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Updates of stock assessment for Pacific saury in the North Pacific Ocean based on indices up to 2019 by using Bayesian state-space production models

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[Note: this document is an updated version of our earlier paper (NPFC-2020-SSC PS06-WP10) submitted at the SSC-PS-06 meeting in order to include the 2019 fishery-dependent abundance indices which were agreed in the SSC-PS-06 to use for review at the Special session in January 2021.]

SUMMARY

Stock assessment for the North Pacific saury was updated based on the specification (2 base cases and 4 sensitivity cases) agreed in the 5th SSC-PS meeting held in November 2019 with additionally available 2019 fishery-dependent indices endorsed in the SSC-PS-06 meeting. 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 with some modifications to accommodate the data period.

As for the combined base case stock assessment result, the 2019 median depletion level was only 20.1% (80%CI=12.9-27.5%) of the carrying capacity, declined from 30.7% (80%CI=20.0-42.0%) in 2018. Furthermore, B-ratio (=B/Bmsy) and F-ratio (=F/Fmsy) in 2019 were 0.437 (80%CI=0.294-0.608) and 1.067 (80%CI=0.754-1.514), respectively. For those three years average values between 2017 and 2019, B-ratio and F-ratio were respectively 0.503 (80%CI=0.349-0.677) and 1.428 (80%CI=1.048-1.948). In addition, the probability of the stock being in the green Kobe quadrant in 2019 was estimated to be nearly 0% , while the probability of being in the red Kobe quadrant was assessed to be greater than 60%. On the weight-of-evidence available now, the current Pacific saury stock is determined to be overfished and subject to overfishing.

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

INTRODUCTION

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

In the 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. Also, in the SSC-PS-06 meeting held in November 2020, fishery-dependent indices were updated up to 2019 and these were endorsed to use in the stock assessment. Here, we will report on our updated stock assessment based on the specification with additionally available 2019 fishery-dependent indices.

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

	New base case (NB1)	**New base case (NB2)**	**Sensitivity case (NS1, NS2)**	**Sensitivity case (NS3, NS4)**
Initial year	1980	1980	1980	1980/2001
Biomass survey	B_obs = B_est*q1 ~ LN(log(q*B), s^2) q~U(0, 1)	Same as left	q~U(0, 2)	q~U(0, 1) 2003-2019
CPUE	CHN(2013-2019) JPN_early(1980-1993) (with time-varying q) JPN_late(1994-2019) KOR(2001-2019) RUS(1994-2019) CT(2001-2019)	CHN(2013-2019) JPN_late(1994-2019) KOR(2001-2019) RUS(1994-2019) CT(2001-2019)	Two sets as on the left for NS1 and NS2 respectively	NS3: Joint CPUE 2001-2019 (no JPN_early) NS4: Joint CPUE 2001-2019 and JPN_early
Variance component	Variances of logCPUEs are assumed to be common and 6 times of that 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 2019

2) standardized CPUE indices by the following five Members up to 2019

3) fishery-independent survey by Japan from 2003 to 2019

4) joint CPUE from 2001 to 2019

Specification of analysis

We basically used the similar statistical models as Chiba and Kitakado (2019) by following the PS06 specification described 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:

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

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.

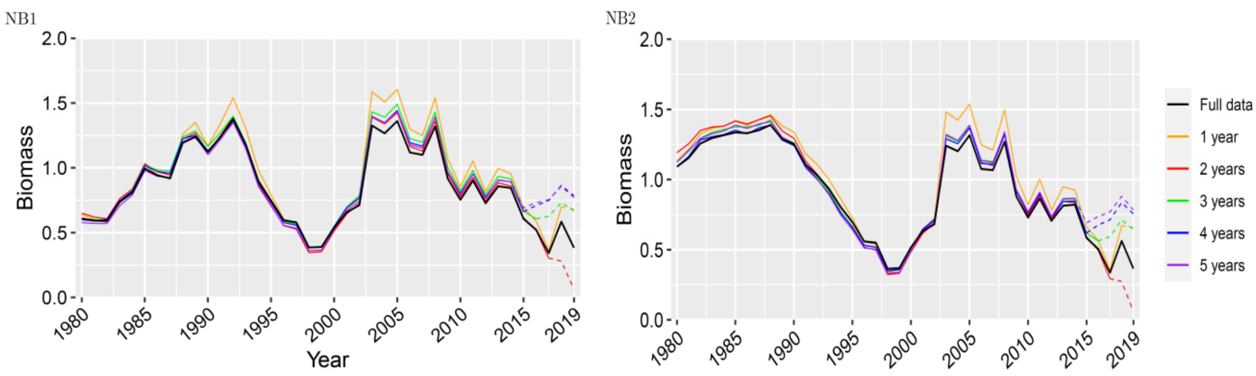


Figure 1. Results of retrospective (solid) and hindcasting (shaded) analyses for the two base cases. The hindcasting (prediction after the retrospective analysis) was carried out using the observed catch records.

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 combined base case stock assessment result, the 2019 median depletion level was only 20.1% (80%CI=12.9-27.5%) of the carrying capacity, declined from 30.7% (80%CI=20.0-42.0%) in 2018. Furthermore, B-ratio (=B/Bmsy) and F-ratio (=F/Fmsy) in 2019 were 0.437 (80%CI=0.294-0.608) and 1.067 (80%CI=0.754-1.514), respectively. For those three years average values between 2017 and 2019, B-ratio and F-ratio were respectively 0.503 (80%CI=0.349-0.677) and 1.428 (80%CI=1.048-1.948).

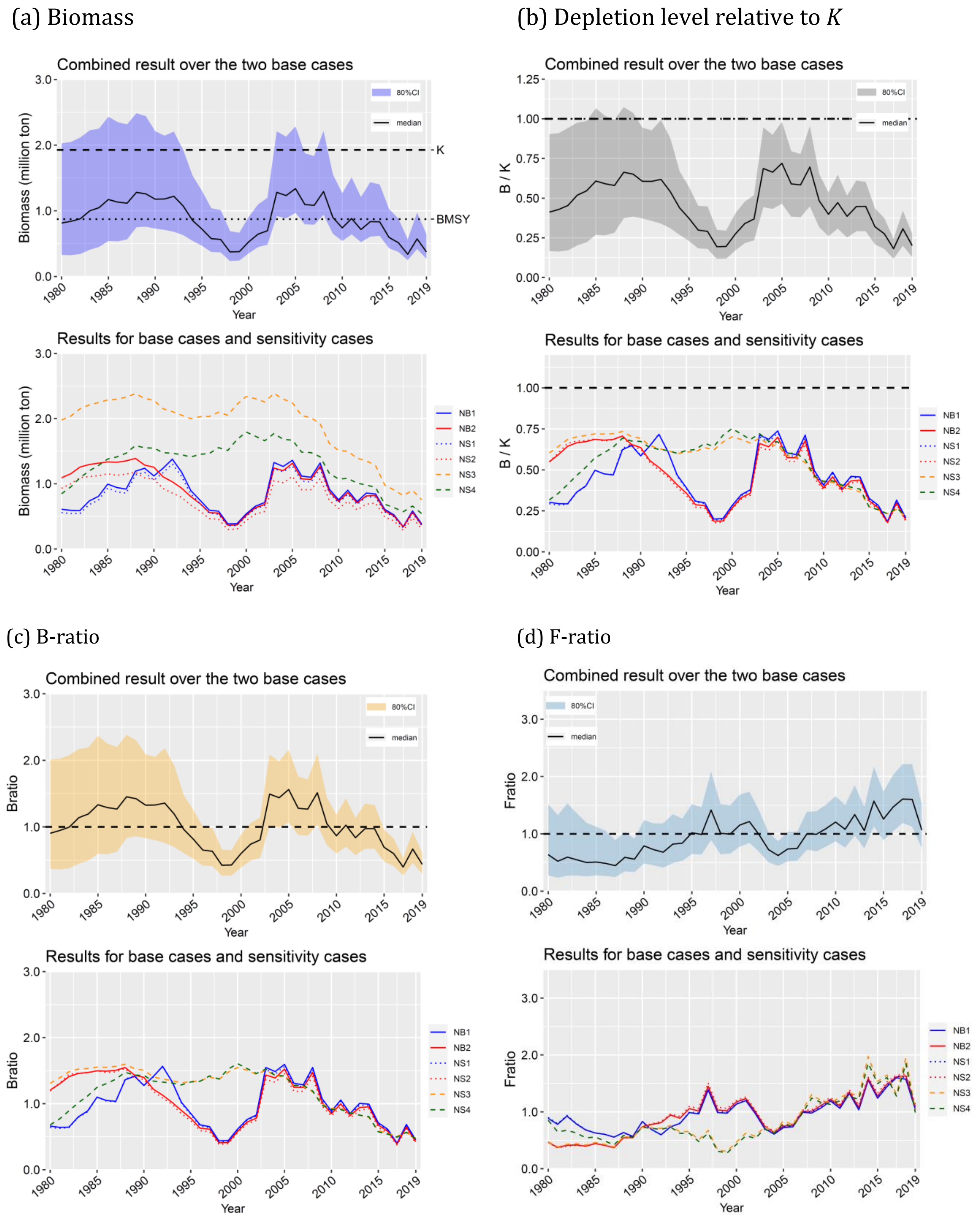


Figure 2. Results of trajectories over the two base cases of (a) biomass, (b) depletion level relative to the carrying capacity, (c) B-ratio and (d) F-ratio.

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

	Mean	Median	Lower10th	Upper10th
C_2019	0.192	0.192	0.192	0.192
AveC_2017_2019	0.298	0.298	0.298	0.298
AveF_2017_2019	0.678	0.691	0.411	0.925
F_2019	0.510	0.515	0.299	0.716
FMSY	0.477	0.480	0.288	0.659
MSY (million ton)	0.428	0.419	0.354	0.510
F_2019/FMSY	1.111	1.067	0.754	1.514
AveF_2017_2019/FMSY	1.477	1.428	1.048	1.948
K (million ton)	2.243	1.928	1.370	3.419
B_2018 (million ton)	0.656	0.572	0.420	0.971
B_2019 (million ton)	0.429	0.374	0.269	0.643
AveB_2017_2019	0.489	0.428	0.319	0.724
BMSY (million ton)	1.003	0.873	0.639	1.485
BMSY/K	0.454	0.443	0.403	0.527
B_2018/K	0.310	0.307	0.200	0.420
B_2019/K	0.203	0.201	0.129	0.275
AveB_2017_2019/K	0.231	0.232	0.151	0.308
B_2018/BMSY	0.684	0.667	0.460	0.929
B_2019/BMSY	0.447	0.437	0.294	0.608
AveB_2017_2019/BMSY	0.510	0.503	0.349	0.677

Evidently, Figure 3, which is the Kobe plot with time series of median B-ratio and F-ratio for 1980-2019, also shows that the probability of the population being in the green Kobe quadrant in 2019 was estimated to be nearly 0% , while the probability of being in the red Kobe quadrant was assessed to be greater than 60%. On the weight-of-evidence available now, the current Pacific saury stock is determined to be overfished and subject to overfishing.

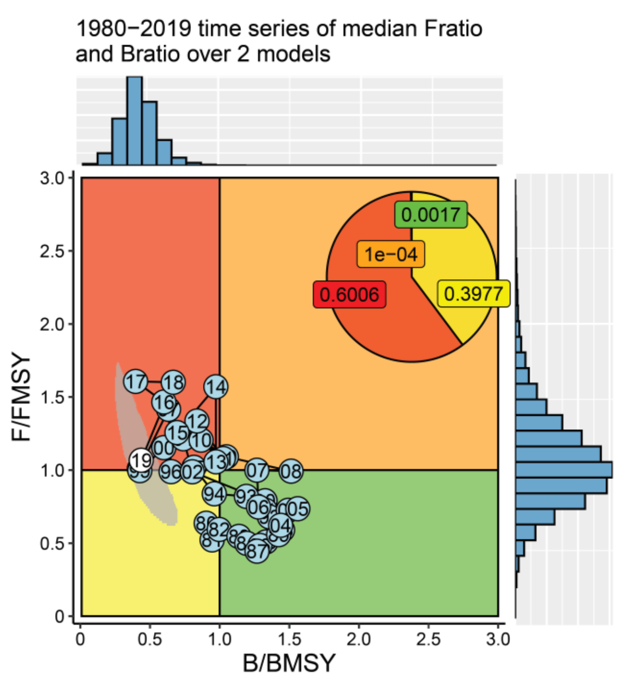


Figure 3. Kobe plot with time series of median B-ratio and F-ratio for 1980-2019.

Future projection and risk analysis

Figure 4 shows the median of biomass trajectory with future projection for different catch levels in 2020-2024 relative to the average catch over 2017-2019 (catch in 2020 is assumed to be the 2017-2019 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.

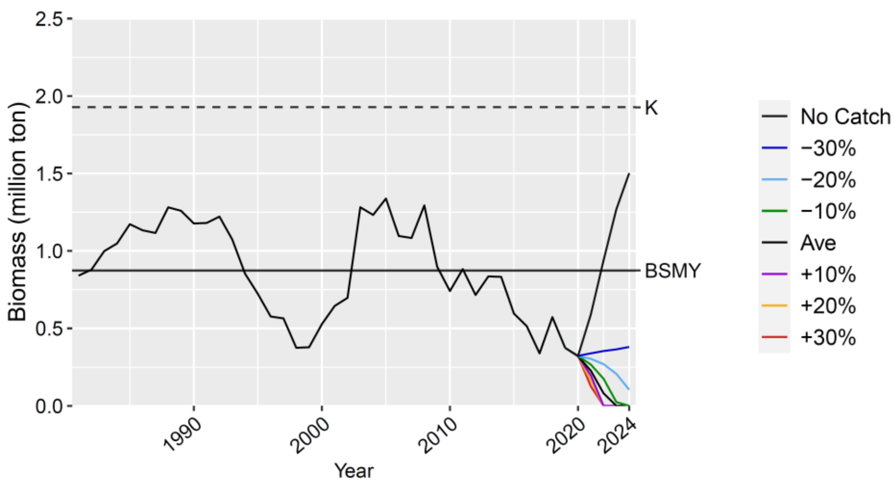


Figure 4. Median of biomass trajectory with future projection under the 8 different catch scenarios.

Table 3. Risk table for different catch levels relative to 2017-2019 average catch.

	Red	Orange	Yellow	Green	B<BMSY	F>FMSY
+30%	0.954	0.004	0.004	0.038	0.958	0.958
+20%	0.931	0.002	0.009	0.057	0.940	0.934
+10%	0.905	0.001	0.017	0.077	0.922	0.907
±0%	0.856	0.001	0.032	0.111	0.889	0.857
-10%	0.783	0.000	0.057	0.161	0.839	0.783
-20%	0.690	0.000	0.098	0.212	0.788	0.690
-30%	0.577	0.000	0.140	0.282	0.718	0.577
No Catch	0.000	0.000	0.163	0.837	0.163	0.000

Conclusion

1) Biomass level: the 2019 median depletion level was only 20.1% (80%CI=12.9-27.5%) 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 2019 were 0.437 (80%CI=0.294-0.608) and 1.067 (80%CI=0.754-1.514), respectively. For those three years average values between 2017 and 2019, B-ratio and F-ratio were respectively 0.503 (80%CI=0.349-0.677) and 1.428 (80%CI=1.048-1.948).

3) The probability of the stock being in the green Kobe quadrant in 2019 was estimated to be nearly 0%, while the probability of being in the red Kobe quadrant was assessed to be greater than 60%.

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

5) The MSY was estimated around 419,000 tons (80%CI=354,000-510,000), 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 X=B2019*Fmsy=374,000*0.480=179,520 (tons).

6) However, the information on further decline in 2020 abundance indices (fishery-independent index and nominal CPUEs) as well as 2020 catches (see the stock assessment report adopted in SSC-PS-06 meeting for more detail) warrants further decrease from X for setting TAC.

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-PS05.

NPFC (2020) Report of the SSC-PS06.

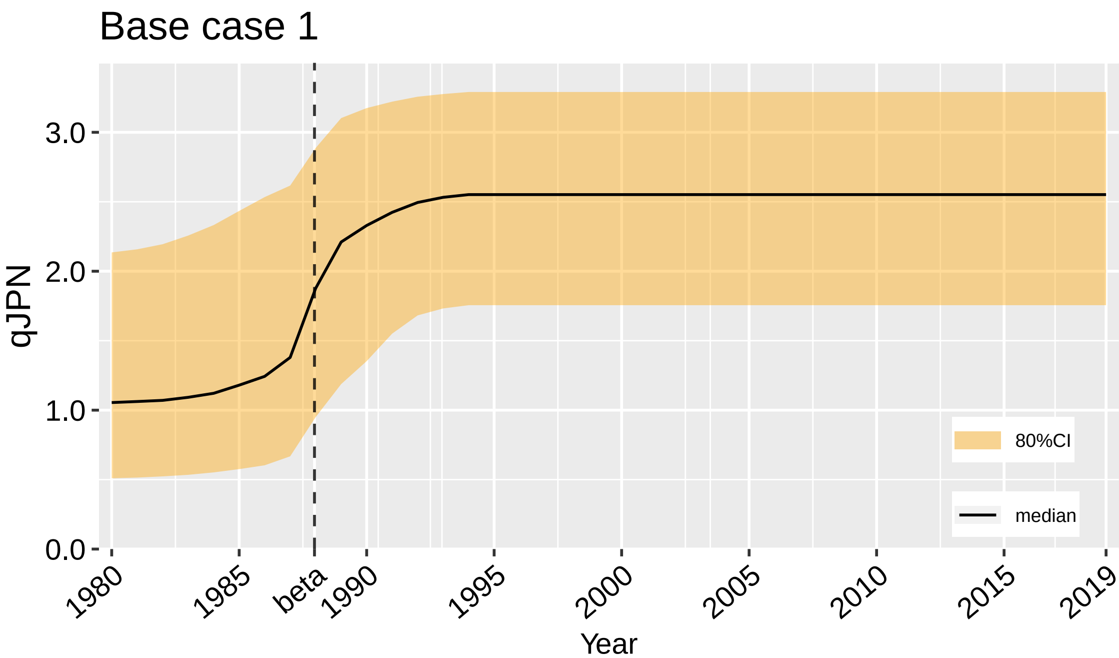
Item	Authors' note
(1) Identify the data that will be available to the stock assessment;	As shown in the main section.
(2) Evaluate data quality and quantity and potential error sources (e.g., sampling errors, measurement errors) and associated statistical properties (e.g., biased or random errors, statistical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

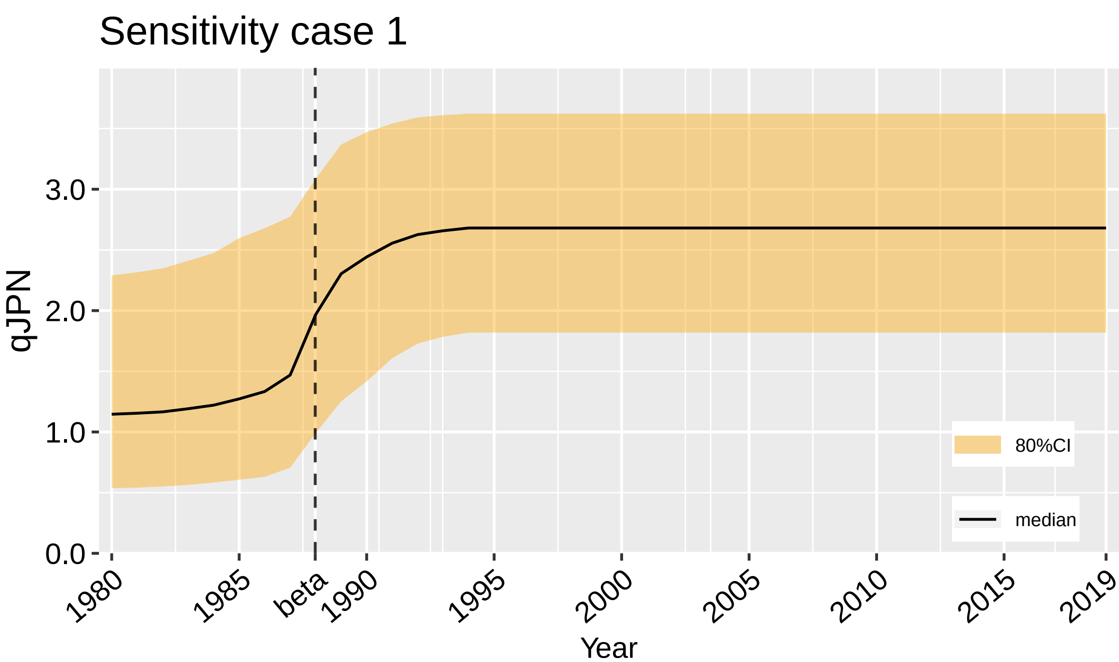
Appendix:

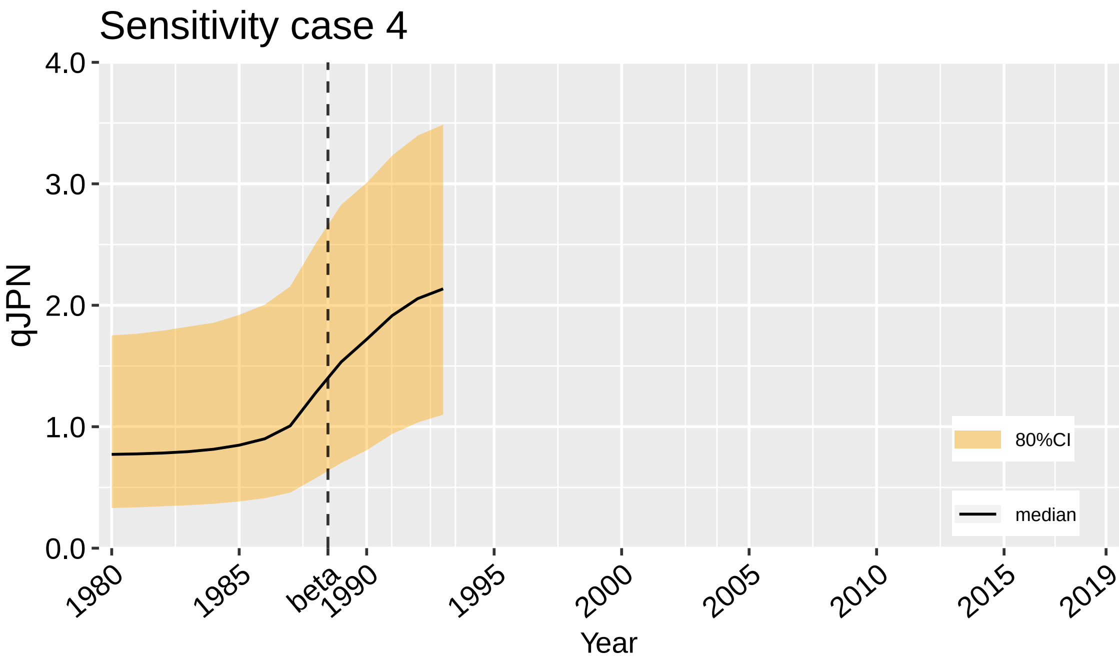
Toshihide Kitakado, Yuki Ueda, Ren Tamura and Nanako Sekiguchi

Contents

1 Estimated time-varying catchability



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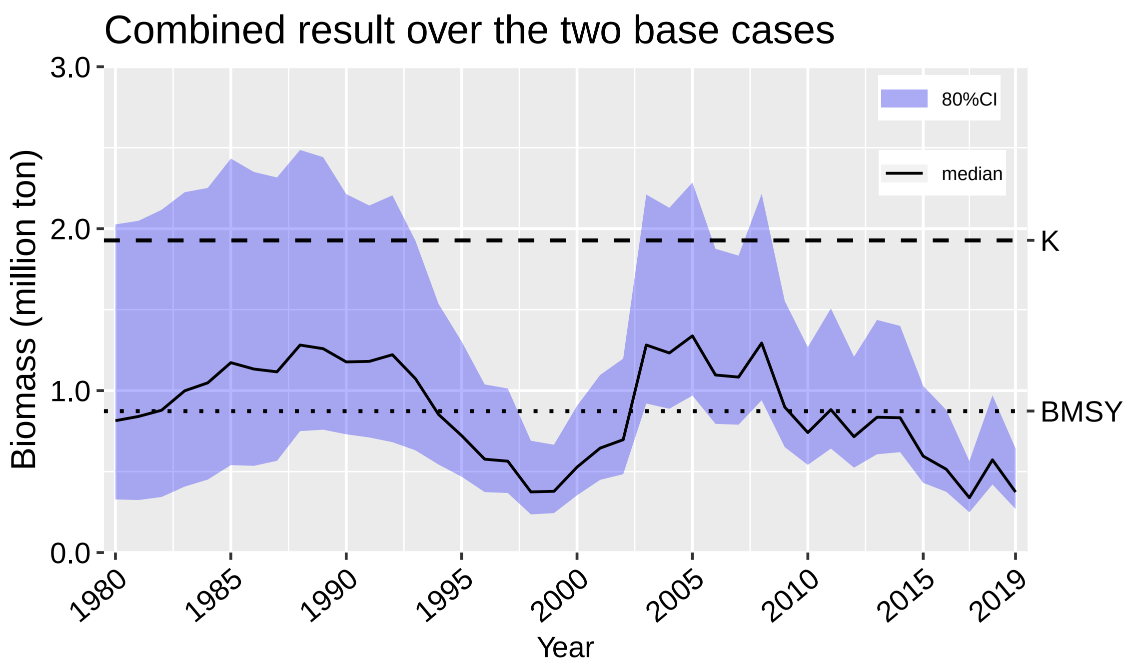
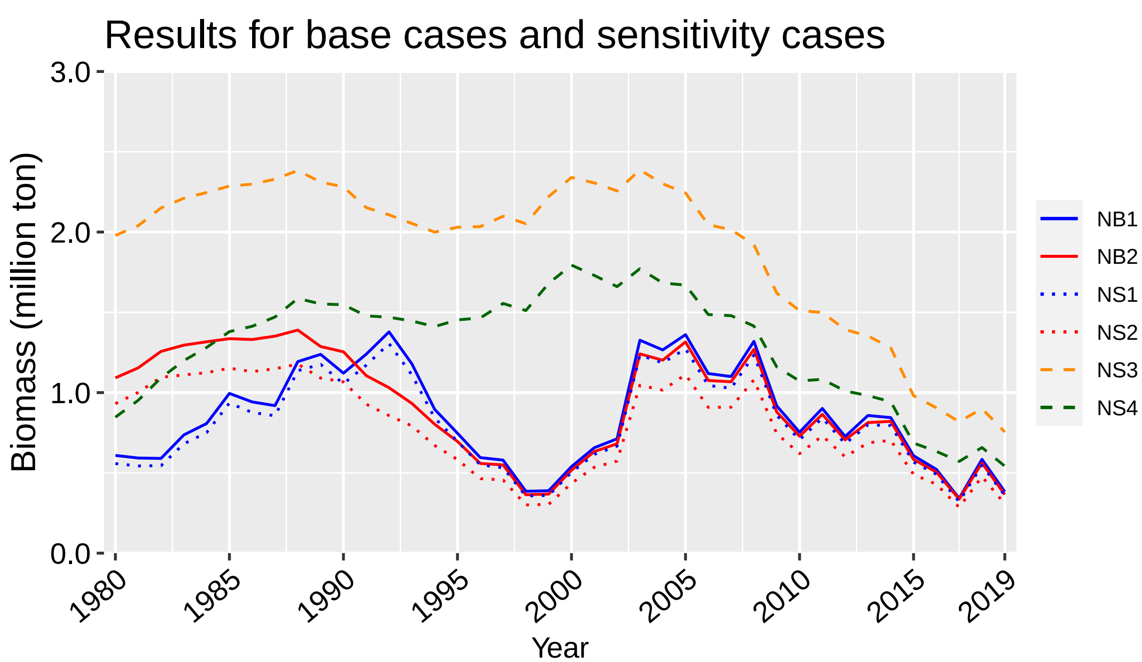
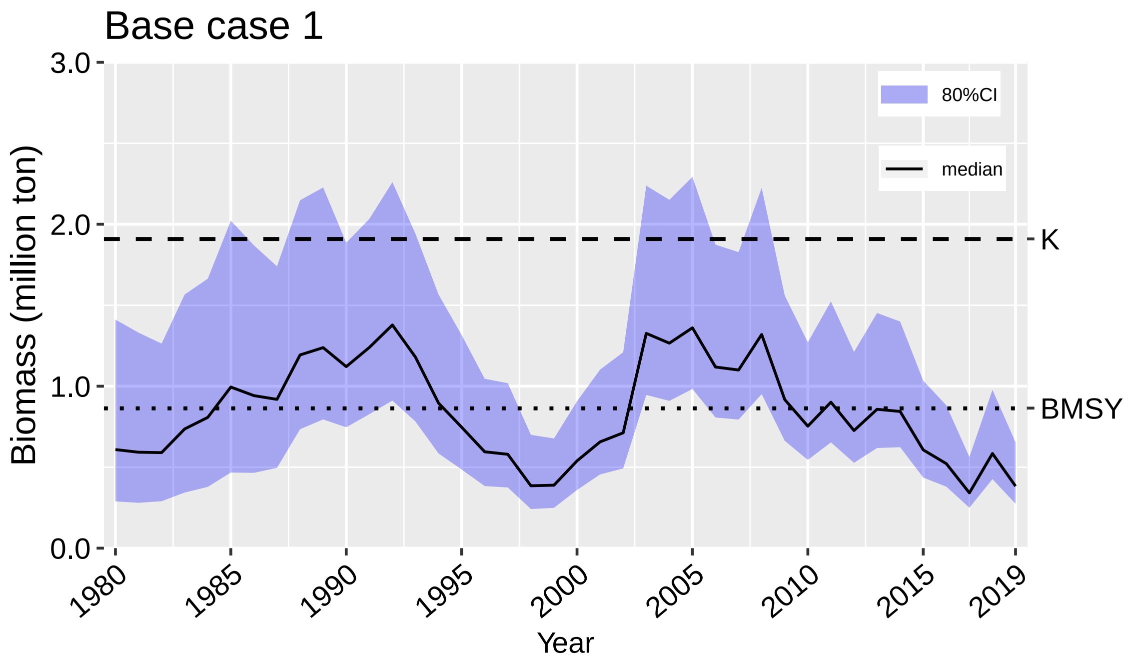
1.0
0.0
qJPN
80%CI
median
1980
1985
beta
1990
1995
2000
2005
2010
2015
2019
Year

