563	2.511	2.614	2.611	2.724	2.660	2.773
qKOR	10.071	10.544	10.720	10.946	10.424	10.883	10.763	11.201	10.655	11.097
qRUS	24.691	25.992	27.099	27.805	26.843	28.308	27.774	29.112	28.408	29.822
qCT	2.186	2.287	2.283	2.323	2.159	2.257	2.088	2.175	2.023	2.116
qBio	0.574	0.615	0.646	0.668	0.634	0.679	0.648	0.689	0.678	0.719
Shape	0.465	0.470	0.555	0.542	0.590	0.604	0.594	0.607	0.586	0.596
sigma_com	0.320	0.324	0.319	0.322	0.320	0.323	0.311	0.313	0.307	0.309
sigma_Bio	0.131	0.145	0.130	0.144	0.131	0.145	0.127	0.140	0.125	0.138
tau	0.336	0.349	0.310	0.321	0.269	0.277	0.278	0.288	0.279	0.291
FMSY	0.463	0.486	0.429	0.439	0.446	0.476	0.470	0.496	0.465	0.490
BMSY (million ton)	0.932	0.922	0.956	0.971	0.941	0.907	0.913	0.894	0.910	0.889
MSY (million ton)	0.432	0.445	0.415	0.426	0.423	0.432	0.430	0.442	0.425	0.435
b	0.602	0.596	0.626	0.613	0.704	0.687	0.714	0.699	0.756	0.738

9.2.5 CPUE

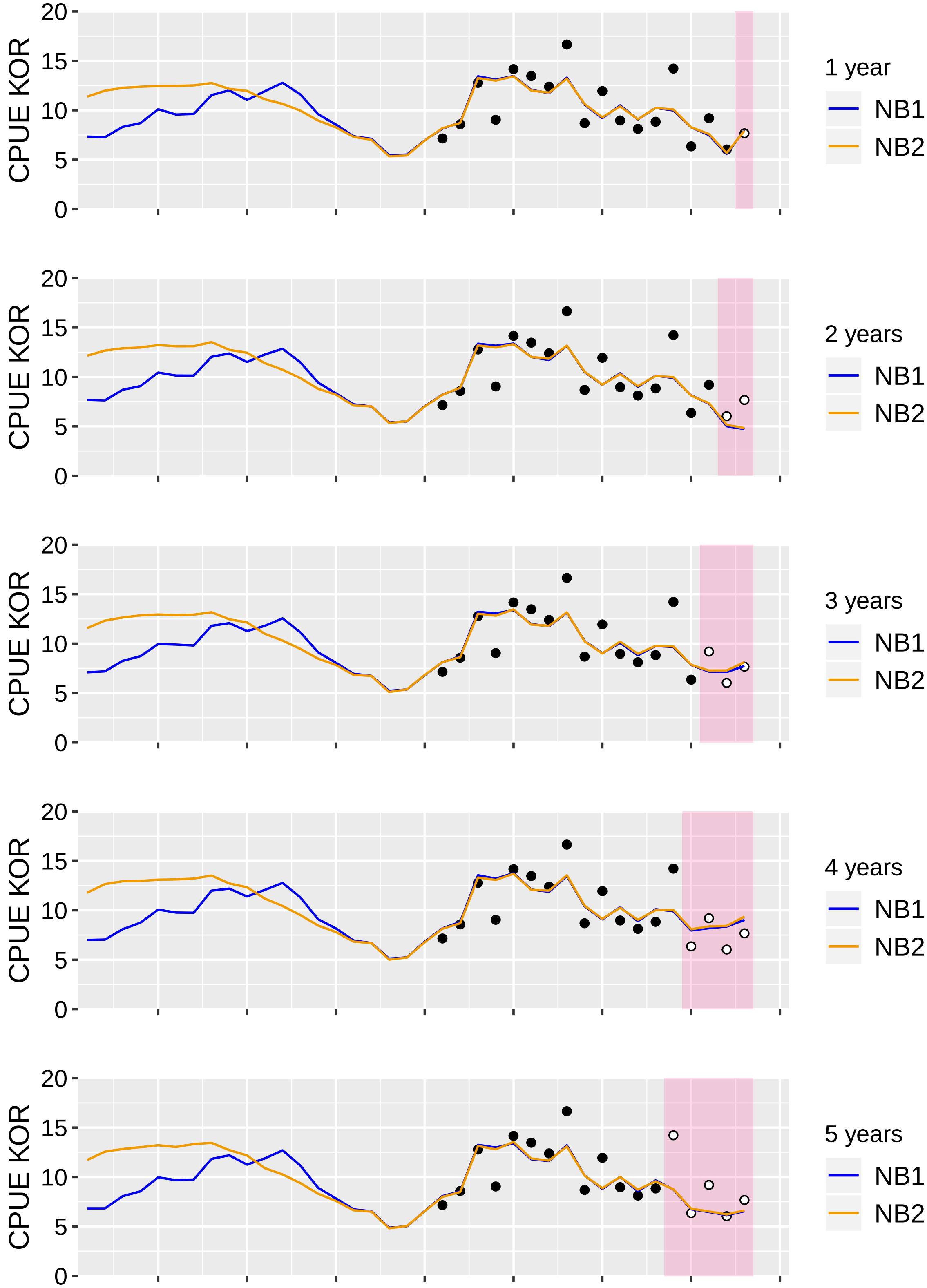
CPUE CHN



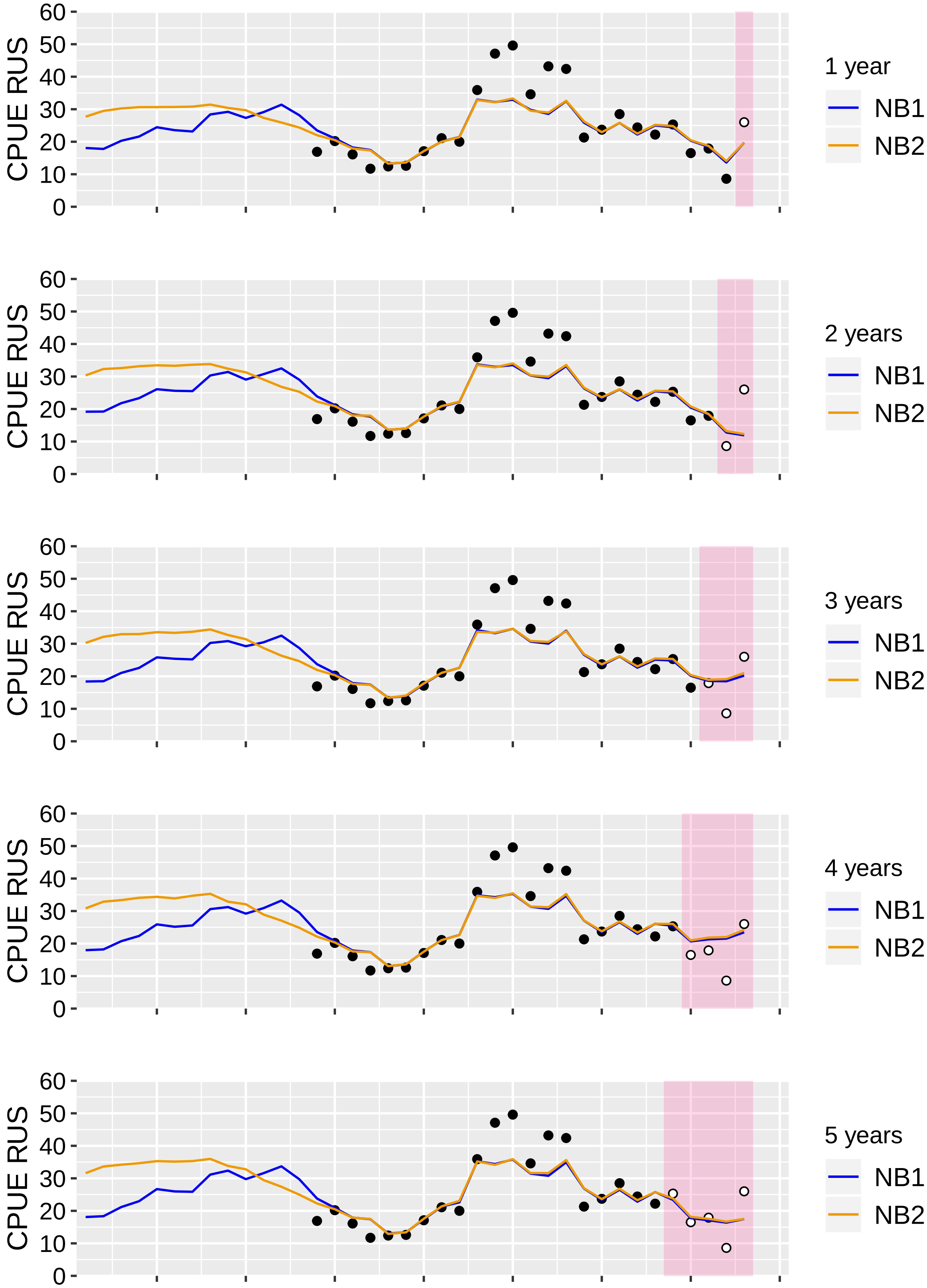
CPUE JPN



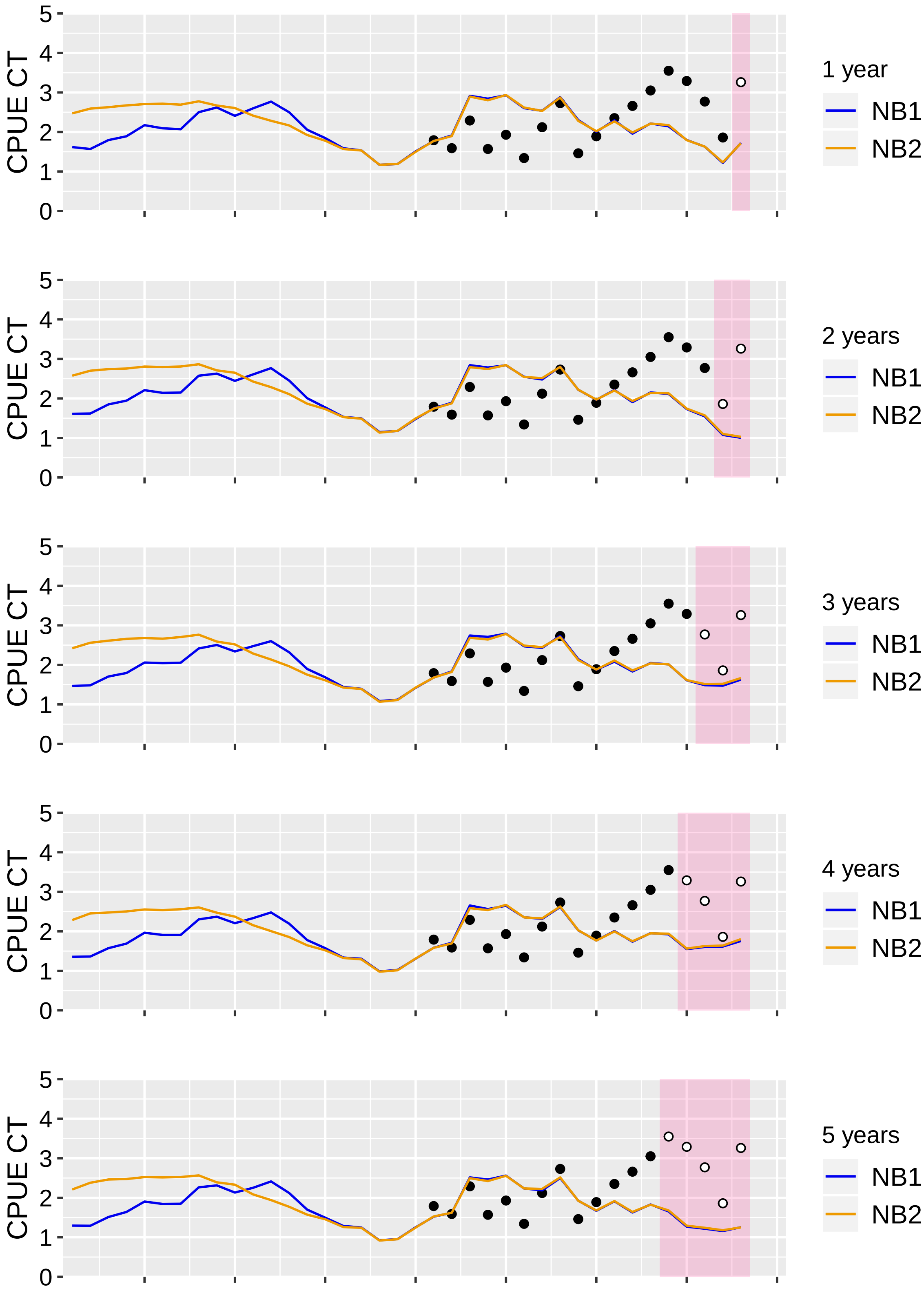
CPUE KOR


CPUE KOR
20
15
10
5
0
1 year
NB1
NB2
2 years
3 years
4 years
5 years

CPUE RUS