2 Results for base and sensitivity cases

2.1 Time series Biomass






Base case 1
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median
K
BMSY
Biomass (million ton)
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3.0
1980
1985
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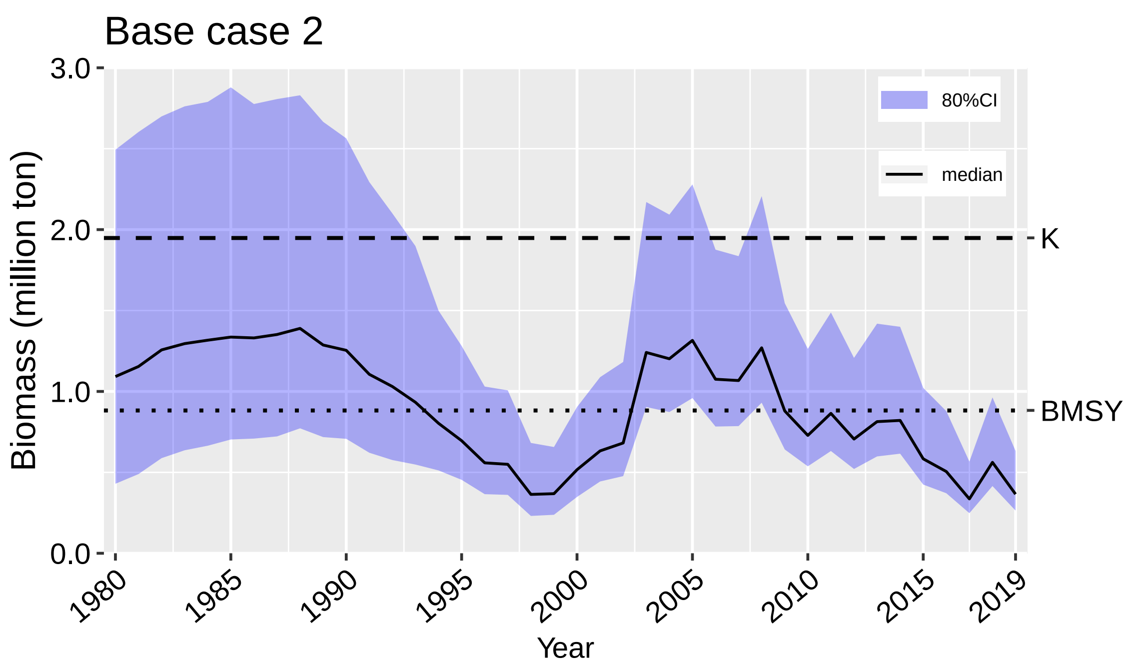
2005
2010
2015
2019
Year


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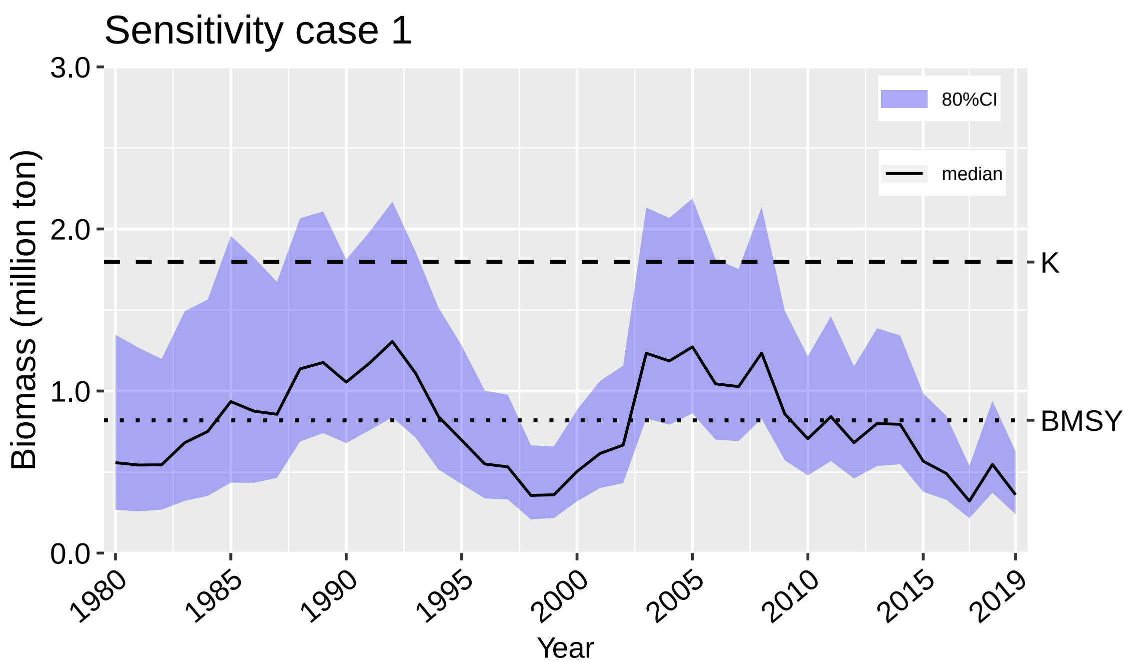
2015
2019
Year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2.0
1.0
0.0
Biomass (million ton)
80%CI
median
K
BMSY
1980
1985
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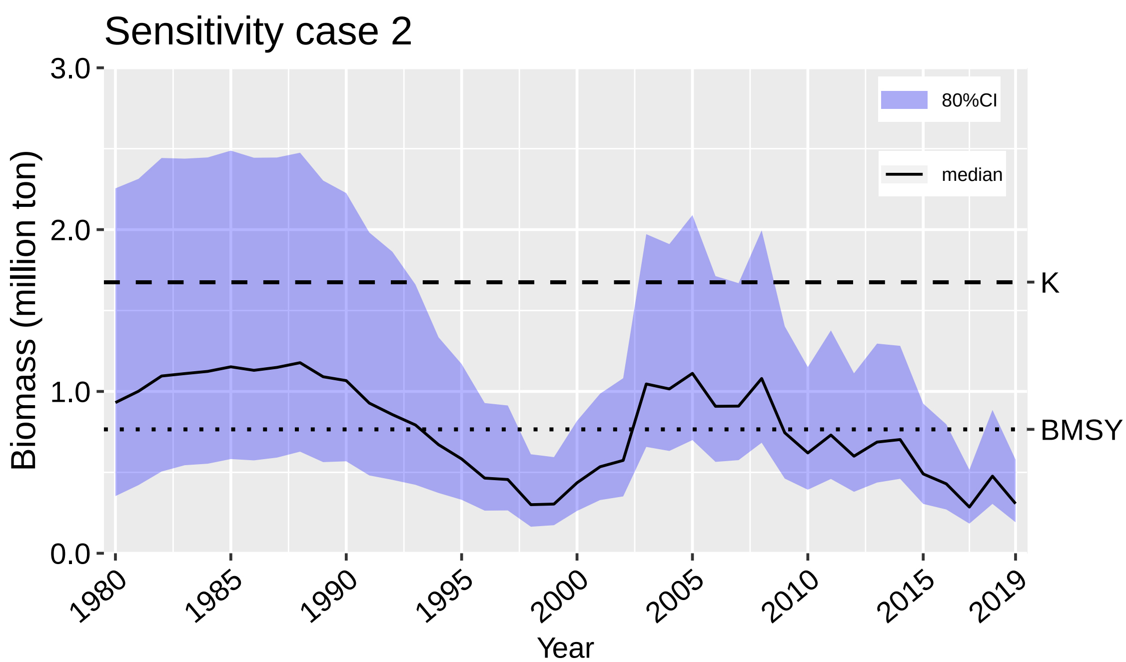
2019
Year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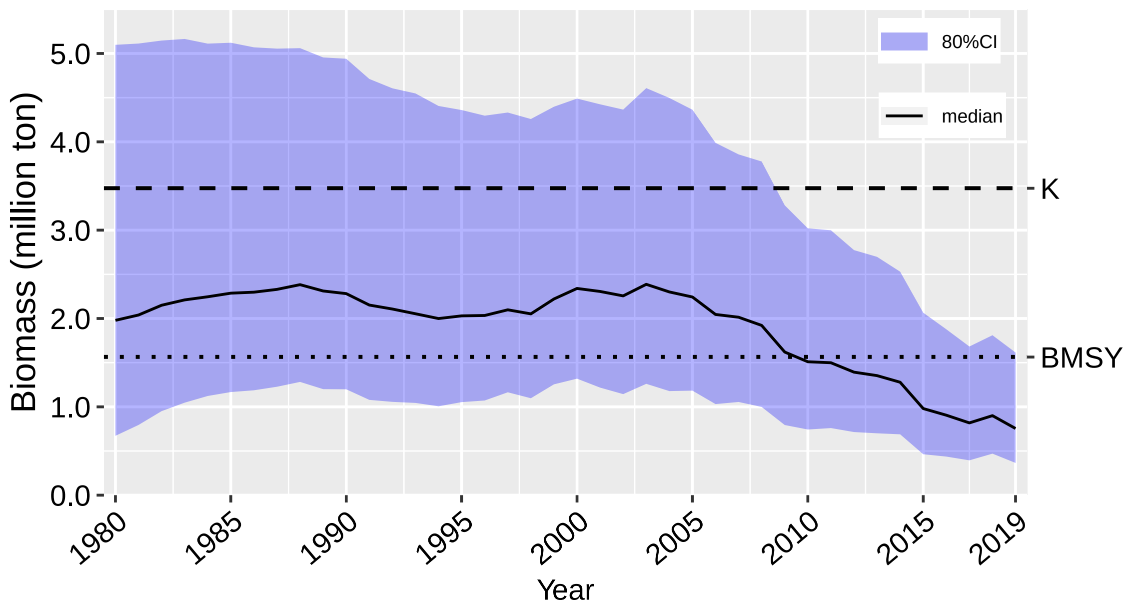
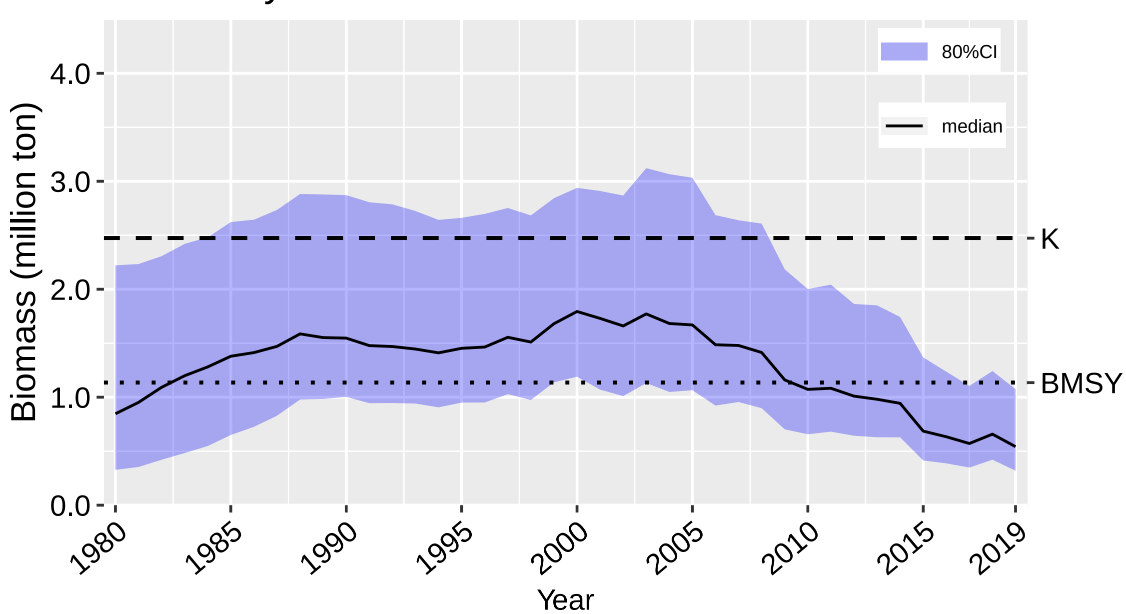
1.0
0.0
Biomass (million ton)
80%CI
median
K
BMSY
1980
1985
1990
1995
2000
2005
2010
2015
2019
Year