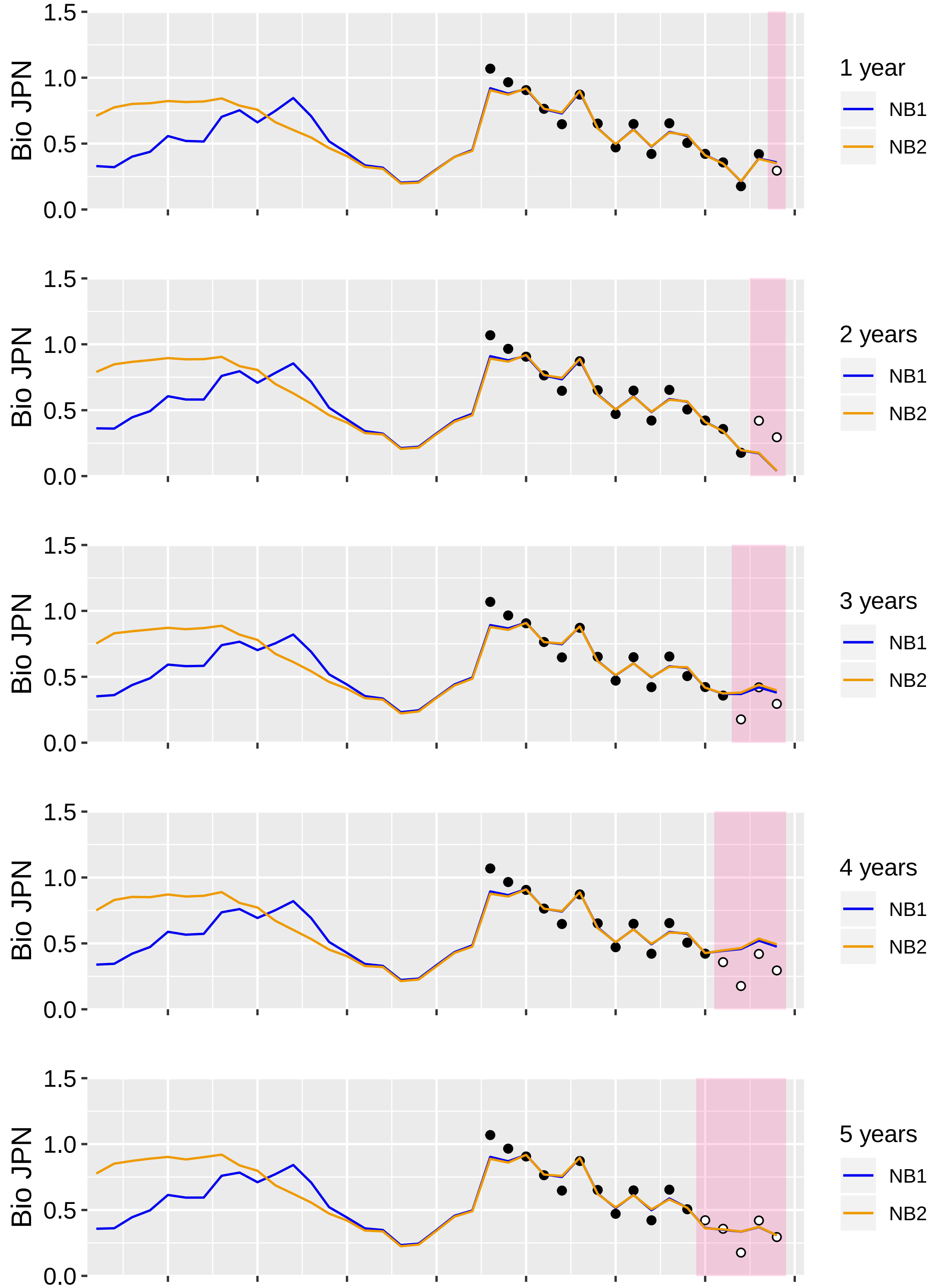

CPUE RUS
60
50
40
30
20
10
0
1 year
2 years
3 years
4 years
5 years
NB1
NB2

CPUE CT



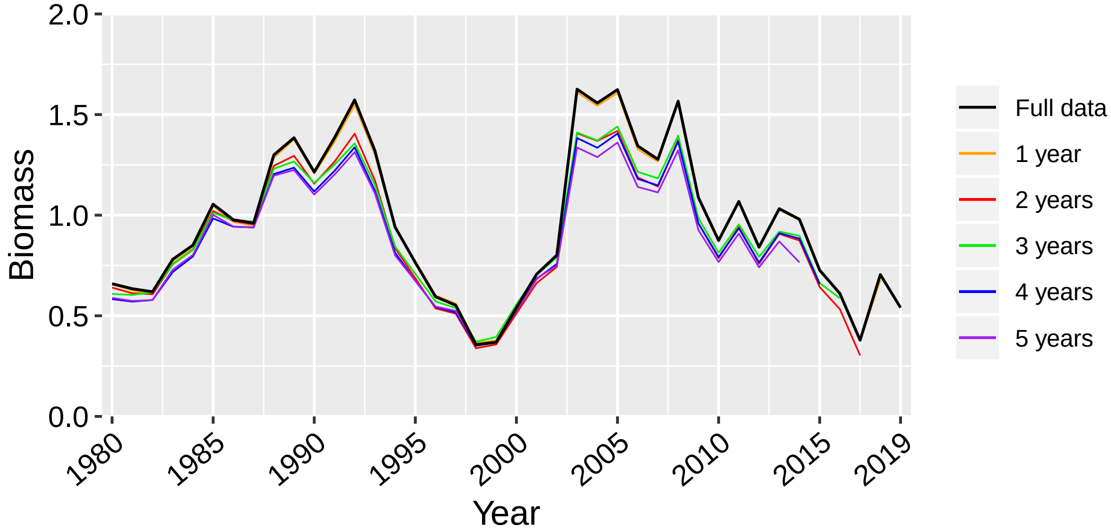
CPUE CT
0
1
2
3
4
5
1 year
NB1
NB2
2 years
NB1
NB2
3 years
NB1
NB2
4 years
NB1
NB2
5 years
NB1
NB2

Biomass JPN

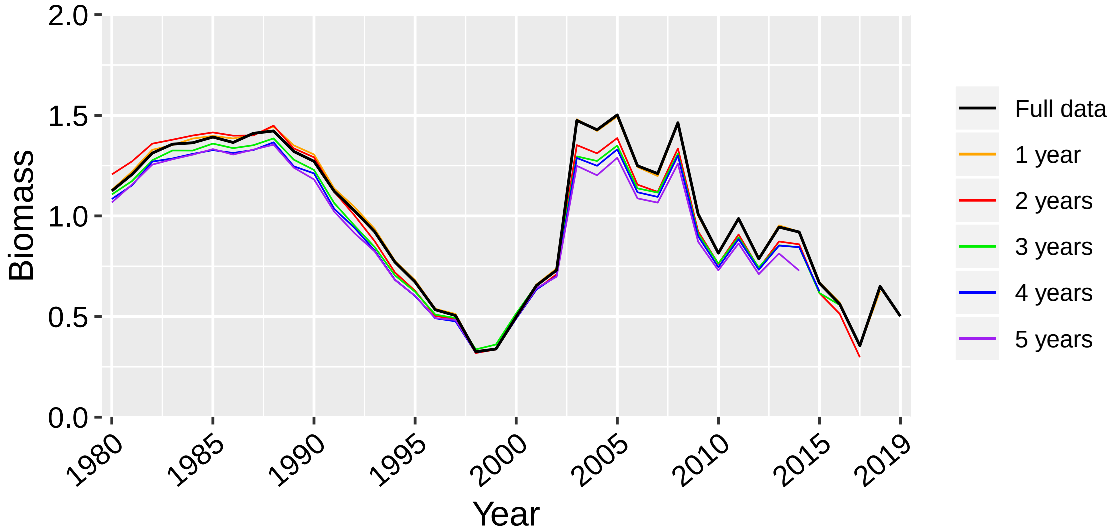

Bio JPN
1.5
1.0
0.5
0.0
1 year
NB1
NB2
2 years
NB1
NB2
3 years
NB1
NB2
4 years
NB1
NB2
5 years
NB1
NB2