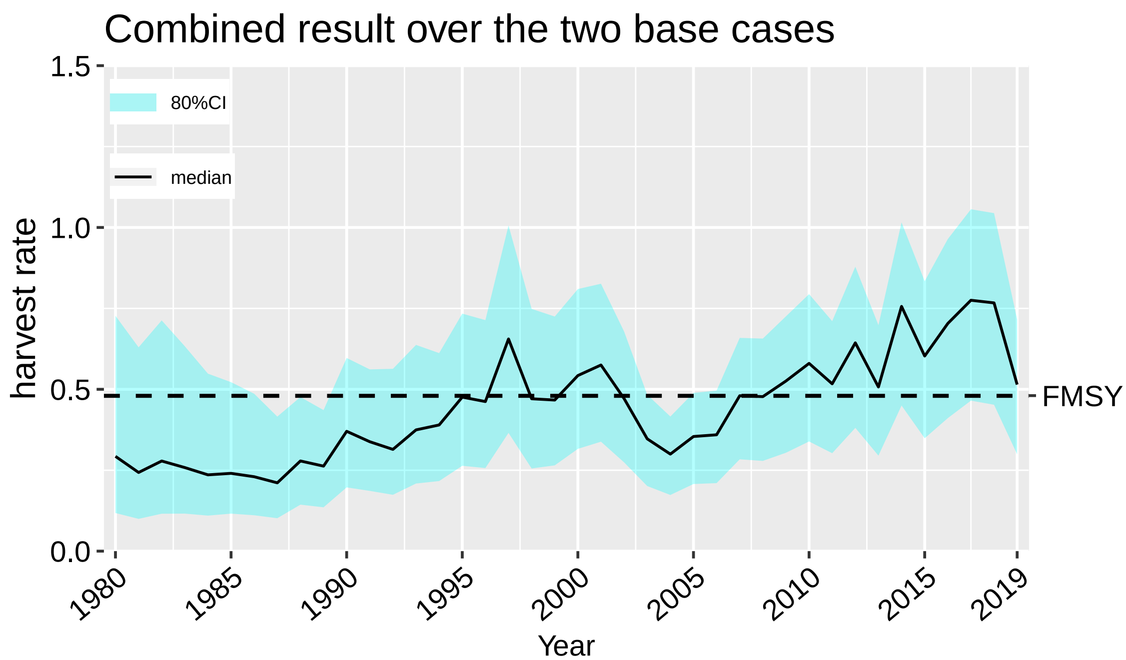
Sensitivity case 3

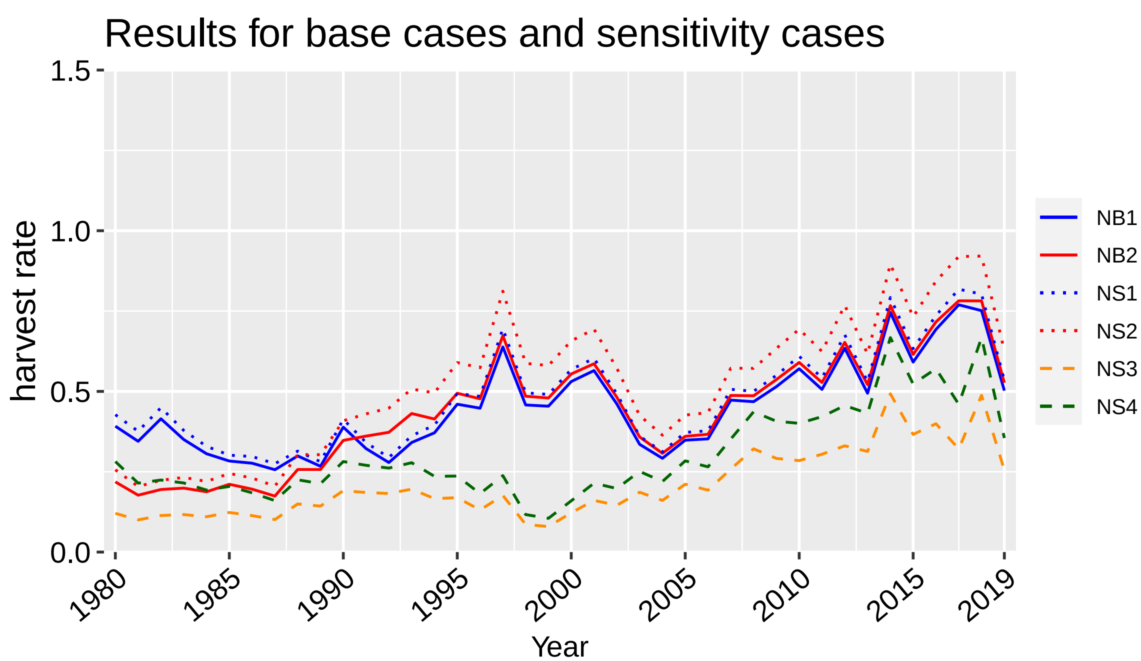


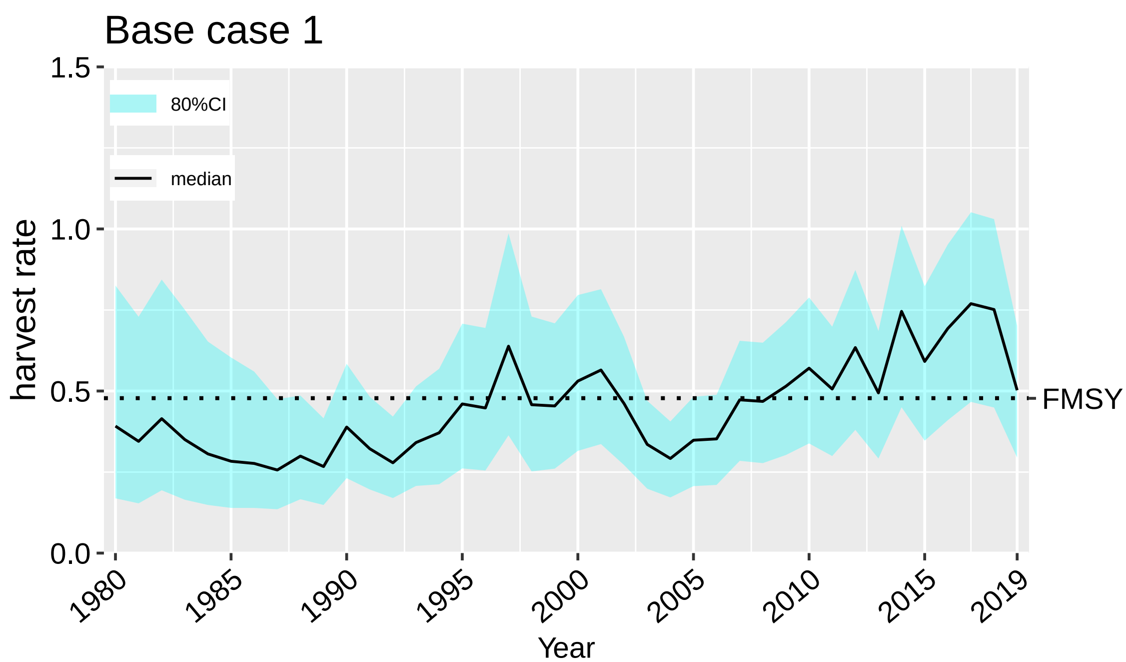
Sensitivity case 4



2.2 Time series Harvest rate



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harvest rate
FMSY
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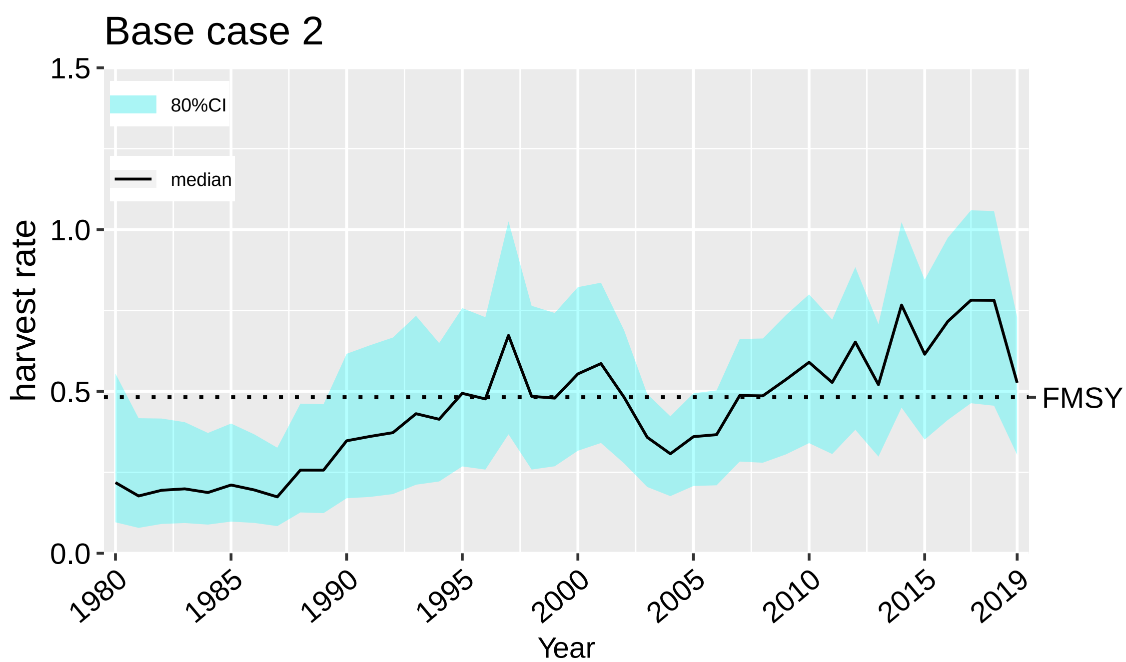
2015
2019
Year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2019
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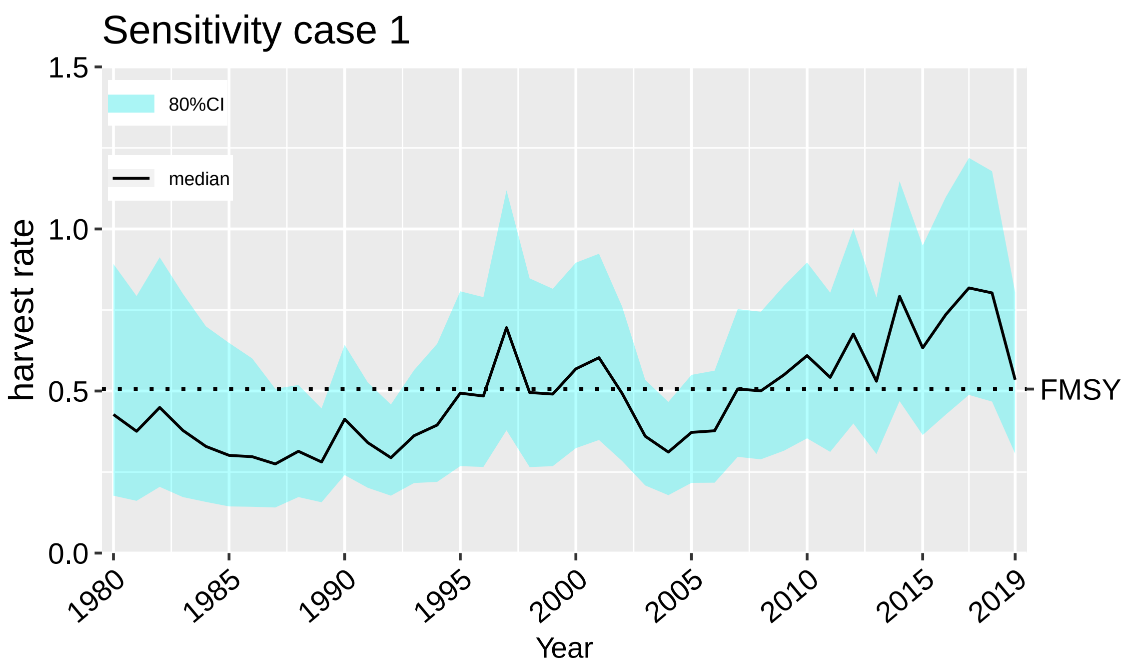
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FMSY
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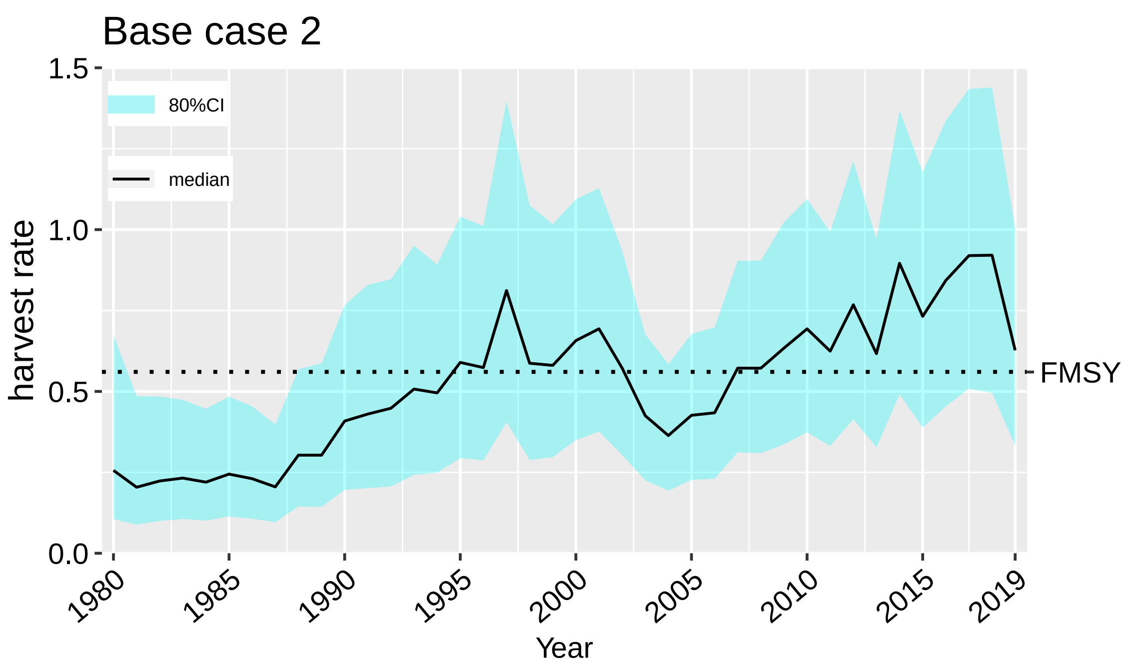
Year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harvest rate
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FMSY
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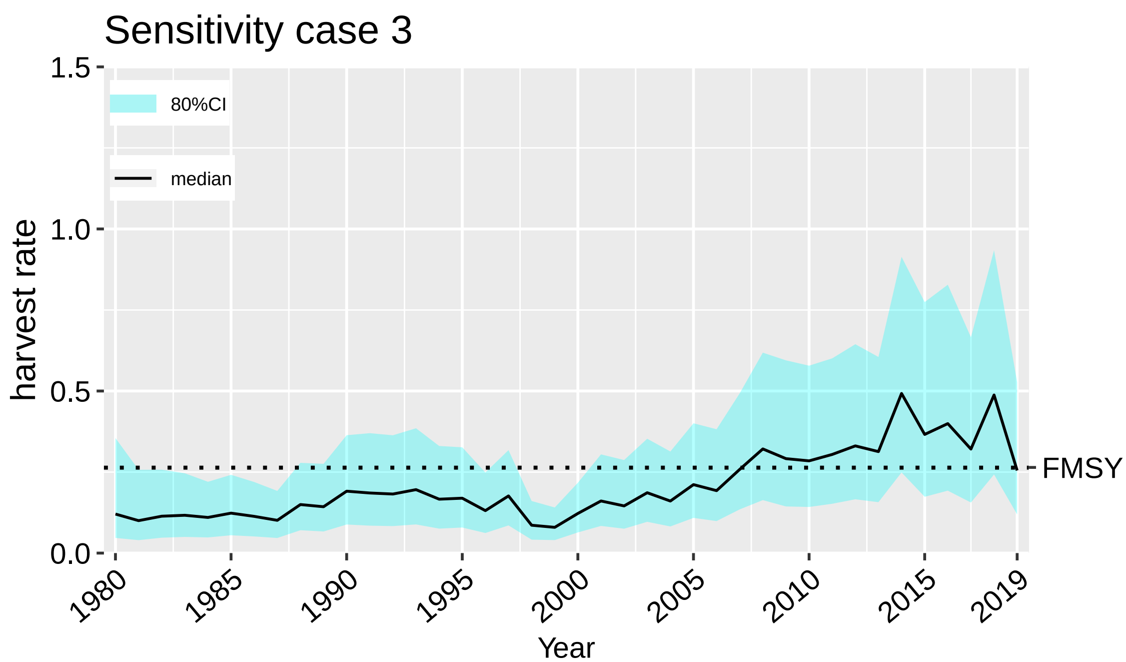
Year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FMSY
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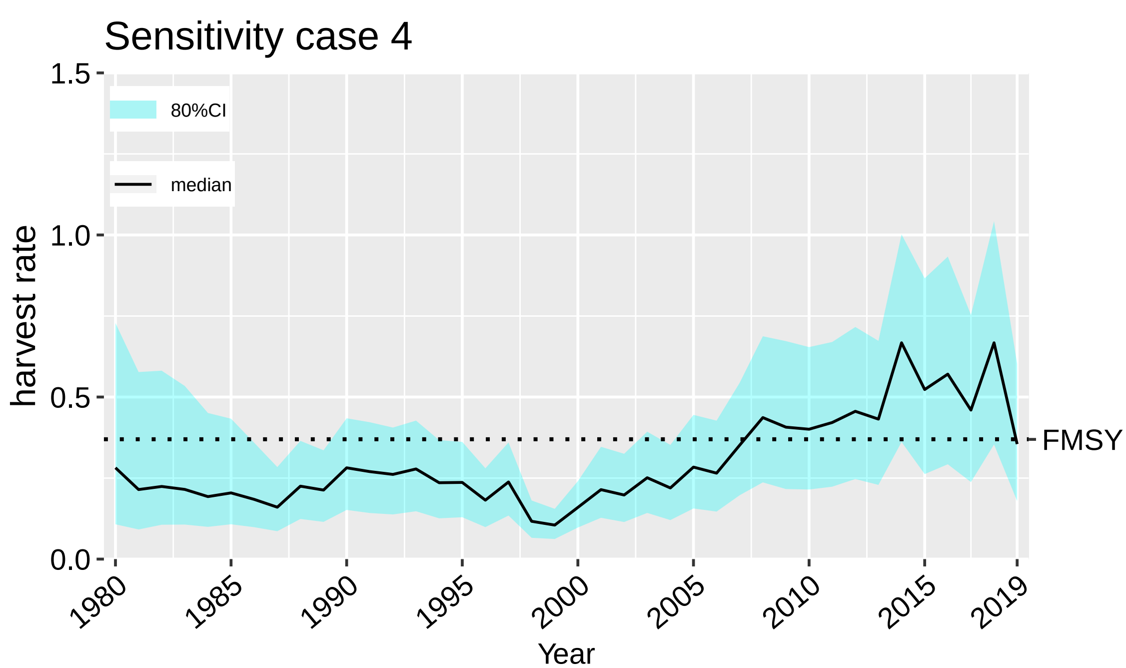
2019
Year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FMSY
1980
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1995
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2005
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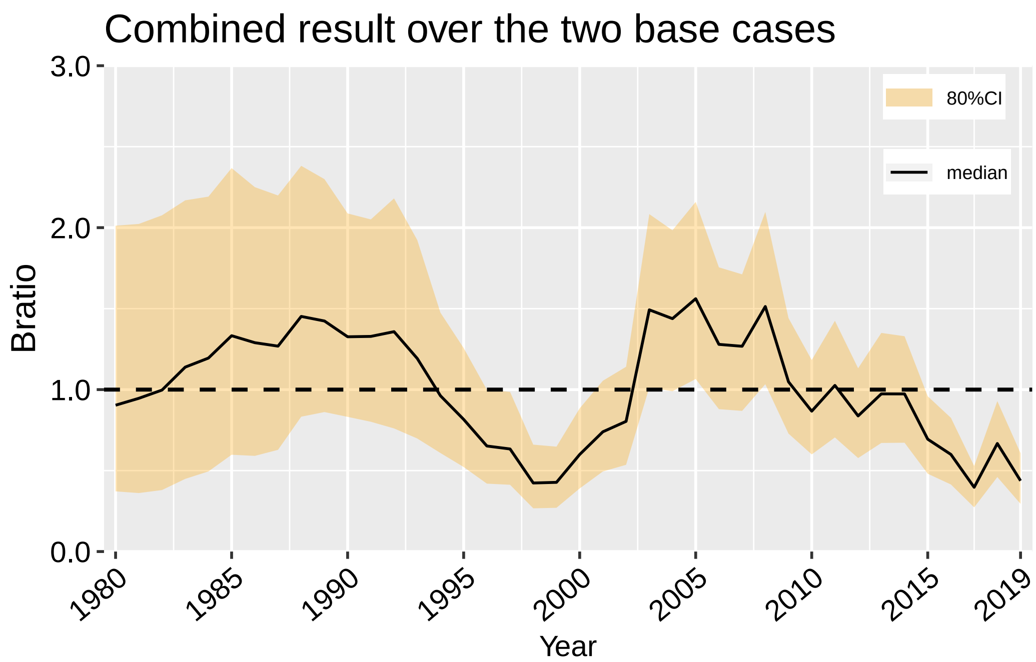
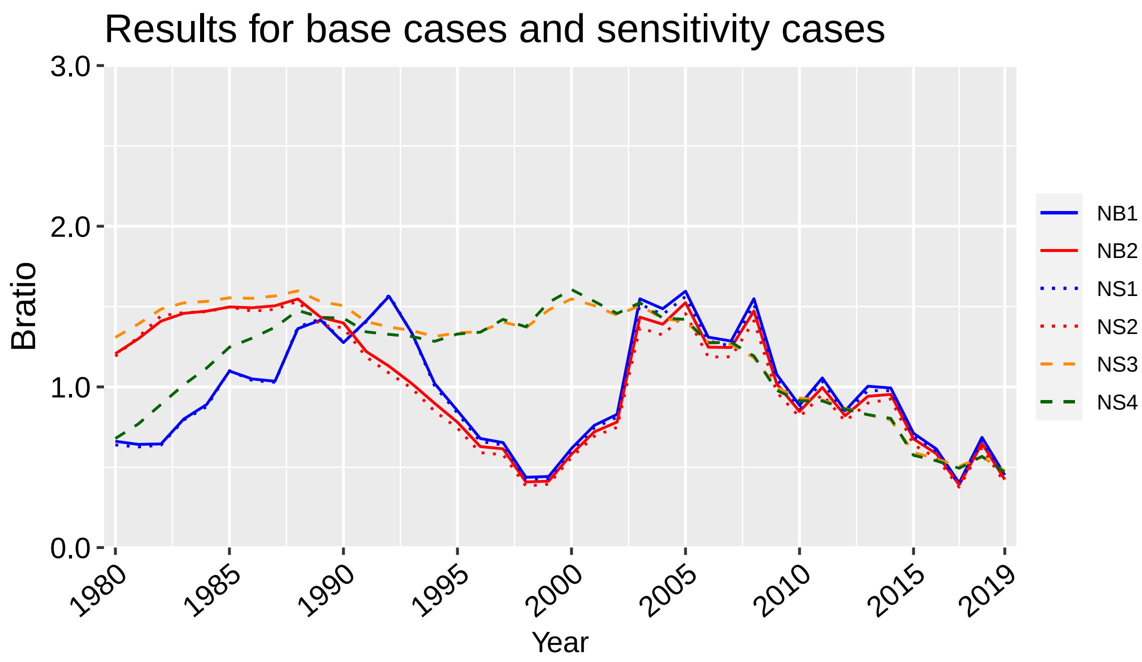
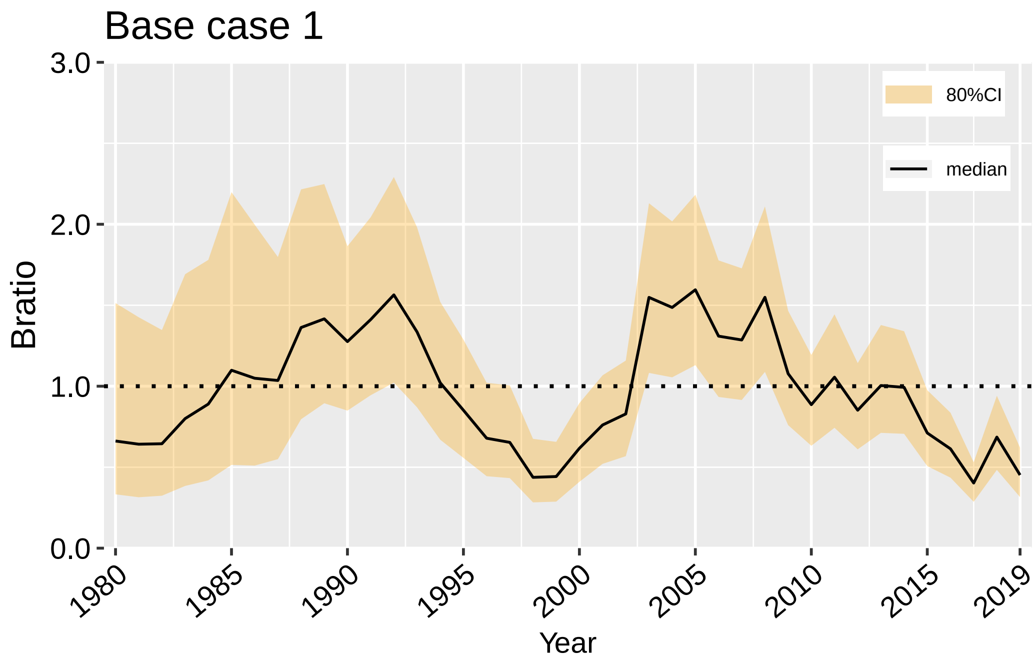
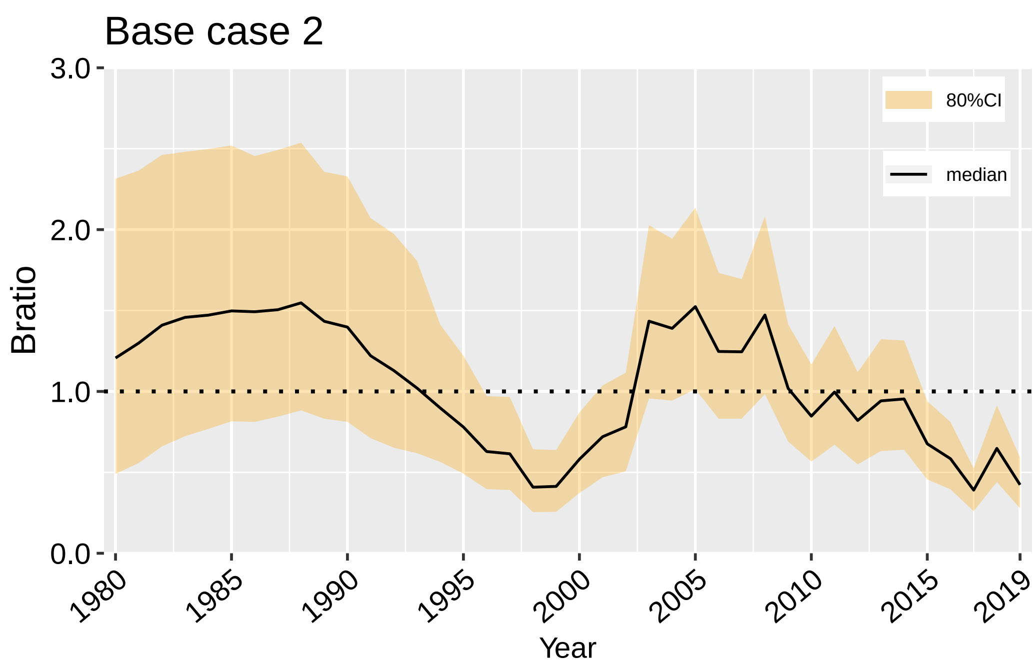
2015
2019
Year

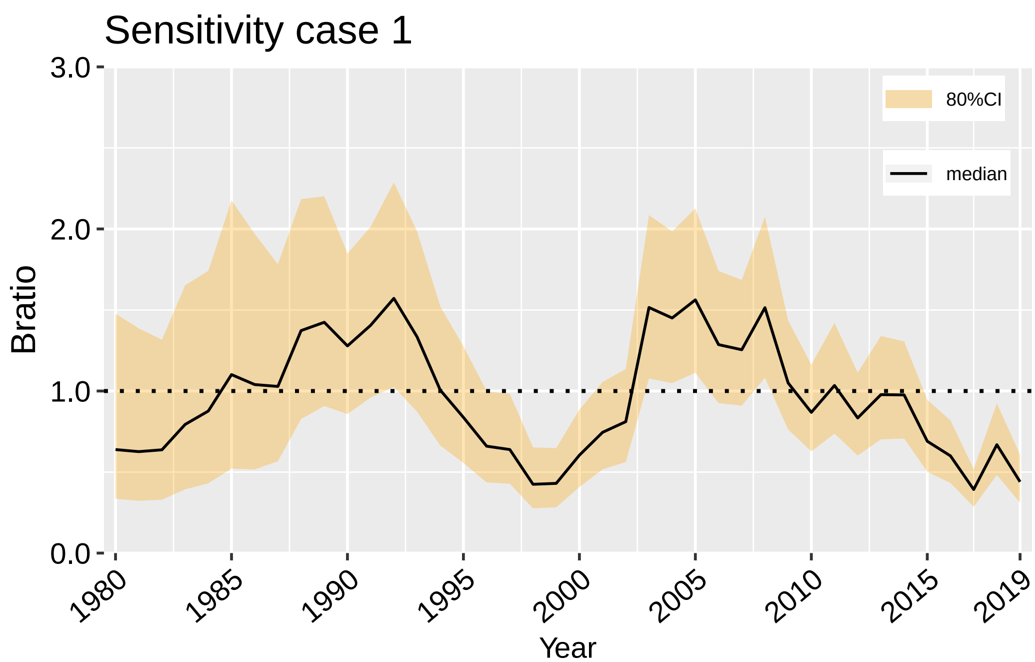
2.3 Time series Bratio

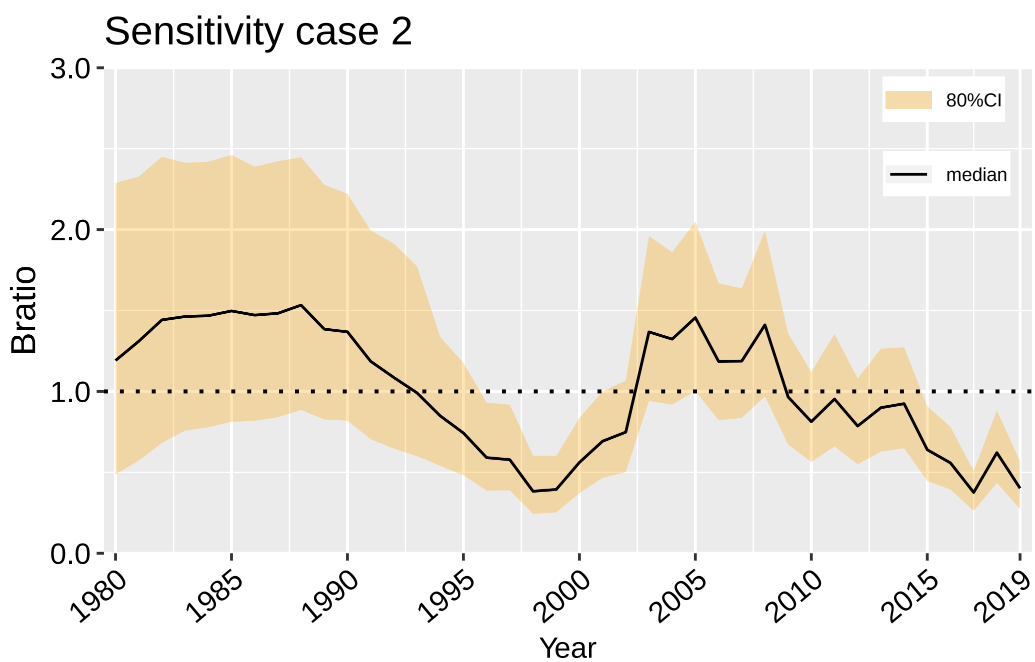


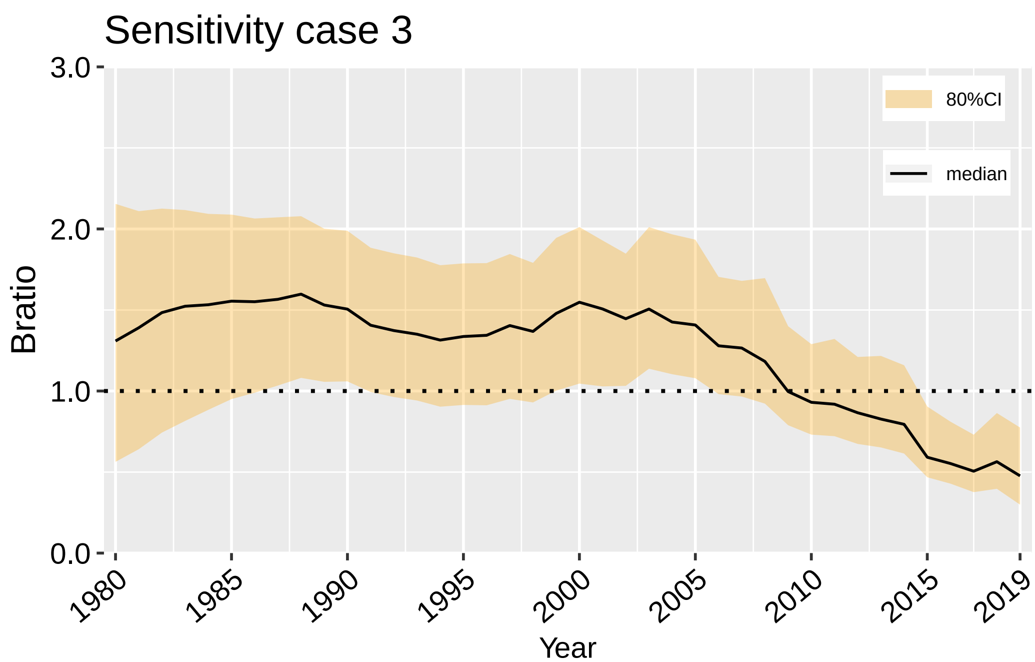



Base case 1
3.0
2.0
1.0
0.0
Bratio
80%CI
median
1980
1985
1990
1995
2000
2005
2010
2015
2019
Year

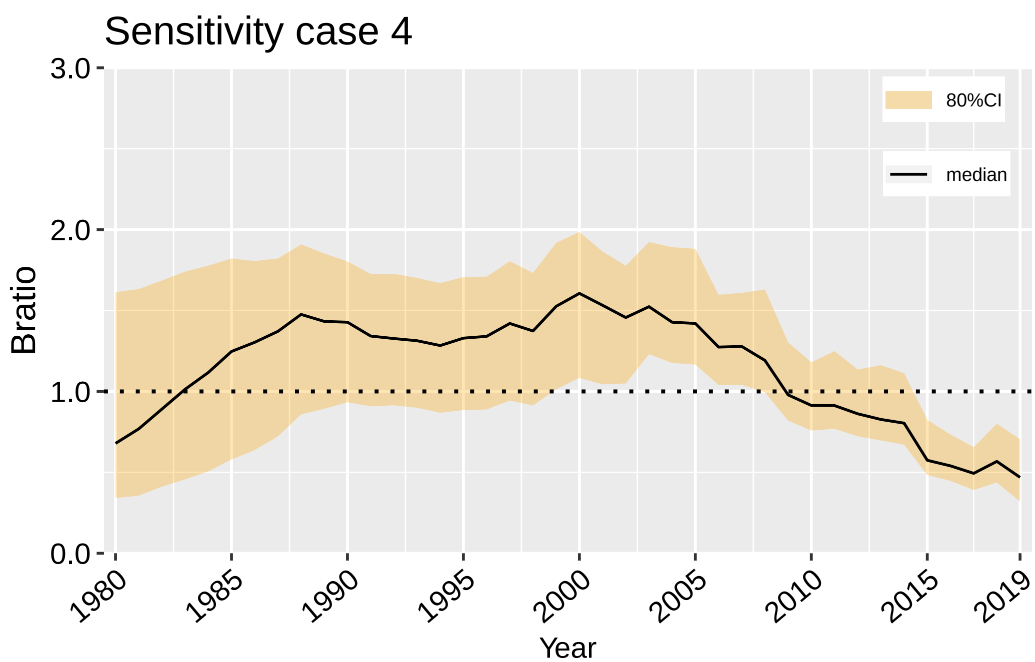

Base case 2
3.0
2.0
1.0
0.0
Bratio
80%CI
median
1980
1985
1990
1995
2000
2005
2010
2015
2019
Year


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


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

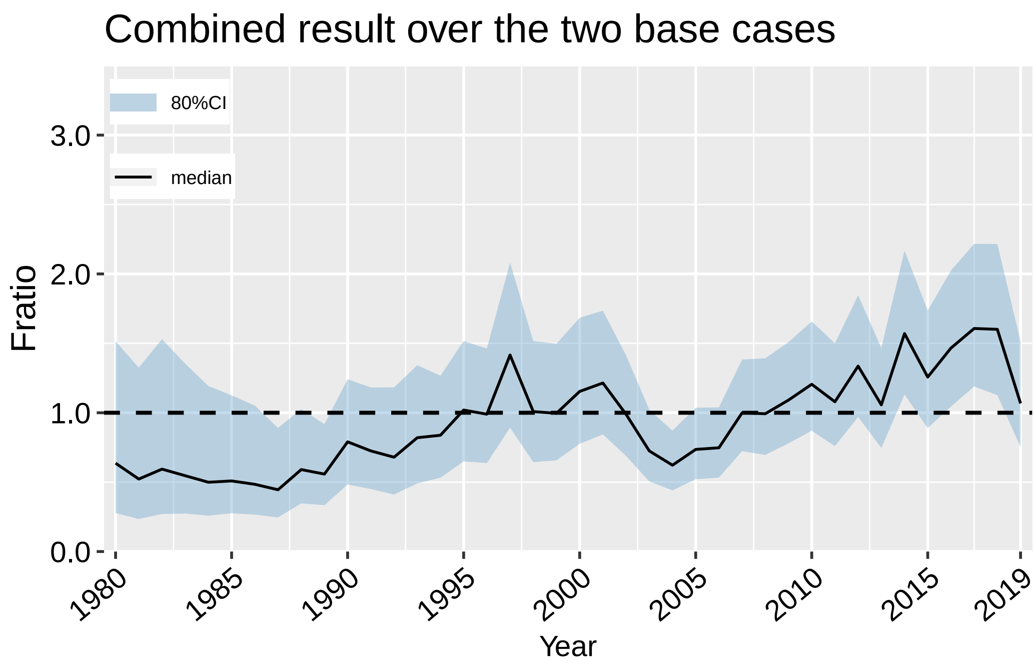


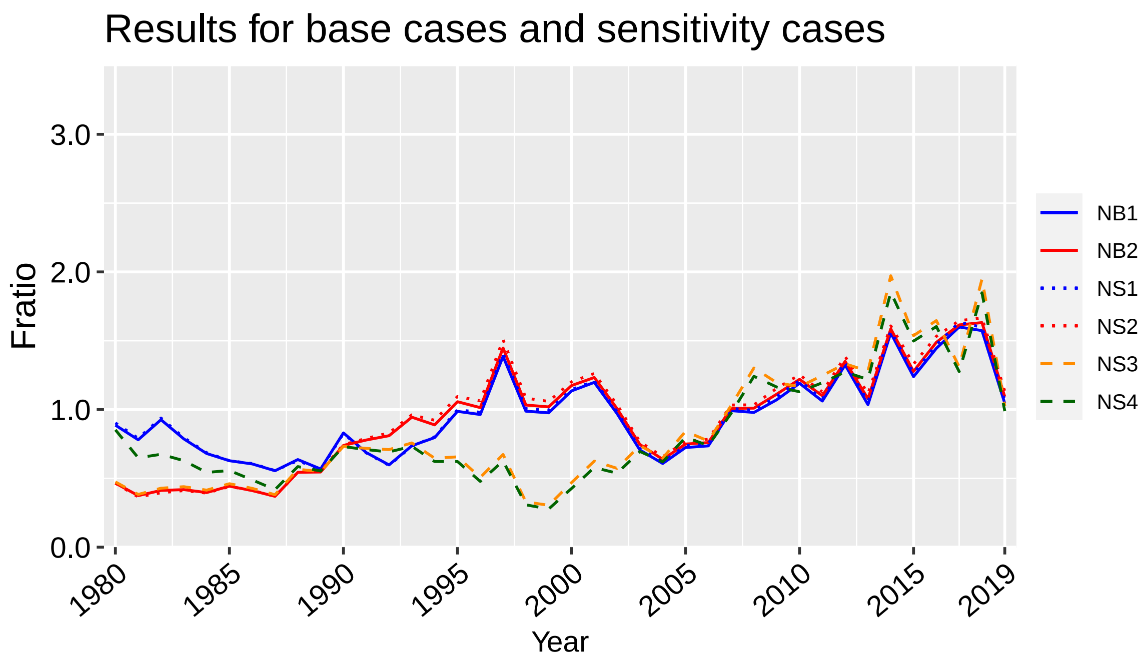
Sensitivity case 3
3.0
2.0
1.0
0.0
Bratio
80%CI
median
1980
1985
1990
1995
2000
2005
2010
2015
2019
Year