9.2.6 Biomass

NB1

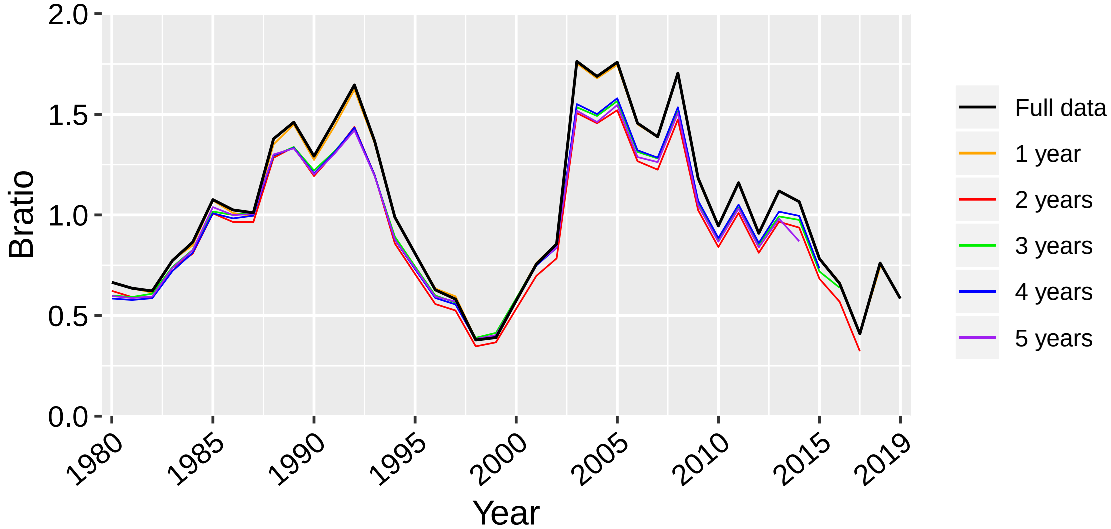


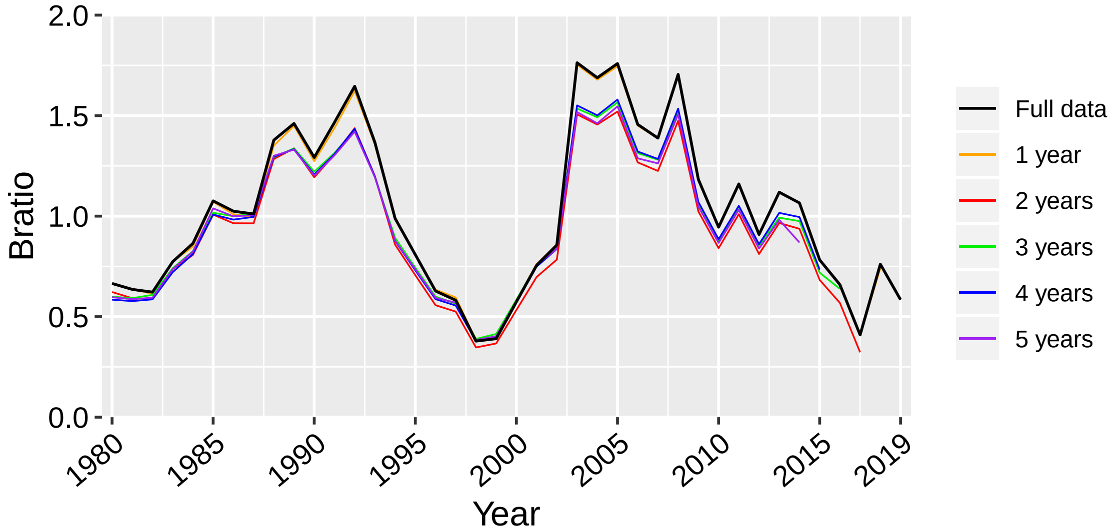
NB2



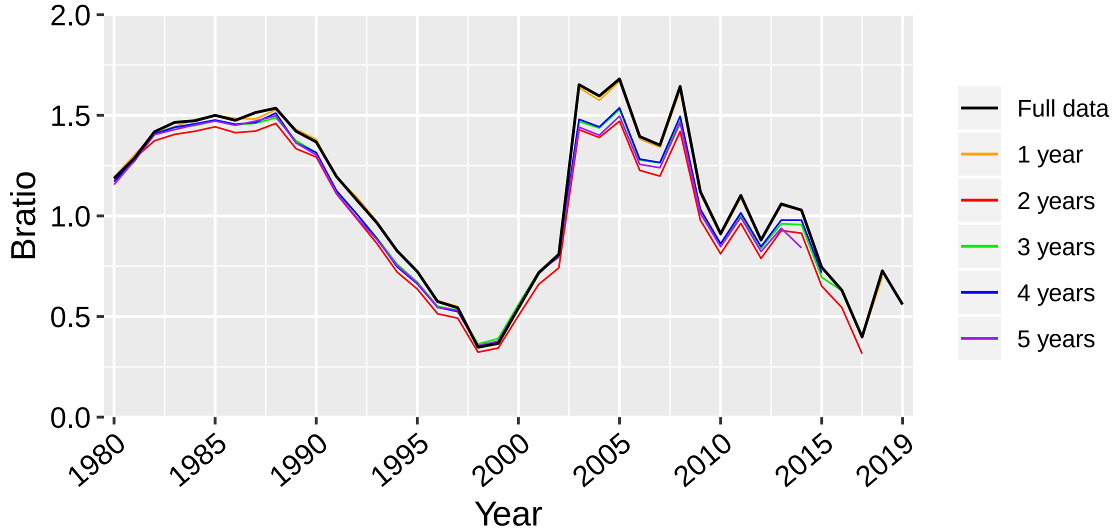
9.2.7 Bratio

NB1





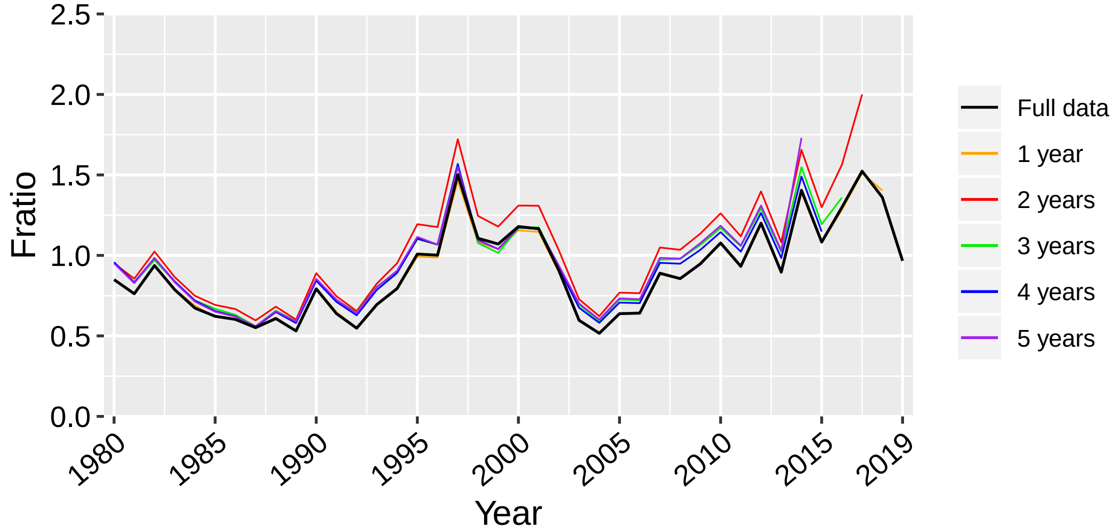
NB2



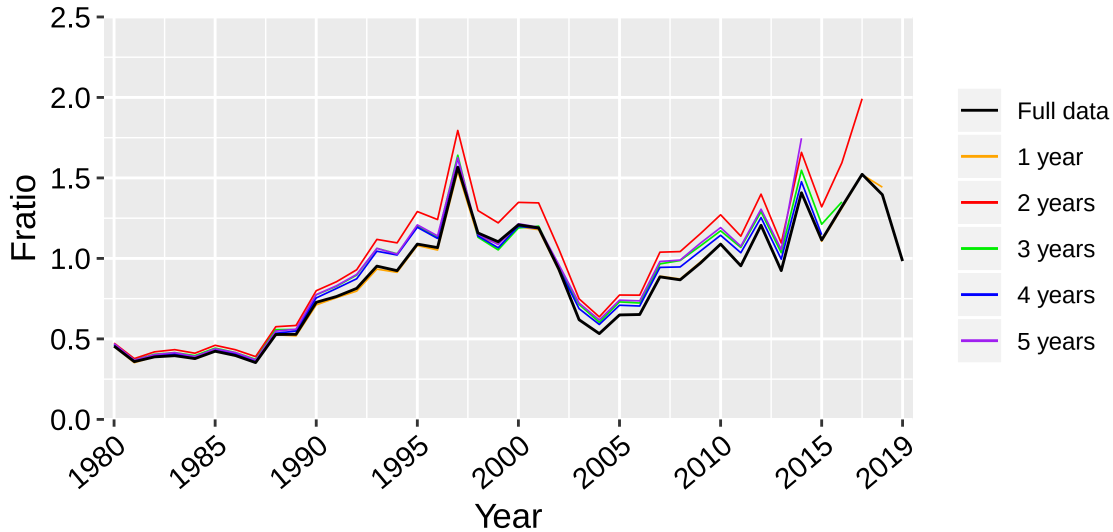
2.0
1.5
1.0
0.5
0.0
Bratio
1980
1985
1990
1995
2000
2005
2010
2015
2019
Year
Full data
1 year
2 years
3 years
4 years
5 years