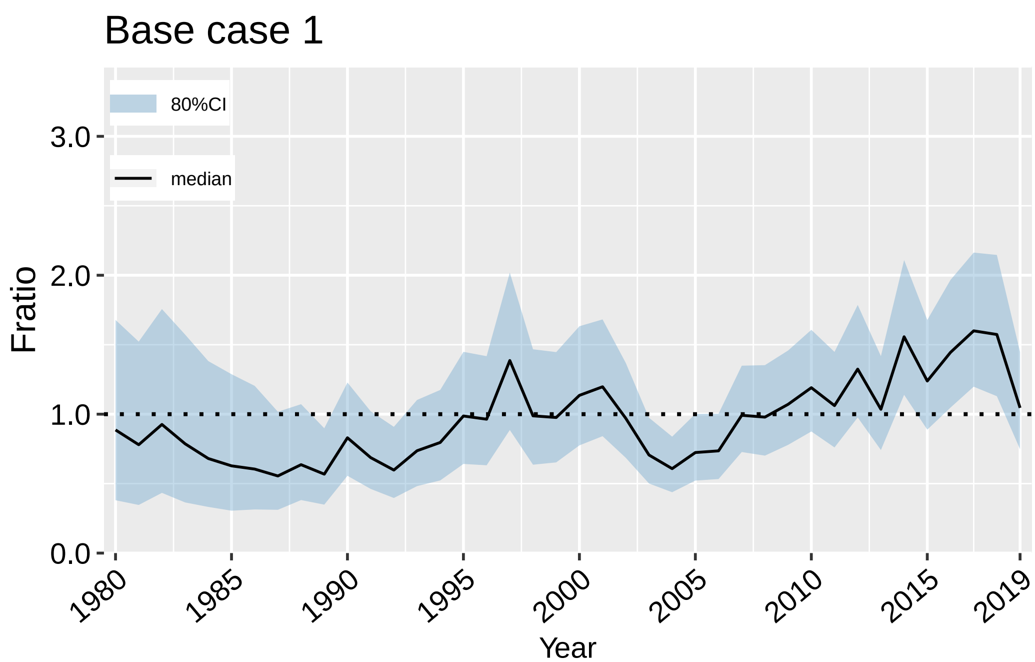


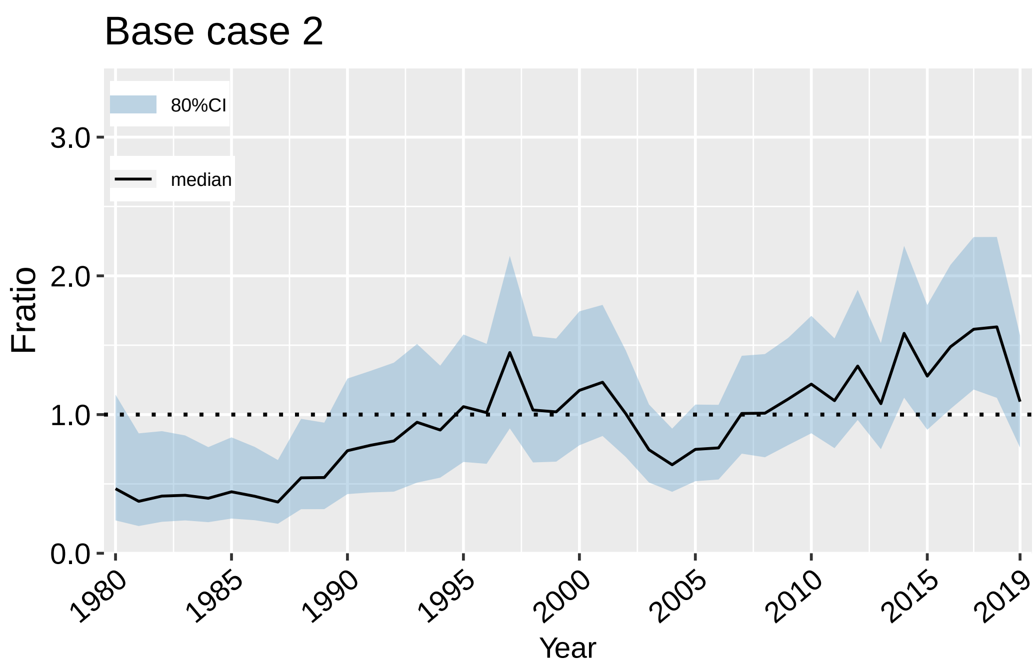
Sensitivity case 4
3.0
2.0
1.0
0.0
Bratio
80%CI
median
1980
1985
1990
1995
2000
2005
2010
2015
2019
Year

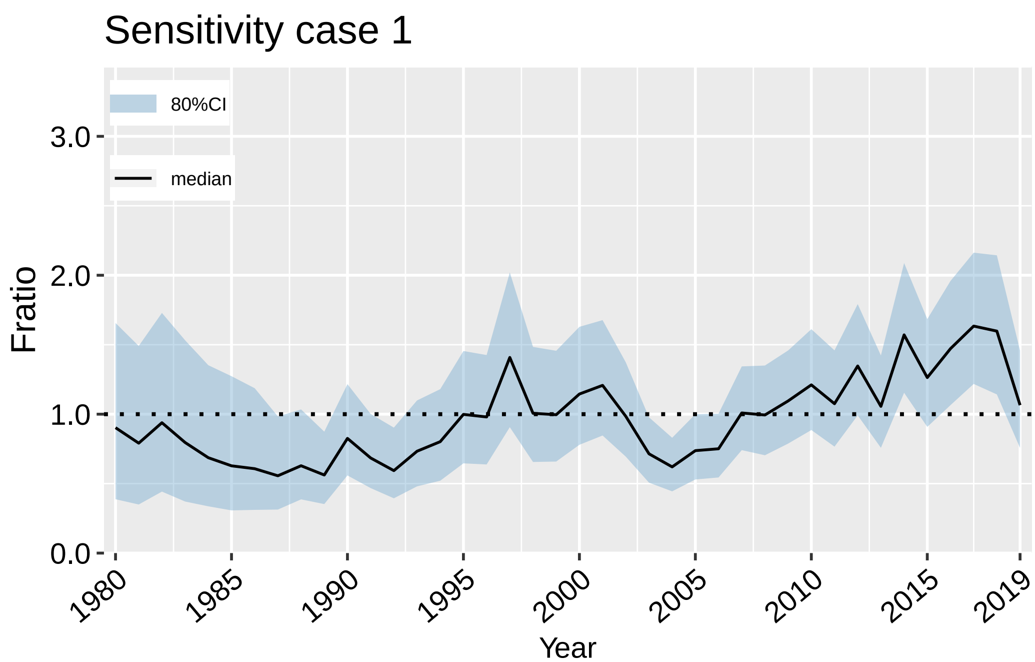
2.4 Time series Fratio

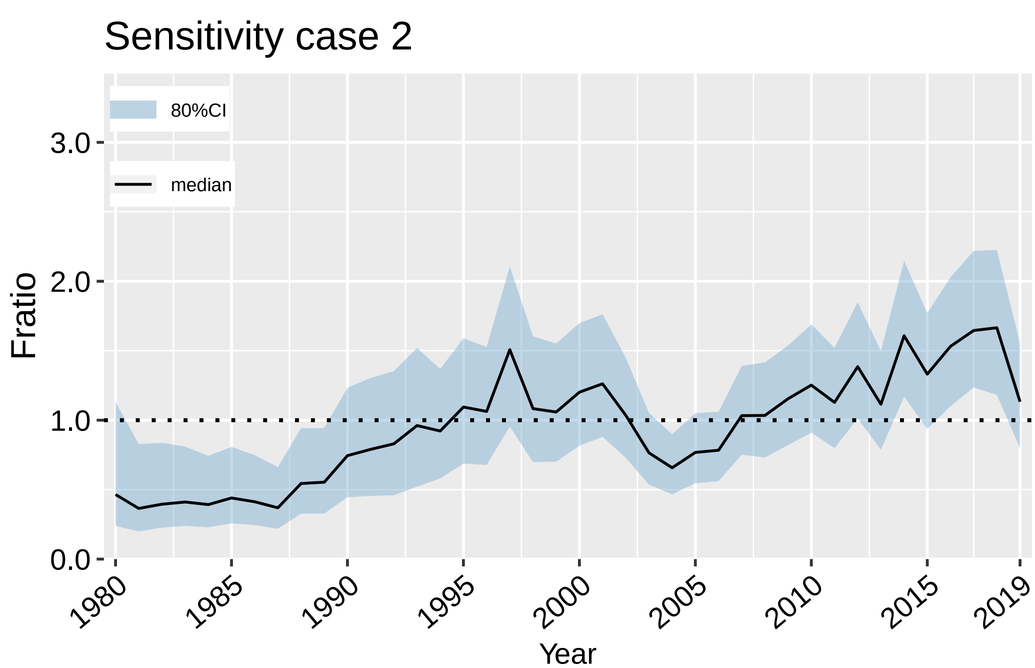


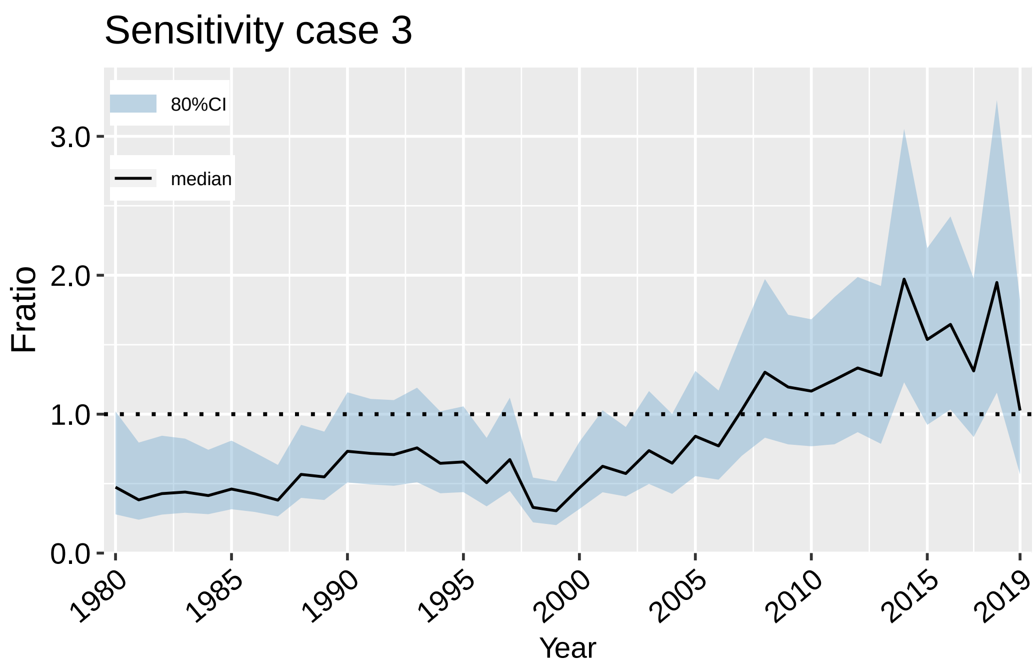


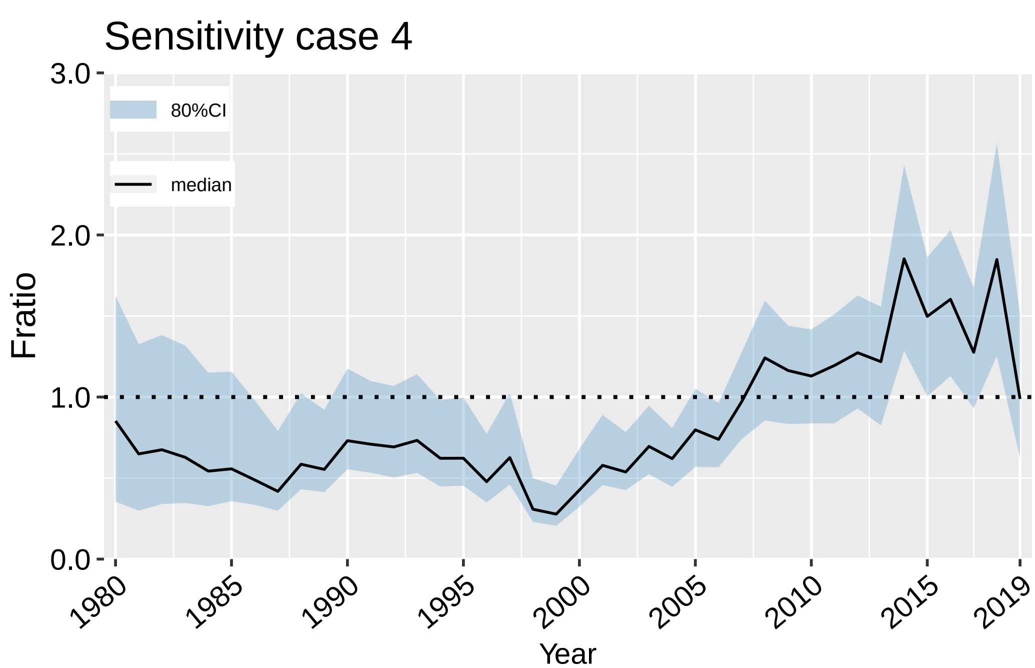

Base case 1
80%CI
median
Fratio
3.0
2.0
1.0
0.0
1980
1985
1990
1995
2000
2005
2010
2015
2019
Year


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

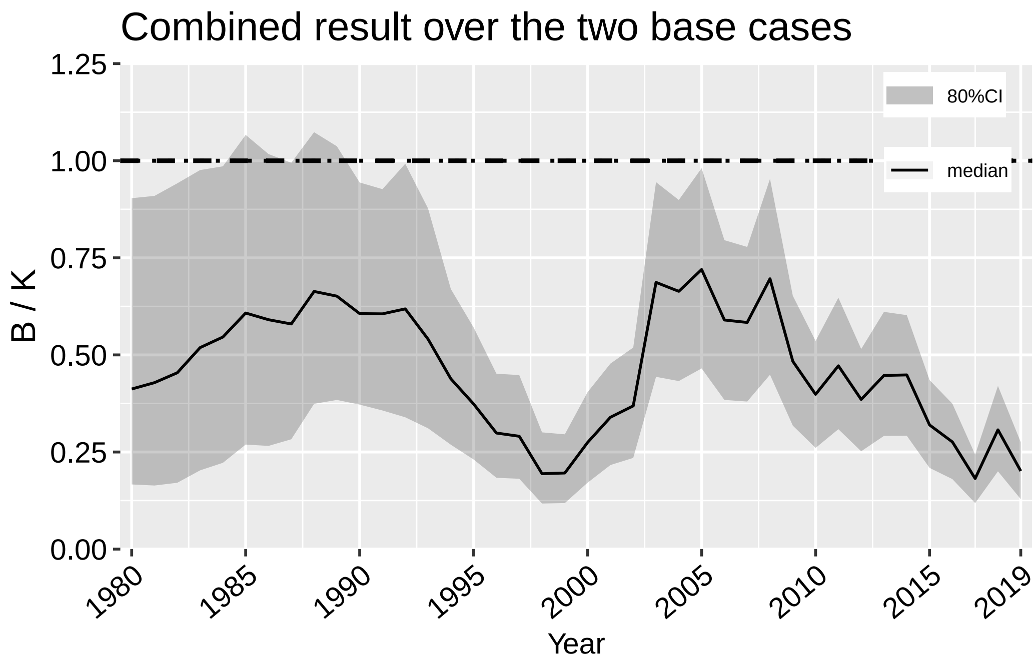

Sensitivity case 1
80%CI
median
Fratio
3.0
2.0
1.0
0.0
1980
1985
1990
1995
2000
2005
2010
2015
2019
Year

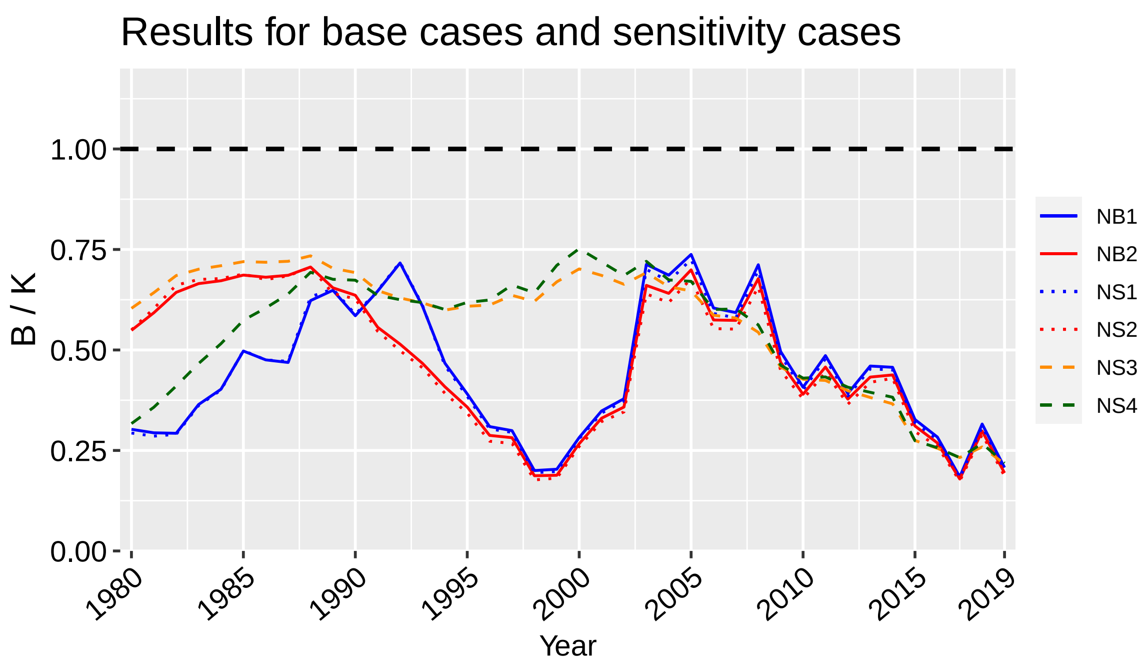

Sensitivity case 2
80%CI
median
Fratio
3.0
2.0
1.0
0.0
1980
1985
1990
1995
2000
2005
2010
2015
2019
Year

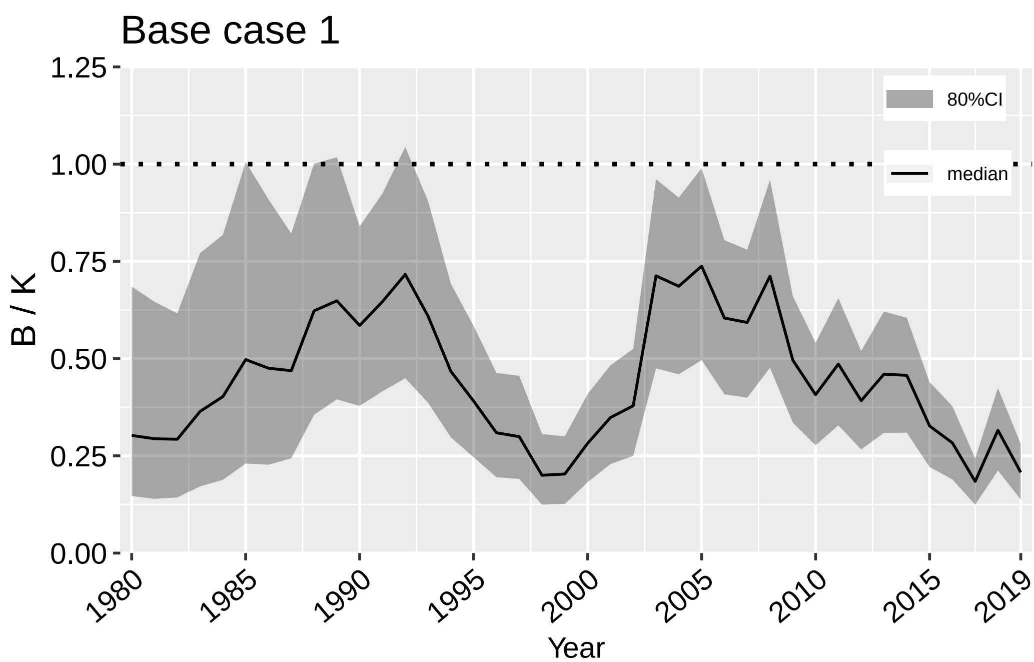

Sensitivity case 3
80%CI
median
Fratio
3.0
2.0
1.0
0.0
1980
1985
1990
1995
2000
2005
2010
2015
2019
Year

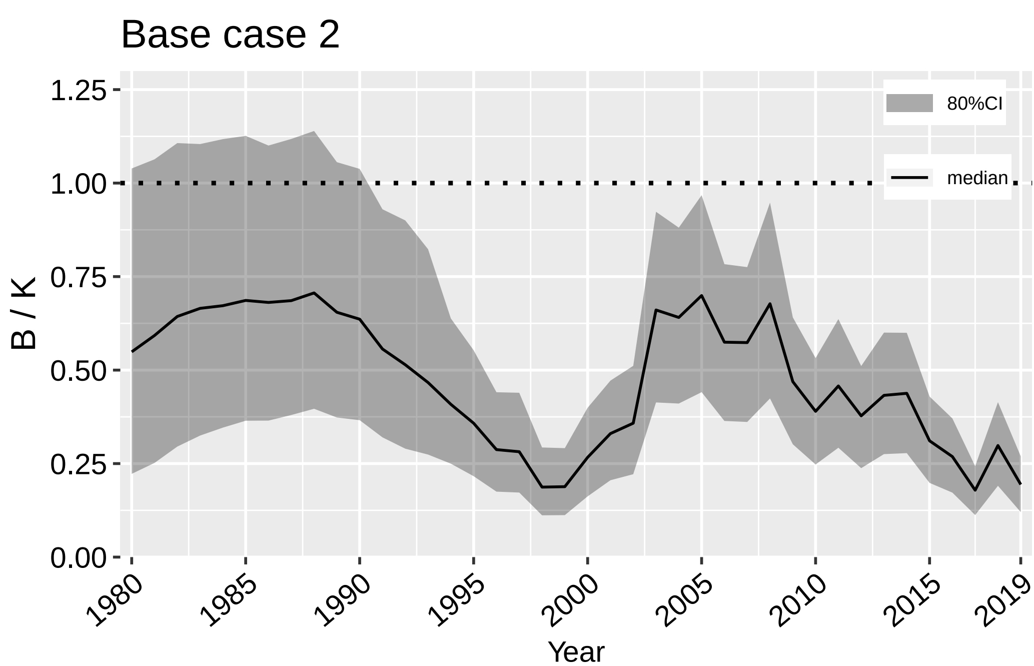

Sensitivity case 4
80%CI
median
Fratio
3.0
2.0
1.0
0.0
1980
1985
1990
1995
2000
2005
2010
2015
2019
Year

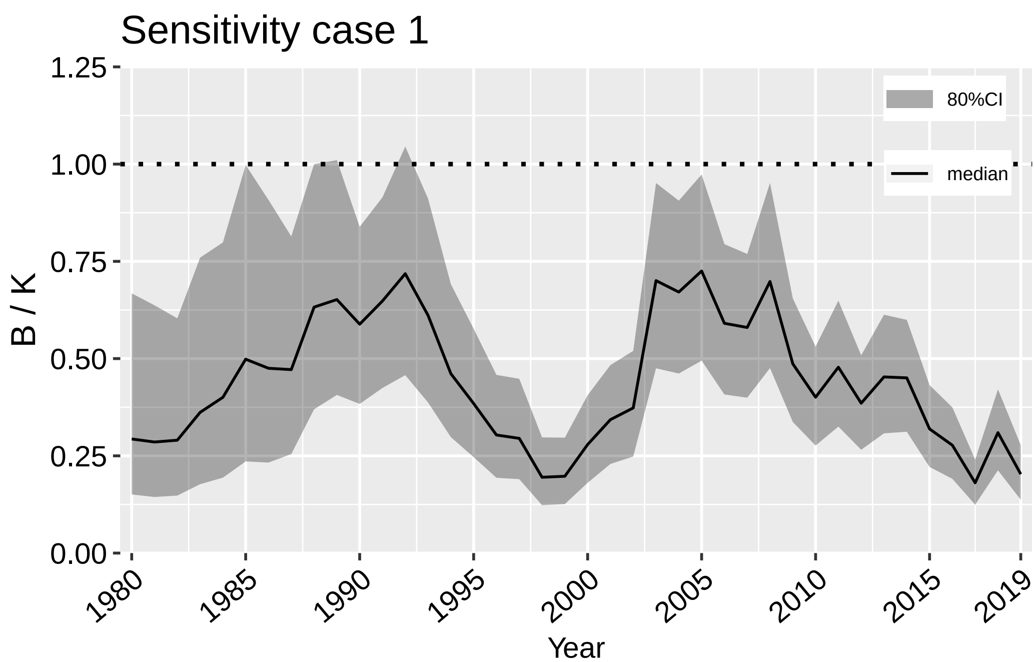
2.5 Time series B/K

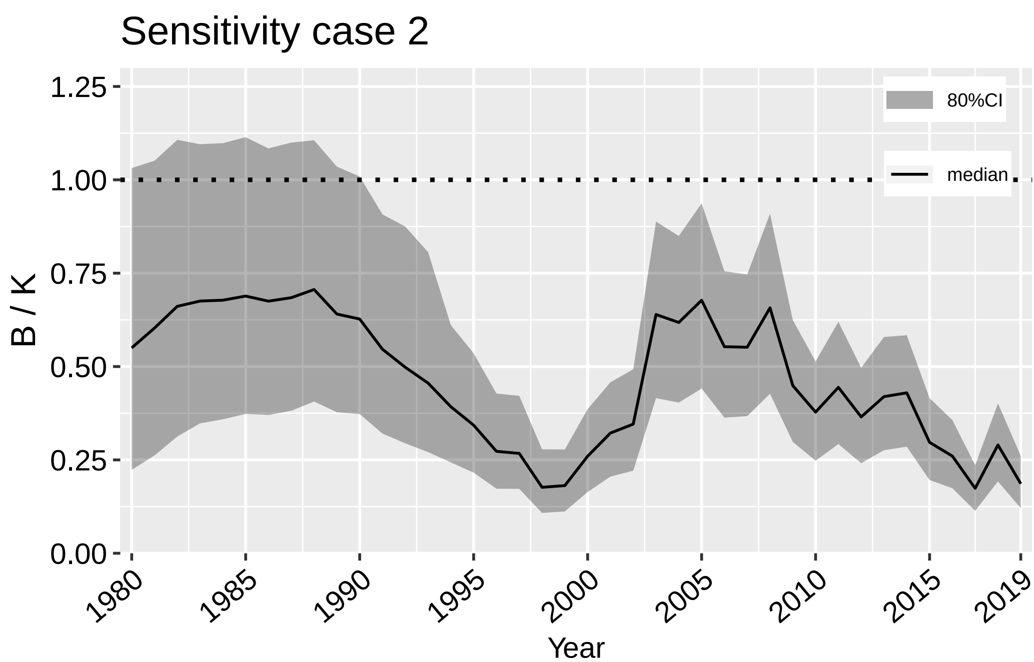


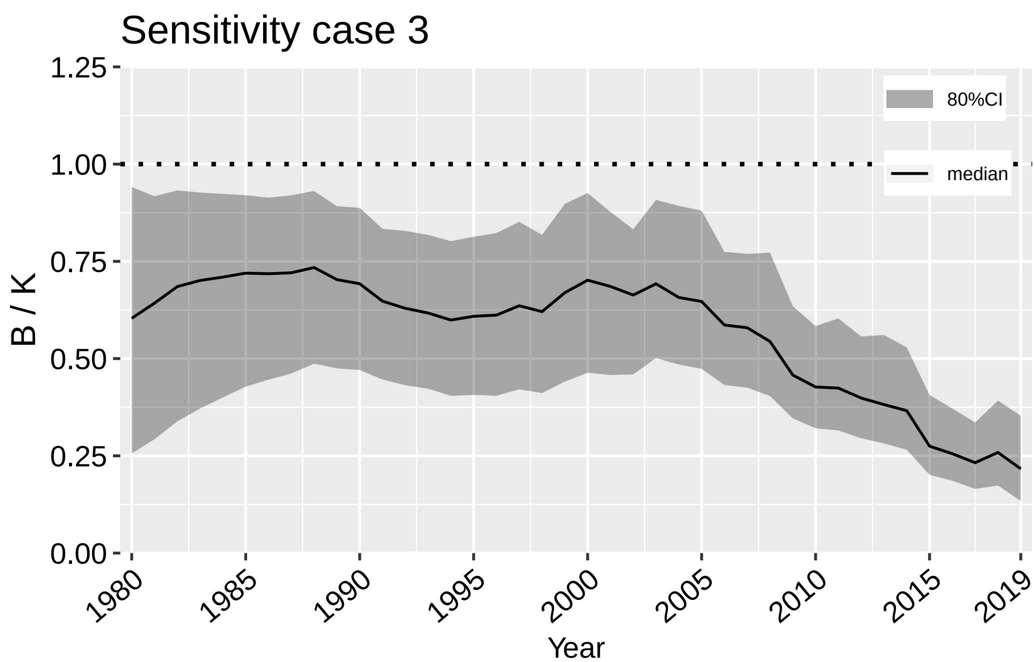


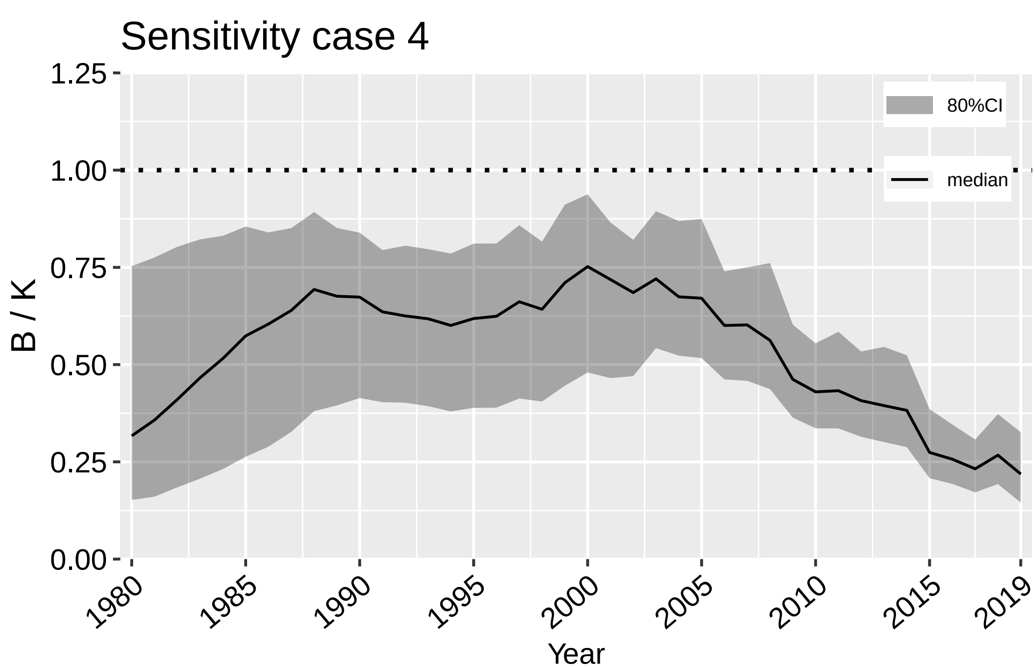

Base case 1
1.25
1.00
0.75
0.50
0.25
0.00
B / K
1980
1985
1990
1995
2000
2005
2010
2015
2019
Year
80%CI
median


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
2019
Year
80%CI
median

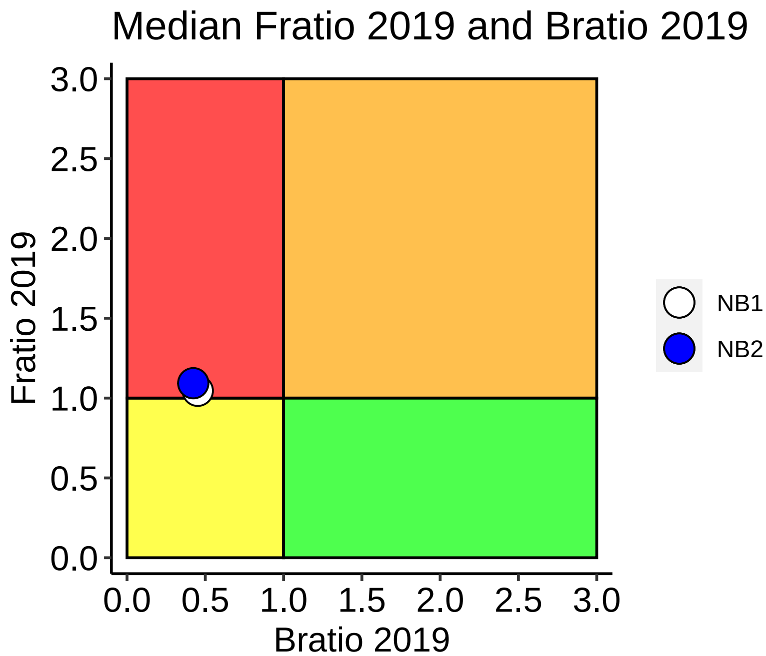

Sensitivity case 1
B / K
Year
80%CI
median
1.25
1.00
0.75
0.50
0.25
0.00
1980
1985
1990
1995
2000
2005
2010
2015
2019

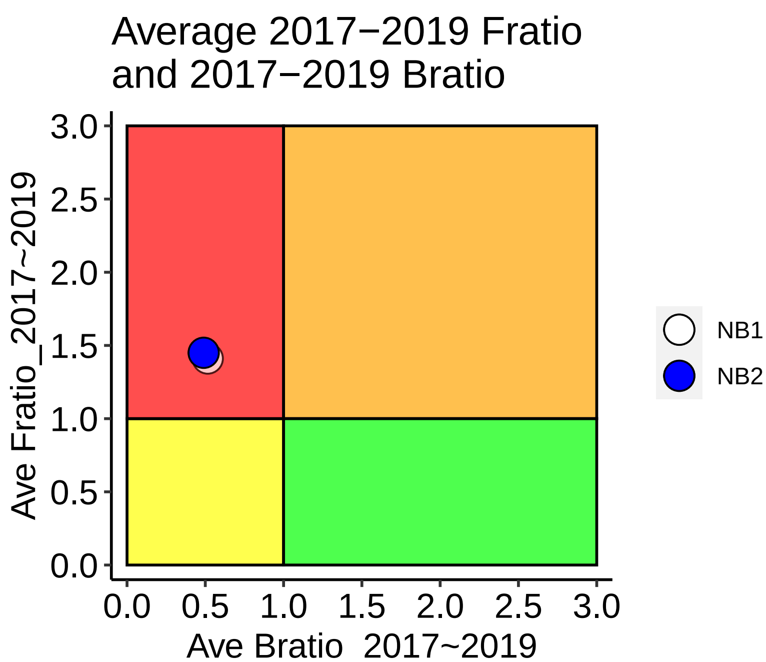

Sensitivity case 2
B / K
Year
80%CI
median
1.25
1.00
0.75
0.50
0.25
0.00
1980
1985
1990
1995
2000
2005
2010
2015
2019


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

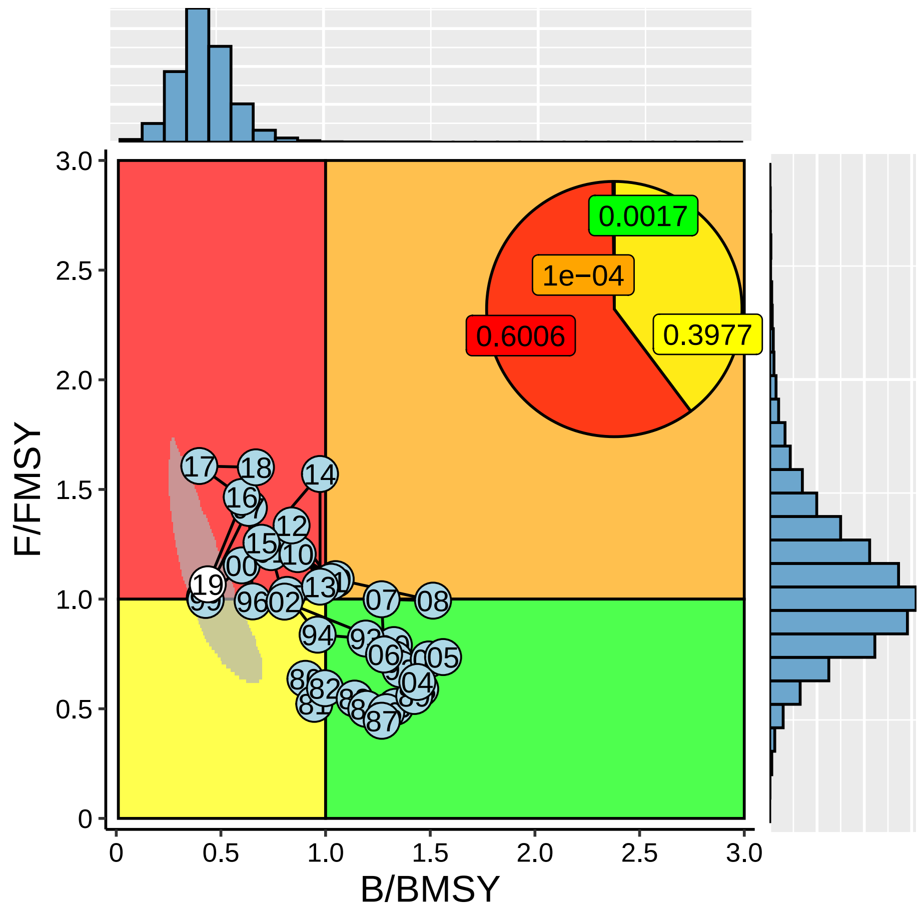

Sensitivity case 4
80%CI
median
B / K
1.25
1.00
0.75
0.50
0.25
0.00
1980
1985
1990
1995
2000
2005
2010
2015
2019
Year

3 Kobe plot


Median Fratio 2019 and Bratio 2019
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Fratio 2019
0.0 0.5 1.0 1.5 2.0 2.5 3.0
Bratio 2019
NB1
NB2


Average 2017−2019 Fratio
and 2017−2019 Bratio
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Ave Fratio_2017~2019
0.0 0.5 1.0 1.5 2.0 2.5 3.0
Ave Bratio_2017~2019
NB1
NB2

1980−2019 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_2019	0.192	0.192	0.192	0.192
AveC_2017_2019	0.298	0.298	0.298	0.298
AveF_2017_2019	0.678	0.691	0.411	0.925
F_2019	0.510	0.515	0.299	0.716
FMSY	0.477	0.480	0.288	0.659
MSY (million ton)	0.428	0.419	0.354	0.510
F_2019/FMSY	1.111	1.067	0.754	1.514
AveF_2017_2019/FMSY	1.477	1.428	1.048	1.948
K (million ton)	2.243	1.928	1.370	3.419
B_2018 (million ton)	0.656	0.572	0.420	0.971
B_2019 (million ton)	0.429	0.374	0.269	0.643
AveB_2017_2019	0.489	0.428	0.319	0.724
BMSY (million ton)	1.003	0.873	0.639	1.485
BMSY/K	0.454	0.443	0.403	0.527
B_2018/K	0.310	0.307	0.200	0.420
B_2019/K	0.203	0.201	0.129	0.275
AveB_2017_2019/K	0.231	0.232	0.151	0.308
B_2018/BMSY	0.684	0.667	0.460	0.929
B_2019/BMSY	0.447	0.437	0.294	0.608
AveB_2017_2019/BMSY	0.510	0.503	0.349	0.677

Base case 1

	Mean	Median	Lower10th	Upper10th
C_2019	0.192	0.192	0.192	0.192
AveC_2017_2019	0.298	0.298	0.298	0.298
AveF_2017_2019	0.731	0.742	0.449	1.000
F_2019	0.498	0.502	0.294	0.701
FMSY	0.475	0.478	0.294	0.650
MSY (million ton)	0.422	0.414	0.351	0.497
F_2019/FMSY	1.080	1.045	0.748	1.448
AveF_2017_2019/FMSY	1.451	1.411	1.052	1.887
K (million ton)	2.196	1.909	1.379	3.269
B_2018 (million ton)	0.664	0.584	0.426	0.978
B_2019 (million ton)	0.438	0.383	0.274	0.653
AveB_2017_2019	0.496	0.436	0.323	0.725
BMSY (million ton)	0.982	0.863	0.642	1.419
BMSY/K	0.454	0.442	0.403	0.527
B_2018/K	0.318	0.316	0.212	0.424
B_2019/K	0.209	0.208	0.138	0.281
AveB_2017_2019/K	0.237	0.238	0.161	0.311
B_2018/BMSY	0.702	0.686	0.483	0.941
B_2019/BMSY	0.462	0.452	0.315	0.620
AveB_2017_2019/BMSY	0.523	0.515	0.369	0.685

Base case 2

	Mean	Median	Lower10th	Upper10th
C_2019	0.192	0.192	0.192	0.192
AveC_2017_2019	0.298	0.298	0.298	0.298
AveF_2017_2019	0.749	0.768	0.451	1.012
F_2019	0.522	0.527	0.304	0.730
FMSY	0.478	0.482	0.282	0.667
MSY (million ton)	0.435	0.423	0.358	0.523
F_2019/FMSY	1.142	1.093	0.762	1.571
AveF_2017_2019/FMSY	1.504	1.450	1.044	2.012
K (million ton)	2.291	1.948	1.361	3.584
B_2018 (million ton)	0.647	0.562	0.415	0.963
B_2019 (million ton)	0.420	0.365	0.264	0.632
AveB_2017_2019	0.483	0.420	0.316	0.721
BMSY (million ton)	1.024	0.882	0.637	1.563
BMSY/K	0.454	0.443	0.403	0.526
B_2018/K	0.302	0.298	0.191	0.414
B_2019/K	0.196	0.194	0.120	0.269
AveB_2017_2019/K	0.226	0.226	0.143	0.304
B_2018/BMSY	0.666	0.648	0.440	0.914
B_2019/BMSY	0.432	0.423	0.277	0.592
AveB_2017_2019/BMSY	0.497	0.490	0.331	0.666

Sensitivity case 1

	Mean	Median	Lower10th	Upper10th
C_2019	0.192	0.192	0.192	0.192
AveC_2017_2019	0.298	0.298	0.298	0.298
AveF_2017_2019	0.802	0.789	0.469	1.151
F_2019	0.549	0.535	0.307	0.804
FMSY	0.513	0.506	0.308	0.724
MSY (million ton)	0.424	0.417	0.357	0.495
F_2019/FMSY	1.095	1.065	0.757	1.457
AveF_2017_2019/FMSY	1.466	1.437	1.063	1.886
K (million ton)	2.067	1.796	1.249	3.147
B_2018 (million ton)	0.622	0.547	0.373	0.939
B_2019 (million ton)	0.409	0.360	0.239	0.627
AveB_2017_2019	0.464	0.410	0.279	0.696
BMSY (million ton)	0.929	0.819	0.584	1.364
BMSY/K	0.457	0.447	0.404	0.527
B_2018/K	0.314	0.310	0.213	0.421
B_2019/K	0.206	0.203	0.137	0.278
AveB_2017_2019/K	0.234	0.233	0.161	0.308
B_2018/BMSY	0.690	0.669	0.482	0.924
B_2019/BMSY	0.452	0.440	0.311	0.609
AveB_2017_2019/BMSY	0.513	0.503	0.369	0.672

Sensitivity case 2

	Mean	Median	Lower10th	Upper10th
C_2019	0.192	0.192	0.192	0.192
AveC_2017_2019	0.298	0.298	0.298	0.298
AveF_2017_2019	0.925	0.898	0.491	1.392
F_2019	0.653	0.627	0.332	1.004
FMSY	0.574	0.560	0.315	0.851
MSY (million ton)	0.439	0.430	0.366	0.513
F_2019/FMSY	1.164	1.133	0.799	1.554
AveF_2017_2019/FMSY	1.521	1.485	1.101	1.968
K (million ton)	1.976	1.675	1.087	3.153
B_2018 (million ton)	0.556	0.477	0.305	0.886
B_2019 (million ton)	0.359	0.307	0.192	0.579
AveB_2017_2019	0.415	0.357	0.230	0.656
BMSY (million ton)	0.890	0.765	0.517	1.388
BMSY/K	0.459	0.450	0.407	0.526
B_2018/K	0.295	0.290	0.192	0.401
B_2019/K	0.190	0.186	0.121	0.261
AveB_2017_2019/K	0.220	0.218	0.145	0.295
B_2018/BMSY	0.645	0.621	0.435	0.883
B_2019/BMSY	0.415	0.402	0.274	0.569
AveB_2017_2019/BMSY	0.481	0.468	0.330	0.647

Sensitivity case 3

	Mean	Median	Lower10th	Upper10th
C_2019	0.192	0.192	0.192	0.192
AveC_2017_2019	0.298	0.298	0.298	0.298
AveF_2017_2019	0.457	0.405	0.199	0.808
F_2019	0.295	0.255	0.119	0.527
FMSY	0.297	0.264	0.104	0.546
MSY (million ton)	0.406	0.401	0.311	0.490
F_2019/FMSY	1.134	1.026	0.565	1.820
AveF_2017_2019/FMSY	1.538	1.431	0.867	2.346
K (million ton)	4.038	3.475	1.739	7.361
B_2018 (million ton)	1.052	0.900	0.470	1.811
B_2019 (million ton)	0.900	0.755	0.365	1.615
AveB_2017_2019	0.969	0.824	0.416	1.702
BMSY (million ton)	1.807	1.565	0.815	3.199
BMSY/K	0.456	0.444	0.389	0.543
B_2018/K	0.276	0.259	0.174	0.392
B_2019/K	0.233	0.217	0.134	0.353
AveB_2017_2019/K	0.251	0.237	0.160	0.358
B_2018/BMSY	0.608	0.564	0.397	0.864
B_2019/BMSY	0.515	0.477	0.299	0.775
AveB_2017_2019/BMSY	0.553	0.516	0.363	0.780

Sensitivity case 4

	Mean	Median	Lower10th	Upper10th
C_2019	0.192	0.192	0.192	0.192
AveC_2017_2019	0.298	0.298	0.298	0.298
AveF_2017_2019	0.587	0.567	0.298	0.905
F_2019	0.378	0.355	0.179	0.602
FMSY	0.384	0.370	0.186	0.602
MSY (million ton)	0.423	0.419	0.362	0.480
F_2019/FMSY	1.053	0.988	0.623	1.514
AveF_2017_2019/FMSY	1.432	1.372	0.955	1.899
K (million ton)	2.890	2.474	1.536	4.835
B_2018 (million ton)	0.773	0.658	0.421	1.242
B_2019 (million ton)	0.645	0.542	0.319	1.075
AveB_2017_2019	0.696	0.592	0.368	1.137
BMSY (million ton)	1.313	1.136	0.742	2.114
BMSY/K	0.465	0.456	0.398	0.547
B_2018/K	0.278	0.267	0.193	0.373
B_2019/K	0.230	0.219	0.145	0.326
AveB_2017_2019/K	0.248	0.240	0.174	0.332
B_2018/BMSY	0.601	0.568	0.437	0.801
B_2019/BMSY	0.497	0.469	0.320	0.705
AveB_2017_2019/BMSY	0.537	0.511	0.390	0.714

5 Summary of estimates of parameters

Base case 1

	Mean	Median	Lower10th	Upper10th
r	1.581	1.476	0.772	2.594
K (million ton)	2.196	1.909	1.379	3.269
qCHN	18.516	18.336	12.308	24.888
qJPN1	1.194	1.055	0.510	2.136
qJPN2	2.538	2.552	1.755	3.290
qKOR	11.429	11.478	7.929	14.778
qRUS	25.286	25.402	17.517	32.792
qCT	2.531	2.540	1.758	3.285
qBio	0.667	0.680	0.407	0.916
Shape	0.628	0.484	0.209	1.304
sigma_com	0.325	0.323	0.294	0.357
sigma_Bio	0.133	0.132	0.120	0.146
tau	0.311	0.307	0.234	0.395
FMSY	0.475	0.478	0.294	0.650
BMSY (million ton)	0.982	0.863	0.642	1.419
MSY (million ton)	0.422	0.414	0.351	0.497
b	0.735	0.732	0.601	0.873

Base case 2

	Mean	Median	Lower10th	Upper10th
r	1.585	1.496	0.766	2.582
K (million ton)	2.291	1.948	1.361	3.584
qCHN	18.953	18.849	12.505	25.452
qJPN1				
qJPN2	2.596	2.627	1.781	3.354
qKOR	11.687	11.842	8.004	15.080
qRUS	25.978	26.259	17.760	33.622
qCT	2.588	2.615	1.775	3.344
qBio	0.687	0.707	0.411	0.930
Shape	0.628	0.490	0.204	1.295
sigma_com	0.328	0.327	0.296	0.362
sigma_Bio	0.147	0.146	0.132	0.162
tau	0.322	0.316	0.232	0.421
FMSY	0.478	0.482	0.282	0.667
BMSY (million ton)	1.024	0.882	0.637	1.563
MSY (million ton)	0.435	0.423	0.358	0.523
b	0.733	0.732	0.599	0.874

Sensitivity case 1

	Mean	Median	Lower10th	Upper10th
r	1.632	1.558	0.796	2.608
K (million ton)	2.067	1.796	1.249	3.147
qCHN	19.793	19.342	12.795	27.323
qJPN1	1.286	1.146	0.537	2.290
qJPN2	2.705	2.680	1.819	3.623
qKOR	12.190	12.043	8.210	16.336
qRUS	27.023	26.640	18.052	36.456
qCT	2.696	2.661	1.813	3.620
qBio	0.733	0.724	0.426	1.050
Shape	0.648	0.519	0.217	1.304
sigma_com	0.326	0.324	0.295	0.358
sigma_Bio	0.133	0.132	0.120	0.146
tau	0.313	0.309	0.235	0.396
FMSY	0.513	0.506	0.308	0.724
BMSY (million ton)	0.929	0.819	0.584	1.364
MSY (million ton)	0.424	0.417	0.357	0.495
b	0.734	0.732	0.601	0.869

Sensitivity case 2

	Mean	Median	Lower10th	Upper10th
r	1.742	1.718	0.852	2.704
K (million ton)	1.976	1.675	1.087	3.153
qCHN	22.294	21.574	13.366	32.460
qJPN1				
qJPN2	3.064	2.984	1.909	4.350
qKOR	13.736	13.369	8.554	19.435
qRUS	30.672	29.725	18.940	43.538
qCT	3.040	2.953	1.890	4.301
qBio	0.856	0.832	0.450	1.296
Shape	0.660	0.541	0.232	1.292
sigma_com	0.328	0.326	0.296	0.362
sigma_Bio	0.147	0.146	0.132	0.162
tau	0.325	0.318	0.235	0.422
FMSY	0.574	0.560	0.315	0.851
BMSY (million ton)	0.890	0.765	0.517	1.388
MSY (million ton)	0.439	0.430	0.366	0.513
b	0.744	0.741	0.608	0.889

Sensitivity case 3

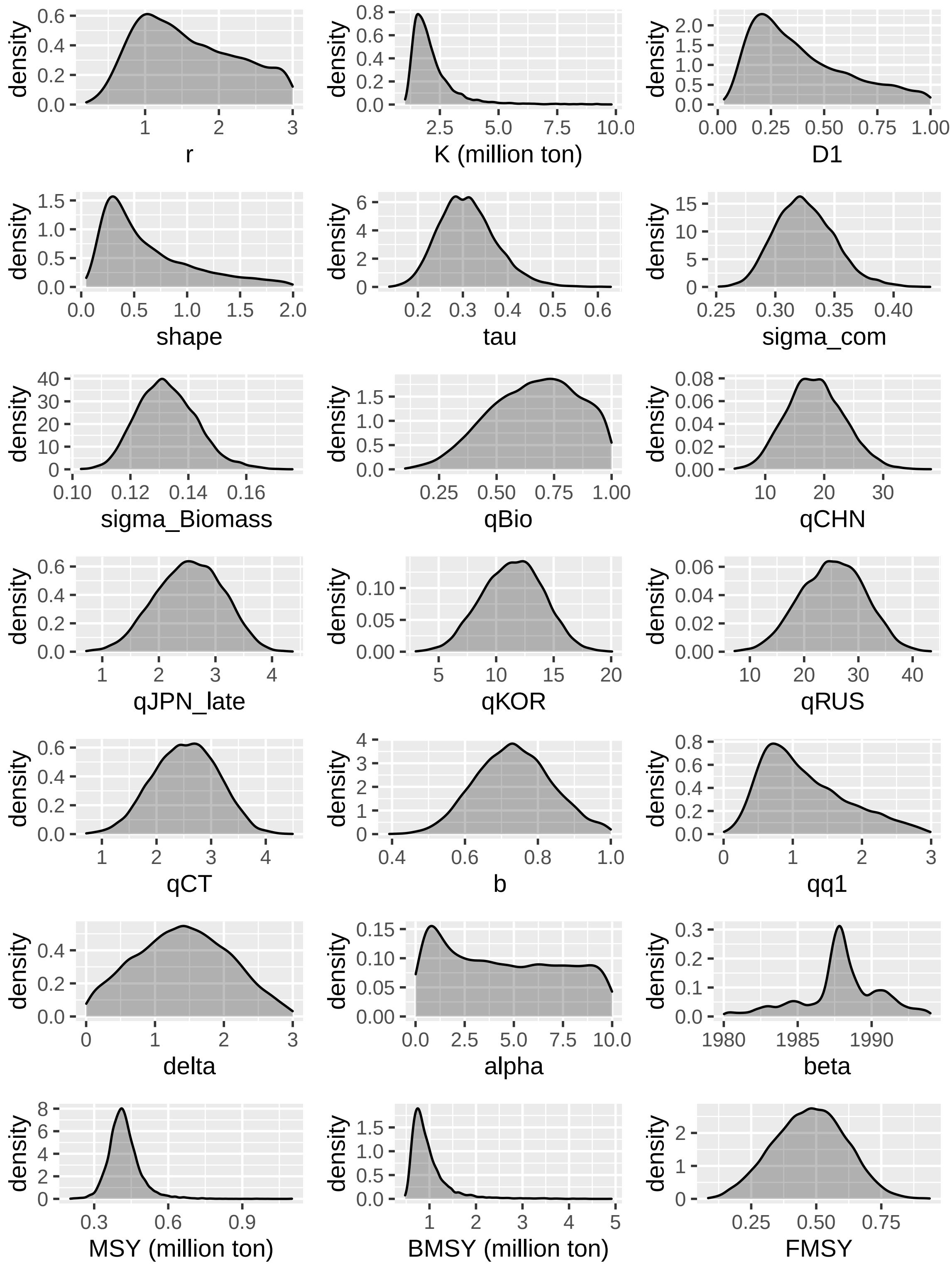
	Mean	Median	Lower10th	Upper10th
r	1.122	0.943	0.290	2.293
K (million ton)	4.038	3.475	1.739	7.361
qJOINT	0.871	0.883	0.679	1.044
qBio	0.432	0.385	0.195	0.755
Shape	0.663	0.499	0.123	1.502
sigma_Joint	0.300	0.295	0.251	0.352
sigma_Bio	0.300	0.295	0.251	0.352
tau	0.124	0.103	0.032	0.247
FMSY	0.297	0.264	0.104	0.546
BMSY (million ton)	1.807	1.565	0.815	3.199
MSY (million ton)	0.406	0.401	0.311	0.490
b	0.268	0.241	0.066	0.500