9.2.8 Fratio

NB1



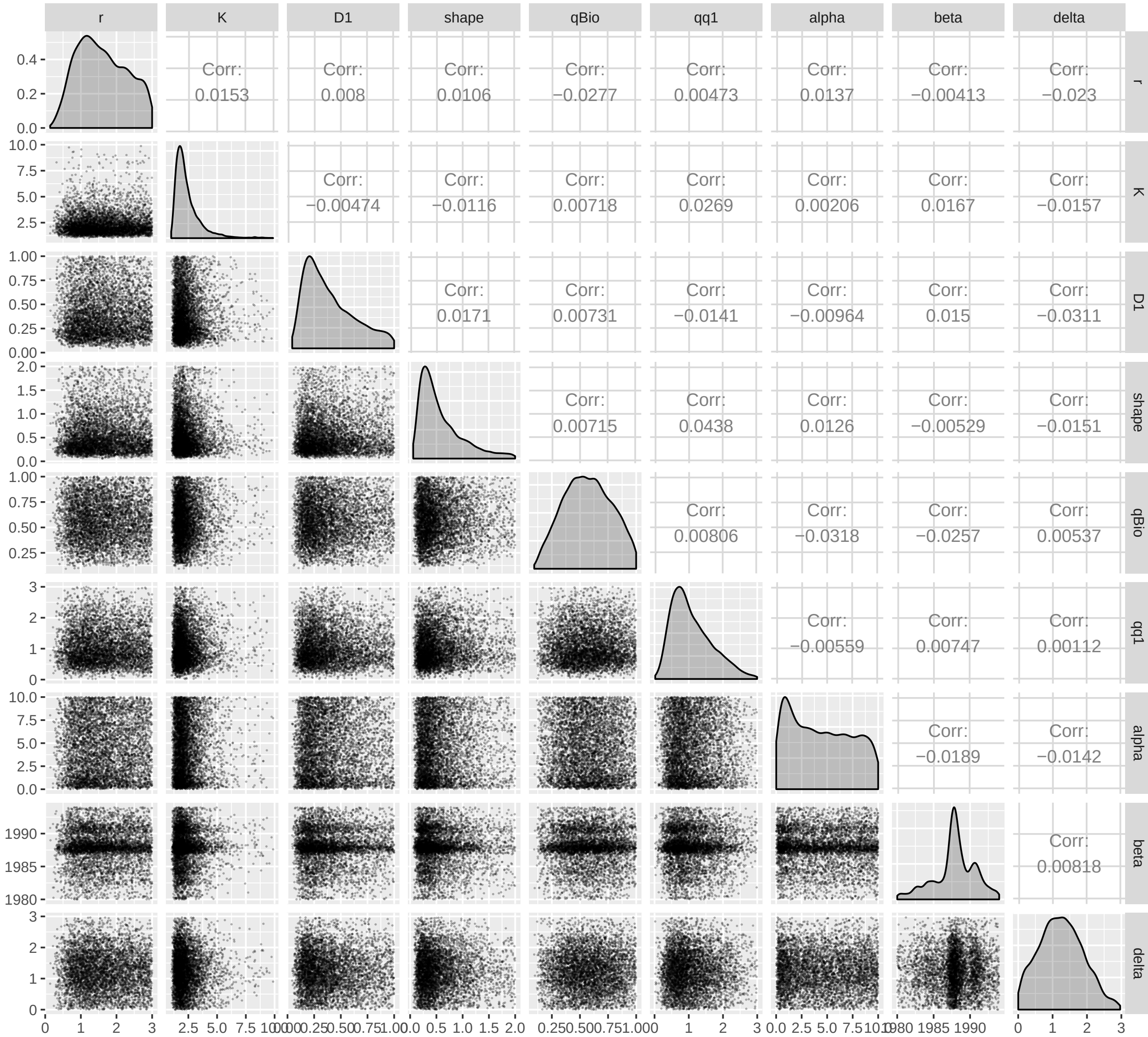
NB2



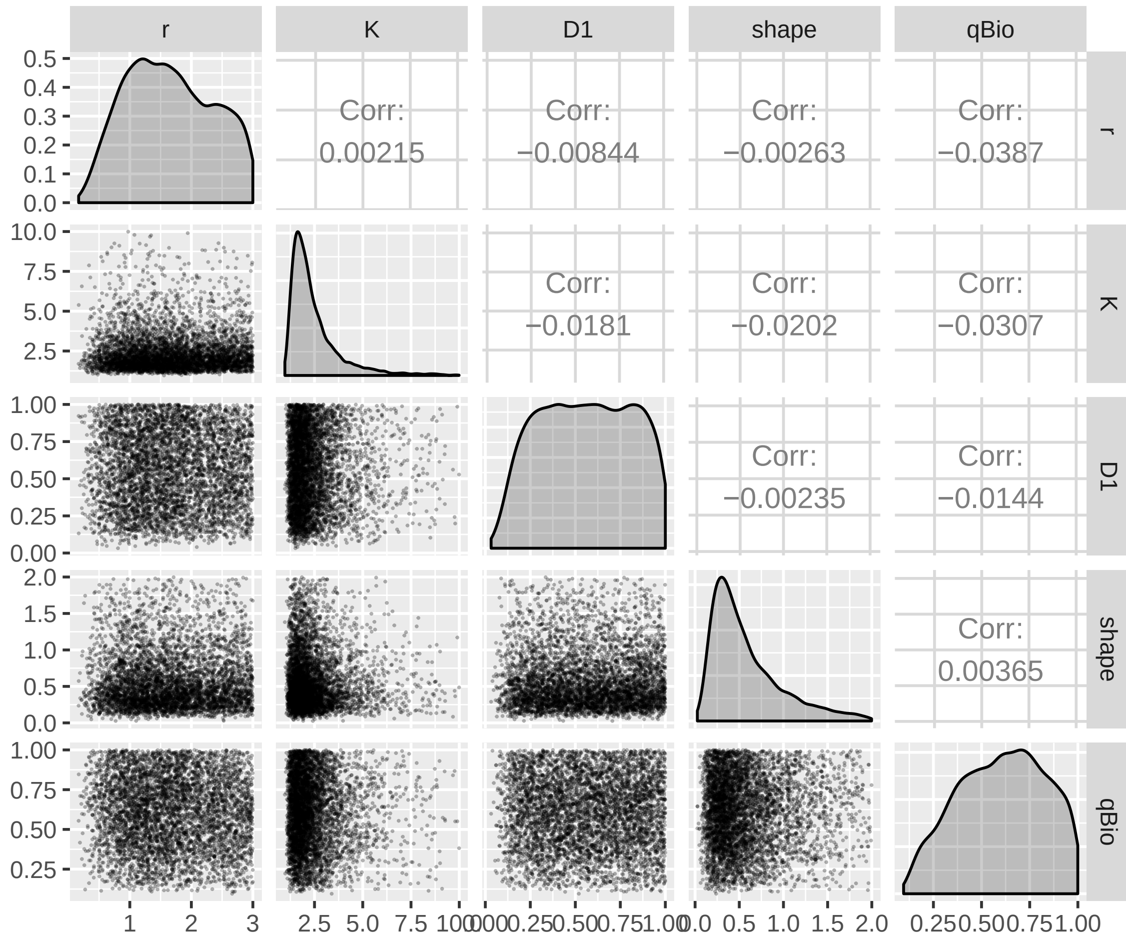
9.3 Correlation

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

Base case 1

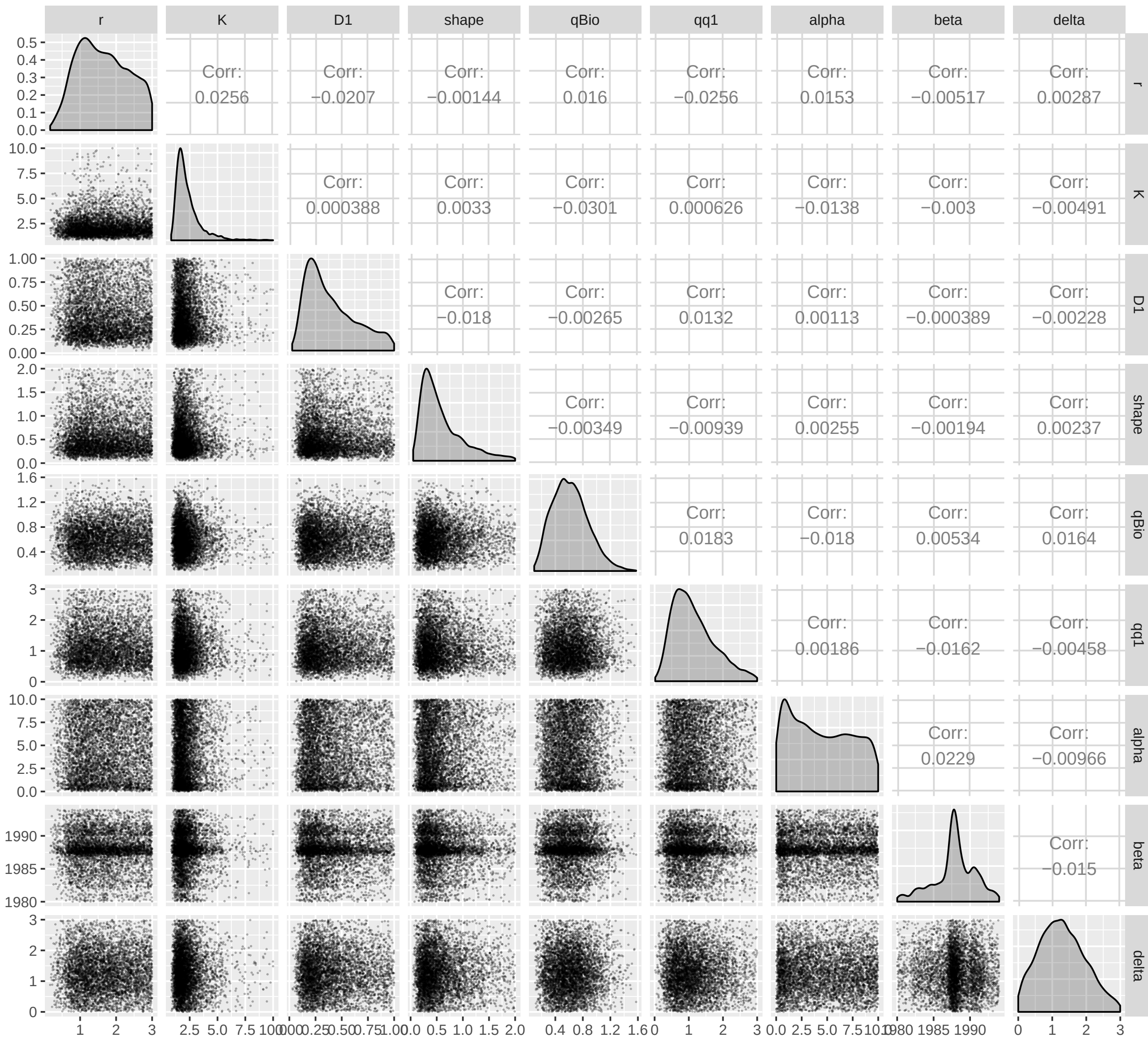


Base case 2

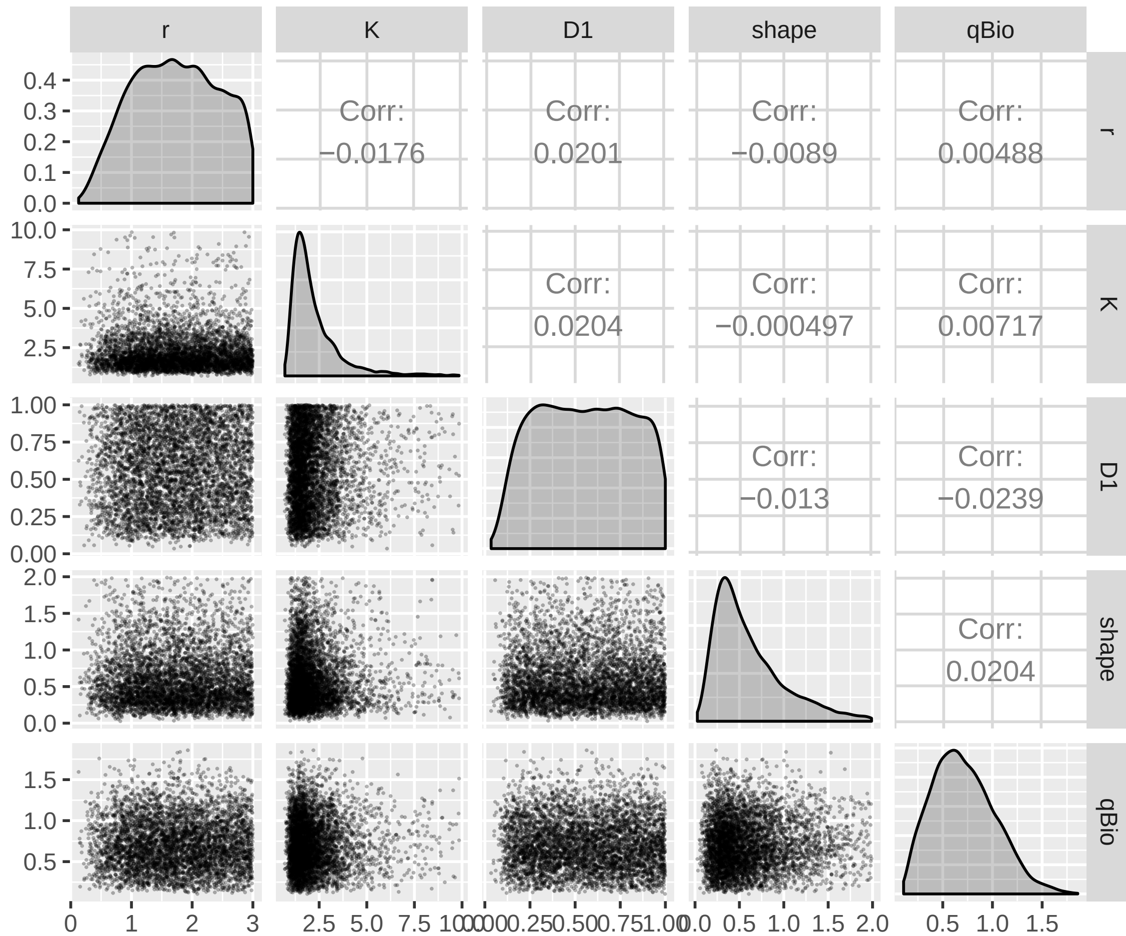


r
K
D1
shape
qBio
Corr:
0.00215
Corr:
−0.00844
Corr:
−0.00263
Corr:
−0.0387
Corr:
−0.0181
Corr:
−0.0202
Corr:
−0.0307
Corr:
−0.00235
Corr:
−0.0144
Corr:
0.00365

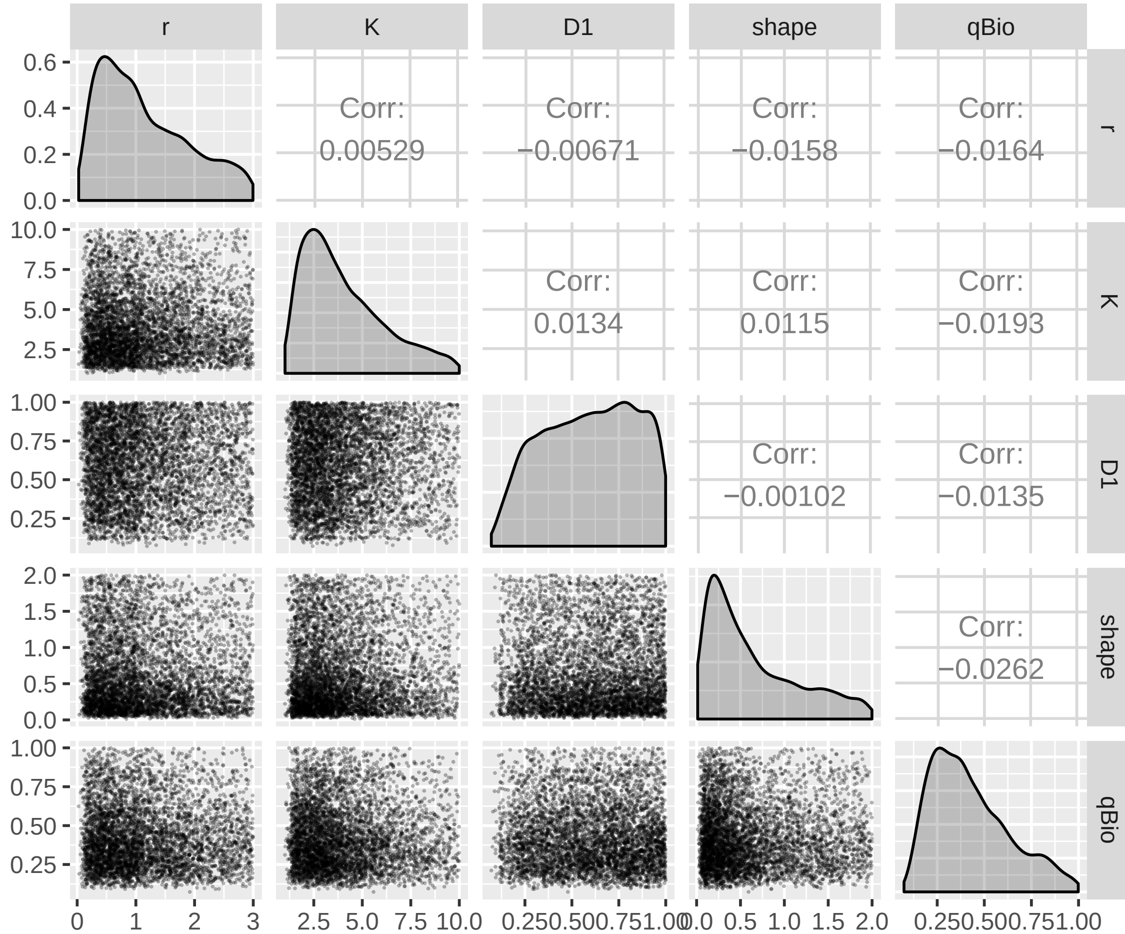
Sensitivity case 1



Sensitivity case 2



Sensitivity case 3



Sensitivity case 4