Sensitivity case 4

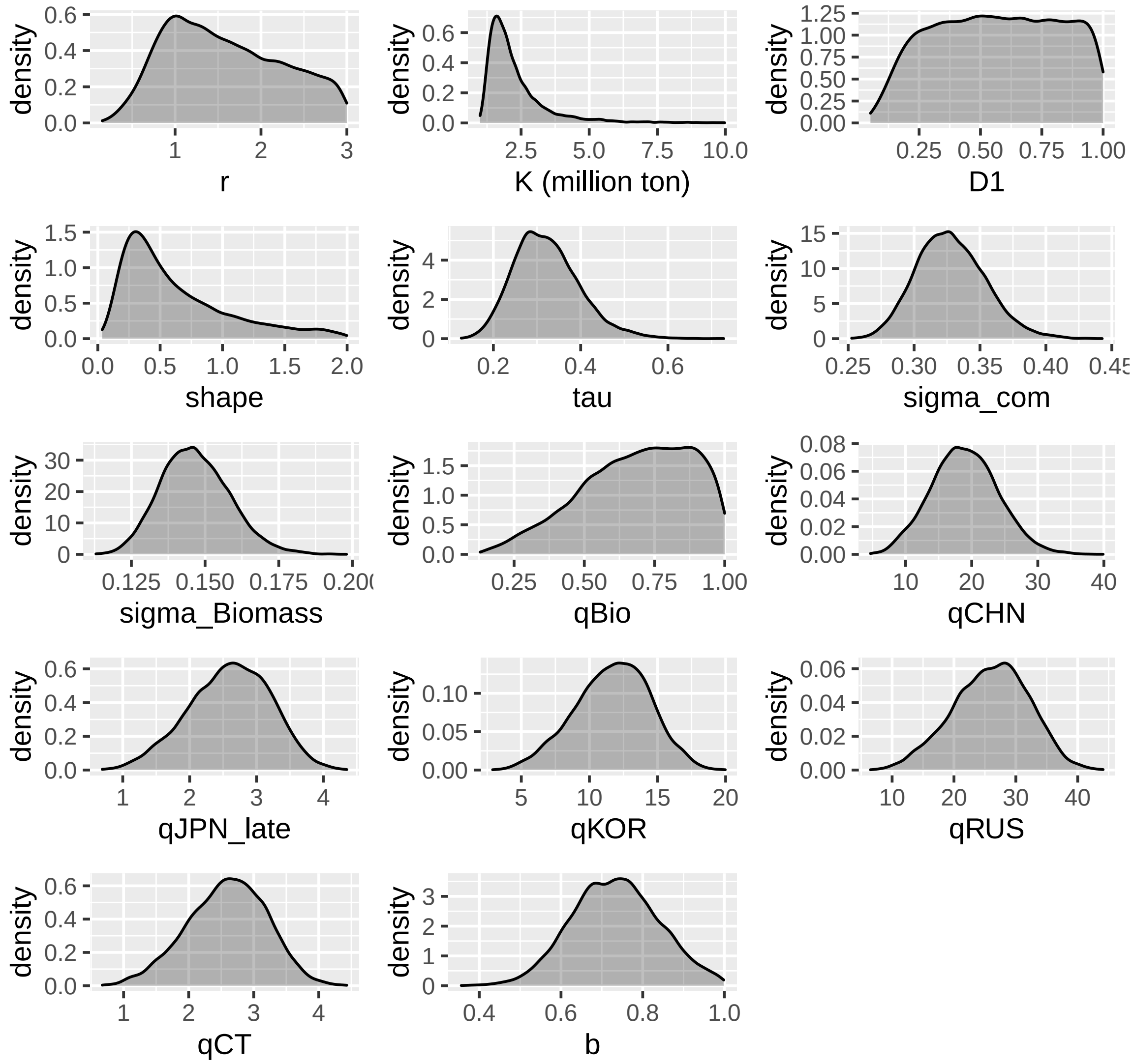
	Mean	Median	Lower10th	Upper10th
r	1.248	1.078	0.490	2.343
K (million ton)	2.890	2.474	1.536	4.835
qJOINT	0.930	0.938	0.769	1.079
qBio	0.550	0.533	0.290	0.841
Shape	0.736	0.592	0.173	1.561
sigma_Joint	0.259	0.257	0.220	0.300
sigma_JPN_early	0.635	0.630	0.539	0.735
sigma_Bio	0.259	0.257	0.220	0.300
tau	0.117	0.097	0.029	0.236
FMSY	0.384	0.370	0.186	0.602
BMSY (million ton)	1.313	1.136	0.742	2.114
MSY (million ton)	0.423	0.419	0.362	0.480
b	0.269	0.245	0.077	0.491

6 Posterior distributions

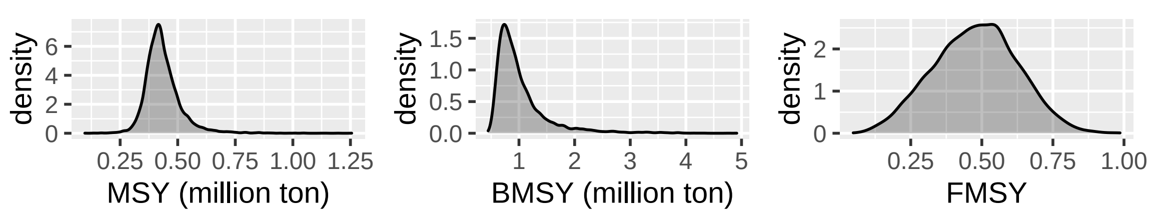
Base case 1



Base case 2

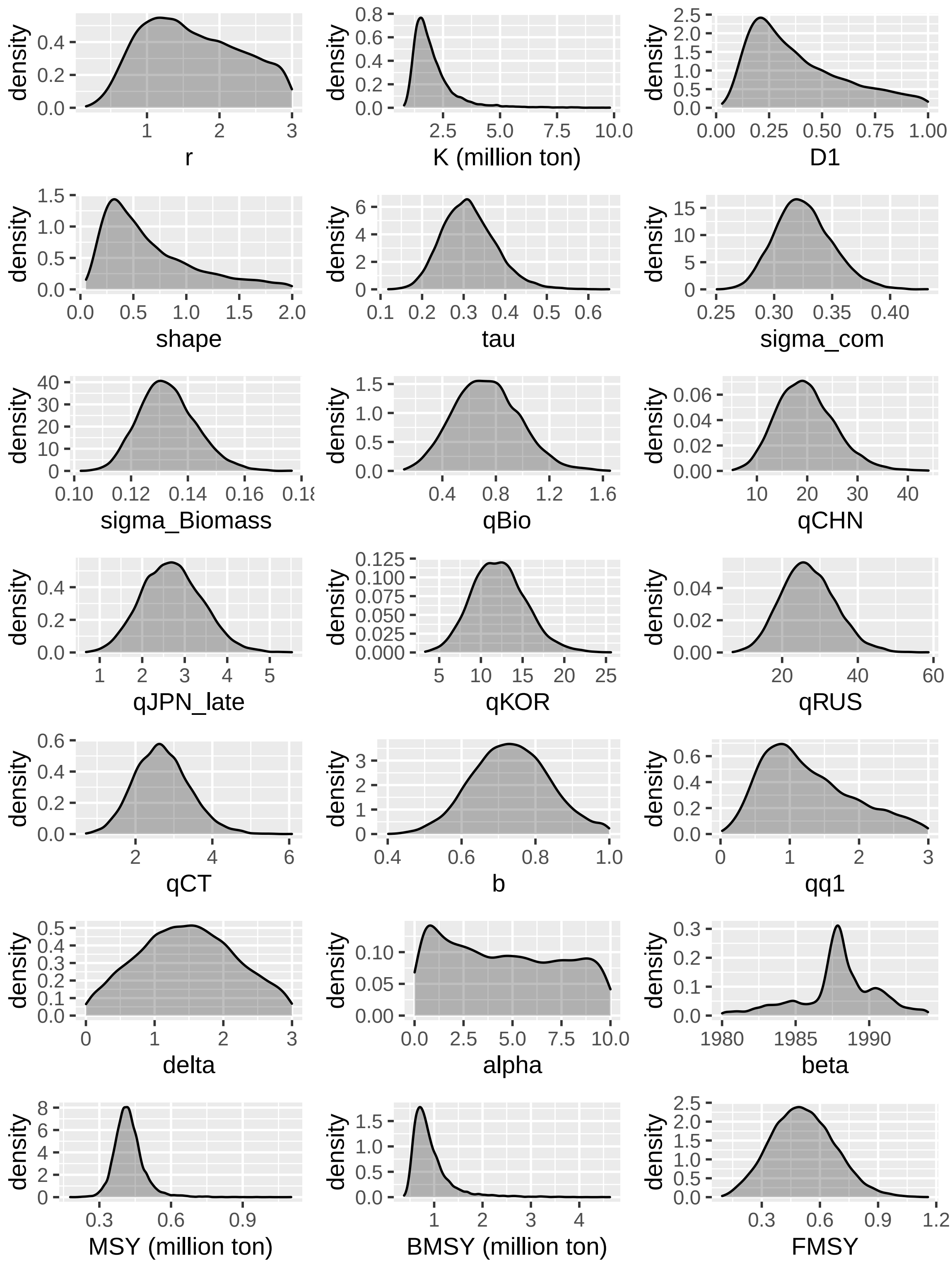


density
0.0
0.2
0.4
0.6
1
2
3
r
0.0
0.2
0.4
0.6
2.5
5.0
7.5
10.0
K (million ton)
0.00
0.25
0.50
0.75
1.00
1.25
0.25
0.50
0.75
1.00
D1
0.0
0.5
1.0
1.5
0.0
0.5
1.0
1.5
2.0
shape
0
2
4
0.2
0.4
0.6
tau
0
5
10
15
0.25
0.30
0.35
0.40
sigma_com
0
10
20
30
0.125
0.150
0.175
sigma_Biomass
0.0
0.5
1.0
1.5
0.25
0.50
0.75
1.00
qBio
0.00
0.02
0.04
0.06
0.08
10
20
30
40
qCHN
0.0
0.2
0.4
0.6
1
2
3
4
qJPN_late
0.00
0.05
0.10
5
10
15
20
qKOR
0.00
0.02
0.04
0.06
10
20
30
40
qRUS
0.0
0.2
0.4
0.6
1
2
3
4
qCT
0
1
2
3
0.4
0.6
0.8
1.0
b

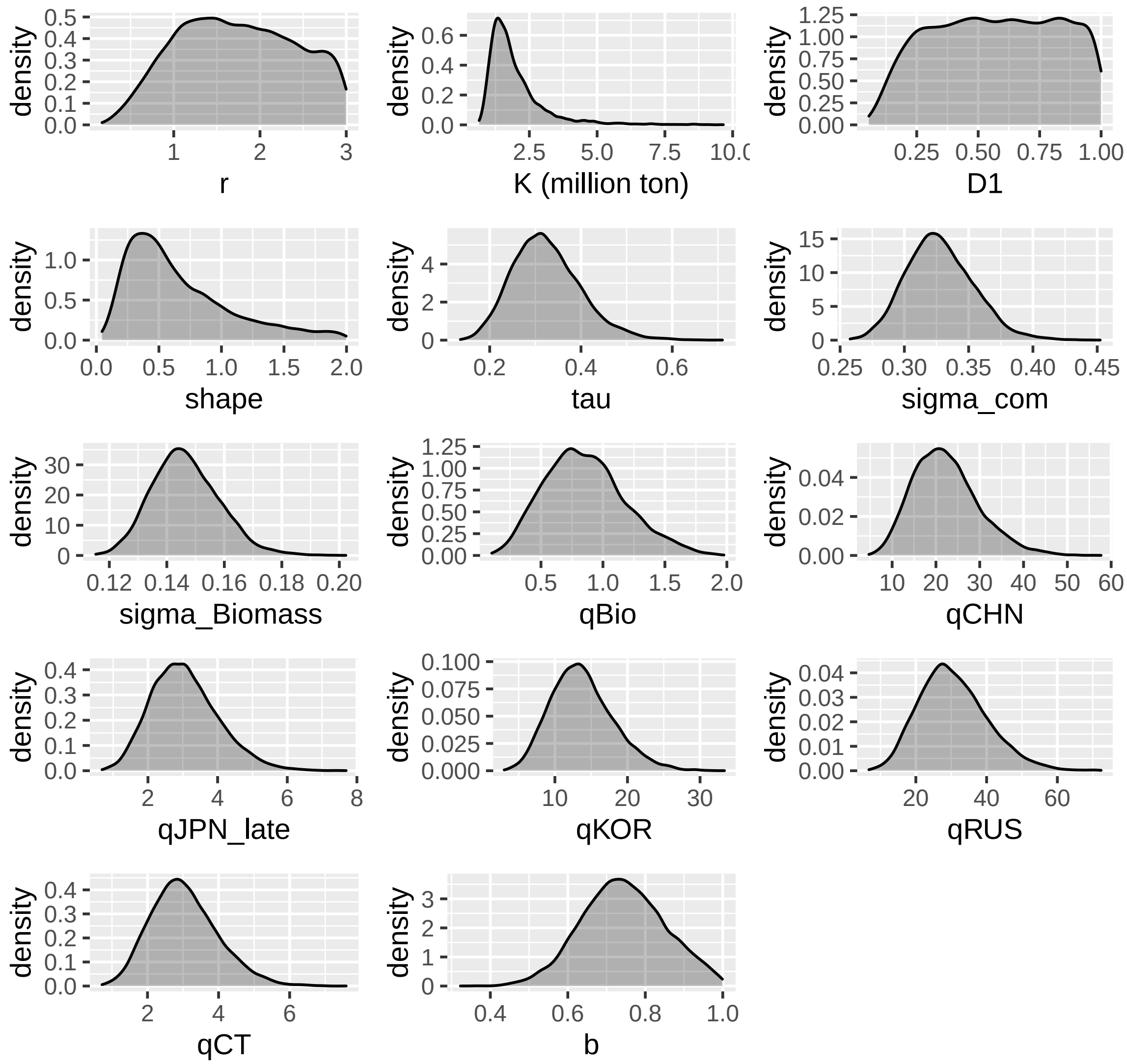


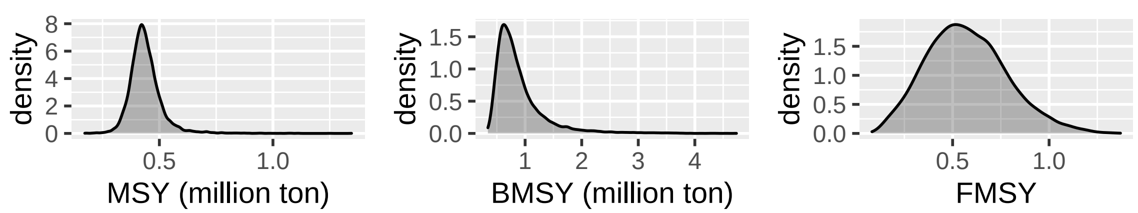
density
0
2
4
6
0.25
0.50
0.75
1.00
1.25
MSY (million ton)
0.0
0.5
1.0
1.5
1
2
3
4
5
BMSY (million ton)
0
1
2
0.25
0.50
0.75
1.00
FMSY

Sensitivity case 1

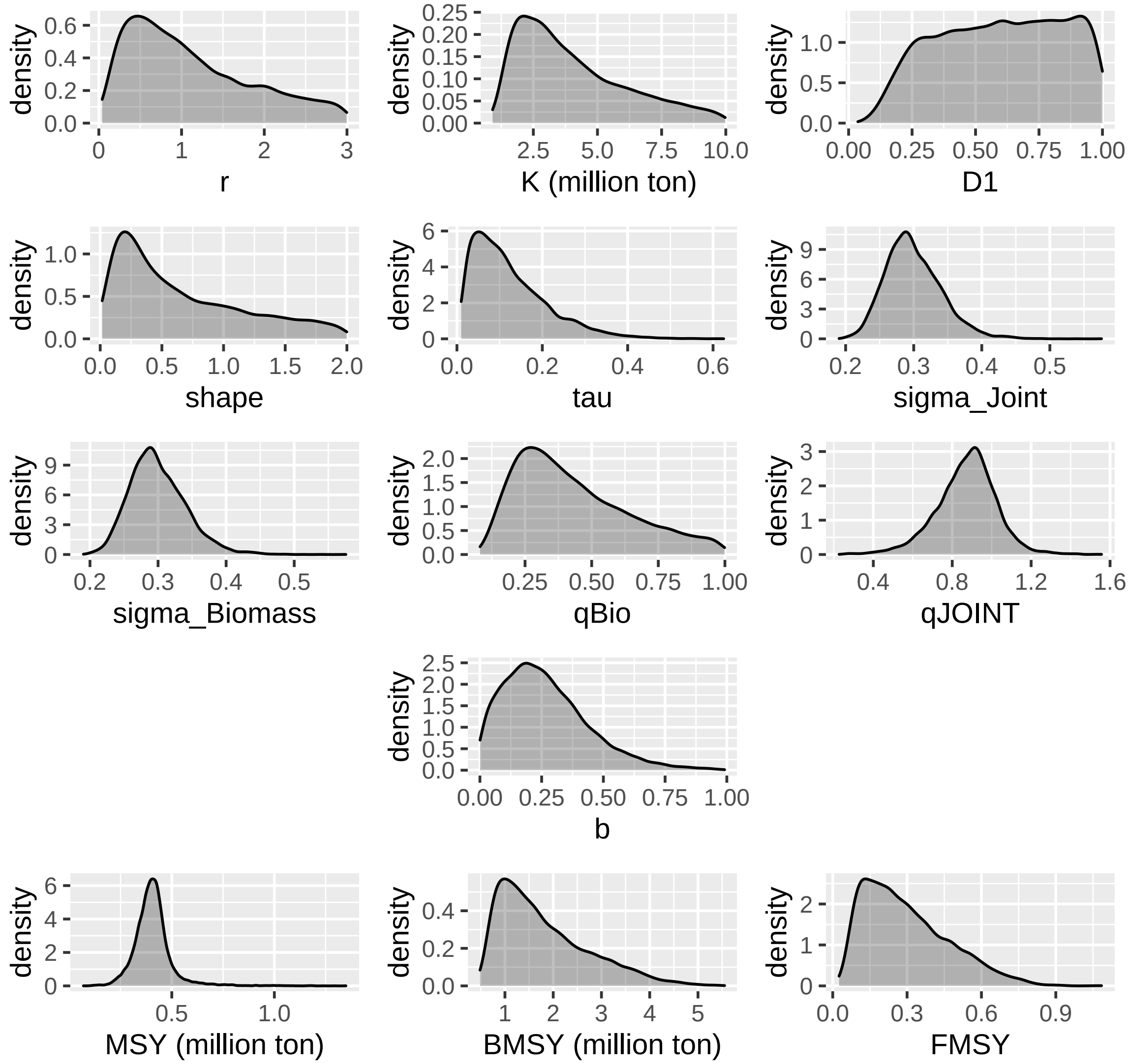


Sensitivity case 2

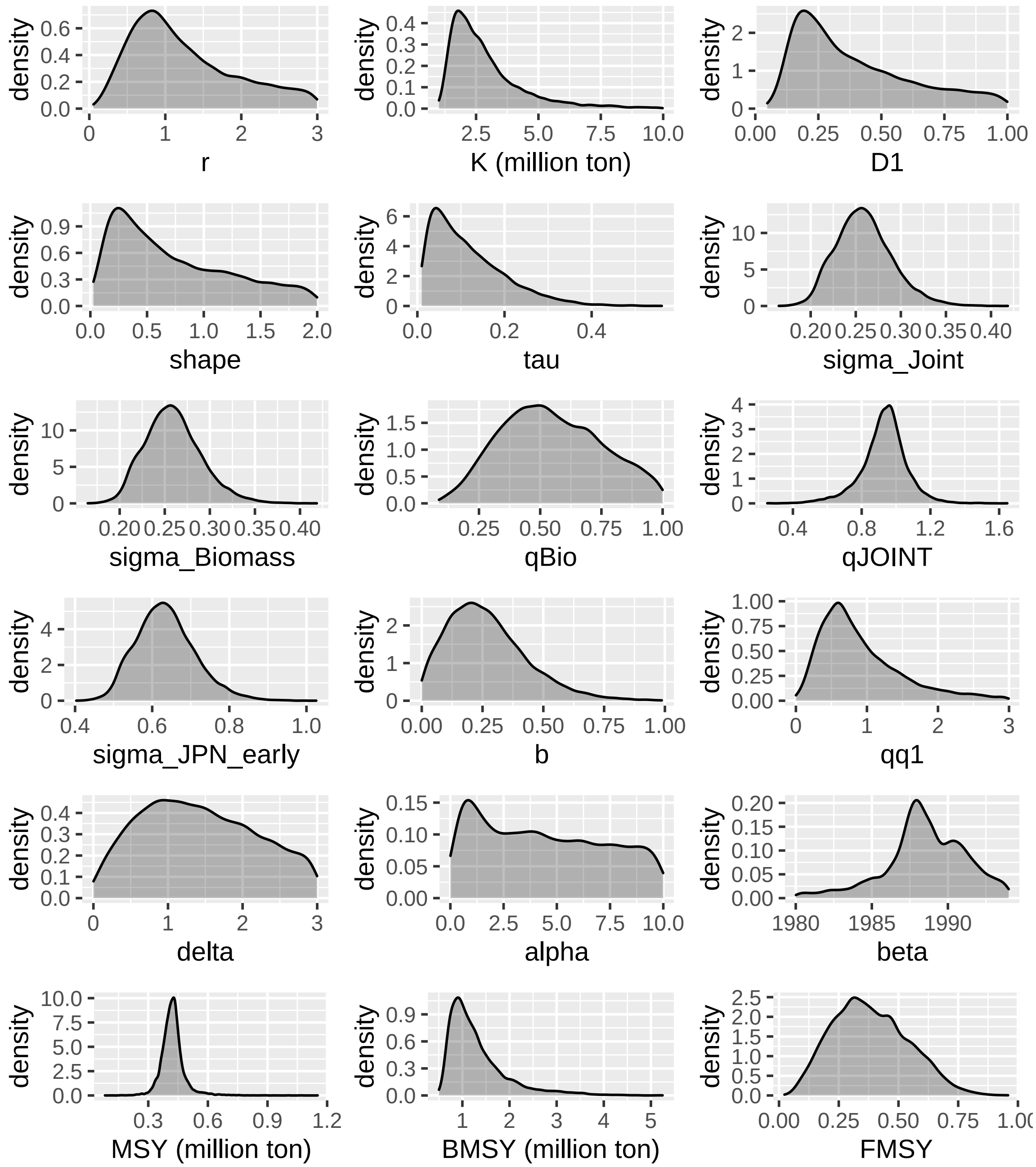




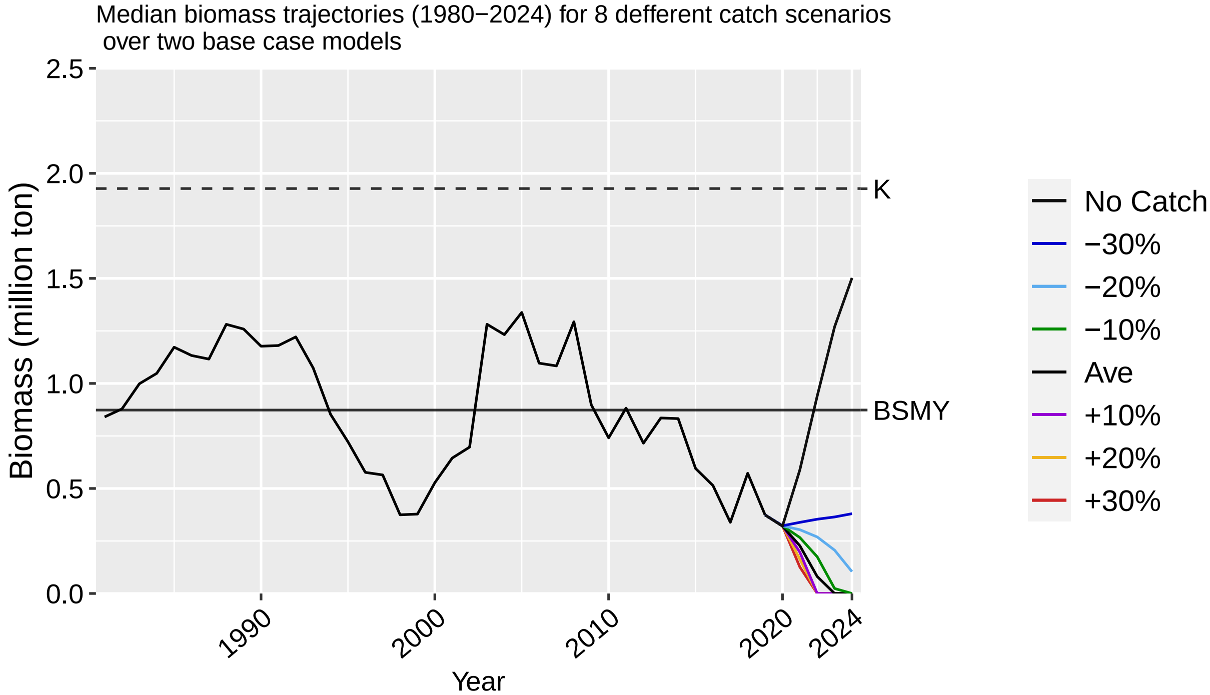
Sensitivity case 3

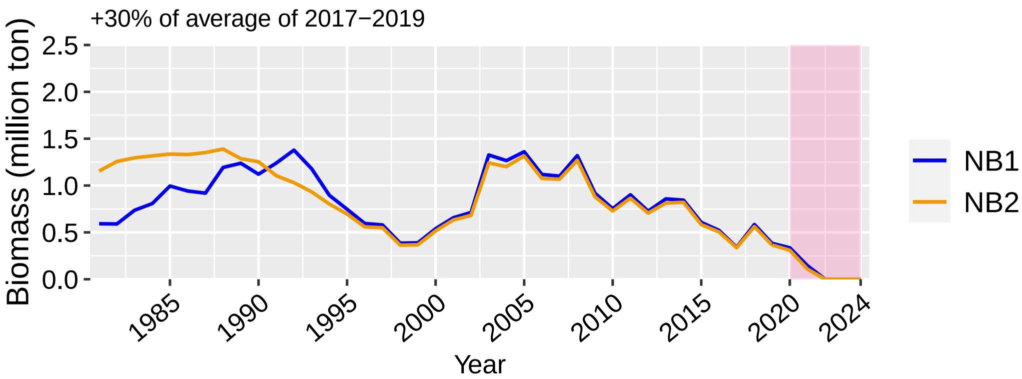


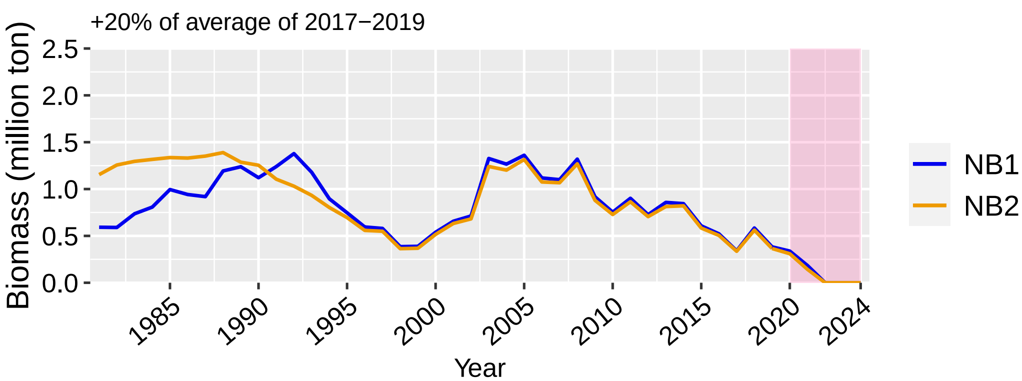
Sensitivity case 4

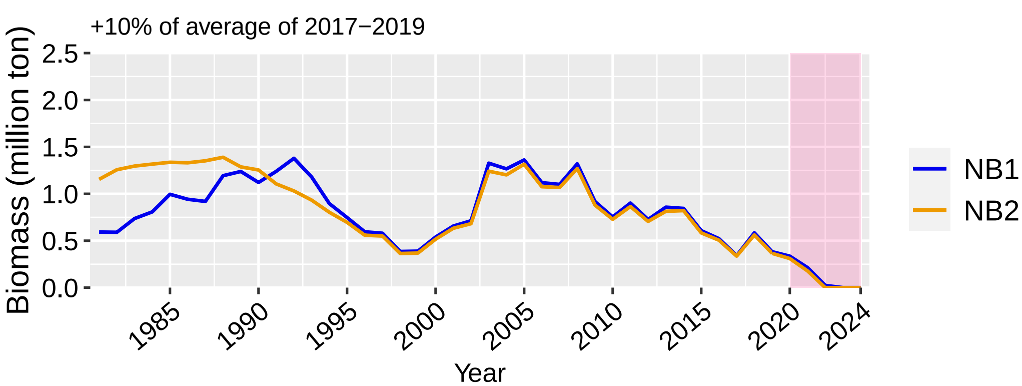


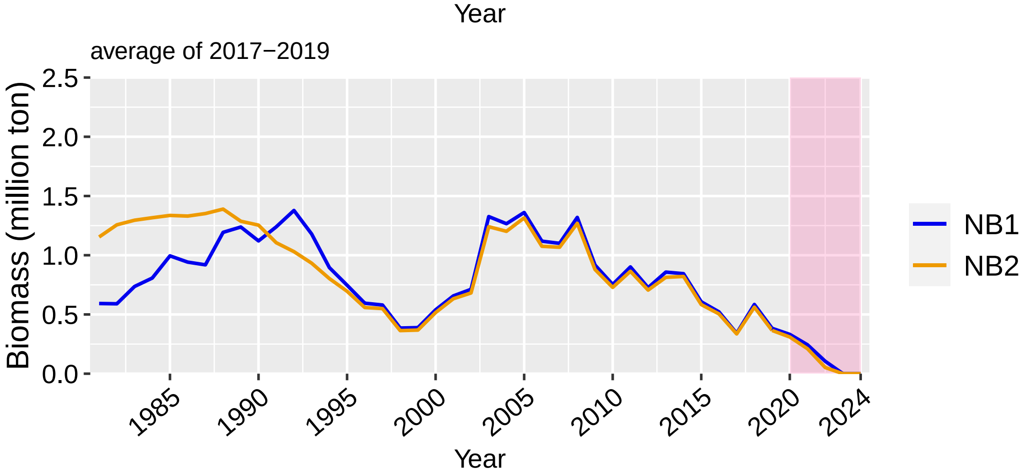
7 Future projection

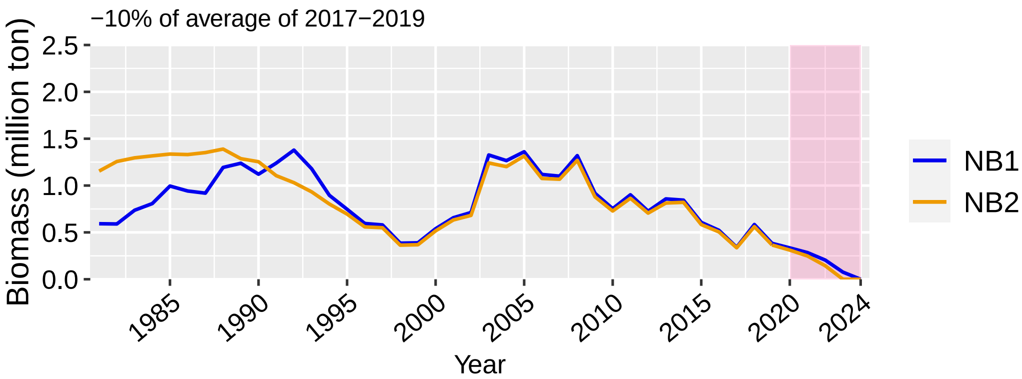


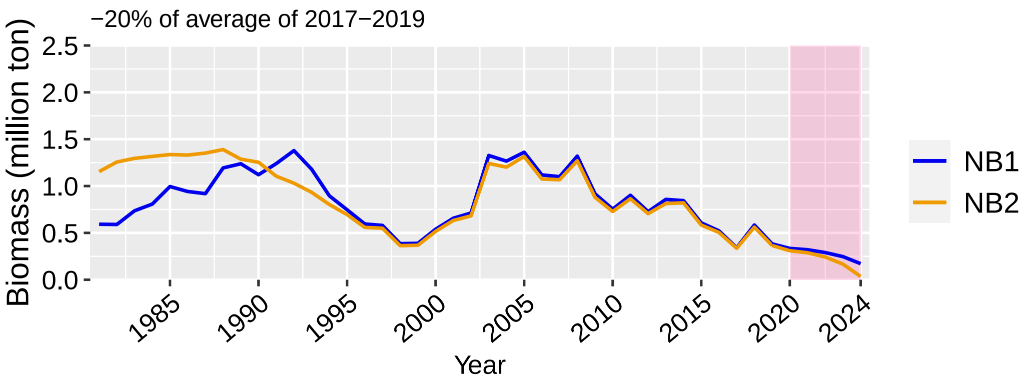

+30% of average of 2017−2019
Biomass (million ton)
2.5
2.0
1.5
1.0
0.5
0.0
1985
1990
1995
2000
2005
2010
2015
2020
2024
Year
NB1
NB2

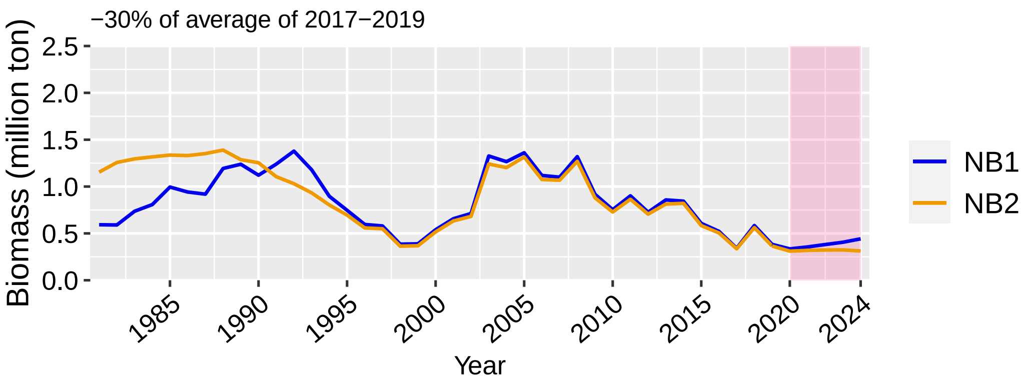

+20% of average of 2017−2019
Biomass (million ton)
2.5
2.0
1.5
1.0
0.5
0.0
1985
1990
1995
2000
2005
2010
2015
2020
2024
Year
NB1
NB2

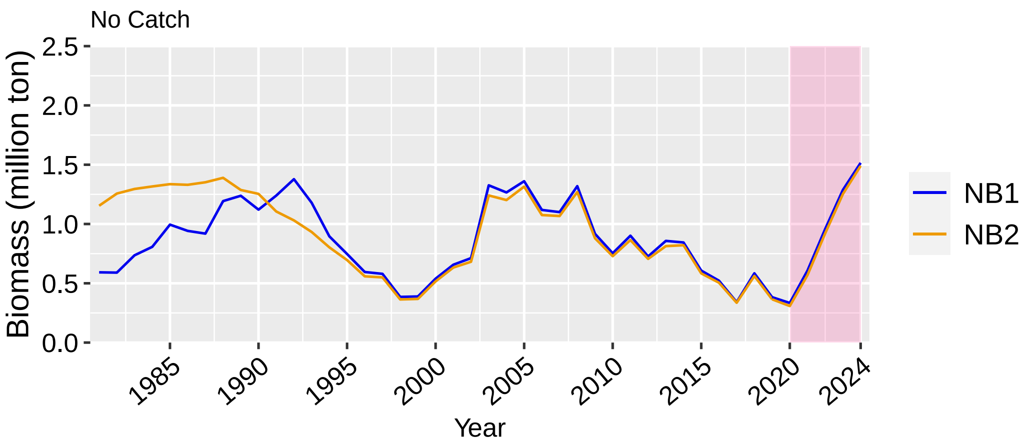

+10% of average of 2017−2019
Biomass (million ton)
2.5
2.0
1.5
1.0
0.5
0.0
1985
1990
1995
2000
2005
2010
2015
2020
2024
Year
NB1
NB2


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


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


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


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


No Catch
Biomass (million ton)
Year
NB1
NB2

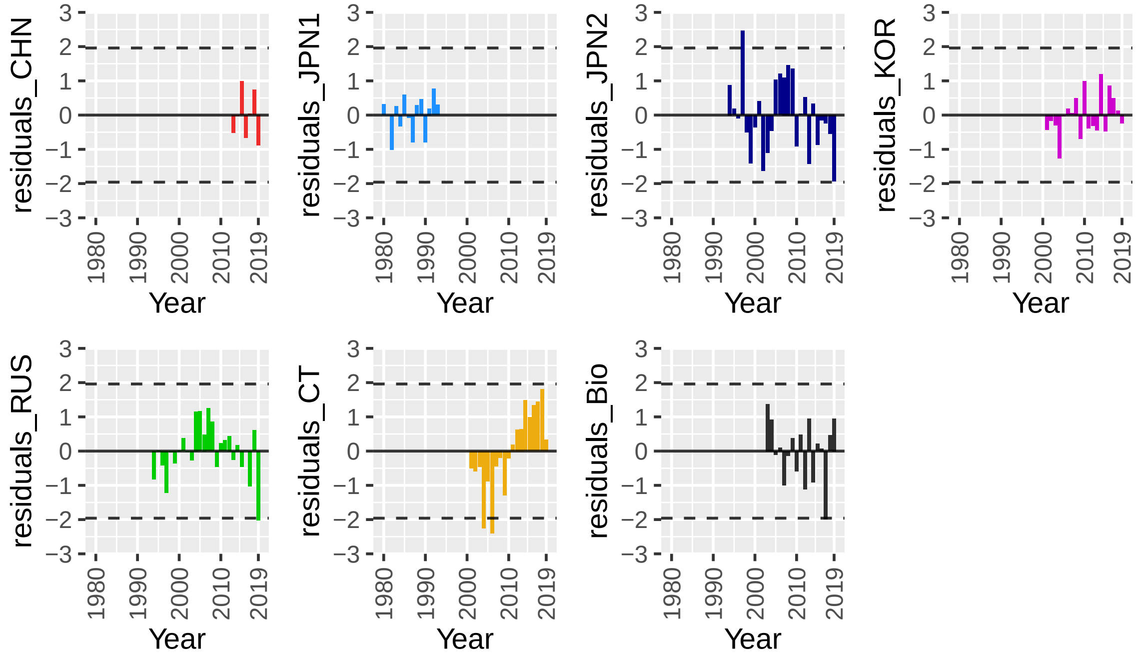
8 Risk table

	Red	Orange	Yellow	Green	B<BMSY	F>FMSY
+30%	0.954	0.004	0.004	0.038	0.958	0.958
+20%	0.931	0.002	0.009	0.057	0.940	0.934
+10%	0.905	0.001	0.017	0.077	0.922	0.907
±0%	0.856	0.001	0.032	0.111	0.889	0.857
-10%	0.783	0.000	0.057	0.161	0.839	0.783
-20%	0.690	0.000	0.098	0.212	0.788	0.690
-30%	0.577	0.000	0.140	0.282	0.718	0.577
No Catch	0.000	0.000	0.163	0.837	0.163	0.000

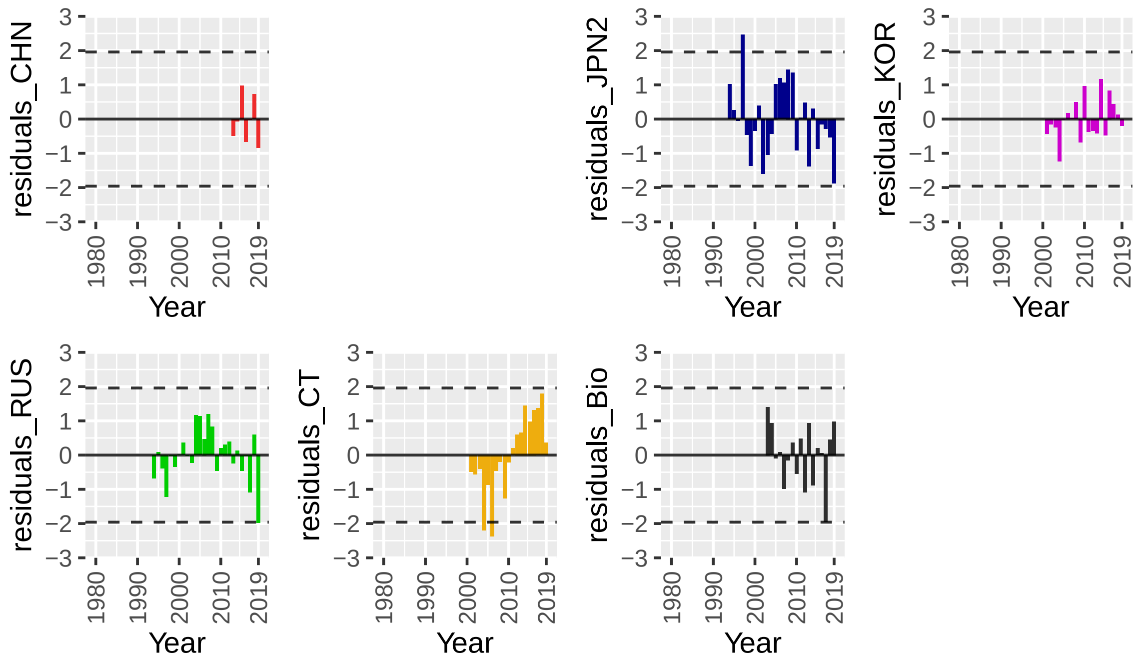
9 Diagnosis

9.1 Standardized residuals plot

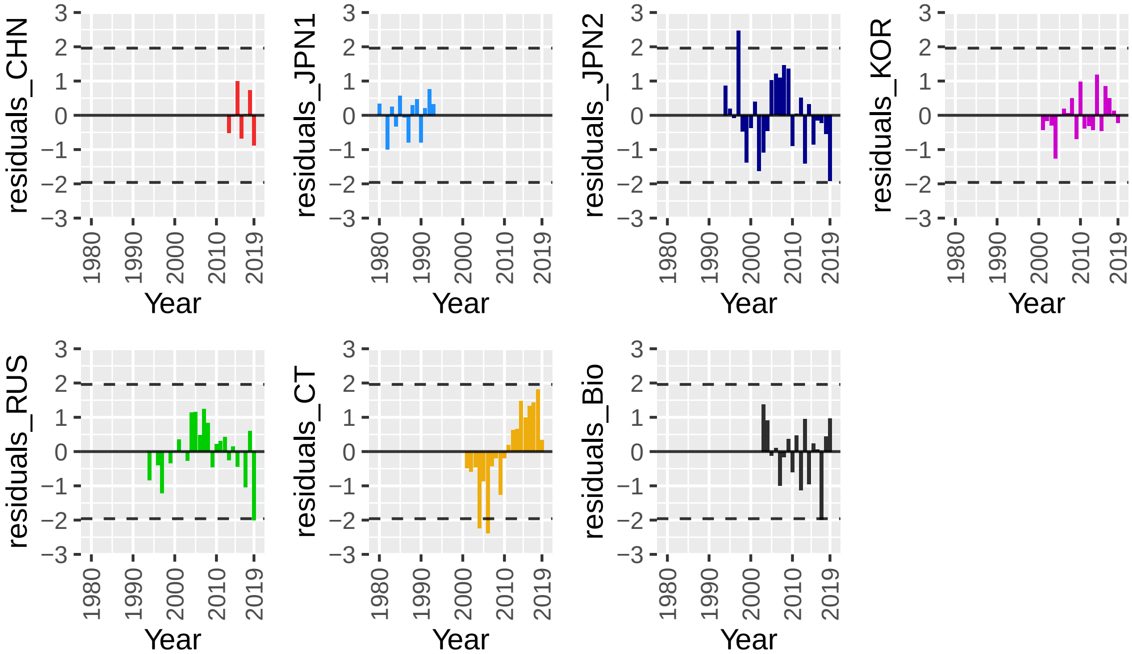
Base case 1



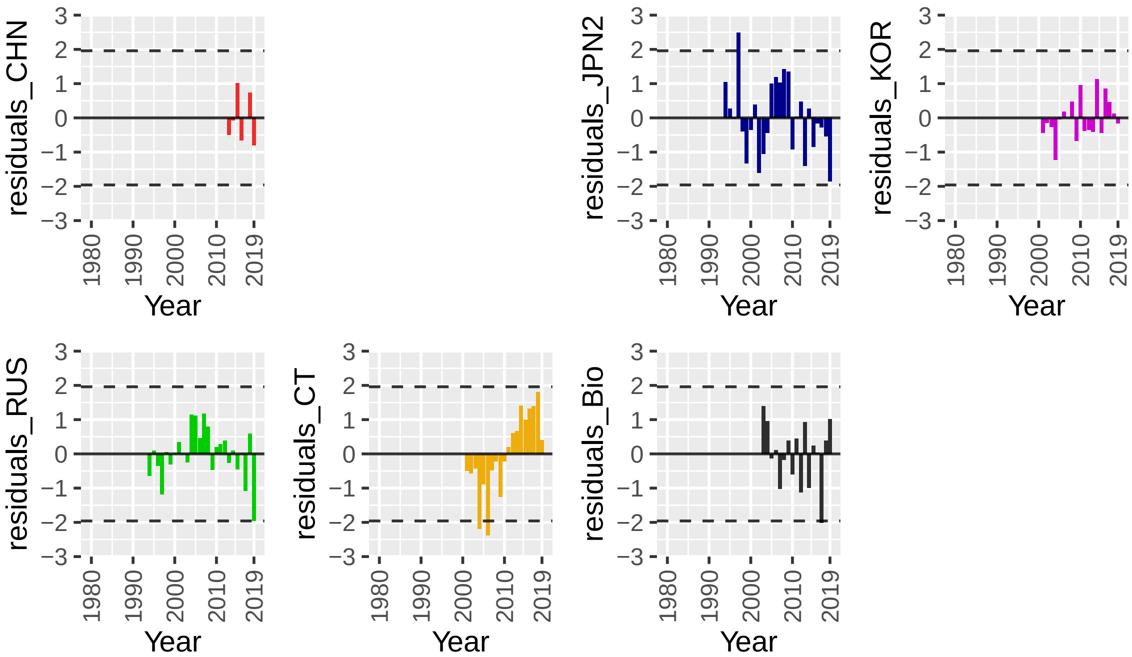
Base case 2



Sensitivity case 1

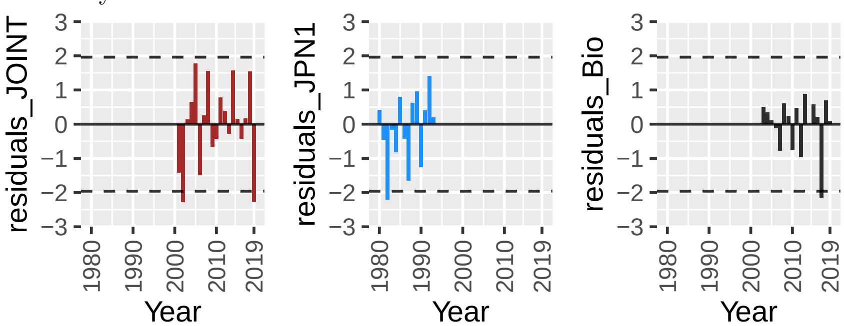


Sensitivity case 2



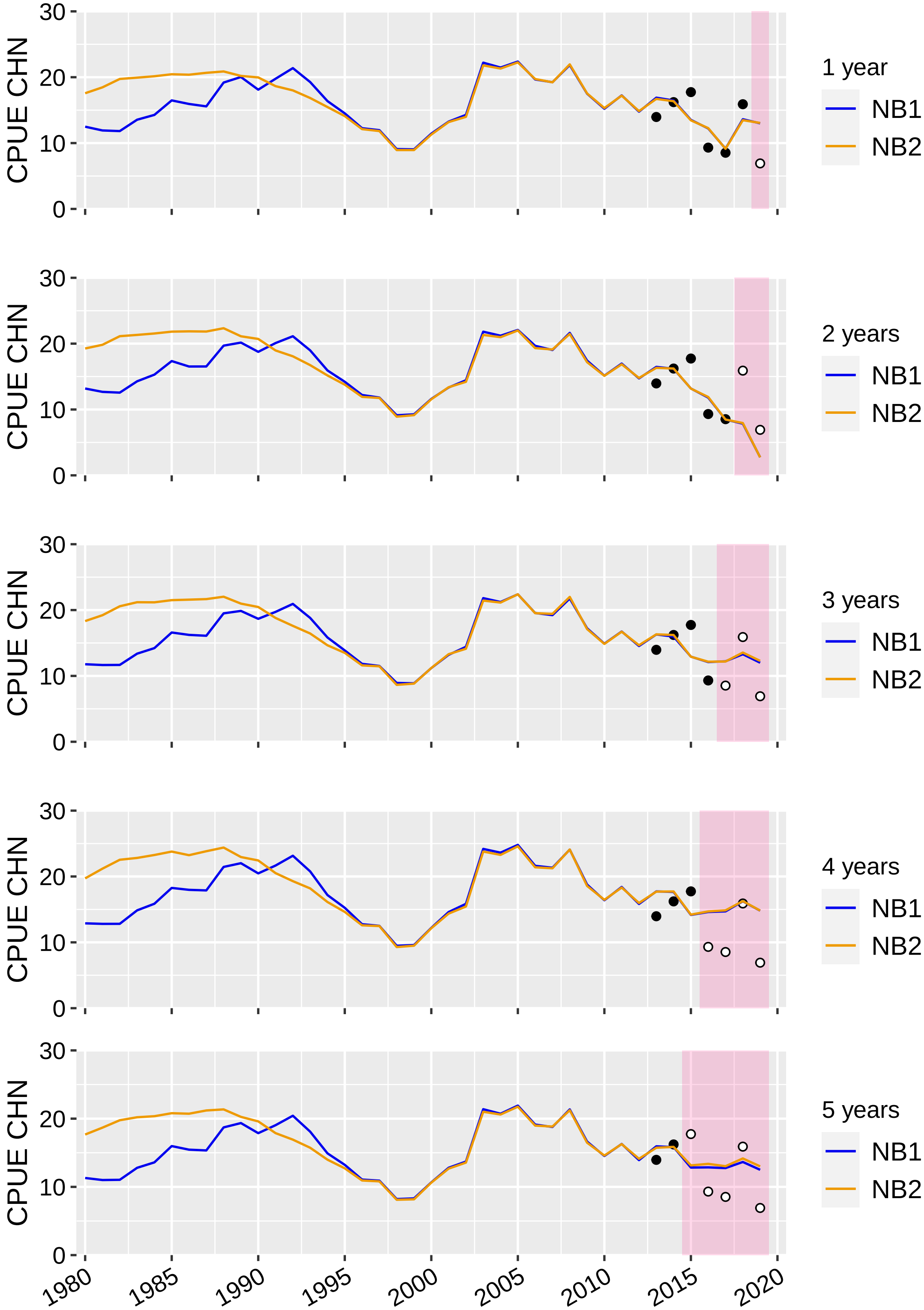
Sensitivity case 3

Sensitivity case 4

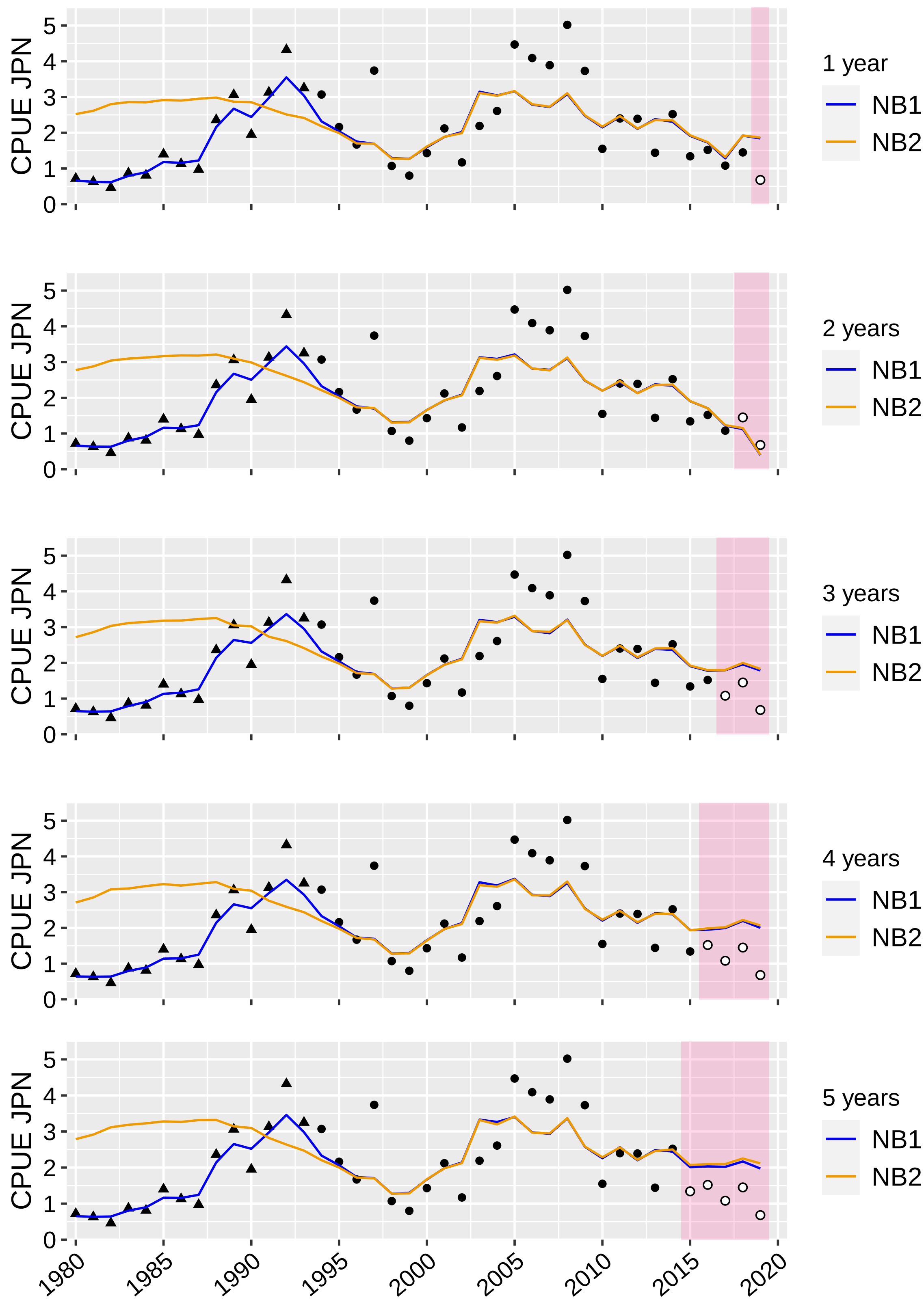


9.2 Hindcasting

CPUE CHN

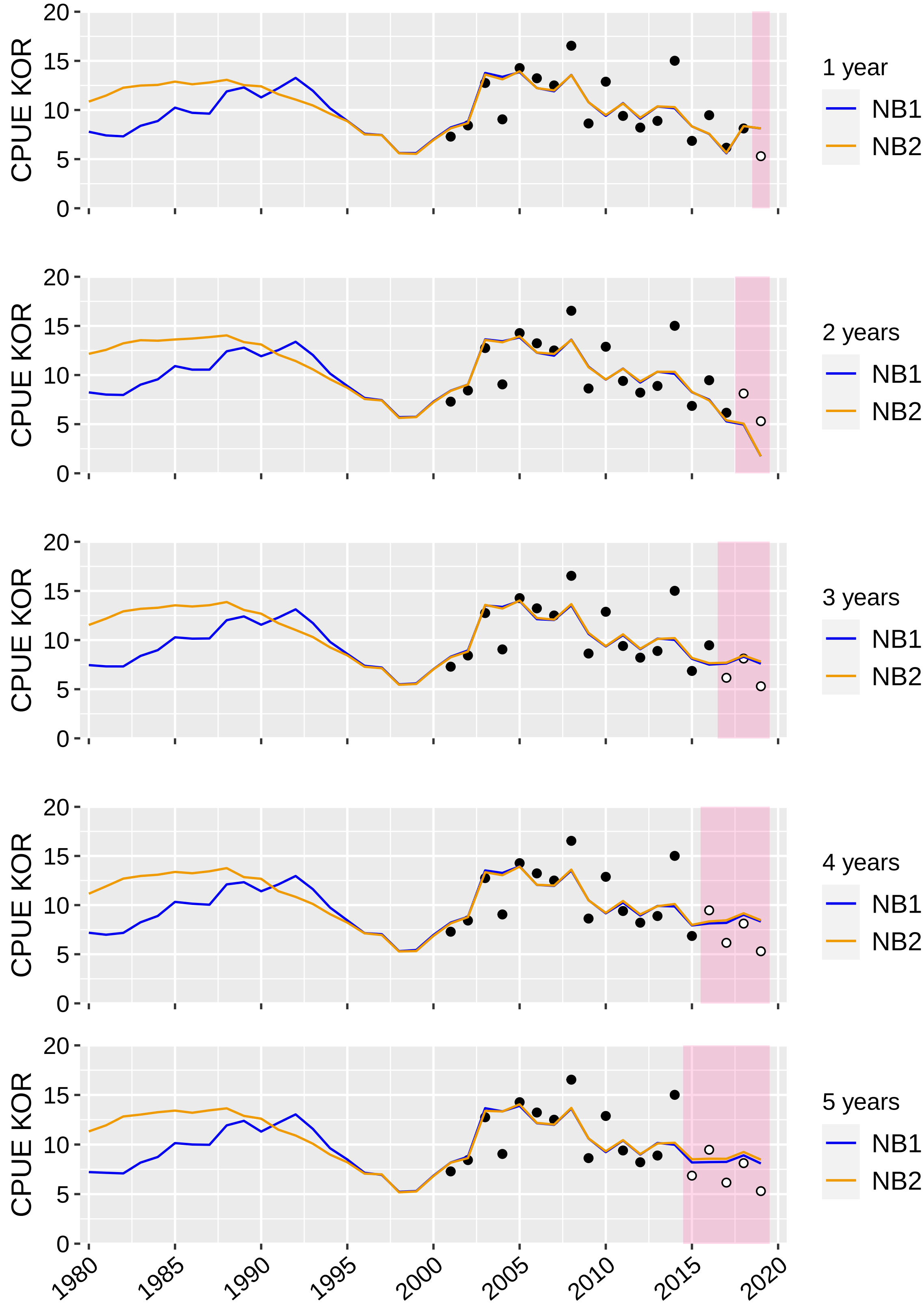


CPUE JPN

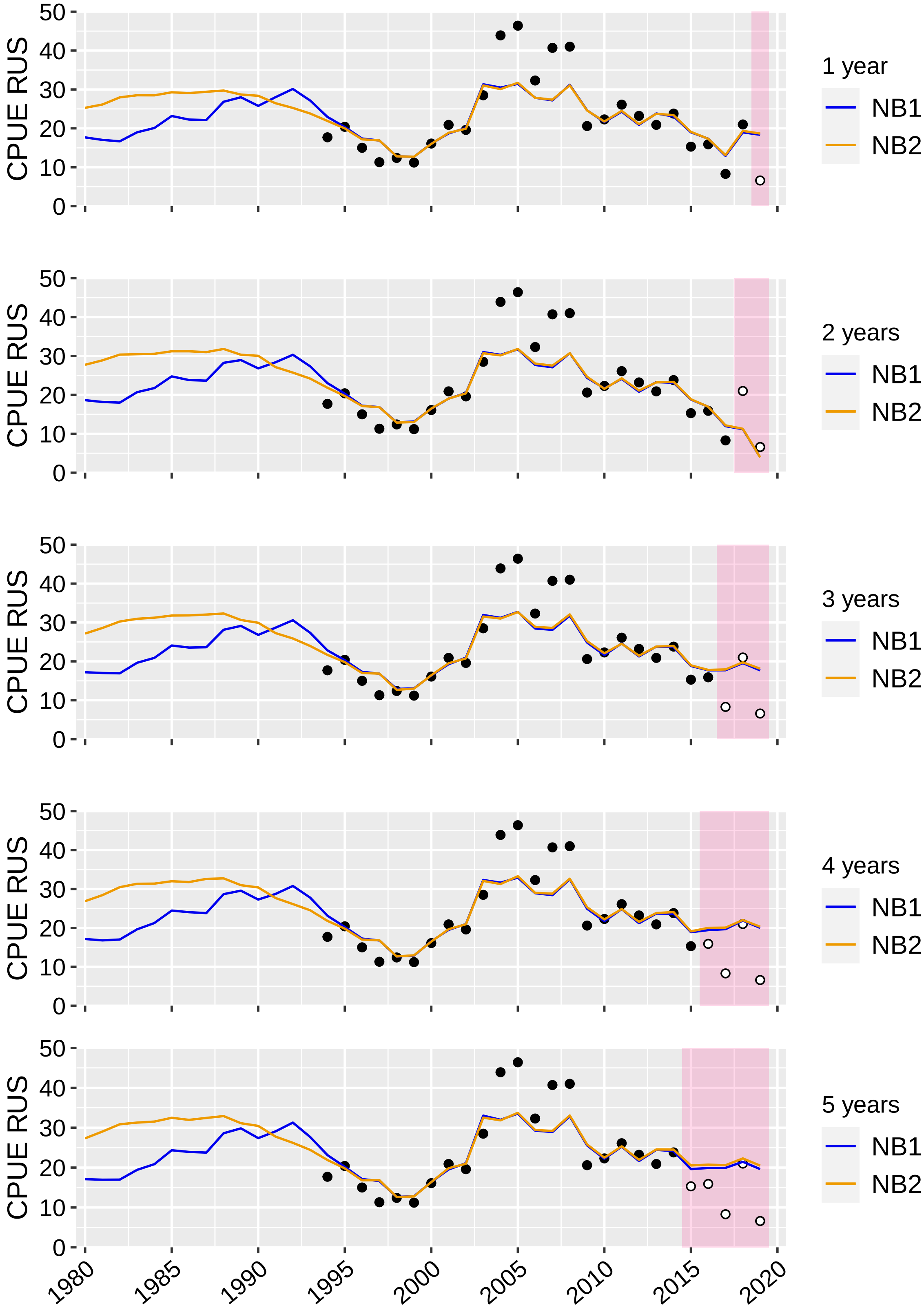


CPUE JPN
0
1
2
3
4
5
1 year
NB1
NB2
2 years
NB1
NB2
3 years
NB1
NB2
4 years
NB1
NB2
5 years
NB1
NB2
1980
1985
1990
1995
2000
2005
2010
2015
2020

CPUE KOR

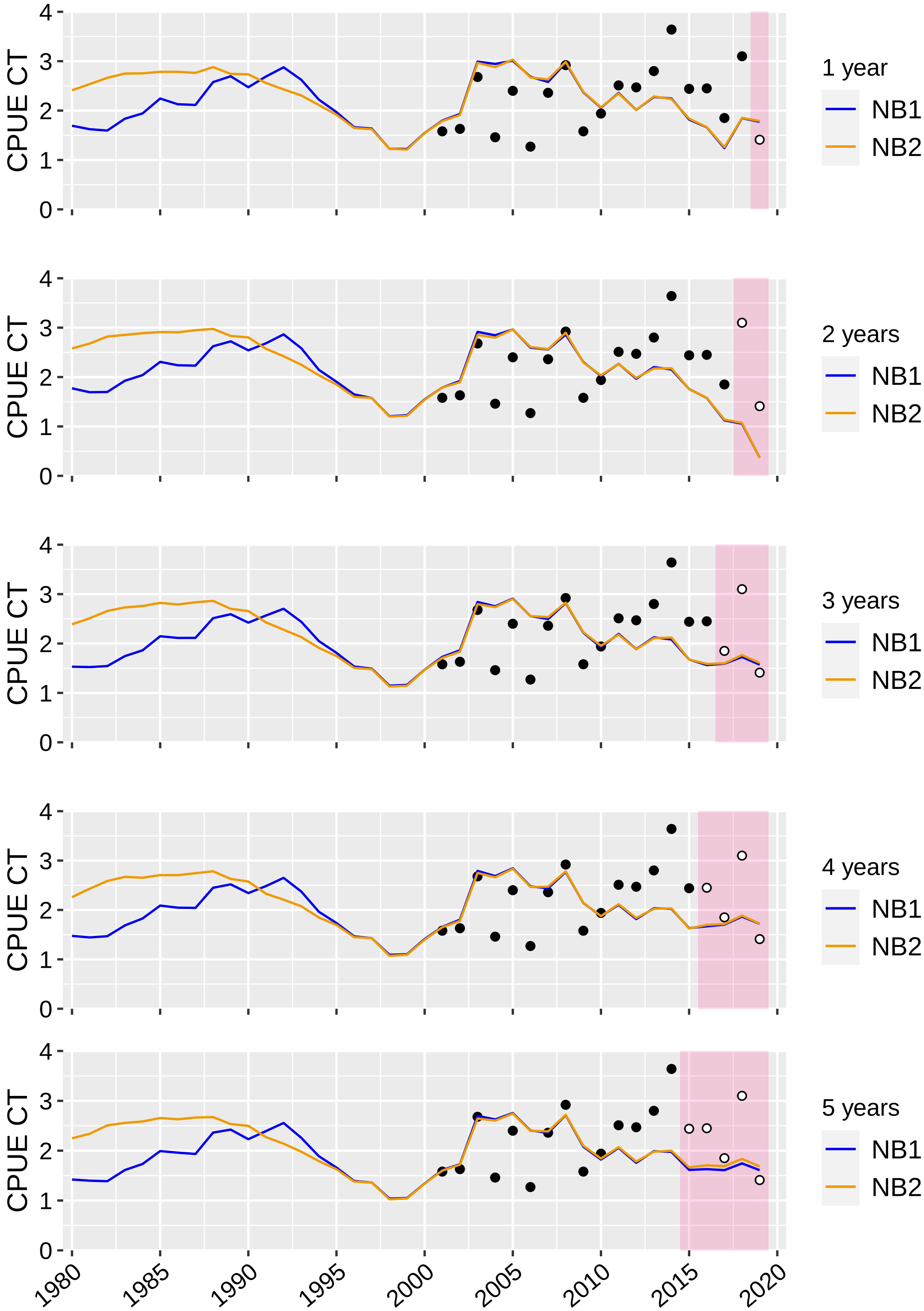

CPUE KOR
20
15
10
5
0
1 year
NB1
NB2
2 years
NB1
NB2
3 years
NB1
NB2
4 years
NB1
NB2
5 years
NB1
NB2
1980
1985
1990
1995
2000
2005
2010
2015
2020

CPUE RUS



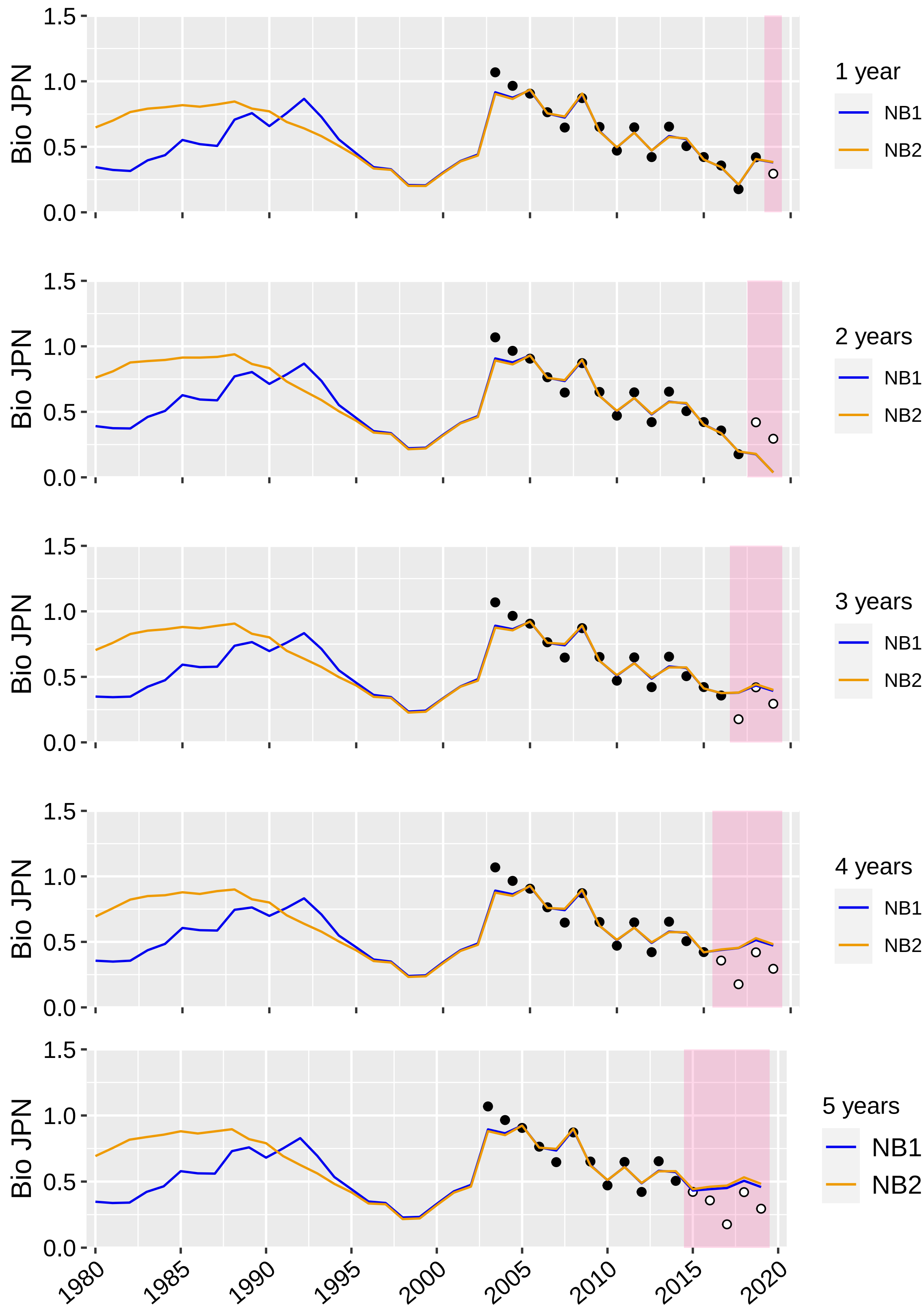
CPUE RUS
1 year
2 years
3 years
4 years
5 years
NB1
NB2
1980
1985
1990
1995
2000
2005
2010
2015
2020

CPUE CT



CPUE CT
1 year
2 years
3 years
4 years
5 years
NB1
NB2
0
1
2
3
4
1980
1985
1990
1995
2000
2005
2010
2015
2020

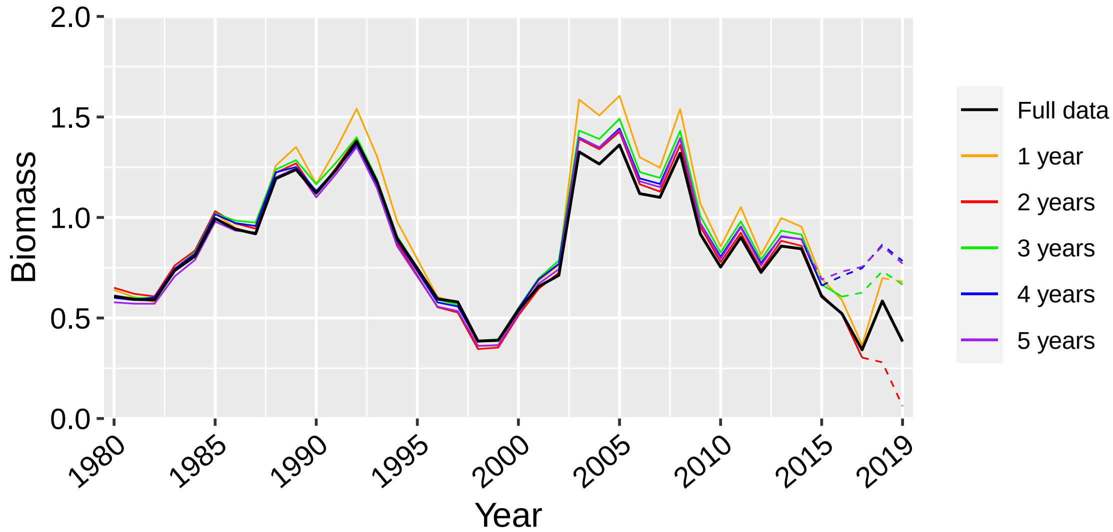
Biomass JPN



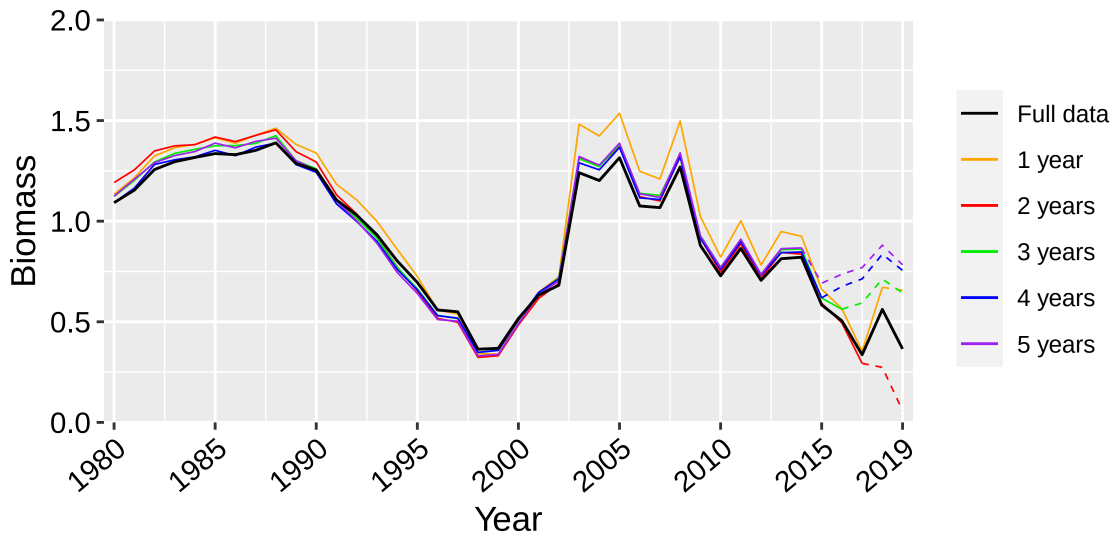
Bio JPN
1.5
1.0
0.5
0.0
1 year
NB1
NB2
2 years
3 years
4 years
5 years
1980
1985
1990
1995
2000
2005
2010
2015
2020

9.2.1 Biomass

NB1

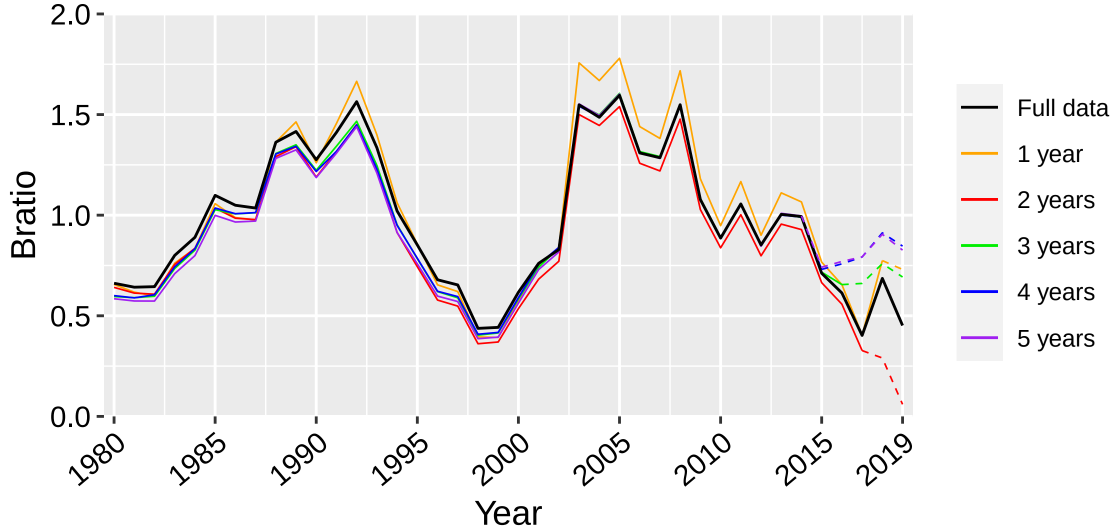


NB2

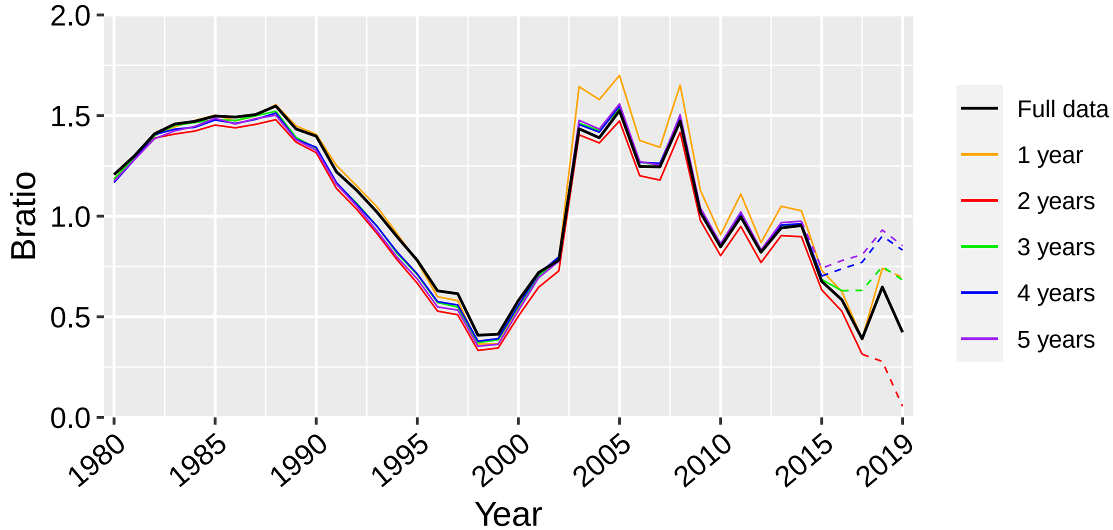


9.2.2 Bratio

NB1

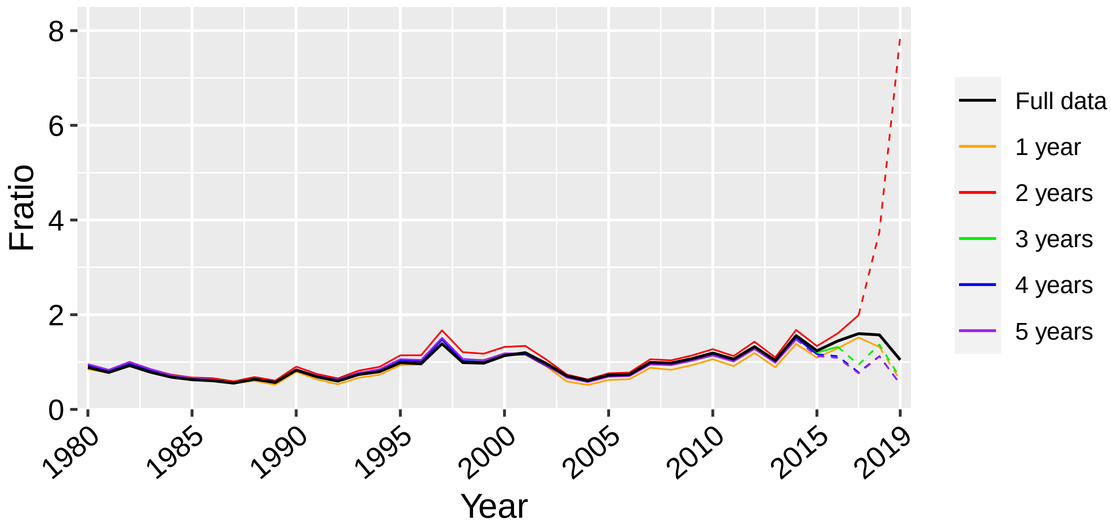


NB2



9.2.3 Fratio

NB1



NB2